A Story of Straying Continents

Dr. Shreerup Goswami
Saumyasree Pradhan

Abstract

Continents are roaming. There was a super-continent known as Pangaea and ocean panthalassa until Carboniferous. Later on Pangaea fragmented and began straying. This break up lead to many changes in the world. The thermal convection generated in the upper mantle is thought to be the cause of this roaming. Different Geometric, Stratigraphic, Palaeoclimatic, Tectonic, Glacial, Geophysical, Palaeontological evidences cited by Wegener and subsequent workers have been summarised briefly in the present article. Forces behind roaming of continents, straying of continents with special reference to Indian sub-continent, probable displacement of present continents have been analyzed and discussed here.

Introduction

We can feel the motion of the earth's surface for a few minutes only during a major earthquake. But the floor beneath our feet, even though it feels stable and motionless, rests upon a landmass that is in continuous motion. This horizontal movement of the continents on a vast scale is called continental drift.

Early in the Earth's history, continents of the world were once united to form a large super-continent known as Pangaea until Carboniferous. The remaining surface of the Earth was covered by a large ocean called panthalassa. The super-continent Pangaea began to break up about 225-200 Ma (million years) ago. Due to some causes in the beginning of Mesozoic era the fragmented Pangaea began straying. Pangaea rifted apart into two large subcontinents called Gondwana and Laurasia. Southern continents such as South America, Africa, Arabia, India, Australia and Antarctica resembled to form Gondwana and northern continents such as North America, Europe, Greenland, Asia and Scandinavia resembled to form Laurasia. There was a sea between these two continents called Tethys (Fig. 1).

Gradually these continents rifted and moved to the present position. The mechanism

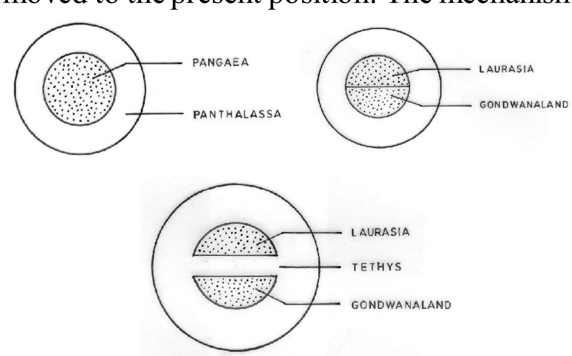


Fig.1

is plate tectonics. Radioactivity in the Earth's core causes uneven heating of the lower mantle. As the semi-molten rock of the mantle is heated, it rises, creating massive, slow convection currents within the Earth. The heated rock spreads laterally at the base of the solid lithosphere, dragging fragments of the Earth's crust with it. This thermal convection generated in the upper mantle is thought to be the cause of plate motion i.e. sole cause of drift. Continents themselves are not moving but they travel on moving lithospheric plates. The Earth's crust has been in constant motion since its formation i.e. 4.6 billion years ago. The modern world is still in motion. Being fractured into a patchwork of plates and floating on currents of molten rock beneath, the plates collide and pull apart. This process of straying continents is called continental drift. The continental crust is significantly less dense than either oceanic crust or the upper mantle rocks.

It explains long-standing puzzles about the distribution of modern and ancient life. It also helps us to understand past environments. By the process the continents have not only been changed but also the Earth's climate has been modified dramatically over time. Chemical changes in the oceans continue to affect many living organisms. Even the air we breathe is radically changed from that enjoyed by earlier inhabitants of the planet.

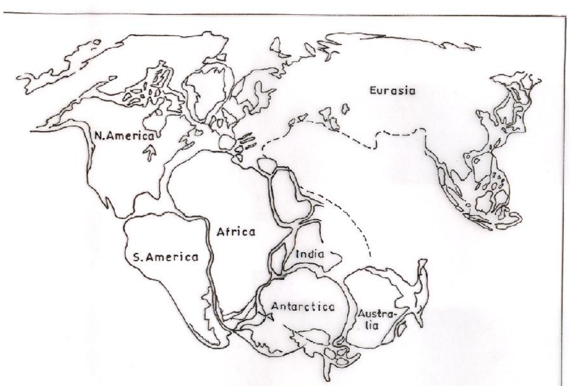
Wegener's concept and evidences supporting drift theory

Alferd Wegener a German geologist, meteorologist, explorer and the pioneer of drift theory 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 evidences that these two continents were once joined. During his long convalescence, Wegener (1915) was able to fully develop his ideas into the Theory of Continental Drift, detailed in a book entitled "Die Entstehung der Kontinente und Ozeane"in German (meaning, The Origin of Continents and Oceans). The book was revised in 1920, 1922, 1929 in response to criticisms of the theory and advances in the earth sciences.

On the basis of geology, biology, climatology and the alignment of the continental shelf rather than the coastline, Wegener (1915) believed that during the late Paleozoic and early Mesozoic eras, about 275 to 175 million years ago, all the continents were united into a vast supercontinent, which he called Pangaea. Later, Pangaea was broken into two supercontinental masses-Laurasia to the north and Gondwanaland to the south. The present continents began to split apart in the latter Mesozoic era about 100 million years ago, drifting to their present positions. According to him the force might be due to (1) the spin of the earth (centrifugal forces) and time to time change in earth's spin axis, (2) the gravitational attraction of the Sun and Moon on the earth. Pole flight force ascribed its origin to rotation of the earth pushed continents from the poles to the equator, while tidal force pushed the continents towards east or west. Finally he proposed that drift might be due to thermal convection, involving the rise of hot rocks under continents and sinking of cold rocks beneath the oceans. His concept explains the variation of the climate in the past, occurrence of identical fossils in separated parts of the earth, similar geological structures in different parts of the earth and mountain building.

Drift of continents, away from poles, was termed by Wegener (1915) as Polflucht. To explain this he stated that (1) African, Eurasian block moved towards equator, (2) Americas drifted towards west, (3) North and South America rotated about a point in North America and were drawn apart leaving scattered fragments which now constitute the West Indies, (4) Australia was left behind in beginning and later on it strayed to the east, (5) Antarctica was recently separated from South America, (6) Labrador and Newfoundland were separated from Europe during Quaternary and they roamed southwest, Greenland was left behind as a separate block. The following evidences in support of continental drift are cited by him and subsequent workers.

The east coast of South America and the west coast of Africa look as though they would fit together like the pieces of a jigsaw puzzle (Fig 3). With a bit of rearranging, most of the continents can be put together too (Fig. 2). This was one of the first clues to the continental drift.



ig.2 : A recent reconstruction of the super continent of Pangea at about 200 Ma. (after Owen, 1983)

South America particularly Brazil can be fitted into Africa in the Gulf of Guinea region. Antarctica can roughly fit into South Australia and South-east Africa coasts. There is


Pre-drift alignment of South America and Africa
Fig.3

similarity of shape between Northwest Australia and Eastern India coast. North America, Greenland and Europe also show a considerable fit. Africa and Arabia join when the Gulf of Aden and Red sea are removed. Besides few gaps and overlaps, New Zealand and Australia can be fitted.

Stratigraphic sequence of rock formations of Southeast Brazil and Southwest Africa are identical. A correlation can be made between the formations of South America, Africa, India, Australia and Antarctica. Especially Permocarboniferous tillites, Permian shales, Lower Triassic red beds and Jurassic lavas all are found in all the above-mentioned continents. With regard to age, mountains of Europe, Greenland and North America are similar.

Appalachian geosyncline abruptly ends in northeast of New Foundland. Like wise Caledonian geosyncline has a common boundary at west of Ireland. Linking segments are absent in the intervening oceans. A reconstruction of Laurasia reveals the continuity of the trends of these geosynclines. In southern hemisphere the same is in case with the Tasman geosyncline ending in Tasmania and Transantarctic geosyncline ending in Victorialand. They may have continuity. Other tectonic evidences are development of fold mountains, mid-oceanic ridges and island arcs.

During Permocarboniferous times all of the southern continents were glaciated. The proof of that glaciation is recorded in all these continents. Beds of tillite, consolidated glacial rubble have been studied in known glaciated regions and are unquestioned evidence of action of deep ice cover. In addition many of the tillites rest on typically glaciated surfaces of hard crystalline rock filled by ice, moving over them. This kind of evidence has been found throughout the Southern Hemisphere. A study of glacial deposits of Brazil and Africa reports that the tillites are uniform and wide spread. Glaciers moved from southeast to northwest as inferred from the grooves, wrinkles, folds and thrusts in the underlying sediments. The ice flow directions and deposits favour the reconstruction of Gondwana land. Unmistakable evidences of wide spread glaciation towards the Palaeozoic era found on the continents of the southern hemisphere support the idea of continental drift.

Wegener (1915) observed palaeoclimatic evidences from the sedimentary rocks of each geologic period and found that many ancient climatic belts were in different position from the present belts. The shift in climatic belt through geologic time is related to the phenomenon of polar-wandering. So poles had remained stationary while continents had actually moved.

Corals and rudist bivalves occur in a belt along the present colder regions of Central Europe and Central America. The growth of them largely depends upon warmer climate. It necessitates the drifting of continents from south to north position. Coal is found in the Antarctica. It means it permitted vegetation once when it was in a different climatic zone. Palaeozoic evaporites are found in colder latitudes. Carbonates are found in Arctic regions. Aeolian deposits reveal the prevailing wind direction during their formation times. An easterly wind direction is inferred from the cross bedding of the aeolian sandstones in the USA and UK contrary to the present westerly direction in those regions. Ordovician glacial deposits of North Africa and South America; Permocarboniferous glacial deposits of South America, Africa, India, Australia, Antarctica all lead to the drift of continents from colder latitudes to present warmer ones. It is inferred that the climates prevailing at the times of their formation were different from the present climate at the respective sites. It could be explained by postulating that the continents had shifted north and south by suitably large distances.

Recently, the magnetic properties of rocks have been used to demonstrate the movement of continents. Magnetic mineral (Magnetite Fe_3O_4; Hematite Fe_2O_3) bearing rocks can record the direction and inclination of the past magnetic field. This is known as Palaeomagnetism or Remnant magnetism or Fossil magnetism.

Earth's magnetic inclination bears a relationship with the latitude, i.e. $\tan i = 2 \tan L$. Here i is Inclination and L is Latitude. Palaeomagnetism reveals the palaeolatitude and not the palaeolongitude.

At the time of cooling of magma the paramagnetic minerals acquire earth's magnetism and get themselves aligned in the vector in the earth's magnetic field, thus preserve a record of the earth's magnetic field when the magma solidifies. This is known as Thermo-remnant magnetism (TRM). In the case of physical alignment of the particles during the general process of sedimentation, the term detrital magnetism is used (DRM). From the study of the magnetic properties of magnetic minerals of the rock, magnetic pole may be located. As a result magnetic pole positions for different times on the earth may be demarcated. A curve called polar wandering curve is obtained when these past pole positions are connected. Polar wandering curve is the line drawn connecting palaeomagnetic poles for successive ages of any continent.

In fact, magnetic poles have not changed their positions on the surface of the earth. It is the continent that moved over the poles. But magnetic polarity reversals may take place from time to time. Palaeomagnetic studies reveal that until Middle Cretaceous the continents were united. Palaeomagnetic study of the rocks shows single polar wandering path up to Middle Cretaceous. Different paths are obtained for later times, which mean the continents were drifting.

Ship borne magnetometers have been used to obtain a detailed picture of the earth's magnetic field in ocean covered areas, which helps in reconstructing a detailed chronology of events. Similar observations on the Indian Ocean reveal that the eastern part of Gondwana-land, comprising Malagasy, India, Antarctica and Australia, separated from the western part consisting of Africa and South America at about 200 Ma. India separated from Antarctica and Australia ca 127 Ma. Australia also started moving north at 45-50 Ma. India collided with Eurasia at about 35 Ma (Chander, 1999).

Same Glossopteris flora (comprising several extinct) has been found in the coal beds of South Africa, South America, Antarctica, Australia, and India. Fresh to Brackish water reptile, Mesosaurus of Lower Permian occurs as fossils in South Africa and Brazil. Antarctica is now bounded by deep oceans; but surprisingly terrestrial reptilian fossils occur in the Antarctic Triassic rocks. Triassic reptiles such as Cystnosdurus, Kannemayeria and Cynognathus found in Antarctica, South America, Africa, India and China. The present day garden snails and earthworms of North America and Europe are related. Here some question arises. Can land dwelling animals cross wide oceans? Is there any contemporary evolution of animals and plants of same species in different parts of the world ? The logical answer will be never, which explains the drifting of continents.

Forces behind the Roaming of continents

The crust and upper part of the Guttenberg layer (a sub-layer of the mantle) together constitute the lithosphere. Lithosphere is underlain by asthenosphere. Asthenosphere is considered to be a comparatively a weaker zone and behaves plastically. It is a low seismic velocity zone. The Lithosphere is divided into a number of small and large plates. The plates move with velocities of 1 to 6 cm per year and behaves plastically. The theory of plate tectonics states that the a number of large and small plates that are moving relative to one another as they ride hotter, more mobile material. The hypothesis of plate tectonics is mainly dealt with the discovery of zones of formation of young oceanic crust (mid oceanic ridges) and zones of the absorption of the crust (trenches). Lithosphere consists of 6 major plates bounded by zones of spreading, subduction and folding. These are Pacific, Eurasian, American, Indian, African and Antarctic. The passive continents move on the spreading oceanic crust, which supports the theory of continental drift. Sometimes the continents (Plates) drifted apart, as in the case of South America and Africa and sometimes they collided as in the case of India and Eurasia. The Himalayas was pushed up due to collision of the Indian subcontinent with the Eurasia.

There is high degree of heat flow at the midoceanic ridges and this is regarded as a hint of thermal convection within the solid earth. According to Holmes (1975), when the difference between the temperature of the top and bottom is so much that it cannot be transferred by conduction, then convection results. Therefore thermal boundary layers, flow pattern of thermal currents, movement pattern of thermal convection current, low velocity zone, benioff zone (characterized by high seismicity) must be studied in detail for knowing basic causes of continental displacement. Dynamic forces such as distribution and quantity of radioactivity in the earth, is the source for force for continental drift. Viscosity of rocks in the substratum, the velocity of movement of the earth and the rate of heat transfer are all important factors. A number of factors like oceanic topography, convection current, gravity, temperature difference between the ridge crest and ocean floor play major role in straying of continents.

Straying of Indian sub-continent

The Indian plate is bordered by the Ninity-East ridge on the east and the Laccadive- Maldive Chagos ridge on the west. Indian Ocean ridge lay to the south and Tethyan trench was to the north. India was a part of Gondwana land. Its present position in space to the north of the equator is recognized to be the outcome of northerly drift of India from South Pole. Starting from a position in the Southern Hemisphere, the Indian Sub-continent may have moved over a distance of about 5000 km to reach its present position, north of the equator. The rectilinear Indian Plate could be visualized to constitute a low-friction system, which could operate independently of the other plates. While the movement of most of other major plates was in an east-west direction, the displacement of the Indian plate from south to north was unique.

Mc Elhinny and Senanayake (1982) observed the rate of movement of Indian plate. During the time span the Deccan Trap erupted, the central part of India moved from 30°S latitude to 20°N latitude. If India reached its present position in space in Miocene times, the 50° change would mean that the plate drifted at a rate of 10 cm per year during Tertiary times.

There are different schools of thoughts regarding the Palaeo-position of the India. They are as follows:

* According to Toit (1937) India was placed along the eastern coast of Antarctica. Smith and Hallam (1970), Bullard et al. (1965) from computer fit study proposed that India and Antarctica was as one unit and was placed against the east coast of Africa with such adjustment that India just touched Africa and Arabia. From the study of magnetic lineament patterns in Indian Ocean, Barron and Harrison (1980) juxtaposed the east coast of India against Antarctica.

* Smith and Hallam (1970) showed the juxta position of Malagasy (Madagascar) along the south western part of India. But it is subject of controversy that whether it was along east coast of Africa or along west coast of India. Smith and Hallam (1970) correlated the Narmada-Sone lineament in central India, with a lineament in north Malagasy. According to Bullard et al. (1965), Malagasy was along the east coast of Africa against Kenya and Tanzania in the north and Mozambique in the south. They opined that Malagasy is a remnant of the easterly extension of the continental crust of Africa.

* Bullard et al. (1965) proposed the models showing Srilanka as a southerly continuation of India. According to them Srilanka was lying close to the South eastern coast of India. Smith and Hallam (1970) described India, Srilanka and Malagasy as one unit and later on Srilanka was detached and placed to the south of India and Malagasy. Later Malagasy was separated from India. The Garnet-Quartz- Sillimanite-Graphite Gneisses (Khondalites) in the southwestern part of India (Kerala) continue into the southwestern series to Srilanka. Jaffna limestone of Srilanka is correlatable with the Quilon-limestone (Miopliocene) of Kerala. From the structural point of view, the impress of the Eastern Ghat trend (NE) and the Western-Ghat trend (NW-SE) in south India is reflected in Srilanka.

* Wegener (1915) showed Australia juxtaposed along the east coast of India. Gradually both were detached and India moved towards from south to north, Australia from west to east. Antarctica can roughly fit into south Australian coasts. The Northwest Australia and Eastern India coast have almost been matched (fitted), but some gaps are found. The pieces required for filling the gaps of Western Australia and Eastern India might be underlying the Indian Ocean. It meant that Indian plate was attached with Australia and Antarctica in the past. After detattachment from India, a part of Australia deformed to form New Zealand. Due to the deformation of New Zealand, gaps and overlaps occur when New Zealand and Australia are united.

Breaking of Gondwanaland: A bird's eye view

It has been concluded from various opinions of geologists (Baumgardner, 1994; Bernhard, 2002; Bullard et al., 1965; Cann, 1998; Chander, 1999; Coe et al., 1995; Dewey et al., 1973; Fraser, 1967; Funnell and Smith, 1968; Hall and Robinson, 1979; Holmes, 1975; Humphreys, 1986; Le Grand, 1988; Mahapatra, 1990; Moresi and Solomatov, 1998; Snelling, 1991; Suess, 1936; Tackley et al., 1993; Tarling and Tarling, 1971; Tarling and Runcorn, 1973; Tanner, 1973; Tyrell, 1954; Vidale, 1994; Wylli, 1976) that:

* In Late Jurassic-Early Cretaceous (140-120 million years ago), rifting and fragmentation of Gondwana land occurred.

* At first South America was separated from Africa (India was at that time a part of Africa).

* Then a major plate comprising India, Australia and Antarctica was separated from Africa.

* In the third step India was separated from Antarctica (By that time India and Australia were united).

* In the fourth step Australia was separated from India.

* In fifth step Srilanka and Malagasy were detached from India and New Zealand from Australia.

It was assumed that this landmass became separated when the intervening continental areas sank to form the present day Indian and South Atlantic Oceans.

Probable displacement of present continents:

On the basis of the evidences of palaeomagnetism and sea floor spreading it has been observed that continents and ocean basins have always been mobile throughout the geological history of the earth and they are still moving in relation to each other. Scientist using Satellite Laser Ranging (SLR) systems, Synthetic Aperture Radars (SARS) and Global Positioning System (GPS) study the motion of the different continental and oceanic plates. The scientists have cited evidences to describe the opening and closing of ocean basins. For example, the Mediterranean Sea is the residual of once very vast ocean (Tethys Sea) and the Pacific Ocean is continuously contracting because of gradual subduction of American plate along its ridge. On the other hand the Atlantic Ocean is continuously expanding for the last 200 million years. Red Sea has started to expand. It may be mentioned that continental masses come closer to each other when the oceans begin to close, while continents are displaced away when the oceans begin to expand.

Satellite studies reflect that North America drifts closer to Asia. Measurements from satellites depicts that North America and Europe are drifting apart at the rate of about 4 centimeters a year. SLR Satellite shows that the island of Maui and Hawaii is moving northwest towards Japan at approximately 7 cm per year. Similarly, Maui is also moving away from South America at 8 cm per year. Plate tectonic theory predict that Srilanka is moving away from India at 3-4 cm per year.

Satellite based GPS observations indicate that India is moving northward at 5.5-6 cm per year relative to an earth fixed coordinate system, but only at 3.5-4 cm per year relative to a point, e.g., Kathmandu, in the Himalayas. Many of earth scientists suggest that the difference in the rates arises because India is sleeping under the Himalayas at about 20 mm per year (Chander, 1999).

Continents are mobile throughout the geological history and have been roaming since their origin. Undoubtedly they will stray here and there.

References :

Baker, H.B. 1912. The Origin of Continental Forms, II. Mich. Acad. Sci., Ann. Rep.: 116-141.

Baker, H.B. 1913. The Origin of Continental Forms, III. Mich. Acad. Sci., Ann. Rep.: 107-113.

Barron, E.J. and Harrison, C.G.A. 1980. An Analysis of Past Plate Motions: The South Atlantic and Indian Oceans. In P.A. Davies and S.K. Runcorn (eds.), Mechanisms of Continental Drift and Plate Tectonics, Academic Press: 89-109.

Baumgardner, J.R. 1994. Computer Modeling of the large scale tectonics associated with the genesis flood. Proc. Third ICC: 49-62.

Bernhard Fristher 2002. Alferd Wegener's "The origin of continents". Episode 25 (2): 100-106.

Bullard, E.C., Everett, J.E. and Smith, A.G. 1965. Fit continents around Atlantic. In Blackett P.M.S. et al. Eds. A Symposium on continental drift. Royal Society London, Phil. Trans., Ser. A, 258:41-75.

Cann, J. 1998. Subtle Minds and Mid Ocean Ridges. Nature 393:625-627.

Chander, R. 1999. Wegener and his theory of Continental drift. Resonance 4 (7):24-41.

Coe, R.S., Prevot, M and Camps, P. 1995. New evidence for extraordinary rapid change of the Geomagnetic Field during a Reversal. Nature 374:687-692.

Daly, R.A. 1923. The Earth's Crust and its stability. Am. Jl. Soc. 349.

Dewey, J.F., Pitman, W.C., Ryan, W.B.F. and Bonnin, J. 1973. Plate Tectonics and the Evolution of the Alpine System. Geological Society of America Bulletin 84:3137-3180.

Fraser, R. 1967. Understanding the Earth. Penguin Books.

Funnell, B.M. and Smith, A.G., 1968. Opening of Atlantic Ocean. Nature 219:1328-33.

Hall, J.M. and Robinson, P.T. 1979. Deep Crustal Drilling in the North Atlantic Ocean. Science 204:573-586.

Holmes, A. 1975. Principles of Physical Geology. Thomas Neison and Sons Ltd.

Humphreys, D.R. 1986. Reversals of the Earth's Magnetic field during the genesis flood. Proceeding First ICC, Pittsburgh, PA 2:113-126

Le Grand, H.E. 1988. Drifting Continents and Shifting Theories, Cambridge University Press, Cambridge.

Mahapatra, G.B. 1990. Text Book of Physical Geology. CBS Publishers and Distributors Pvt. Ltd.

McElhinny, M. W. and Senanayake, W. E. 1982. Variations in the Geomagnetic Dipole I: The Past 50,000 Years. Journal of Geomagnetism and Geoelectricity 34: 39-51

Moresi, L. and Solomatov, V. 1998. Mantle Convection with a Brittle Lithosphere: Thoughts on Global Tectonic Styles of the Earth and Venus. Geophysical Journal International 133:669-682.

Smith, A. G. and Hallam, A. 1970. The fit of the southern continents. Nature 225: 139-144.

Snelling, A. A. 1991. Fossil Magnetism reveals rapid reversals of the Earth's Magnetic Field. Creation 13(3):46-50.

Suess, F.E. 1936. Europaische und nordamerikanische Gebirgszusammenhange. Cong. Geol. Inter. XVI 2: 815-828.

Tackley, P.J., Stevenson, D.J., Glatzmaier, G.A. and Schubert, G. 1993. Effects of an Endothermic Phase Transition at 670 Km Depth on Spherical Mantle Convection. Nature 361:699-704

Tanner, W.F. 1973. Deep sea trenches and the compression assumption. Amer. Assoc. Pet. Geol. Bull. 57:2195-2206.

Tarling, D., and Tarling, M. 1971. Continental Drift. G. Bell & Sons, Ltd.

Tarling, D., and Runcorn, S.K. 1973. Implications of Continental Drift to the Earth Sciences, Vol. I, Academic Press, N.Y.

Taylor, F.B. 1910. Bearing of the Tertiary Mountain Belt on the origin of the Earth's Plan. Bull. Geol. Soc. Amer. 21:179-226.

Taylor, F.B. 1923. The Lateral Migration of Land Masses. Proc. Wash. Acad. Sci. 13:445-447.

Taylor, F.B. 1925. Movement of Continental Masses under the action of the Tidal Forces. Pan-Amer. Geol. xliii: 15-50.

Toit, A.L. Du 1937. Our wandering continents. Oliver and Boyd, London.

Tyrell, G.W. 1954. Earth and Mysteries. Bell, G. and Sons Ltd. London.

Vidale, J.E. 1994. A Snapshot of whole mantle flow. Nature 370:16-17.

Wegener, A. 1912. Die Entstehung der Kontinente. Peterm. Mitt.: 185-195; 253-256; 305-309.

Wegener, A. 1915. Die Entstehung der Kontinente und Ozeane. 1-94, Braunschweig; 2nd ed. (1920):1-135; 3rd ed. (1922):1-144; 4th ed. (1929):1-231.

Wegener, A. 1966. The Origin of Continents and Oceans, 4th edition of 1929, translated by John Biram, Dover Publications Inc., New York 1966.

Wylli, Peter J. 1976. The dynamic Earth:Text Book of Geosciences. John Wiley and Sons, Inc. New York, London.

Dr. Shreerup Goswami, P.G. Department of Environmental Science, Fakir Mohan University, Vyasa Vihar, Balasore-756019 (Orissa), India

Saumyasree Pradhan, P.G. Department of Biotechnology, Fakir Mohan University, Vyasa Vihar, Balasore-756019 (Orissa), India