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The Great Continental Drift Mystery

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Plate tectonics, the study of the movements and interactions of the lithospheric plates, has a history which shows how scientists work by studying one another's work, arguing, disagreeing, and proposing new hypotheses. It demonstrates the importance of researching a problem carefully and being open to new information. It is a wonderful example of interdisciplinary work among the various branches of science with paleontologists, climatologists, oceanographers, ecologists, biologists, and geologists all working to solve the same mystery; continental drift. It also reveals an important source of global change; changes that are reflected in the climate, landforms, and lifeforms.

We will begin with a brief introduction presenting some of the early history of the concept of continental drift. This will include the first ideas of landbridges connecting the various land masses. Then the work of Wegener and Dutoit will be looked at in more detail. We will use Wegener's clues to draw and assemble a partial map of Pangaea. Next we will look at some of the clues that have been found in support of the plate tectonic theory. Comparisons of strata on different continents, and looking at the specific kinds of sediments and how they form will tell us some things about climate and about movements in the region involving rifting or colliding of continents. Glaciation clues can tell us not only about climate but also possible alignment of early land masses and their geographic locations. Changes in global climate resulted in changes in the endemic plant and animal forms, all being influenced by the changes in geographic location of the moving continents. Paleomagnetism and the concept of magnetic reversals will be looked at in order to determine the earliest placement of the continents.

My students always respond well to ideas involving animals so I will use both living and fossil species of plants and animals extensively to show the "mystery" of biogeography as it relates to plate movement. We will look at fossils of dinosaurs and early Cenozoic mammals to maintain the interest level.

We will be doing a lot of drawing as we look at maps, draw maps, and draw in clues. Hopefully the students will be able to use some clues to figure out some maps of their own. A final exercise will be to look at some of the unsolved mysteries of animal distribution and try to come up with some of our own ideas. The unit must be very visual since so many of the words we will use are long and threatening. All the representative species will be drawn and colored; the maps will be constructed using continent outline tracings; and posters of geologic eras and periods will be drawn and hung along the wall for constant reference, with representative species listed, drawn, and colored.

This unit is designed for the middle-school age level, to be used in an Earth Science curriculum.

The idea of continental movement has been with us since the middle of the last century. The understanding of the driving force is relatively recent, the 1960's. The basic concept extends all the way back to early map makers who noticed that the coastlines of Africa and South America had a remarkable similarity. As early as 1858 a French scientist, Antonio Snider-Pelligrini wrote that the Atlantic Ocean had formed when powerful forces broke apart a great continent. However at that time the idea was not given serious consideration by most geologists. Evidence supporting this concept, however, gradually developed from geological and paleontological observations in the continents of the Southern Hemisphere and India.

There is great similarity between the animals of India and Madagascar, two land areas now separated by 2,500 miles of ocean. In order to explain this observation an early idea was that the continents were joined by land bridges of granitic rock that later sank into the ocean's basaltic crust. This idea also supported the Austrian geologist Eduard Suess's work with the fossil plant *Glossopteris* which he found to be distributed throughout India, South America, southern Africa, Australia, and Antarctica. He felt that the presence of a land bridge connecting all of these continental areas would explain the distribution of this group of fossil plants over such widely separated locations. He named this land mass of continents and land bridges Gondwanaland (named for a district in India where *Glossopteris* was found in the coal beds.) [1]

Between 1872 and 1876 The British H.M.S. Challenger expedition took soundings throughout the Atlantic Ocean which revealed an extensive ridge running north-south down the middle of the ocean floor roughly half-way between the American continents and Europe-Africa. Using these data Frank Taylor in 1908 proposed that the continents had at one time been adjacent but had been pulled apart by tremendous forces, and that the central ridge, the Mid-Atlantic Ridge, was the site of this ancient boundary.

Not long after Taylor's work was published Alfred Wegener, a German meteorologist, presented his theories in his 1915 book *On the Origin of Continents and Oceans* . He proposed that at one time all the continents were joined into one huge supercontinent which he named Pangaea (Greek for "all the land") and that at a later date the continents split apart, moving slowly to their present positions on the globe. He felt that the idea of land bridges was wrong because it called for less-dense granitic rock to sink into more-dense basaltic rock which he felt was clearly impossible. And possibly because he was trained in meteorology rather than geology he was able to view the earth's surface as less immutable than his contemporaries. He searched for analogies and found them in the rift valleys of eastern Africa, an area that is now considered to be a possible site for rifting to become drifting. In matching up coastlines he found that by including the continental shelves the fit was much more accurate, and by doing so large blocks of ancient rock called cratons, the oldest core of a continental land mass, were found to form a contiguous pattern across the boundary of South America and Africa. He also looked at other geologic formations and saw patterns such as the presence of ancient mountains in South Africa which align with the mountains near Buenos Aires in Argentina when the two continents are "fitted" along coastlines. Layers of sandstone, shale, and clay interspersed with coal in both South Africa and Brazil seemed to match in sequence. (This will be discussed more fully later in the paper.) Wegener's theory was however so radical that he was not given serious consideration by most of the scientific community. But he persisted in his study of the idea finding more and more supporting evidence. In a second and a third edition of his book he included fossil and rock evidence of vastly different climates in the past that could only be explained by a relocation of the particular continent to different latitudes. He also pointed to diamond fields of South Africa and Brazil, coal deposits in Britain and the Appalachians, and a thick band of red sandstone which runs from the Baltic, through Norway, across Britain and Greenland and into North America. Still the acceptance for his theory did not come. In fact he was subjected to ridicule and insult for daring to present his “preposterous” ideas.

Although some of Wegener’s information was off the mark the largest part was accurate,but his theory’s greatest weakness was his explanation of cause. He suggested that the centrifugal force of the spinning planet would tend to force the continents equator-ward and that tidal pull from the sun and moon might cause lateral movement. He did not seem very confident in those mechanisms however as he also stated that the “complete solution of the problem of the driving forces will still be a long time coming.” [2]

The first map that the students will construct uses Wegener’s clues to bring the continents together to form Pangaea. Directions are in the Appendix Activity 1. At this time the students should also review some geography by doing Activity 2, also in Appendix I.

While in Europe and North America Wegener’s ideas were being attacked, in the southern hemisphere some of his staunchest supporters were collecting data to support the theory of continental drift. One, a South African named Alexander duToit traveled to Brazil, Uruguay, and Argentina where he found remarkable similarities in fossils and strata to his native land. He also studied the Karroo sequence, expanding on earlier work to show the parallel development of South America, Africa, Antarctica, and India. In the early Permian layers of both South America and South Africa were found the fossil remains of a freshwater reptile called Mesosaurus, and bands of coal were found extending through each of the southern continents which contained fossil remains of a plant group *Glossopteris* . Du-Toit also mapped glacial sediments and striations which pointed to a very different orientation of the southern hemisphere in its geologic past. The presence of ancient mountain remnants running through Australia, Antarctica, South Africa, and South America were also used to reinforce the idea of a supercontinent at least in the southern hemisphere, Suess’s Gondawanland. Living species were also introduced as evidence. Earth worms, very unlikely to be long-distance migrators, were found in soils of all the Gondwanaland continents.

But despite the evidence presented by supporters most of the scientific community still did not accept the theory of continental drift. It was not until thirty years after Wegener’s death that scientists of the 1960’s described sea-floor spreading and plate tectonics which were the undeniable proof of continental drift.

Although the ideas of Wegener and his colleagues were not widely accepted in their lifetimes, the data they collected provides a wonderful set of clues to a grand mystery. By having the students look more carefully at each of the clues and placing this information visually on maps we can help them see the world as a more organized place and how scientists constantly seek to make sense of what they observe.

Clues to the Mystery

Stratigraphy

Among the earliest supporters of Wegener was DuToit whose careful study of the Gondwana sequence focused on his native South African Karroo. In the Karroo he found a base layer of shale scratched by glaciers and covered by layers of tillite, which is mixed glacial sediments that have hardened into stone. Above this lies marine deposits, and then fresh water deposits containing the fossilized remains of *Mesosaurus* . Next are coal beds containing *Glossopteris* flora. Moving upward are found layers of shale rich in a wide variety of fossil reptiles, then a sequence of dune deposits signifying a hot arid environment. Topping off the Karroo is a thick layer of basaltic lava flows. When DuToit went to South America he was astounded by the close similarities he found there in the rock. Again tillites covered by coal beds and *Glossopteris* with shales containing Mesosaurus tucked between, and dune deposits finally capped by basalt flows. When later researchers continued the hunt they found that Antarctica and India also followed the sequence of tillite, coal beds, and basaltic toppings. Although *Mesosaurus* was not found there, *Glossopteris* is there in abundance. DuToit was certain that this incredible parallel development of strata could only have occurred if the land masses were contiguous and therefore susceptible to the same geologic processes. [3]

Glaciation

There are several geologic clues to ancient climate which in turn can tell us about continental placement on the globe. Deposition of glacial sediments is one that is very useful in indicating cold climates and therefore possible pole positions. The specific things to look for are glacial scratches, varves, and tillites. Scratches on rock created as large glaciers passed over can indicate direction of movement. Varves which are sediments carried by glacial meltwater into lakebeds at the edges of the glacier, display seasonal variations dependant on increase and decrease of melt due to summer-winter temperature variation. From this fairly accurate annual counts can be made. And tillites, the mixture of rocks and pebbles pushed forward by advancing glaciers that have been buried and turned to stone, stand as witness to the former presence of massive ice flows.

These clues tell us of several periods of glaciation; the first appears in the geologic record of Canada just above Lake Huron where varves and tillites alternate in 2 billion year old formations. Tillites of similar age are also found in India and southern Africa, indicating extensive glaciation on a worldwide scale. The next appearance of tillites occurred about 800 to 850 million years ago on a grand scale. They have been found on all major continents except Antarctica, which would indicate the most extensive glacial episode in earth's history. [4]

Moving forward in time to the Ordovician Period, about 450 million years ago, we find the southern continents again covered by ice sheets. The massed continents of Gondwanaland were located over the South Pole region at this time, with northern Africa just at the pole. Grooves and striations in the bedrock buried by tillites have been found in what is now the Sahara Desert. These markings indicate the point from which the glaciers moved northward.

Tillites of the Devonian have been found in Argentina and Carboniferous and Permian Period tillites can be found in widespread areas of southern South America. In South Africa, too, tillites have been found that are similar to those found in Antarctica, India, and Australia. When we look at the striations left by the moving glaciers of the late Paleozoic we see what appears to be two central points with scratches radiating outward. One of these points is in South Africa and the other is in eastern Antarctica. When these deposits of tillite and the grooves caused by glacial movement are placed on a map of Gondwanaland as it passes over the South Pole the information has much more meaning. The position of the land mass over the pole had a significant affect on its climate. However other evidences that point to periods of relative warming during the middle Paleozoic indicate that many factors were at work besides just position during the Paleozoic.

As the terms for the various eras and periods are introduced and used it is important to defuse the threat of being overwhelmed by vocabulary. At this time the students should begin their study folders by drawing out an "era chart" which gives the eras, periods, and representative plants and animals for each. Additionally a very large time line with period names and dates should be displayed for easy and constant reference.

Path of Gondwanaland over the South Pole A. Ordovician

B. Carboniferous

C. Permian

Figure available in print form

Sediments of Continental Rifting

When an area is in the process of rifting generally huge block faults appear which create valleys into which rivers bring a variety of sediments. Boulders and pebbles which form conglomerates, or finer alluvial sandstones and mudstones which oxidize into redbeds can be found in these ancient rift beginnings. If lakes form and then dry up mineral crystals precipitate out forming evaporites. Later as the rift opens further it might allow small amounts of seawater in which if it evaporates more rapidly than it is replenished will form marine evaporites. And finally as the sea gains complete access typical marine sediments are deposited. When this particular sequence of strata is found the presence of an ancient rift zone can be suspected. The Connecticut River now flows through such a rift zone, considered to be a failed rift of the Jurassic breakup of Pangaea.

The breakup of Pangaea is well marked by the sediments of rifting. In the Atlantic area as fault blocks sank water from the Tethys Sea to the east occasionally spilled into that region and evaporated forming the extensive evaporite deposits now found along the coast of Morocco and off the Canadian provinces of Nova Scotia and Newfoundland. During the middle of the Mesozoic the rift between North and South America filled the Gulf of Mexico with water from the Pacific, resulting in massive evaporites. The rifting that formed the South Atlantic began late in the Mesozoic when Africa and South America began to pull apart. Water from the south must have flowed in over time forming the evaporites now found along the coastlines there.

Another characteristic formation of spreading boundaries is the plateau basalt. As the dividing crust is split great floods of lava well up and out filling in lowlands and depressions which are later uplifted into plateaus. Major plateau basalts are located along the edges of the Gondwanaland continents giving further evidence of Mesozoic rifting.

Just as rifting zones have characteristic geologic formations so also do areas where plates have collided have sediments and rock strata that indicate their past history.

Evidences of Colliding Boundaries

When an ocean plate edge collides with a continental plate its denser composition causes it to dive beneath the lighter continental crust. This subduction creates both great heat and pressure. The heat results in volcanic activity on the continental edge and therefore igneous rock can be found there. The pressure results in extremely deformed rock along the edge where the subduction takes place. Most of the metamorphosed rock found there is deep-ocean sediment or ocean crust origin which was scraped from the descending plate as it sank.

A slightly different story unfolds when two continental masses collide. Since they are both of the less dense characteristic neither will subduct, rather they will create enormous faults and extensive folding resulting in mountain building. Often the forward moving continental plate is preceded by a subducting oceanic portion. As it moves forward deep ocean sediments are scraped off and forced upward by the advancing continental mass. As the continents buckle and lift to form mountains the segments of ocean floor are also elevated. These rocks are called ophiolite and are composed of deep-sea materials and pillow lavas. Finding ophiolite gives us clues about ancient vanished oceans. [5]

Figure available in printed form

Tropical Marine Corals

Since the formation of coral reefs is dependent on the temperature of the water they are good indicators of past climate and geography. At present reefs occur within a 30°N to 30°S range and primarily on the western side of ocean basins (due to the warm water ocean current flow.) The distribution of fossil coral reefs of the Silurian seem to suggest an equatorial position for the continents of Laurentia, Baltica, and China. During the Devonian organic reefs became widespread indicating shallow water, and warmer climate than at any other time. By the late Devonian global cooling reduced the numbers of corals,with the exception of reef building on the western border of Australia which was on the equator at this time. From late Devonian to the early Permian the reduction of corals suggested continental massing and the closing of seaways resulting in less total continental margins available for reef formation.

With the formation of Pangaea during the late Paleozoic a huge tropical sea formed in the indentation of the continent's eastern edge. During the Mesozoic this sea, the Tethys, extended westward as Africa separated from Europe and North America. The break up of Gondwanaland and the opening of the Atlantic allowed a major east-west current of tropical water to travel around the globe with resulting extensive coral reef formation. Fossil remains of coral reefs are found all aong the coast of North America from Florida to Nova Scotia. By the end of the Mesozoic the corals were again widespread.

During the late Cretaceous the Atlantic widened so much that coral larvae were no longer able to traverse it and Caribbean species began to differentiate from Tethyan types. During the middle Cenozoic the uplift of the Isthmus of Panama separated the Caribbean from the Pacific causing more differentiation. Later cooling as a result of the Pleistocene glaciation severly inhibited coral growth on the Atlantic side and the Caribbean is now at the lower end of the temperature limit for coral growth, so few species still exist there. Demonstrate these changes using the maps.

Mountain Belts

A geologic record of ancient plate tectonic activity is preserved in mountain belts around the world. Suture zones which indicate boundaries between ancient mobile plates can be dated to determine when continents joined and contiguous mountain belts reveal the placement of continents along ancient subduction zones.

Dutoit, one of Wegener's earliest supporters, described the grouping of mountain ranges named the Samgrau Mountain Belt (derived from *S* outh *Am* erica, A *fr* ica, and *Au* stralia). This belt runs along the present western edge of South America, the Cape fold Belt at the tip of southern Africa, the western edge of Antarctica, and the eastern Tasman Belt in Australia. When the continents of Gondwanaland are assembled it is easy to see the continuous nature of this chain. The dating of this formation places it at about 400 million years ago. [6]

Figure available in printed form

Following the formation of the Samfrau Mountain Belt was a series of mountain building extending from northeastern Canada and Scandinavia in the early Devonian called the Acadian/Caledonian orogeny (orogeny: mountain building) southward with the joining of eastern United States with northwest Africa in the

Carboniferous called the Appalachian orogeny. Illustrate these and the following collisions by using the continental drift maps.

Alps and Himalayas Acadian/Caledonian orogeny

(50 MYA) (300 MYA)

Figure available in printed form

The Alps and the Himalayas are examples of much more recent mountain building episodes. The formation of the Alps began about 50 million years ago with the northward movement of the African plate. Although Africa has not made contact with Eurasia, small plates caught between the two larger plates have been pushed up against Europe causing mountain building there.

The Himalayas formed when north-bound India crashed into Asia. The eastern edge of India made first contact with Indochina perhaps 45 million years ago and the plate continued advancing northward until contact with Eurasia was attained 15 million years ago. The Himalayan crust is extremely thick possibly due to the wedging of the Indian plate beneath the Eurasia plate. These and other mountain belts contribute to our understanding of plate movements and the closing of ancient oceans.

When the student has been introduced to these concepts; subduction, mountain-building at colliding boundaries, and plate movement, have the students look at a world map locating mountain ranges. Have them compare these locations to their placement on a map of tectonic plates and try to explain the relationship between the two.

Magnetic Reversals and Paleomagnetism

Despite the abundance of evidence for drifting continents the idea was not accepted until the 1960's. At that time a number of researchers had been working with paleomagnetic studies of both continental areas and the sea floor. It had already been established that earth's magnetic polarity had reversed itself many times throughout geologic time. (There have been at least nine reversals in the last 4.5 million years.) Several researchers provided evidence that as new magma wells up out of a rift it is magnetized in the direction of earth's polarity. Scientists found that to the left and right of a spreading boundary the hardened magma carried a matching record of polar reversals that resulted in a zebra-striped appearance which was a record of the spreading movement over time, proof that the plates were moving. This magnetic record of reversals can be used to date both igneous rock and iron-rich sediment deposits. The Scott-Foresman or Prentice Hall Earth Science texts can be used to supplement this discussion.

Paleomagnetism has yet another use in the understanding of continental drift. Not only does the magnetic record reveal the continent's northsouth orientation, it also holds information about latitude position. Since a compass needle at the equator is nearly horizontal and at the poles has a vertical tilt, the natural rock magnets also demonstrate this characteristic called dip. Unfortunately the magnetic record cannot tell us anything about longitudinal location. [7]

Figure available in printed form

When scientists began collecting magnetic data for North America and Europe it appeared that the north pole seemed to be moving about over time. However when data from other continents was collected for the same time frames it showed quite different polar locations. As this could not be possible the idea that the continents themselves were moving about gained further support.

Fossil Evidence

The fossil record can also contribute to the students' understanding of plate tectonics by helping to establish a timetable for the breaking apart and coming together of land masses. Some basic biological principles must be understood by the students before they begin to use these clues. The concept of convergence and divergence of evolution of species is important. Convergence is the general homogenization of populations that are in the same area for an extended period of time usually due to the ability of some species to out compete other species for resources. An example of this is the change in the mammal populations of North and South America some two million years ago with the rising of the Isthmus of Panama. Prior to the uplift there were about 27 mammalian families in North America and some 29 completely different families in South America. After the joining of the two continents by the Panama land bridge there remained 22 families of mammals in common.

Divergence of biological populations is the opposite. When animals with a common ancestor are isolated they tend to evolve in very individualistic ways. The longer the isolation the more unique a species may become. Keeping these two ideas in mind we will look at both fossil forms and living genera to get a better understanding of the timing of the movements of the plates.

If we go back in time to the Cambrian period we would find an aquatic world inhabited by many varieties of trilobites; on each side of a body of water separating North America and Europe large populations of differing forms were thriving. As the two land masses came together many of these trilobites were preserved as fossils. Some 300 million years later the northern supercontinent of Laurasia split apart carrying bits of land bearing these fossils to the east and west. By looking at the locations of these varying forms of trilobites we can determine the ancient outline of a 500 million year old sea. In Activity 3 the students can map out this ancient boundary. [8]

Scientists have been collecting information on fossil locations for over a hundred years and although undoubtedly new finds will cause changes in their interpretation we can make some explanations for distribution based on the available data.

One of the earliest fossil forms to be used as a clue to continental drift was the plant *Glossoptera* . It was a rather cold-hardy species with a substantially large seed. Because of the seed's size it is unlikely that the extremely wide distribution could be easily attained by wind or water dispersal. Members of this genera have been found in South America, Africa, Madagascar, India, Antarctica, and Australia; all the continents of Gondwanaland.

Other fossil forms which reinforce the idea of the joined continents are the Permian reptile *Mesosaurus* , a fresh-water dweller, and the Triassic reptiles *Cynognathus* and *Lystrosaurus* . Activity 4 will help the students understand the use of these fossil forms as clues to continental drift.

As we move out of the Paleozoic and into the early Mesozoic we find a world with one huge supercontinent called Pangaea. As the dinosaurs evolved they were able to spread out over large areas of the earth. *Lystro saurus* and *Cynognathus* are examples of this. During the Jurassic the super continent Pangaea separated into two parts; Gondwanaland and Laurasia. However the presence of sauropod fossils such as the giant *Brachiosaurus* in both Colorado and Tanzania tells us there must have been connections between North America, Europe, and Africa. An interesting problem is presented by the presence of these large sauropods in

India during a time when it was previously believed to be isolated from the other continents by its northward drift toward Asia. Have the students use their continent pieces from Activity 4 to try to explain how this mystery might be solved. Useful information to provide would be the locations of important dinosaur fossils of the Late Jurassic; southeastern Africa, Madagascar, India, Australia, northwest Africa, Spain, western Europe, central United States, and northeastern China. [9]

As Pangaea continued to breakup during the Cretaceous the range of animal and plant diversity increased dramatically. This probably was influenced somewhat by the increasing isolation of individual continents, but another important factor was the rise of flowering plants and the increased food source this provided. A shallow sea ran north-south down the middle of the North America but an extensive land bridge joined northeastern Asia with western North America. This resulted in the dispersal of giant carnivorous dinosaurs such as *Tyrannosaurs* , armored dinosaurs, duckbilled dinosaurs, and horned dinosaurs throughout the American west and Mongolia.

Again in the Cretaceous we see the mystery of the movement of India in the discovery of large sauropods of the same genus in Argentina, India, and Madagascar. Wherever the connection of India to some part of Gondwanaland was we cannot be sure but we can be sure that during that time dinosaurs were moving over connecting pathways between the continents. [10]

The Age of Reptiles, the Mesozoic, lasted about 200 million years and produced 20 reptilian orders, and the Age of Mammals, the Cenozoic, has so far encompassed some 65 million years and produced 30 mammalian orders. The Mesozoic was the time of Pangaea, one huge continuous supercontinent, while the Cenozoic is marked by the breaking up of Pangaea into many individual isolated continents. This isolation was the impetus for species diversity. The three Laurasia continents produced 16 orders; South America, 6; Africa, 4-6; and Australia, 3. As the Cenozoic progressed these isolated continents moved into contact. Laurasian animals moved into Africa and African animals spread worldwide. Some South American animals migrated north but the North American mammals were much more successful in their move south. Only Antarctica and Australia remain isolated island continents. The Antarctic mammals are not known but the Australian marsupials (including bandicoots and kangaroos) and the monotremes (the platypus and the spiny anteater) are still extant on their island home. But the contact between the other continents resulted in extinction for 13 of the original 30 orders of mammals in the latter part of the Cenozoic. [11]

Living Genera

In looking for clues to the mystery of continental drift among living organisms the marsupials of Australia stand out as most revealing. Marsupials and placental mammals both appeared about the same time during the Cretaceous while South America, Antarctica, and Australia were still joined. The marsupials of both South America and Australia seem to share a common ancestor but the subsequent isolation of those two continents led to the evolution of significantly different forms. By the time the continents divided placentals had established themselves in South America but were not found in Australia. The marsupials and placentals of South America shared that continent until the Isthmus of Panama land bridge linked it with North America. North American placentals migrated south and outcompeted virtually all the marsupials and many of the endemic placentals. Prior to the formation of the land bridge there were 29 families of mammals in South America and 27 families in North America; after the joining only 22 families remained, most of which had originated in the north. Of the South American marsupials only two species survived. In comparison on the island continent Australia where placentals did not take over some 200 species of marsupials flourish today filling every ecological niche that on the other continents of the world are filled by placentals. Only by its timely movement away from Gondawanaland were Australia's marsupials preserved to the present. [12]

Another more lowly group of living organisms that illustrate the clues to drifting are earthworms of the family Megascolecina. Their distribution is a peculiar sprinkling across South America, Africa, Madagascar, India, Australia, and New Guinea which makes little sense until their locations are plotted on a map of Godawanaland. Then the contiguous nature of the land and the incredibly vast amount of time available for migration makes the possibilities of such events more realistic. [13]

Distribution of four genera of living earthworms of the family Megascolecina Figure available in printed form

Of all the stories of animals affected by the drifting of the continents the green sea turtles of Brazil are the most peculiar. For years biologists tried to understand the long-distance migration of the sea turtle from the coast of Brazil to tiny Ascension Island halfway across the Atlantic Ocean where the females lay their eggs. The motivation for choosing an island for egg-laying is well understood; lack of predation on the adult females and reduced destruction of egg nests. But until the understanding of the effects of plate tectonics on the formation of some islands the whole thing was a mystery. Once scientists realized that volcanic islands were being formed at the Mid-Atlantic ridge, wearing down, and new more distant replacement islands were then forming, did the biologists theorize that the migration had originally begun when the continents were first rifted and the offshore islands were still within easy distance. Over time the islands migrated to changed and increased in distance from the home range but the instincts of thousands of generations of sea turtles still sent them off into the rising sun to find their nesting islands.

Acceptance of the Theory of Continental Drift

Although much of this supporting evidence for continental drift was known and available for many years, the concept received little acceptance and in fact open derision, until researchers began to formulate explanations for the mechanisms of movement. Pieces of information from many sources were assembled over time to develop a uniform concept. An understanding of the importance of convection currents in the mantle goes back to the Dutch researcher Felix Menesz in 1930, long before any kind of acceptance of that idea. In 1959 Maurice Ewing, Bruce Heezen, and Maria Tharp used echo-sounding profiles to draw a topographical map of the North Atlantic floor. The plotting of the data produced a map that stunningly revealed the extent of the Mid-Atlantic Ridge and the presence of a deep central rift within. Harry Hess' work, *History of Ocean Basins* , described sea-floor spreading in 1960; and in 1963 Fred Vine and Drummond Matthews wrote about the geomagnetism of the Indian Ocean. Tuzo Wilson in 1965 proposed an explanation for the movements of transform faults along the rift zone and in 1968 W. Jason Morgan produced mathematical support for the possibilities of plate movements. In 1968 also, Bryan Isacks, Jack Oliver, and Lynn Sykes plotted the occurrences of shallow and deep focus earthquakes along the plate edges.

Many other researchers did important and landmark work on this problem at that time. Scientists are still investigating the many mysteries that remain. Fifty years after Wegener first proposed his theory of continental drift the science of plate tectonics finally came to the rescue of his intellectual honor and his life's work was vindicated.

Questions for Group Analysis

1. Look at a world map— locate the following and mark them on a world outline map; Urals, Alps, Iceland, San Andreas fault, Andes mountains, volcanoes in Italy. Use a plate tectonics map (page 199 in the Scott Foresman *Earth Science* text) to explain why these formations are found where they are.
2. On a world map locate the placement of some of the recent geological events; earthquakes or volcanoes. Use the plate tectonics map to explain what has happened and why.
3. Look at the continental drift maps in Appendix II. Using the maps given follow the changes that occurred along the eastern edge of Pangaea beginning in the Triassic. What happens to the Tethys Sea as it becomes the Mediterranean? What can you predict might happen there in the future?
4. Ancient coral reefs are porous and can trap and hold petroleum. Look at the Devonian map to find some promising areas to drill for oil. Look at a map of the present continents to determine whether you are drilling on land or offshore. Place your findings on a world outline map.
5. Look at the Cambrian map to determine which continents probably had a warm climate. Where would you expect to find coral limestone deposits and why? On a world outline map locate the present position of those places. Which of those areas might have coral reefs growing there now?
6. Remembering that species begin to differ when separated and appear most alike when able to spread freely over a range; and that barriers to ocean life include land masses, deep ocean water, and cold temperatures; how did the corals change over geologic time? Look especially at the Devonian, the Permian, the Cretaceous, and the present.

Appendix I

Activity 1

Objective; to understand the concept of Pangaea by using Wegener's clues to construct a map of the continents joined together.

Materials; outlines of continents with clues

2 sheets of construction paper(different colors)

carbon paper

paper clips

pencil or pen

sissors

tape or glue

Procedure; Arrange the outline, carbon paper, and construction paper so that the outline is on top, the carbon beneath (ink side down) and the construction paper is on the bottom. Hold the papers together securely with several paper clips. Trace the continental outlines and the outlines of the clues onto the colored paper. Remove the outline and the carbon paper and cut out the continent shapes. Emphasize the clue areas with pencil or color pencil. Use the clues to assemble the map of Pangaea. Glue or tape the pieces into position on the second piece of construction paper. Label the map.

Discussion; On the outline map (which is on the following page) the clues the students will be using are ancient mountain chains, ancient rock which is the same age and composition, glacial scratches on bedrock which appear to move in the same direction. The geographic fit of the continents along their continental margins will also be very helpful.

Key to Symbols;

ancient mountain ranges

ancient rock of similar form

glacial scratches

Figure available in printed form

Questions

1. What are the names of the mountain ranges used as clues?
2. Why do the continents appear to have two borders in some areas?
3. Why don’t the continent’s edges match up perfectly?
4. What were some of the other clues Wegener used?

Figure available in printed form

Activity 2

Objective; to refamiliarize the student with some important geogra-

phic locations and to locate some new ones.

Materials; world atlas

world outline map

pencil or pen

color pencils

Procedure; Using the world atlas the student should locate the following places and formations. They should be drawn in and labeled on the world outline map. A key should be designed for rivers and mountains and noted on the map.

List of locations and geographic features;

equator Amazon River

North pole Mississippi River

South pole Nile River

North America Mediterranean Sea

South America Caspian Sea

Greenland Black Sea

Europe Baltic Sea

Asia Lake Victoria

Africa Lake Tanganyika

Australia Lake Rudolf

New Zealand Lake Nyasa

Madagascar Red Sea

India Persian Gulf

Norway Indian Ocean

Antarctica Atlantic Ocean

Spain Pacific Ocean

Italy Arctic Ocean

Saudi Arabia Caribbean

Great Britain Gulf of Mexico

Brazil Bering Strait

Argentina Himalaya Mts.

Nova Scotia Urals Mts.

South Africa Caucasus Mts.

China Alps

Atlas Mts.

Caledonian Mts. Appalachian Mts.

Andes Mts.

Rocky Mts.

Figure available in printed form

Activity 3

1. Use an atlas to identify and label land areas A-J.
2. Use your text (page 195) to find the Mid-Atlantic ridge. Draw this on your map with a brown line.
3. Color all the squares blue and the circles red. These represent fossil trilobites of two distinct species that lived 500-600 million years ago in shallow seas along the continent edges.
4. Draw a green line running between the blue squares and the red dots. What does this line represent?
5. Remove the Atlantic Ocean by cutting the paper along the coast of North America and the eastern edge of Greenland. Next overlap the halves so that the continents meet. What does this show?

Activity 4

Objective; to understand how fossil distribution can be used to enhance the study of continental drift.

Materials; continental land mass pieces

sissors

pictures of fossil organisms

colored paper (red, green, blue, purple) cut into squares

glue or tape

sheet of colored paper

Procedure; Cut out the Gondwanaland continent pieces. Arrange them on your colored paper in their proper place for the Triassic period. Leave a space near the top for your fossil key with pictures. Arrange the fossil organism pictures with key colored squares next to each. Glue each piece down when you are sure it is where you want it.

Next, using the data chart below place a colored square for each of the representative fossils on the appropriate continent.

Data chart;

Mesosaurus a fresh water reptile of the Permian found in Brazil and Africa

Cynognathus a large land reptile (9 feet long) of the Triassic found in Argentina, southern Africa, India and China

Glossopteris a seed fern of the Carboniferous period found in South America, Africa, Madagascar, India, Antarctica, and Australia

Lystrosaurus a herbivorous reptile with a very distinctive skull shape, from the Triassic period found in Africa, India, Antarctica, Indochina, western China, and central eastern China

Questions

1. China and Indochina are not usually included in the Gondwanaland map. How might *Lystrosaurus* have gotten to those areas? Be creative in your answer, scientists don't know either!
2. *Mesosaurus* is distributed only through South America and southern Africa, unlike the other fossil forms we mapped. Why didn't Mesosaurus spread into the other Gondwanaland continents? Use your data chart information and the continental drift maps for the Permian and Triassic.
3. Using the continental drift maps and your data chart determine whether *Glossopteris* was adapted to a warm or cold climate.

Figure available in print form

Continental Land Mass Pieces Figure available in printed form

Appendix II

Continental Drift Maps Figure available in printed form

Notes

1. S. Stanley, *Earth and Life Through Time* , p 173.
2. R. Miller, *Continents in Collision* , p 49.

3. S. Stanley, p 177.
4. *Ibid.* , p277-278.
5. *Ibid.* , p 201.
6. *Ibid.* , p 178.
7. K.Turekian, *Oceans* , p 98.
8. C. Raymo, *The Crust of Our Earth* , p 46-47.
9. Tarling and Runcorn, *Implications of Continental Drift to the Earth Sciences* , p 406.
10. *Ibid.* , p 408-411.
11. Scientific American Readings, *Continents Adrift and Continents Aground* , p 173.
12. R. Miller, p 158.
13. S. Stanley, p 175.
14. McElhinny and Valencio, *Paleoreconstruction of the Continents* , p 33-36.

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Coble,C., Rice, D., Walla, K., Murray, E., *Earth Science* , Prentice Hall, N.J., 1988.

Cooney, T., Pasachoff, J., Pasachoff, N., *Earth Science* , Scott Foresman, Glenview, Ill., 1983 and 1990.

Both of the New Haven Science Dept. approved texts cover plate tectonics, sea-floor spreading, and magnetic striping of the ocean floor. Maps of tectonic plates and regions of geologic activity are also contained in the student texts. These should be used as supplemental material.

Bibliography

Eicher, D. and McAlester, A.L., *History of the Earth* , Prentice-Hall, N.J., 1980.

Excellent silhouette drawings of plate movements over geologic time.

Hamblin, W.K., *The Earth's Dynamic Systems* , Macmillan Publishers, N.Y., 1989.

Excellent drawings of geologic processes, and explanation of terms.

McElhinny, M.W., and Valencio, D.A., Editors, *Paleoreconstruction of the Continents* , American Geophysical Union, Washington, D.C., 1981.

Good maps of plate movement from Late Cambrian to Late Permian, but text is quite difficult.

Miller, Russell, *Continents in Collision* , Time-Life Books, Alexandria, Va., 1983.

Extremely well written book dealing with history and process of plate movement.

Raymo, Chet, *The Crust of Our Earth* , Prentice-Hall, N.J., 1983.

A very basic book which could be used with children.

Scientific American, Readings from, *Continents Adrift and Continents Aground* , W.H. Freeman and Co., San Francisco, 1976.

Readings range from historical to physical geology of plate movement to fossils and evolutionary significance of movement. A good overview of the subject.

Stanley, S., *Earth and Life Through Time* , W.H. Freeman and Co., N.Y., 1986.

This text was the source of most of my information. It is easy to read and understand but at the same time covers a huge amount of information. For further study this would be my number one suggestion.

Tarling, D., and Tarling, M., *Continental Drift* , G. Bell & Sons, Ltd., 1971. This book deals well with ancient life and ancient climates.

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

Discussion of polar wandering and much information on life forms of the various geologic periods and extinctions.

Turekian, Karl, *Oceans* , Prentice-Hall, New Jersey.

This text is a good source of information about the ocean floor and its clues to plate movement, especially paleomagnetic research.