CHAPTER 22

EVIDENCE FOR EXTINCTIONS—WHY DO WE GET THEM?

THEY DOMINATED THE EARTH, AND THEN WERE GONE—HOW DOES THE WORLD CHANGE COMPLETELY?

We use the term "dominant species" or "dominant type" in a rather loose and arrogant fashion. If we wanted to be accurate, we should refer to those types of organisms that make up the largest biomass (the total weight of all individuals of that type on the earth) and in this sense we would have to conclude, in a somewhat humiliating fashion, that—using different assumptions and calculations—the dominant species of our era are bacteria, nematode worms (bloodworms), or insects. This viewpoint however does not appeal to us, and we prefer to designate as dominant species obvious large organisms on the planet. Thus if you are suddenly dropped into an undisturbed temperate area on the globe, for instance northeastern United States, what would strike your eye would be oaks, maples, and many mammals ranging from rabbits to deer, bear, wolves, and coyotes. You might notice some birds, but reptiles and amphibia would not be particularly prominent and insects, though numerous, would not attract too much of your attention. Thus, from our viewpoint, the dominant species would be the big broad-leafed trees and the mammals. We would therefore fully agree that this is the age of mammals.

But now that we can read the fossil record fairly well, we understand that the world was not always so. Before the Cambrian era, there were many very strange apparently invertebrate animals, but almost all of them died by the beginning of the Cambrian. Then there was an era (the Paleozoic) filled with fish, amphibians, tree ferns, and some insects and relatively small plants, but no reptiles, birds, or mammals and no flowering plants or true trees. These too nearly vanished—one can hardly consider today's world to be overwhelmed by frogs and ferns—and we encounter an era (the Mesozoic) in which reptiles are everywhere. If you lived near a forest at that time, first, the forest would not have flowering trees, and there would be no true flowers; and, second, the large animals that browsed or hunted in the forest would have been reptiles. Anything that flew overhead was also a reptile, and instead of porpoises, otters, and seals, there would have been reptilian equivalents. Some of the dinosaurs—a subgroup of reptiles—were indeed truly massive, much larger than elephants (though still smaller than the largest mammal, a blue whale). The only mammals were small rodent-like creatures, perhaps adept at stealing eggs at night. Yet the dinosaurs vanished. Although the occasional alligator or anaconda is indeed a threatening creature, by and large we do not spend our lives in fear of these creatures. Why do they no longer rule the world? And is it possible that we could go the way of the dinosaurs, and that the age of mammals and flowering plants (the Cenozoic) could be superseded by an era of very different creatures? We must ask these questions.

THE VIOLENCE OF THE EARTH—CONTINENTAL DRIFT

To most of us, the land that we know is a pretty stable thing. People are born, live, and die in the shadow of a mountain or along the shores of a lake. Ancient paintings illustrate landscape features that we recognize today. References in the Bible, Koran, or other holy books identify mountains and rivers that are still present. The idea, therefore, that the earth was once very different is certainly not an intuitive one. Thus, when Antonio Snider-Pellegrini pointed out in 1858 (the year before Origin of the Species was published) the close fit of the eastern coasts of the Americas to the western coasts of Europe and Africa (Fig. 22.1) he was only emphasizing what others had seen, but adding also the note that the soils of the opposing sides had some relationship to each other. The curious mirror symmetry between the East and West Coasts of the Atlantic Ocean is even more similar if one follows not the current coastline but the continental shelves. (In several areas of the world, the

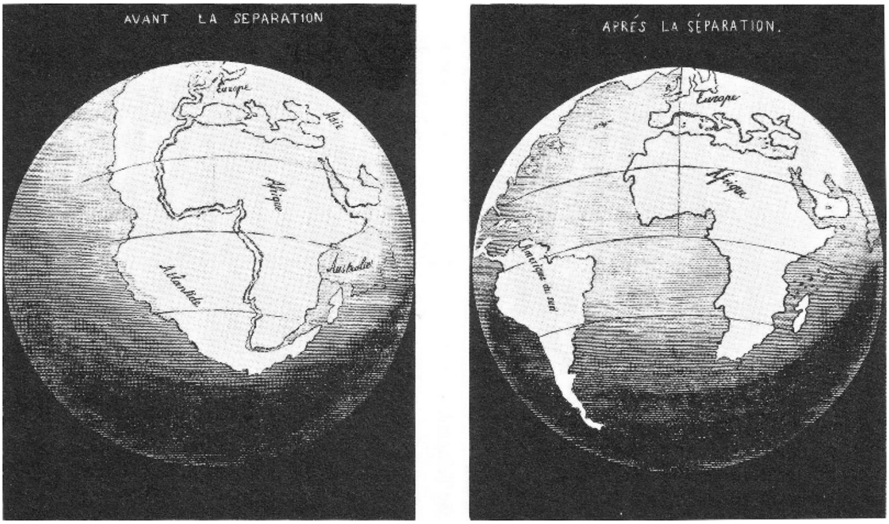

Figure 22.1. Snider-Pellegrini's identification of the close fit between the east and west coasts of the Atlantic Ocean. He was a little bit fanciful—note how he wrapped South America around the horn of Africa—but he was generally quite correct in his supposition. The title on the left is "Before the Separation" and on the right, "After the Separation". Credits: Snider-Pellegrini map - http://pubs.usgs.gov/gip/dynamic/historical.html

land surface continues its gradual descent for several miles into the ocean suddenly dropping off in a cliff-like structure to a depth hundreds or thousands of feet deep. This dropoff can sometimes be recognized as an abrupt change in the color of the water, if it occurs where the initial depth of the sea is sufficiently shallow to reflect light from the bottom, and is called the continental shelf. The mid 19th C was a period of formation of concepts of geology and the fit was noted as a curiosity. Snider-Pellegrini suggested that the lands had once been connected (Fig. 22.1). Once it was understood that the earth was quite ancient, and that the earth might have formed as a very hot body that had pulled off from the sun, the physics of the structure of the earth became more obvious. Granite rocks are heavy. Technically, the appropriate description is that they are dense or have a high specific gravity, meaning that a given volume (one cubic centimeter, or a cube approximately ½ inch on each side) weighs quite a bit. Rocks are dense, but they are not as dense as metals. Thus they will float on liquid metals. For instance, if you put a rock of specific gravity approximately 3 g/cc onto a pool of liquid mercury, specific gravity approximately 13 g/cc, the rock will float on the mercury in the same way that oil (specific gravity approximately 0.8 g/cc) will float on water (specific gravity 1 g/cc). If the earth was once hot enough so that metals such as iron were molten, then the rocks (continents) would float on them, much as pieces of bread float on a dish of soup. From here it is a very short step to assume that the continents broke apart during this period before they finally settled into place.

As late as the 1950's, this was the argument that was taught: The continents bordering the Atlantic had once been part of the same mass and had subsequently separated, but this separation had happened very early in the history of the earth and had no bearing on evolution. Still, there were anomalies that were confusing. Among them were the following:

1. The fossil record indicated tropical plants and animals in locations that are today far too cold to support them.
2. The natural magnetism of certain rocks has a north and south pole, like any magnet, but sometimes these rocks—part of a large mass, not just loose on the ground—point somewhere other than to the north pole.
3. The distribution of animals and plants on the planet is rather curious. There are large flightless birds in Africa (ostriches), Australia (emus), New Zealand (the now extinct moa and its cousin the kiwi), and South America (rheas). In the 1950's it was assumed that these were the result of convergent evolution, or similar circumstances producing similar selection and similar results among unrelated organisms (see Fig. 7.3). However, similar birds were not found in North America, Europe, or Asia. Likewise, although monkeys are found in South America, they are all of the tailed variety, and there are no tailless, or anthropoid, apes in South America. Marsupials (animals with pouches for their young) are found in Australia and South America. Some situations undoubtedly provoke convergent evolution, such as the similar shapes of seagoing creatures (see Fig. 3.4), but the similarities of ostriches, rheas, and emus derives from different forces, as was gradually understood during the 1960's and dramatically

confirmed in the 1990's and the 21st Century by analysis of DNA. The story of this changed viewpoint represents a realization derived from the convergence of findings from several disciplines, one of the most convincing arguments of science (Chapter 9, page 114). Watching the change in attitude is one of the marvelous stories that makes the history of science so similar to a mystery novel.

4. The distribution of volcanoes and earthquake zones on earth is not random. Both tend to occur in coastal mountain zones and otherwise in high and rough mountain settings. In fact, they are so characteristic of the Pacific coasts that almost the entire boundary of the Pacific Ocean is known as a "ring of fire" (Fig. 22.2). Since science is always about how things work, geologists were anxious to understand what drove volcanoes and earthquakes.

The story begins in the 1960's with a seemingly useless project of the type that is often described by politicians as a "waste of taxpayers' money". The National Science Foundation agreed to sponsor the full mapping of the floors of the ocean, especially the Atlantic, to understand the trenches, mountain ranges, and volcanoes of the Atlantic. It was known that there was one major by a mountain range, down the center of the Atlantic, and that the volcanoes of the Atlantic (Iceland, the Canary Islands, the Cabo Verde Islands, Tristan da Cuna) bordered the trench.

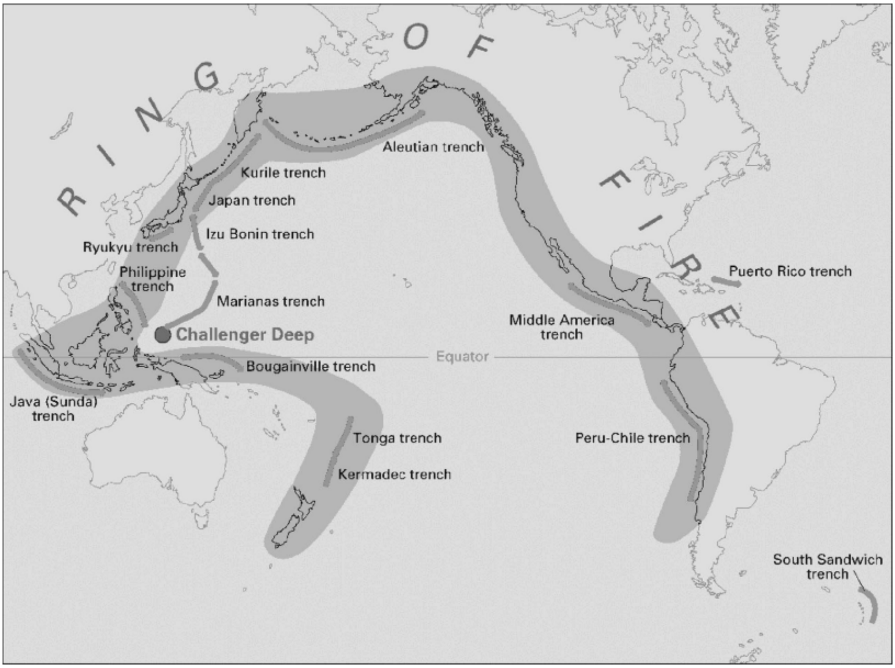

Figure 22.2. The Ring of Fire. The dark gray area is the Ring of Fire, the belt along which numerous volcanoes are found. The darker lines indicate deep trenches, areas in which there is substantial subduction. Credits: Ring of fire - http://pubs.usgs.gov/publications/text/fire.html

The boats of the NSF were to map the depths, the variations of the magnetic fields, and other physical measurements, while crisscrossing the ocean. The project was to learn more about the structure of the oceans, on the basis of pure science as well as for the practical purposes of aiding navigation and fishing industries. As a part of the project they undertook to map the magnetic fields of the Atlantic Ocean, the modest deviations from true north that affect magnets when the magnets are near iron-containing rock. What they found very much altered our view of the history of the earth as well as of the mechanics of evolution. In brief, the evidence indicated that the continents had actually drifted during the period in which plants and animals were evolving, and that they were continuing to drift. As the great French physiologist, Claude Bernard, had remarked, if the evidence contradicts the hypothesis, one must accept the evidence, even if the hypothesis is supported by the most influential scientists. In this case the hypothesis was that the position of the continents was set prior to the origin of life on earth. The evidence, however, indicated that the continents could drift and were still drifting. The evidence was very solid, and it gave an interpretation to the mechanics of earthquakes and volcanoes. The evidence was as follows:

- In the middle of the oceans there are usually ridges, such as the mid-Atlantic ridge running north-to-south in the middle of the Atlantic (Fig. 22.3). They are in effect underwater mountain ranges, occasionally bursting above the surface to form, in the case of the mid-Atlantic ridge, islands such as Iceland, the Canary Islands, Tristan da Cunha, and the Falkland (Malvinas) Islands. These islands are typically volcanic and subject also to earthquakes.
- Near the shores of continents are often deep trenches, such as along the Pacific coast of the Americas. These trenches are also areas of earthquake activity.
- Along the mid-ocean ridges and elsewhere, there are often underwater volcanoes, which erupt but, because of the weight and cooling properties of the water, never reach the ocean surface.
- If you heat a magnet to red heat or even to molten iron and allow it to cool, when it solidifies it takes on the orientation of the prevailing magnetic field. Thus, if you heated an iron rod and laid it in an east-west direction to cool, you would create a magnet for which one side of the rod was the north pole and the other side was the south pole. If you laid the hot iron rod in a north-south direction, the entire rod would be magnetized so that one end was north and the other end was south (Fig. 22.4).
- Molten lava contains iron and other magnetic metals. Thus, when lava solidifies, it creates a permanent magnetic record of the direction of the magnetic poles at the time that the lava cooled.
- The magnetic poles of the earth are known to drift slowly, so that they are near to but not identical with the celestial poles (the axis on which the earth turns). This drift is reflected in the magnetism of successive lava flows from a volcano.

The surprising result of this basic information was that, along the mid-Atlantic ridge, successive changes in magnetism indicated that the oldest lava was furthest from the ridge, and that the changes in magnetism were symmetrical on both sides

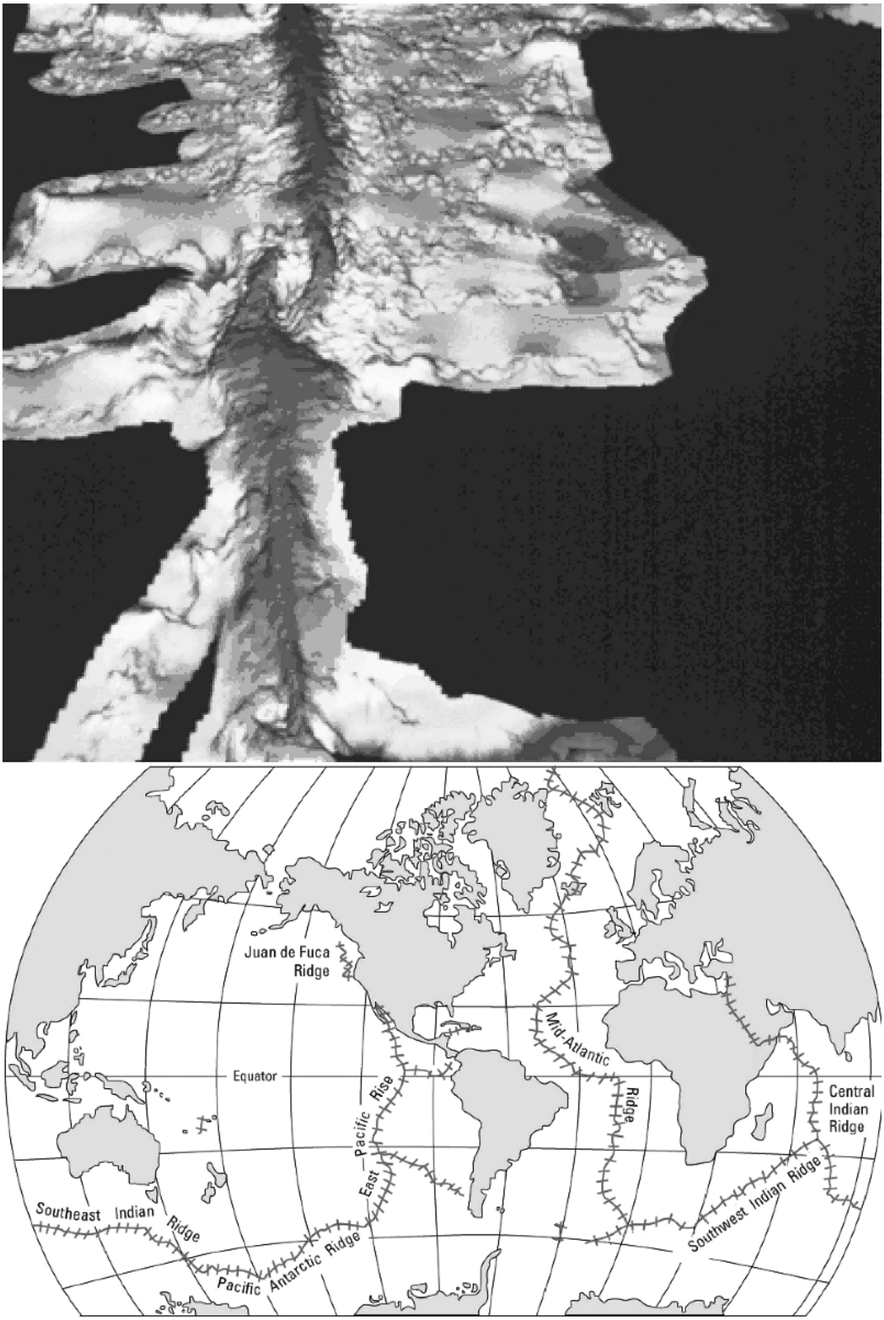

Figure 22.3. Upper: False-color image of the Mid-Atlantic Ridge. Lower: The major ocean ridges. Credits: Mid-Atlantic ridge - http://pubs.usgs.gov/publications/text/topomap.html, Last updated: 05.05.99, Major ridges - http://pubs.usgs.gov/gip/dynamic/baseball.html, Ocean ridges - http://pubs.us.gov/gip/dynamic/developing.html

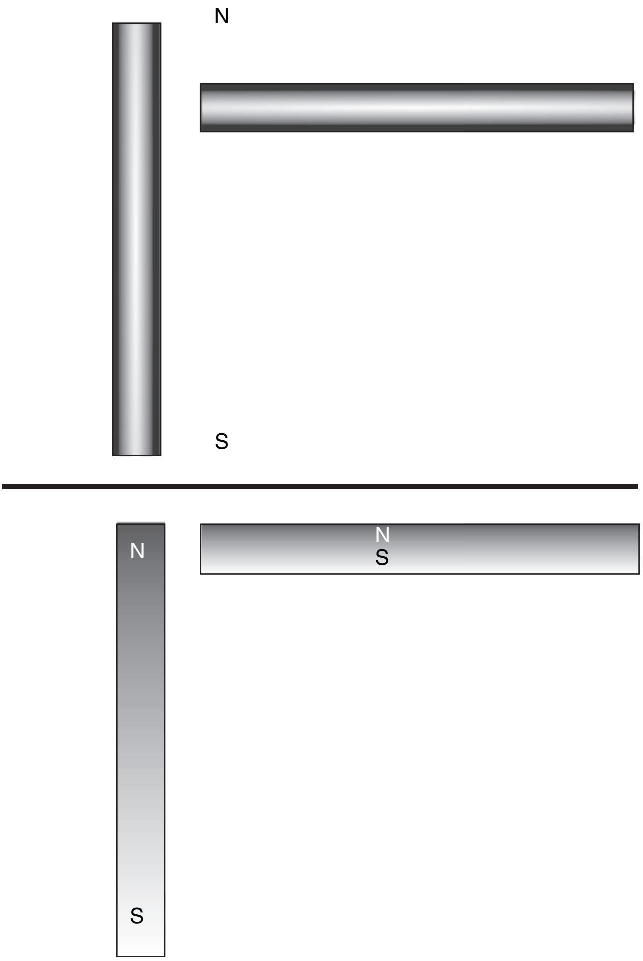

Figure 22.4. Alignment of magnets. If iron rods are heated to red hot and allowed to cool in a magnetic field, they will become magnets with the orientation of the field to which they were exposed

of the ridge (Fig. 22.5). This result indicated that the lava was spreading in both directions from the center of the ridge. Other geological evidence indicated that the lava was in fact the formation of new ocean floor, and that it was shoving the outer edges further away.

The next task is to measure the speed at which this expansion occurs. Again judging from evidence of magnetic fields on land, and from the ages of the rocks dredged from the ocean floor, it is possible to measure the age of the rocks on the east and west sides of the ridge as well as the distance from the ridge. In other words, it is possible to measure the rate of expansion, and to estimate when the continents were connected and since when they are being pushed apart by the

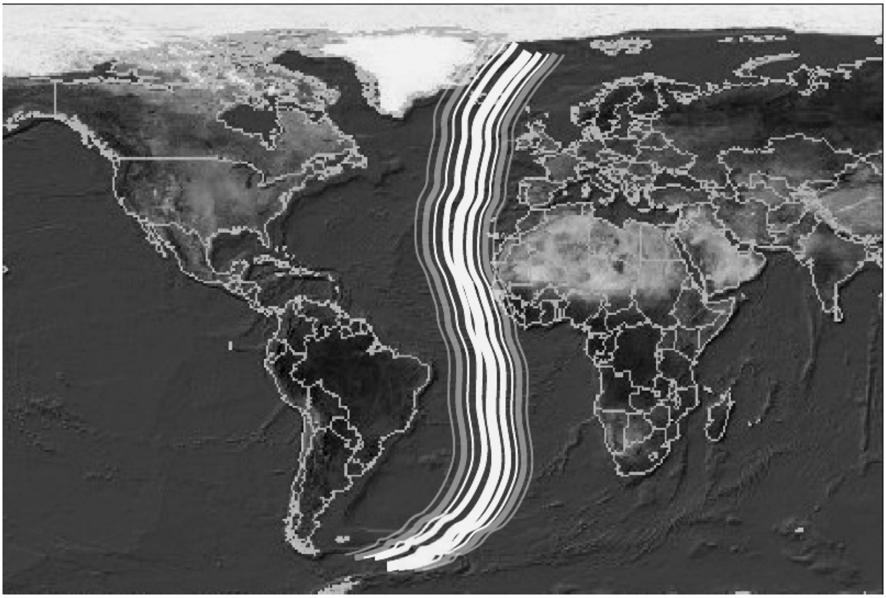

Figure 22.5. Symmetry of magnetic ridges. The explorations of the National Science Foundation traced the magnetic anomalies (indicated by lines of different colors and widths) in the Atlantic Ocean. The results produced two surprises: First, the farther the anomaly was from the Mid-Atlantic Ridge (thickest line in center), the older it was. Second, the anomalies were symmetrical on both sides of the ridge. In other words, if the anomaly in the second line to the west of the ridge pointed 3º west of today's magnetic north, the second line to the east of the ridge also pointed 3º west of magnetic north. The most reasonable interpretation was that there was outflow from the ridge, pushing both eastward and westward

expansion of the Atlantic floor. To the surprise of almost everyone, the calculations indicated that the continents were connected in biological time. Snider-Pellegrini was right, but the time scales were very different. Today, satellites are capable of measuring the movement of the continents and have confirmed that the Atlantic Ocean is expanding at a rate of a few inches per year.

Trenches, mountain ranges, and volcanoes exist in many parts of the world, and similar arguments have led to a very different image of the earth. The center of the earth is hot and molten, as is easily recognized from volcanoes; and the movement of this fluid phase is responsible for the gradual change in the magnetic fields of the earth. The continents—rocks that are less dense than the metal-rich liquid core—float like pieces of bread in soup on the core, drifting apart and occasionally colliding. The collisions create crumpling, like two trains colliding. From space, the folds of the Appalachian mountains look very much like a blanket that has been shoved up from the side, as indeed they are: they represent the buckling of the continent (Fig. 22.6). Where the movement is more rapid and more recent, the collisions lift the mountain ranges of the Alps (Africa colliding with Eurasia), the

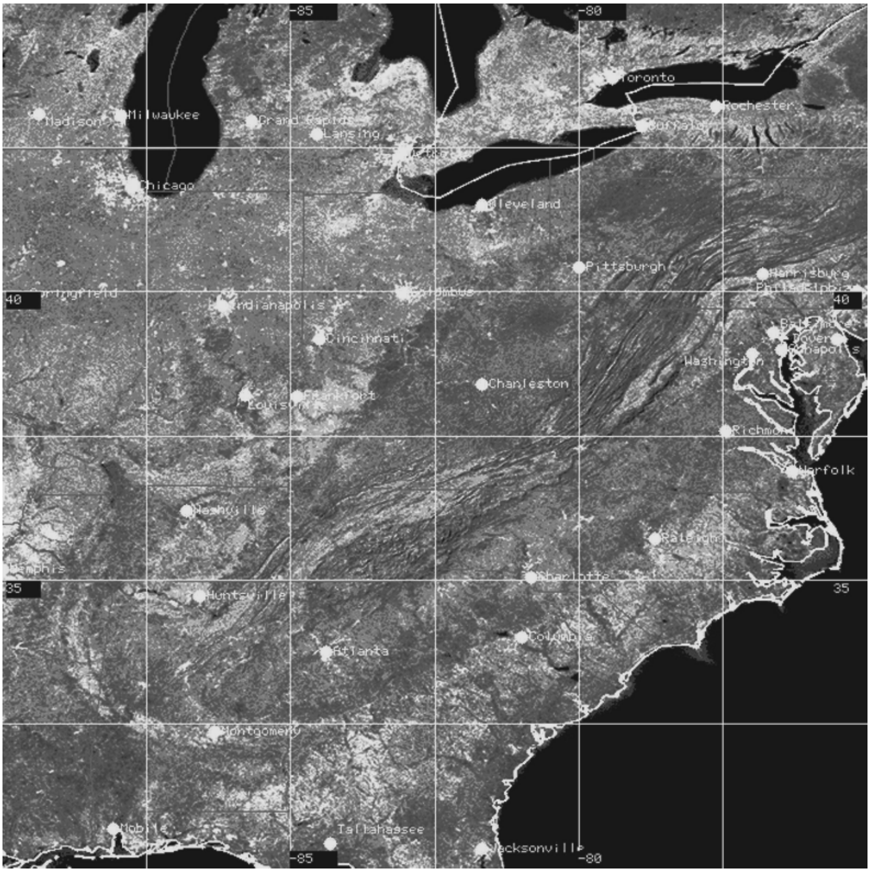

Figure 22.6. Buckling of Appalachians. Note, in this satellite image, that the Appalachian mountains are folded like a blanket. This folding comes from the pressure of plates pushing against the continent. Credits: http://eol.jsc.nasa.gov/sseop/clickmap/map078.htm

Himalayas, (India colliding with Asia), and the Rockies through the Andes (the westward movement of North and South America against the Pacific plates). In some areas of the world, the mechanics of the process is obvious to the trained eye. In northern India and Tibet, the soils and rock structures on the north and south sides of some valleys are very different, since the valley represents the line of collision. (It is a valley, created by the process of subduction, described immediately below.) Where the pieces of bread pull apart, they leave deep trenches, such as the deep depression that forms the Dead Sea, the Red Sea, and the Afar Depression of East Africa, or Death Valley in the United States.

Sometimes, again like the collision of two trains, one continent (or tectonic plate) slips beneath the other. This process is called subduction. Its slipping beneath creates a deep rift or valley, often dipping deeply enough to allow the escape of molten lava and the production of volcanoes. Particularly in the Pacific, volcanoes follow the coastlines in what is called the ring of fire (Fig. 22.2); and the subduction lifts mountain ranges beside the trenches. The continual movement causes earthquakes, much as continual tugging on a rusty bolt evokes occasional jerky slips of the bolt.

This interpretation gave a plausible interpretation of the coastal mountain ranges, which in this sense would be buckled as the push of the ocean floor crumpled the edge of a continent, as a throw rug would buckle if you pushed it from one edge (see below).

From the standpoint of evolution, the most important aspect of these findings was that, through radioactive dating (see Chapter 8, page 104), measurements of magnetism, and other techniques, the rate of this spread could be measured; and the measurements indicated, to most scientists' surprise, that the movement had occurred within biological time—that is, within the last 300 million years. (It is likely that there had been movements before this, but these are the ones that interest us). If indeed the continents were recently connected, some of the bizarre distributions of animals and plants can be understood. There are no placental mammals in Australia because Australia was connected with the other continents during the time that warm, furry animals were evolving but was separated before truly effective placentas had evolved. In competition with other animals, the true placental mammals succeeded very well, driving the marsupials to a very minor part of the animal world, but the Australian marsupials did not face this competition. The rhea of South America, the emu of Australia, and the ostrich of Africa were similar not because of convergent evolution but because a large flightless or nearly flightless ancestor roamed the land when South America, Africa, and Australia were connected (but were not connected to North America, Europe, or Asia). Their similarity reflects common ancestry, and their distribution the connectedness of the continents at the time of their appearance. Subsequent DNA testing has confirmed this hypothesis: the birds are indeed closely related. There are monkeys but not apes in South America because South America was still in contact with Africa when primates evolved but was separate before the apes evolved. The appearance of tropical fossils in currently cold lands may reflect a different position of the continent rather than a different temperature of the earth. Today the biology of distribution of organisms and the geological data confirm each other, and we have a far more meaningful understanding of the otherwise idiosyncratic distribution of organisms on earth.

The bulk of the geological evidence, including also the distribution of magnetic fields, comparison of soils, the activity of volcanoes and earthquake zones, and the existence of fossils inappropriate to current climatic conditions where they are found, leads to a hypothesis that is now very well defended and widely accepted: Approximately 250 million years ago, the continents were connected in what was essentially a single land mass, now given the name Pangaea. At this time, the period of the "old animals" (Paleozoic, see Chapter 20), there were fish, amphibia, and ferns, which were distributed worldwide. By the Mesozoic ("middle animal") period approximately 135 million years ago, the southern hemisphere continents and Africa

(Gondwana) were separating from the northern hemisphere continents (Laurasia). At this time, there were dinosaurs and early mammals, as well as the ancestors of birds. Dinosaur fossils are identical in eastern South America and western Africa. Fossils of the ancestors of the large flightless birds are found; they give rise to the ostriches, rheas, and emus. DNA evidence (Chapter 15) now has established that these birds are related and are not the result of convergent evolution (page 305). There are no ratite birds in the northern hemisphere (other than in Africa) because Laurasia and Gondwana were separated by this time (Fig. 22.7).

By the beginning of the Cenozoic ("recent animals"; modern period, 65 million years ago) South America had definitively separated from Africa, and Australia and Antarctica were likewise distant from the other continents. The Australian group had separated from the European complex before true placental mammals had become established, and thus it has no native true mammals, only marsupials (other than, of course, flying bats). The marsupials also reached South America. However, separation of South America was becoming definitive, and fewer mammalian groups reached it. Thus the rodent-like, arboreal (tree-living) monkeys that actively use their prehensile ("grabbing" or "holding") tails to climb arrived but the later tailless anthropoid apes did not.

The hypothesis of continental drift explains the peculiar distribution of animals and plants around the globe. (Differences in plant distributions are less marked, since seeds can be widely dispersed by wind, birds, or even sea currents. Darwin cultivated over 200 species of plants from islets consisting of one or two palm trees ripped from Caribbean shores by a hurricane and drifting in the Gulf Stream to England.) It also explains much of the violence of the earth. The violence of the earth is very similar to that of a traffic accident, in this instance one of a light-weight car colliding with a more massive one.

The violence of the earth. Volcanoes, glaciers, and meteors

Assume that the cars will not bounce, roll, or otherwise undergo any movement other than inexorably plowing into each other. In this case, two changes are likely to occur: they will crumple, and the lighter one will go above the top of the heavier one. This is what happens when the expanding sea floor plows into the side of a continent. The earth is divided into large pieces floating on the molten iron core, called plates, which include the major continents and the sea floor. These drifting plates bang into each other. The crumpling pushes the mountains up. The diving of the sea floor under the floating continent creates the trench. Since the push of one plate against another creates pressure, the pressure builds until one plate slips against the other, like pushing two boards against each other; the sudden slippage produces an earthquake. At the trench and where the rock cracks (fault lines) the heat of the inner earth pushes to the surface, melting rocks and producing volcanoes, hot springs, and lava (Fig. 22.8).

Now that we understand the mechanism, it is relatively easy to collect vast amounts of data, both dramatic and mundane, in support of the hypothesis of

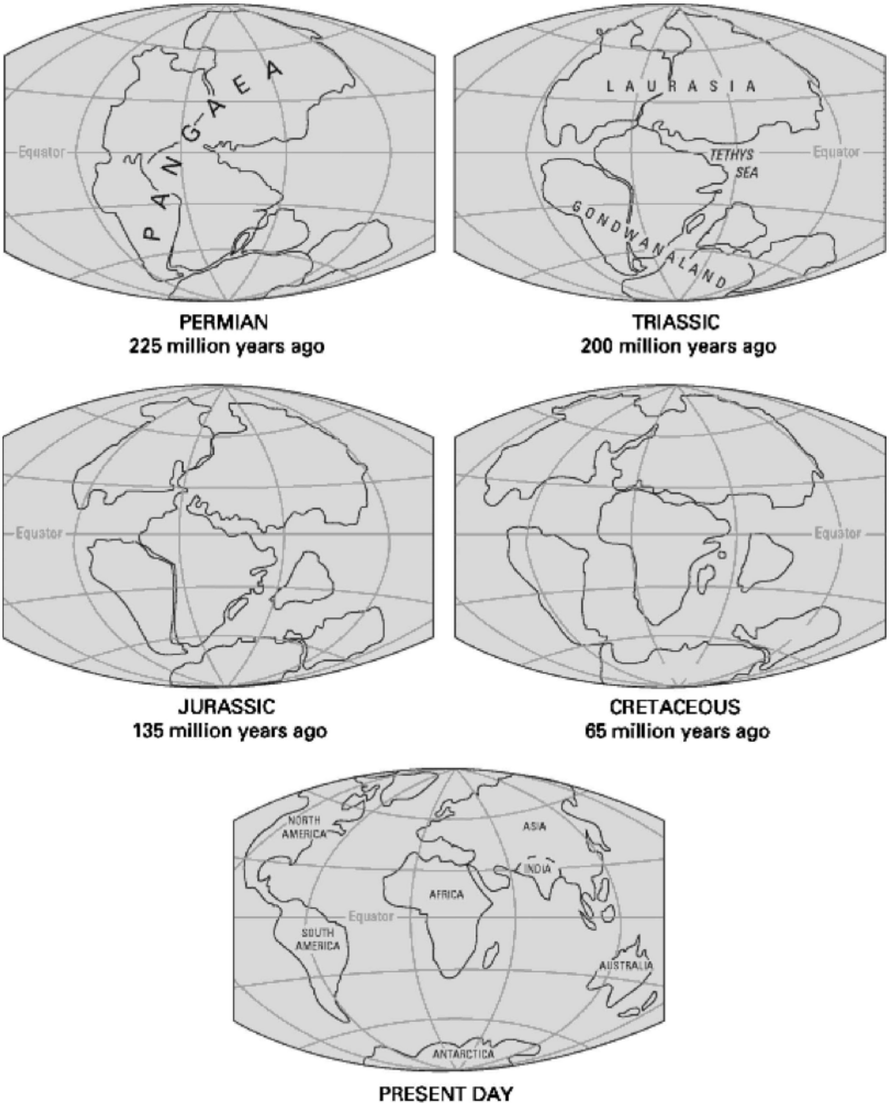

Figure 22.7. Movement of continents. The migration of the continents, based on evidence of magnetism, the fossil record, and calculations from plate tectonics. Credits: http://pubs.usgs.gov/gip/dynamic/historical.html

continental drift. Seen in overview, the central Appalachian mountains have the appearance of a crumpled blanket, as indeed they are, pushed into shape by the expanding plate (Fig. 22.6). Anomalies such as Staten Island, an island within a few hundred feet of the New Jersey shore, but with soil and rock compositions

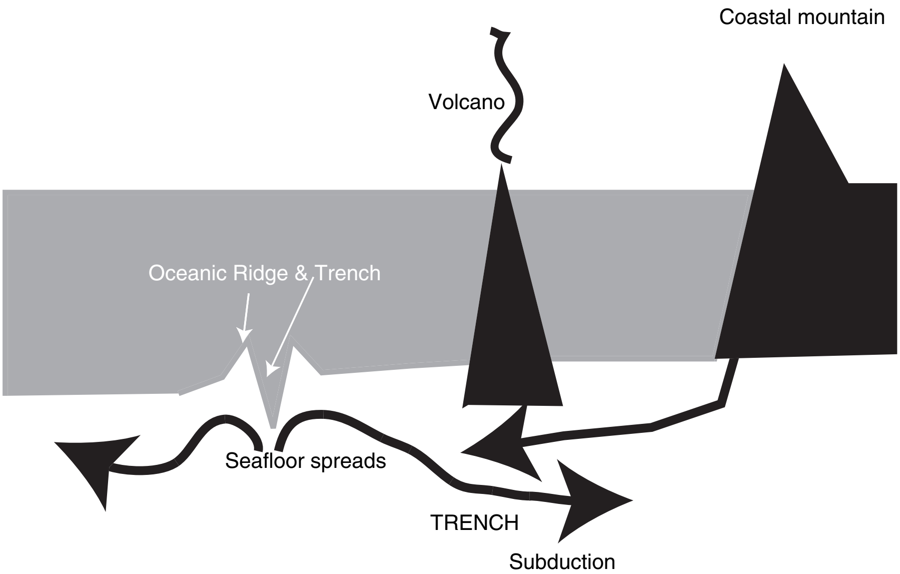

Figure 22.8. Subduction. (Left) Lava flows upward from a deep trench, flowing to either side of the trench and creating a ridge. (Right) The continent is pushing toward the left (west). (Middle) Where the two flows meet, the heavier material flows under the lighter material (subducts). Where it dives down creates a trench through which lava can flow, occasionally reaching the surface of the ocean and creating a volcano. The subducting material causes the overlying material to buckle, lifting a coastal mountain range

that do not at all resemble those of any neighboring region, are explained (with other evidence) by the argument that Staten Island first appeared far at sea and was pushed toward the coast by continental drift. In the Himalayas, there is a deep valley in which the hills and mountains on the north side differ considerably from those on the south side. The Indian subcontinent is pushing into the Asian continent. The more dense Indian side is subducting, or going under the edge of the Asian continent, shoving the Himalayas into the air. The region is a very active earthquake zone. In a similar fashion, the Alps are lifted by the gradual rotational (counter-clockwise) movement of Africa, pushing the eastern edge of Africa into Europe. The very deep valleys on earth, such as Death Valley in California and the Dead Sea valley in the middle east, are regions were two plates are separating, as if one pulled on two sides of a piece of bread. (The Dead Sea valley in fact extends from the Jordan River through the Dead Sea, through the Red Sea, and into Africa as the Afar Depression. The eastern edge of Africa is separating from the rest of the continent.) The current movement of the continents is summarized in Fig. 22.9.

Continental drift has consequences well beyond whether a land is tropical or temperate or whether or not animals and plants can migrate from one location to another. The mountain building and rifting create major differences in climates and therefore niches. Consider for instance that the Grand Canyon is such a barrier for

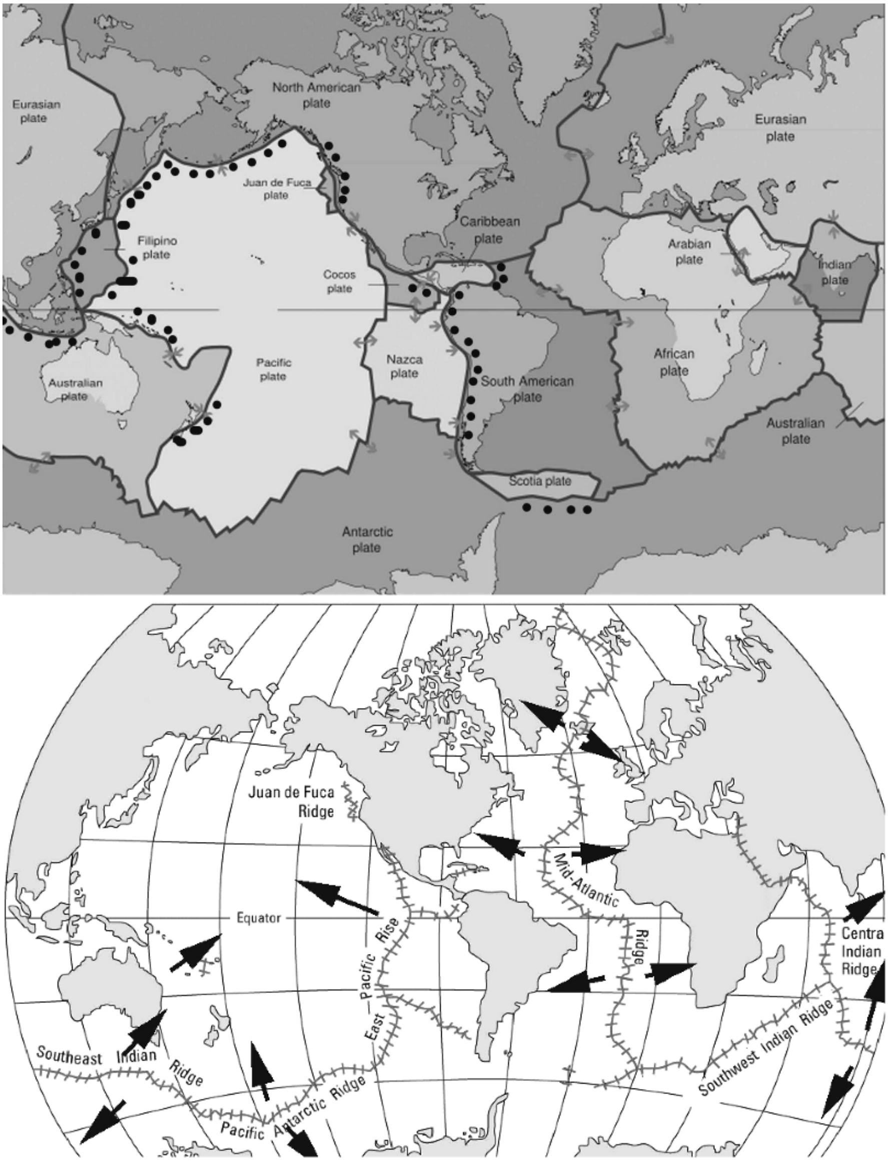

Figure 22.9. Upper: The major tectonic plates of the world. The dots indicate areas of active volcanoes, which are found along the edges of the plates. The volcanoes around the rim of the Pacific are called the Ring of Fire. Lower: Major current movements of the plates. (The movements are shown in finer detail, but more subtly, in the upper figure). Credits: Major tectonic plates - http://pubs.usgs.gov/publications/text/slabs.html, Movement of plates - Plates_tect2_en.svg This is a file from the Wikimedia Commons

squirrels that the squirrels on the north side of the canyon are substantially different from those on the south side, or consider the difference in climate between a sea floor or seashore and a land, formerly seashore, now 7,000 feet above sea level. We will address these issues in the next chapter.

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http://pubs.usgs.gov/gip/dynamic/world_map.html (Explanation of continental drift from US Geological Survey)

STUDY QUESTIONS

1. What reasons, besides intellectual curiosity, were there to explore the characteristics of the ocean bottom?
2. Would it have been possible before the mid-20th C to identify continental drift?
3. How many questions can be answered by the theory of continental drift?
4. If you can do so safely, heat a soft iron rod to red heat. Set it down and allow it to cool undisturbed, noting its position. Once it has fully cooled, by use of a magnet or iron filings determine if it is magnetic and, if so, where its north and south pole are. (Hint: if you hang it balanced on a string, its north pole will point toward north.) Repeat the experiment, but this time allow it to cool in proximity to as large a magnet as you can find. Are the results different?
5. What is the Ring of Fire? Is there only one? Why or why not?
6. What other limited distributions of animals and plants would you predict according to the hypothesis of continental drift? Why?

CHAPTER 23

THE VIOLENCE OF THE EARTH: RAINSHADOWS AND VOLCANOES

The violence associated with continental drift has a substantial impact on living creatures. Individual earthquakes can be disruptive, but they generally are local and threaten a specific species only if the species is very limited in range and confined to a tiny area (but see also Chapter 29, page 326 on the Indian Ocean tsunami). However, in the longer range, mountains are built by these processes. The building of mountains creates new habitats for animals and plants and thus increases variation in environment, allowing a greater variety of species (see Chapter 24, page 336). As an example, note that one can find very cold-weather organisms, such as are found in the arctic and Antarctic, in the snow-covered mountains of the Andes at the equator. More importantly, mountains markedly alter the climate over a very large range.

RAINSHADOWS AND CLIMATE CHANGE

Changing geography, such as the building of mountains, changes climate in more ways than the obvious ones that mountains are much colder at the top than the bottom. They create barriers to the movement of many animals and plants, separating the populations on the two sides of the range. This can be an important force for speciation as is discussed on page 317, Chapter 22. One of the most important changes that mountain building brings about is climate change, by directing and limiting the pattern of winds. Some of the more curious among you may have noticed that the deserts in the west of North America lie just to the east of mountain ranges. The same is true of South America, southern Africa, and elsewhere. These deserts develop because of an effect called rain shadow. An excellent example is shown in Fig. 23.1, which depicts the north and south sides of the Alborz Mountains, photographed on the same day. In this part of the world, the prevailing winds blow south across the Caspian Sea, absorbing water and becoming moist as they go. When they reach the mountains, they are forced upward. The air expands because the weight of the air above it is less. If you have ever allowed gas to escape rapidly from a cylinder or a tire, you know that expanding gas cools rapidly. Also, if you have breathed out through your mouth on a cold day or seen "steam" collect on the inside of windows of a warm car on a cold day or on the outside of a glass of a