sometimes superhuman effort. Some of their theoretical contributions have been important as well. One, Cope's Rule, has been a standard organizing principle in paleontology since he propounded it more than one and a quarter centuries ago. The rule states that all species, from fungi to whales, tend to increase in size over time. A recent comprehensive analysis suggests, however, that while it is certainly true for some species, it does not hold up in all cases. Marsh would have been delighted.

CHAPTER 8

Wegener versus Everybody

Continental Drift

Early in this century, Alfred Wegener, a young German scientist, proposed his theory of continental drift. The basic idea was this: All of Earth's continents were, at some time in the distant past, joined into a single great land mass, which he called "Pangaea," and the various parts we see today broke apart some 200 million years ago and have been sailing majestically across Earth's surface, like huge icebergs over a denser substratum.

Today, we have little problem with his idea; in fact, it is the foundation on which all of modern earth science is based. When Wegener put it forth, however, the reaction was not only negative, but so intense that many who might have found themselves in his corner hung back in fear of endangering their own careers. For five decades, its few proponents were dismissed contemptuously by scientists on both sides of the Atlantic, but most strongly by those in the United States. Critiques often included such words as *preposterous, antiquated, serious error, footloose,* and even *dangerous.*

The reasons for the dismissal of both the idea and its author are many and instructive. It may have been partly the idea's connection, however tenuous, with catastrophism, which was out of favor at the time. Today, we know that Earth's history incorporates elements of both catastrophism and uniformitarianism. Thus, Lord Kelvin was intuitively correct in supporting catastrophism, *and* Thomas Henry Huxley, on the side of the geologists, had reason to support uniformitarianism.

Some of the reaction also had a kind of not-in-my-back-yard flavor, for Wegener—an astronomer and meteorologist—was an outsider as far as the earth scientists were concerned. And in truth, continental drift was of peripheral importance to him. His own father-in-law, a respected meteorologist in his own right, was one of Wegener's earliest critics and tried to dissuade him from straying out of his own field of expertise.

So strong was the reaction that the name of Galileo was invoked more than once by his few supporters. In 1926, for example, Harvard's Reginald A. Daly published a book called *Our Mobile Earth;* on its title page appeared the words *E pur su Muove* (roughly, "But it does move"), which Galileo is said to have mumbled under his breath after his humiliating abjuration.

Although the literary allusion to Galileo is a strong one, Wegener's case has far more in common with that of Darwin. In fact, a fascinating set of parallels between the two situations practically tells the story.

A Strong Parallelism

Wegener (1880–1930), like Darwin, was born and brought up in comfortable circumstances. Driven by dreams of exploring northern Greenland, he built up his endurance with long days of walking, skating, mountain climbing, and skiing. Vigorous, healthy, and daring, he participated in some audacious adventures, including (with his brother Kurt) a balloon flight of more than 52 hours. This flight set a record and was an especially bold venture, considering the primitive equipment available at the time.

Both Wegener and Darwin undertook long, difficult expeditions in their young lives and did extensive data collecting—Darwin mainly during a five-year voyage on the good ship *Beagle,* and Wegener during several long sojourns in Greenland. In 1913, Wegener's expedition was threatened during the ascent of the inland glacier by major calving (splitting) of the ice, extending right up to the camp. The group's crossing of the island lasted two months and was completed only with the greatest difficulty.

Like Darwin, Wegener was trained in an area of study that had little to do with the topic in which he made his mark. Darwin had studied medicine and theology and did early scientific work in geology. Wegener took a doctorate in astronomy and became a practicing meteorologist. After returning from his first sojourn in Greenland (1806–1808), he became a lecturer in both astronomy and meteorology at the University of Marburg, in Germany. He is reported to have been a fine, popular teacher.

Brave and robust in those younger years, he was apparently also a peace-loving person. This made his service during World War I all the more difficult for him. Also, as with Darwin, he did his major work in the midst of a health problem. Shot twice, he was no longer fit for active duty and was transferred to full-time employment in the military's field meteorological service. Further, although he first presented his ideas on continental drift in an article and lecture in 1912 (before World War I), his fame rests on the book he wrote during the war (published in German in 1915). This means that he somehow managed to come up with a major, earth-shattering book while on sick leave and while finishing out the war in the field meteorological service.

His book was titled, significantly, *The Origin of Continents and Oceans.*[1] Like Darwin, he used the term *origin* in the title, and he dealt, essentially, with evolutionary concepts.

And in both cases, the basic concept also cut across many lines. "The book," Wegener wrote in his foreword, "is addressed equally to geodesists, geophysicists, geologists, palaeontologists, zoogeographers, phytogeographers [phyto = plant] and palaeoclimatologists. Its purpose is not only to provide research workers in these fields with an outline of the significance and usefulness of the drift theory as it applies to their own areas, but also mainly to orient them with regard to the applications and corroborations which the theory has found in areas other than their own."[2]

In other words, like Darwin, he had brought together evidence from a wide diversity of fields. Therefore, he and his few followers were sparring with a whole range of opponents, each of whom saw him as an interloper. At this time, for example, the idea of a cooling, contracting Earth was still held by most geologists, who felt that such cooling and contracting was the only possible explanation for a variety of observations, including mountain building. Like a rotting, shriveling tomato, they thought, a contracting Earth produces both peaks and valleys in its skin. Wegener pointed to the discovery of radium and argued that the idea of a cooling Earth no longer made sense, offering in its place his own idea that the movement of continental masses slowly mashing together at some point in the past was a better explanation of mountain building.

Nevertheless, he, like Darwin, recognized the weaknesses in his theory, so he too put out several editions of his book, each heavily revised on the basis of new information and criticism. In Wegener's fourth revised edition (1929), he was still writing, "In spite of all my efforts, many gaps, even important ones, will be found in this book."[3]

Like Darwin, he was not the first to come up with his theory. In Wegener's case, the broad outline of the idea had been tentatively broached several times. Wegener wrote, "I encountered many points of agreement between my own views and those of earlier authors." One of those he mentions is H. Wettstein, who in 1880 "wrote a book in which (besides many inanities) the idea of large horizontal relative displacements of the continents is to be found. . . . However, Wettstein . . . regarded the oceans as sunken continents, and he expressed fantastic views, which we pass over here."[4]

The jigsaw fit of the continents was obvious and had been noticed as far back as the sixteenth century, when the first reasonably accurate maps began to be drawn of the New World. Francis Bacon is usually given priority credit for seeing the rough congruence, which he mentioned in his great *Novum Organum* of 1620. Actually, he was only commenting on the similar shapes of South America and Africa. In 1994, a professor of classics at Bard College, James Romm, traced the drift lineage back to a Dutch cartographer named Abraham Ortelius; according to Romm, Ortelius proposed the idea in 1596.[5]

It was Wegener who put meat on the idea, however, and developed it into something that could not be ignored. As with Darwin, then, Wegener's *Origin* became an in-the-face kind of thing. The result was a theory that was not only dramatic but also so all-embracing that few of his opponents felt they could attack it as a whole. Therefore, they went after it piecemeal, depending, of course, on their own interests and disciplines.

Details, Details

The details were indeed attackable, for at the time, far less was known about Earth than is known today. The ocean depths, covering fully 70 percent of Earth's surface, were a deep, dark secret. Sonar, deep drilling, and many other modern techniques lay in the future, so the regions far below the continental lands were just as mystifying as those beneath the oceans. As a result, Wegener had to guess about many of these details. But he felt that the grand sweep of his idea was what counted.

Today we are impressed with the audacity of a single hypothesis that could explain not only the origins of mountains and oceans, but also many of the puzzles that confronted the various specialists Wegener mentioned in his foreword. Among these puzzles were intriguing similarities on both sides of wide oceans—similarities in rock formations, as well as in living things past and present. Another was a distribution of climates in the past that was different from today's, shown for example by glacial leftovers in Africa and evidence of tropical species in the far north and south.

In Wegener's day, however, a zoogeographer looking at similarities in living things in Africa and South America might never hear of equally strange correspondences in rock formations that would intrigue geologists. Wegener, the outsider, could take the broader view, and he could see the forest, while the specialists could see only the trees. Yet, as with evolution, after the first flurry of activity, there was a long, slow fading of the theory from view, then a subsequent resurgence of interest in the mid-twentieth century, as new evidence showed the strength and beauty of Wegener's hypothesis.

Mechanism

Another striking similarity between the two cases is that Wegener, like Darwin, was not able to propose a satisfactory mechanism for his theory. With Darwin, you recall, it was the genetic aspects of selection that were missing and were not found until later.

Although Wegener knew he was right, and that everything pointed in the right direction, he too could not come up with an appropriate mechanism—in his case for the grand march of the continents. What kind of engine could drive continent-size masses through a rocky underlayer, soft or not?

The best he could come up with was a pair of candidates. One was what he called *polflucht,* pole-fleeing forces; these were due to the rotation of Earth and caused a migration of the continents toward Earth's equator. The second, which had to do with lateral displacement, he attributed to some sort of tidal drag due to gravitational forces from the Sun and Moon.

He suspected that these forces were not powerful enough to drive continents and fold mountains, but he felt that they could perhaps suffice if acting over long periods of time. And he had nothing better. Modest and sensible, he admitted that "The Newton of drift theory has not yet appeared."[6]

This weakness was to provide strong ammunition for his critics. Harold Jeffreys, whose influential book *The Earth, Its Origin, History and Physical Constitution* (1924) established a firm mathematical basis for geophysics, did some calculations and showed that the pole-fleeing and tidal forces were about one-millionth as strong as would be needed to displace continents and produce mountains. He also produced a complex quantitative theory of cooling and differential contraction that, he claimed, provided the needed forces. The logic, à la Kelvin, was unassailable and effectively stifled drift theory for decades.

Finally, like Darwin, Wegener could not prove his theory. Broad-ranging theories such as evolution and continental drift are, by their very nature, difficult to prove. A geological theory is especially unlikely to submit to conventional laboratory experimentation, and even field observations are difficult because of the great time and space requirements. As a result, Wegener could present only indirect evidence.

Wegener thought he had some direct evidence when he compared historical readings of Greenland's longitude with new ones taken in his day. Unfortunately, the measurements were not up to the task, as was easily shown by his critics.

Differences

No analogy is perfect, however, and there were some surprising differences between Darwin's and Wegener's situations. A major one had to do with time and preparation. The first known notice that Wegener took of the jigsaw-puzzle fit occurred in 1903, when he mentioned it to a fellow astronomy student. What happened next is best explained in his own words, written some years later:

> The first concept of continental drift . . . came to me as far back as 1910, when considering the map of the world, under the direct impression produced by the congruence of the coastlines on either side of the Atlantic. At first I did not pay attention to the idea because I regarded it as improbable. In the fall of 1911, I came quite accidentally upon a synoptic report in which I learned for the first time of palaeontological evidence for a former land bridge between Brazil and Africa. As a result I undertook a cursory examination of relevant research in the fields of geology and palaeontology, and this provided immediately such weighty corroboration that a conviction of the fundamental soundness of the idea took root in my mind.[7]

He first presented his idea in two addresses in January 1912, just 4 months after seeing those reports. Even if, to keep the field even, we wait until publication of Wegener's *Origin,* the time span between eureka and publication is only 5 years, a far cry from the 20 years Darwin took to produce his masterpiece. In addition, although Wegener's relative unfamiliarity with the various fields involved may have enabled him to see their weaknesses more easily, it also meant that he was to present the idea without an inkling of the storm that was to fall on him—again, a far cry from Darwin's fears and hesitations.

Another difference is that the attacks on Wegener were not religiously based. This lack of religious fervor could explain why the theory of continental drift is today recognized as a powerful, if incomplete, picture of Earth's evolution, while Darwin's evolution continues to be attacked as untrue, at least by fundamentalist groups.

Pet (and Pat) Theories

When Wegener first presented his thesis in 1912, the scientific world was only just extricating itself from the bonds of Kelvin's confining age-of-the-Earth calculations. This relative freedom provided a great deal more room for speculation on prehistoric conditions on our planet, and interest was more intense than ever. But the idea of a cooling, contracting Earth remained a potent one.

The early twentieth century was also an era when broad areas of earth science were thought to have been established on solid scientific grounds. Few welcomed an idea that overturned almost everything then believed about the earth sciences. As late as 1928, the American geologist R. T. Chamberlin could still write, "If we are to believe in Wegener's hypothesis we must forget everything which has been learned in the last 70 years and start all over again."[8]

One of the things that had been learned was that something had to bridge the wide Atlantic Ocean in order to explain the increasing number of reports noting similarities being found on both sides. An important example of these reports concerned *Glossopteris,* a well-preserved fern unearthed in coal beds of the late Paleozoic era (roughly 250 million years ago). Beautifully preserved fossils of this fern had been found over the years in areas as widely separated as India, South Africa, Australia, and South America. It just didn't make sense to believe that the same species of this fern could have arisen independently in these various areas. Some connection was needed.

Well, if two continents such as North and South America can be connected by a land bridge, why couldn't the same be true for, say, South America and Africa? The only difference would be that the bridge between North and South America has remained in place, while the other has subsided over the course of time. Another idea that achieved some prominence was that continent-size masses had once existed but had been buried or had sunk. The land bridge seemed the most likely choice.

In other scientific areas, other ideas came into being. By the end of the nineteenth century, extensive gravity surveys added strength to an idea called "isostasy," which suggested that mountains and the crust beneath them comprised material that was less dense than that of the ocean floors. If both the continents and the ocean basins were floating on a denser substratum, it is easy to see that the lighter continental portions would float higher in the underlying material. If the bases of mountains have the lowest density of all, this lightness would explain why mountains rise above the rest of the land areas. It was known that vertical movements do take place: Careful observations had shown that Scandinavia had sunk under the weight of glaciers during Pleistocene times and has been rising again in the warmer postglacial climate. If isostasy explained mountain-building, it thereby supported another powerful idea of the time: the permanence of the world's layout of continents and oceans. With permanence comes an argument against a contracting Earth.

Facing these factors, Wegener stated in his book: "So here we have the strange spectacle of two quite contradictory theories of the prehistoric configuration of the earth being held simultaneously—in Europe an almost universal adherence to the idea of former land bridges, in America to the theory of the permanence of ocean basins and continental blocks."[9]

"Where does the truth lie?" he continued. "The earth at any one time can only have had one configuration. Were there land bridges then, or were the continents separated by broad stretches of ocean, as today? . . . There clearly remains but one possibility: there must be a hidden error in the assumptions alleged to be obvious."[10]

If vertical movements of major portions of Earth are possible, then why not horizontal ones too? Wegener threw out his challenge, one that brought down the wrath of scientists, not only from varying disciplines, but also from different sides of the Atlantic.

Objection!

The first German edition of Wegener's *Origin*, only 94 pages long and lacking an index, did not excite much interest. Four years later, in 1919, another German edition appeared; this one—better organized, with more evidence, and with an index—caught the attention of scientists on the European continent. Colleagues in the United States remained blissfully unaware of the storm that was brewing until the third edition (1922) was translated into several languages, including English.

Two important geologists—the Briton Philip Lake and the American Harry Fielding Reid—then wrote critical reviews, and at this point the chorus of attacks rose to shrill levels, including some that questioned Wegener's credibility as a scientist. Lake complained, "he is not seeking truth; he is advocating a cause, and is blind to every fact and argument that tells against it."[11] Lake also argued, "It is easy to fit the pieces of the puzzle together if you distort their shape, but when you have done so, your success is no proof that you have placed them in their original positions. It is not even a proof that the pieces belong to the same puzzle, or that all of the pieces are present."[12]

The Americans also went after Wegener in earnest. Paleontologist E. W. Berry called his theory "a selective search through the literature for corroborative evidence, ignoring most of the facts that are opposed to the idea, and ending in a state of auto-intoxication in which the subjective idea comes to be considered as an objective fact."[13] American geologist R. Thomas Chamberlin (son of one of Kelvin's powerful adversaries) wondered whether geology can still be considered a science if it is "possible for such a theory as this to run wild."[14] Bailey Willis, another respected American geologist, maintained that "further discussion of it merely incumbers the literature and befogs the mind of fellow students. [It is] as antiquated as pre-Curie physics."[15] He also called it a "fairy tale."[16]

Among the strongest objections were those raised by geophysicists. Wegener had argued that the continents consisted of a rocky material called "sial," and that these were gliding along on a denser but softer substratum, which he called "sima." He explained the softness by assuming that sima melted (i.e., attained a fluid state) at a lower temperature than sial. Unfortunately, physical experiments contradicted his conjectures regarding the melting point of sima. In addition, observations of seismic waves showed the ocean floor to be rigid, not soft, so his theory was taken to be unscientific.[17]

We know now that Wegener was nevertheless right in concept. Oddly, as this chapter subsequently shows, he was thinking not too big, but too small. Recall his hypothesis that pole-fleeing forces and gravitational forces, acting over long periods of time, could perhaps cause continental drift. Wegener was a good enough scientist to recognize these forces as a major problem in his theory, so that the mechanism for continental drift was a weak link in his theory.

Among those who challenged this aspect of his work was Harold Jeffreys, mentioned earlier in this chapter. Jeffreys called the drift idea "a very dangerous one, and liable to lead to serious error."[18]

Helpless against the onslaught, Wegener could only complain. To his father-in-law, he wrote, "Professor P.'s letter is typical! He will not allow himself to be taught. Those people who insist in treating only with the facts and want to have nothing to do with hypothesis, themselves are utilising a false hypothesis without appreciating it! . . . there is nothing in his letter about the struggle to get to the bottom of things, but only about the pleasure of exposing the limitations of other men."[19]

Wegener believed that the individual potshots taken at the drift hypothesis could not bring it down. He was wrong there. On the other hand, he also believed that the truth of the theory could be established only by combining all the evidence. He was one of the very few who seemed able to do so.

Allies

Wegener, although utterly outgunned, was not completely alone. In 1928, about two years before Wegener died, an Edinburgh University geology professor, Arthur Holmes—who did important work with geological dating—calculated that volcanic activity was not sufficient to account for the heat generated by radioactivity. He thereby postulated the idea of thermally driven convection currents in the earth. The process was similar to that in a large pot of boiling water. Heat generated by the burner at the center of the pot's bottom will produce currents of water moving up from the bottom and out to the circumference. Here then was a potentially appropriate motor for continental drift, and Wegener immediately included it in his 1929 edition of *Origin*. Unfortunately for Wegener, although such convection currents could serve as a motor, it was still not clear just how this would happen. Also, there remained plenty of other unsolved problems, so the idea, while basically correct, was not very helpful.

At about the same time, Alex du Toit, a South African and one of the most important field geologists of that time, had noted a striking similarity between the Paleozoic and the Mesozoic geology of his native country and that of eastern South America. He gathered other evidence and became an enthusiastic advocate of continental drift. Wegener included some of this evidence in the 1929 edition of his book.

But there still was nowhere near enough evidence to lift Wegener's theory from the depths of controversy. The important question of mechanism still had no satisfactory answer. Even many of those who had been converted to drift theory felt it was better to keep quiet and await further developments. In fact, attitudes seemed in some ways to harden against the theory.

As late as 1943 (13 years after Wegener's death), the American paleontologist George Gaylord Simpson remarked on the near unanimity of feeling against it among his peers. He himself argued, "The known past and present distribution of land mammals cannot be explained by the hypothesis of drifting continents . . . the distribution of mammals definitely supports the hypothesis that the continents were essentially stable throughout the whole time involved in mammalian history."[20] As late as 1950, T. W. Gevers, a disciple of du Toit, would refer to a "marked regression away from continental drift."[21]

Turnabout

During the laying of the transatlantic cable in the mid-1800s, a curious formation was discovered in the seabed, about halfway between the coasts of the New World and the Old World. Known as the Mid-Atlantic Ridge, it turned out to be part of a long, submerged mountain range that roughly paralleled the coastal forms of the two coastlines it rested between.

Wegener knew about this submerged range but did not feel it had anything to do with his hypothesis. In his description of the continents' movements, he said it made no difference where the center of movement was placed, that it was the *relative* movement that was important. He laid out three possibilities—with Africa, the ridge, and South America all being possible centers from which the other landforms were moving away.

In terms of relative movement, he was right. If a rubber band with two markings on it is stretched, and you want to measure the new distance between the markings, it makes no difference which mark is chosen as the zero point. In terms of drift theory, however, it mattered a lot which landform was chosen as the center. The answer did not come easily.

With the advent of World War II, a series of major improvements in equipment and techniques for mapping led to many discoveries. These discoveries not only provided an answer to the landform question, but also, finally, changed the theory's fortunes. These revelations came about in two quite separate areas.

The first discovery, derived from deep-ocean mapping, showed that the Mid-Atlantic Ridge was just one of many such ridges. The series can be described as a worldwide, submerged mountain chain, but one that is quite different in shape and constitution from any found on land.

Ridges are, in fact, found in all the oceans. They also form a sort of continuous seam, like that on a baseball. Further, the seam is dotted here and there with submarine volcanoes and scattered volcanic islands; such islands include the Galapagos Archipelago, Ascension Island, and Iceland. The hottest and youngest areas of the ridges, significantly, are found near the center lines of the ridges.

Scattered observations in the world's seas, like clues in a murder mystery, continued to pile up. Here's another clue: As dating techniques were refined, they showed that no part of the seafloor is more than 200 million years old, which is far less than the age of the continental rocks. This discovery was a real shock; the traditional view, remember, was that the ocean floors and the continents had all been created at the same time. Studies also showed that (a) the continental crust is made of different material from ocean crust, (b) the ocean crust is much thinner than the crust underlying the continents, and (c) a denser material underlies *both* ocean crust *and* continental crust.

The second area of research that changed the fortunes of drift theory had to do with magnetic information sealed into Earth's rocks over its long history. By the late 1950s, data from years of magnetic readings taken with magnetometers towed behind ships showed several surprising phenomena. One was a strange pattern of magnetic stripes along the ocean floors. They appeared symmetrically along both sides of, and more or less parallel to, the ridges, and with alternating polarity. These stripes were particularly puzzling, but understanding was not long in coming.

Seafloor Spreading

In 1960, Harry H. Hess of Princeton University advanced an idea that, like Wegener's, integrated information from a variety of sources. It was simple and brilliant: The seafloor comes into being at the midocean ridges, rising from Earth's depths as hot, ductile lava (or magma). Like a new, long volcano rising from inside Earth, the material builds up as it emerges, forming the great mountain chain that rises miles above the ocean bottom. The magma also spreads out in two opposite directions, away from the ridges, forming new ocean floor. In all known cases, these ocean floors are no more than 200 million years old.

The idea, at first, had little more effect than Wegener's did at the beginning—but help was coming. Thanks to work by several other scientists,[22] the alternating magnetic stripes could be seen as a kind of fossilized magnetic tape. As the molten-rock material emerges and cools, the orientation of Earth's magnetic field is locked into this material.

The worldwide magnetic field is known to have reversed itself many times during Earth's long history, and the alternating stripes show the direction of the field at the time the rock emerged and cooled. As the material was pushed away from the center, it retained this orientation, and, as new material emerged after a reversal, this new material showed the opposite polarity. Clearly, large portions of Earth's surface were moving. Here, then, was good supporting evidence for the continental drift hypothesis.

Hess's idea came to be called seafloor spreading. Among yet other puzzles that it solved was why the lava at the crest always seems to be younger than the lava lying farther away from the center. Most important for our story, however, Hess's idea provided a satisfactory, and powerful enough, motor for Wegener's continental drift. The continents are carried along for the ride by the overall process, which is driven by convection currents in the *mantle* (the thick layer between Earth's crust and its core deep within). Hess spelled out the difference thus: "The continents do not plough through oceanic crust impelled by unknown forces, rather they ride passively on mantle material as it comes to the surface at the crest of the ridge and then moves laterally away from it."[23]

At this point, continental drift was back in business. Not a complete answer in itself, it became part of another growing theory, called "plate tectonics." What the modern synthesis has done for evolution, plate tectonics has done for earth science.

Plate Tectonics

In this new scenario, the continents are not ships at sea, sliding through Earth's crust. Rather the outermost portion of Earth is divided up into a series of hard, rigid plates that vary in thickness. According to the most recent belief, the plates include not only Earth's crust, but also a portion of the upper mantle. Under the oceans, the plates range in thickness from a mere 4 or so miles to perhaps 80 miles in the oldest parts of the ocean floor; the continental plates are generally much thicker, ranging from about 20 miles down to a depth of some 180 miles below Earth's surface.

This grouping of plates, the outer layer of Earth, is known as the "lithosphere" (*lithos,* from the Greek word for "stone"). The plates are floating on a plastic layer of the lower mantle called the "asthenosphere" (from the Greek *asthenēs,* "weak"). These gargantuan plates, which may or may not correlate with the continental margins, are moving about on Earth's surface, driven by slow but powerful currents of molten rock.

Where the edge of one plate meets that of another, all kinds of interesting things can happen. One of the plates may descend back into the mantle; it may ride up on top of an opposing and lighter block; or perhaps it will mash up into a mountain range. The western margin of the United States and the eastern edge of Asia are believed to be the boundaries of moving plates. As these blocks move, they are prone to cracking or breaking up along the edges, which could account for the high concentration of earthquakes and young mountains in these regions. Further, friction created where two blocks meet generates tremendous heat, which can melt underlying strata of rock. The great pressures within Earth force the resulting magma up and out, creating volcanoes and the lava that flows out of them.

Today

Happily for geologists, there remain plenty of unresolved questions in this expanding field. As a matter of fact, the mechanism problem faced by Wegener has not been fully solved even today. Plate tectonics does a satisfactory job in explaining the movement of oceanic crust. It does less well, however, in explicating the movement of continents, which are thicker than oceanic plates and extend deeper into Earth's mantle. A 1995 proposal suggests that the tug of old ocean floor sinking back into Earth is what powers most plate motions.[24]

The search goes on in many areas. One has to do with the bucking contest going on right now between the continental plates underlying India and the rest of Asia. For 50 million years, India has been driving north into the rest of the Asian continent at about 5 centimeters per year. So far, says K. Douglas Nelson, a geologist at Syracuse University, it has "pushed up the Himalayas and the Tibetan Plateau, and pieces of central Asia are pushing out like melon seeds into the Pacific."[25]

In other words, the Indian plate is sliding down under Asia, with the aforementioned results. Recent research adds a twist to the situation, for a kind of melting pot seems to be underlying the region. This was unexpected but may answer a long-standing question: Why is the Tibetan plateau, an area ringed by mountains, so flat? Researchers suggest that the soft underbelly somehow permits the land here to flatten out, just as a viscous fluid such as peanut butter will, if given enough time. Lessons learned from this research can also be applied to a better understanding of earlier collisions.[26]

How about the plates themselves? What determines their size? Theory suggests that they should be no more than about 3,000 kilometers (1,860 miles) wide. Why is the plate under the Pacific Ocean four times that size? New work points to a greater viscosity in the deep mantle than was thought to be the case, which in turn may have a bearing on plate size.[27]

Even the number of plates may be in dispute. The latest count is an even dozen major plates, along with several smaller ones. Recent observations, however, suggest the possibility that the tectonic plate on which India and Australia have been riding together is now splitting apart, which would increase the number of major plates to 13.[28]

With so much still in question, is it any wonder that Wegener didn't get everything right? This complexity makes his basic guess—that Pangaea began to split up about 200 million years ago—all the more amazing, for that's one of the few areas on which everyone seems to agree.

Wegener, throughout his ordeal, managed to continue his own career. In 1919, he received an appointment in the Meteorological Research Department of the *Deutsche Seewarte* in Hamburg, where he was able to combine both civil and academic functions. Five years later, in 1924, he was appointed to a newly created Chair of Meteorology and Geophysics at the University of Graz, in Austria.

Still physically active at age 50, he made plans for a major expedition to Greenland, his fourth, to run from 1930 to 1931. But it ended in disaster; he lost his life attempting to cross from a camp on the central ice cap to the base camp on the west coast. When he died, in 1930, his theory was still in a sort of scientific limbo. His legacy lives on, however—bigger, grander, more comprehensive, and more majestic than even he could have imagined.

CHAPTER 9

Johanson versus the Leakeys

The Missing Link

It isn't often that a scientific feud hits the front page of the austere *New York Times*. On the morning of February 18, 1979, however, there it was, including a three-column picture spread across the bottom of the page. Just under the picture was the headline,

RIVAL ANTHROPOLOGISTS DIVIDE ON 'PRE-HUMAN' FIND

No great drama there. We wonder why this is on page 1. The body of the article begins,

> Two well-known anthropologists challenged each other today in what could become a wide-ranging debate over whether a finding last month was indeed a new species of pre-human being ancestral to all other known forms of human and human-like creatures.
>
> Richard Leakey, the Kenya anthropologist, is challenging the announcement last month by two American scientists that they had discovered such a new species. Dr. Donald C. Johanson, one of the Americans, appeared with Mr. Leakey at a symposium here on human evolution and vigorously defended his interpretation.

"Vigorously?" Were there insults? Fists? Knives? No, nothing like that. What then could have prompted the editors to