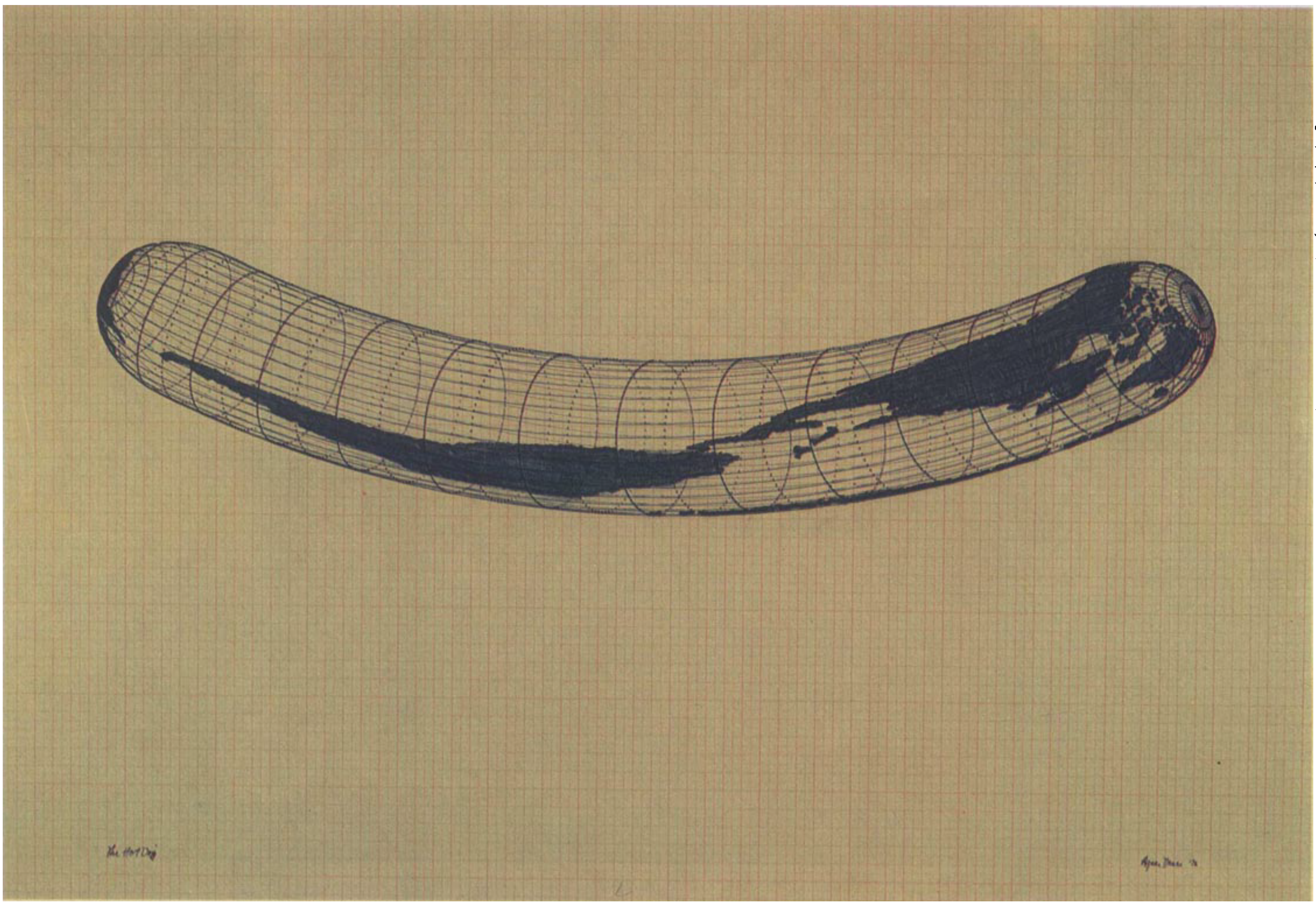
Faulting Continental Drift

A skeptic's view of an entrenched theory

by Paul D. Lowman, Jr.



Ink & charcoal on graph paper & mylar. Collection of the artist, New York

Agnes Denes,* Isometric Systems in Isotropic Space: Map Projections—The Hot Dog, *1976

An entire generation of geology students has now reached maturity convinced that continental drift is as well established as the value of *pi.* The phrase *plate tectonics and continental drift* appears everywhere in today's geology literature, reflecting the belief of nearly all Earth scientists that the two concepts are inseparable. But, in fact, the evidence for continental drift, considered by itself, is far weaker than the strong and direct proof for plate tectonic processes. In short, plate tectonics need not imply continental drift.

In plate tectonic theory, continents play the parts of passengers on a ferry, drifting about only because the plates that carry them move. There is a curious parallel between these passenger continents and continental drift theory itself. Drift theory, like the movable continents it predicts, is only a passenger, a corollary to plate tectonics—the theory that the Earth's crust is divided into seven major plates and perhaps twelve smaller ones. These segments raise mountains when they collide, widen oceans when they separate, and cause earthquakes as they scrape and grind one against the other.

Despite its present passenger status, continental drift theory came a good fifty years before the theory of plate tectonics. The saga of "drift theory", as it was called by its author Alfred Wegener, opened in 1912. Influenced by geologist Frank B. Taylor's theory explaining the origin of the world's young mountain belts, Wegener published a paper entitled "The Origin of Continents." Just three

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years later, his book, *The Origin of Continents and Oceans,* appeared. (Like Einstein's popularization of relativity, Wegener's own book is still one of the best presentations of continental drift theory, though outdated in many specifics and demonstrably wrong in others.)

Impressed by how neatly the east coast of South America would fit against the west coast of Africa if only the Atlantic Ocean were closed, Wegener proposed that today's continents were formed when a single supercontinent, Pangaea, fragmented in the late Paleozoic era, about two hundred million years ago. According to his theory, the fragments drifted slowly through the Earth's mantle more or less the way ice floes drift through water, and they are still, and measurably, drifting. As evidence, Wegener cited longitude measurements showing that North America was moving westward relative to Europe, at a speed of about thirty-two centimeters per year. Oddly enough, the very feature that stimulated Wegener's original speculation—the parallelism of coastlines around the Atlantic Ocean—was mentioned only in passing in the 1928 edition of his book.

The geological community of the 1920s took drift seriously. But the great figures of the day, including Walter Bucher and Harold Jeffreys, generally rejected drift (Jeffreys, in fact, *still* rejects it), for no one had found a mechanism that could move continents. By 1940, skepticism reigned. Most geologists, with a few notable exceptions, such as Arthur Holmes, relegated continental drift to the class of interesting speculations. But things began to change in the late 1950s. Rocks and fossils found in ocean basins, which were once considered very ancient terrain (perhaps even part of the Earth's original crust), were found to be surprisingly young compared to the 4.6 billion-year-old Earth itself. In addition, it turned out that layers of deep-sea sediment were much thinner than they would have been had they accumulated over billions of years. It became clear, in short, that at least part of the Earth's crust is not at all ancient.

Very few scientific theories have been originated by admirals, but the essentials of plate tectonic theory, modestly labeled "an essay in geopoetry," were first outlined in 1960 by the late Harry Hess, professor of geology at Princeton University and rear admiral in the U.S. Naval Reserve. Hess suggested that the Earth's mantle is a plastic solid (analogous, one might say, to Silly Putty). The hot rock of the mantle, he discovered, rises in large convection currents, at a rate of about one centimeter per year, under the mid-ocean ridges (the globe-girdling undersea mountain chains that snake some forty thousand miles along the floors of the Atlantic and Pacific). When these currents reach the crust in the form of boiling lavas and igneous intrusions, they spread outward in both directions from the ridges and push along not only the older, rigid, and relatively inactive segments of the Earth's crust and mantle—the plates—but also continents riding as passengers on top of the plates. This process, termed sea-floor spreading by the marine geologist Robert Dietz, was the missing mechanism that drift theorists had been looking for.

Geologists soon found that they could calculate how fast the plates move by measuring the age of lavas at given distances from the mid-ocean ridges. Revising the estimate cited by Wegener, they figured that the plates move at a speed of between one and eight centimeters per year—not exactly hair-ruffling speed, but over geologic time it adds up. (A point moving five centimeters each year, for example, would travel twenty-five hundred kilometers in fifty million years, about one-sixteenth of the way around the world.)

IN THE 1960s, plate tectonics began to take on a shape quite distinct from Wegener's vision. Now continental drift, which was once the core of Wegener's concept, became more or less only an afterthought of sea-floor spreading. While Wegener described the movement of continents, this new theory described the movement of *plates,* which are generally the same size as continents, but are not necessarily—in fact, generally are *not*—equivalent to continents. (The North American plate, for example, includes that continent and the western half of the northern Atlantic Ocean; the Eurasian plate subsumes the eastern half of the north Atlantic as well as Eurasia itself.) The plates—not the relatively thin sheets of crust visualized by Wegener, but thicker segments extending to depths of more than one hundred kilometers and including much of the Earth's upper mantle as well as its crust—came to be seen as the active pieces.

Tectonic theory provided not only a mechanism for the movement of plates but also a place for the plates to go. When an oceanic plate reaches a continental margin, oceanic crust is thrust under the continent at a trench, or subduction zone. For example, as the Nazca plate, which contains an eastern segment of the Pacific Ocean, spreads eastward from the East Pacific Rise toward South America, it disappears in a subduction zone under the Peru-Chile trench. The catastrophic earthquakes that plague the Andean countries are caused when two plates grind against one another; and volcanoes in this region result when oceanic crust is carried down into hotter regions deep inside the Earth where the crust and mantle are partially melted, forming masses of upwelling magma. Similarly, the volcanoes of North America's Cascade Range are formed as the plate that ferries them descends under North America.

But when a plate carries a continent on its leading edge toward another continent, a collision results; continental crust, not being as dense as oceanic crust, simply cannot be driven down into a trench. According to plate tectonic theory, the Himalayas and the Tibetan Plateau formed when India and Asia collided. This supposed collision illustrates again the incidental nature of continental drift in plate tectonic theory. The continents are thin layers on top of thick plates; if a plate moves, the continent goes along for the ride. John Bird, of Cornell University, and John Dewey, of the University of Durham, in England, put it concisely in 1970 when they called continental drift "merely a corollary" of plate motion.

Corollary or not, continental drift was given a powerful boost in 1966 by the Canadian geophysicist Tuzo Wilson. There are many faults that cut perpendicularly into the mid-ocean ridges. As the rock shifts on either side of a fault, the ridge becomes offset and begins to look less like a straight line and more like a ragged zig-zag, with many short ridges stitched crookedly together by faults. (Because these faults are transformed into part of the ridge itself, Wilson named them transform faults.) Geologists used to suppose that transform faults simply mark the common margin of two sections of a mid-ocean ridge slipping past one another horizontally. In this case, we should see two adjacent offset ridges grinding against one another along the entire length of a fault, which can sometimes extend hundreds of miles. But Wilson reasoned that if offset ridges are the sites from which newly formed crust moves outward by sea-floor spreading, the two ridges would grind against one another only along that short section of the transform fault stitching them together.

Within a few months the so-called transform fault theory was tested. Lynn Sykes, of Columbia University, investigated the motion of the crust at offset ridges along some of the supposed transform faults in the Atlantic and Pacific Oceans. In one of the most striking verifications of a scientific theory in the decade, Sykes found that in every case the newly formed crust moved exactly as the transform-fault concept predicted. This demonstration verified not only transform faulting but also the broader concept of sea-floor spreading—an essential feature of Wilson's theory.

At the 1966 meeting of the Geological Society of America, in San Francisco, Sykes reported his work, helping to break the back of the opposition to what rapidly became known as the new global tectonics and shortly thereafter plate tectonics. Since then nearly all scientists have accepted continental drift theory as conventional wisdom. Let me explain why I am not one of them.

FIRST, AND MOST IMPORTANT, unlike sea-floor spreading, continental drift has not been demonstrated geodetically, as Wegener claimed in 1928 when he stated that North America was measurably moving away from Europe; that is, it has not been directly measured by long-range intercontinental surveys, simply because until very recently the necessary precision was not possible. This can now be done, using radio telescopes and laser-tracking of satellites, techniques that are accurate to a few centimeters over trans-oceanic distances. If continental drift is a reality, we should know it within five to ten years. But right now, continental drift, as distinguished from local movement along such plate boundaries as California's San Andreas fault, has not yet been proven.

The other classic arguments for drift compiled by Wegener and his followers would require a book comparable in size to the 1928 edition of *The Origin of Continents and Oceans* for adequate discussion. But even though nearly all of the evidence, which is locked up in fossils, rocks on the ocean floors, dead volcanoes, quiet coastlines, and parallel continental margins, can lead to a theory of continental drift, it need not.

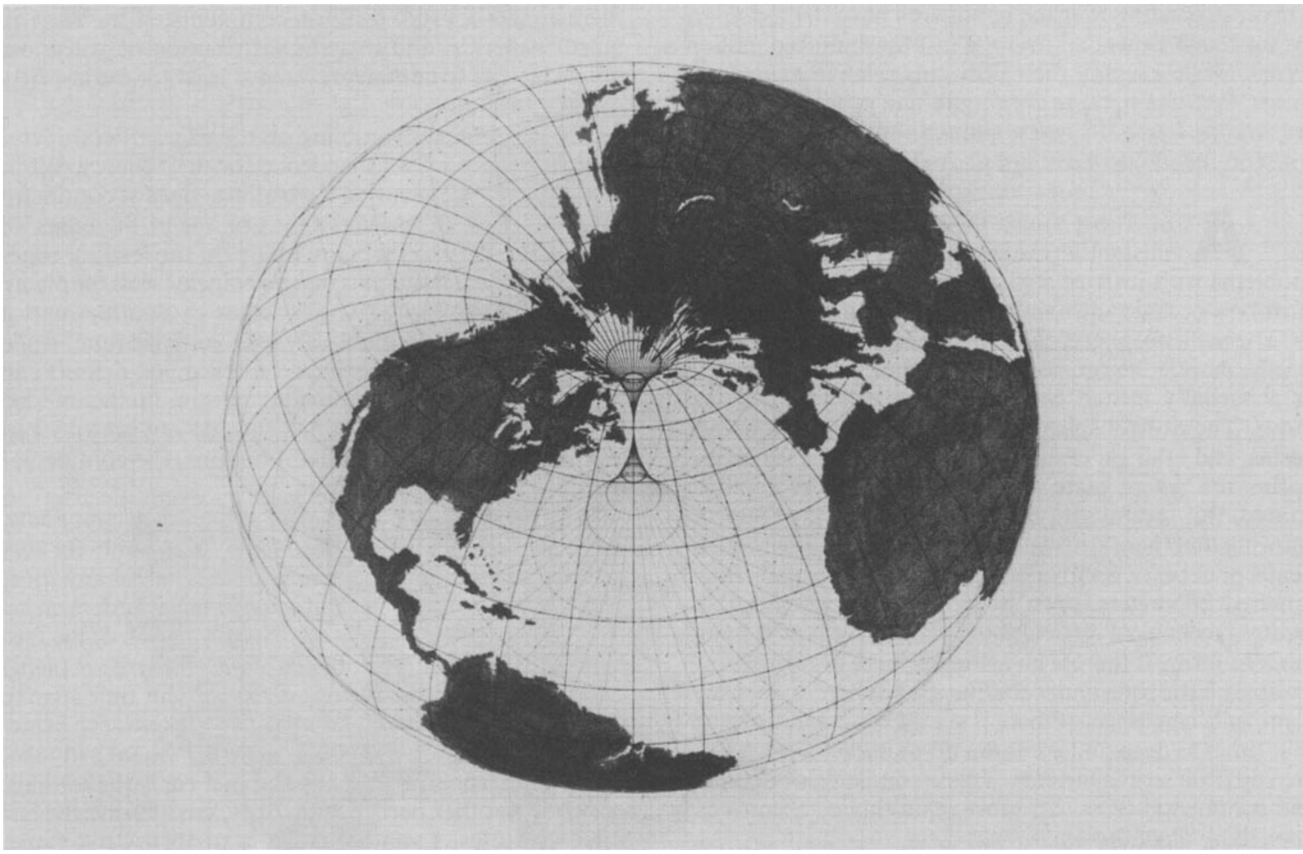
The best evidence for continental drift—the congruence of opposing Atlantic coastlines—cannot easily be dismissed, if only because it is obvious to anyone who looks at a map. This congruence, or fit, is even more precise than it looks. A mathematical fit of the Atlantic continental margins (the true boundaries of the continents, as opposed to the coastlines themselves) by the English scientists J.E. Everett and Alan G. Smith has shown that the parallelism is far too close to be the result of chance. A related demonstration, presented in 1968 by Patrick Hurley, of the Massachusetts Institute of Technology, and his colleagues, shows that a geologic boundary in western Africa meets a corresponding boundary in Brazil, if the continents are reassembled by closing the South Atlantic. Similar fits for other oceans, particularly the Indian, have been constructed by Dietz and John Holden. (Disturbed by the uncritical acceptance of drift, Holden has since founded the semi-facetious International Stop Continental Drift Society.)

Most geologists would consider a rebuttal of congruent margins impossible, and I agree that the matching coastlines on each side of the Atlantic Ocean are not accidental, especially considering the parallelism of a third element, the Mid-Atlantic Ridge. But is continental drift the only explanation for parallel margins? I think not. As strikingly as the puzzle fits together, when it is completed there are holes and extra pieces left behind. Take for instance the Mid-Atlantic Ridge, which continues northward into the Arctic Ocean. Seismic activity along this section of the ridge shows clearly that the sea floor is spreading (though extremely slowly, according to my colleague Pat Taylor), and so land masses on either side of the Arctic Ocean—Canada and the Soviet Union—should have been pushed apart, leaving a pair of parallel margins. But any modern depth map of the Arctic Ocean shows no parallelism, much less a mathematically precise fit.

A second problem with the Pangaea puzzle arises when the Atlantic Ocean is closed, as it supposedly was hundreds of millions of years ago, by nestling the east coast of North America up against the west coast of Europe: there is no room left for a large part of southern Mexico. Certainly this extra piece cannot be new continental material formed since the supposed opening of the Atlantic—much of southern Mexico is very old crust, Precambrian in age.

There is also a sense in which the puzzle fits together too well. Several geologists, notably Oakley Shields, have shown that not only the Atlantic margins but also those of the Pacific Ocean can be fitted together, with Australia against western South America, for example. But if the Pacific Ocean formed by the division of Australia and South America at the same time that the Atlantic formed by the division of Africa and South America, all continents must have been drifting away from each other. This, of course, is impossible unless the Earth, like the universe, has expanded within the last few hundred million years. Such expansion, in fact, has been ably argued by the Australian geologist S. Warren Carey. But there are great weaknesses in the expanding Earth theory. In order to conserve its rotational momentum, an expanding Earth would have to spin slower, like a skater extending her arms; that is, it would take longer to complete one rotation, and the day would increase by the extra amount of time it takes. Fossil corals do show that the day has increased by about two hours over the last 370 million years. But this is far short of the lengthening that would be required to conserve rotational momentum in a greatly expanded planet.

Another problem with the expanding Earth theory is that there is no mechanical reason for an expansion. Some scientists have proposed that the Earth's gravity, which holds the globe together, has weakened because the universal gravitational constant has gotten smaller. If gravity weakened throughout the universe, all the planets and



Ink & charcoal on graph paper & mylar. Private collection, Milan

Agnes Denes, **Isometric Systems in Isotropic Space: Map projections—The Doughnut,** *1974*

satellites, including Earth's moon, also would have expanded. The moon, however, has undergone no major expansion in nearly four billion years. In short, the expanding Earth theory is stimulating but quite unlikely.

Another of Wegener's classic arguments concerns both animal and plant fossils. For instance, remains of Mesosaurus, a small, long-extinct reptile, are found embedded in Paleozoic rock on continents now separated by wide oceans. Wegener and his modern defenders have argued convincingly that such creatures could hardly have swum across the present oceans, and that their prehistoric presence in both Africa and South America implies that these continents were once joined as Gondwanaland, the southern half of Pangaea. Other drifters use *Glossopteris,* a fernlike plant found in South America, Africa, and Antarctica, as evidence. Since this plant's seeds could not survive in salt water, drifters argue, its presence on three continents, now separated by briny oceans, points to a time when all three were joined.

Many such examples have been refuted. For instance, A.A. Meyerhoff, a petroleum geologist who has studied the original literature on Mesosaurus, learned that these fossils were found in rocks formed from deep-sea sediments, suggesting that Mesosaurus, like some modern reptiles, may have been a better swimmer than we realize. And Preston Cloud, professor emeritus at the University of California at Santa Barbara, has pointed out that *Glossopteris* has winged sporelike bodies easily dispersed by the wind.

Granted, there are hundreds of bits of fossil evidence that geologists marshall in support of continental drift. But Cloud, who has been converted to continental drift by *other* evidence, has not retracted his view that the *biogeographical* evidence does not lead to continental drift. And the late Walter Bucher, of Columbia University, concluded many years ago that the pieces of biogeographical evidence, particularly certain dinosaur fossils, are best explained not by drift theory but by a theory of unmoving continents. He pointed out that if Africa and South America were indeed once parts of a single landmass, certainly there should be many more fossils from that time common to both continents than the small number we have actually found.

Not only fossils but also traces of the Earth's poles have been used to support drift theory. In the late 1950s Keith Runcorn, of the University of Newcastle upon Tyne, and others measured the magnetism of terrestrial rocks to find out where the magnetic poles had been. By gathering enough samples, whose ages range over hundreds of millions of years, they discovered that the poles had wandered. Three hundred million years or so before the north magnetic pole assumed its present location, it was in central Asia, and before that in the South Pacific.

If all continents have maintained the same position with respect to one another, rocks from different continents should all yield one polar wander curve; that is, all rocks of a certain age should indicate the same fossilized magnetic pole. But Runcorn found that each continent has its own polar wander curve, and so drifters have argued that the continents must have moved with respect to one another. Since then, though, two New Zealanders, B.J.J. Embleton and P.W. Schmidt, have shown that rocks between 1.5 and 2.2 billion years old collected from several continents yield essentially one polar wander curve, suggesting that the continents have drifted apart as the Earth expanded over the last few hundred million years, while keeping their positions relative to one another. But, again, there are gargantuan problems with an expanding Earth. I suggest a much simpler explanation: the continents just have not drifted at all.

ASIDE FROM THESE EXAMPLES of dubious circumstantial evidence, there are mechanical problems with drift as well. Specifically, it is not at all clear how oceanic and continental crust can move together. The asthenosphere, the supposed plastic layer in the Earth's mantle, serves, according to plate tectonic theory, as a partially melted bearing surface on which plates move. The asthenosphere has been found in the ocean basins, and I think it clearly no coincidence that the ocean basins are where plate tectonics can be best demonstrated. But several geophysicists have published papers showing that there is no asthenosphere under most continents, or at best a poorly developed, very deep one—four hundred kilometers down or more. In either case, this creates mechanical difficulties for continental drift in its modern form. If there is no asthenosphere or other comparable plastic zone under continents, it is hard to see how continents can move. If there is such a zone, but three or four times as deep under continents as under oceans, it is then difficult to imagine how a plate consisting of oceanic and continental crust can move smoothly as a unit—as implied by plate theory.

Similarly, the distribution of volcanoes serves well to prove a theory of sea-floor spreading and plate tectonic motion, but it does not point to continental drift. Hot spot trails are lines of volcanoes with the youngest at one end and the oldest at the other; the classic example is the Hawaiian Island chain and its continuation to the northwest, the Emperor Seamounts, an arc of extinct, submerged volcanoes. Tuzo Wilson and Jason Morgan, of Princeton University, among others, have proposed that such chains form as a moving plate passes over a fixed magma source in the mantle. There are several such island chains, especially in the Pacific, and the plate motions they imply are generally consistent with plate motions implied by completely independent data.

If continental crust moves as oceanic crust does, we should see hot spot trails on the continents as well as in oceans. But when Wilson and Kevin Burke, of the State University of New York at Albany, considered the distribution of volcanoes in North Africa, they found no hot spot trails and concluded that the African continent had been stationary with respect to the Earth's mantle for some twenty-five million years—an especially interesting conclusion coming from two enthusiastic proponents of continental drift. I made a similar study of volcanic fields in North America, and came to the same conclusion. The San Juan Mountains of Colorado, for example, are an immense volcanic pile that erupted for more than thirty million years. If North America had been drifting over a hot spot, as most geologists believe, the San Juans should be just one end of a chain of volcanoes some 750 kilometers long reaching to the Pacific coast (if the San Juans are at the young end) or into central Kansas (if they are at the old end). Instead they are simply a roughly circular pile one hundred kilometers wide. From this I infer that there are no hot spot trails on continents, at least not on North America, and that the distribution of volcanoes points instead to continents fixed at least for the last fifty million years or so.

The earthquakes rumbling on the edges of continents have also been used as evidence for drift theory. While few earthquakes occur on the trailing edges of continents (those continenal margins that are *not* at the edges of plates themselves), there are many on the leading edges (those continental margins that *do* coincide with the plates' margins). Asked why the west coast of South America has been shaking continuously over geologic time, while the east coast from Venezuela south is quiet, drifters can logically explain that continental margins on the interior of plates, so-called passive margins, do not get knocked around as much as do "active" margins, the continental margins at the edges of plates.

But this simple view of active and passive continental margins is correct only in relative terms and only for very narrow spans of time. There are obviously many more earthquakes per year in California, which borders an active plate margin, than in a comparable stretch of the East Coast, a passive continental margin. But there *are* plenty of earthquakes in the East if we expand our time span to a few centuries. Charleston, South Carolina, for example, was partly destroyed by a major earthquake in 1886, and many strong, if not catastrophic, earthquakes have occurred in other parts of the East Coast during the last three centuries. Lynn Sykes, of transform-fault fame, has proposed that the long-term seismic activity of several such passive continental margins is concentrated along faults that originally formed the jagged continental margins, even those now on the interiors of plates, when Pangaea broke up. So it is possible to explain earthquakes along passive margins in terms of orthodox plate theory, as it is possible to explain parallel margins in those terms. But I suggest that plate tectonics without continental drift is a far simpler explanation for both, and for many lines of evidence generally cited for continental drift.

SUPPOSE THAT THE SEA FLOOR is spreading, as we are virtually certain it is, away from the Mid-Atlantic Ridge, but that North America and Europe remain solidly in place. If the oceanic crust moves outward in both directions from the ridge without pushing continents along as parts of the plates involved, the oceanic crust still must go somewhere. The logical place is under the coasts of continents obstructing its passage. In plate tectonic terms, there would be subduction zones under passive continental margins, such as our East Coast, just as there are under active margins, such as our West Coast. Drifters will reasonably ask, "Why, if oceanic crust is being subducted under passive margins, don't we see signs of a subduction zone, for instance, seismic activity?" The reason, I suggest, is different rates of sea-floor spreading.

Spreading rates have been estimated for various oceanic ridges, most recently by Bernard Minster, of Systems Science and Software, in La Jolla, California, and Tom Jordan, of the Scripps Institute of Oceanography, and an interesting pattern emerges. The zones where recognizable subduction occurs are generally, though not always, complementary to oceanic ridges with rapid spreading rates, typically greater than three centimeters per year in

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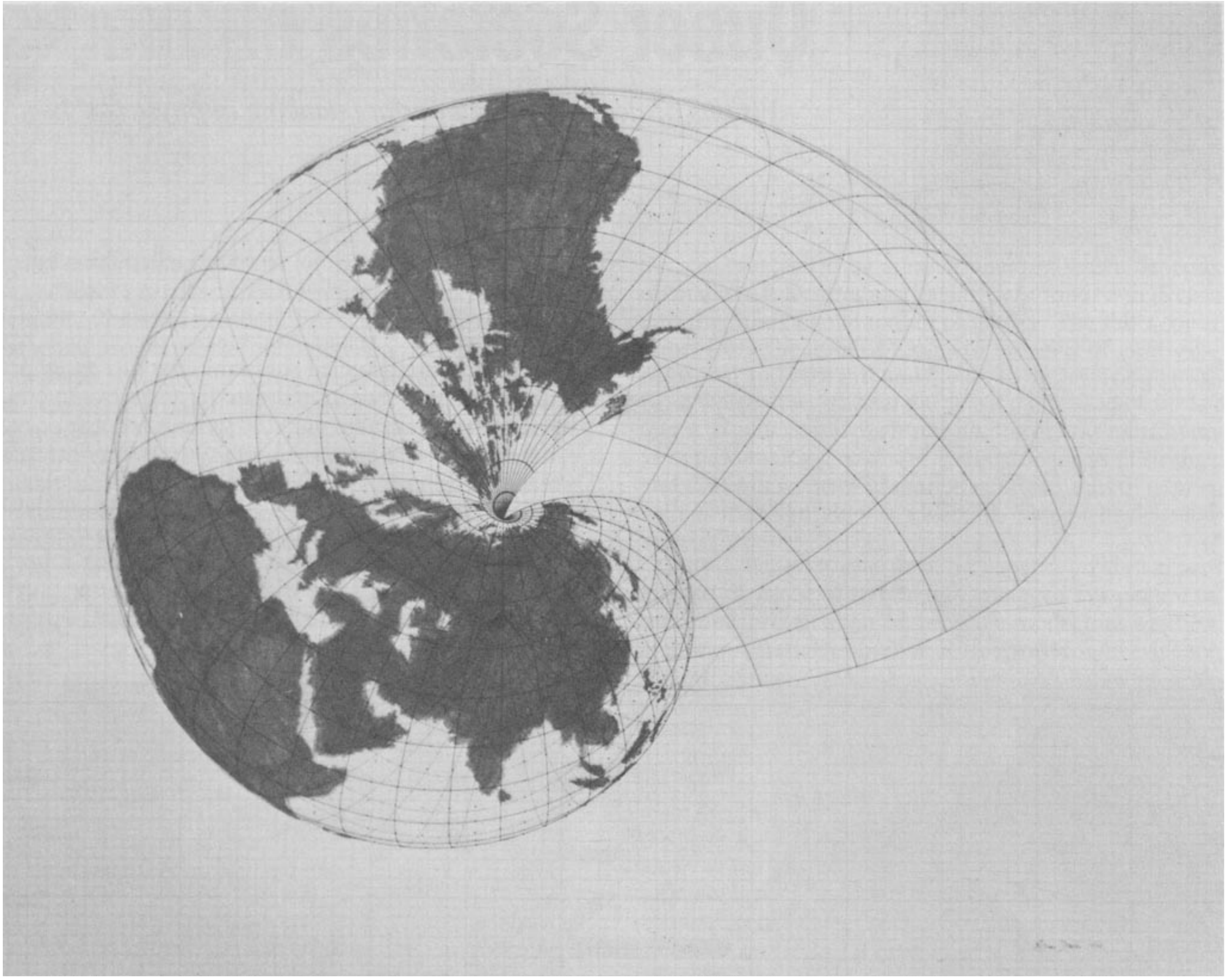

Agnes Denes, **Isometric Systems in Isotropic Space: Map Projections—The Snail,** *1974*

each direction. The clearest example is South America: the continent's active west coast lies opposite the East Pacific Rise, with spreading rates (actually half-rates) of about eight centimeters per year, whereas the quieter east coast lies opposite the Mid-Atlantic Ridge, with half-rates of about two centimeters per year.

Such a sluggish subduction zone would have much less seismic activity, and probably less volcanic activity, because the heat generated by friction in the down-going slab could be slowly conducted away rather than quickly released by the generation of magma. I'm treading lightly here; it's not at all clear that frictional heat is a major cause of volcanoes along subduction zones. But, in general, the geologic activity of passive margins, such as eastern North America, is about what we would expect from slow subduction.

The parallel continental margins around the Atlantic Ocean, as I've said, are the strongest evidence for drift. My theory accounts for them thus: If sea-floor spreading from the Mid-Atlantic Ridge is symmetrical—as it appears to be—sediment should be carried down at similar rates along corresponding latitudes of the Atlantic continental margins. This would explain not only the parallelism of the margins but of the third geometric element, the Mid-Atlantic Ridge.

I propose *plate tectonics with fixed continents* instead of plate tectonics and continental drift. This is a radical modification of currently accepted thinking, but it has one virtue essential for any useful scientific theory: it can be tested. First we can see whether the distance between North America and Europe is increasing. Techniques using radio telescopes are now measuring that span with extreme accuracy. Plate tectonic theory now predicts that this distance should be increasing by about one and a half to two centimeters per year; my theory obviously predicts no increase. So if we see the Atlantic Ocean widening over the years, my theory is falsified. On the other hand, we may find by geophysical investigation that the east coast of North America does have a subduction zone, that the moving oceanic crust has a place to go. In this case, my theory, though not proven, would at least be supported.

Very few geologists today can deny the essential processes of plate tectonics—sea-floor spreading, subduction, and transform faulting. They have all, geophysically speaking, been observed. Continental drift, in contrast, depends heavily on incomplete or conflicting evidence. Only a widening gap between continents would serve as direct evidence for drift. If no one finds the Atlantic broadening soon, perhaps plate tectonic theory will no longer carry continental drift as a necessary passenger. ■