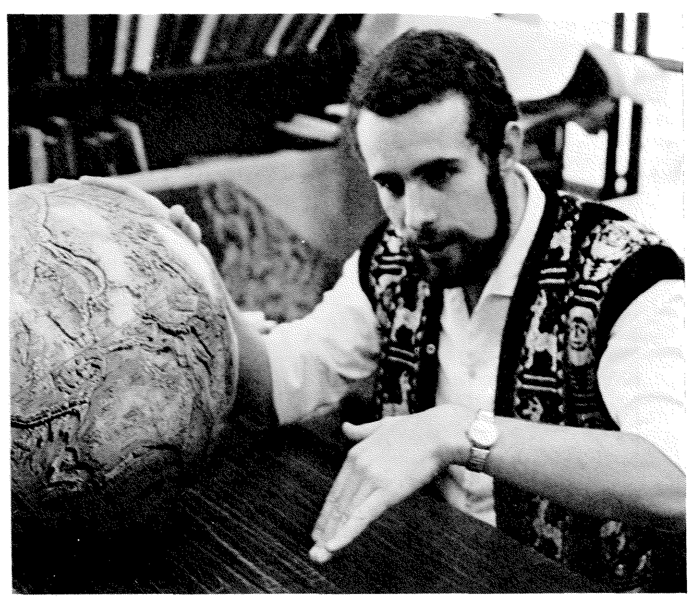
A New Look at Our Restless Earth

Every now and then a revolution occurs in scientific thinking, and the result is an about-face in our understanding of an idea or a phenomenon. The classic example, of course, is the upheaval caused by the Copernican view that we do not live in an earth-centered planetary system but rather in a sun-centered one. Of almost equal impact is the relatively new geological concept of "plate tectonics," which explains the evolution of continents and oceans in dynamic rather than static terms. It proposes that the earth's surface down to a depth of about 45 miles (the lithosphere) is composed of a mosaic of massive, rigid plates that float on an 80-mile-thick layer of plastic rock (the asthenosphere).

The speeds at which two or three of these plates are moving relative to each other have been measured in the past, but now Bernard Minster, graduate research assistant in geophysics, has calculated the velocities of ten of the plates at the same time. Working with Thomas Jordan, a Caltech alumnus (BS '69, MS '70, PhD '73) now at Princeton; Eldon Haines, visiting associate in nuclear geochemistry; and Peter Molnar of the University of California at San Diego, Minster used a computer to figure the speeds and directions of the motion of the plates. Earthquake data and the orientation of large fracture zones observed on the ocean floors gave them local directions of plate motions. Data from magnetic alignments of rocks along the ocean floors provided them with clues to the velocity of the movements over long periods of time.

The computer's analysis of these data shows that the plates move in a complexly choreographed slow-motion dance with respect to each other. Each rotates around an imaginary axis that passes through the earth's center (not necessarily coinciding with the earth's rotational axis). At their boundaries, the plates exhibit any one of three types of motion relative to each other: divergent, convergent, or simple shear. And each type of motion results in characteristic alterations of the earth's total surface. For example, along mid-oceanic ridges, plates move away from each other as molten rock rises to form new ocean floor; in zones such as at the border between the Pacific and South American plates or along the Japanese Trench, one plate is consumed as it slides under the leading edge of the other; and along transform faults like California's San Andreas, plates slide horizontally past each other, and surface area is neither created nor destroyed.

As if all this were not complex enough, the relative velocities between plates vary widely. The European Plate, for example, is moving away from the North American Plate in the North Atlantic at a rate of three-quarters of an inch a year, but the East Pacific Rise at Easter Island is spreading at a rate of about eight inches a year. The research has also shown—contrary to what had previously been assumed—that North and South



Bernard Minster

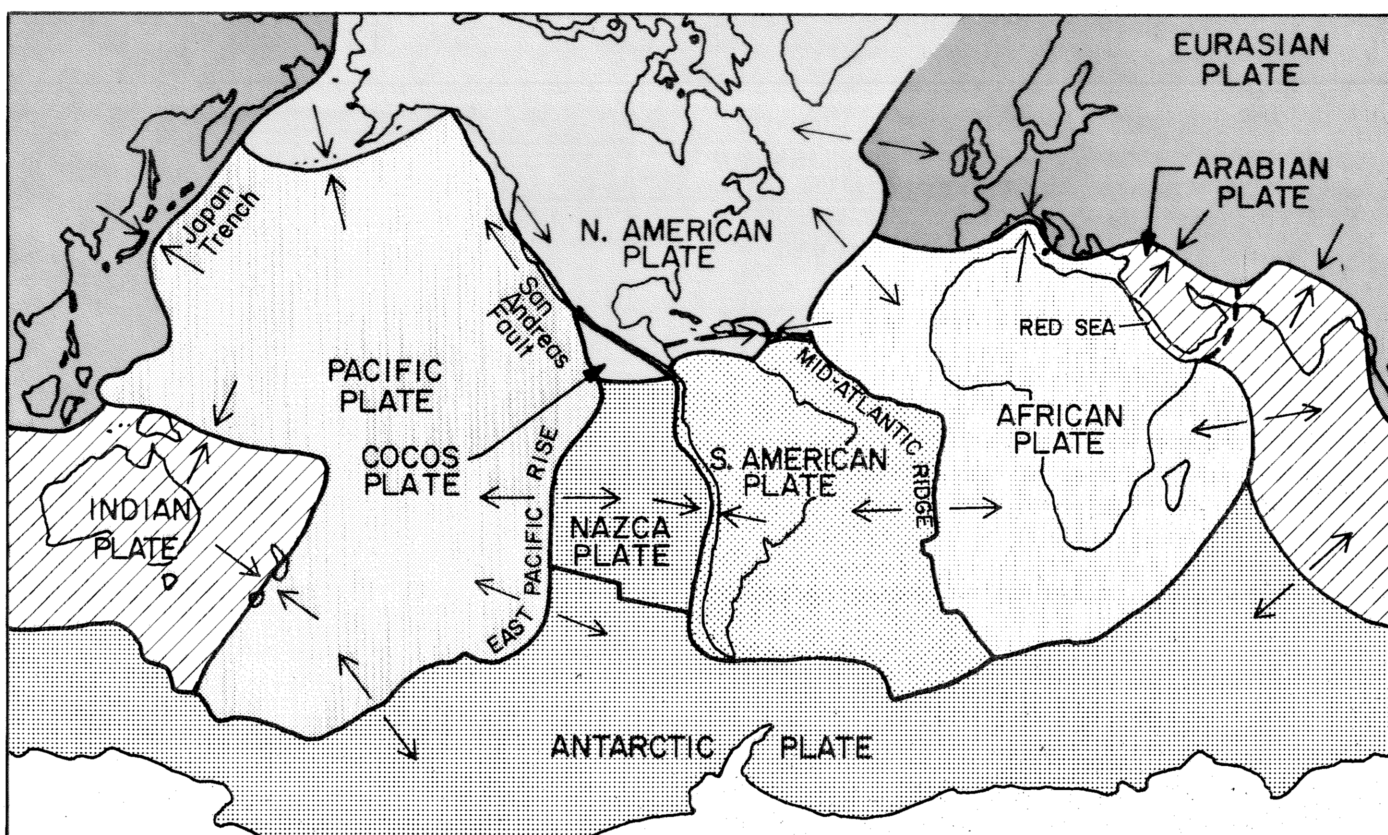
America do not behave as one plate; relative to South America, North America is moving westward at a quarter of an inch a year.

Baja California, along with a slice of western California, belongs to the Pacific Plate. The rest of Mexico, California, and the continental United States are part of the North American Plate. The Pacific Plate is moving northwesterly at a rate of a little more than an inch a year in relation to the North American Plate—a movement that caused Baja to break away from the Mexican mainland about five million years ago. As a result, the Gulf of California was formed and is widening about two inches a year. Eventually it will open at its northern end, because the North American Plate will break somewhere in that area. Most scientists consider the San Andreas fault to be the current plate boundary.

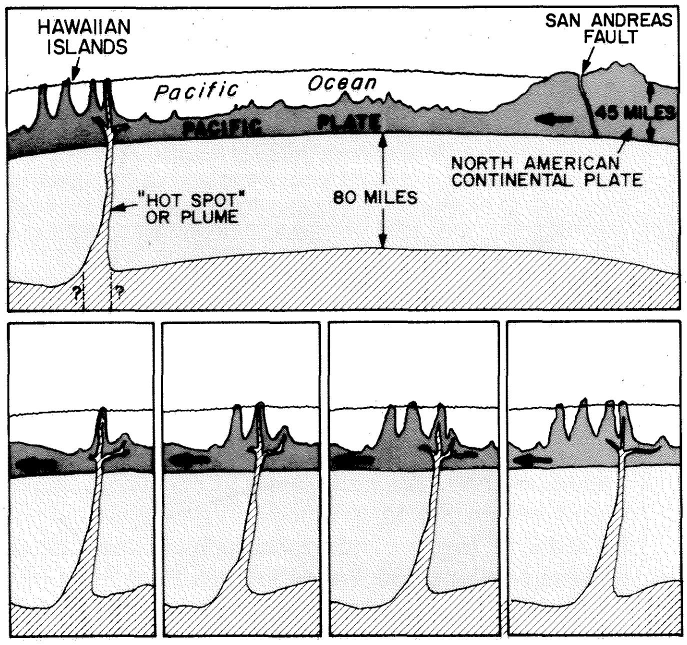
The boundaries of plates often coincide with the most active seismic areas of the earth, but they are sometimes difficult to determine precisely. The boundaries do not always correspond to the margins of continents, since most plates are partly oceanic and partly continental. And the plates vary greatly in size. The great Pacific Plate, for example, reaches from California to Japan and from Alaska to the South Seas. On the other hand, one of the small plates is essentially coextensive with Turkey.

Obtaining the relative motions of the plates gave the Minster group the opportunity to test the Wilson-Morgan "hot spot" hypothesis for the formation of chains of volcanic islands. This theory was formulated by J. Tuzo Wilson, professor of geophysics at the University of Toronto (who will be a Sherman Fairchild Distinguished Scholar at Caltech in 1975); and W. J. Morgan, professor of geophysics at Princeton. According to their theory, there are hot spots in the earth's crust which may be fixed with respect to each other and may represent plumes of molten material rising from the outer core of the earth

The principal tectonic plates of the lithosphere are outlined on this world map. The paired arrows indicate whether—in that particular area of its boundary—the movement of a plate is convergent or divergent to that of the adjacent plate.



In the last ten million years the Pacific Plate appears to have drifted about 500 miles to the northwest



A cross-section cut of about 150 miles down through the Pacific Plate would reveal a hot spot currently below the southernmost Hawaiian Islands. Assuming that the hot spot is fixed, the northern end of the island chain may represent "finished" islands, carried beyond the hot spot by the drifting of the plate to the northwest. The exact structure of the "plume" is still the subject of speculations.

through the mantle. If they are fixed, it should be possible to determine motions of the plates over them that explain the formation of island chains and are consistent with the relative motions of the plates.

Minster and his colleagues have found evidence to support this explanation of island formation. They have studied a ten-million-year period during which the Pacific Plate appears to have drifted about 500 miles to the northwest. As it glided over the hot spot that is now beneath the Hawaiian Islands, molten plate material expanded upward as volcanoes. When this material reached the surface of the ocean, it solidified and an island was born. The process repeated itself as the plate continued to drift, forming a chain of islands—from the island of Hawaii in the southeast in an almost straight line to Midway in the northwest.

Assuming that the hot-spot theory is correct, the researchers found that the plates do not move at the same rates with respect to the earth's interior. On the average, oceanic plates move about four inches a year, and continental plates less than three-quarters of an inch. In addition, it appears that the entire lithosphere may be drifting westward at a maximum of four-tenths of an inch per year—with respect to the earth's interior.

The group is now attempting to extend its studies back another ten million years in order to test further the fixed hot-spot theory. It is important to determine what has happened to these spots—whether they have moved a little, a lot, or not at all. If they are fixed, it places strong constraints on various theories of planetary formation.

Working to understand the reasons for the motions of the plates, the researchers are looking at three basic but competitive mechanisms: that the plates are being pulled down by the deep oceanic trenches; that they are "gravity sliding" off bulges in the configuration of the earth; or that the motion is closely linked to the fixed hot spots. It may be that the chemistry of the asthenosphere—that mushy layer on which the plates slide—is not the same below the continents as it is below the oceans. Greater friction between the continental plates and the asthenosphere than between the oceanic plates and the asthenosphere would slow the movement of the continents appreciably.

The comparatively high speed of the oceanic plates may reflect the fact that they are, in effect, taking a dive. They are growing in some places, as material oozes up from below. But they are disintegrating in others, as one edge of an oceanic plate shatters against another plate (usually a continent) and is forced back down into the lower layers of the earth. Once it begins to slide, it may go rather quickly.

No one knows just how long this kind of plate tectonics has been operating, but it surely has been going on for at least 200 million years—and possibly for 2 billion years. There is evidence that 200 million years ago the major land masses were assembled into one single supercontinent that has been splitting into pieces and moving into new alignments ever since. The results have already led to some rather strange associations, and the end is not in sight. Given enough time, it even seems likely that the relentless northwesterly movement of the Pacific Plate will make Los Angeles and San Francisco across-the-channel neighbors.

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