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Division of earth's upper layer into six rigid, migrating plates accounts for many gross features of geology.

PLATE TECTONICS

The new view of the world

Unifying plate theory is explaining diverse geological observations

by Kendrick Frazier

The last few years have been a time of unprecedented revolution and ferment for scientists studying the geology of the earth.

For decades there was a planet whose crust was essentially a static feature, a rigid structure disturbed only by local effects and some vertical adjustments due to the weight of continental areas. Now they view the upper layer of the earth as a mobile, ever-changing system. Its sections scoot about the sphere in massive horizontal migrations like the pieces of a puzzle that a child might shift about in an effort to amuse himself with the variety of possible combinations of shapes and colors.

To be sure, a motion-picture view of this scene of shifting continents and ocean basins can be captured only by some imaginary, time-lapse geological camera, for the movements involved are measured in a few centimeters per year. But on a geologist's time scale, such dynamism proceeds at a dizzying pace that can open whole ocean basins in a matter of a hundred million years.

The Canadian geophysicist J. Tuzo Wilson likes to compare this dramatic change in our view of the earth to the intellectual revolution in physics after the turn of this century when the birth of quantum theory and relativity yanked that science out of its classical and into its modern phase.

"I don't think the analogy is at all exaggerated," says seismologist Dr.

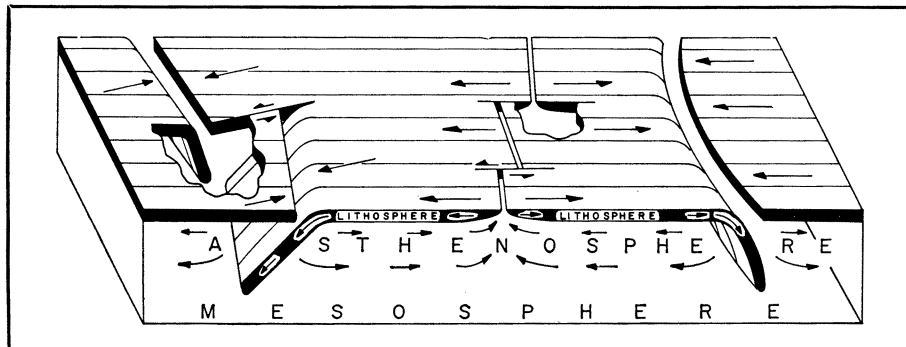
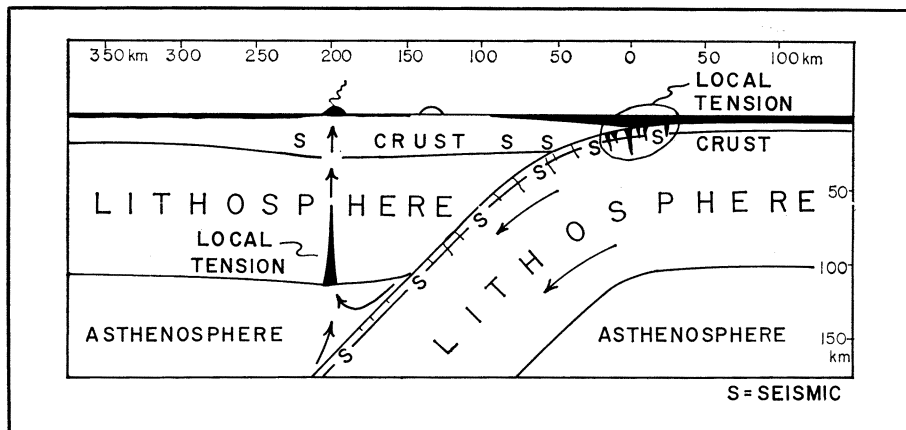
Bryan Isacks of the Lamont-Doherty Geological Observatory. "I think this is as important to geology as that was to physics."

The revolution is the product of the last decade's investigations by earth scientists from many disciplines, many of whom took to the seas to record the ocean floor's magnetic genealogy, monitor its reactions to seismic signals and extract revealing cores from its sediments. The consequence is the rebirth and affirmation of the once-dead and often scoffed-at theory of continental drift as refined and modernized by the demonstration of sea-floor spreading (SN: 5/10, p. 449).

Out of this all, in the last year or so, has evolved a kind of theoretical world-view of these vast systems of movements variously described as the new global tectonics or, more specifically and simply, plate tectonics. The former term was coined by Dr. Isacks and two Lamont colleagues, Drs. Jack Oliver and Lynn R. Sykes, to refer in a general way to the now-current concepts of the large-scale structural movements and processes within the earth.

Central to plate tectonics is the concept of a rigid upper layer of the earth called the lithosphere, which is composed of the crust and the uppermost layers of the mantle. This layer, which has considerable strength and is roughly 100 kilometers thick, rests or floats on a second layer called the asthenosphere, which has essentially no strength and





Lamont-Doherty

All the world's a set of slabs, say Drs. Sykes, Oliver and Isacks. Crashing slabs or plates cause mountains, trenches and seismic activity.

extends from the base of the lithosphere down several hundred kilometers.

The situation is analogous in many ways to a layer of rigid ice floating on water; the supporting material offers practically no resistance to the horizontal movement of the floating mass.

The lithosphere is divided into vast plates or blocks which are bounded by the ocean ridges, by certain faults and by the great systems of arc-like structures such as those around the rim of the Pacific Ocean. The plates spread apart at the ridges, grind against each other at the faults, and are underthrust at the island arcs and similar structures.

Dr. Xavier LePichon, a French scientist who has carried out work at Lamont, has proposed a simplified model that requires only six plates to provide a consistent picture of the global pattern of surface motion, based on the data from sea-floor spreading.

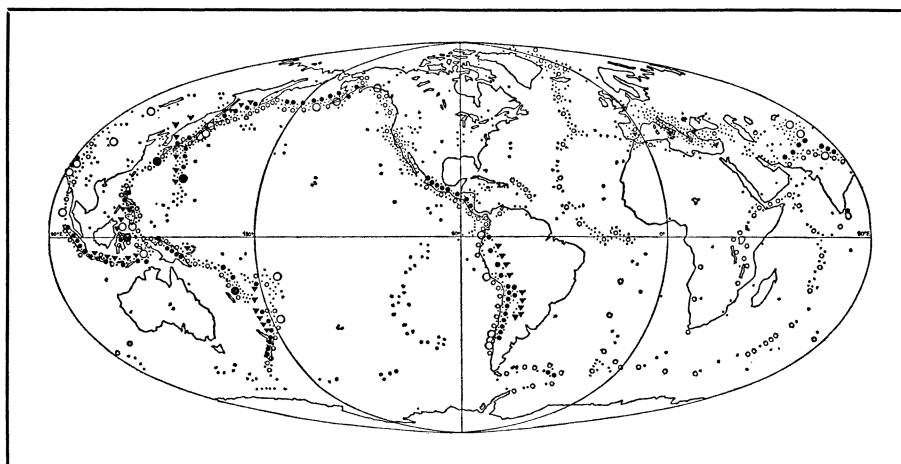
The plates are enormous:

- The American plate carries the North and South American continents and the western half of the Atlantic Ocean floor.

- The African plate carries the eastern half of the South Atlantic floor, all the African continent, and part of the Indian Ocean floor out to the mid-Indian Ridge.

- Europe and Asia, except for India and Arabia, are on one block.

- The Pacific is the only entirely oceanic block. Its eastern edge is overridden by the west coast of the



Major seismic zones correlate well with boundaries of lithospheric plates.

United States, then extends south along the East Pacific rise.

- Australian and Antarctica blocks have less well-defined boundaries.

For finer detail a few smaller plates need to be brought into play, such as a Caribbean block, which is apparently absorbing whatever differential movement there may be between North and South America.

Over geologic time, then, these plates move about over the surface of the earth carrying their cargo of continents or oceanic sediments. Where they spread apart at the ocean ridges, hot basaltic material from the mantle rises up and joins their trailing edge.

The ridges are frequently broken

into sections creating faults perpendicular to the ridge. Along these fault lines, plates moving in opposite directions rub together, creating small earthquakes. The absence of earthquakes beyond the ends of these fault lines has supplied one of the strongest pieces of evidence in support of the theory.

But the minor frictions and small earthquakes along the faults at the ridges are dwarfed by the events going on at the leading edges of the plates. There plates are frequently colliding with each other in interactions that over geologic time apparently produce some of the earth's major topographical features.

Dr. LePichon has found that what

... plate tectonics

happens at the collision of two plates apparently depends on how fast they are moving toward each other. If the rate is less than about six centimeters per year, they tend to buckle and fold, creating a range of young mountains such as the Himalayas, where the Indian and Eurasian plates are in collision.

If the rate is more than about six centimeters per year, one plate thrusts under the other, descending into the asthenosphere at about a 45-degree angle, eventually to be destroyed in the mantle. These areas of underthrust have produced the great ocean trenches, such as the Tonga Trench in the southwestern Pacific, the Kuril, Japan, and Mariana Trenches in the northwestern Pacific, and the Peru-Chile Trench off the western edge of South America.

Seismologists can trace in rough outline the path of the sloping lithospheric plate as it dives into the earth because seismic waves from earthquakes and explosions travel faster down its length than they do in other directions through the warmer asthenosphere. The impact of two plates also produces the islands and volcanoes and accounts for the major earthquakes characteristic of the trench and island-arc systems.

Where the collision happens at the edge of a continent, it appears that some of the sediment may be scraped off and piled up along the edge of the continent and become incorporated into mountain ranges such as the Andes in South America.

The forces responsible for such vast movements are still only poorly understood. Despite their importance, no completely satisfactory account has yet been given.

The traditional view is that the differences in temperatures under oceans and continents can create convection within the mantle, which then slowly moves like a conveyor belt, splitting the plates apart to form a ridge and then carrying them along horizontally. But there are problems with this view, and an alternative possibility gaining favor is that the sinking plate cools the mantle to produce convection currents to move the plates.

Recently Drs. Isacks and Peter Molnar published evidence in support of still a different view—that gravitational forces on the downgoing slab exert a pull on the surface plate (SN: 10/11, p. 330). These may be important in driving the global system.

Although plate theory is still in the formative stages, it provides ways to predict and possibly observe interrelationships on a large, perhaps worldwide scale, points out Dr. Oliver. "It ap-

pears," he says, "that this is a, or perhaps the, golden era of geology." Plate theory opens the way to relating seismic activity in one area to that in an adjoining, or perhaps distant, area associated with the same lithospheric plates. Propagation time for the effect may be long, but stresses may be transmitted over large distances through the plates.

The theory offers great promise for developing methods of earthquake prediction and prevention, say Drs. Oliver and Isacks. It is now contributing to a basic understanding of the earthquake phenomenon—a necessary antecedent to prediction. Already, they point out, it has provided a theory that predicts over-all strain rates in tectonic areas throughout the world.

"I think plate theory is having and will continue to have a profound effect on most geologists' thinking," says Dr. Isacks. "You can hardly read a journal article that doesn't take some recognition of it."

But while the theory is successful in explaining large-scale features in and around the ocean basins, many major problems remain. "For the gross picture, it is right," says Dr. W. Jayson Morgan of Princeton University. "But there are many details, especially if you call Hawaii a detail; there is no reason why Hawaii should exist."

He also points to inability of the theory to account for seismic activity in Nevada or for the creation of the Rocky Mountains, areas some distance from any plate collisions.


But Dr. Oliver feels that the explanation of major land topographic forms will be the next area of application of plate theory. For example, a Cambridge University geologist, Dr. John F. Dewey, has recently made use of plate tectonics to explain in remarkable detail structural and stratigraphic features of the Appalachian Mountains in North America and the Caledonian Range in northwestern Europe. The two ranges form a continuous belt when the North Atlantic is squeezed together by fitting the 500-fathom line of the present continental margins.

"I think this is the direction we will be going in the future—applying the theory to the geology we can see in the field," says Dr. Oliver.

"The general features of plate motion are about as close to certain as anything is," says Dr. Isacks. "But the details, the driving forces, what exactly is happening at great depths, are all still in the form of a hypothesis. So I think in the future we will be working in these areas and also applying the ideas to the geological history of land features." □

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