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101 American Geo-Sites you've Gotta See by Albert B. Dickas

PLATE TECTONICS THEORY

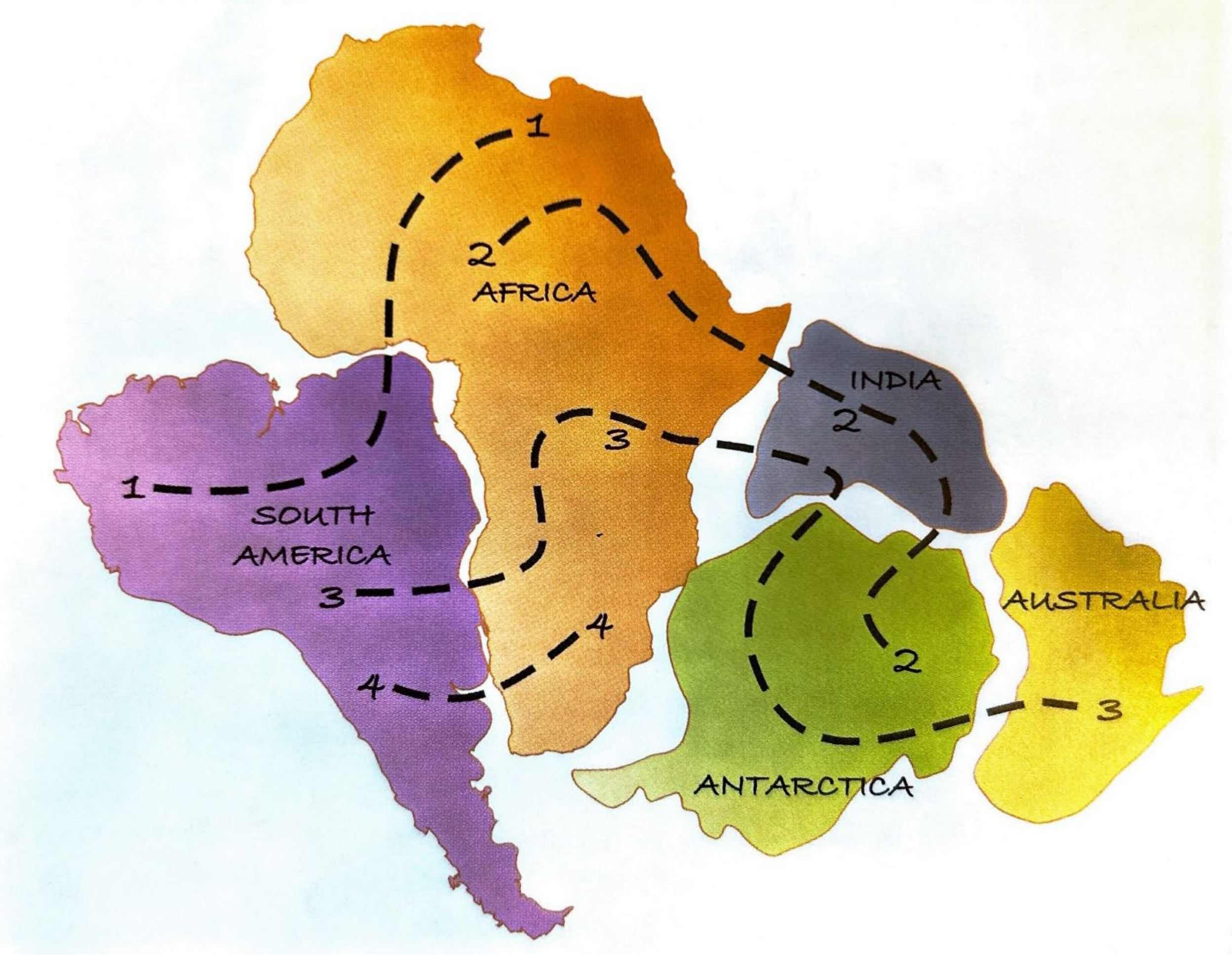
The ideas behind plate tectonics have been around for a long time. As soon as maps of the various landmasses became available with shapes, sizes, and coastlines akin to reality, individuals who spent time studying them became intrigued by the configuration of Africa, South America, and North America. The coastline of each one seemed to be related to the coastlines of the other two. Most specifically, the eastern protuberance of South America appeared to have been created for the sole purpose of eventually being fit into the curve of western Africa. It was as if these continents had once been one and then were torn apart by some Earth rending force.

Abraham Ortelius, acknowledged as the editor of the first modem atlas, suggested as early as 1596 that consideration be given to the "projecting pans• of Europe and Africa. In the decades that followed, other prominent men added their thoughts to the developing theories that, far from being an immobile planet, Earth is continually being altered by regenerative processes. For example, Sir Francis Bacon suggested in 1620 that the mapped coastlines of South America and Africa were "no mere accidental occurrence. Benjamin Franklin thought the fossils he collected in the high hills of Derbyshire, England, in 1782, had reached elevated heights because Earth's crust was "floating on a fluid interior" and thus was "capable of being broken and disturbed." During his five-year exploration of South America, beginning in 1799, Alexander von Humboldt recognized that the mountainous terrain ending at the continents eastern shoreline appeared to continue beyond the vast Atlantic Ocean and onto the western edge of Africa. He was one of the first to suggest that "matching edges" be combined with "geologic fabric" to support the concept of a once-singular landmass

These early ideas had one common thread: the obvious fit of the continents had something to do with the Noachian flood, the catastrophic event in biblical history that supposedly altered the face of the planet. In 1858, however, French naturalist Antonio Snider-Pellegrini presented a refreshingly different idea. He argued that the biblical flood was the result, not the cause, of continental breakup. Soon, the rush was on to find fossil and rock evidence to support the processes of continental rupture and displacement-often with astounding results. for example, in 1885 Austrian geologist Edward Seuss presented evidence th.at similar fossil plantforms could be found in South America, India, Australia, Africa, and even Antarctica. Convinced these landmasses were once one, he named that hypothetical mother continent Gondwanaland.

With support for the idea of a universal flood waning, and continental fit no longer considered a coincidence, in the latter half of the nineteenth century the community was finally set free from the restraints of theological approval. More than 250 years had passed since Onelius published his maps. IL was time for a new and succinct approach to the understanding of global geologic process.

During the 1908 meeting of the Geological Society of America, Frank Taylor, a geomorphologist with special interest in glacial landforms. argued against conventional concepts regarding global geologic process. He methodically presented his thesis: "A great world-belt ... of Tertiary foldmountains almost circling the Earth" had been formed by massive lateral forces over an "extended period of time; the result of a "mighty creeping movement" directed by crustal fragments moving "from polar to equatorial latitude." Referring to a crude bathymetric chart, he became the first geologist to identify the Mid-Atlantic Ridge as a "submerged mountain range of a different type," one that marked "the original place of the great fracture" that "remained unmoved whilst the two continents on opposite sides have crept away in nearly parallel and opposite directions."



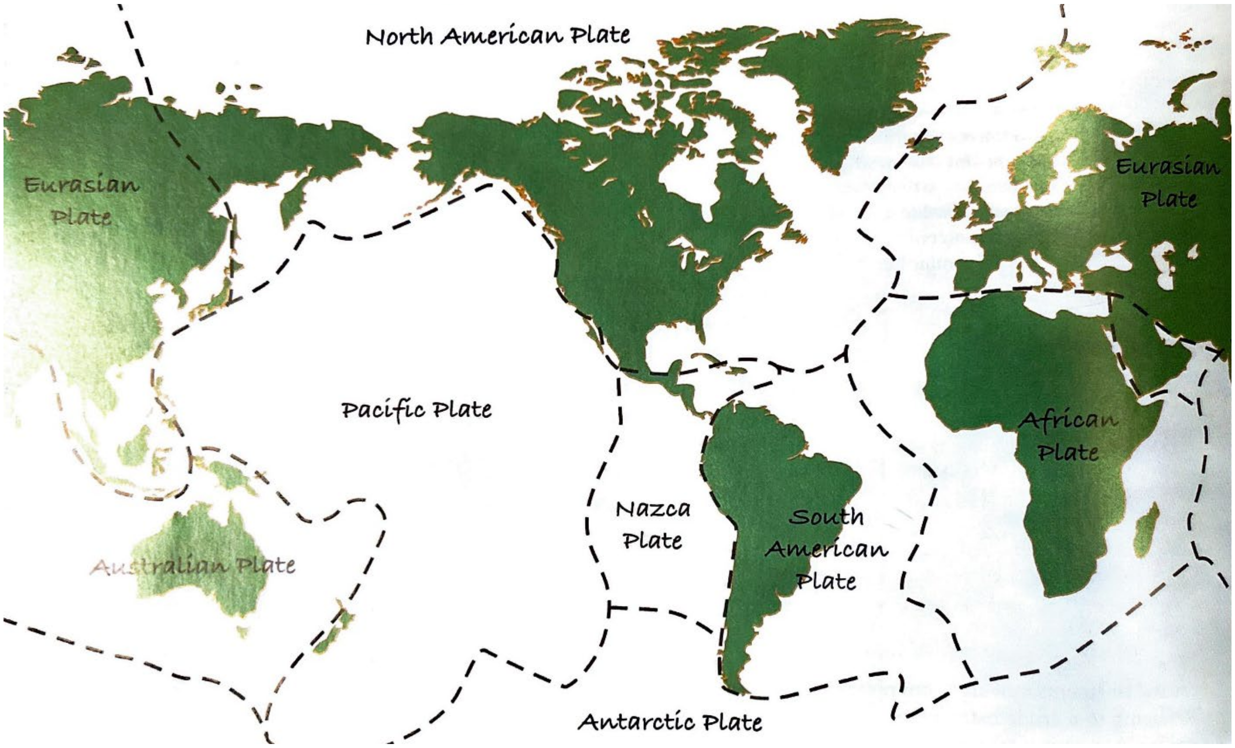
The presence of similar fossil species (1 through 4) in various southern hemisphere continents, separated by vast oceans, makes sense when the continents are joined together in a single landmass according to the precepts of continental drift.

These thoughts are believed to be the very first discussion of the processes that six decades later would become the scientific framework of the seminal, universally accepted theory of plate tectonics. What the theory of evolution did for the understanding of life and the discovery of radioactivity did for the comprehension of the atomic world, the theory of plate tectonics did for a better understanding of Earth processes, by assembling previously discombobulated geologic data and binding them together in a unifying framework of understanding.

This revolutionary theory can be presented with four basic concepts: (1) The crust and the uppermost region of the mantle of the Earth are composed of a series of rigid plates that fit together like the plates that make up a turtle's shell. (2) These plates are in slow but constant movement relative to each other, at a rate about as fast as the human fingernail grows. Some collide, others move apart, and a few grind against each other. (3) Most of the world's geologic activity, such as mountain building, volcanic eruptions, and earthquakes, takes place along the edges of the plates. (4) Geologic activity is minimal in the interior regions of the plates.

The theory of plate tectonics explains the distribution of the plots of seismic and volcanic activity; the global array of ancient reef, coal, and fossil deposits; the geometry and evolution of the continents; and the location of folded and faulted mountain ranges. It is extremely valuable in identifying areas most apt to contain fossil fuel reserves versus regions more adaptable to the formation of mineral deposits. No longer is the Earth viewed as merely a combination of continents and ocean basins. It is, instead, a mosaic of major and minor plates that are constantly interacting in a time continuum affecting the very essence of planetary process, ranging from the evolution of flora and fauna to the rise and fall of mountains and ocean levels.

The birth of plate tectonics can be traced to the 1915 publication of *The* Origin *of Continents and Oceans,* by a then-obscure German meteorologist named Alfred Wegener. Universally acknowledged today as the originator of the theory of continental drift, the precursor to the plate tectonic theory, Wegener was a Renaissance man whose thoughts ranged far beyond wind, rain, and sunshine. He was the first to compile the myriad of Earth-process thoughts that had arisen over the centuries into a compact text. He was also the first to argue that all the continents had been joined together at one time as a supercontinent. He named the supercontinent Pangaea, meaning "all Earth," and said it had been surrounded by a universal ocean he called Panthalassa.



The theory of plate tectonics posits that the crust and upper mantle of the Earth are made up of a mosaic of eight major plates (shown) and six or more minor plates (not shown). Zones along which the plates are moving apart, coming together, or grinding past each other identify their boundaries.

His book was widely read and generated much opposition. One major point of contention dealt with the "force" behind his ideas of drifting continents. Since he wasn't sure what that might be, he attempted to answer by analogy: imagine lightweight continents sailing through a denser crust like icebreakers plowing through a frozen ocean, while periodically they break up and drift apart. The reaction was immediate and ranged from "a footloose idea” to “utter damned rot." When he died on the Greenland ice cap in the1930, his beliefs were temporarily buried with him.

After the conclusion of World War II, geologists undertook the gargantuan task of converting tens of thousands of miles of collected ocean-sounding profiles into a world-wide catalogue of bathymetric charts. From this effort emerged the first realistic, three-dimensional representation of topography of the ocean floor. Early in this process, cartographers recognized a sharply defined ridge in the Atlantic Ocean, halfway between Europe and North America and halfway between Africa and South America.

The existence of segments of this ridge had been part of general knowledge for decades, but this new information fully identified the Mid-Atlantic Ridge and extended its trend into the Pacific, Indian, and Arctic regions in the form of a 40,000-mile-long, world-encircling mountain chain that contains the highest peaks--as measured from the ocean floor-known on the face of Earth. Along with the oceans and continents, the ridge, once discovered, was recognized as one of the most prominent features defining the surface of the planet. And so the modem era of oceanographic research had begun. Each new discovery quickly prompted a series of questions. By the mid-1960s, volumes of new data updated the once-rejected ideas of Wegener, which ultimately were repackaged as the plate tectonics theory.

Post-World War II research that revealed the presence of a mushy, semiliquid zone confined to the uppermost layer of the Earth's mantle resolved Wegener's question of driving force. Geologists today believe that convection cells, heat-driven currents of semimolten rock fueled by the extreme high temperatures of the Earth's core, are the force behind plate movement. As these rising currents approach the underside of the crust, they spread apart and move laterally, dragging the overlying plate along much like a conveyor belt transports its load of material. The currents then slowly cool, become dense, and finally sink back into the base of the mantle, where they are reheated and begin the journey upward again.

The rise and fall cycle of convection cells produces three categories of plate movement: divergent, where plates move apart; convergent, where plates slowly collide; and transform, where plates grind against each other in opposing directions.

Let's start with divergent boundaries. Real-time data from deepwater cameras used to study the development of the Mid-Atlantic Ridge have been correlated with other sources of information to show that the Atlantic Ocean was born through a mechanism called seafloor spreading. As rising convection cells diverge from one another, they cause the tectonic plate above to fracture. Magma oozes into the fracture, slowly crystallizes, and temporarily heals the wound. Soon, however, fracturing begins again, and more divergence takes place, along with more magma injection. In this manner, the entirety of the Atlantic Ocean continues to grow in width, on average 1 to 2 inches per year, as seen by the eruptions of lava that periodically take place on the islands of Iceland and Tristan de Cunha, which are part of the ridge.

Not all divergent boundaries are as old as the Mid-Atlantic Ridge. Along the East African Rift, divergence is in a very early stage of development. There it appears that a portion of the African Plate is splitting into two smaller plates. Further north, the Red Sea represents a more advanced state of divergence. Some divergent boundaries never grow beyond the youthful stage-meaning they never become ocean basins. The Midcontinent Rift, a structure of Precambrian age that underlies the waters of Lake Superior, is a case in point. Born some 1,100 million years ago, it ceased to be active after a mere 22 million years, when the collision of proto-North America with a smaller landmass named Grenvillia altered its tectonic character from divergence to convergence, closing the rift.

New rock is constantly being generated along divergent boundaries. However, because the surface area of Earth has remained essentially constant throughout time, new-rock volume must somehow be balanced by the consumption of an equal volume of rock elsewhere. Convergent boundaries are, by definition, the zones along which rock is consumed by the mantle.

Although all convergent zones are basically the same in their overall mode of operation, the specifics of plate collisions are determined by the nature of the involved plates. Convergence can take place between two oceanic plates (composed of seafloor rock), two continental plates (composed of continental rock), or one of each type.

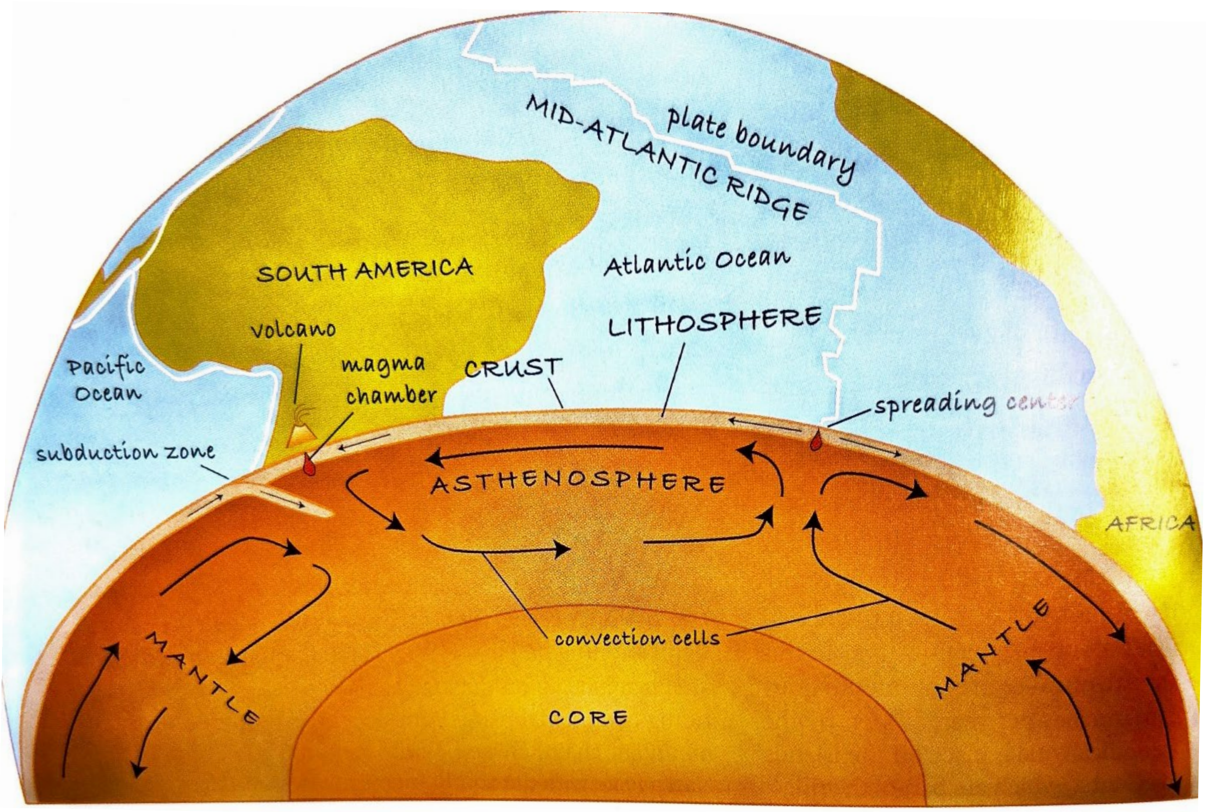
The convergence of two oceanic plates has created some of the great island trends of the world. When oceanic plates collide, the plate with the higher density will plunge, or be subducted, beneath the other. At a depth of about 60 miles in these subduction zones, the leading edge of the descending plate will partially melt and form a pocket of magma that will rise slowly to the surface and erupt, forming an island arc, a linear chain of volcanic islands. Interesting examples exist throughout the northern and western portions of the Pacific Ocean, including the Aleutian, Japanese, and Philippine Island arcs. The eighteenth-century eruption of Mount Fuji and that of Mount Pinatubo in 1991 are evidence that these islands are indeed volcanic.

When an oceanic plate collides with a continental plate, the denser oceanic slab is always subducted beneath the lighter continental mass. Magma is still produced as the oceanic plate melts, producing chains of volcanoes on the overriding continental plate. Prime examples include: the Andes Mountain chain, created by the continuing collision of the Nazca Plate with the South American Plate, and the Cascade Range of Washington and Oregon, the result of convergence of the North American Plate with the Pacific Plate. The eruption of Mount St. Helens in 1980 is evidence that the Cascade Range is still growing through plate tectonic activity.

Continent-with-continent convergence has created some of the largest mountain ranges in the world. Because the colliding edges of both plates are composed of relatively low-density material, making them quite buoyant, neither one is subducted. The result can be a fender-bender collision of humongous proportion. The Himalaya Range, home to more than one hundred peaks that exceed 23,000 feet in elevation and Mount Everest, the highest mountain in the world, is a textbook example. Others are the Alps of Europe and the Atlas Range of North Africa. Closer to home, continent-to-continent collisions between early versions of the African, North American, and Eurasian plates formed the Appalachian Mountains over a period of several hundred million of years, during the Paleozoic era.

The third type of plate boundary takes place where two plates, either of a continental or oceanic nature, grind past each other in a lateral movement known as transform motion. While volcanism is generally absent within these zones, they are home to earthquake belts of international fame. The best example is the San Andreas Fault, a very active zone of seismic activity caused as the Pacfic Plate grinds past the North American Plate.

Before the years of World War I, the Atlantic Ocean was known to the extent of only one depth sounding for every 5,400 square miles, and the Pacific to only or every10,000 square miles. Today, practically every segment of the world’s oceans has been depth sounded and age dated. The oldest ocean floor found anywhere, in the western Pacific Ocean, is some 180 million years old. This age is but 4 percent that of the oldest known continental rock, a stark indication that Earth's continents are not recycled and its seafloors are. Throughout geologic time continents have grown by accretion-increasing their size through collision with island arcs and other microcontinents. In contrast, oceans continue to open and close, the victim of plate boundary divergence and convergence.



The driving force of plate tectonics is a system of clockwise and counterclockwise convection cells that create within Earth's crust spreading centers (divergent boundaries), subduction zones (convergent boundaries), and transform boundaries.

As soon as the principles of the theory of plate tectonics were accepted, geologists began collecting additional information to test the theory. hoping to build an even stronger foundation to this concept of Earth process. Earthquakes provided some of this new information.

For years seismologists had been interested primarily in plotting the world\\ide d1suibution of earthquake epicenters, those geographic points vertically above the heart, or focus, of Earth tremors. When they began to study the relationship between focus and epicenter, they quickly recognized an interesting pattern. For example, along the convergent boundary forming the western border of the Pacific Plate, in the western Pacific Ocean, shallow-focus quakes occurred immediately below the deep-sea trench that marks the surficial contact of the Pacific and Eurasian plates. In contrast, intermediate- and deep-focus earthquakes occurred progressively farther to the west, toward the shoreline of China. In essence, the plots painted a picture for seismologists. Clearly, the Pacific Plate was the denser of the two and plunged westward underneath the Eurasian Plate in a subduction zone, generating earthquakes with ever-deeper origins.

Deep-sea drilling from the decks of specially designed oceanographic vessels provided information that also supported the theory of plate tectonics. Comparing the oldest ocean floor sediment from each drill site to its distance from the nearest active oceanic ridge (spreading center) revealed that the sediment age increased with increasing distance from the ridge. Thus, the most juvenile ocean crust was adjacent to the axis of the oceanic ridges, where new crust was being or had most recently been created, and the oldest was along the subducted margins of the plates.

Radiometrically age dating rocks from the Hawaiian Island-Emperor Seamount chain of volcanic islands in the Pacific Ocean showed that age increased with increasing distance from the still-growing island of Hawaii, the youngest of this several-thousand-mile-long chain. Geologists proposed that this linear relationship was due to a hot spot, a rising plume of magma, beneath the Pacific Plate. As the Pacific Plate moved northwesterly over this site of volcanic activity, periodic eruptions created new volcanic island. Hawaii is currently positioned over the hot spot, which is why it is so volcanically active.

Finally, the most startling new information in support of the theory of plate tectonics is associated with the 1977 discovery of black smokers along the crest of the spreading-center ridge in the eastern portion of the Pacific Ocean Subsequent discoveries show that these erupting hot springs-a mixture of boiling water, hydrogen sulfide and other gases under great pressure that are in reality the exhaust of the thermal energy that drives ocean spreading-occur exclusively along divergent boundaries. The more than three hundred new species of life found living in close association with these vents are dependent not on the energy of the sun, but on the chemicals dissolved in the smoker fluids. Some scientists have suggested that black smokers once served as the very incubation sites for life on Earth.