PLATE TECTONICS

I believe this revolution will unite branches formerly fragmented and that the new unified science of a dynamic Earth deserves a new name—*geonomy*. [This name has not caught on.] —Tuzo Wilson.[1]

g8 Kinematic theory of plate tectonics < lithosphere plates >

Kinematic theory cannot yield absolute motions. For example, Giambattista Riccioli's *Almagestum novum* (1651) includes an account of the work of Johannes Kepler and weighs against his Copernicanism with 49 arguments for and 77 against the motion of Earth.[2]

The kinematic theory of plate tectonics subsumes the hypothesis of seafloor spreading (in that it is supported by all the tests, and more, that supported the latter).

In the plate-tectonics model, the outermost part of the solid Earth is a rocky shell called the *lithosphere* (Gk. *lithos*, rock). The lithosphere is broken into various sized pieces called *plates* (*see* Figure *d7.1*, p. 201). The plates are in motion with respect to each other. Yielding mantle rock below is called the *asthenosphere* (Gk. *asthenos*, weak). The asthenosphere exists because through its depth the increasing temperature's weakening effect is not exceeded by the strengthening effect of increasing lithostatic pressure. In the mesosphere below, the reverse holds.

Fragments of lithosophere-shell glide as "rigid" plates on the "plastic" asthenosphere. The plates can break brittlely (releasing frequent edge, and sometimes intraplate shallow-focus earthquakes)[3] and can bend elastically where they turn down along an edge to subduct as a slab through the asthenosphere into the mesosphere below. The down-going slab (***Footnote g8.1***) releases earthquakes from foci to 60 km depth in the subducting oceanic crust caused by dehydration reactions as basalt and/or serpentinite heats and is pressurized with depth, and from deeper foci by yet unknown mechanisms[4] to depths of 670 km. Where two plates move apart, the asthenosphere rises in obedience to isostasy to fill the otherwise gap. The rising asthenosphere cools and so transitions to lithosphere. Thereby, the trailing edge of an advecting plate is continually added to.[5]

The reality of the plates, and our certainty of their movement (***Footnote g8.2***), is a protreptic. However, kinematics is a geometrical description of movement in terms of velocity, acceleration, and jerk vectors, and is not an explanation of observed displacements. What causes plate movement (the dynamics of it) in terms of acting forces, is another question entirely (*see* Topic *g14*).

Footnote g8.1 "We [**Jack Oliver** and B. Isacks in 1967] were able to draw a now-famous cross section showing a layer of strength, the lithosphere, dipping beneath Tonga.

"It was a true Eureka moment for us. ... a 60 mile (100 kilometer) thick slab of lithosphere from near the surface to depths of at least 450 miles (720 kilometers) ...

"We were more or less onto the concept of the moving plates then, but we called it the *mobile lithosphere model*, using the terms *lithosphere and asthenosphere*. ... The term *plate tectonics*, which is so well known and widely used today, had then not been invented.

"[Then] Lynn Sykes, Bryan Isacks, and I ... set out to relate all relevant information from earthquake seismology to the plate model so as to test and further develop it. ... [O]ur paper, 'Seismology and the New Global Tectonics,' published in the *Journal of Geophysical Research* in 1968,[6] became something of a classic. It showed that the global pattern of earthquake belts, including the sites of deep earthquakes, the global pattern of earthquake focal mechanisms, and a variety of other evidence from earthquake studies, was in accordance with the plate model (although the term *plate tectonics* was still not in use [even as late as 1969 [7]])."

—Jack Oliver [Quotations from *Plate Tectonics*, pp.160-161, Naomi Oreskes, 2001][8]

Footnote g8.2 Wilson's inference of fixed mantle hotspots [9] was revamped by W. Jason Morgan's explanation in 1971 of the origin of the Hawaiian island chain (***Figure g8.2***) as a feature of plate tectonics.[10]

A plate-tectonics test is: The age of the islands should agree with seafloor magnetic stripe chronology. This is found to be so, to a first approximation, and the hypothesis is supported.[11]

Beneath the plates, and not affected by their movement, Morgan postulates columnlike mantle convection plumes. These, (if they rise from the core-mantle boundary) will be 200-300 ºC hotter than is the normal mantle. Decompression partial-melting of the plume head will then deliver basaltic magma to the base of the plate. The "hotspot" volcanism at Earth's surface is due to these magmas melting through the plate. Norman Steep vividly, if spuriously, describes the geometry as "similar to a series of burns caused by moving your [*sic*] hand slowly over a candle flame"(***Figure g8.3A***).

Worldwide, 47 hotspots have been identified. They are widely separated and no pattern shows in their occurrence. The chemistry (trace element abundances) of hotspot basalts, which are melts from plumehead garnet-facies mantle peridotite at great depth, differ from MORB (mid-ocean ridge basalts), which are melts from plagioclase-bearing mantle peridotite at shallow depth.[12]

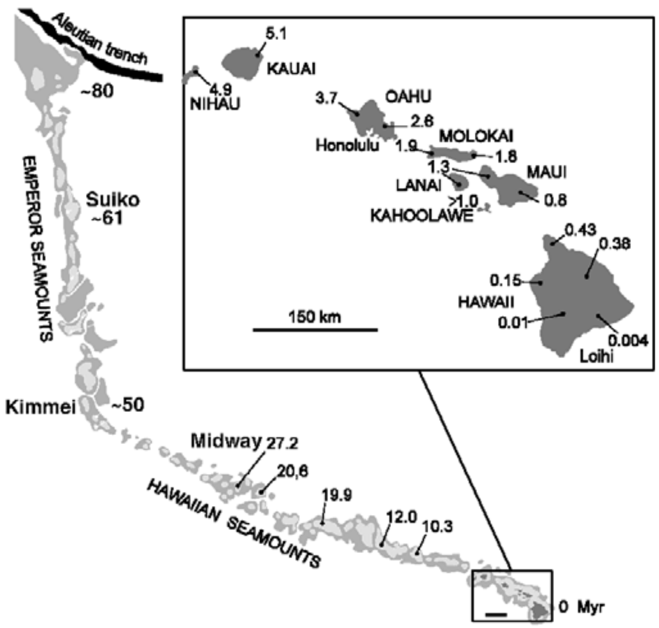
Hawaiian aseismic-ridge seamounts increase in age northwest to Kimmei seamount, which Warren D. Sharp and David A. Clague find formed ~50 Ma years ago, and from there, north-northwest along the Emperor seamounts, the age increases to ~80 Ma near the Aleutian trench.[13] The abrupt 60 degree bend in the Hawaiian-Emperor seamount chain is evidence that the direction of plate movement does not drag the hotspot with it or cause the rising hot plume to deviate significantly from its vertical rise. Individual plumes (~100 km diameter) are apparently too narrow to be much effected by, or themselves effect, the broad mantle convections which plate motion implies.

A complication can arise when a plume is near a ridge. Then the buoyant plume-material may also flow along the inclined base of the lithosphere and from it lava can erupt at times at the ridge axis or at some remove when intraplate stress fracturing controls the location of volcanoes that tap a spreading plume-head. For example, radiometric dates from the Cook-Austral chain, with a range of ages spanning 34 My, reveal it, according to M. K. McNutt, to be a composite of short volcanic chains with inconsistent age progressions: Macdonald seamount, the only active volcano on the chain, is midchain. A hotspot directly beneath it, certainly cannot account for the chain or its complications, but a diffuse (broad plume-head) source could be the feeder (***Figure g8.3B***).[14]

In 1987, Peter Molnar and Joann Stock found that Pacific hotspots *do* move relative to those in the Atlantic at rates of 1-2 cm per year. The kinematic model must now be refined to consider plate movements, hotspot mobility, and true polar wandering.[13-15] In particular the Hawaiian hotspot was not at its present 19ºN latitude where it has been for the last 40 million years, but, paleomagnetic-latitude measurements of Emperor seamount-lavas record, it was moving rapidly south before. The trend of the Emperor ridge is mostly due to the movement of the hotspot during the Paleogene.[16]

In 2003, at the Penrose conference, some points advanced were: volcanism in the western Pacific plate has produced linear, age progressive, and parallel seamount and island chains since it became largely bordered with subduction zones following closure in the Eocene of Tethys by continental collisions (Martin F. J. Flower). The Emperor-Hawaiian bend does not record a substantial change in direction of the Pacific plate, as may be seen from the continuity of seafloor-spreading patterns and transform zones of the same age (Warren Bell Hamilton), but may represent a change in the orientation of stress imposed on the plate from its edges. Scattered Pacific magmatism could be related to shear heating generated by the so-called westward drift of the lithosphere (Carlo Doglioni). In short, plume theory mostly perpetuates a myth. Gillian R. Foulger reminds that since 1963 "given the rate at which plumes were multiplying," urgently needed was someone "to prove that they don't exist before it was too late."[17]

Figure g8.2 [18] The Hawaiian-Emperor volcanic aseismic-ridge (gray) is a chain of volcanic seamounts and islands that does not lead away from a ridge, is not parallel a trench, and is not associated with an active fault. In the figure, numbers are ages in millions of years (My) of the youngest volcanic flows of each island (dark gray) or seamount (light gray).

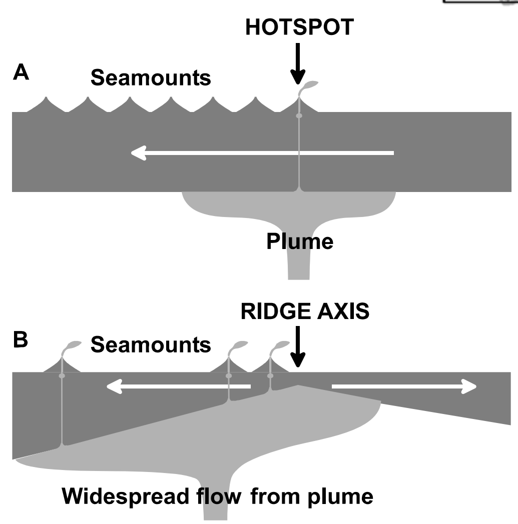


The volcanically active island of Hawaii is at the southeast end of Hawaiian-Emperor volcanic seamount & island 6000 km chain. The Hawaiian seamounts increase in age northwest to Midway Island and on to Kimmei seamount that went extinct ~50 My ago. From there, going north-northwest, the Emperor seamounts increase in age of their youngest volcanics to ~80 My near the Aleutian trench.[13]

The chain's origin has been explained by volcanism that punches through the moving lithosphere plate from a stationary hotspot below. However, John Tarduno reports that paleomagnetic and radiometric age data from samples recovered by ocean drilling define an age-progressive paleolatitude history, indicating that the Emperor Seamount trend was principally formed by a moving (at over 40 millimeters per year) hotspot plume.[19]

Figure g8.3 The South Pacific Cook-Austral chain of volcanoes have a non-progressive increase of age away from the South East Pacific ridge. For such, Norman Streep conceptualizes a broad region of warm mantle upwelling that travels beneath the lithosphere. Cracks in the oceanic plate let magma erupt to form chains of volcanoes that are not pathlines over hotspots.

A. Standard hotspot model (candle analogy).
B. Hotspot model proposed by Norman Steep.[20]



Footnote g9.1 For measuring water depth (sounding), standard were 20- and 100-fathom lines weighted with 7- and 14-lb lead masses respectively. To sample the seafloor, the weights had hollow bases filled (known as arming the lead) with tallow to which loose bottom sand, mud, stones, and shells, would stick. "These particles," Alan Gurney writes in *Compass*, 2004, "provided vital information for coastal sailing and are still to be found on British Admiralty charts. Sprinkled among the numerals on the chart, giving the depth of water, can be found cryptic and mysterious letters: S for sand; M for mud; Si for silt; St for stones; Sh for shells; Oz for ooze; and, giving a hint of more pellucid and warmer waters, Co for coral. Hydrographers can even become garrulous, in a nautical text-messaging style, with mixed types of seabed: fS.P.bk.Sh.G.Ck, for instance, meaning fine sand, pebbles, broken shells, gravel, and chalk."[21] Indispensable on any ship of the day, Scott Huler tells us in *Defining the Wind*, 2004, was *Moore's Practical Navigator* in which were handy tables for such as knowing distance to objects appearing on the horizon by height of eye above sealevel to, in its words, "saving Lives from a Ship lost on a Lee-shore" which when faced with immanent shipwreck by the driving wind "must be allowed to be one of the greatest acts of humanity."[22]