

Is plate tectonics withstanding the test of time?

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Abstract

Since the theory of plate tectonics was first proposed thirty years ago, some problems have arisen in its practical application. These call into question its fundamental assumptions of horizontal plate motion, hotspot fixity, true polar wander, Panthalassa, and the Earth's constant size while leaving seafloor spreading and subduction intact. A rapidly expanding earth solves these problems and provides an alternative viewpoint worth reconsidering.

Key words *plate tectonics – earth expansion – paleomagnetism – rift valleys – orogenic belts – hotspots*

Time reveals the truth

Seneca, 43 A.D.

1. Introduction

Plate tectonics has enjoyed tremendous success as a working hypothesis of earth history and has had a spectacular unifying effect upon the earth sciences.

It views the lithosphere as comprised of rigid plates that move about with respect to one another over an earth that has remained a constant size since very early in its history, in accordance with spherical geometry principles. Each plate thus interacts with adjacent plates by mid-ocean ridge migration, collisional thrust-folding, subduction, obduction, and/or fault displacement along mutual boundaries that are seismic.

The continents rift apart, disperse away from one another by being embedded in the moving plate, and ultimately collide again. All plates, trenches, and spreading ridges are thus assumed to be in relative motion.

But how well does the theory assimilate new discoveries not originally predicted in its formulation and clarify any obstructing problems that have subsequently developed? The enormous tensional force required to rupture Pangea into individual continents and the large compressional force required to initiate trenches are not easily explained by the theory, for example. (*cf.* McKenzie, 1977; Wilson, 1988). Here I will explore some other problems that the theory encounters and will offer an alternative explanation that better explains these.

2. Seafloor spreading and rigid plates

Plate tectonics originally had continents moving away from stationary spreading ridges, which would be impossible for Africa and Antarctica since they are surrounded by actively spreading ridges. In the case of Africa, these ridges are located on opposite sides of the continent and are migrating away from it

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(Schilling, 1991), with the extensional East African rift zone located in between. Mid-ocean ridge «migration» by asymmetric spreading is away from the African plate and toward the Pacific plate on a global scale (Stein *et al.*, 1977). Plate tectonics has since abandoned the view that mid-ocean ridges are fixed and now considers all plates to be moving simultaneously relative to one another.

Plate tectonics assumes, for the purpose of mathematical model rigor, that each plate is perfectly rigid (Morgan, 1968). Such an assumption, however, is patently false since all plates exhibit internal tensional deformation along numerous faults and fracture zones and broad zones of deformation within orogenic belts well away from plate margins. Instead, the ocean floor is subdivided into a series of fault-bounded plate segments each spreading at a slightly different rate and direction (Salisbury, 1974). Mid-ocean ridges are thus subdivided into much smaller segments that are frequently offset from one another by fracture zones. Many plate tectonic models had predicted that these segments would show ridge-push, yet later exploration demonstrated that ridge-pull prevails (Shields, 1990), and the flanks away from mid-ocean ridge axes exhibit an extensional topography (*cf.* Wernicke and Burchfiel, 1982; Lister *et al.*, 1986). An underlying magma chamber below each rift axis periodically allows the asthenosphere to penetrate to the surface in the form of lava flows, seamounts, pillow lavas, and hydrothermal vents. Seismic velocity anomalies, however, remain distinct and continuous down to 300 km in the upper mantle below mid-ocean ridges (Su *et al.*, 1992).

3. Subduction

To maintain an earth of constant diameter, the amount of seafloor subducted in trenches must be equivalent to the amount of seafloor added at the spreading ridges. This holds for the Pacific where geodesic measurements yield subduction rates that are about half those of the estimated full spreading rates and where the North Pacific is contracting while the South

Pacific is expanding by approximately equal amounts (*cf.* Minster and Jordan, 1980; Dunn, *et al.*, 1990; Smith *et al.*, 1990, 1994). However, the total length of globally convergent ocean margins is 43 450 km, while the total length of globally active mid-ocean ridges is *ca.* 53 000 km (after transform fault displacements are subtracted), or nearly 10 000 km longer for mid-ocean ridges (*cf.* Shields, 1990; von Huene and Scholl, 1991). Also, except for the eastern margin of East Asia and the western margin of North America, the oldest seafloor is always located adjacent to continental margins (see, *e.g.*, Cande *et al.*, 1989), usually as magnetic quiet zones, and is much less extensive than the youngest seafloor located along the plate margins, such that all continental plates have been growing larger over the past 200 Ma. Since it is the Pacific where most trenches reside, consumption rates there must greatly exceed spreading rates if all plates elsewhere have been growing in size, yet the Pacific geodesic measurements show this is not the case. Seafloor reconstruction models that incorporate magnetic anomaly patterns indicate that the current episode of seafloor subduction along the western margin of the Americas commenced only *ca.* 26-30 Ma ago (*cf.* Handschumacher, 1976, fig. 20; Wilson, 1988, fig. 9), and most of the marginal seas along the Western Pacific margin were initiated by subduction and trench rollback in the Cenozoic (*cf.* Otsuki, 1989; Aubouin, 1990; Tamaki and Honza, 1991).

4. Rift valleys

Continental rift valleys are precursors to the formation of some ocean basins and are located near, and largely parallel with, the basin's margins. For example, an Upper Triassic to Lower Jurassic rift valley system, located along the eastern margin of North America, preceded basinal opening by seafloor spreading in the North Atlantic.

Continental rifts form under very high-temperature/low-pressure conditions (Wickman and Oxburgh, 1985). The presence of Upper Triassic rift valley systems along the cratonic mar-

gin of the Pacific basin would indicate that continents surrounding the Pacific were joined prior to when extant seafloor spreading began in the Lower Jurassic, as opposed to plate tectonics which instead widely separates these continents by a huge Panthalassa ocean in the Triassic.

Upper Triassic rift valleys along the Eastern Pacific margin can be positively identified in several instances. An Upper Triassic to Middle Jurassic graben depression formed along the cratonic margin of Eastern California, Southwestern Arizona, and probably Central Sonora (Busby-Spera, 1988). She interprets its alkaline to calc-alkaline volcanism as a continental arc; however, alkaline volcanics are more indicative of a rift valley, particularly since regional uplift accompanied their emplacement (see Reynolds *et al.*, 1989), and the volcanics closely compare with those of the Colima graben which is connected with the Late Tertiary rifting of the Jalisco block (Luhr *et al.*, 1985). From Upper Permian to Upper Triassic, the encratonic Eastern Cordillera of Southeast Peru and Northwest Bolivia was the site of a rift valley that accumulated alkaline and peralkaline volcanics and appears independent of any subduction influence (Kontak *et al.*, 1985). Alkaline granites 200 ± 12 Ma in age occur in a narrow band along the ensialic Cordillera Real of Central Ecuador (Aspden *et al.*, 1992) and probably represent another rift valley.

5. Orogenic belts

Abrupt shifts in rate and direction of seafloor spreading are synchronous with episodes of world-wide orogenic activity for the post-Triassic (Schwan, 1980, 1985). Thus, except for marginal foreland thrust-fold belts (Coney, 1973), plate tectonics theory is a poor descriptor of orogenic activity since it calls upon collision, obduction, and subduction between two rigid plates, rather than a global plutonic system, to produce this crustal compression, although the roles of melt and flow in orogenic belts are now becoming more recognized (*cf.* Meyerhoff *et al.*, 1992; Hollister, 1993; England, 1996). The episodic uplifts of

the Transantarctic Mountains did not result from thrust-folding but from crustal extension and melt that were geodynamically tied to the rifting and breakup of Gondwanaland (*cf.* Smith and Drewry, 1984; Stump and Fitzgerald, 1992; Wilson, 1993; Sorkhabi and Stump, 1994). The Alpine-Himalayan orogenic belt forms the loci for counter-clockwise spiraling geosutures that are global in extent (Neev and Hall, 1982, fig. 2) and was more likely folded by a wrench fault system than by plate collision (Pavoni, 1961). Likewise the High Atlas Mountains of Morocco do not fit a plate tectonic scenario very well since they formed by Mesozoic filling up of a rift basin with marine sediments which were then uplifted in place during the Tertiary (Wurster, 1982).

Ribbon cherts and ophiolites in orogenic belts were more likely deposited in marginal basins than in wide ocean basins (*cf.* Upadhyay and Neale, 1979; Harper, 1980; Sugisaki *et al.*, 1982; Jenkyns and Winterer, 1982). Supposed Panthalassa remnants, *e.g.*, in Southern Chile, Southern British Columbia, and Japan, also contain ribbon cherts (*cf.* Mpodozis and Forsythe, 1983; Cordey and Schiarizza, 1993; Kimura *et al.*, 1994) that are unique to orogenic belts and are absent from ocean basins (Hein and Karl, 1983). The plate tectonics equating of continental thrust zone blueschists with ocean basins shear zone subduction blueschists is not supported by associated ophiolite ribbon cherts of marginal sea environments and fails paleobiogeographic tests performed on Southeast Asian terranes for Permo-Triassic time (*cf.* Jenkyns and Winterer, 1982; Shields, 1996b). Orogenic uplift and compression conform much better with an earth expansion model with plate curvature relief (Rickard, 1969) and certainly involve more than one process.

6. Continental-upper mantle coupling

Since plate tectonics was first proposed, continents were discovered to possess deep roots that extend to at least 400 km in the upper mantle, as defined by a high seismic velocity cool zone under their shields. In addition, the shields lack a low-velocity partial melting

zone that is present beneath oceanic lithosphere (Lowman, 1985).

Except under Southern Africa and Western North America, seismically-defined continental roots appear to extend to the 660 km transition zone (Gossler and Kind, 1996). The presence of a fossil plume extending to at least 500 km in the upper mantle beneath the Parana plume event implies that the upper mantle and lithosphere beneath South America have remained coupled since the Mid-Cretaceous (VanDecar *et al.*, 1995). Evidence of lower crustal growth by mantle-derived underplating in a non-shield area of Italy (Rudnick, 1990) is also difficult to reconcile with a decoupled lithosphere-upper mantle plate tectonics model. How is it possible, then, for a continent and its surrounding ocean plate to slide uniformly over the asthenosphere while continental shields remain anchored to the upper mantle?

These observations are in accordance with paleomagnetic analyses showing that the lithosphere as a whole has not moved significantly with respect to the paleomagnetically-defined pole back to at least the Late Cretaceous and probably even as far back as the Early Proterozoic (*cf.* McElhinny, 1973; Jurdy, 1981; Schmidt and Embleton, 1981).

7. Hotspots and true polar wander

Plate tectonics postulates that hotspot tracks define plate motion with respect to the mantle as the plate moves over more or less fixed hotspots. Intraplate motion of hotspots at least appears to agree with the fixity but there is also interplate motion of about 1.5 cm/yr between hotspots, or about 25° in 180 Ma (*cf.* Shields, 1990, table I; Duncan and Richards, 1991). True polar wander studies assume that hotspots are relatively fixed, but the discordance found between paleomagnetic and hotspot frames would not reflect true polar wander or mantle roll if hotspots indeed move (*cf.* Hargraves and Duncan, 1973; Kent and May, 1987). Spherical harmonic and magnetic inclination analyses of the Earth's paleomagnetic field show that the axial dipole has remained fixed in position over the past 300 Myr

(Benkova *et al.*, 1973; Piper and Grant, 1989), and the axis of symmetry of the inner core is currently aligned with the Earth's spin axis (Dziewonski and Woodhouse, 1987). Any significant amount of true polar wander (the movement of the whole lithosphere relative to the spin axis) would be prohibited by the separate apparent polar wander paths for the various continents which are dissimilar and converge toward the present geomagnetic poles, rather than forming a single path common to all continents (McElhinny, 1971-1972).

Even the intraplate fixity of hotspots is now in serious doubt. Between 124 and 88 Ma during North America's Mid-Cretaceous paleomagnetic standstill, the New England hotspot track migrated through about 11° of latitude, or more than 1500 km of apparent motion over a comparable time interval (Van Fossen and Kent, 1992). Also, the Tristan da Cunha hotspot has a remnant of its original plume conduit beneath the Parana plume event (Van Decar *et al.*, 1995), more simply interpreted as hotspot motion for 130 Myr than coupled motion of the South American plate with its underlying upper mantle. Of all the continents, South America remains closest to its present latitude and orientation for apparent polar wander paths back to 160 Ma (*cf.* Briden *et al.*, 1981; DiVenere *et al.*, 1995). There is now general agreement that the Earth's magnetic field is generated in the molten outer core while hotspots originate in the thermo-chemical D''-layer just above the core/mantle boundary. Thus hotspots would become deflected over time by upper mantle convection shear flow (see Skilbeck and Whitehead, 1978), or by passage through the 670 km transition zone (see Liu *et al.*, 1991), rather than representing tracks of lithosphere motion over fixed points. Andrews (1985) found that the hotspot framework indeed shifts through time with respect to the spin axis.

8. Apparent polar wander

Apparent polar wander is the apparent motion of the spin axis relative to a fixed continent (or plate). An apparent polar wander path

is a plot of the sequential positions of age-varying paleomagnetic poles, as seen from an individual continent, in the present geographic coordinates. Each continent defines a unique apparent polar wander path that leads away from the geographic pole, with apparent polar wander paths for northern hemisphere continents usually shown as leading away from the north geographic pole and southern hemisphere continents away from the south geographic pole. The paleomagnetic pole then is a plot of the paleoposition of the spin axis with respect to a particular fixed continent. Since only one spin axis could have existed, the continent, in plate tectonics, is moved latitudinally to a new position where its paleomagnetic pole then coincides with the present geographic pole (see Butler, 1992, chapter 10), thus demanding plate motion. A useful reconstruction method has been to rotate one of the adjacent continents about an Euler pole that is fixed with respect to the spin axis until their apparent polar wander paths coincide or until their earlier paleomagnetic poles for a particular age coincide, although the resulting paleolongitudinal position is arbitrary and apparent polar wander paths never match exactly (see Kearey and Vine, 1990). Nevertheless, European and North American apparent polar wander paths for the Middle Ordovician through Early Jurassic match almost precisely when a quality index for reliability criteria is applied (Van der Voo, 1990). When Euler poles are precisely determined using magnetic anomalies and/or fracture zones, however, they systematically migrate a few degrees for increasing age intervals (*cf.* Stock and Molnar, 1982; Shaw and Cande, 1990). Paleomagnetically determined paleolatitudes for Pacific plate sediments are up to 20° farther north than expected when compared with a reference apparent polar wander path for Pacific seamounts, indicating the sediment paleolatitudes are biased and therefore unreliable (Gordon, 1990). Since the spin axis and the entire lithosphere are fixed, it is difficult to see how individual plates can be moved to align paleomagnetic poles with the spin axis as required by plate tectonics.

Plate tectonics creates a Panthalassa-Tethys configuration that violates some terrestrial pa-

leobiogeographic data for the Permo-Triassic that are to the contrary (see Shields, 1993, 1996b). The wide Tethys sea is created by bringing only south paleomagnetic poles into coincidence, but simultaneously north paleomagnetic poles must also coincide (*cf.* Otofujii *et al.*, 1979; Sasajima *et al.*, 1978).

Twenty years ago, all methods used to determine past earth radii by paleomagnetism were shown to fail (Carey, 1976, pp. 185-194). The method most commonly used to «disprove» expansion is that of Ward (1963). Schmidt and Clark (1980) modified Ward's method so that Earth's center becomes invariant and found that relative geographic co-latitudes and pole positions would remain the same before and after expansion. They conclude, as did Cox and Doell (1961), that paleomagnetic sites cannot be used to detect radial expansion. However, geodesic distances measured from two fossil sample sites on the same continent to their mutual paleomagnetic pole will almost always be shorter or longer than their geodesic distances measured to the present pole on the present-size earth (see, Eged, 1961).

This suggests the spin axis must be shortened to bring all fossil poles into coincidence for a given age on a smaller globe (see Scalera, 1990, fig. 5), although new tests are needed and should be performed as soon as new high quality data will be added in the gaps (regional, temporal, quality) of the Global Paleomagnetic Databases (see Scalera *et al.*, 1996).

9. Conclusions

I conclude that the theory of plate tectonics has encountered too many practical problems since its inception to be valid and that rapid earth expansion better explains all of these problems. Problem areas include non-rigid plates, non-motion of the entire lithosphere, Euler pole motion, the plate growth-subduction budget, ridge-pull without ridge-push, Pacific margin rift valleys, the plutonic nature of orogeny, continents deeply rooted in the upper mantle, hot-spot motion, spin axis stability without true polar wander, the inability of a continent to move toward both paleomagnetic

poles simultaneously, and violation of Panthalassa-Tethys by paleobiogeography. To these can be added northward plate convergence toward the extending Arctic (Wilson, 1985), paleomagnetic equators appearing in two places at once, Pacific perimeter widening, the Africa-Antarctica paradox, and others (cf. Carey, 1976, pp. 198-219; Smith, 1986, p. 110; Carey, 1988, pp. 150-173; Shields, 1996a). Some criticisms of earth expansion still persist, e.g., paleogravity, sea-level, and subduction problems (Hallam, 1984), but they are not as insurmountable as the numerous problems now confronting plate tectonics, which all stem from the postulate that Earth's size must always remain constant.

The rapid acceptance and great success of plate tectonics (see Le Pichon, 1986; Pitman, 1995) unfortunately have been achieved at the expense of downplaying, neglecting and suppressing various problems that have arisen, which is certainly not how science should operate. Geology is so inherently complicated that declaring victory early on for plate tectonics over all competing theories was probably premature. Ultimately world reconstructions must be congruent not only with the data from geology and geophysics, but also with paleobiogeography, paleoclimatology, and paleogeography. The success of any scientific theory is not measured by being in fashion or by how many followers it garners but by whether it can stand up to the test of time.

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