j23 The Wilson Cycle < the opening and closing of an ocean basin >

> I wish to propose for the reader's favourable consideration a doctrine which may, I fear, appear wildly paradoxical and subversive. The doctrine in question is this: that it is undesirable to believe in a proposition when there is no ground whatever for supposing it true.
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> —Bertrand Russell.[1]

In 1966, John Tuzo Wilson, by publishing in *Nature* the paper: *Did the Atlantic close and then reopen?* scooped (for forgotten was du Toit's claim in 1937 that Pangea was assembled from several "*Urkontinente*": an equatorially centered Laurasian collection; and, Gondwana) the possibility of continental drift *before* the break up of the once supercontinent Pangea.[2] This contravened S. Warren Carey's 1958 hypothesis of continental drift as "apparent" lateral motion due to *once only* global radial expansion, and consequent seafloor widening, that began 200 million years ago.

"April 12, 1968, in Philadelphia," Kevin Burke (who coined the term *Wilson Cycle*)[3] recalls, "Wilson told his American Philosophical Society audience that if you look at a map of the world you can see oceans opening in some places and closing in others. He therefore suggested that, because the ocean basins make up the largest areas of Earth's surface, it would be appropriate to interpret earth history in terms of the life cycles of the opening and the closing of the ocean basins." [4]

In the 1970s, the simplest plate tectonics scenario (described below) that could account for the ancestral (Paleozoic) Appalachians and now referred to as the Wilson Cycle, does *not* account for what has since been learned of the plate tectonics history of North America, Laurasia, Pangea, ORS, and Laurentia, but early (in plate tectonics infancy) had value as an organizing concept.

The Wilson Cycle, now usually couched in terms of plate tectonics, begins when tensionally rift-apart, conjugate, continental margins are created by plate-divergence. Between these continent margins, deep-seafloor opens as divergence continues. The line of opening is thenceforward a mid-ocean volcanic ridge that has come into being. Basalts erupted at the ridge are magnetized by the ambient geomagnetic field as they cool to become oceanic crust. Frederick J. Vine and Drummond H. Mathews in 1963 emphasized that the newly formed oceanic crust moves orthogonally away from the ridge, as is evidenced by the geomagnetic-field polarity reversal anomalies in it that remain aligned to the ridge.[5] As the lithosphere ages it cools and increases in thickness and column density, and in isostatic equilibrium with the column height of the asthenosphere at the ridge, the seafloor deepens and the margin of the continent, which is in it, subsides. On the passive trailing edge of the continent, a geosyncline develops: Nonvolcanic clastic sediments shed from the continental interior, and chemical sediments, accumulate on the continental margin as shallow-water platform sediments and, beyond these, as miogeoclinal shelf-sediments with a wedge-shaped cross section that thickens seaward and is underlain by continental crustal rock. In the outer part of the geosyncline, which is the eugeocline, deepsea-turbidite sediments and basaltic volcanics accumulate on oceanic crust.

Having opened, the reverse occurs.

The ocean that opened to separate continents to its either side, now begins to close. The oceanic crust "is destroyed" (Wilson's phrase) or "subduction" (a word that appeared in geological literature in 1970)[6] occurs where it is oldest along the margins of the separated continents. (However, away from the ridge, oceanic lithosphere has negative buoyancy and, wherever so, it can subduct). Orogeny is most intense in the eugeoclines, which become island arcs. Miogeoclines become foredeeps and receive flysch then molasse sediments shed from the island-arc mountains. The orogenic cycle runs its course in the eugeocline with granite batholiths intruding into regionally metamorphosed rocks. The ocean closes completely and, at this time, cratonward directed thrusts and foldings deform the sediments of the miogeoclines.

The Wilson generalization was a continuation of his 1962 view that "The present random arrangement of the continents can be expected to be normal."[7] That is to say, continental blocks can join and rift at random. The present southern North Atlantic opening, approximately parallels the line of a former ocean's closing. The line of closing of that former ocean is marked by ultramafic rocks

in the Appalachians along *Logan's Line* named to honor William Edmond Logan (1798-1875) and now called (by some)[8] *Emmons' Line* to honor Ebenezer Emmons (1799-1869). In that latter, he was correct.[9] Ophiolites wherever identified are found to mark plate collision boundaries. This neatly resolves the otherwise paradox that while the *field evidence* of no contact metamorphic aureole indicates that ophiolites were emplaced as "cold" solid masses, by a process picturesquely referred to as "pip-tectonics," the *petrologic evidence* is of layers of the ophiolite pip being pillow lavas of a basaltic magma extruded in a deepsea environment, a gabbroic suite from a high temperature magma that had undergone steady differentiation at intermediate depth, and "Alpine" (that is, metamorphosed to serpentinite) peridotite mantle rock. For these last, pioneer Italian geologists named the whole sequence an *ophiolite* (Gk. *ophis*, serpent). This name entered the geological lexicon through a formal definition by A. Brongniart in 1827.[10] An ophiolite is now understood to be part or all of an obducted slice of oceanic seafloor ooze, basaltic & gabbroic crust, and peridotite uppermost mantle ("the Steinmann's trinity" as Eldrige M. Moores and Frederick J. Vine referred to it in 1971).[11]

But what is opening either side of the Atlantic is nothing like what closed. Indeed, what at different times transform-faulted into position, and then closed to constitute the Appalachian mobile belt, has been a variety of paleoterranes and paleocontinents (***Figure j23.1***). This was tacitly recognized when W. B. Harland and R. A. Gayer in 1972 proposed that, rather than proto-Atlantic, the name Iapetus Ocean be used (cognoscenti are aware that in Greek mythology Iapetus fathered Atlas after whom the Atlantic is named).[12] But this correction is wanting as three oceans closed: the Rheitic, the Iapetus, and the Theic.[13]

A generalization often elicited, but false, is that oceans open and close essentially along the same line: the suture of closing, in some way, continues to be a line of weakness. Wilson, 1962, "It seems likely that rifting often tends to follow the line of old ranges, for example, the opposite sides of the South Atlantic ..."[2] But what he could be referring to is a mystery and anyway this statement is strikingly at odds with his observation, in the same paper, that, "Today the young mountain systems, both continental and mid-ocean, form continuous zones about the earth for great distances. Backwards in time it becomes progressively harder to discern more than short sections of mountain systems. It is particularly hard to establish connections between continents. Were ancient mountain systems formed in a different way or have the chains been disrupted?" The answer can now be supplied: They have been disrupted. Where aseismic coasts of continents move apart, the rift between more often than not cut across the strike of ancient fold belts. At joins, the trench provides a mill to metamorphose sediments and continental margins so that, in Wilson's words, "After such an event it will be difficult if not impossible to match formerly adjacent coasts." Not that one can easily find these. Before fragments join, drift occasions great lateral offsets and rotations of the fragments which travel, with different times of departure, from far separate places.[14]

To reiterate, the rifting that opens oceans, does not (in any known instance) break free continents in the size and shape of those that joined. Some examples:

> The opening of the Gulf of California, beginning in the Neogene, has started to shear off a terrane west of the San Andreas fault. This terrane is not one that previously joined.
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> Greenland and Eurasia came to be with the opening of northern North Atlantic, begun 60 million years ago, that broke a continental fragment produced by the opening, begun 75 million years ago, of the Labrador sea, Davis strait and Baffin bay northwest passage that split away North America and ended the existence of Laurasia. Evidently, as here, even the most ancient craton can be rifted. The California-sized island of Madagascar and the (then) island continent India separated beginning 88 million years ago. Pangea fragmented into the continents Laurasia and Gondwanaland 180 million years ago (near the beginning of the Middle Jurassic) when left-lateral faulting of an *S*-break (and interestingly not a triple junction) entering through the proto-Mediterranean and leaving through the proto-Caribbean began the opening of the southern North Atlantic between.
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> *Ad pleniorem scientiam* . . . The Penrose Conference 2000 on the Iapetus Ocean.[15] ❑

Figure j23.1[16] **Paleoterranes in the eastern margin of North America (Exploded view)**

Fragmentation of Pangea began late Middle Jurassic, with the opening of the southern North Atlantic deep-ocean between the ends of left-lateral transform faults, the one passing east through the Gibraltar strait into the Tethys and the other passing west though the proto-Caribbean.

In the Late Paleozoic, the S.E.USA-Brunswick-Meguma paleoterrane was added when Gondwana joined ORS. The force of the collision transmitted via a dêcollement (slip on a horizontal fault) up-thrust the Blue Ridge gneissic block and folded platform sediments to create the Valley and Ridge province. The orogeny that resulted, and closed the Theic ocean, was the Appalachian.

In the Devonian, a long southern appendage to wandering Paleobaltica called *Avalonia* and the associated Iapetus ocean to its west was inserted the into the Rheitic ocean. The Iapetus ocean between the Avalon paleoterrane and the Piedmont was still closing when to the north the ORS-to-be was partly formed by continent-continent joining of Laurentia's terrane accreted margin and Paleobaltica. The Acadian-Caledonian was the associated orogeny.

In the Ordovician, Laurentia straddled the equator. Its southern coast was a passive margin to the deep Rheitic ocean. A colliding Piedmont-Gander-Dunnage paleoterrane, possibly a microcontinent sheared off Gondwana, caused the Taconic orogeny. The suture is Logan's Line.

In the Late Proterozoic, a continental fragment called *Laurentia* broke out of a Late Proterozoic supercontinent called *Rodinia*. The Rheitic ocean opened between.