i10 Wegener's mechanism for continental drift

< continental drift, true polar drift >

It is no disgrace to be mistaken, only to refuse revision when mistakes are found.
—Preston Cloud.[1]

Wegener in *Die Entstehung der Kontinente und Ozeane* (The origin of continents and oceans), 1915, described the *kinetic* motion of the continents as two concurrent motions: *Polflucht* (flight from the pole) and westward drift:[2]

> *Polflucht* from the South Pole is evidenced by tillites of Late Paleozoic age that the southern continents have carried to low latitudes, and even to north of the equator in the case of India, and by the coals, which are the accumulations of Late Paleozoic equatorial plants, that the northern continents have carried north to temperate latitudes. Antarctica, an area of Pangea that was over the pole, has been left stranded there.
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> Westward drift with respect to the Pacific seafloor is evidenced by the crumpling of the Cordilleras on the leading edge of the westward moving Americas, by the opening of the Atlantic due to the lagging behind of the Old World, by the trailing island arc of the Antilles between the Americas, and by the trailing island arc of the South Antilles between the horn of South America and the Antarctic Peninsular. Africa may not have moved west at all. But west movement of Eurasia is evidenced by the narrow ocean openings between its eastern margin and the island-arc festoons left stranded on the western edge of the Pacific seafloor.

Wegener in 1922 proposed uniformitarian *dynamic* mechanisms for *Horizontal-verschiebungen der Kontinente* (horizontal displacements of the continents). The continents are sial-blocks (200 km thick) floating in yielding sima (density difference between sial and sima = 0.034).[3] Four forces act on them: 1) the Eötvös force that is a consequence of the theory of isostasy on an Earth held to an oblate-spheroid shape by its spin; 2) lunar tidal attraction; and, of lesser importance, 3) the force of precession; and, 4) the gravitational attraction between the continents.

In passing, he considered convection beneath the sial continents as a possible driving force. The continent acts as a blanket and the sima below radioactively heats. This hot sima rises and spreads outwards. The continental block of sial that are floating in it are progressively separated and between the surface of the sima is new deep-ocean floor. All are reasonable concepts, but he needed the sima to behave fluidly ahead of the continents and not just behind them. He proposed, therefore, that by the Mesozoic a critical global temperature gradient had been reached that made the sima yielding and allowed for continental drift. Body forces, which exist (see below), were ready and waiting to pull the continents laterally through sima that yielded passively as is evidenced (seemingly) by the map patterns of the Antilles and the Scotia arcs. The unique thermal state that allowed the continents to drift was soon exhausted. Rapid hardening of the sima to the condition that it has today, he held responsible for the crumpled cordilleran prows of continents then underway. Just so.

Wegener explanation of continental drift as the ongoing separation of blocks formerly together as a single primordial continental assemblage suggests (to those who only read Wegener 1922 and later) a one-time event (which false and limiting idea lingered in driftist thinking into the 1960s giving heart to Earth-expansion theories). However, in his earliest writings,[4] when he was of the erroneous impression that "sima must be more plastic, because, related to the melting point, its temperature will always be 200 to 300 º[C] greater than that of the sial," his ur-continent (Pangea) is an assemblage of blocks that themselves were formed from an original, world-enveloping, thin, sial layer that real polar wandering at several times caused to be tensionally broken into thin blocks that, where pressed together, turned up (which accounts for the ubiquity of vertical foliation in basement rocks) and *irreversibly* welded into thick blocks. In the "3 km deep ocean 'Panthallasa,'" Pangea was isostatically emergent in some places and in others accumulated platform sediments. Where free of covering sial, the surface of the sima is deep ocean floor.

But never truer did Viscount Bolingbroke's famous caution toll: "Truth lies within a little and certain compass, but error is immense."[5]

Wegener's failed mechanisms and inferences

Polflucht (flight from the poles) is the movement since the Carboniferous "exhibited in a general way by the [tensional separation] of continental blocks in the polar regions and the compressive thrust which acts on them towards the equator." Earth's rotation, which produces its equatorial bulge, provides for continents (in that they have elevations above the equilibrium prolate spheroid) a force that "acts to drive the continents over their substratum towards the equator." And Wegener continues: "As far back as 1913, Eotvos stated its existence in a comment [***Footnote i10.1***] which, to be sure, passed unnoticed at that time."

The movement of the continental blocks since the Carboniferous also involved westward drift. The force operating was sought in Moon's gravitational pull on the floating, and so protruding, continental sial. This tidal drag on the continents, provides a west-directed body force. The redistribution of mass also caused true polar wandering (Earth reorients with respect to its rotation axis). Evidence of this was the Cretaceous inundation of the continents where a watery equatorial bulge existed while Earth's rocky equatorial bulge lagged in its adjustment by slow yielding.

All these mechanisms exist, or are possible, but Wegener's incautious use of them to move continents, when to elevate existing, and former, mountains require that "displacement forces have arisen that were much larger," allowed his work to be ridiculed. Better had he rested on his laurels. The responsibility of an historical geologist is to establish the facts of prehistory; *not* to find a mechanism to explain them. To attempt to do so, is a classic mistake. For example, geologists can prove as a fact of prehistory that there was an Ice Age. This is not disproved by the lack of any certain mechanism for its cause. Not soon enough was L. C. King's 1957 reiteration of this advise:

> The driftist is no more obliged to adduce a mechanism to prove the fact of drift than the user of an electric appliance is obliged to define the nature and mechanism of electricity.[6]

Harold Jeffreys (1891-1989) in his authoritative treatise: *The Earth,* 1924, had earlier stated:[7]

> ... We cannot therefore accept hypotheses of the widespread migration of continents, unless forces enormously greater than any yet suggested are shown to be available.
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> *C.2.* A further impossible hypothesis has often been associated with hypotheses of continental drift and with other geological hypotheses based on the conception of the earth as devoid of strength. This is, that the small force can not only produce indefinitely great movement, given a long enough time, but that it can overcome a force many times greater acting in the opposite direction for the same time. In Wegener's theory, for instance, not only is a tiny force supposed to have moved America right across the present Atlantic, but the resistance of the Pacific floor to the motion is supposed to have uplifted the Rocky mountains. Now, given a sufficiently weak earth and enough time it might be possible to twist the outside of the earth over the inside to any extent. So long as the layers of equal density remained symmetrical about the polar axis, no elevation or depression of rocks taking place, deformation could proceed undisturbed, America going steadily on its way without mountain-building or any other phenomenon observable by geologists. In order that mountain-building may take place, however, energy must be supplied to raise and lower the rocks affected against gravity; and the stress available must overcome gravity, and therefore must exceed the pressure due to the weight of the mountain. Tidal friction and differences between the values of gravity at the tops and bottoms of continents are the agencies usually considered in theories of this type; they are capable of producing stresses of the order of 10^{-6} dynes per sq. cm., whereas to elevate the Rockies about 10^{9} dynes per sq. cm. [that is, one million billion times greater] would be required.

By expounding at length against continental drift (and was still doing so in 1976!), Jeffreys bolstered the (false) principle of the fixity of the continents. Nevertheless, in 1924 Wegener with W. Köppen in *Climate and Geological Pre-history* detailed an evident path of true-polar wandering.[8]

This was altogether too much for the establishment. Wegener was a maverick and had to be put in his place. In 1926, a symposium on Wegener's continental drift was organized by the American Association of Petroleum Geologists. Wegener was otherwise occupied. He was preparing to revisit Greenland (but not to make geodetic measurements to prove its westward drift relative to Europe, as this, at meters per year that initial measurements had found, he left to be confirmed by the better equipped Danes as they measured longitudes in Greenland).[9] He died in a blizzard there in 1930.[10] For the symposium, he had contributed two papers, one on his geodetic program, and another on the

Carboniferous climate of North America. The chairman, W. A. J. M. van Waterschoot van der Gracht, then vice president of the Marland Oil company gave the lead paper, and was sympathetic: "I am personally convinced that there *is* continental drift." Nevertheless, the heart-felt, and later to be taught to their students, position of American professors who attended the symposium was "that Wegener has taken extraordinary liberties with the earth's crust," and geologist might well ask if theirs could still be regarded as a science, when it is "possible for such a theory as this to run wild."[111]

Confident that any throwaway remark that could calm flutterings in stabilist dovecotes was all for the good, Jeffries in *The Earth*, 1924, wrote: "On a moment's examination of the globe, this [fit of South America into the angle of Africa] is seen to be a misfit by almost 15º."[12] One wonders what map he was examining, but what ever it was he repeated the statement in the 1952 third edition of his book.[13] Edward Bullard, for one, could not see what Jeffries was on about, and his computer test of the "Bullard fit" in 1965 removed any doubt that at least in this Wegener had been right.[14]

Wegener had concluded that continental drift was underway after the Carboniferous. The former assemblage of the present continental blocks is now a simple exercise to rediscover by reversing known seafloor spreading. But how long had this reconstructed primordial continent itself been in existence? Quite clearly, from Wegener's writings, it had formed only once. So agreed those few of his contemporaries who favored his views, such as **Reginald Aldworth Daly** (1871-1957) in *Our Mobile* [by down-hill siding of once polar continental masses toward a sea-flooded equatorial low] *Earth*, 1928.[15] But in keeping with the uniformitarian paradigm, continental drift is not a one-time phenomenon. Drift by moving apart fragments of a supercontinent will also reassemble (Earth being a sphere) a supercontinent. Unbeknownst to Wegener, an example, of the beginning of this, has been the flight of India to join Asia. Wegener was not prompted by this example as, in his reconstruction, India did not cross an ocean to Asia. In his view, the sial Lemurian block (India) was always a southern appendage of Asia, and his north-directed drift forces caused its soft sedimentary northern end to crumple against a more resistive Asiatic block into the Himalayas. Supercontinents will have come and gone (*see* Topic *k35*). ❑

Footnote i10.1 **Eötvös force** [Roland Eötvös (1848-1919)—Hungarian name: Vásárosnaményi Báró Eötvös Loránd—did pioneering work on gravitational problems, capillarity behavior, and geomagnetism.]

Earth, due to its gravitation and rotation has, as a yielding body, the equilibrium shape (to a first approximation) of an oblate spheroid (polar radius = 6,356 km, equatorial radius = 6,378 km).

On any point mass of a rotating, viscous, homogeneous Earth, an equatorward centrifugal force component due to rotation is balanced by a poleward centripetal force component due to Earth's gravity. In a nonhomogeneous Earth, i.e. one with a floating continental block of strong sial in a viscous sima, the center of gravity of the continent is higher than that of the center of gravity for the part of it within the equilibrium ellipsoid of the sima (Archimedes principle).[16] At the center of gravity of this continental block, the equatorward centrifugal force component will be as in the homogeneous Earth but the countering centripetal poleward force component will be less as the gravity acting there will be less (Airy isostasy). The resultant is the Eötvös force directed towards the equator.

An excerpt from Eötvös, 1913,[17] (a work not in everybody's library but fully discussed in 1921 by Lambert)[18] in Wegener[3] is "that the direction of the vertical in the plane of the meridian is curved, so that the concave side faces the pole, and that the centre of gravity of the floating body (the continental block) lies higher than that of the mass of liquid displaced. Thus, the floating body experiences two forces acting in different directions, the resultant being directed towards the equator and away from the pole. The continents would therefore tend to move towards the equator, and this movement would give rise to a secular variation of latitude, as surmised in the case of the Pulkovo observatory [in St. Petersburg, Russia]."