Alfred Wegener and continental drift

Marco Segala, professor of history of philosophy, University of L'Aquila, Italy
associate researcher, CNRS, Centre Alexandre Koyré, Paris

***Figure 1:* Alfred Wegener (1880-1930), ca. 1912**

Our present knowledge of the physical structure and geological dynamics of our planet is integrated within the powerful theory called "plate tectonics". According to it, nothing is permanent on the Earth's crust, every major feature is ever-changing: continents and oceans are formed and destroyed; the plates constituting ocean floors and continental basements move and collide producing mountain formation, earthquakes, and volcanism. Plate tectonics provides a coherent understanding of the geological history of the Earth's surface and is supported by enormous evidence from the many disciplines of the Earth sciences, like geophysics, geology, palaeontology, climatology, geodesy. Moreover, satellites make available direct evidence of continental movements and then we can affirm that plate tectonics, formulated in the 1960s, has established the truth of continental drift – a notion introduced by Alfred Wegener in 1912.

The paper here presented was Wegener's first printed communication on the subject. It was a "preliminary" account, published while he was writing a longer and more refined paper, but anyway it includes the most important arguments supporting the revolutionary idea of continental drift. This paper on *The origins of continents* represents "the origins" of our present view of the Earth.

WEGENER'S FIRST WRITINGS ON CONTINENTAL DRIFT

On January 6th, 1912, Alfred Wegener presented his hypothesis of continental drift at the general assembly of the German Geological Union in Frankfurt. In the following months he published two papers whose contents are very similar: one in *Petermann's Mitteilungen*, a geographical journal, and the other in *Geologische Rundschau*, the official journal of the Geological Union. While recovering from a war wound, in 1915, he completed and published a 94-page book with 20 images under the title: *Die Entstehung der Kontinente und Ozeane* (The formation of continents and oceans). It underwent four editions during Wegener's life and was translated into several languages.[1]

In a letter to his mentor Wladimir Köppen (December 6th, 1911) Wegener explained he had collected a considerable amount of scientific evidence sustaining the idea that Africa and South America were anciently connected. He refused as unjustified – from a physical point of view – the supposition of a sunken continent between them and proposed instead the "revolutionary" idea of an ancient single landmass (Pangea) that later broke apart.

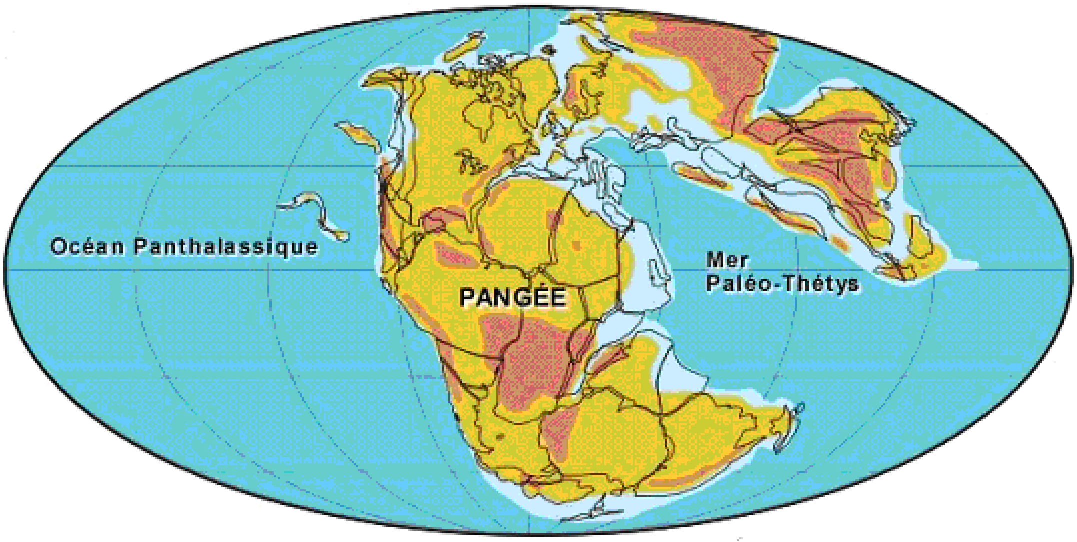


Figure 2 : Present reconstruction of Pangea. *This supercontinent existed about 225 million years ago. The name* Pangea *derives from Greek language: Pangea = all the lands, from* pan- *= all and* gaïa- *= the Earth (map © Paleomap Project, C. Scotese)*

The paper *Die Entstehung der Kontinente* presents in detail the hypothesis and introduces the notion of *Kontinentalverschiebungen* (continental

1. *Die Entstehung der Kontinente*, "Geologische Rundschau", 3, 1912, pp. 276-292. *Die Entstehung der Kontinente*, "Petermann's Mitteilungen", 58, 1912 pp. 185-195; 253-256; 305-309 (English translation in *Journal of Geodynamics*, 32, 2001, pp. 29-63). *Die Entstehung der Kontinente und Ozeane*, Braunschweig, Vieweg, 1915; II ed., 1920; III ed., 1922; IV ed., 1929. The Russian (1923), English (1924), French (1924) and Spanish (1924) translations were based the third edition (1922).

displacements) in a way that triggered vast response – first in Germany and, after the war, in the rest of the world. It would be the most important and seminal paper in the geological sciences until the development of the plate tectonics theory in the 1960s.

Wegener : biographical elements

Wegener was not a geologist. He had a doctorate in astronomy (1904) and had developed strong interests in meteorology. He investigated in the field through balloon flights and in 1906 gained notoriety for establishing the world record for an uninterrupted flight of 52 hours. As a meteorologist he joined a Danish expedition to Greenland (1906-1908) and published the important handbook *Thermodynamik der Atmosphäre* (1911).

Curiosity about the tectonic structures of the Earth (continents, oceans, and mountain ranges) arose in December 1910 while examining the Atlantic coasts of Africa and South America. He wondered whether they could have been formerly united and developed such a hypothesis by extensive reading of scientific literature in paleontology, glaciology, orogeny, and geophysics.

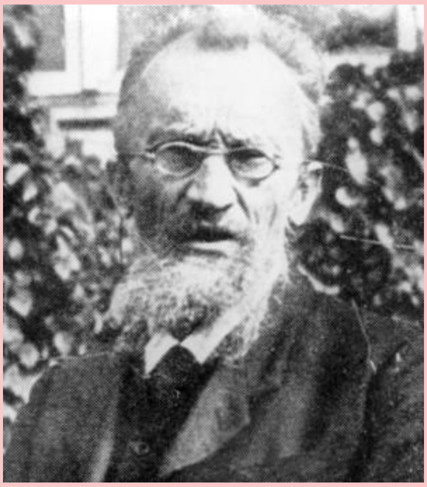


***Figure 3 :* Wladimir Köppen (1846-1940), Wegener's father-in-law, mentor and co-worker.**

Notwithstanding his commitment to continental drift, his main research work continued to be in the field of meteorology. After serving the German army during the Great War in 1919 he replaced his father-in-law Wladimir Köppen as director of the Meteorological Department at the Hamburg Marine Observatory. Together they contributed to the emergence of paleoclimatology as a discipline (*Die Klimate der geologischen Vorzeit*, 1924: Climates in geological prehistory). Finally, in 1926 he was called to Graz (Austria) as university professor of meteorology and geophysics.

He died prematurely in 1930 during his third expedition to Greenland.

Priority

The very idea of continental movements through the oceans sounded as heretical before Wegener (and even after), and nonetheless a certain number of researchers had proposed that hypothesis before Wegener. He himself, in the following years, traced his "precursors" and presented a more and more enriched list of them.[2]

The reason why Wegener was explicit in admitting that other scientists had already envisaged some form of continental mobility is clear: he was convinced of the superiority of his own version. It is not easy for historians to serenely judge about such claims, but from our privileged viewpoint on the history of geology in the 20th century we can state he was right. His hypothesis was well grounded and argued; opposed to others', it gained actual attention and stimulated debate, new research, and transformed tectonics in a mature discipline.

In the introduction to the paper here presented Wegener already mentioned two people who anticipated continental migrations: the astronomer William Henry Pickering (1858-1938) and the geologist Frank Bursley Taylor (1860-1938), both Americans.[3] He easily dismissed Pickering's version of continental displacement as grounded on the erroneous hypothesis that the Moon had been a part of the Earth. According to Pickering (1907), the separation of the Moon from our planet had produced the fracture of the Earth's crust and dislocated the continents to their present, definitive position. Differently said, Pickering was stating that continents had drifted in the past and are now permanent, while Wegener's theory clearly asserted continental drift as still occurring.

Wegener acknowledged Taylor's contribution as much more important, first of all because the American scientist had introduced continental mobility as an essential constituent of the Earth's crust dynamics, not as single episode. According to Taylor, only continental drift could explain the orogeny of the enormous mountain belts from Alps to Himalayas in the Tertiary era (around 50 millions years ago).

Since the first half of the 19th century, orogeny was more or less successfully explained by the so-called "contraction theory". It was admitted that

2. See the "Historical introduction" to *Die Entstehung der Kontinente und Ozeane*, 1929.
3. Pickering, *The Place of Origin of the Moon - The Volcanic Problem*, "Journal of Geology", 15, 1907, pp. 23-38. Taylor, *Bearing of the tertiary Mountain Belt on the Origin of the Earth's Plan*, "Bulletin Geological Society of America", 21, 1910, pp. 179-226

after its formation from hot and molten matter, Earth had began a process of solidification and cooling that resulted in progressive shrinking and the relative accommodation of the crust to the smaller dimension through folding and crumpling – the mountain belts. The contraction theory was later developed to explain the origin of the two main features of the Earth's crust – continents and oceans –, their permanence through geological eras, and the stability of their relative positions.

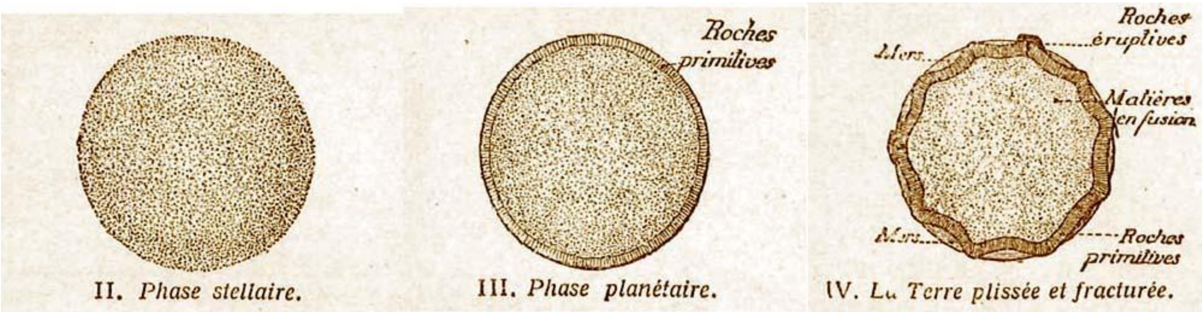


Figure 4 : An illustration of the now obsolete contraction theory. *Following this theory, Earth would have been cooling, and its surface would have creased, creating mountain ranges and oceanic depressions (from* Livre de Géologie de classe de 4ème, *V. Boulet, 1925)*[4]

Taylor's notion of drift as explaining orogeny was a devastating attack not only against permanence but also against contraction. Wegener was aware of it and this is the reason why he described Taylor's view as really important. His criticism was that the American geologist had not seen how relevant his hypothesis was to explaining riddles in other disciplines connected with geology.

CONTINENTAL DISPLACEMENTS

At the beginning of the paper Wegener introduces continental drift as challenging the notion of "continental links" among landmasses separated by oceanic waters. As postulated by the notion of permanence, scientists regarded the present dislocation of continents and oceans as unchanged and unchangeable through time. Nonetheless there was evidence of ancient connections between distant lands, and "continental links" – either "sunken continents" or "land bridges" – were introduced to explain it. If the idea seemed acceptable, for example, regarding the 85 km wide and 50 metres deep Bering Strait, it was much less believable with reference to the oceanic 2500 km separating Senegal

4. Cited by V. Deparis and P. Thomas, « La dérive des continents de Wegener », *Planet'Terre* (ENS Lyon), may 2011 (online).

from Brazil. Yet, no better idea had gained support among scientists and evidence of ancient connections across the oceans was considered marginal and not worthy of deeper attention.

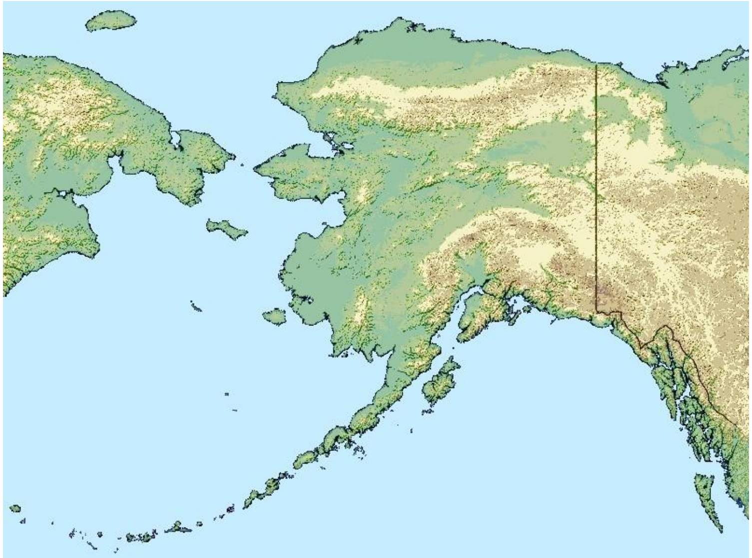


***Figure 5 :* Bering Strait, between Russia and Alaska.** *It owes its name to Danish navigator Vitus Bering (1681-1741), who crossed it in the summer of 1728.*

Wegener's argumentative strategy through the paper is to bring such evidence under the eyes of geologists and to show that it was both qualitatively and quantitatively more relevant than they usually assumed. Continental drift can benefit geology because it offers "surprising simplifications and correlations" of either unaccounted for or unexplained evidence. It is a valuable *Arbeitshypothese* (working hypothesis) whose "heresy" – mobility against permanence – is however much more plausible than the hypothesis of "sunken continents" – which, by the way, conflicts with the notion of permanent, unchanged geographical positions, too.

GEOPHYSICAL ARGUMENTS

A bit surprisingly, the first subject confronted by Wegener is not evidence of ancient connections among continents but geophysics, i.e. physical and chemical knowledge of the Earth's crust. He refers to the hypsographic curve (see below) as evidence of two different materials constituting the Earth's crust: one lighter composing continental plates and the other much heavier forming oceanic bottoms. Such "irrefutable" evidence grounds recent geophysical research, which both has challenged the contraction theory as satisfying explanation for orogeny and casts doubts on the permanence theory. According to Wegener, science lacks a viable global interpretation of the major features of the Earth's crust and this is the reason why he trusts the hypothesis of "continental rifts and horizontal displacements".

Continental and oceanic crusts

A hypsometric curve is a graph that shows the proportion of land area that exists at various elevations.

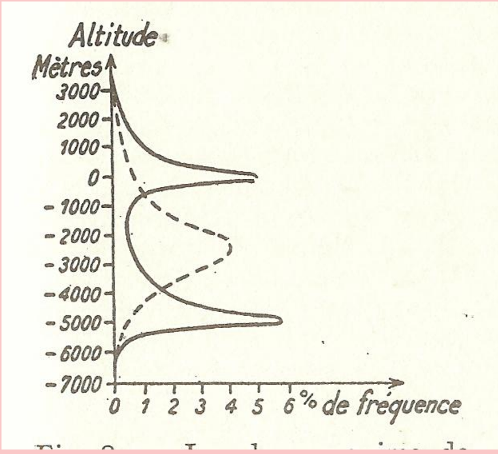
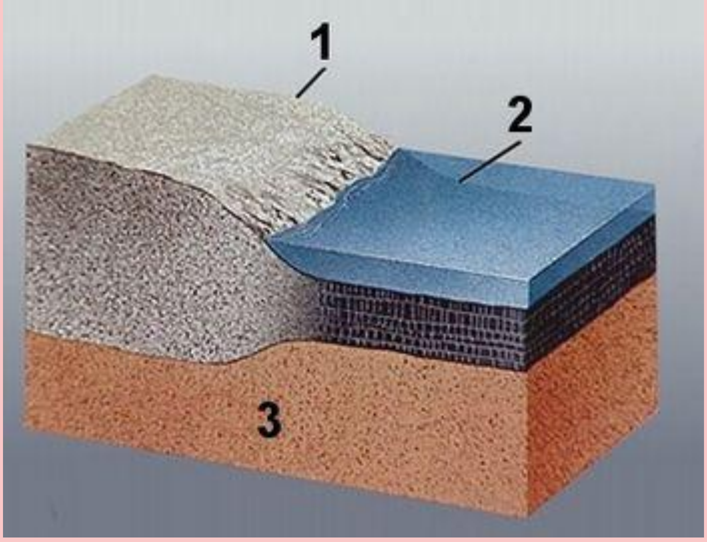


***Figure 6 :** Hypsometric curve of the Earth's surface, given by Wegener in his book.*

On the hypsometric curve of the Earth's surface, appear two peaks: the first one, at +100m, which corresponds to the average height of continental plateaus; the second one, at -4700m, which corresponds to the average height of oceanic abyssal plains. This evidence goes counter the contraction theory: a uniform surface that would have been contracted would let appear a single Gaussian peak, corresponding to average height after contraction.

Wegener sees in that curve the idea of two, and not one, initial land levels constituting Earth's crust. Nowadays, it can be said with Wegener that the crust has two constitutive parts:

- continental crust, about 30 km thickness, about 2,7 g/cm^3 density, made of old granite rocks (2 billion years in average);
- oceanic crust, about 7 km thickness, about 2,9 g/cm^3 density, made of more recent basaltic rocks (200 million years in average);



<u>Figure 7 :</u> Simplified breakdown of the Earth's crust (WikiCommons). *1 : continental crust ; 2 (under the blue): oceanic crust ; 3: upper mantle.*

The most important geophysical question concerns chemical composition and physical behaviour of continental and oceanic plates. Wegener accepts Eduard Suess's distinction between Sial (Silicon + Aluminum) and Sima (Silicon + Magnesium) and establishes their correspondence to continents and oceans. Most importantly he proposes that those two layers have a plastic nature: by prolonged application of the enormous pressure exerted by their own weight they flow like a liquid. Wegener's conclusion is: "from the physical point of view there is no reason to refute the possibility of extraordinarily slow and yet imposing horizontal displacements of continents".

Unfortunately the hypothesis is still lacking in adequate mechanisms and forces to explain such displacements. Wegener refers to lunar tide as a possible cause but he seems sceptical and prudent. He imagines currents under the Earth's crust, too, but he genuinely admits that it is too early for such speculations. Yet, in the following years, while updating his book on continental drift, he did not resist speculation. Still convinced that "time is not yet ripe", as he had written in the paper, he was nonetheless conscious that the plausibility of his hypothesis was linked to the existence of viable causes.

It should be noted that the question of the driving forces remained unsolved during Wegener's life and was one the strongest arguments against continental drift. It was acknowledged that the hypothesis was able to accommodate evidence within a consistent theoretical model, but the actual mobility of continents was still perceived as impossible.

Figure 8 : ***The influential[5] Austrian geologist Eduard Suess (1831-1914).*** *He proposed the hypothesis of the existence of the Gondwana supercontinent. He was a supporter of the contraction theory, which was later invalidated by continental drift theory.*

Geological arguments

This is the most solid and impressive part of the paper. Wegener gathers evidence and intertwines information that are generally scattered or marginalised or ignored by his fellow scientists. He offers a comprehensive explanation of rift valleys and tectonics depressions of the Earth's crust.

Figure 9 : ***The Great Rift Valley.*** *A rift zone is a large area of the Earth in which plates of the Earth's crust are moving away from each other. The rift (dash line) cuts the Horn of Africa, from South of the Red Sea (north of the map) to Zambia (south of the map).*

5. For example, Suess wrote the foreword of French seismologist Fernand Montessus de Ballore's book in 1907, *La science séismologique : les tremblements de terre* (see BibNum analysis by H. & M. Le Ferrrand, oct. 2012).

The Somalian plate (east of the line) moves away from the African plate (west of the line), in a more important manner at the north of the rift. The whole rift is subject to intense volcanic activity, from the Ethiopian volcanoes (North of the rift) down to Mounts Kilimanjaro and Kenya (south of the rift) (WikiCommons image, cc-by-sa, auteur Sémhur)

He cogently assembles geological information about the striking similarities of stratigraphic structure on the two side of the Atlantic: from Greenland to South America and from Scandinavia to Africa. He lists specialists in biogeography who postulated the existence of land connections between the two coastlines and "exchange of living forms" between Brazil and Africa (in Mesozoic) and between North America and Europe (first Tertiary). All this can be more easily understood and convincingly displayed by the continental drift theory, which finally clarifies the "entire phenomenon of ice ages" in north hemisphere.

What is impressive, in these pages, is the kind of evidence displayed by Wegener: it is never first-hand; for one person it would be impossible to assemble such numerous and different instances on the field. But it is not only possible but also appropriate and meaningful to collect them in disparate scientific literature. Wegener is introducing a new vision of geology as a collective enterprise – the Earth sciences – where different disciplines concur to establish a new image of the world. It is a breakthrough - and something that nowadays characterizes plate tectonics.

Wegener is conscious of how difficult his path is. This is the reason why he supports his revolutionary view with different kinds of evidence. He shows how continental drift can explain the orogeny of Andes by invoking the friction of South America against the Pacific seafloor while moving west. The famous and puzzling supercontinent called Gondwana – introduced by the influential Austrian geologist Eduard Suess and matter of serious discussion in geology since the 1880s – is revisited and enlightened by continental drift. An impressive amount of proofs from geology and palaeontology had pointed out that South America, Africa, India, Australia, and Antarctica had been connected from Palaeozoic through Mesozoic. What was an impossible puzzle that required both gigantic and unbelievable land bridges within the permanence theory becomes a powerful case in favour of continental drift. Also, the migration of India towards north and its crash into Asia in the Tertiary era offers the mechanism of the Himalayan orogeny.

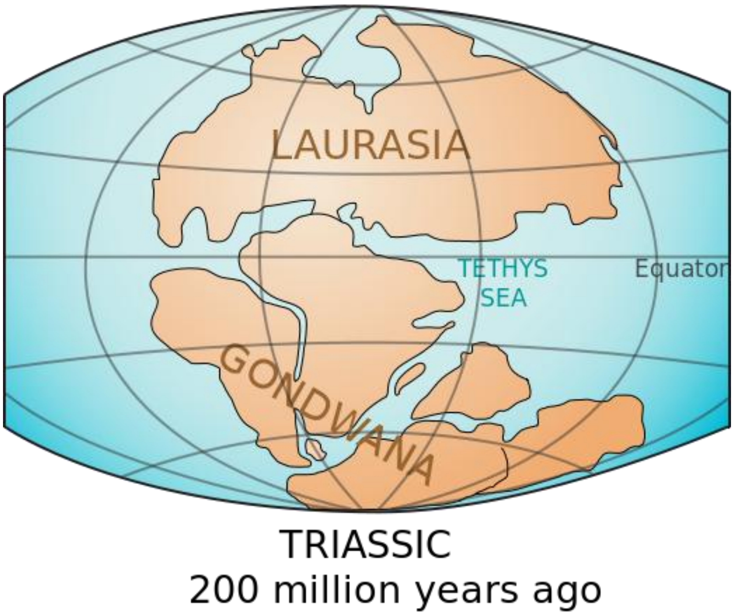


Figure 10 : ***The Gondwana supercontinent of the Mesozoic Era.*** *During the Triassic Period (part of the Mesozoic Era), Pangea (figure 2) splits in two parts, starting from the rift between current Africa and current North America. Two different supercontinents arise: Gondwana and Laurasia. Laurasia is formed by current North America and current Eurasia.*

A similar elegant and simple explanation is given for the Permian ice age, a period of severe climate that touched the continents regrouped in Gondwana. If land bridges could explain the life of similar organism on distant continents, they were unable to interpret the evidence of glaciations in equatorial or tropical lands like India and north Australia. Wegener is crystal clear about that: without continental displacements, the Permian ice age is "an unsolvable problem".

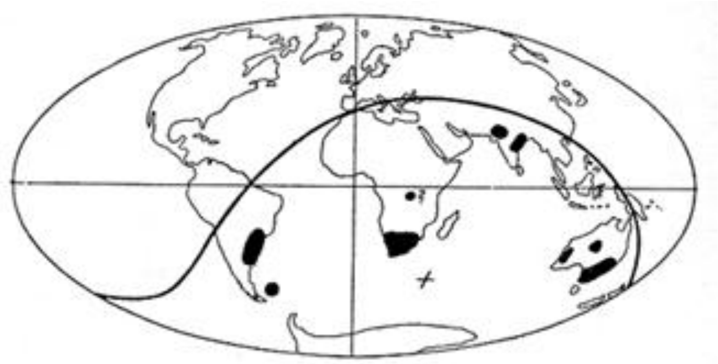
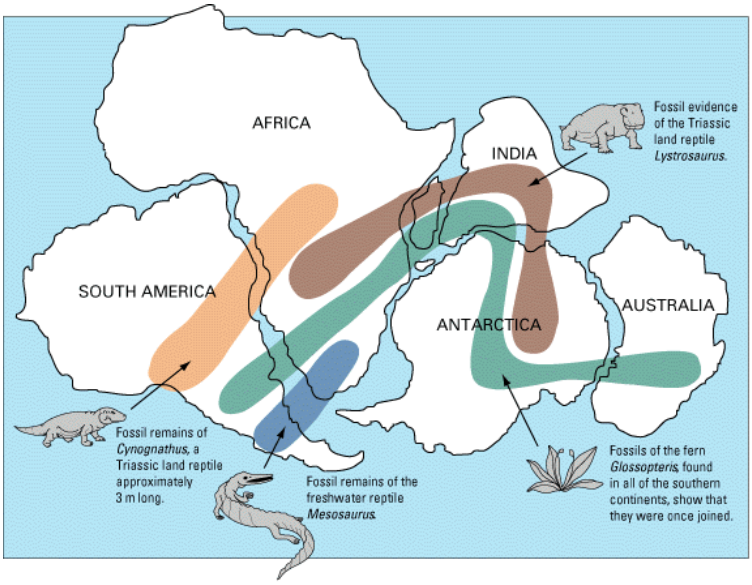


Figure 11 : ***Evidence of the Permo-Carboniferous glaciation.*** *It shows that the spotted regions were connected (drawing from Wegener's book, 1922).* ***11 bis, below :*** *Modern reconstitution of fossil elements that are common to several continents (map: United States Geological Survey, online).*



Continental drift is presented by Wegener as the unique valuable theory capable of giving plausible reasons of a long series of phenomena and discoveries that defied a both unified and convincing theory in geology at the beginning of the 20th century. Why is the Atlantic seafloor younger than the Pacific? What can geology tell about the variation of inclination of the terrestrial axis in geological history – the so-called "Polar wandering"? Those were puzzling questions for geology: they either were unanswerable or required sets of hypotheses not easy to combine in a coherent set. That was not the case for continental drift. The Atlantic Ocean was younger than the Pacific just because it came in existence much later, only when during Cretaceous South America began its separation from Africa and shifted west. Even the variation of the terrestrial axis could fit the general notion of continental displacements: changing their position, continents altered weight and balance on different regions of the planet; to restore equilibrium an adjustment of the terrestrial axis followed.

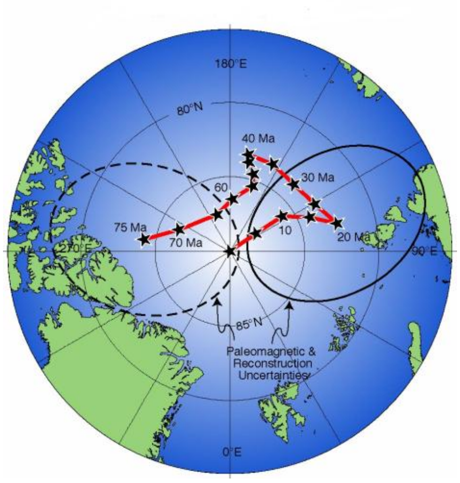


Figure 12 : ***Polar wandering starting -75 million years ago, up to current position.*** *The magnetic poles are an epiphenomenon of the rotation of the Earth's*

internal core. Polar wandering is caused by a change in density distribution in the mantle. It is not accepted anymore that continental displacements can contribute to it (image University of California at Davis).

PRESENT CONTINENTAL DISPLACEMENTS

Wegener's paper does not introduce a general history of the movement of continents. That appeared later, in the book on continental drift, and was shown graphically by the following famous map.

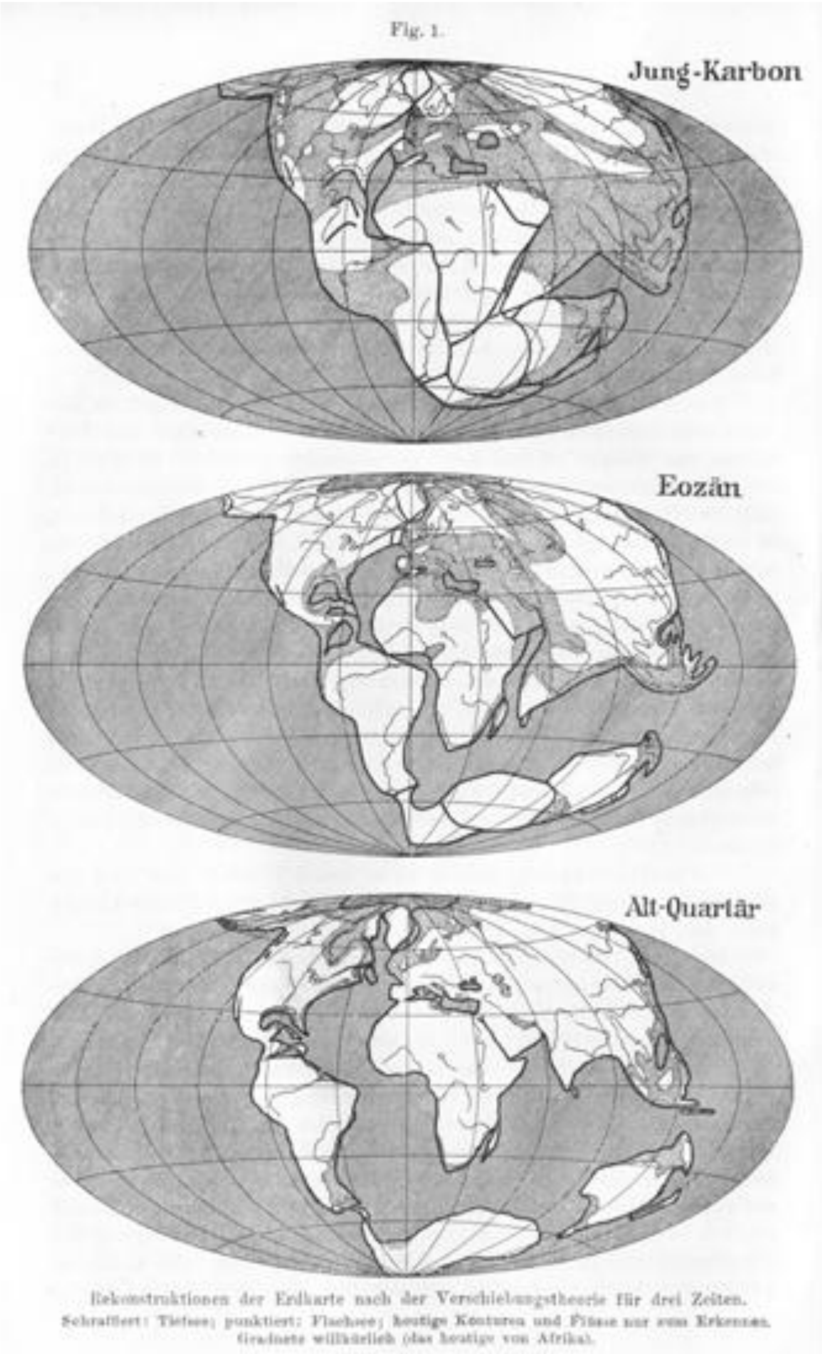


***Figure 13 :* Wegener's reconstruction of continental drift (1922).** *The first image refers to 300 million years ago, the second one to 60 million years ago, the third to 2 million years ago. Figure 15 below shows a current reconstruction.*

In his first paper Wegener seems more anxious to deliver a message: continental drift is a powerful, progressive, and inclusive hypothesis. And it is characterised by an epistemic feature that contraction, permanence, and continental links lack: it is directly provable. As horizontal displacements of the continents are normal consequence of the dynamics of the Earth's crust, they are not relics of the past, like land bridges. This is the reason why even today continental movement should be detectable and measurable.

The last section of his paper is then dedicated to presenting westwards movements of Greenland and North America. Nineteenth century measurements seem to confirm displacements, but there is too much incertitude, and Wegener prefers to wait for new, better data. In fact, at the end of the 1920s geodetic quantification of continental drift was still questionable and against Wegener's expectations was not able to convince his opponents.

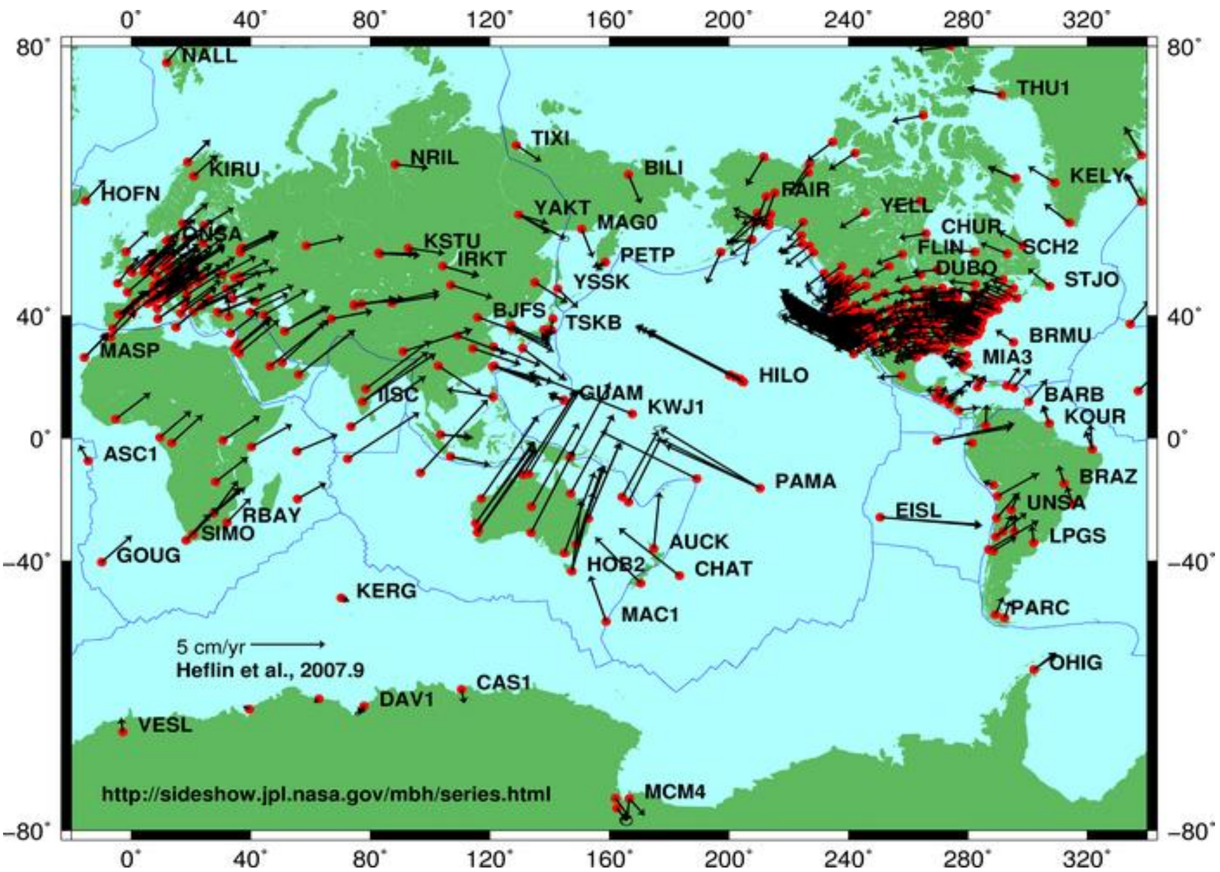


Figure 14 : Continental drifts measured by GPS satellite. *This map confirms Greenland and North America westward drift, and Europe eastward drift.*

METHODOLOGY

There were different kinds of reaction to Wegener's idea, from sharp refusal to enthusiastic acceptance. In a word, a controversy arose – which lasted many decades and was dissolved by the appearance of plate tectonics in the 1960s[6]. The paper here presented, together with the other one of the same year and the 1915 book, sparked off discussion and new research that ultimately brought to the emergence of plate tectonics[7].

As already said, Wegener was not the first to hypothesise continental mobility. The reason why he was the only one capable of fighting permanentism – and of nourishing an enduring controversy – is to be found not only in the amount of evidence he produced, but also in his methodological approach.

The very first lines of the paper are to be underscored: they promise a "genetic" interpretation of the great structures of the Earth's crust according to the comprehensive principle of mobility of the continental plates. This accent on the unifying nature of the mobility principle states a very important point of method. One century ago, scientists admitted ancient connections among lands now separated by sea and consequently they speculated about sunken continents or continental bridges, even if no physical mechanism explained them. Wegener pointed out that the very notion of "land connections" was a typical *ad hoc* hypothesis – useful in specific cases but not a generalising principle. How to explain common ancient climates or similar stratigraphic structures in continents separated by oceans and located at different latitudes? Continental drift was unique solution to disparate problems.

Wegener's substantial contribution to geology was more than an inspiring hypothesis: he sustained the idea that Earth science required both a multidisciplinary approach and a general theory capable of explaining evidence from separate fields. He pushed geology to share methods and criteria with physics. Prediction is one characterising feature of physics – and very far from historical geology. Nevertheless, in his paper Wegener introduces prediction: he foresees the rise of magma from the layer under the crust through the Mid-Atlantic Ridge (verified in the 1950s); he predicts the present mobility of continents (verified in the 1970s). The surprising idea of continental drift is absolutely new in geology not only in contents but also in methodology: it can be directly proven or disproven.

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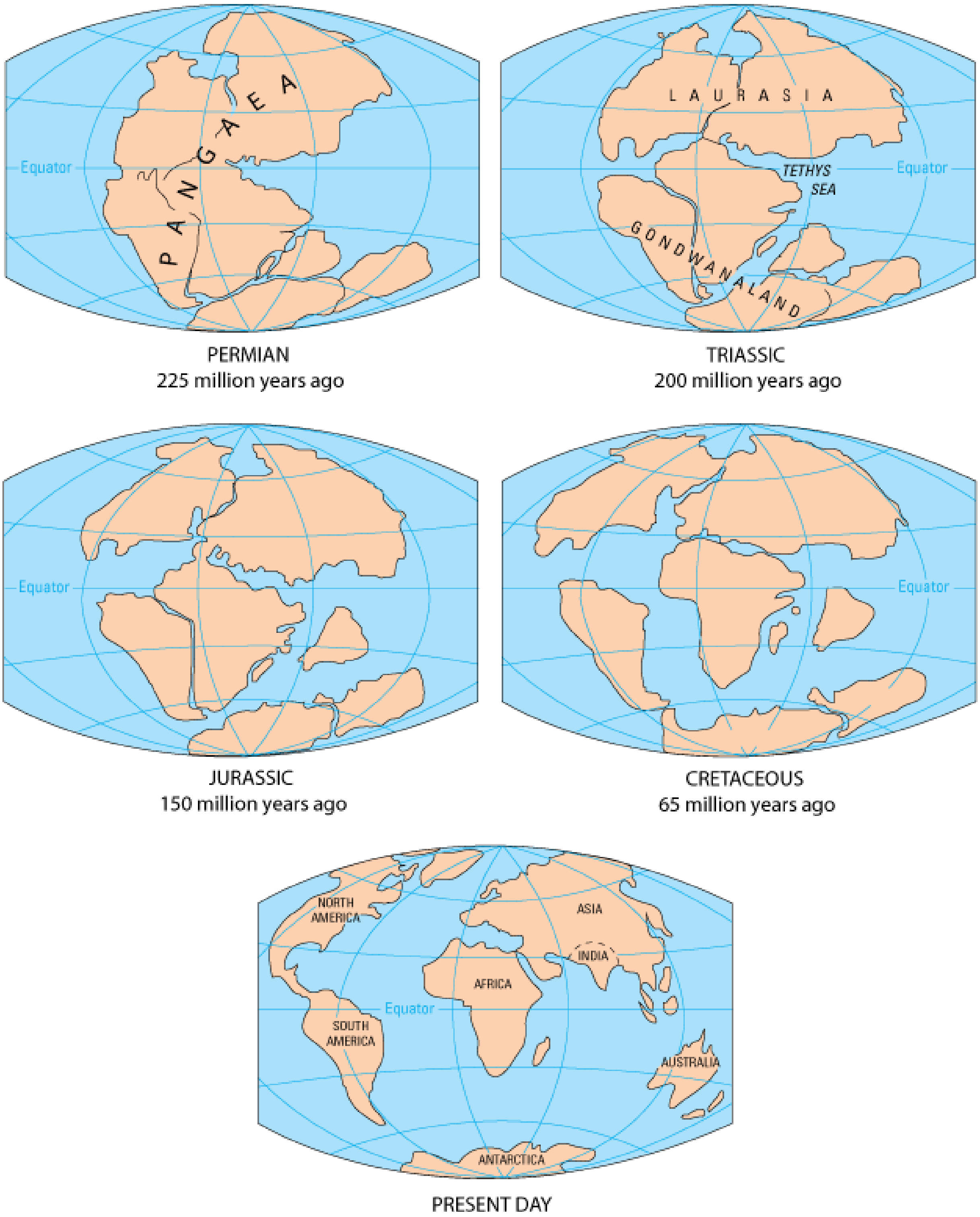
6. On the controversy, see: H. E. Le Grand, *Drifting Continents and Shifting Theories*, Cambridge, Cambridge University Press, 1988; M. Segala, *La favola della terra mobile*, Bologna, Il Mulino, 1990; N. Oreskes, *The Rejection of Continental Drift: Theory and Method in American Earth Science*, Oxford, Oxford University Press, 1999.
7. On the rise of place tectonics, see H. Frankel, *The Continental Drift Controversy,* vol. II: *Paleomagnetism and Confirmation of Drift*, vol. III: *Introduction of Seafloor Spreading*, Cambridge, Cambridge University Press, 2012.

Considering the importance of methodology in Wegener's approach renders comprehensible why his first two papers begin with geophysics, even if he admits he cannot provide any convincing mechanism for continental drift. Against people like Willis, who in 1910 had emphatically asserted that current research in paleogeography "appears to place the permanence of ocean basins outside the category of debatable questions"[8], he underlines that geophysics does not support contraction and permanence anymore and quotes Böse's remark on the lack of an alternative theory (see p. 277). Continental drift is the needed alternative: the powerful and complete *Arbeitshypothese* whose firm grounds are both evidence and sound methodology.

■

(november 2012)

[8] B. Willis, *Principles fo paleogeography*, "Science", N. S., 31, n. 790, 1910, p. 245.



<u>Figure 15 :</u> Current reconstruction of past continental drift *(source: This Dynamic Earth: The Story of Plate Tectonics. Reston, Virginia, USA: United States Geological Survey, online)*