"During the last decade, there has been a revolution in Earth sciences ... which has lead to the wide acceptance that continents drift about the face of the earth and that the sea-floor spreads, continually being created and destroyed. Finally in the last two to three years, it has culminated in the all-embracing theory known as 'plate tectonics.' ... [It] has taken the Earth sciences to the stage where they can not only explain what has happened in the past, and is happening at the present time, but can also predict what will happen in the future."
By 1904 it was obvious that there were problems

- The Cooling-Earth model was contradicted by radioactivity.
- Even if the Earth was contracting, it wasn’t doing so enough to cause the observed folding and faulting.

Osmond Fisher
1817 – 1914

- Continental rocks were composed of relatively light silicates of aluminum (“sial”)
- The ocean floor was composed of relatively heavy silicates of magnesium (“sima”)
- The former can be visualized as floating on the latter.

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Clarence Dutton
1841 – 1912

- Proposed “isostasy”
- Continents are floating on the underlying crust of sima
- They rise and fall as material is eroded or deposited (or ice ages occurred), thus altering the density and weight of the continental mass.

Mesozoic
251 to 65.5 mybp
Glossopteris

10/29/2008

- PhD in Astronomy
- Meteorologist
- Supported theory that ice ages were caused by fluctuations in amount of heat received from sun
- Research in Greenland on polar air currents
1910 – Recognized fit of continental shelves.

1912 – Paper on “The geophysical basis of the evolution of the large-scale features of the Earth’s crust (continents and oceans)”

1915 – Die Entstehung der Kontinente und Ozeane (“The Origin of Continents and Oceans”)

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**Wegner's Displacement Theory**

1. The continents are composed of less dense material than the ocean basins;

2. The material that composes the ocean floor also underlies the continents, and the difference in density between them permits the continents to “float” in equilibrium within the denser oceanic substrate;

3. The continents are able to move through the substrate because it behaves over time as a highly viscous fluid;

4. The major geological features – mountain chains, rift valleys, oceanic island arcs – and the major geological phenomena – earthquakes and volcanoes – are cause by the horizontal motions and interactions of the continents.
Predecessors

- Francis Bacon (1620)
- Benjamin Franklin
- Alexander von Humbolt
- Antonio Snider-Pellegrini (1858)
- Abraham Ortelius (1596)
- Franklin Coxworthy (1848)
- Roberto Mantovani (1889)
- William Henry Pickering (1907)
- Frank Bursley Taylor (1908)

Alfred Wegener

I “became acquainted with all these works only when the displacement theory in its main outlines had already been worked out.”
Tidal friction & differential gravitational effects due to the Earth being an oblate spheroid.

“The Newton of drift theory has not yet appeared … It is probable that the complete solution of the problem of the driving forces [of continental displacement] will still be a long time coming.”

Periodic melting of the substratum facilitated movement of the continental rafts (1925)

1927 – suggested that convection currents may bring hot matter to the surface while subducting cooler matter

1928 – realized that this could be a mechanism for continental drift as the continents rested on crust in motion.
"Many geologists have hesitated to accept this straightforward and consistent reading of the rocks, because so far it has not been found possible to discover any gravitational forces adequate to move the continents ... Admitting that the continents have drifted there seems no escape from the deduction that slow but overwhelmingly powerful currents must have been generated in the underworld at various times during the Earth's history ... namely that convection currents may be set up in the lower layer as a result of differential heating by radioactivity." – Arthur Holmes, 1929

British Response
- If the theory were true it would be a “revolution in thought” similar to “the change in astronomical ideas at the time of Copernicus” would occur. (Anon, Nature 1922)
- The geological similarities were “evidence as good as could be expected ... nearly demand[ing] some such explanation” as drift (W.B. Wright, 1923)
- “[E]xtensive changes of mean annual temperature could only be brought about by movement of the crust relative to the poles in the manner described by Wegener.” (Royal Society, 1930)
- In short, drift was a likely but unproven hypothesis.

American Response
- American Association of Petroleum Geologists (Tulsa, 1926) – Lack of driving force for drift.
- Attacks on Wegener’s training and methodology.
- Bailey Willis – the fit between the continents was too good!
Edward Berry, 1928

“My principal objection to the Wegener hypothesis rests on the authors method. This, in my opinion, is not scientific, but takes the familiar course of an initial idea, a selective search through the literature for corrobative evidence, ignoring most of the facts that are opposed to the idea, and ending in a state of auto-intoxication in which the subjective idea becomes an objective fact.”

R.T. Chamberlin, 1928

“Taking the situation as it is now, we must either modify radically most of the present rules of the geological game or else pass the hypothesis by.”

Quoting another – “If we are to believe Wegener’s hypothesis, we must forget everything which has been learned in the past 70 years and start all over again.”

Alexander du Toit
1878 – 1948

- South African who spent time in Brazil, Uruguay and Argentina.
- A Geological Comparison of South America with South Africa (1927).
- Our Wandering Continents (1937).
  - Dedicated to Wegener
  - “An hypothesis of continental drifting”
- Two super-continents
**Unconvincing ...**

“The dumbfounding spectacle of the present continental masses, firmly anchored to a plastic foundation yet remaining fixed in space; set thousands of kilometers apart, it may be, yet behaving in almost identical fashion from epoch to epoch and stage to stage like soldiers at a drill; widely stretched in some quarters at various times and astoundingly compressed in others, yet retaining their general shapes, positions and orientations; remote from one another throughout history, yet showing in their fossil remains common or allied forms of terrestrial life; possessed during certain epochs of climates that may have ranged from glacial to torrid or pluvial to arid, though contrary to meteorological principles when their existing geographic positions are considered – to mention but a few such paradoxes!”

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**Accumulating Evidence**

1940’s – 1960’s

- Mapping of mid-Atlantic ridge using sonography (Maurice Ewing, 1947)
- Measuring the magnetic field above the seafloor using magnetometers (Harry Hess, 1950’s)
- Timing of the north-south reversals of the Earth’s magnetic field using the magnetic memory of continental rocks and their radioactive ages
- Determining very accurately the location of earthquakes using a worldwide network of seismometers (1960’s)
- Suggestion that there were 12 rigid plates (W.J. Morgan, 1968)

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**Xavier Le Pichon**

1937 –

*Publishes the first complete model for plate tectonics in 1968*
The mid-ocean ridge (shown in red) winds its way between the continents much like the seam on a baseball.
Harry Hess
1906 – 1969

› Sea floor spreading
› Unpublished manuscript (1960)
› *History of Ocean Basins* (1962)
As early as the 1920s, scientists noted that earthquakes are concentrated in very specific narrow zones (subduction zones). In 1954, French seismologist J.-P. Wójtitz published his map showing the concentration of earthquakes along the zones indicated by dots and cross-hatched areas.

Volcanic arcs and seamount chains partially encircle the Pacific Ocean. The so-called Ring of Fire, a zone of frequent earthquake and volcanic activity. The volcanoes are shown in blue-green. The volcanic island arcs, although not labelled, are parallel to, and move beneath and up the trenches. For example, the island arc associated with the Aleutian Trench is represented by the long chain of volcanoes that make up the Aleutian Islands.
The Plate Tectonic Model

Provides a mechanism by which:

- continents can move across the surface of the globe
- patterns of volcanism can change and shift across the globe as plates and their boundaries evolve and move
- new oceans may grow and different sedimentary basins evolve
- oceans and sedimentary basins close and are deformed to produce mountains
Naomi Oreskes (1988)

“Plate tectonics was demonstrated by an entirely different data set that had been used to support continental drift.”

Differing types of evidence

- Palaeontological parallels between continents
- Stratigraphic similarities between continents
- Interlocking fit on continental shelves
- Indicator of similar climatic conditions
- Land-based paleomagnetic measurements demonstrated divergent polar wandering paths on different continents.
- Marine paleomagnetic measurements confirmed sea-floor spreading.
- Seismographical resolution of earthquake zones confirmed subduction
- Modeling of plate motions

Why American Skepticism Over CD.

- American interest in geophysics and instrumentation over “traditional” geology
- American inexperience with “traditional” reasoning and field-based inquiry
- American inexperience with non–American geology (especially South Africa, South America & India)

Frank Press, 1974

I “once wrote a paper dealing with the permanence of the ocean basins. If [I] were allowed to expunge the one scientific contribution [I] regret most, this would be it. The notion of the stability of global geographic features was not only a tenet of the old geology, but seems to be firmly rooted in the human psyche.”
Lyell vindicated

- Uniformitarianism – slow processes over long periods of time.
- Relatively catastrophic events (volcanoes, earthquakes) are actually a product of these slow processes.

I. Bernard Cohen

“In a sense, Wegener’s original theory never produced a revolution in science, but the eventual revolution in science did embody the central concept of continental mobility and the idea of two types of domains (continents and ocean floors) of Wegener’s theory.” (p. 447).

Revolution Talk (Scientists and Historians)

- J. Touzo Wilson (1963) – “earth science is ripe for a major scientific revolution.”
- A Revolution in the Earth Sciences: From Continental Drift to Plate Tectonics (Hallam, 1973)
- Critical Years of the Revolution in Earth Sciences (Glen, 1982)

“[A] revolution in Earth sciences ... has taken the Earth sciences to the stage where they can not only explain what has happened in the past, and is happening at the present time, but can also predict what will happen in the future.”