

THE IMPORTANCE OF MAGNETIC ANOMALIES IN THE DEVELOPMENT OF SEA FLOOR SPREADING THEORY

Abstract

Magnetic anomalies were crucial in the development of sea floor spreading theory from continental drift. In the 1950s, land-based magnetic reversal timescales were produced from thermal remanent magnetism in basic lava flows. Within a decade, survey ships reported distinct patterns of magnetic anomalies on the ocean floor; these were used to formulate the early sea floor spreading theory in 1961. Sea floor spreading states that alternating normal and reverse epochs in the Earth's magnetic field produce linear anomalies as new ocean crust cools and solidifies from melt at spreading centers. This theory has continued to develop, now using magnetic anomalies as a marker for the initiation of ridge systems from rifts.

Introduction

Sea floor spreading developed from continental drift. In 1912, citing the geometric fit of the continents across the Atlantic and the similarity of ages, fauna and glacial patterns; Wegener proposed that continents were originally in one mass, although speculation probably predated him. On rifting, continents ploughed through the ocean floor to their current positions. Similarly, in 1931, Holmes speculates of a convecting mantle and thinning, stretching crust creating continental separation (Meyerhoff, 1968; Dietz 1968). Such ideas may have inspired Hess and Dietz as they discussed crustal evolution and continent development in 1960 (Hess, 1968).

The phrase “sea floor spreading” was coined by Dietz. New topographic and geophysical data from ocean ridge transects were available and a hypothesis was formulated (Dietz, 1961). The sea floor spreading hypothesis derives directly from a earth structure model where ocean floor is thought of as the exposed part of the lithospheric mantle and is assumed to be layered. The surface layer is chert and pillow lavas, underlain by sheeted dykes and gabbro, with eclogite beneath the Moho. Thermal convection cells in the upper asthenosphere are coupled to the gabbroic layer and oceanic lithosphere is carried along by drag forces at the lithosphere-asthenosphere boundary. Sea floor slowly spreads from upwelling zones of convection cells (mid-ocean ridges) to downwelling zones (subduction zone trenches) in a conveyor belt fashion (Dietz, 1968).

Sea floor spreading improved upon continental drift, where one concern was the similarity in strength of continental and oceanic lithosphere, restricting relative motion. The solution is that new lithosphere is created at ridges, the spreading of the sea floor moves the continents apart; thus no relative motion is needed. The buoyancy of the continents prevents recycling to the asthenosphere and addition of granites occurs from melting subduction zone debris; explaining the persistent height of the continents despite erosion. Dietz hoped that magnetic anomaly data soon to be published would provide evidence for this hypothesis.

Magnetic methods

Rocks with a large proportion of ferrimagnetic minerals have remanent magnetism. Ferrimagnetic minerals contain atoms with antiparallel, unequal dipole coupling of electrons, associated with the quantum spin of unpaired electrons in outer orbitals. These minerals have a strong spontaneous magnetism and high susceptibility to an imposed magnetic field.

Experimental data indicates that a basic rock cooled through the Curie temperature in a magnetic field will acquire thermal remanent magnetism (TRM) in the direction of the imposed field. This polarization remains after tectonic movement, if no melting has occurred. The latitude of the rock at cooling can be inferred from palaeoinclination, but longitude is not calculated, as declination gives a non-unique solution.

Land-based magnetic reversals and remanent magnetism were documented in the 1950s and analyzed to demonstrate rigor in data collection and interpretation (Hospers, 1951). K-Ar dating was used to find the ages of normal and reversely magnetized lava flows. Subsequently limits were assigned to the different polarity epochs seen in lava sequences and reversal timescales dating back several million years (e.g. Cox et al., 1963) were produced.

Magnetic data from the ocean floor is collected by a magnetometer towed in a cradle (fish) behind a research vessel. The fish is strung 2.5 ship lengths behind the vessel to avoid interference. The data is reduced; the magnetic reference field is subtracted, then corrections for the diurnal variation, elevation and terrain are applied and any remaining signal is known as an anomaly.

In the northern hemisphere, positive anomalies are seen when rock is magnetized in the present direction of the earth's magnetic field (normal magnetism). In the southern hemisphere, normally magnetized rock produces a negative anomaly and at the magnetic equator, no anomalies are seen. A stunning pattern of linear anomalies (figure 1) was discovered west of North America in 1961.

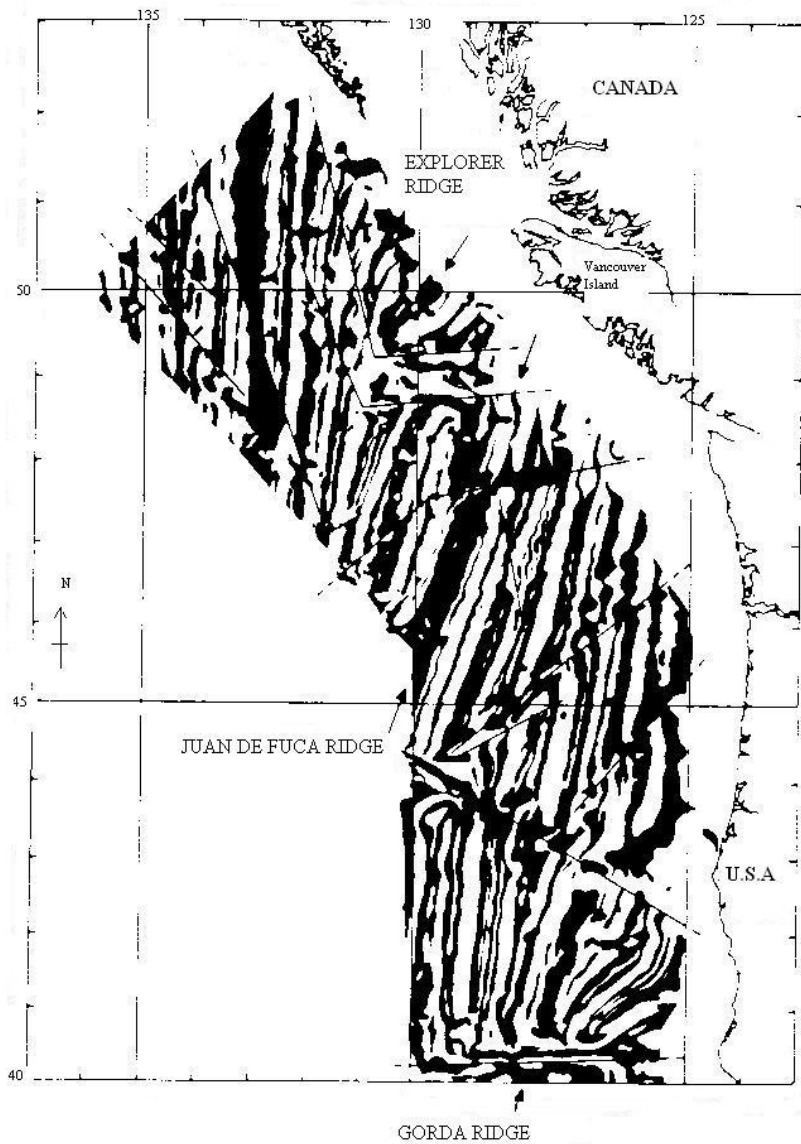


Figure 1; linear patterns in magnetic anomalies west of North America, after Fowler 1990. Positive anomalies are black; arrows indicate ridge centers and lines are transform faults.

Sea floor spreading

Magnetic anomaly patterns and sea floor spreading were combined by Vine and Matthews (1963). In their model, the sea floor moves away from mid-ocean ridges at an equal speed on each side. At a ridge, new ferrimagnetic material cools through the Curie temperature and acquires a TRM in the direction of the Earth's magnetic field. In a reverse field epoch, TRM exhibits reverse palaeomagnetism and negative anomalies are seen in the northern hemisphere. Linear, parallel anomalies form in a symmetric pattern across the spreading center. In the ridge system, the pattern of anomalies picks out the median valley and high flanking peaks.

Sea floor spreading is more elegant than the vertical boundaries, high susceptibility contrasts or different lithologies between adjacent sections of crust that competing hypotheses invoked to explain the linear pattern, given that anomaly shapes are not unique to magnetic body shape. Still unexplained was the observed replacement of shorter wavelength anomalies by high amplitude long wavelength anomalies at distance from the ridge. If bathymetry is the only factor, the high amplitude anomalies should be closest to the ridge, where sediment is thinner, as deeply buried bodies give small anomalies.

Theory development

With more evidence from sections across different ridges, the theory was refined (Vine 1966) and a driving force formalized. Thermal convection cells are assumed to operate in the upper asthenosphere by creep processes and lithospheric fragments ride passively away from upwelling zones at rates of a few cm per annum. The ocean floor conveyor belt is a “tape recorder” (Vine, 1966) of the magnetic field direction, without major lithologic or susceptibility contrasts. The developed theory explained the wavelength variation in terms of changes in field intensity and reversal frequency at 25 Ma, because frequent reversals give short wavelength anomalies. Frequency change is seen to be valid on consideration of the long Cretaceous magnetic quiet zone, where no reversals occurred. Transform faults in the ocean basins explain the fracture zones that offset anomalies, representing periods when the plate rotation poles changed and bracketing discrete stages of spreading across the ridge system.

Modern work uses data from satellite observations of the ocean floor (Purucker & Dymment, 2000) to try and understand complex areas such as the zone of north-south trending anomalies in the South Atlantic. Others focus on the initiation of spreading centers from rifting continents (Minshull 2002). Here, the magnetic anomaly pattern is used as a marker for active spreading, to study the differences between continental rifts that become aulacogens and those like the Red Sea that make the transition to a spreading center.

References

Cox, A., Doell, R.R., Dalrymple, G.B., (1963), Geomagnetic polarity epochs and Pleistocene geochronometry: *Nature*, **198**, pp1049-1051.

Dietz, R.S., (1961), Continent and ocean basin evolution by spreading of the sea floor: *Nature*, **190**, pp854-857.

Dietz, R.S., (1968), Reply: *J Geophys Res.*, **73**, pp6567.

Hess, H.H., (1968), Reply: *J Geophys Res.*, **73**, pp6569.

Hospers, J., (1951), Remanent magnetism of rocks and the history of the geomagnetic field: *Nature*, **168**, pp1111-1112.

Meyerhoff, A.A., (1968), Arthur Holmes: Originator of spreading ocean floor hypothesis: *J Geophys Res.*, **73**, pp6563-6565.

Minshull, T.A., (2002), The break up of continents and the formation of new ocean basins: *Phil Trans Roy Soc London A*, **360**, pp2839-2852.

Purucker, M.E., Dymant, J., (2000), Satellite magnetic anomalies related to sea floor spreading in the South Atlantic Ocean: *Geophys Res. Lett.*, **27**, pp2765-2768.

Vine, F.J., (1966), Spreading of the ocean floor: *Science*, **154**, pp1405-1415.

Vine, F.J., Matthews, D.H., (1963), Magnetic anomalies over oceanic ridges: *Nature*, **199**, pp 947-949.

General reading

Fowler, C.M.R., (1990), The solid earth; an introduction to global geophysics: Cambridge University Press.

Kearey, P., Brooks, M., (1984), An introduction to geophysical exploration: Blackwell Science.

<http://ruby.colorado.edu/~smyth/G1010/20PlateTectonixHO.PDF>

<http://www.scotese.com/method1.htm>