The Earth's Magnetic Field and Plate Tectonics

Investigations of the earth's magnetic field played a key role in the acceptance of plate tectonic theory. The observations of lineated marine magnetic anomalies over the seafloor and the emerging radiometric dating techniques in the early 1960's led to the realization of seafloor spreading at mid-ocean ridges. Seafloor spreading, in turn, provides a mechanism for large scale motions of the continents. Today, marine magnetic anomaly patterns constitute the primary means of determining the age of the ocean basins and the history of relative plate motions. Moreover, the geomagnetic polarity time scale (GPTS) provides a means of global stratigraphic correlation and directional records of the earth's magnetic field provide key information on the past motion of continents. Today we will examine:

Basics of the earth's magnetic field and paleomagnetism

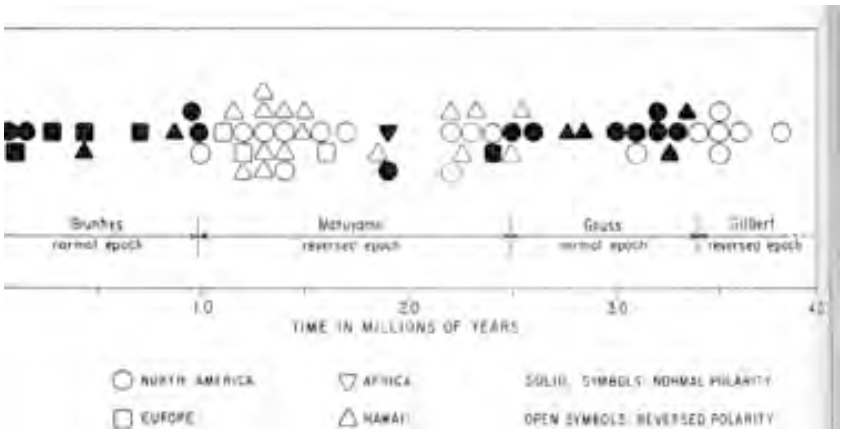
Reversals of the geomagnetic field and development of the GPTS

Lineated marine magnetic anomalies and the Vine-Matthews-Morley hypothesis

The Jaramillo event: confirmation of seafloor spreading

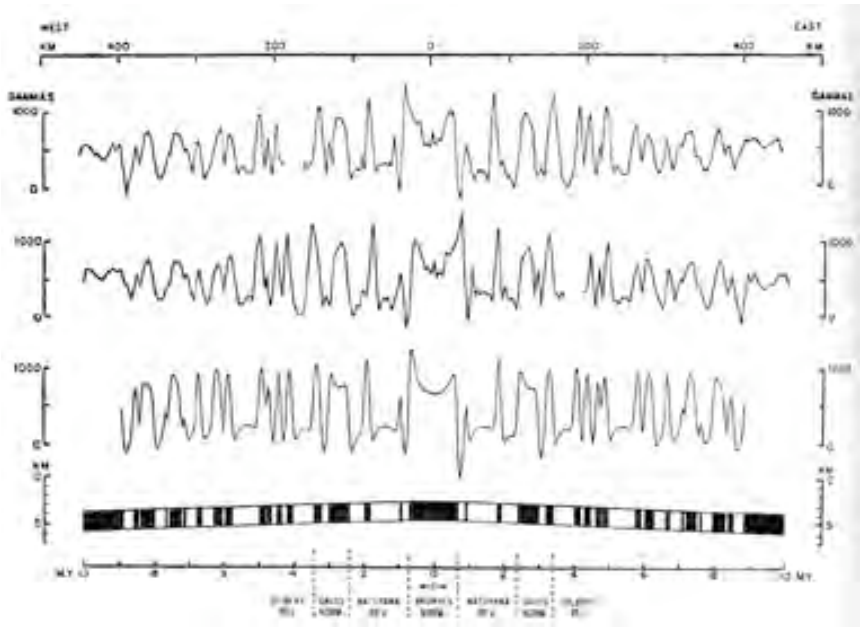
Applications of the geomagnetic polarity time scale

The geocentric axial dipole hypothesis and apparent polar wander



An early version of the polarity time scale (Cox, Doell and Dalrymple, 1965)

Magnetic stripes off the northwest coast of the U.S. (Raff and Mason, 1961).



Symmetry of lineated marine magnetic anomalies on the Eltanin 19 profile (Pitman and Heirtzler, 1966)

Lecture 16: Earth's Magnetic Field Oct. 30, 2006

Basics of the magnetic field and paleomagnetism

The Earth as a giant magnet: Gilbert (1600)
fashioned lodestone into a sphere
moved compass needle near surface
same pattern of declination and inclination variations as noted by navigators

General features of the field
a) on average corresponds to that of an geocentric axial dipole (GAD)
namely inclination varies as function of latitude
b) internal origin (Gauss ~1840)
c) secular variations known from early magnetic observatories

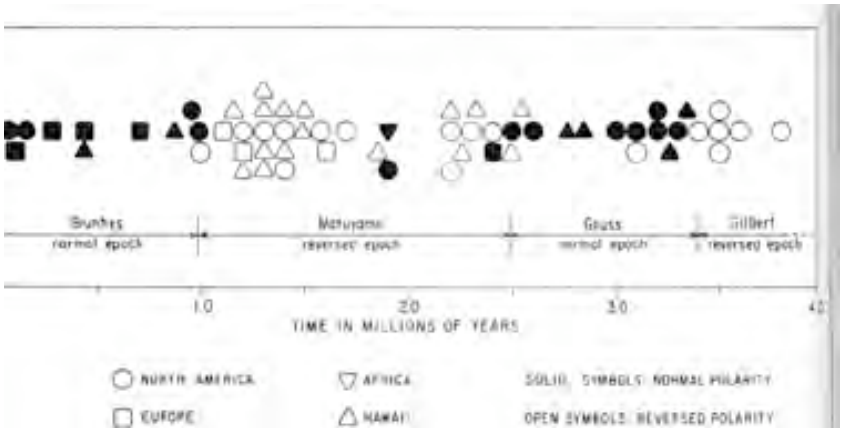
How rocks become magnetized
cooling and thermoremanence in lavas
Curie point
small statistical alignment of moments parallel to field
other types of remanence (e.g. sediments)

Reversals and early development of time scale

David (1904) and Brunhes (1906) first noted rocks magnetized in *R direction*
Little done with this information until 1950s, early 1960s
Paleomagnetism developed, primarily directional studies

Improvements in K/Ar dating method that allowed dating relatively young rx
Spurred several groups to combine age and polarity studies
lively debates about the significance of reversed directions

Several early timescales published in early 1960s



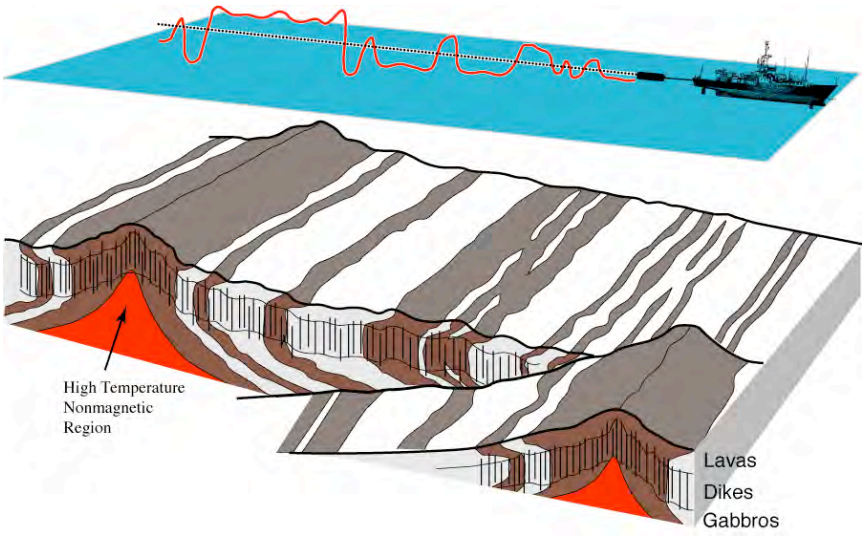
Cox, Doell and Dalrymple (1965) - timescale #9

Marine magnetic anomalies

Since 1950's Navy and increasingly research vessels had towed magnetometers
Raff and Mason (1961)
puzzling pattern of magnetic anomaly stripes along NW coast of US
nothing comparable over land
variety of explanations advanced, but none very plausible

Vine-Mathews (Morley) hypothesis

Nearly simultaneously in 1963, V&M and Morley developed an explanation for the stripes. They suggested that the anomaly pattern reflected spreading at the MOR, with basaltic lavas acquiring a remanence parallel to ambient (reversing) field and then rafted away.



Data that accompanied this suggestion in 1963 paper was less than compelling.

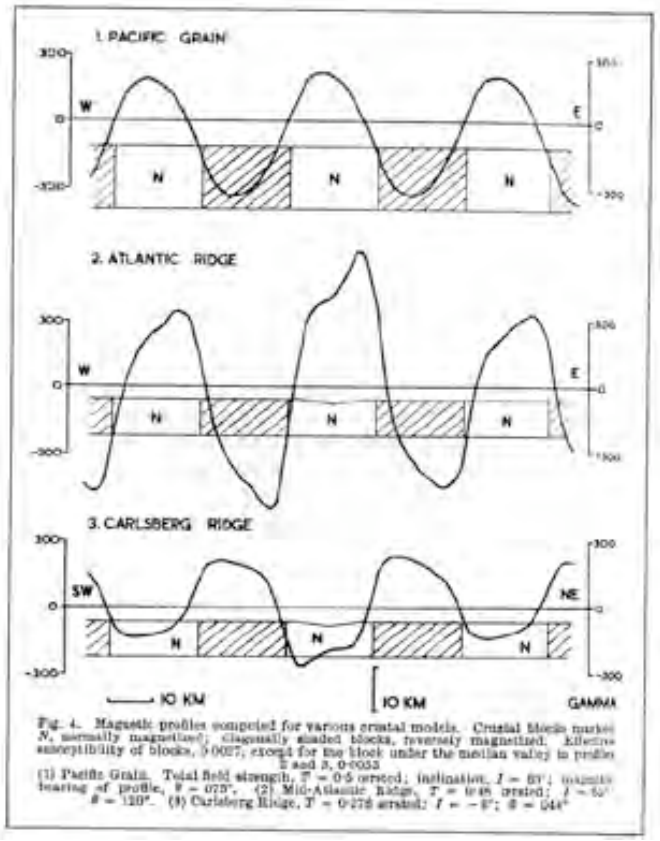


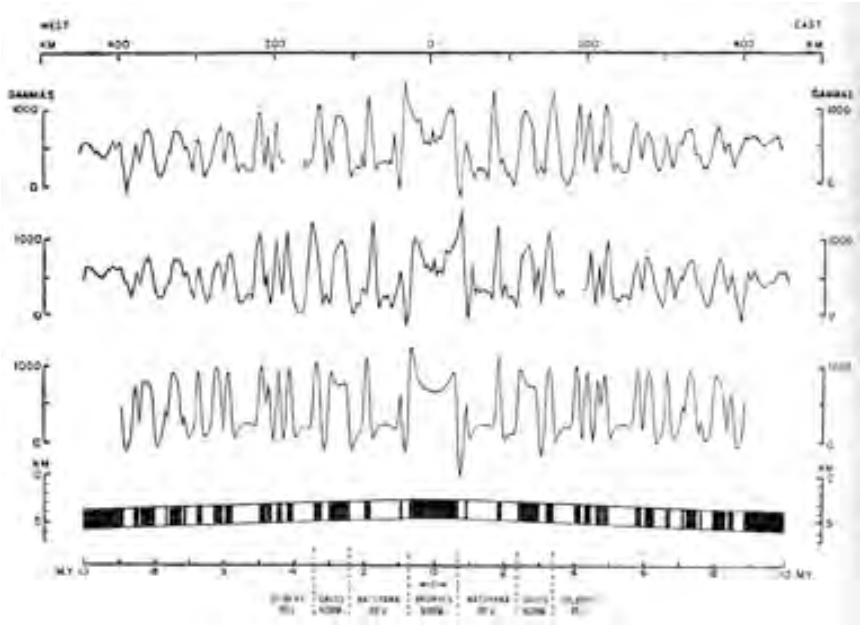
Fig. 4. Magnetic profiles computed for various crustal models. Crustal blocks marked N, normally magnetized; diagonally shaded blocks, reversely magnetized. Effective susceptibility of blocks, 0·0027, except for the block under the median valley in profile 2 and 3, 0·0055.

(1) Pacific Grain. Total field strength, $T = 0{\cdot}5$ oersted; inclination, $I = 67°$; magnetic bearing of profile, $\theta = 075°$. (2) Mid-Atlantic Ridge, $T = 0{\cdot}48$ oersted; $I = 51°$, $\theta = 120°$. (3) Carlsberg Ridge, $T = 0{\cdot}378$ oersted; $I = -8°$; $\theta = 044°$

Confirmation with Eltanin profile and Jaramillo

From 1963 to 1966, the ideas of seafloor spreading as the origin of the magnetic anomaly stripes were gaining support but still were not very convincing. Two developments in 1966 resulted in widespread acceptance of this idea.

1) Update to GPTS to include Jaramillo
2) Eltanin 19 profile (Pitman and Heirtzler, 1966)
   a) demonstrated remarkable symmetry on either side of ridge
   b) had small normal polarity event just where predicted from the Jaramillo



1968 GPTS
   limitations with K/Ar method on young rocks
      error is proportional to age, so at some level error is too large continue
      reliable ages and polarity stratigraphy from 0-5 Ma
   seafloor records extended considerably further
   extrapolation from these two tie points to age of ocean basin (South Atlantic)
   remarkably, present time scales differ by only about 10%

Present use of the GPTS
   anomaly pattern used to date seafloor
   age calibration
      a) oldest sediments on top of seafloor (DSDP)
      b) direct dating of seafloor lavas on known anomalies
      c) cross calibration of reversal pattern with land sedimentary sections
   a relative motion history for the ocean basins

Paleomagnetic poles

The understanding of marine magnetic anomalies as a manifestation of seafloor spreading and the reversing magnetic field played a key role in the acceptance of plate tectonics. In addition, the directional record of the magnetic field has also played an important role in documenting past motions of plates.

Geocentric axial dipole (GAD) hypothesis

as noted above, the earth's field is similar to that of a geocentric axial dipole

$$\tan(I) = 2 \tan(\text{lat})$$

however, secular variation is also well documented

if we take samples spanning few thousand years, mean direction is GAD

tests of the GAD hypothesis

sediment cores from the global ocean basins

young lavas from around the world

Apparent polar wander paths (APWP)

magnetization at the site >> VGP (dipole direction that would have produced D,I)

beginning in late 1950s, considerable amount of directional data produced

APWP - sequential plot of such VGPs

comparison of European and North American APWP

Current uses: arrangement of continents in past

No paleolongitude information