Lots here

magnetic field
obsv
by
Cluster in 1990
Extreme Range

Lecture 10 : Planetary & Solar Magnetic Fields

10 v #1

A. The Earth (Outer core = Mag dynamo)

Science requires observation + Theoretical interpretation.

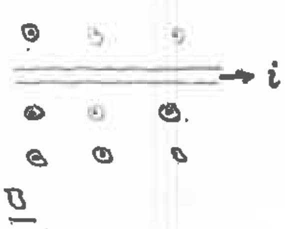
The magnetic fields + their
The electric connection

We have the fluid dynamic tools to interpret. Now we need some observations. We start with the earth's magnetic field.

The magnetic field is defined as the force exerted on one coulomb of charge, q_0, moving with velocity $\underline{u}$ through the magnetic field, $\underline{B}$:

(10-1) $$\boxed{\underline{F}\,[\text{nt}] = q_0\,[\text{coul}]\,\underline{u}\,(\text{m/s}) \times \underline{B}\left[\frac{\text{nt}}{(\text{coul})(\text{m/s})}\right]}$$

$$= \left[\frac{\text{nt}}{\text{amp-m}}\right] \equiv \text{weber/m}^2$$



B is wrapped around wire

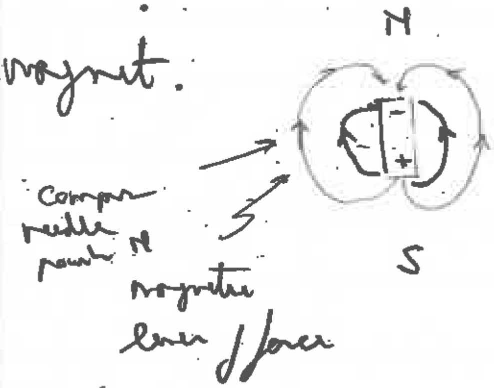
$$1\ \text{weber/m}^2 \equiv 10^4\ \text{gauss}$$

Earth's magnetic field ~ 0.5 gauss $= 0.5\times10^{-4}$ weber/m^2

$$\left(1\ \text{gamma} \equiv \gamma = 10^{-5}\ \text{gauss} = 10^{-9}\ \text{weber/m}^2\right)$$

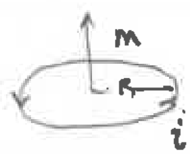
(E's mag fld = 50,000 γ)

The earth's magnetic field is dipolar, like a magnet.



A magnetic dipole can be characterized by its moment, M.

M can be defined by a current loop



$$m = i \pi R^2$$

← current

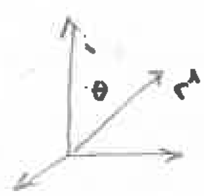
or by a uniform magnetization of a sphere, J:

$$M = \frac{4}{3}\pi R^3 J$$

A scalar magnetic potential can be defined in terms of m:

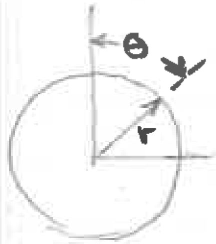
$\nabla \times B = 0$
$\therefore B = -\mu_0 \nabla V$ satisfies

$$V_m = \frac{\underline{m} \cdot \hat{r}}{4\pi r^2} = \frac{m \cos\theta}{4\pi r^2}$$



where the dipole magnetic field is given by

$$\underline{B} = -\mu_0 \underline{\nabla} V_m$$



$$B_\theta = -\mu_0 \frac{1}{r}\frac{\partial V_m}{\partial \theta} = \frac{\mu_0}{4\pi}\frac{m}{r^3}\sin\theta$$

$$B_r = -\mu_0 \frac{\partial V_m}{\partial r} = \frac{\mu_0}{4\pi}\frac{2m}{r^3}\cos\theta$$

at $r = R$

$$B_\theta = B_0 \sin\theta$$

$$B_r = 2B_0 \cos\theta$$

$$B_0 = \frac{\mu_0}{4\pi}\frac{m}{R^3} = 3\times10^{-5}\ w/m^2$$

$$= \underline{0.307\ \text{gauss}}$$

R_{earth} = 6,370 km

$\mu_0 = 4\pi \times 10^{-7}$ weber/amp-m

$m_E = 7.94 \times 10^{22}$ amp-m²

$$B_{Total} = \sqrt{B_\theta^2 + B_r^2} = B_0\sqrt{\sin^2\theta + 4\cos^2\theta}$$

$\sin^2\theta + \cos^2\theta = 1$

$$= B_0\left(1 + 3\cos^2\theta\right)^{1/2}$$

B_{Tot} ($\theta = 0$ pole) = .614 gauss Pole

B_T ($\theta = 90$ equator) = .307 gauss Equator

Actual:

$B_{N.Pole}$ = 0.615 gauss @ 75°N 101°W

$B_{S.Pole}$ = 0.725 gauss @ 67°S 143°W

~ 0.250 ≤ $B_{equator}$ ≤ 0.420 gauss

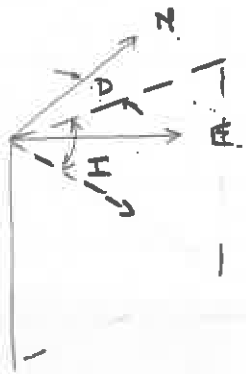
Horiz Fld

Declination – rot.

$B_{overall}$ ~ 0.5 gauss = 50,000 γ

Anomalies ~ 100 to 1000 γ

So the magnetic field of the earth is dipolar, but not purely so. It also changes with time, a fact very important to compass-based navigation.



D = Declination - deviation from N
I = Inclination - dip

variat

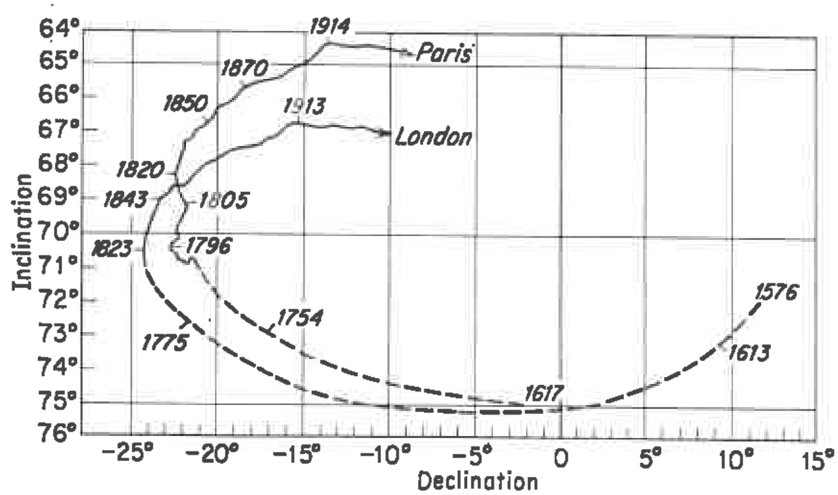


FIG. 6-4. Secular variation of the field direction in Paris and London. (*After Gaibar-Puertas.*)

On average (over ~1000 yrs) the earth's magnetic field is dipolar with the magnetic pole at the rotational pole and compass needles point to the rotational pole. But strong wrist of time. compasses do <u>not</u> point to the poles but up to 30° from them.

The cause of compass direction variations are largely due to the <u>westward drift of the anomalies in the dipolar field</u> (<u>westward drift of the magnetic vectors</u>). Drift is fairly regular and the field changes thus somewhat predictable!

VF

Magnetic field is in fact <u>decreasing</u> in intensity at ~ <u>4% per 100 years (0.04%/yr)</u>. In fact we now know that the polarity of the earth's magnetic field has changed irregularly in the past. This is a <u>major</u> recent story in the solid earth sciences that led to the discovery of <u>plate</u> tectonics (<u>Morgan + Vine</u>) — and one I witnessed happening as a <u>graduate student</u>.

1400 mag field

We thus have a dynamic dipole field.

Cannot be from rock magnetization. Curie point of iron is 750°C and pressure increases that mostly by ~10°C. A T_g 760°C is reached at $\frac{760}{20^{\circ}C/km} = 40$ km depth.

Magnetized in upper 40 km no chance near sufficient to produce field, and it wouldn't be dynamic.

- broad anomalies
- westward drift of magnetic isopors

suggest deep (filter out short wavelengths by upward continuation). But how generated?

- current loops in Earth — how generated
- magnet in inner core
- ?

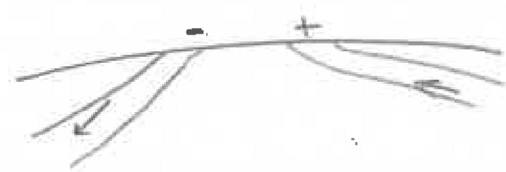
And how/why does field irregularly reverse itself?

B. The Sun

Insight comes from stars. All stars have "dipole" magnetic fields, but the polarity of the sun's dipole field flips every 11 years. Maunder butterfly diagram

- start at higher latitude
- move toward equator
- each spot lasts several weeks
- spots are outbreak of strong magnetic field
  - solar flares
  - 1000's of gauss ← E's mag field ~0.5 gauss

- Spots are pairs of spots with diff polarity (bipolar groups)



Toroidal field outbreak

- during each 11 yr cycle one polarity to west, another to east. Next cycle the polarity has changed

- solar poloidal field ~ 1 to 2 gauss but rapidly varies + variations in N + S hemispheres do not correlate. ∴ poloidal field is

two
201
VG

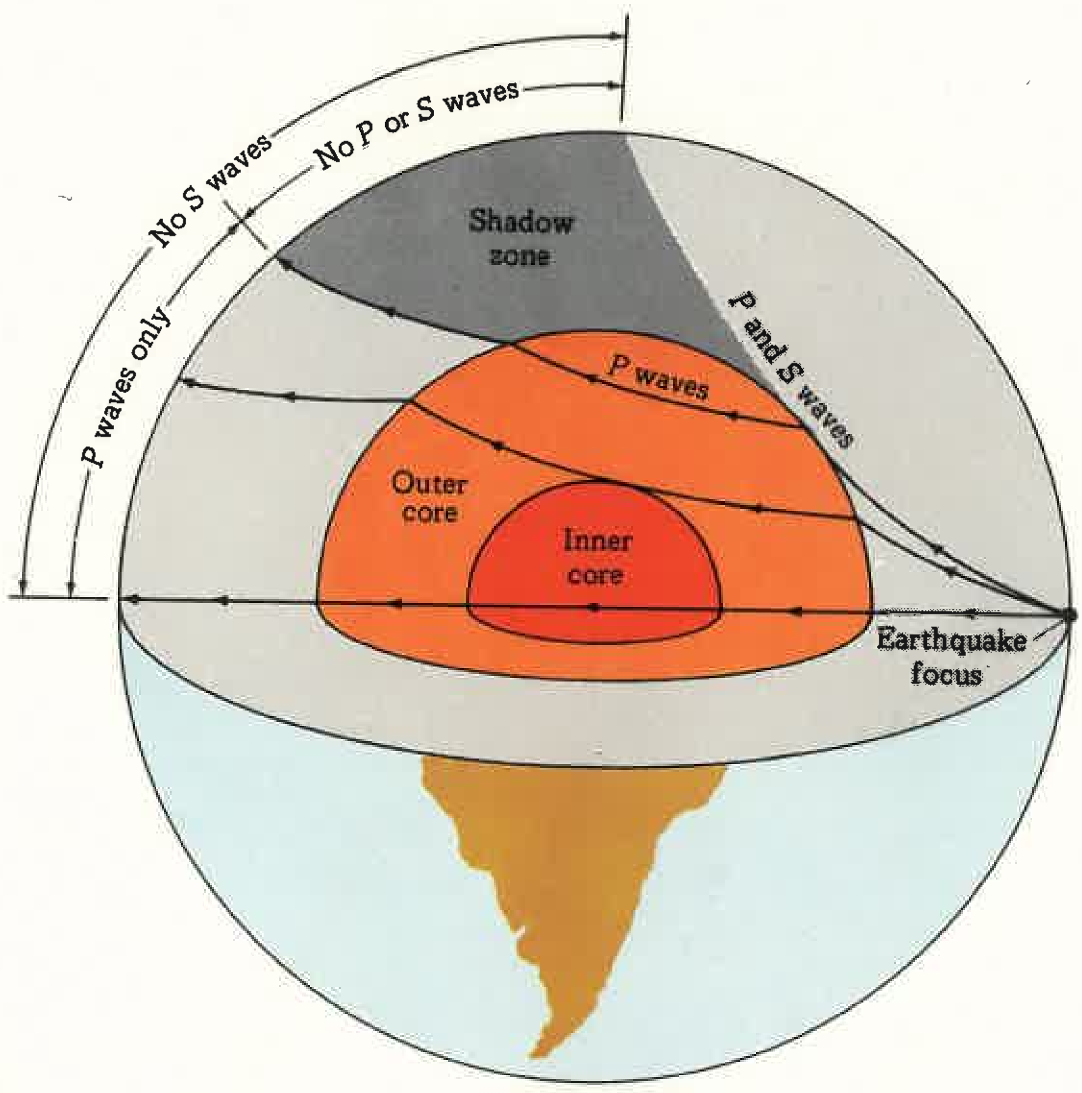
controlled in a local fashion

Idea: • Mag field frozen in electron "fluid"
• Turbulent convection's differential rotation
wraps frozen field into strong toroidal fld
• Buoyed toroidal strands break out
• Rotate cyclonically producing poloidal
field of opposite polarity

repeat

We will delve into This in detail next time, focussing
on differences between E + Sun. Key is cyclonic twist, and
This is controlled by the smooth surface. Sun's smooth surface
is top, Earth's is inner-core / outer-core boundary.

SEISMIC WAVES & EARTH'S INTERIOR (Fig. 10.29, p. 196)



$r_E \cong 6370$ km

PHYSICAL GEOLOGY, 7th ed.
by Judson, Kauffman, and Leet

H_{horz} [gauss]

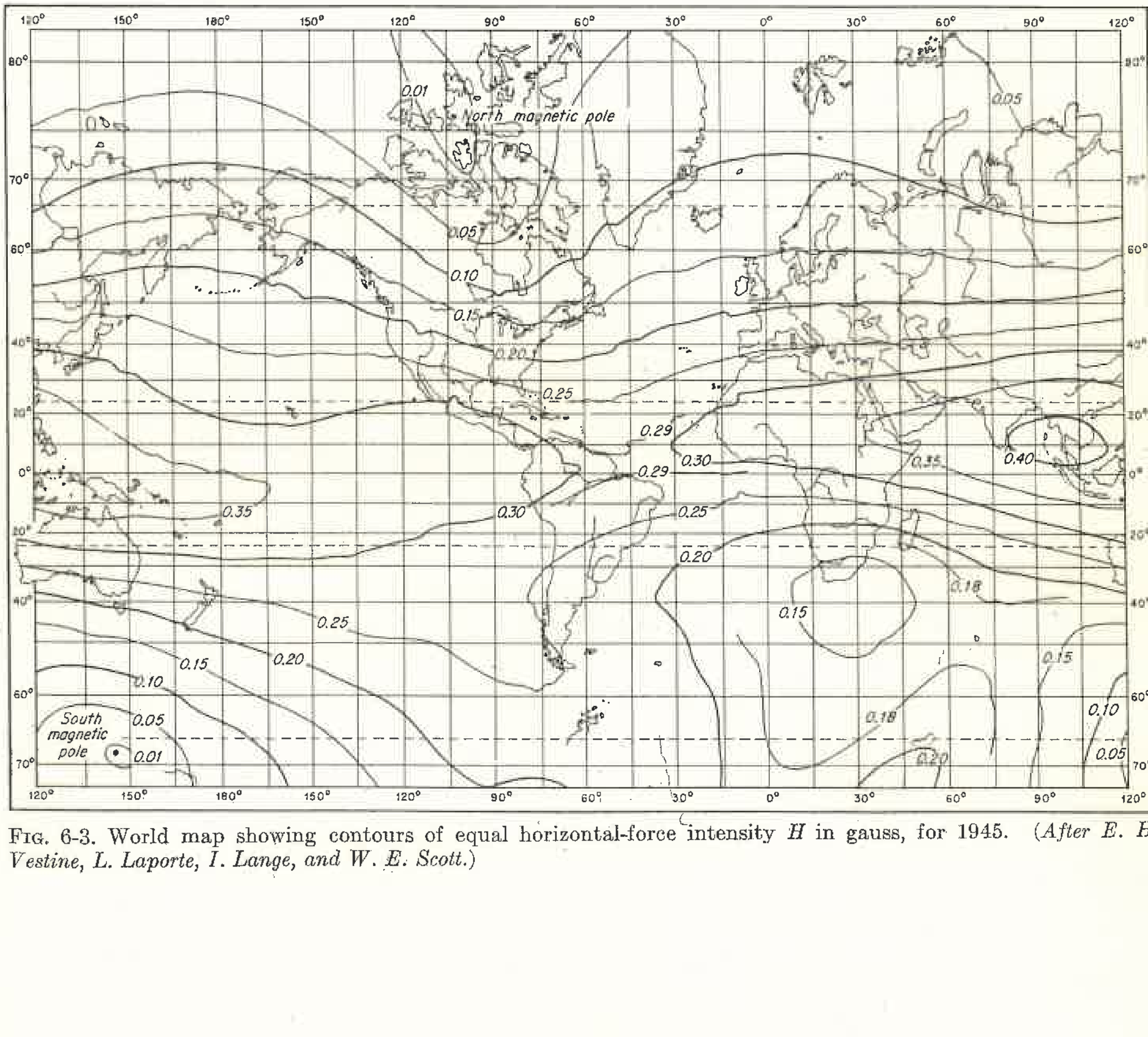
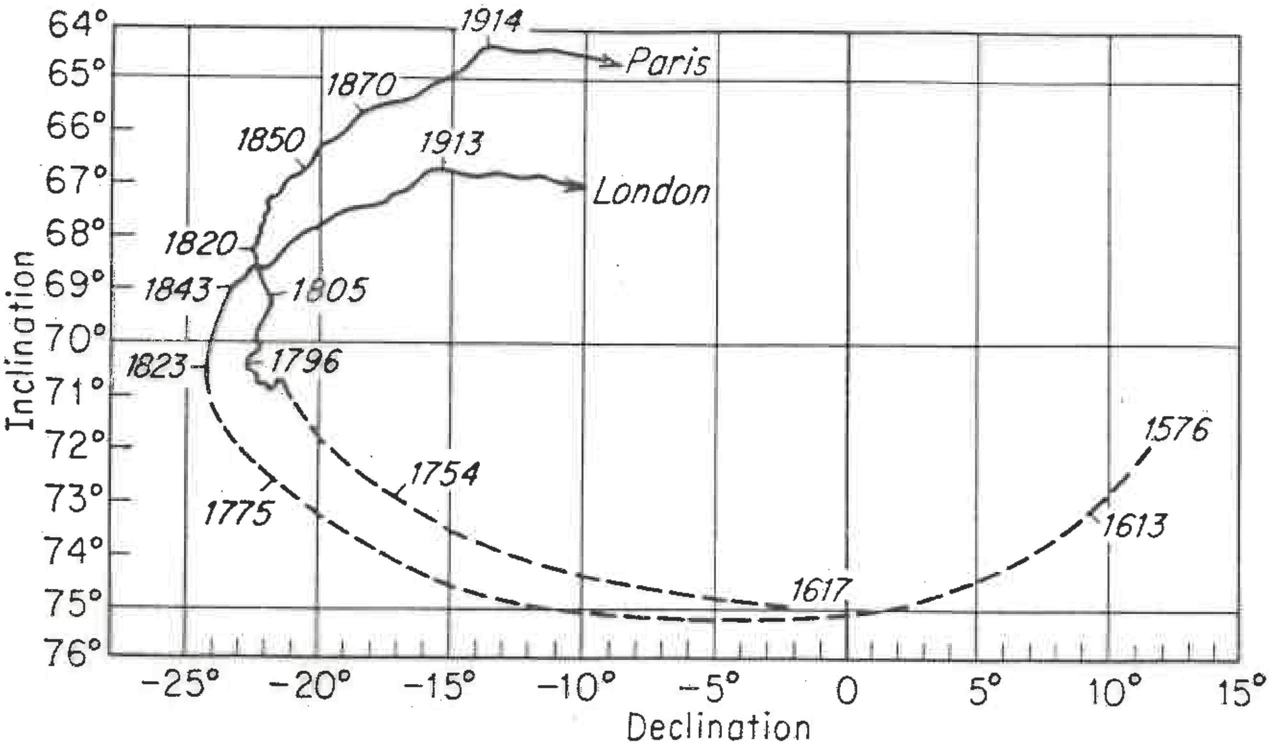


FIG. 6-3. World map showing contours of equal horizontal-force intensity H in gauss, for 1945. (*After E. H. Vestine, L. Laporte, I. Lange, and W. E. Scott.*)



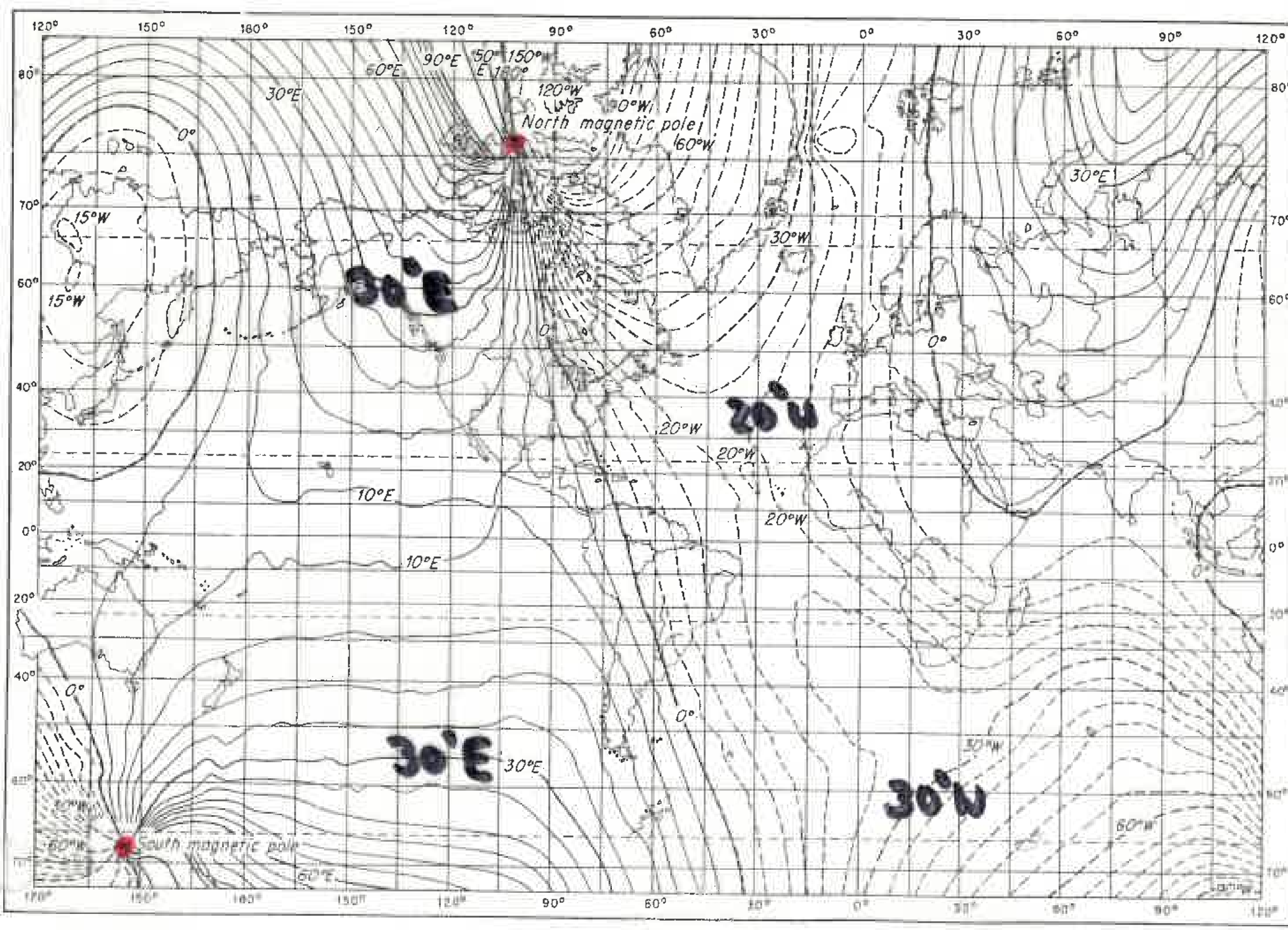


FIG. 6-2. World map showing contours of equal declination for 1945. (*After E. H. Vestine, L. Laporte, I. Lange, and W. E. Scott.*)

Westward drift of Magnetic Isopores

1922.5

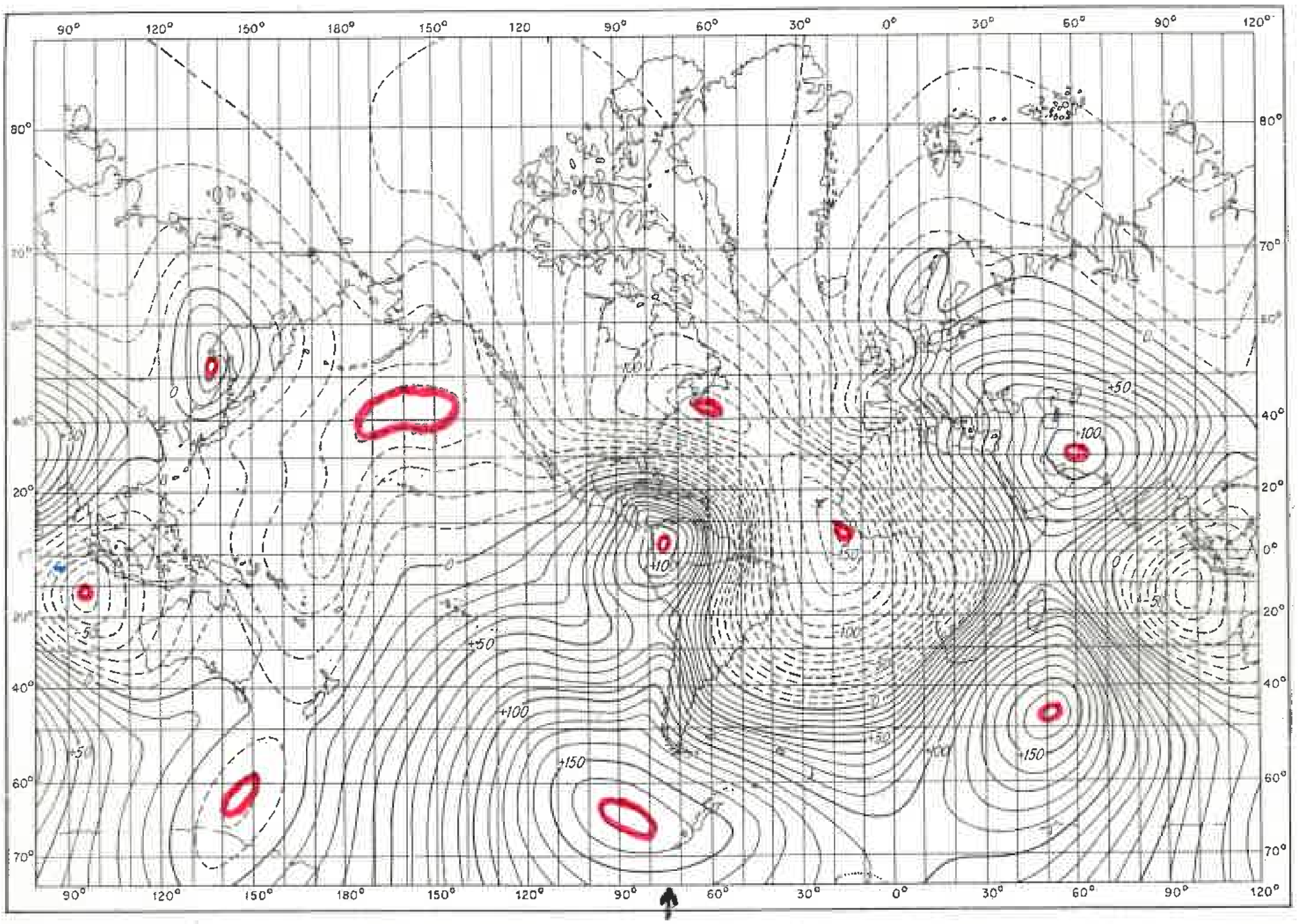


FIG. 6-5. World map showing the geomagnetic secular variation of the vertical component Z. Epoch 1922.5. (*After E. H. Vestine, L. Laporte, C. Cooper, I. Lange, and W. C. Hendrix.*)

75° W

1942.5

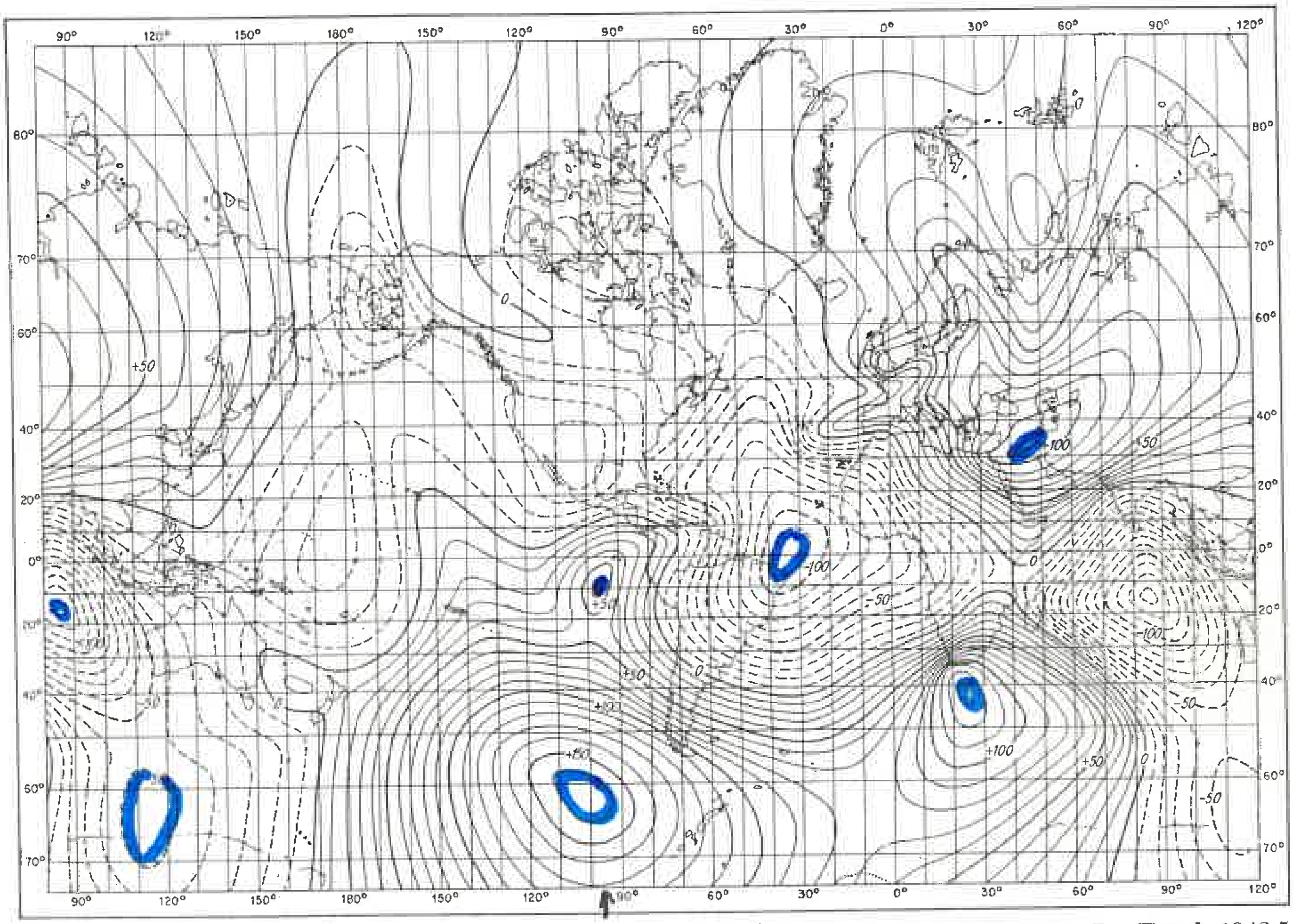


FIG. 6-6. World map showing the geomagnetic secular variation of the vertical component Z. Epoch 1942.5. (*After E. H. Vestine, L. Laporte, C. Cooper, I. Lange, and W. C. Hendrix.*)

95°W

Westward drift $\sim \frac{20^\circ}{20\,\text{yrs}} \sim 1^\circ/\text{yr}$

Westward drift of Magnetic Isopores

1942.5

1922.5

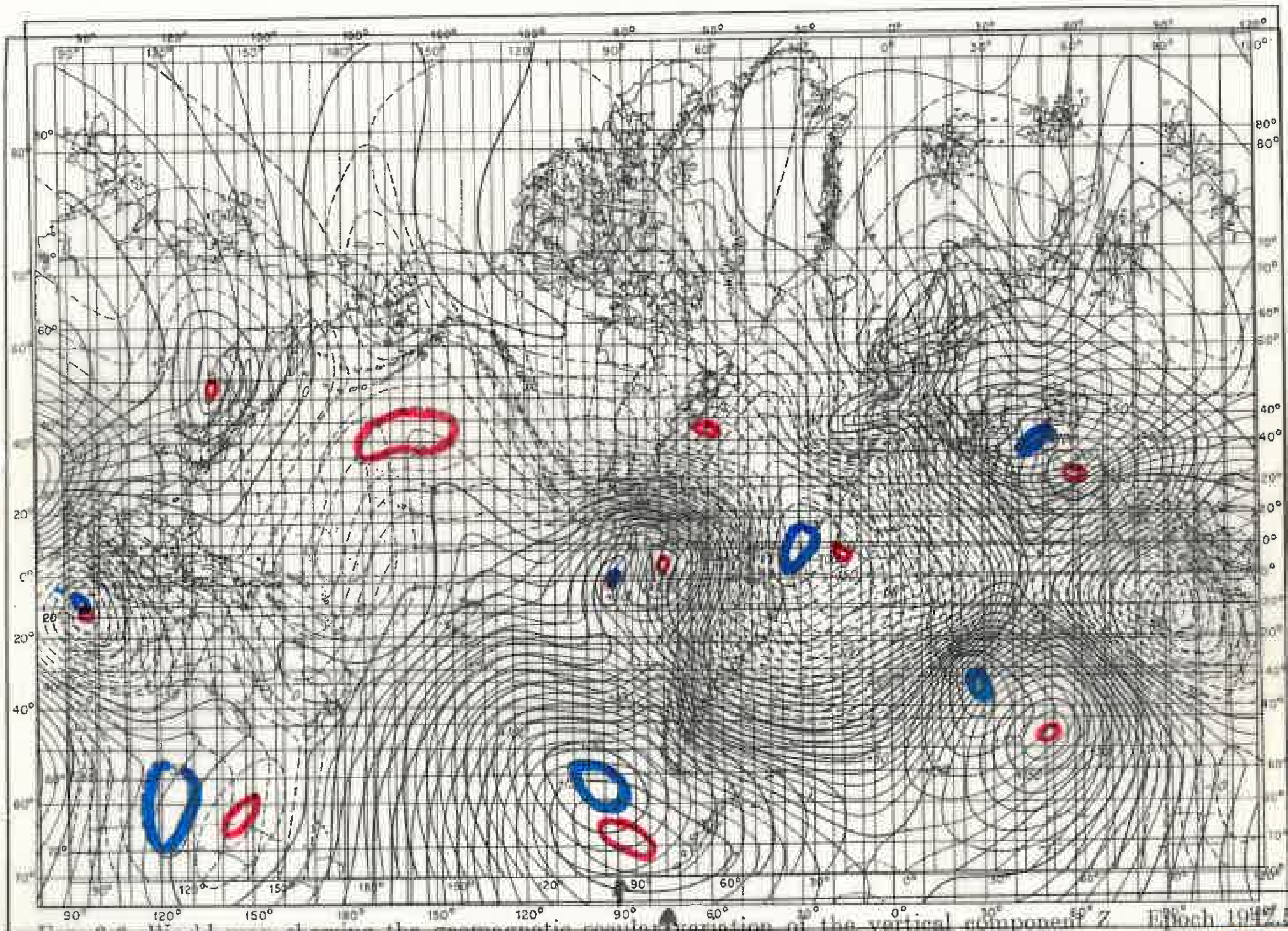


FIG. 6-6. World map showing the geomagnetic secular variation of the vertical component Z. Epoch 1942.5. (After E. H. Vestine, L. Laporte, C. Cooper, I. Lange, and W. C. Hendrix.)

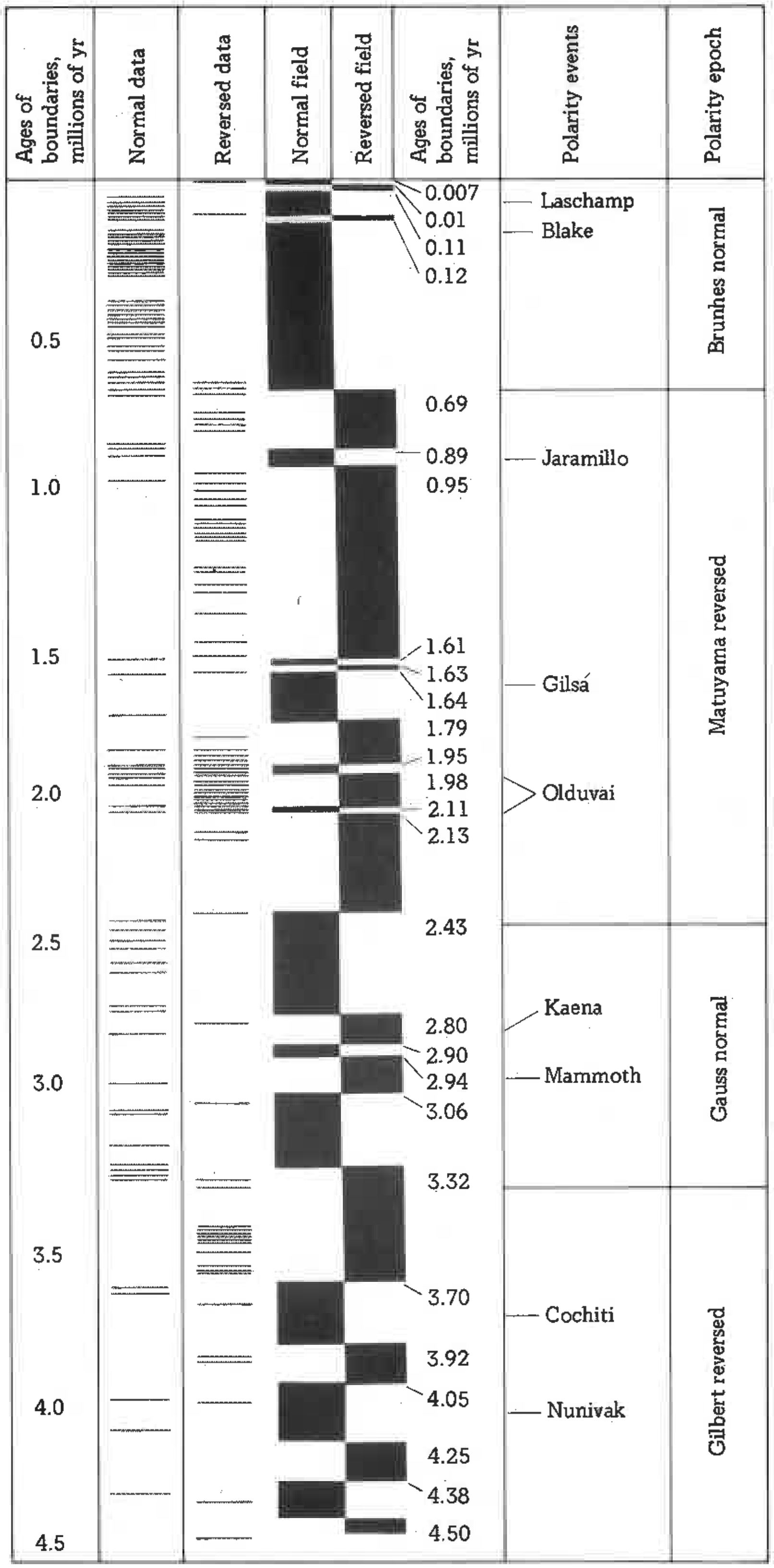
FIG. 6-5. World map showing the geomagnetic secular variation of the vertical component Z. Epoch 1922.5. (After E. H. Vestine, L. Laporte, C. Cooper, I. Lange, and W. C. Hendrix.)

95°W

75°W

Westward drift $\sim \frac{20°}{20 \text{ yrs}} \sim 1°/\text{yr}$

GEOMAGNETIC REVERSALS (Fig. 11.11, p. 212) T31



PHYSICAL GEOLOGY, 7th ed.
by Judson, Kauffman, and Leet

Vine

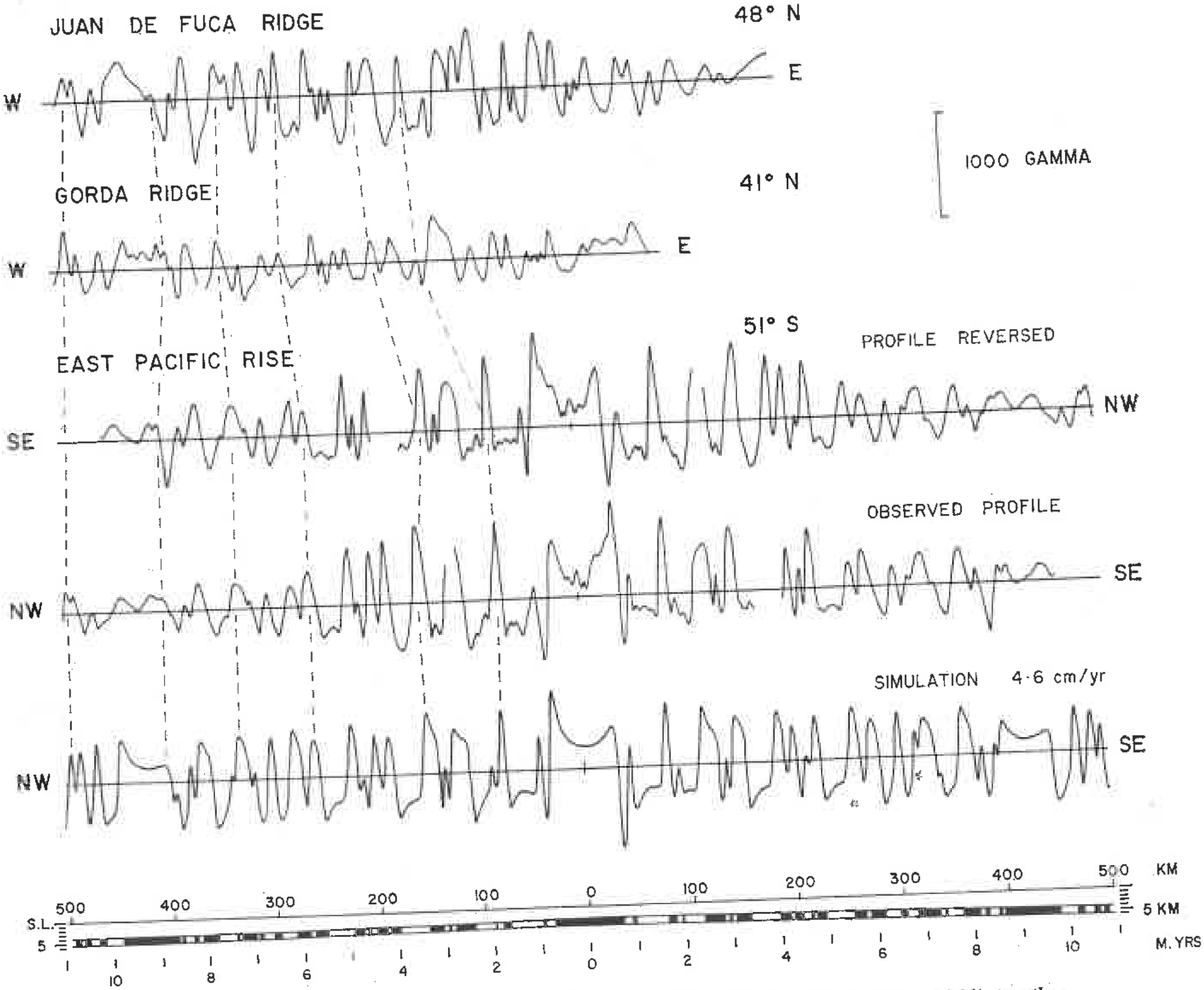
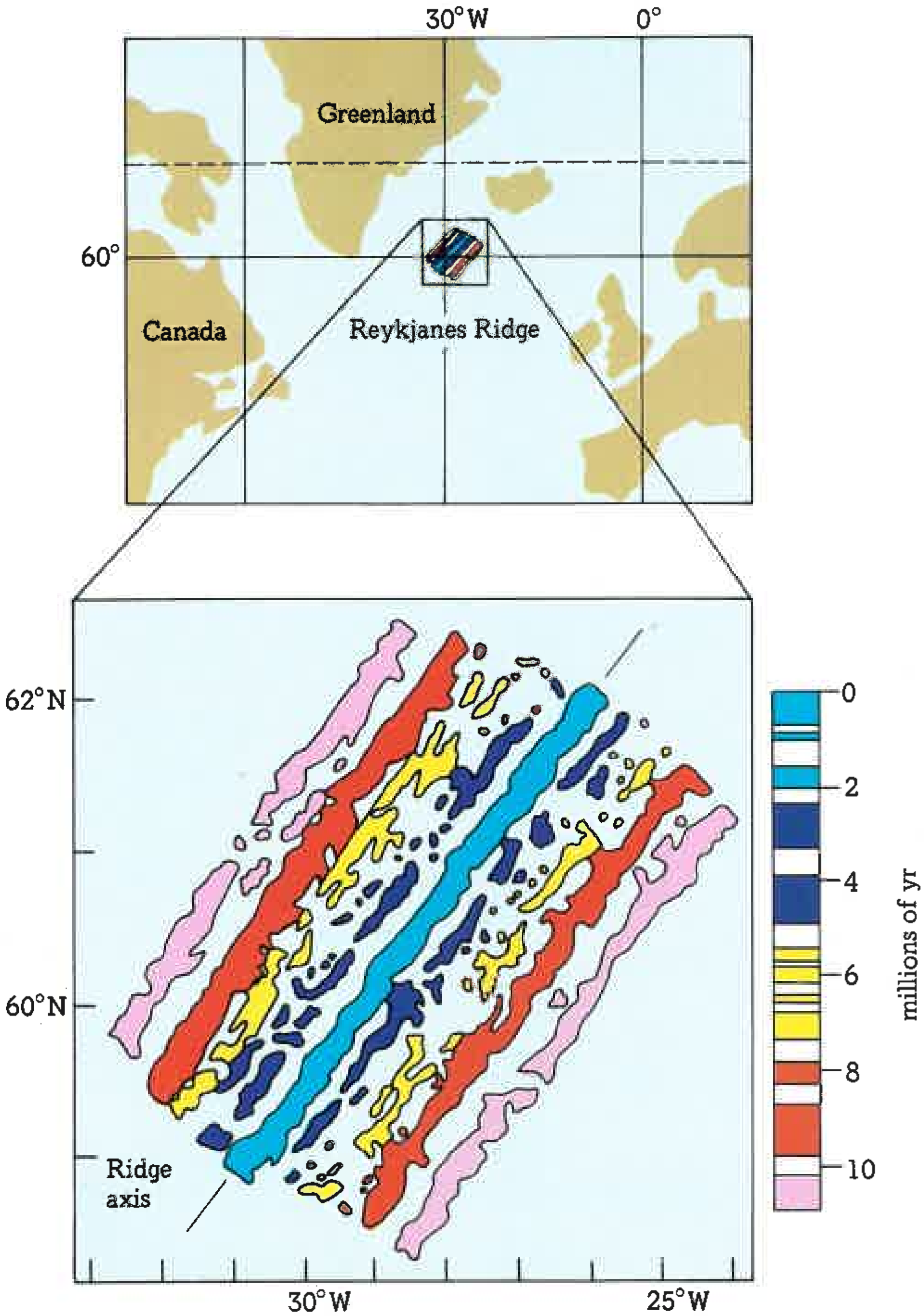


Figure 3. The *Eltanin* 19 profile across the East Pacific Rise (Pitman and Heirtzler, 1966) together with the profile reversed about its midpoint to demonstrate its symmetry, and a computed profile assuming the reversal time scale for the past 11 m.yrs. listed in Table 1, a total field intensity and dip of 48,700 gamma and −62.6° respectively, and a magnetic bearing of 102° for the profile. The profile is also compared with a composite profile across and to the northwest of the Juan de Fuca Ridge, and a profile normal to the strike of the anomalies across and to the west of the Gorda Ridge (Raff and Mason, 1961; Vacquier et al., 1961).

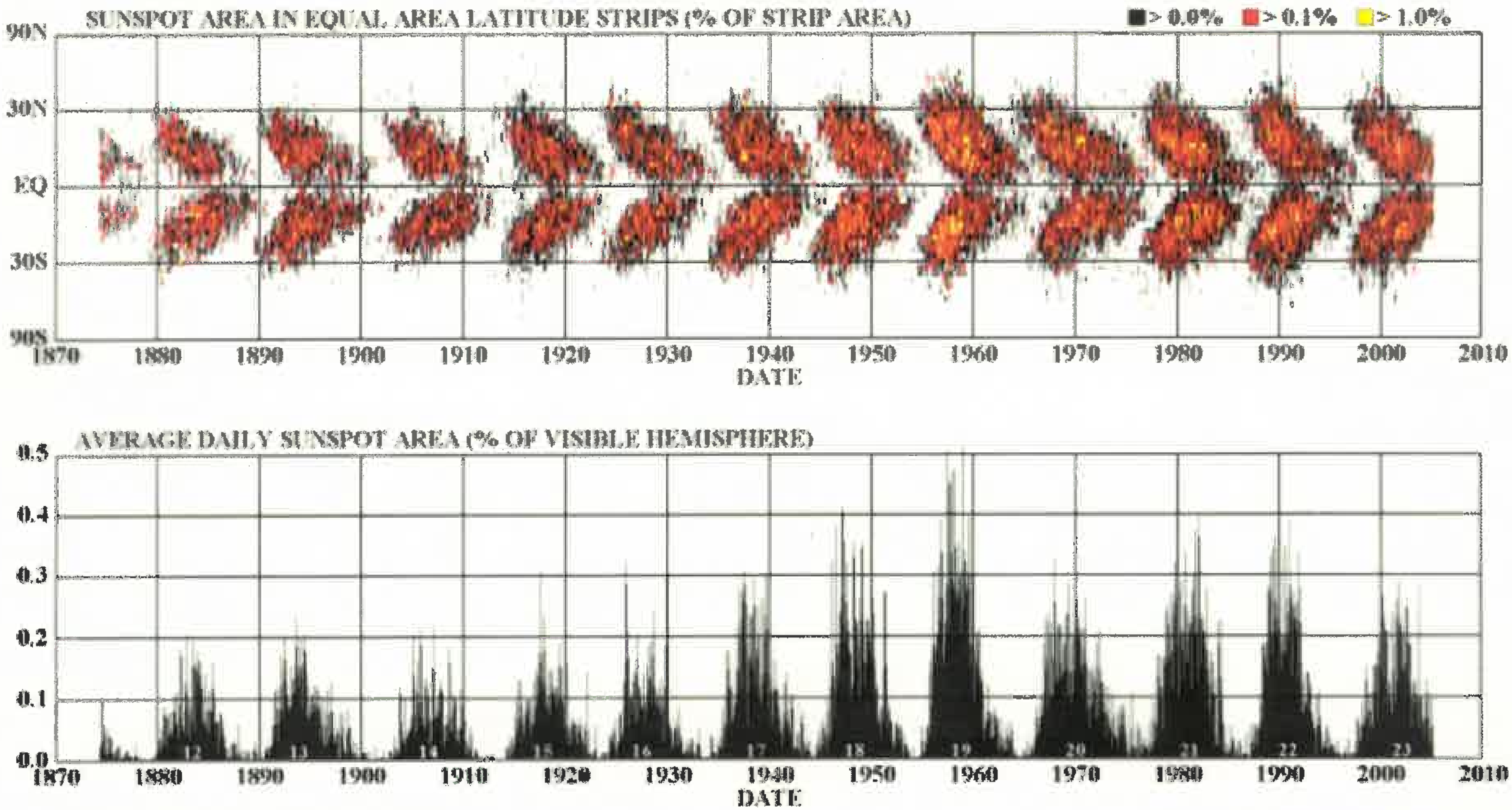
Juan de Fuca and Gorda ridges in the northeast Pacific correlate with those along the East Pacific Rise profile at 51°S and 11,000 km away. Such a direct comparison between these profiles is valid because their latitudes, orientations, and rates of spreading are such as to produce directly comparable anomalies from the same reversal time scale. This correlation suggests that one might assign dates to the summary of anomalies in the Juan de Fuca area given by Raff and Mason (1961), implying in turn an age for the underlying ocean crust (Fig. 4).

MAGNETIC ANOMALIES - REYKJANES RIDGE (Fig. 11.5, p. 207)



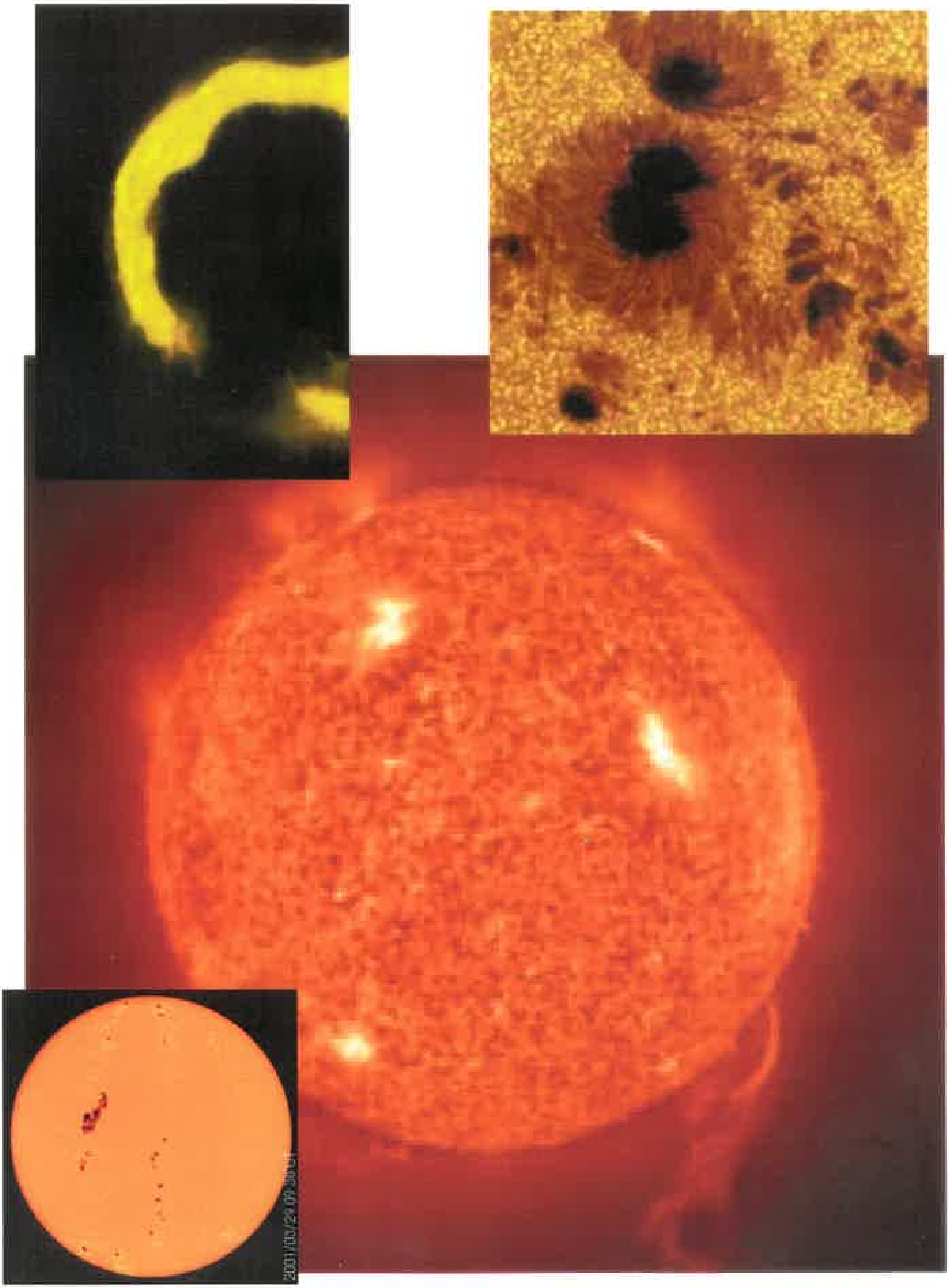
PHYSICAL GEOLOGY, 7th ed.
by Judson, Kauffman, and Leet

DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS



http://science.msfc.nasa.gov/ssl/pad/solar/images/bfly.gif

NASA/NSSTC/HATHAWAY 2005/03


2001/03/29