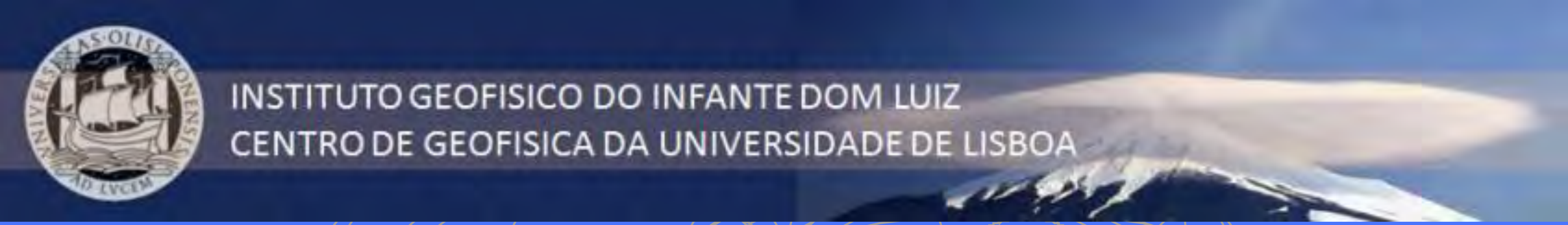
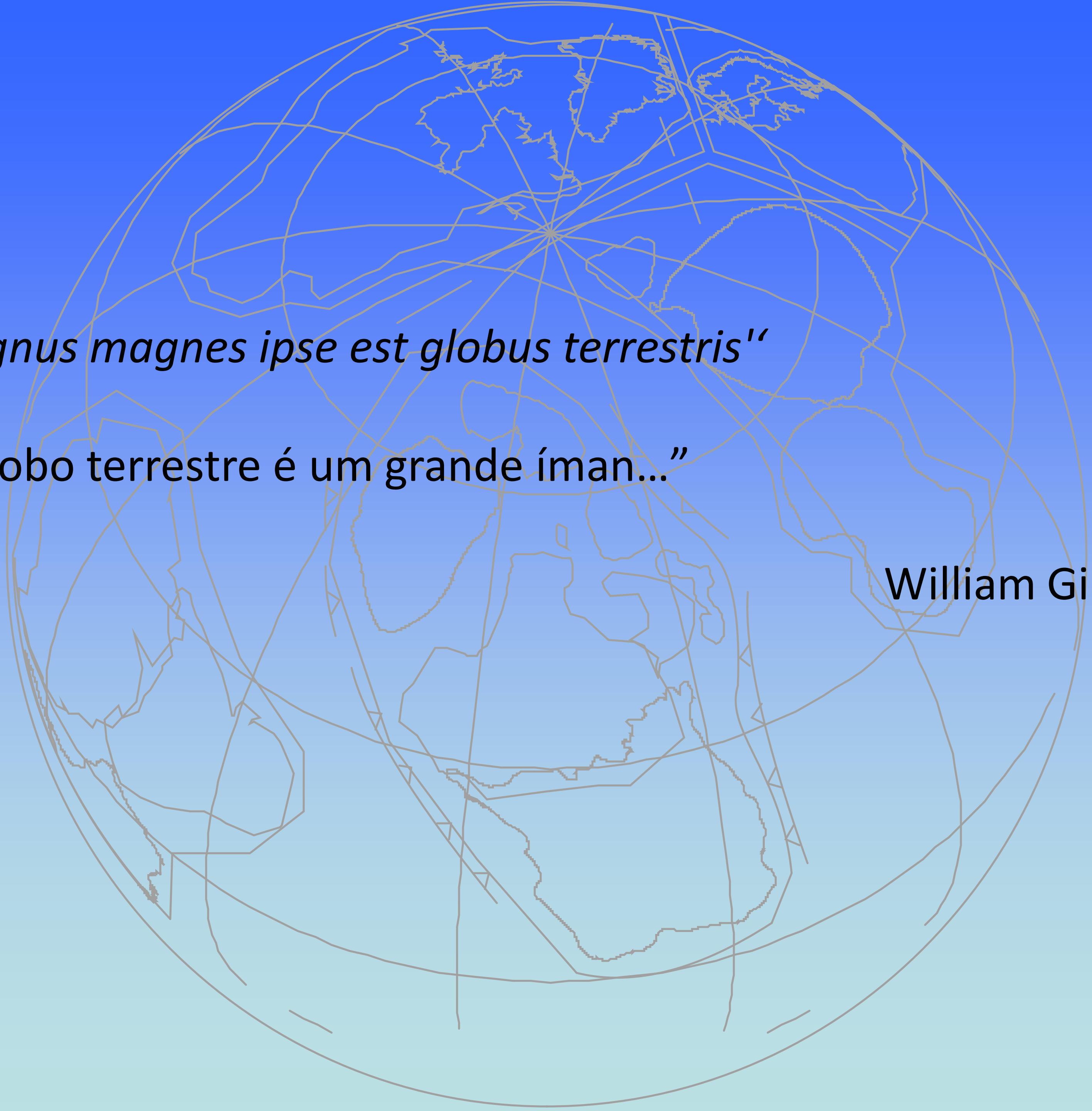


Cap. I:

O CAMPO MAGNÉTICO DA TERRA

Dr. Eric FONT

IDL-FCUL



"magnus magnes ipse est globus terrestris'‘

“O globo terrestre é um grande íman…”

William Gilbert.

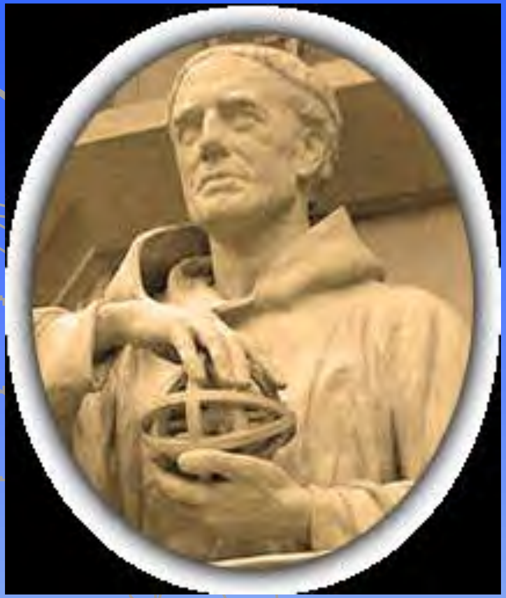
HISTÓRICO

Cidade de ***Magnésia*** pelos gregos.
Conhecimento das propriedades de **ATRAÇAO** da **magnetita** na China e Europa (Thales).

600 300 JC 300 600 900 1200 1500 1800 2100

HISTÓRICO

Bússola: colher de magnetite com prato de bronze



Thales…..

Os Chineses inventam a primeira bússola magnética

Na Europa, em 1190, **Alexander Neckham**

"Epístola" de **Petrus Peregrinus** (Pierre de Maricourt) em 1269
(lei do dipolo, bússola…)

600 | 300 | JC | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100

HISTÓRICO

Bússola Portuguesa do Século XV para navegação.

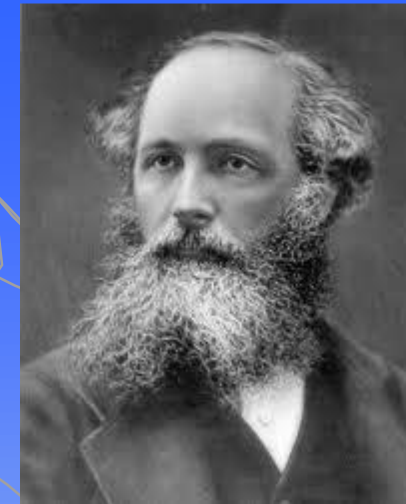
William Gilbert, autor da obra intitulada "**De Magnete**", publicada em 1600.

As grandes navegações, **Colombo** e seu diarío de bordo. **João de Castro**, em 1538, realizou viagem entre Lisboa e Goa par levantamento magnético

"De Magnete" de **Wílliam Gilbert**, publicado em 1600.

600 | 300 | JC | 300 | 600 | 900 | 1200 | 1500 | 1800 | 2100

HISTÓRICO



XIX, Maxwell define o CMT

1830-1845, C.F. **Gauss** e 1eiro programa de colaboração científica internacional, padronização de instrumentos, métodos de medida e rotina de observação, etc..

600 300 JC 300 600 900 1200 1500 1800 2100

HISTÓRICO

Em 1948, Edward **Irving** usa o magnetômetro de P. **Blackett** para analisar as direções magnéticas gravadas nas rochas e confirma a teoria da **Tectônica de Placa**.

Ultra-High Resolution Scanning Superconducting Quantum Interference Device Microscope (UHRSSM)

1940 1950 1960 1970 1980 1990 2000 2010

Noções básicas

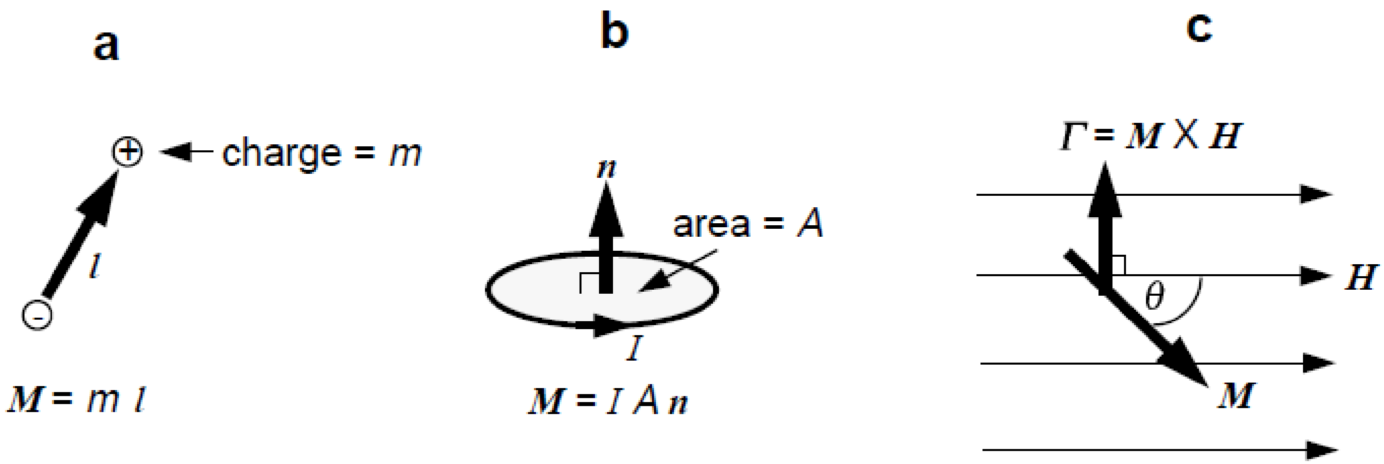


Figure 1.1 (**a**) A magnetic dipole constructed from a pair of magnetic charges. The magnetic charge of the plus charge is *m*; the magnetic charge of the minus charge is –*m*; the distance vector from the minus charge to the plus charge is ***l***. (**b**) A magnetic dipole constructed from a circular loop of electrical current. The electrical current in the circular loop is *I*; the area of the loop is *A*; the unit normal vector ***n*** is perpendicular to the plane of the loop. (**c**) Diagram illustrating the torque ***Γ*** on magnetic moment ***M***, which is placed within magnetic field ***H***. The angle between ***M*** and ***H*** is θ; ***Γ*** is perpendicular to the plane containing ***M*** and ***H***.

Noções básicas

The magnetic intensity, or *magnetization*, $\mathbf{J}$, of a material is the net magnetic dipole moment per unit volume. To compute the magnetization of a particular volume, the vector sum of magnetic moments is divided by the volume enclosing those magnetic moments:

$$J = \frac{\sum_i M_i}{\text{volume}} \quad (1.5)$$

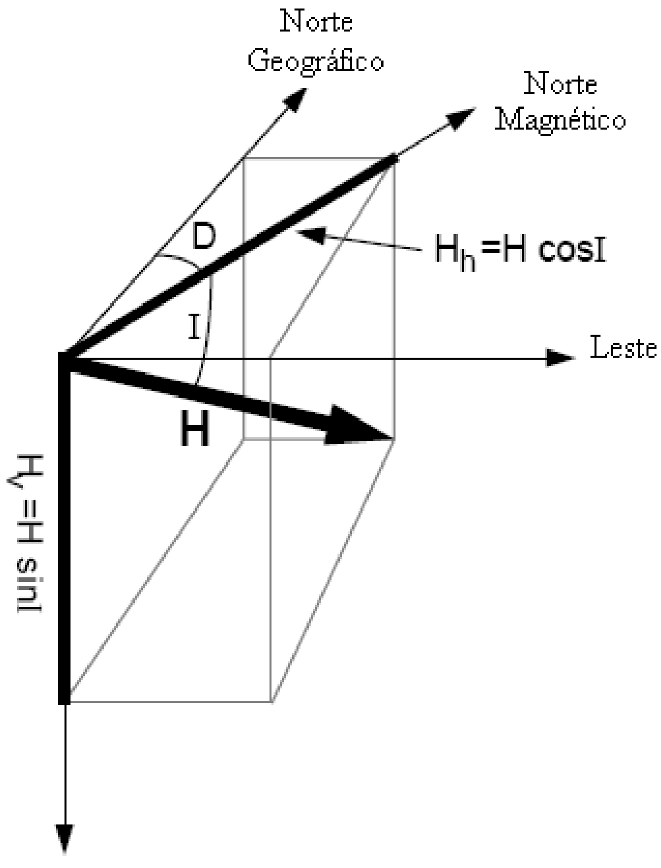
where $\mathbf{M}_i$ is the constituent magnetic moment.

There are basically two types of magnetization: induced magnetization and remanent magnetization. When a material is exposed to a magnetic field $\mathbf{H}$, it acquires an *induced magnetization*, $\mathbf{J}_i$. These quantities are related through the magnetic susceptibility, χ:

$$\mathbf{J}_i = \chi \, \mathbf{H} \quad (1.6)$$

Thus, *magnetic susceptibility*, χ, can be regarded as the *magnetizability* of a substance. The above expres-

Noções básicas



$$H_v = H \sin I$$

$$H_h = H \cos I$$

$$H_N = H \cos I \cos D$$

$$H_E = H \cos I \sin D$$

$$H = \sqrt{H_N^2 + H_E^2 + H_V^2}$$

Geocentric Axial Dipole (GAD)

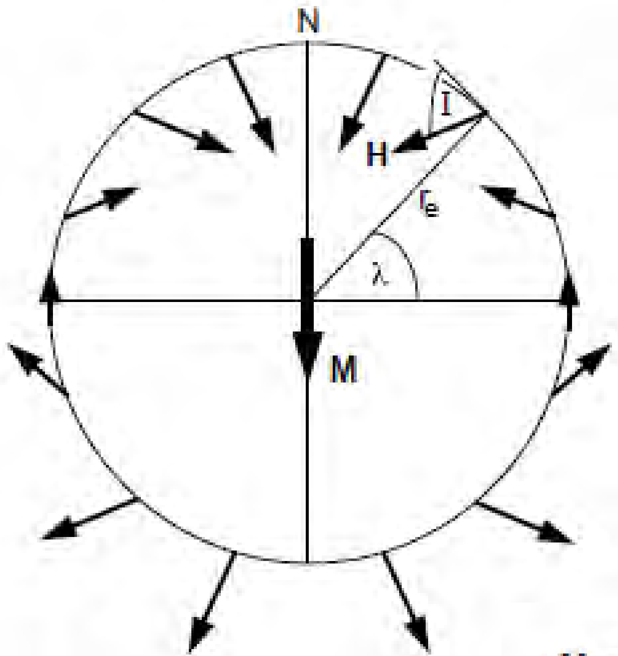


Figure 1.3 Geocentric axial dipole model. Magnetic dipole ***M*** is placed at the center of the Earth and aligned with the rotation axis; the geographic latitude is λ; the mean Earth radius is r_e; the magnetic field directions at the Earth's surface produced by the geocentric axial dipole are schematically shown; inclination, *I*, is shown for one location; N is the north geographic pole. Redrawn after McElhinny (1973).

$$H_h = \frac{M\cos\lambda}{r_e^3}$$

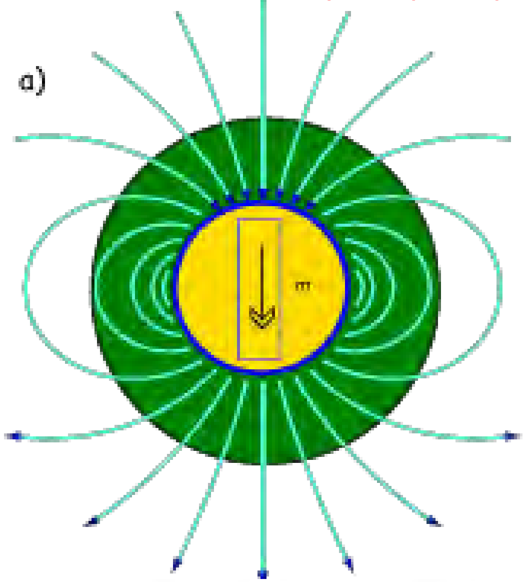
$$H_v = \frac{2M\sin\lambda}{r_e^3}$$

$$H = \frac{M}{r_e^3}\sqrt{1+3\sin^2\lambda}$$

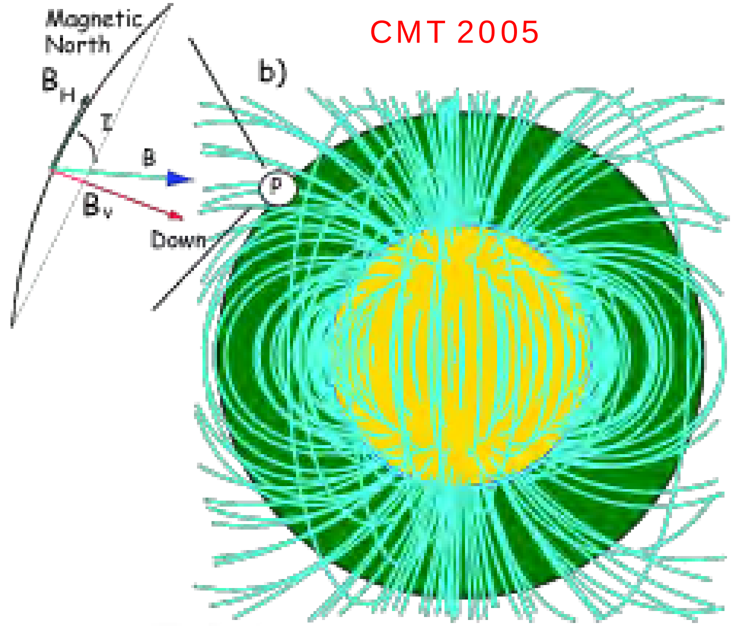
$$\tan I = \left(\frac{H_v}{H_h}\right) = \left(\frac{2\sin\lambda}{\cos\lambda}\right) = 2\tan\lambda$$

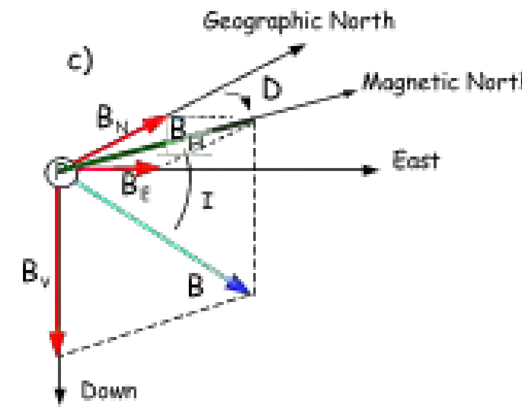
Campo Magnético Terrestre Actual

Geocentric Axial Dipole (GAD)



CMT 2005





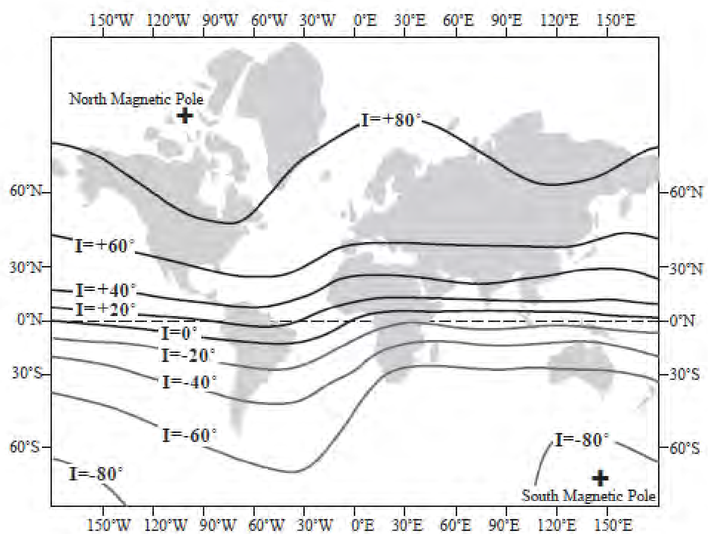


Figure 1.4 Isoclinic chart of the Earth's magnetic field for 1945. Contours are lines of equal inclination of the geomagnetic field; the locations of the magnetic poles are indicated by plus signs; Mercator map projection. Redrawn after McElhinny (1973).

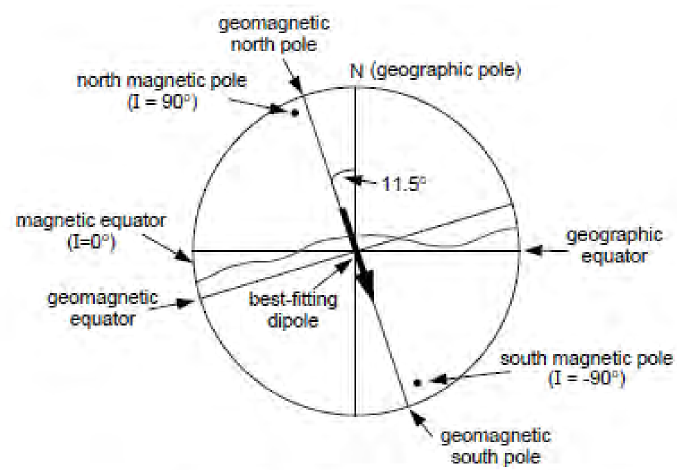


Figure 1.5 Inclined geocentric dipole model. The best-fitting inclined geocentric dipole is shown in meridional cross section through the Earth in the plane of the geocentric dipole; distinctions between magnetic poles and geomagnetic poles are illustrated; a schematic comparison of geomagnetic equator and magnetic equator is also shown. Redrawn after McElhinny (1973).

Componente não dipolar

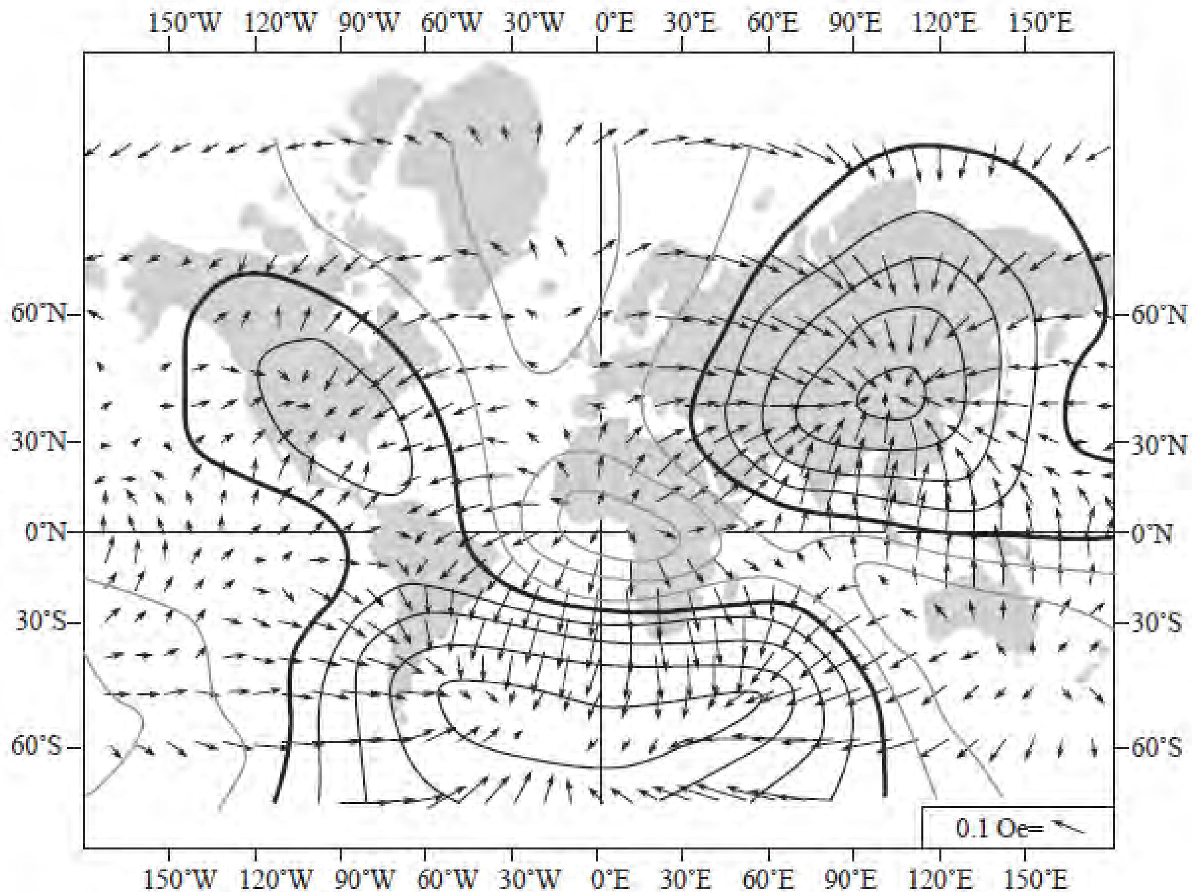


Figure 1.6 The nondipole geomagnetic field for 1945. Arrows indicate the magnitude and direction of the horizontal component on the nondipole field; the scale for the arrows is shown at the lower right corner of the diagram; contours indicate lines of equal vertical intensity of the nondipole field; heavy black lines are contours of zero vertical component; thin black lines are contours of positive (downward) vertical component, while gray lines are contours of negative vertical component; the contour interval is 0.02 Oe. Notice the clown-face appearance with the nondipole magnetic field going into the eyes and mouth and being blown out the nose. Redrawn from Bullard et al. (*Phil. Trans. Roy. Soc. London*, v. A243, 67–92, 1950).

Variação secular

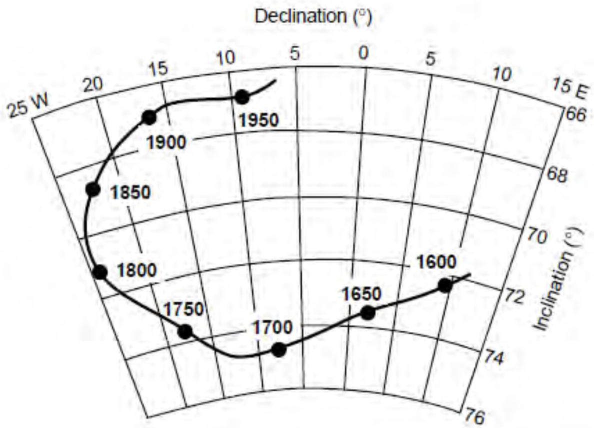


Figure 1.7 Historic record of geomagnetic field direction at Greenwich, England. Declination and inclination are shown; data points are labeled in years A.D.; azimuthal equidistant projection Redrawn after Malin and Bullard (*Phil. Trans. Roy. Soc. London*, v. A299, 357–423, 1981.)

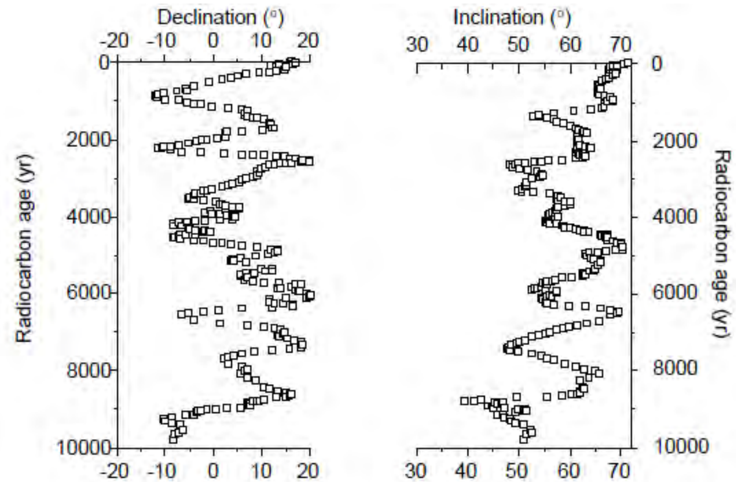


Figure 1.8 Record of Holocene geomagnetic secular variation recorded by sediments in Fish Lake in southeastern Oregon. Declination and inclination are shown against radiocarbon age. Data kindly provided by K. Verosub.

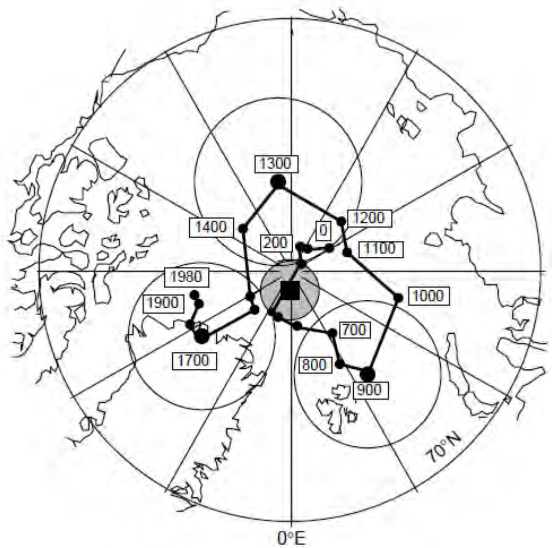
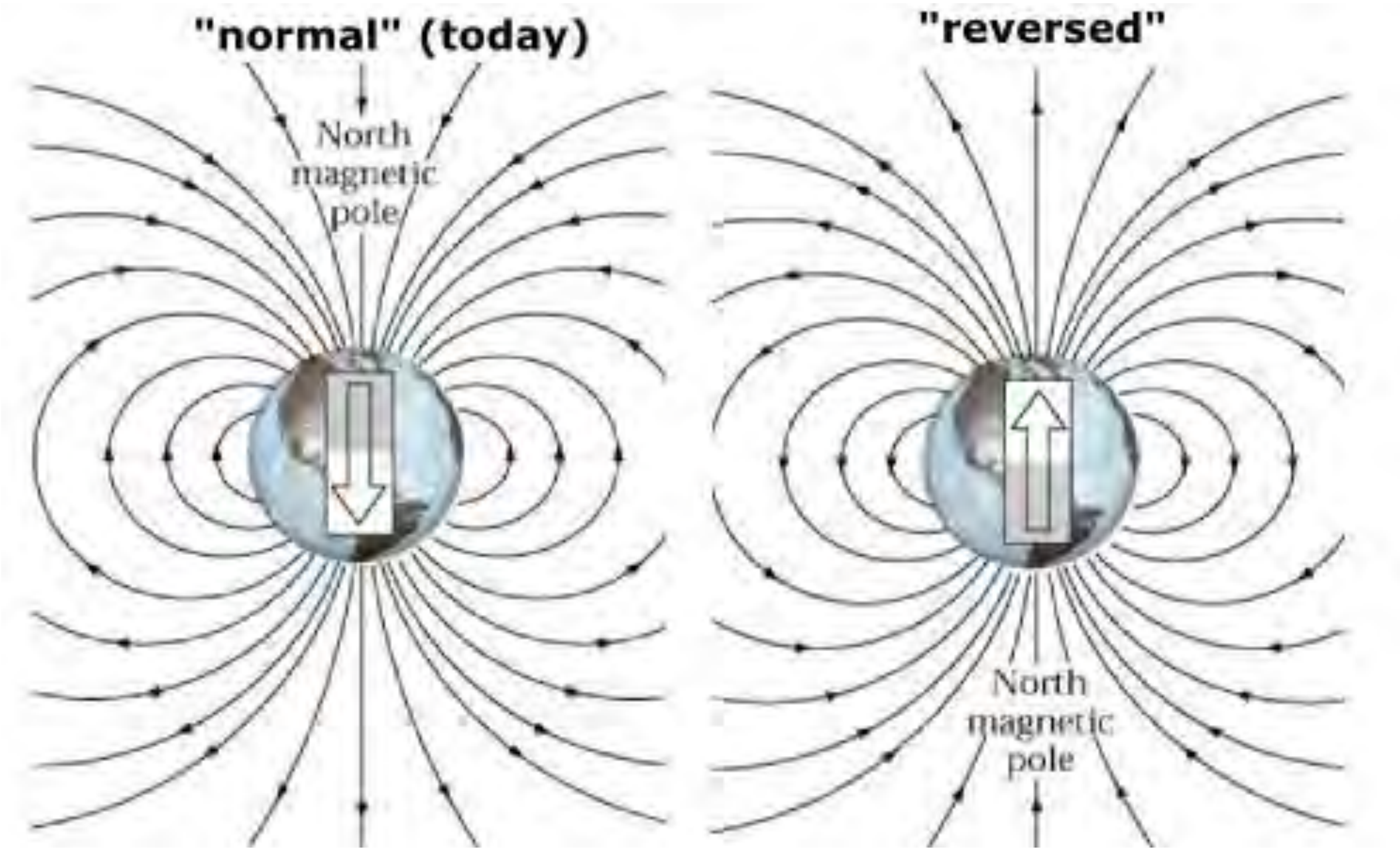
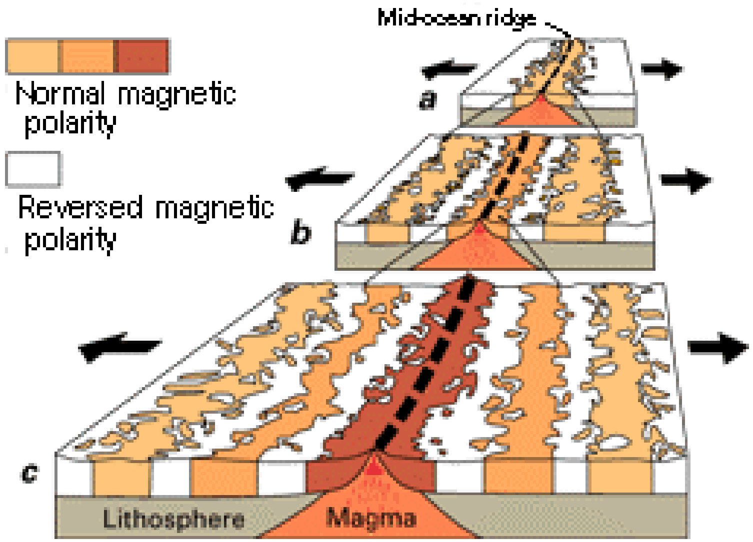


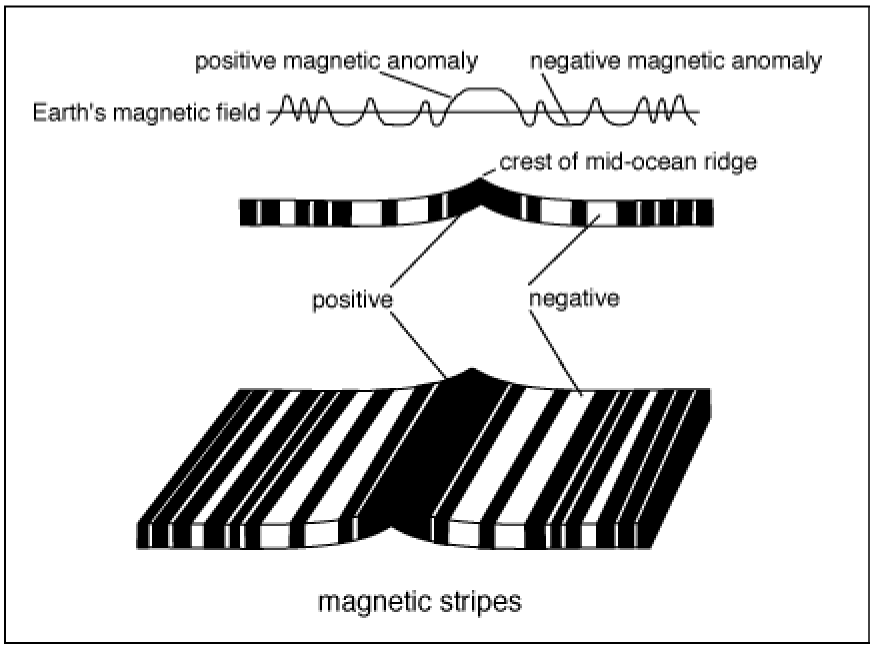
Figure 1.9 Positions of the north geomagnetic pole over the past 2000 yr. Each data point is the mean geomagnetic pole at 100-yr intervals; numbers indicate date in years A.D.; circles about geomagnetic poles at 900, 1300, and 1700 A.D. are 95% confidence limits on those geomagnetic poles; the mean geomagnetic pole position over the past 2000 yr is shown by the square with stippled region of 95% confidence. Data compiled by Merrill and McElhinny (1983).

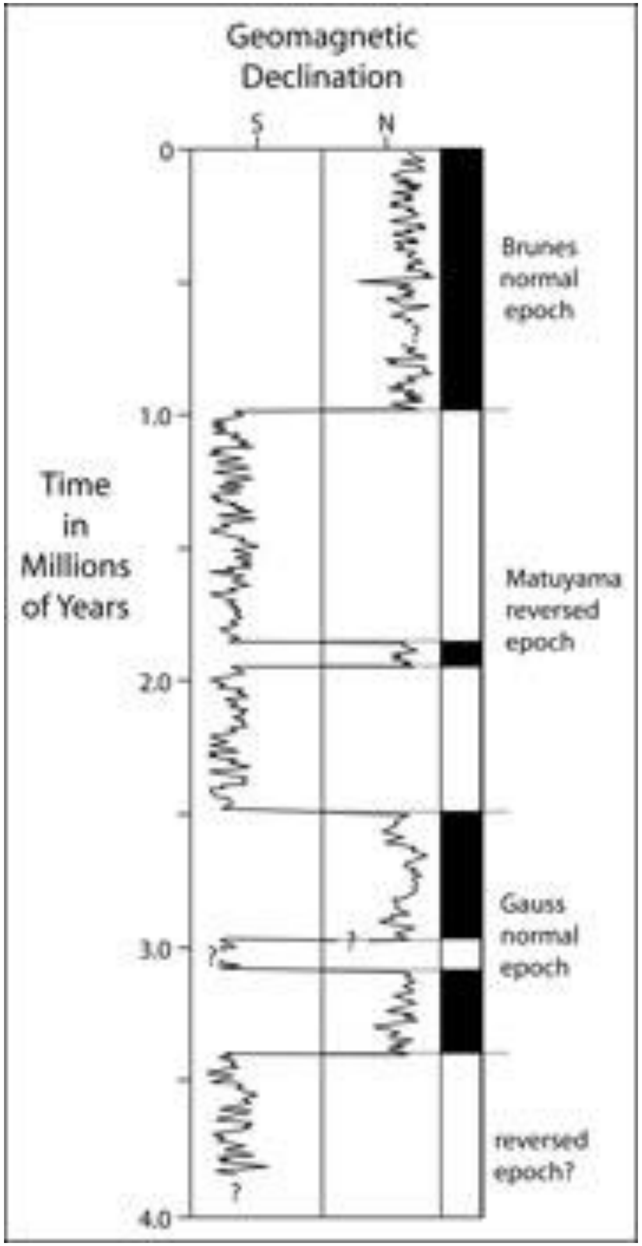
Geomagnetic reversals



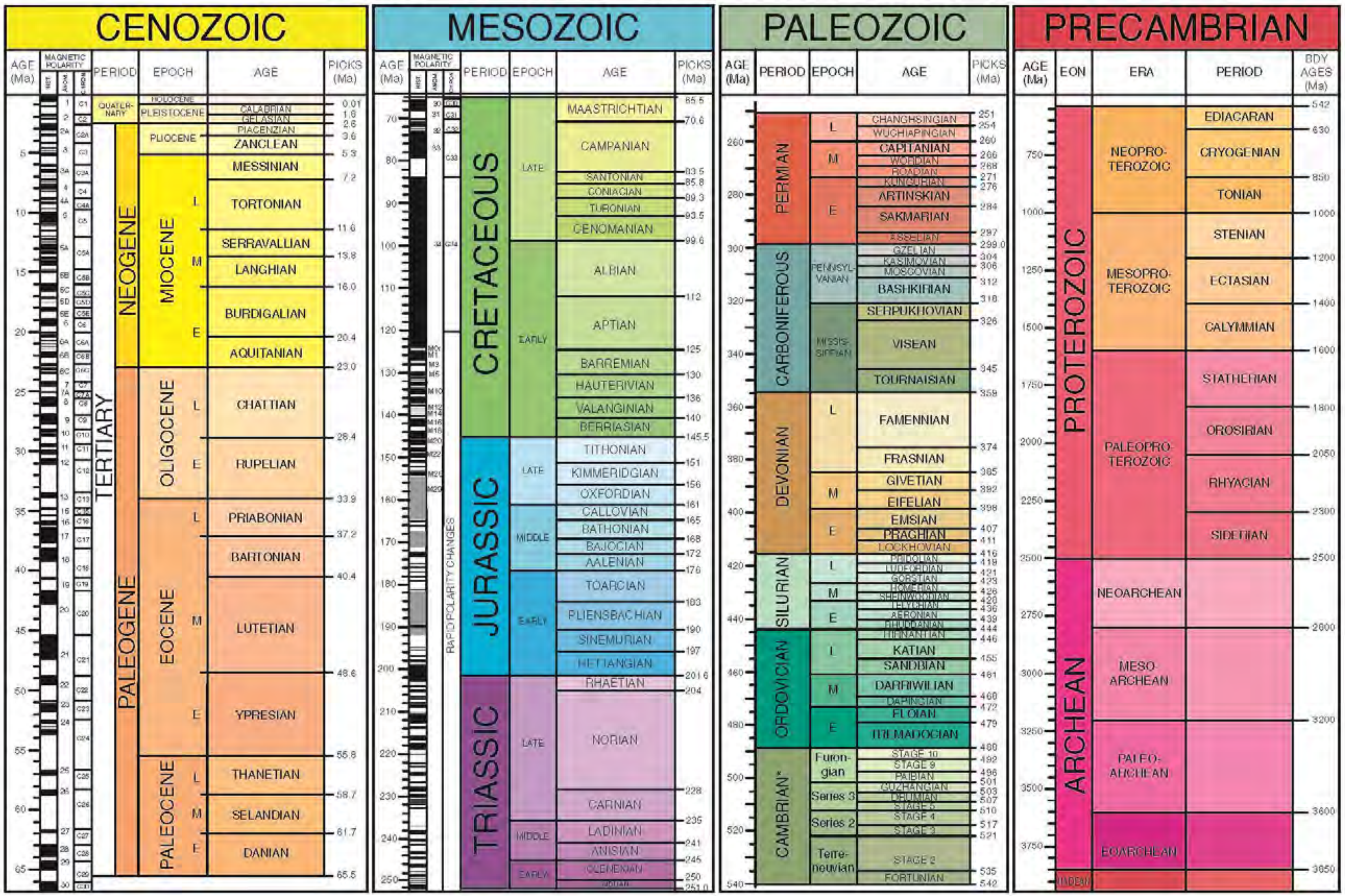
Geomagnetic reversals







2009 GEOLOGIC TIME SCALE



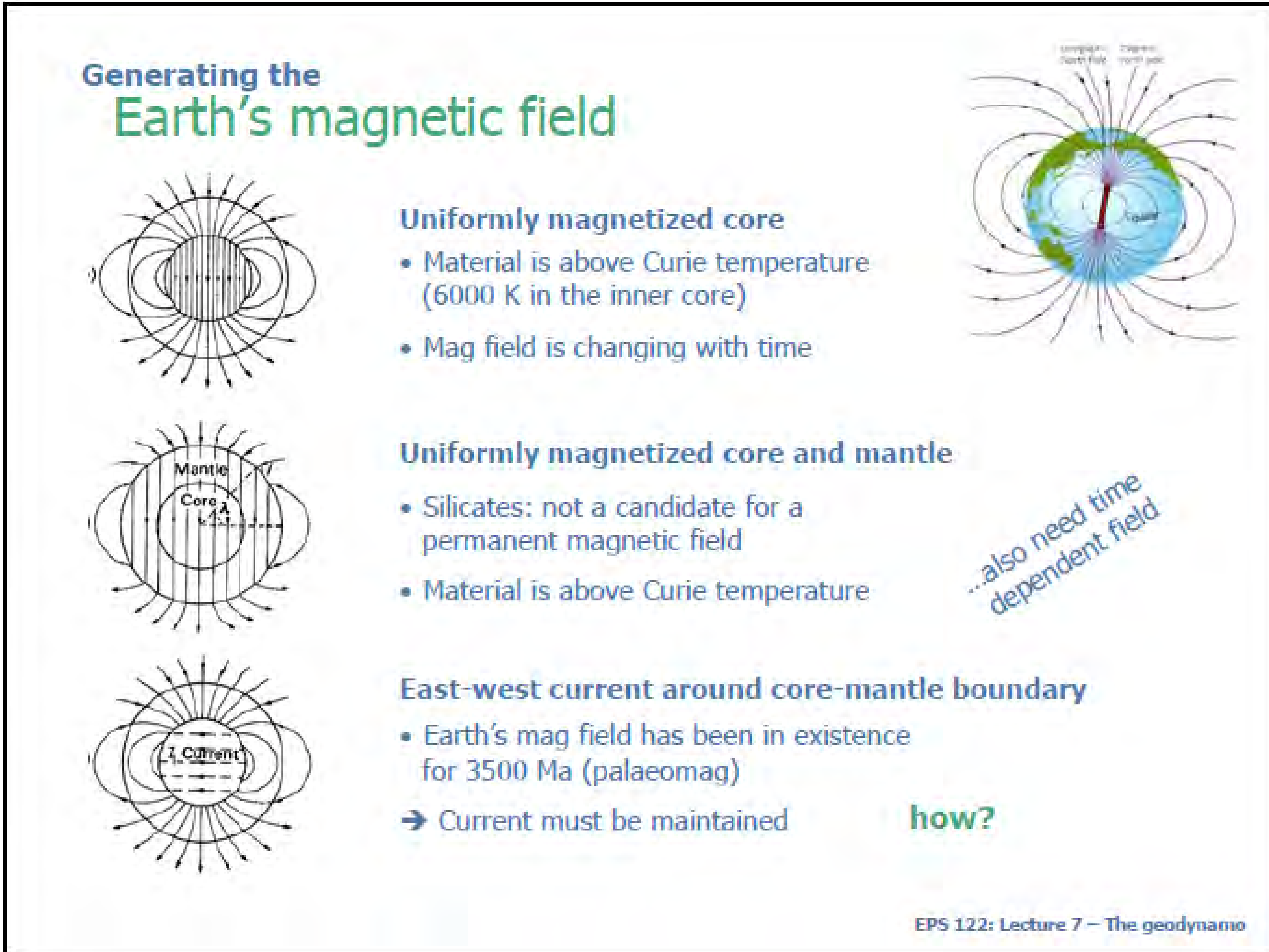
*International ages have not been fully established. These are current names as reported by the International Commission on Stratigraphy.

Walker, J.D., and Geissman, J.W., compilers, 2009, Geologic Time Scale: Geological Society of America, doi: 10.1130/2009.CTS004R2C. ©2009 The Geological Society of America.

THE GEOLOGICAL SOCIETY OF AMERICA®

Sources for nomenclature and ages are primarily from Gradstein, F., Ogg, J., Smith, A., et al., 2004, A Geologic Time Scale 2004: Cambridge University Press, 589 p. Modifications to the Triassic after: Furin, S., Preto, N., Rigo, M., Roghi, G., Gianolla, P., Crowley, J.L., and Bowring, S.A., 2006, High-precision U-Pb zircon age from the Triassic of Italy: Implications for the Triassic time scale and the Carnian origin of calcareous nannoplankton and dinosaurs: Geology, v. 34, p. 1009–1012, doi: 10.1130/G22967A.1; and Kent, D.V., and Olsen, P.E., 2008, Early Jurassic magnetostratigraphy and paleolatitudes from the Hartford continental rift basin (eastern North America): Testing for polarity bias and abrupt polar wander in association with the central Atlantic magmatic province: Journal of Geophysical Research, v. 113, B06105, doi: 10.1029/2007JB005407.

Origem do CMT

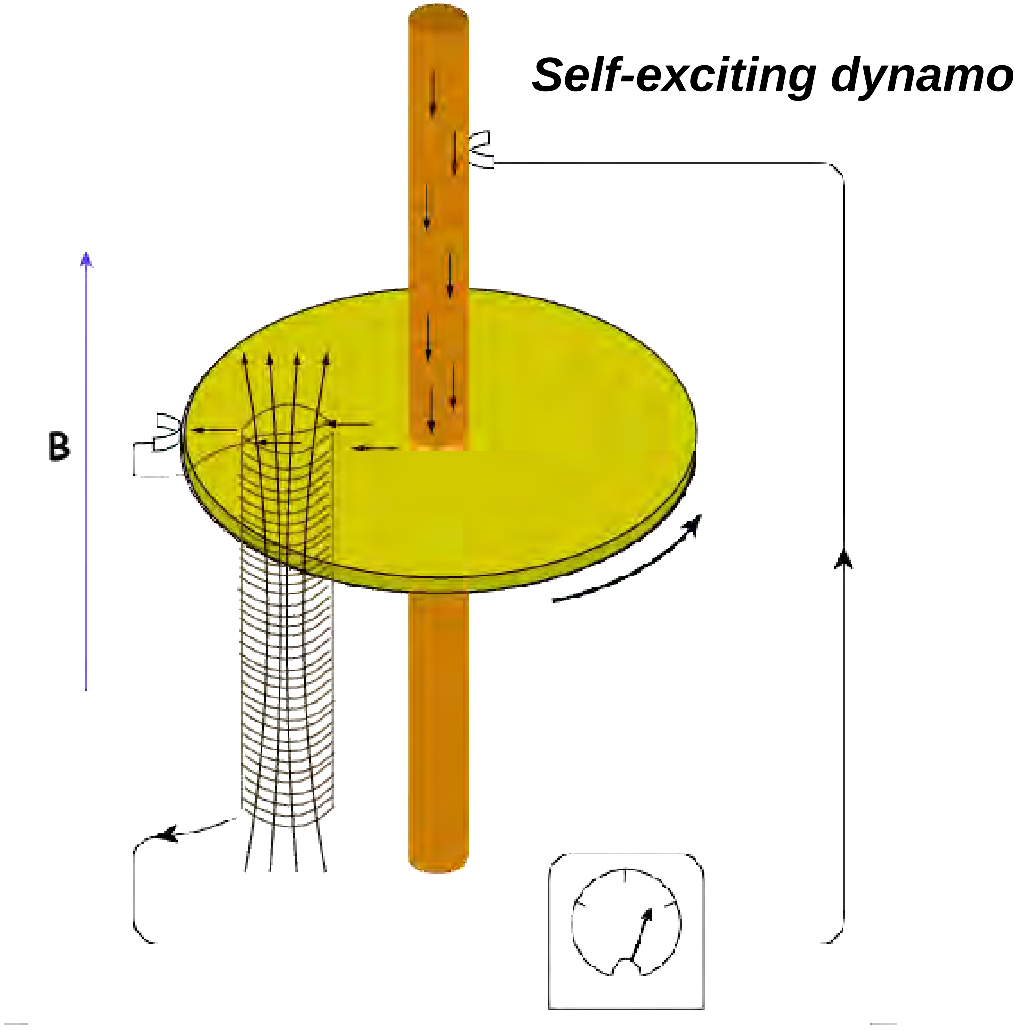


Origem do CMT

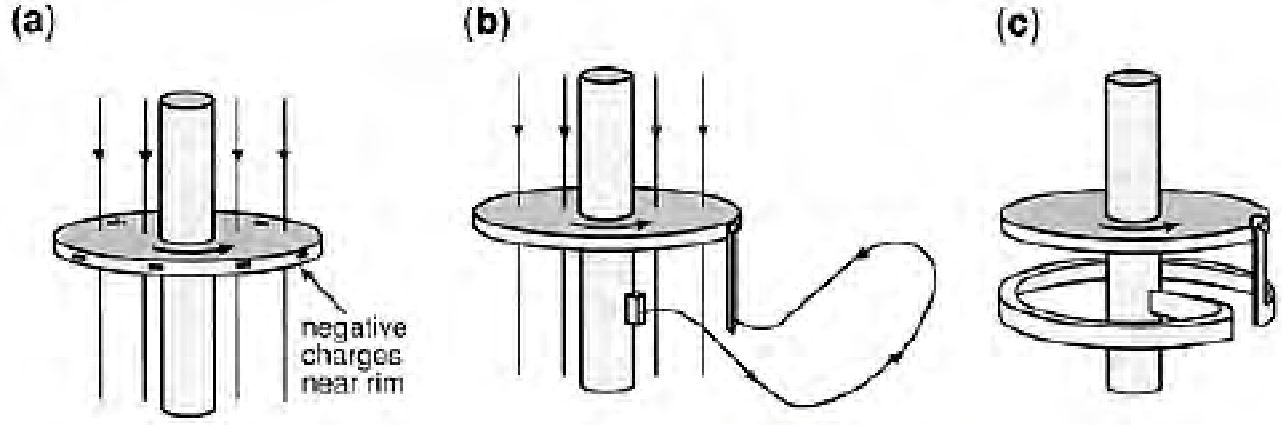
Força de Lorentz:

$$F_L = qv \times B,$$

q = carga eléctrica dos electrões
v = velocidade dos electrões



Self-exciting dynamo



Note: can reverse the current and field – magnetic reversal

But, the field cannot reverse itself

plus, seems unlikely that this process can operate in the conductive core without short-circuiting itself

Earth's magnetic field

What continues to generate the Earth's magnetic field?

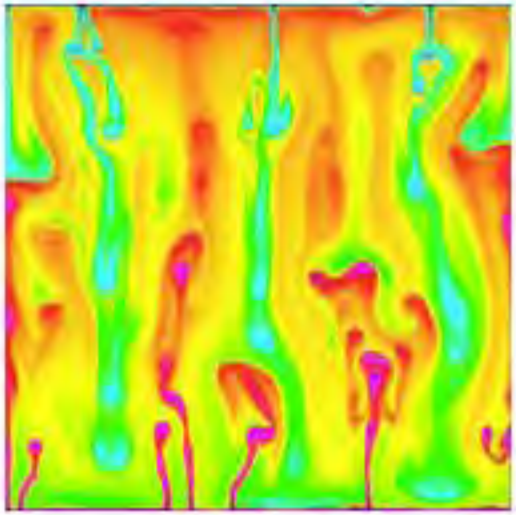
- Temperature of the Earth's core is too high for a permanent magnetic field
- Magnetic field reverses every ~200,000 years (5,000 to 50 mill)
- The magnetic field would decay away within 20,000 years given the size and electrical conductivity of the Earth's core

➔ the field must be continually generated

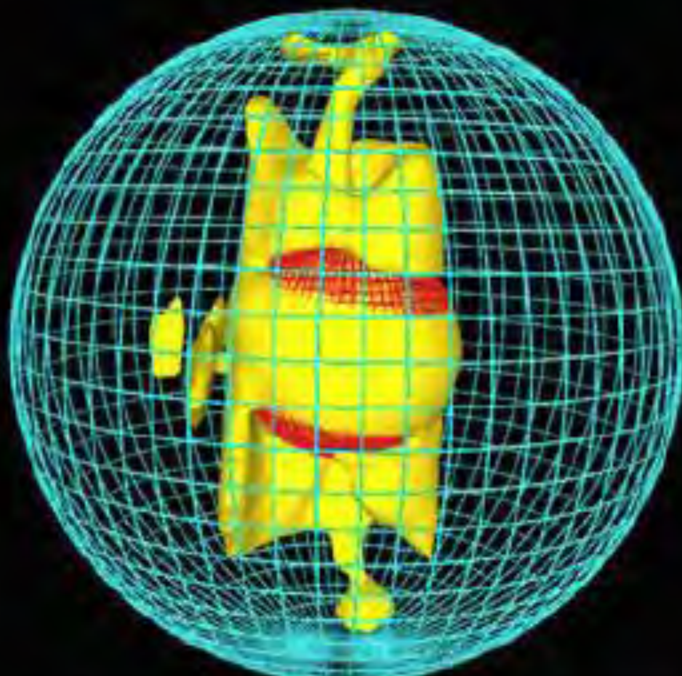
A convective dynamo operating in the Earth's fluid outer core?

➔ Magnetohydrodynamics

Coupling of fluid motion and generation of a magnetic field



A convective dynamo?



Red mesh: inner-outer core boundary
Blue mesh: core-mantle boundary
Yellow: region of greatest flow

Glatzmaier and Roberts 1995

Thermal and compositional buoyancy causes flow

Earth's rotation – the Coriolis force – results in helical flow within tangential cylinder

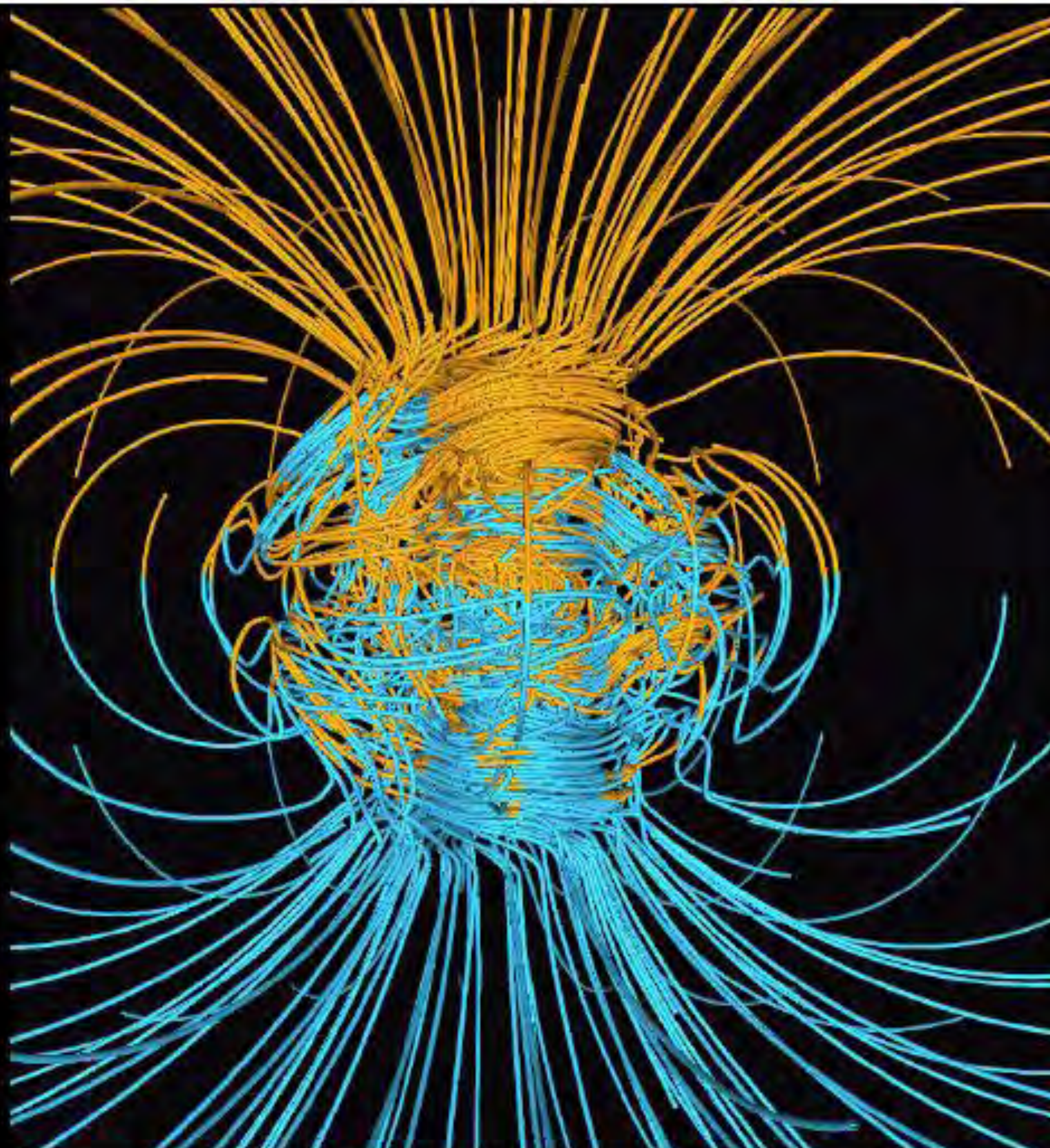
Glatzmaier and Roberts solved the magnetohydrodynamic equations to test this hypothesis

Inner core:
- size of the moon (r_{moon} = 1,738 km)
- temperature of the surface of the Sun (~6000°C)

Magnetic field generated by outer core flow

Simulated magnetic field has

- intensity and a dipole dominated structure that is very similar to the Earth's
- westward drift of non-dipolar structure

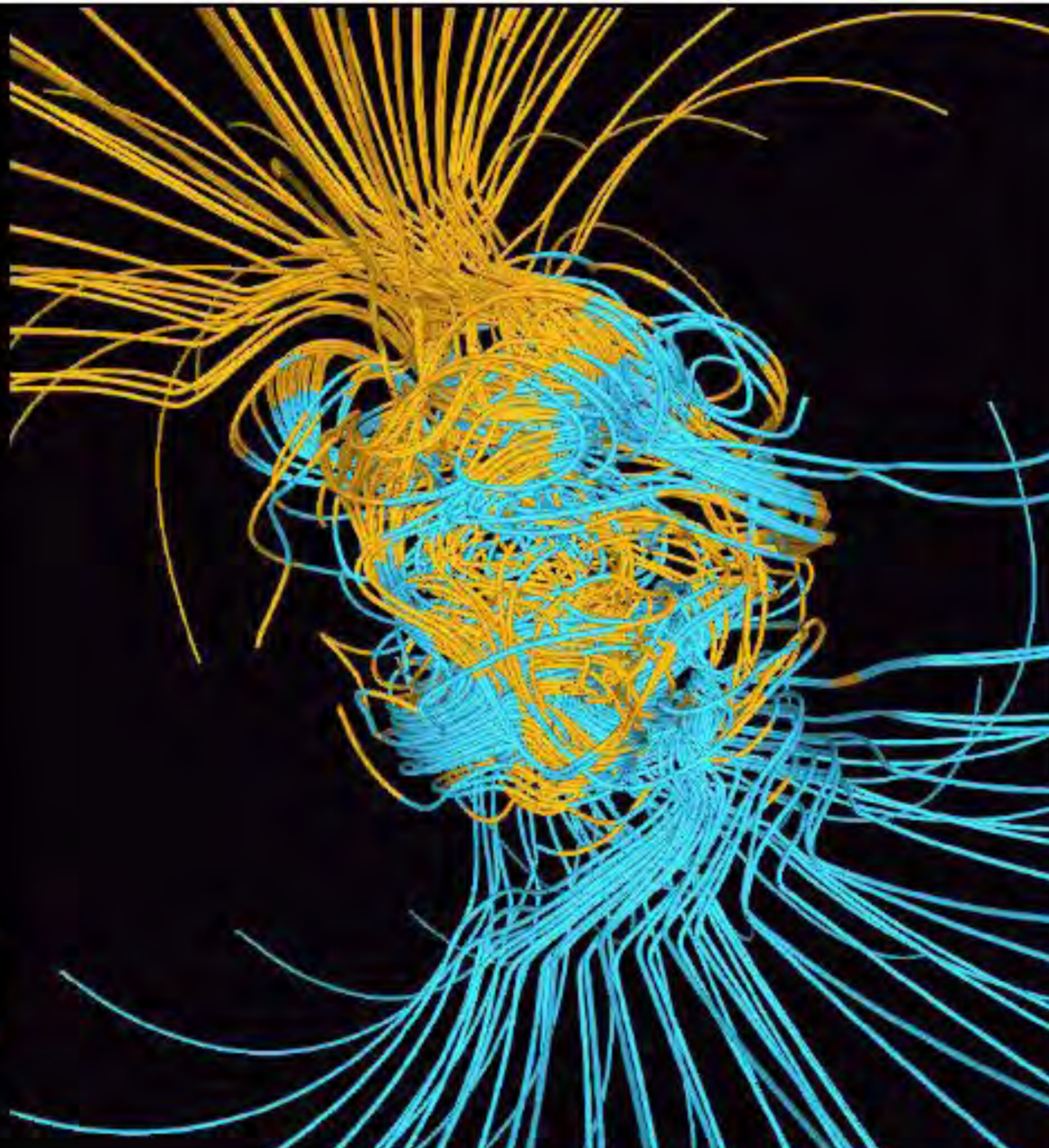


Blue: inward field

Orange: outward field

Glatzmaier and Roberts 1995

Magnetic field reversal

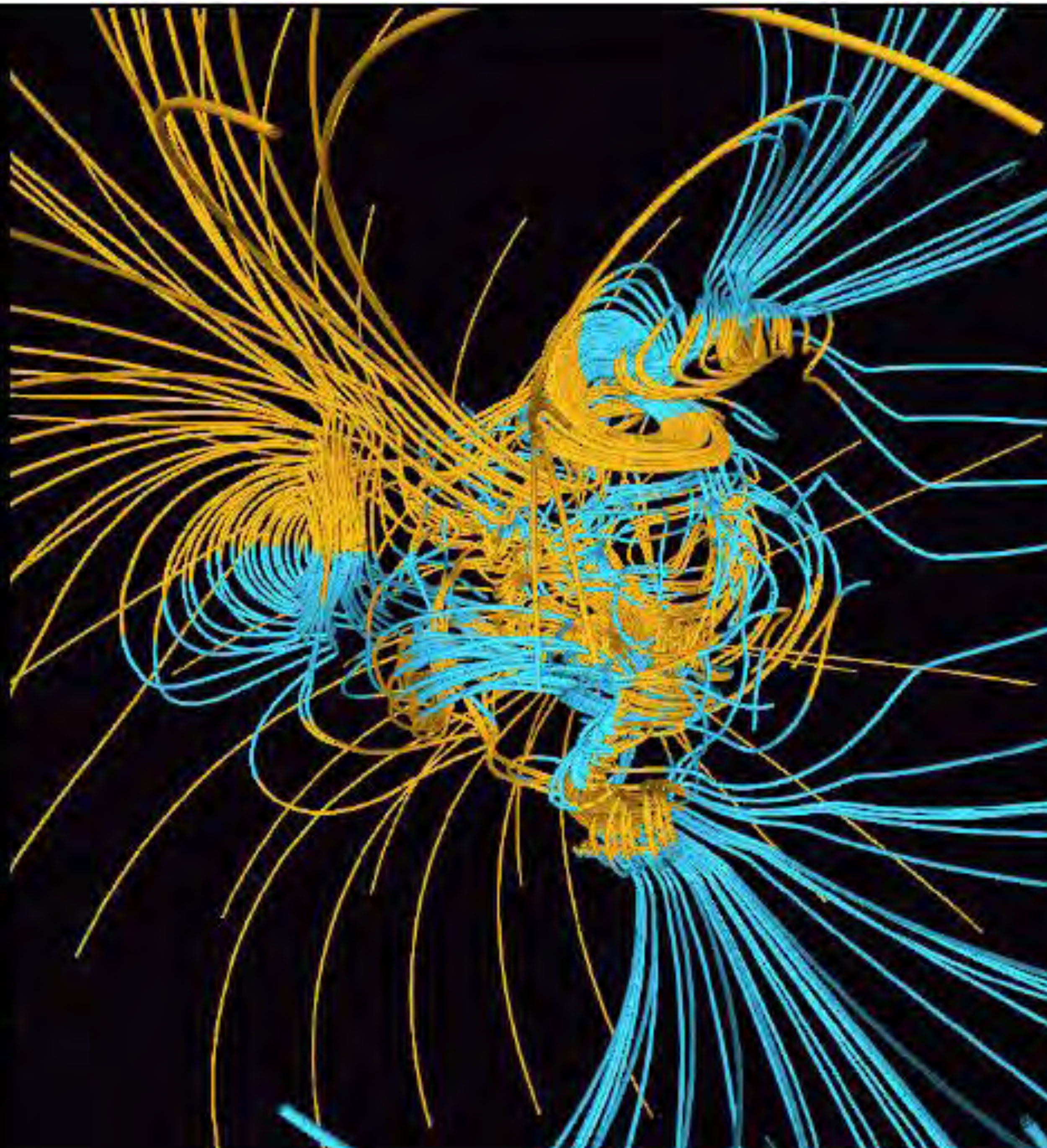


500 years before the middle of the reversal

Glatzmaier and Roberts 1995

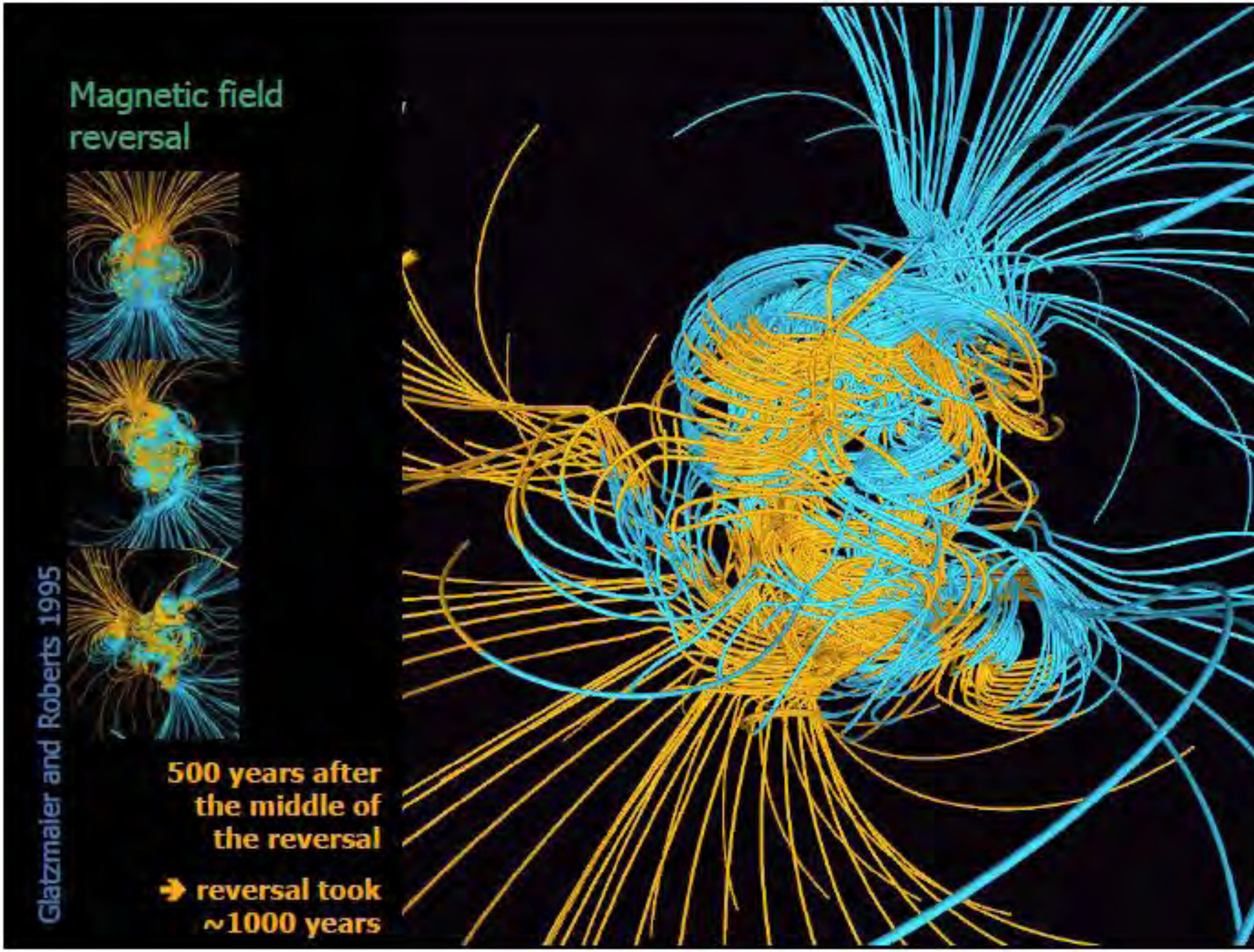
Magnetic field reversal

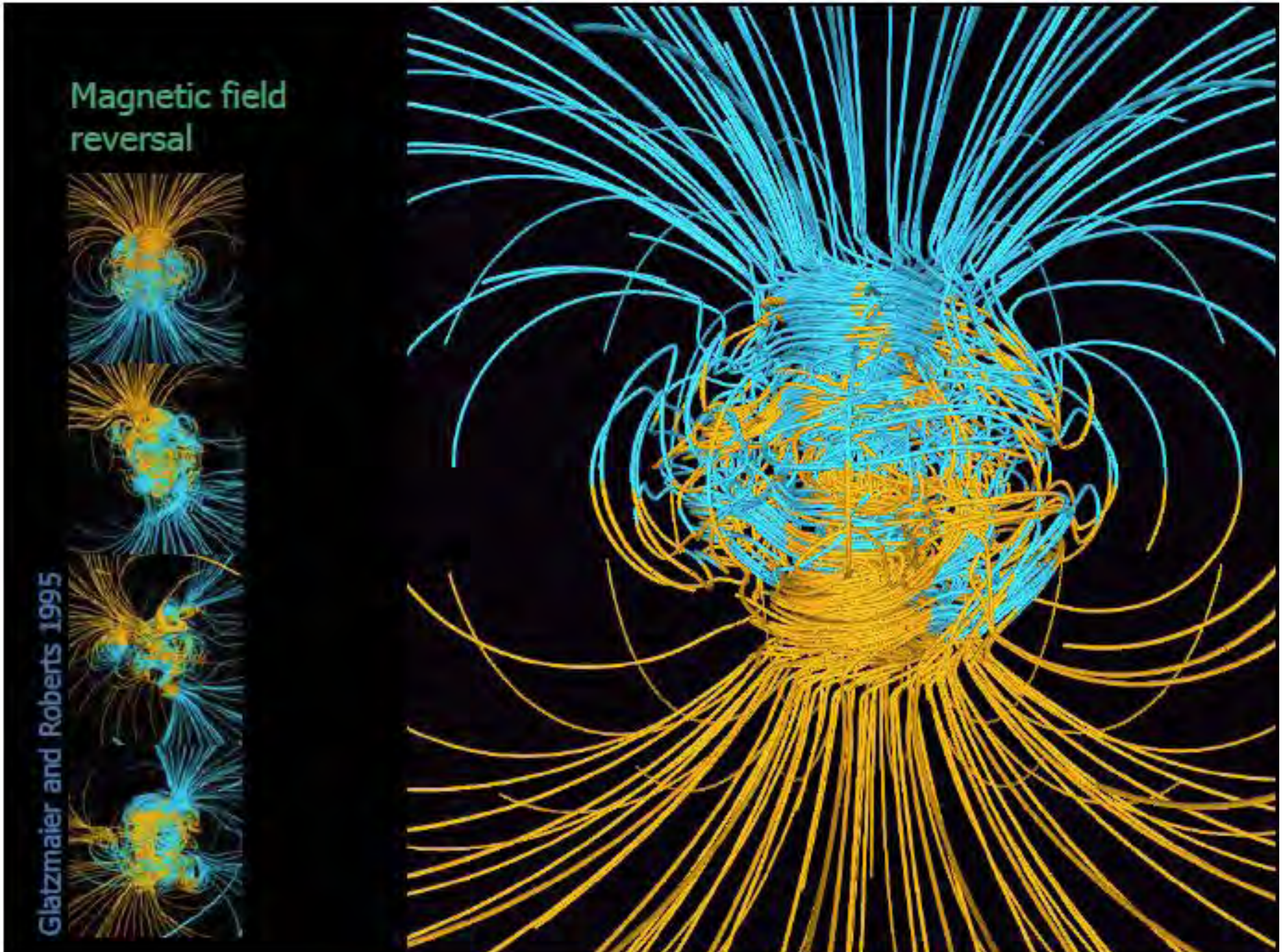
Glatzmaier and Roberts 1995



Middle of the reversal

Fewer field lines: weaker field


Magnetic field reversal
Glatzmaier and Roberts 1995
500 years after the middle of the reversal
➔ reversal took ~1000 years


Magnetic field reversal
Glatzmaier and Roberts 1995