MAHIDOL UNIVERSITY
Wisdom of the Land

[SCPY384]

Geophysical Prospecting

Class 4: 25 Feb 2019

Content: *Magnetic survey [1]*

Instructor: Puwis Amatyakul

Today's Goals

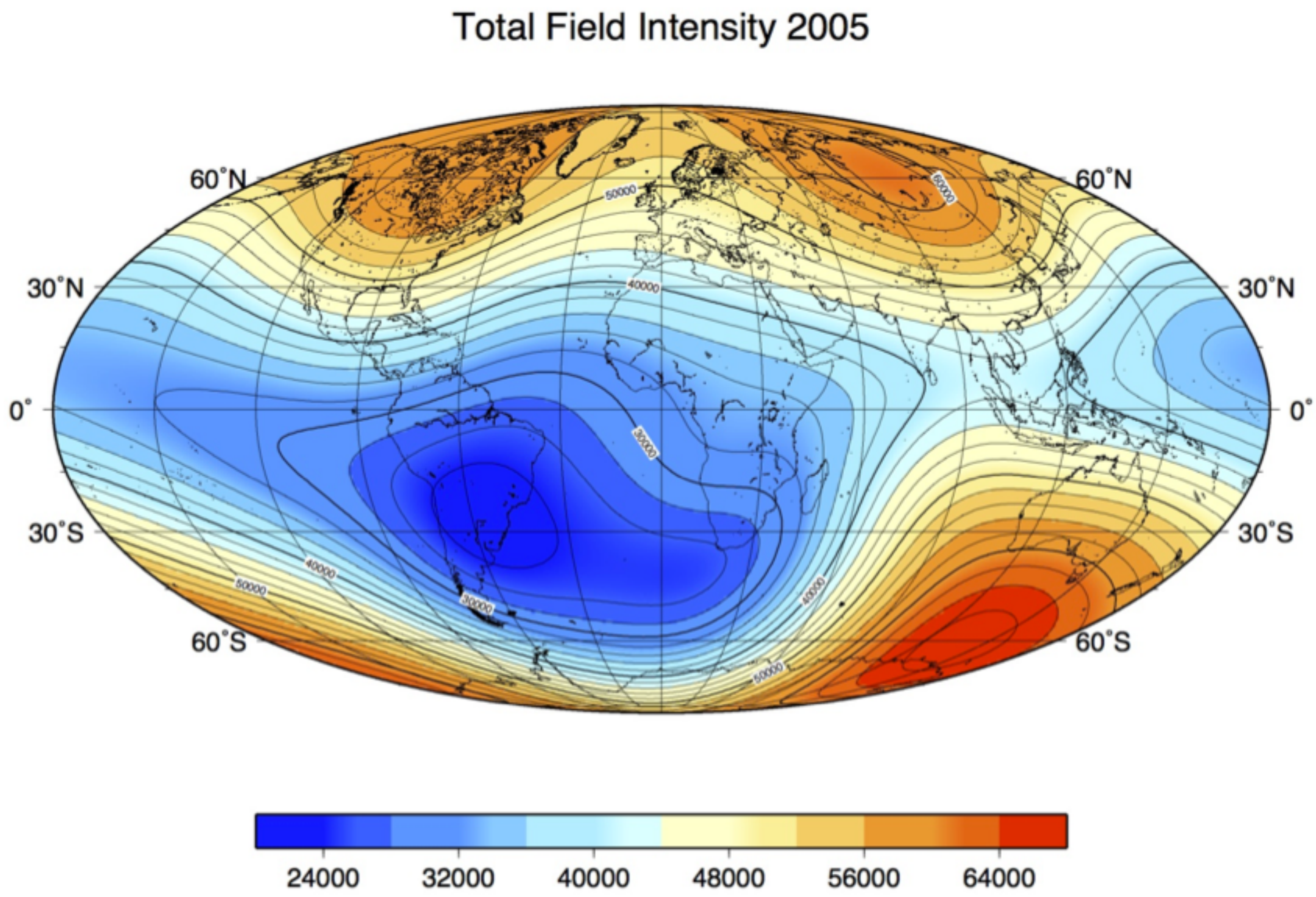
Part I: Geomagnetism
Part II: Earth magnetic field and magnetic anomaly

Geomagnetism

How well you know the compass?

Where is it pointing to?

Geomagnetism



NOAA NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Geomagnetism

Useful Video

Magnetism - Defending Our Planet, Defining The Cosmos

https://www.youtube.com/watch?v=DGzL3dodGC4

Geomagnetism

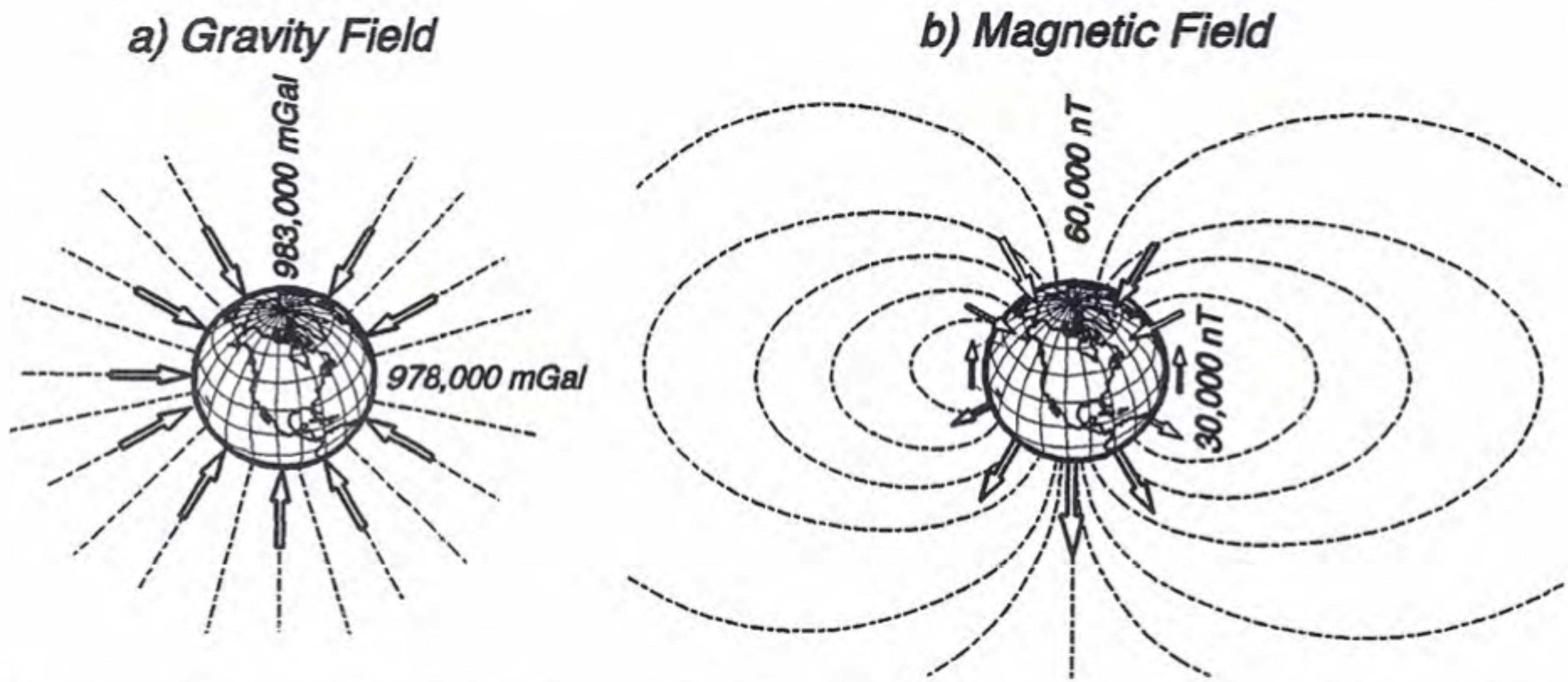
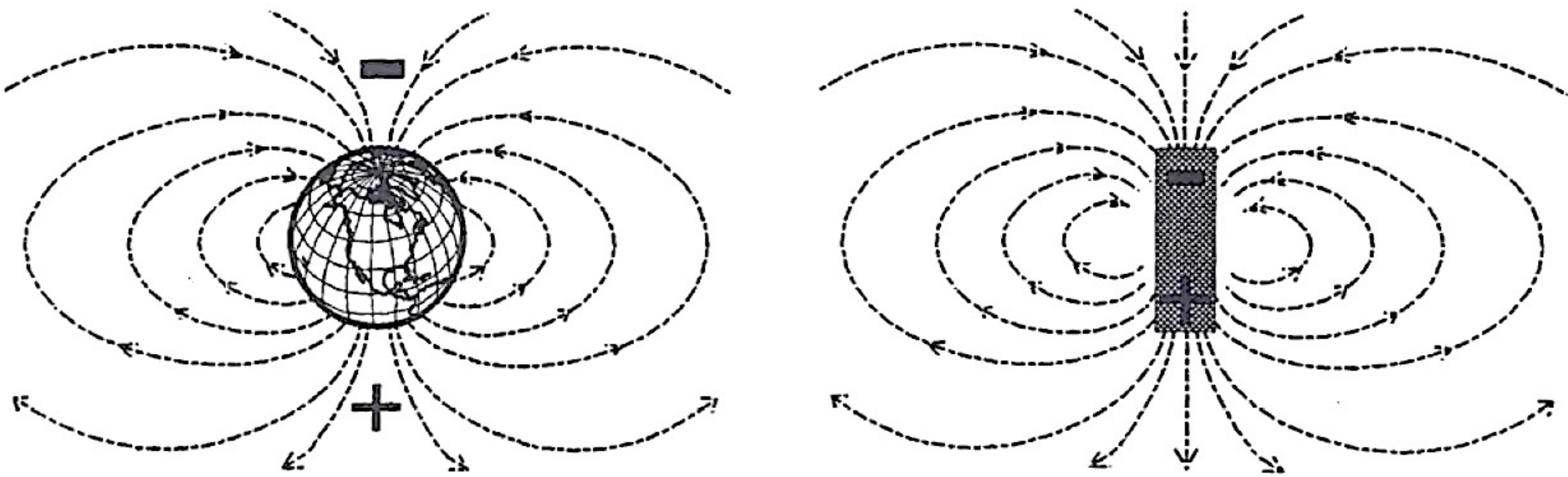


FIGURE 9.1 *Magnitudes and directions of Earth's gravity and magnetic fields.* a) The gravity field is approximately vertical, with only slight variation in magnitude from equator to pole. b) The magnetic field shows strong variations in both magnitude and direction.

Axial Dipolar Model



a) Earth b) Bar Magnet

Earth's Poles

How many Earth's poles who already known of?

- Geographic pole
- Geomagnetic pole
- Magnetic pole

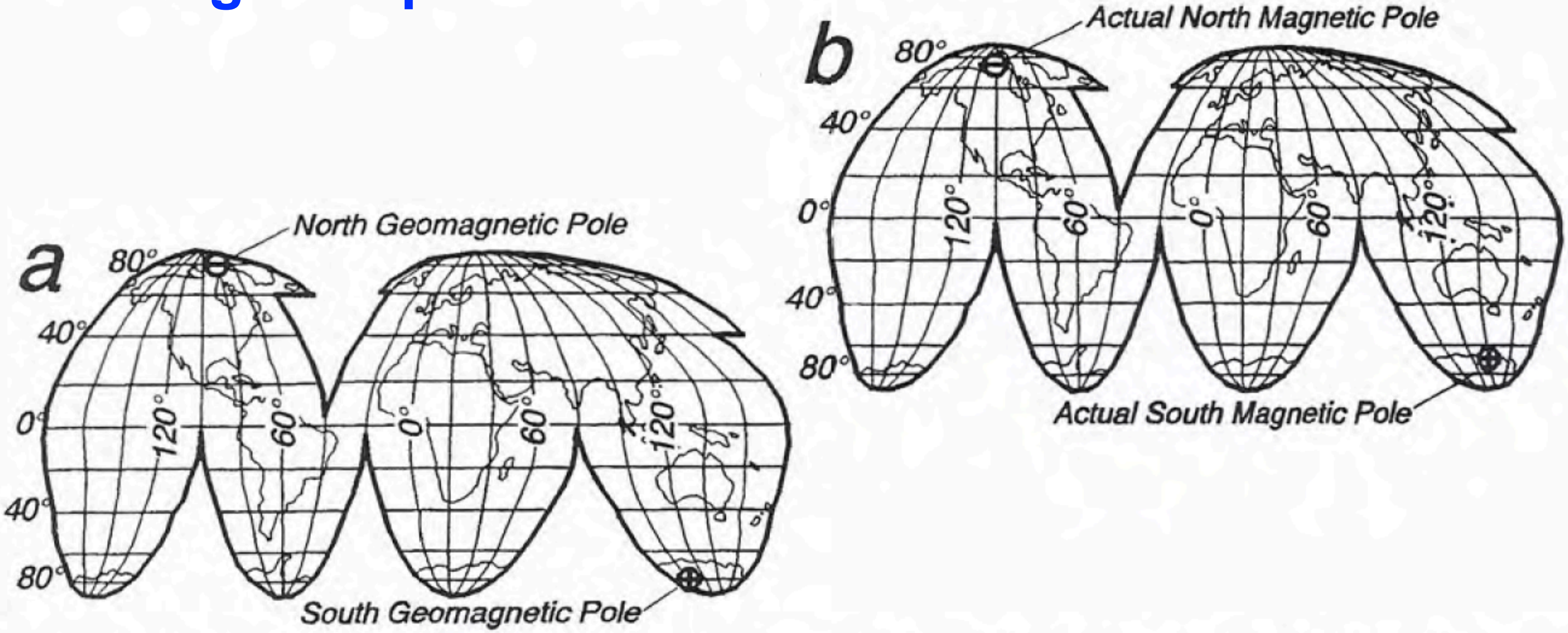


FIGURE 9.3 *Earth's magnetic poles.* a) *Geomagnetic poles*, according to a best-fit dipolar model. These poles are exactly 180° apart, deviating 10.9° from the geographic poles (North Geomagnetic Pole = 79.1° N, 71.1° W; South Geomagnetic Pole = 79.1° S, 108.9° E). b) *Actual magnetic poles*, where the magnetic field is vertical, are not 180° apart (North Magnetic Pole = 75° N, 101° W, on Bathhurst Island, Canada; South Magnetic Pole = 67° S, 143° E, in northeast Antarctica).

Geomagnetism

Geomagnetism is something that many of us are not aware of as we don’t feel it and don't see it. Yet few of us may be sensitive to it.

Over 2000 years ago, the Chinese discovered the **magnetic needle** that always aligned itself in the North-South direction.

The magnetic needle was the first evidence of the existence of the Earth’s magnetic field.

Travelers believed that the needle of the compass indicated the direction of the north geographic pole.

It was only 100 years ago that geodesists and other scientists realized that a compass shows the direction of the northern **magnetic pole** not the northern geographic pole.

Geomagnetism

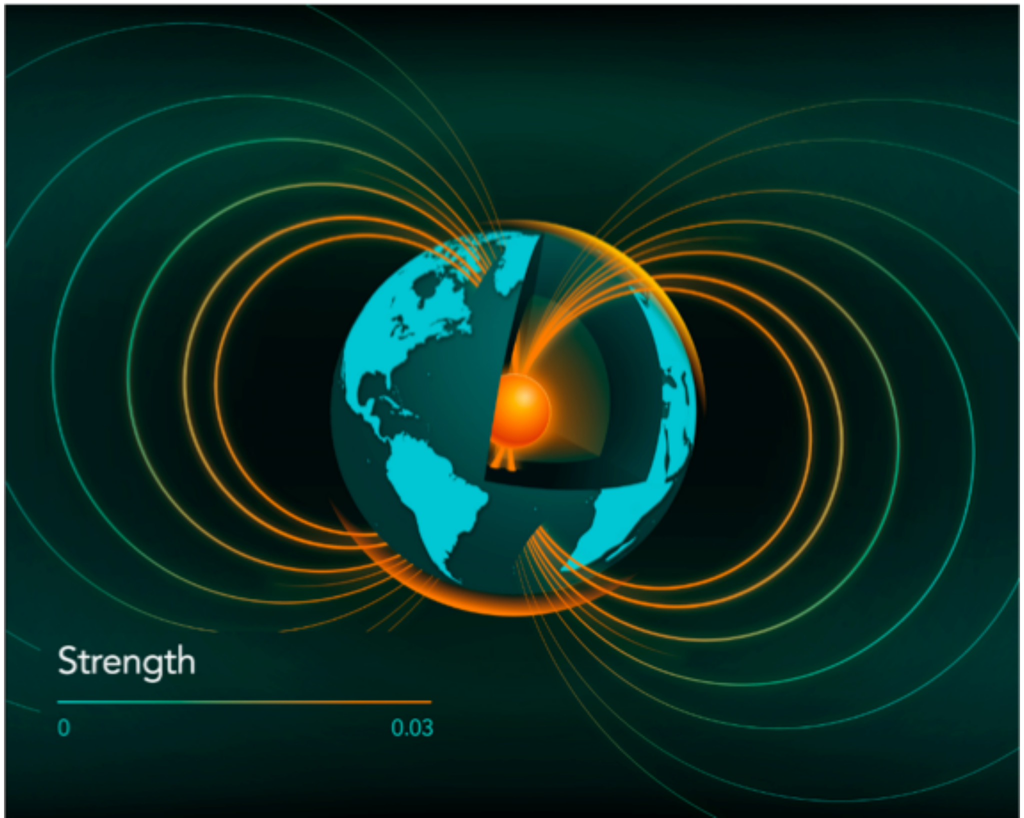
Geomagnetism Explained

The geomagnetic field, also referred to as the Earth’s magnetic field

The field is a continuous, nearly spherical zone originated at and generated by the Earth’s core

Within the Earth and on its surface, the geomagnetic field is symmetrical about Earth's geomagnetic axis.

Where it extends above the atmosphere, it becomes influenced by the solar wind, which “blows” some of the magnetic field away from the Sun.



Geomagnetism

Most of the magnetic field is produced by a huge, dynamo-like, rotating solid core of iron-nickel alloy at the center of the Earth.

That core is spherical, with a radius of 1220 km. It effectively acts like a **huge bar magnet** with an axis.

The Earth's magnetic field is generated by

- ✓ Spatio-temporal variations in temperature,
- ✓ Viscosity and conductivity produced in Earth's fluid outer core rotation of Earth's inner core (varying in both time and space),
- ✓ followed by the spatially varying crustal field,
- ✓ the external disturbance fields, such as the highly space and time varying solar wind.

Geomagnetism

Conductive Core

The main magnetic field of the Earth is thought to be produced by electrical currents in the conductive core.

Outer Core

- ✓ Convection currents in the molten metal flow caused by temperature difference, pressure and composition.
- ✓ This flow of liquid iron generates electric currents, which in turn produce magnetic fields.
- ✓ Charged metals passing through these fields go on to create electric currents of their own, and the cycle continues.

“Geodynamo”

The magnetic field, in turn, controls the direction and speed at which Earth's inner and outer cores spin, even though they move in opposite directions.

https://websites.pmc.ucsc.edu/~glatz/geodynamo.html

Geomagnetism

The **geomagnetic poles** are located where this geomagnetic axis intersects the surface of the globe.

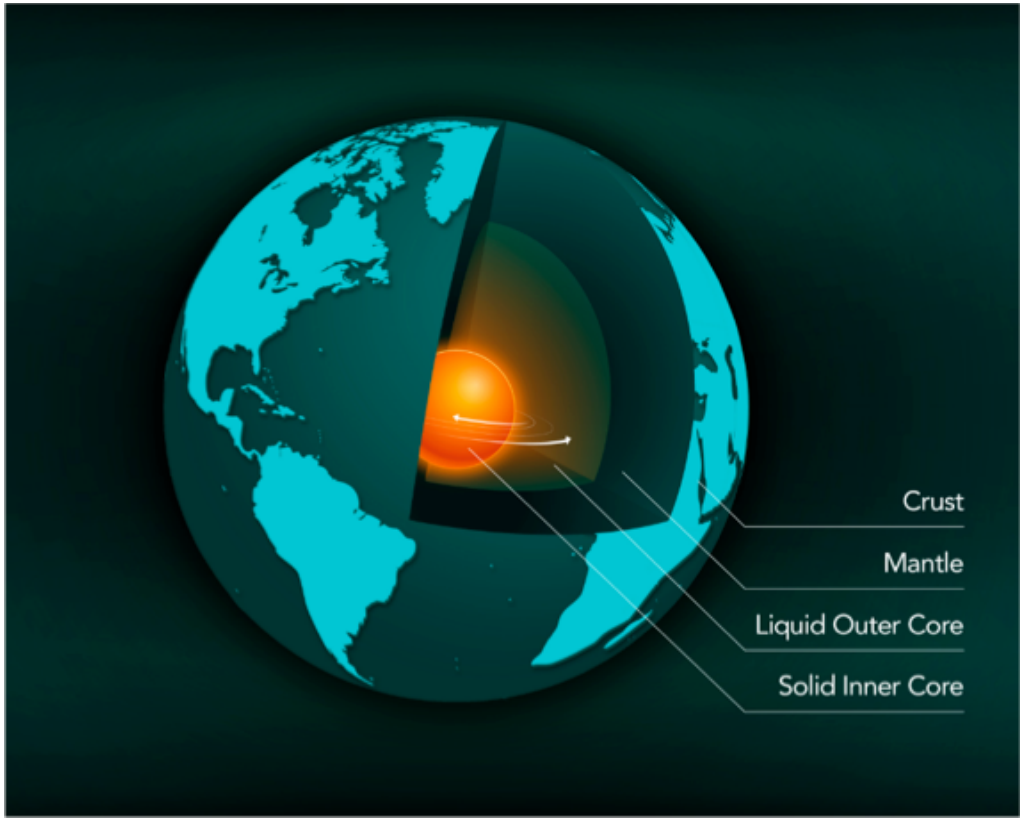
Importantly, the **geomagnetic poles** are not the same as what we refer to as the true North and South poles.

The Earth spins on the axis that connects the northern and southern **geographic poles**.

The directions toward these poles define true North and South, respectively.

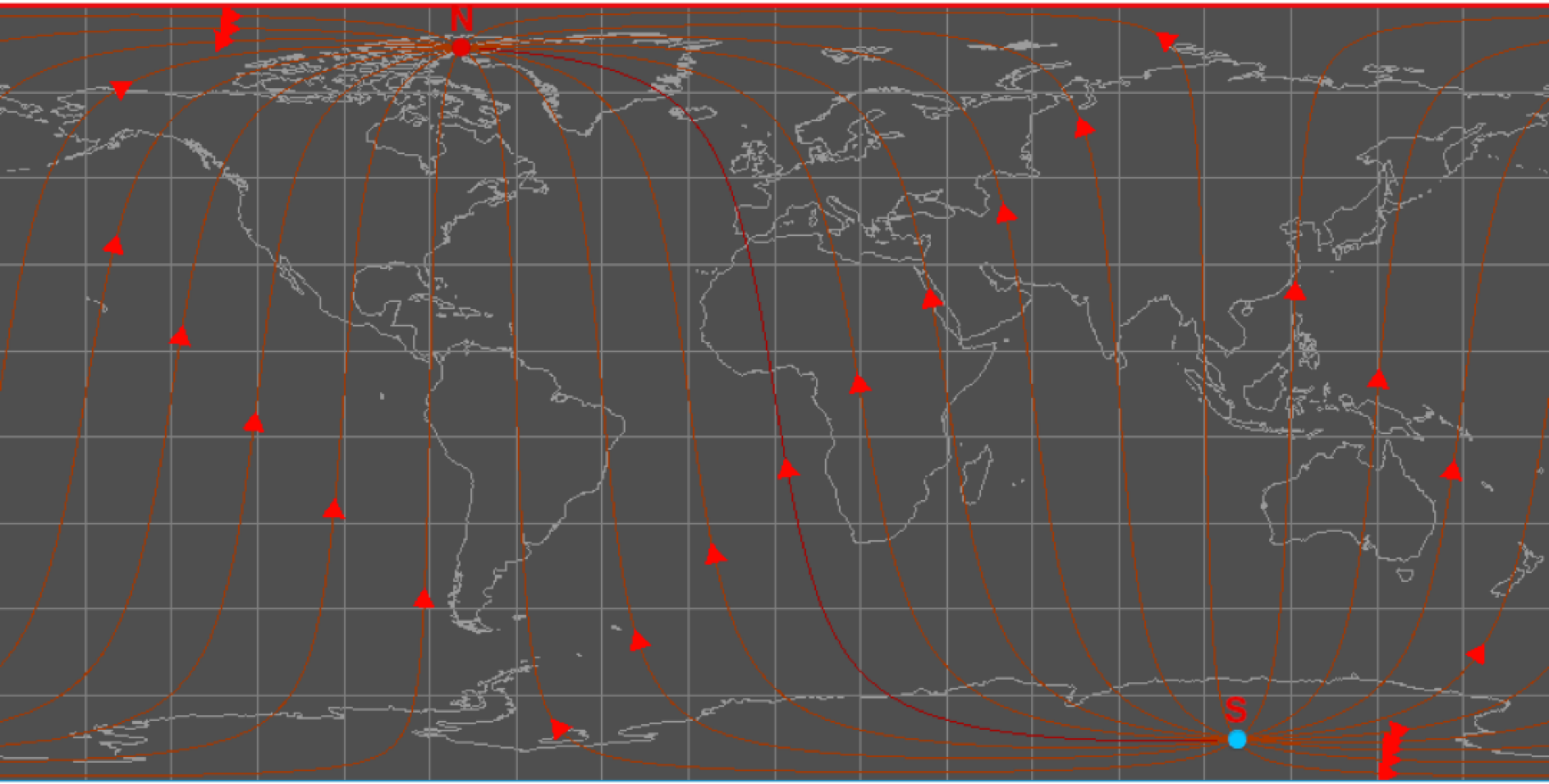
The **magnetic poles** are defined as the north and south points on the Earth's surface as indicated by a compass.

These are also sites where the magnetic field is perpendicular to the surface of the globe. **At these two locations the magnetic needle would be vertical.**



Geomagnetism

Meridians of Geomagnetism



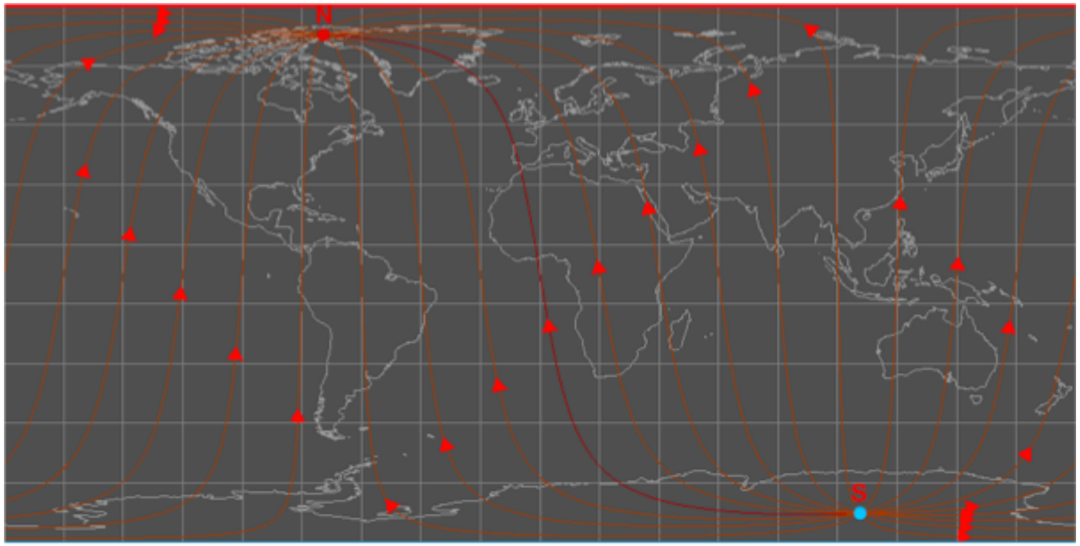
The **geomagnetic** meridians of the **Main Field**

Geomagnetism

Meridians of Geomagnetism

The **geomagnetic field** is a combination of several magnetic fields external to the Earth and inside the Earth. A few of these sources are:

- ✓ a spinning iron-nickel core
- ✓ unevenly magnetized crust
- ✓ solar wind varying in space and time
- ✓ electric currents flowing between the tectonic plates
- ✓ ocean currents.



These fields are superimposed on each other.

~**90%** of Earth's magnetic field is generated within the **planet's outer core**.

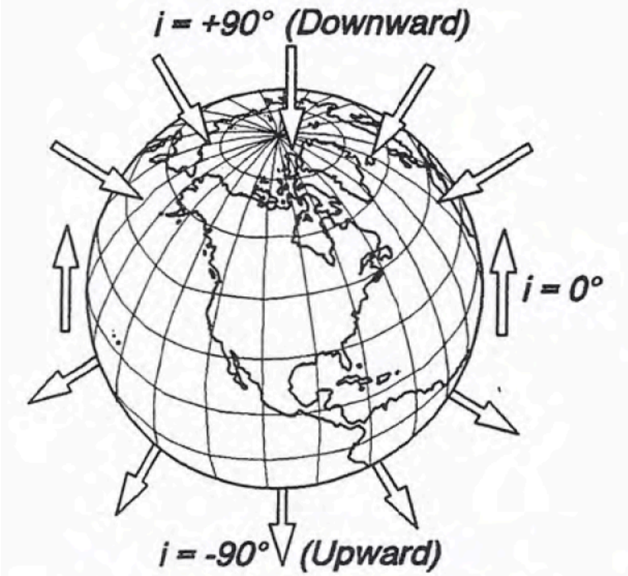
The strongest component of the magnetic field is referred to as the **Main Field**. The Main Field is consistent enough that it can be described by mathematical models.

Today's Goals

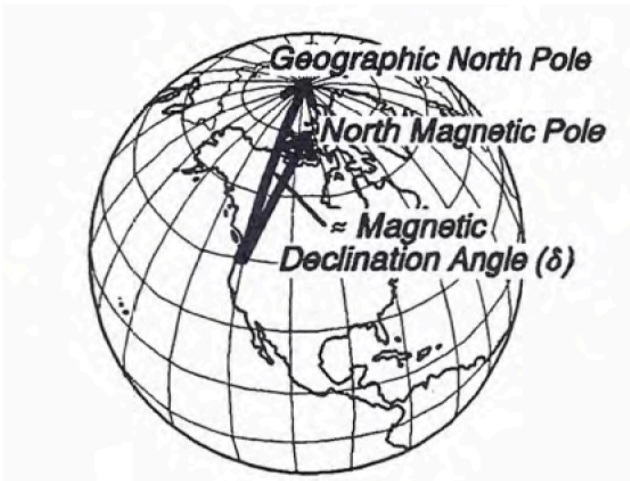
Part I: Geomagnetism
Part II: Earth magnetic field and magnetic anomaly

Earth's magnetic field

(Butler, 1992)



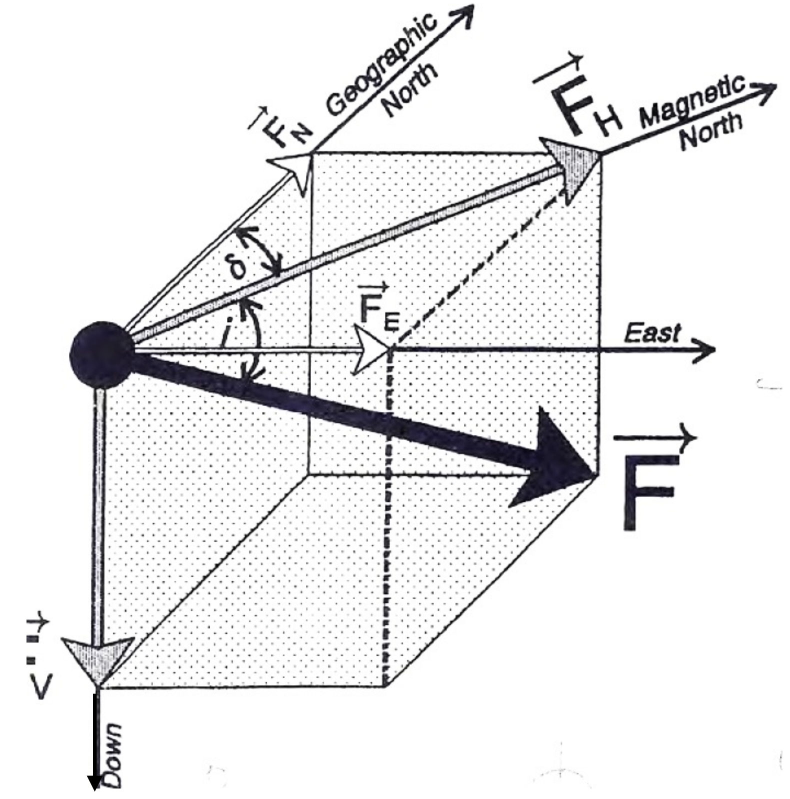
a) Magnetic Inclination



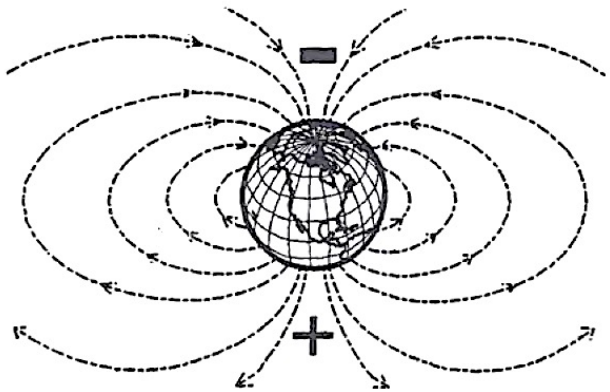
b) Magnetic Declination

F: Total magnetic field vector (total field intensity)

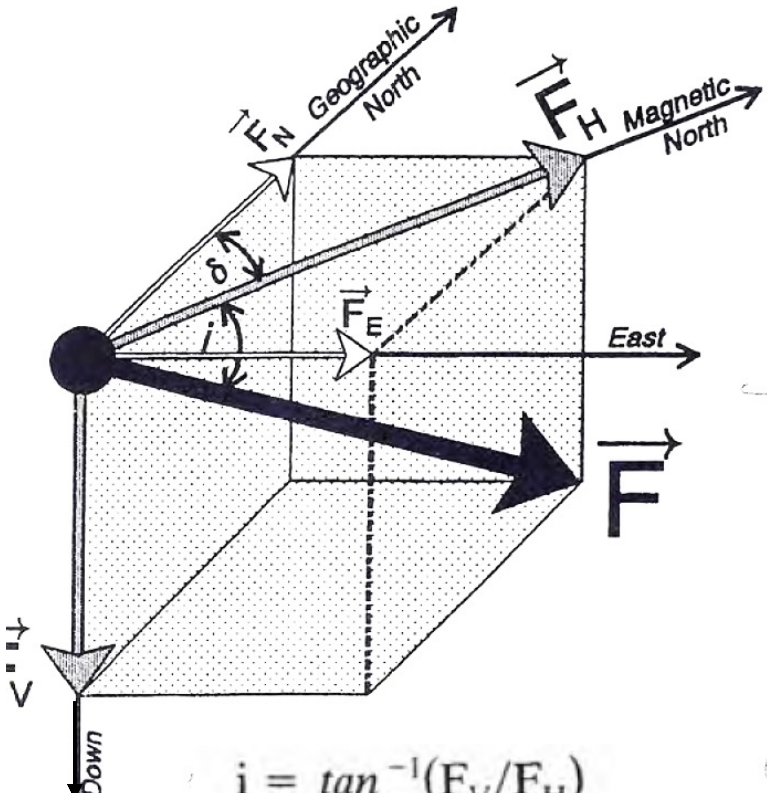
$$F = \sqrt{F_H^2 + F_V^2} = \sqrt{F_N^2 + F_E^2 + F_V^2}$$



Earth’s magnetic field



a) Earth



$$F_H = \frac{M\cos\phi}{R^3}$$

$$F_V = \frac{2M\sin\phi}{R^3}$$

$$F = \frac{M\sqrt{1+3\sin^2\phi}}{R^3}$$

$$i = \tan^{-1}(F_V/F_H)$$

$$\delta = \tan^{-1}(F_E/F_N)$$

i = angle of magnetic inclination
δ = angle of magnetic declination.

R = radius of the Earth
M/R^3 = total field intensity at the magnetic equator
ϕ = magnetic latitude (for axis inclined 10.9° from the true rotational axis; Fig. 9.3a)

Earth's magnetic field

Exercise I: At the equator, $F = M/R^3 = 30{,}000$ nT. Calculate the total field intensity at the magnetic pole. [~60,000 nT]

Earth's magnetic field

Earth's Magnetic Field

How strong of 1 T (tesla)?

Fundamental Unit of Tesla = $kg \cdot s^{-2} \cdot A^{-1}$

$$T = \frac{V \cdot s}{m^2} = \frac{N}{A \cdot m} = \frac{J}{A \cdot m^2} = \frac{H \cdot A}{m^2} = \frac{Wb}{m^2} = \frac{kg}{C \cdot s} = \frac{N \cdot s}{C \cdot m} = \frac{kg}{A \cdot s^2}$$

10 kG = 1 T (tesla), so 1 G = 10−4 T

Strength of Magnetic Field

- ✓ 31.869 μT (3.2×10^{-5} T) – strength of Earth's magnetic field at 0° latitude, 0° longitude
- ✓ 5 mT – the strength of a typical refrigerator magnet
- ✓ 0.3 T – the strength of solar sunspots
- ✓ 1.25 T – magnetic flux density at the surface of a neodymium magnet
- ✓ 1 T to 2.4 T – coil gap of a typical loudspeaker magnet
- ✓ 1.5 T to 3 T – strength of medical magnetic resonance imaging systems in practice, experimentally up to 17 T[12]
- ✓ 4 T – strength of the superconducting magnet built around the CMS detector at CERN[13]
- ✓ 8 T – the strength of LHC magnets
- ✓ 11.75 T – the strength of INUMAC magnets, largest MRI scanner[14]
- ✓ 13 T – strength of the superconducting ITER magnet system[15]
- ✓ 16 T – magnetic field strength required to levitate a frog[16] (by diamagnetic levitation of the water in its body tissues) according to the 2000 Ig Nobel Prize in Physics[17]
- ✓ 17.6 T – strongest field trapped in superconductor in lab as of July 2014[18]
- ✓ 27 T – maximal field strengths of superconducting electromagnets at cryogenic temperatures
- ✓ 35.4 T – the current (2009) world record for a superconducting electromagnet in a background magnetic field [19]
- ✓ 45 T – the current (2015) world record for continuous field magnets [19]
- ✓ 100 T – The magnetic field strength of the average White dwarf star
- ✓ 10^8 – 10^{11} T (100 MT – 100 GT) – magnetic strength of the average magnetar

Magnetic Anomaly

Magnetization

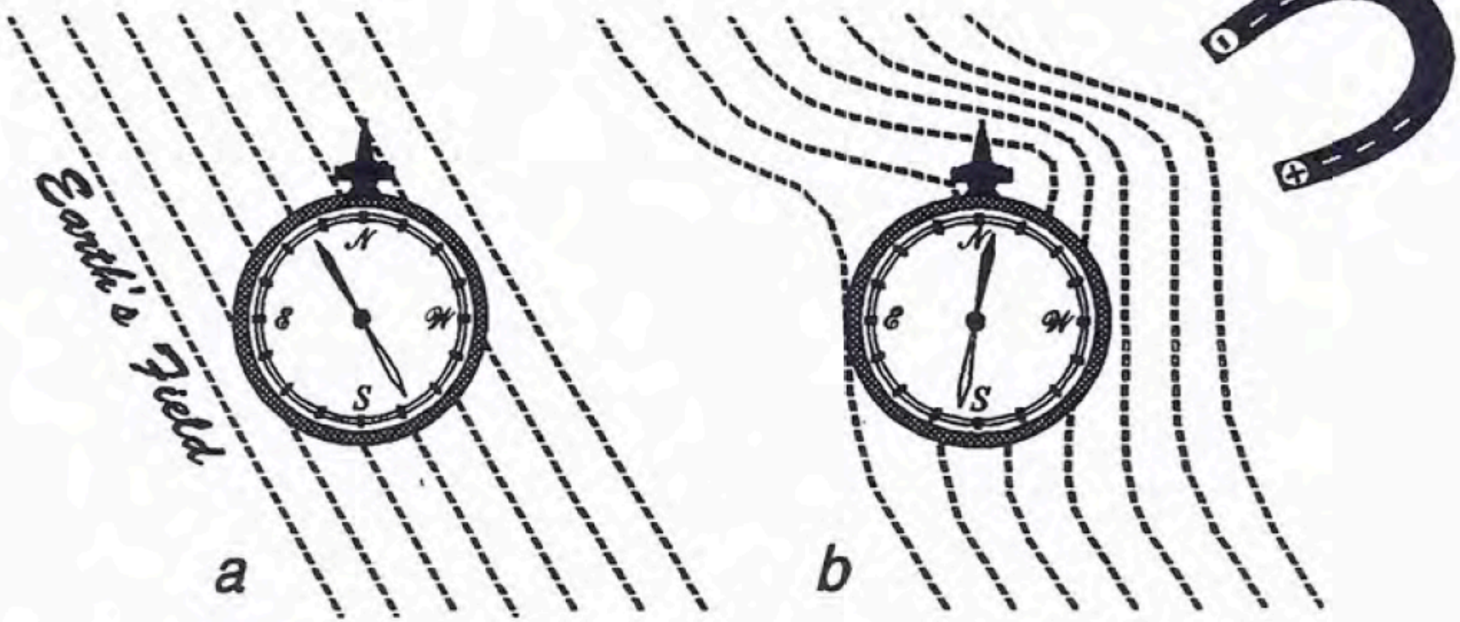


FIGURE 9.7 a) Compass responding to Earth's ambient magnetic field. b) Magnet causes a local deviation of Earth's field.

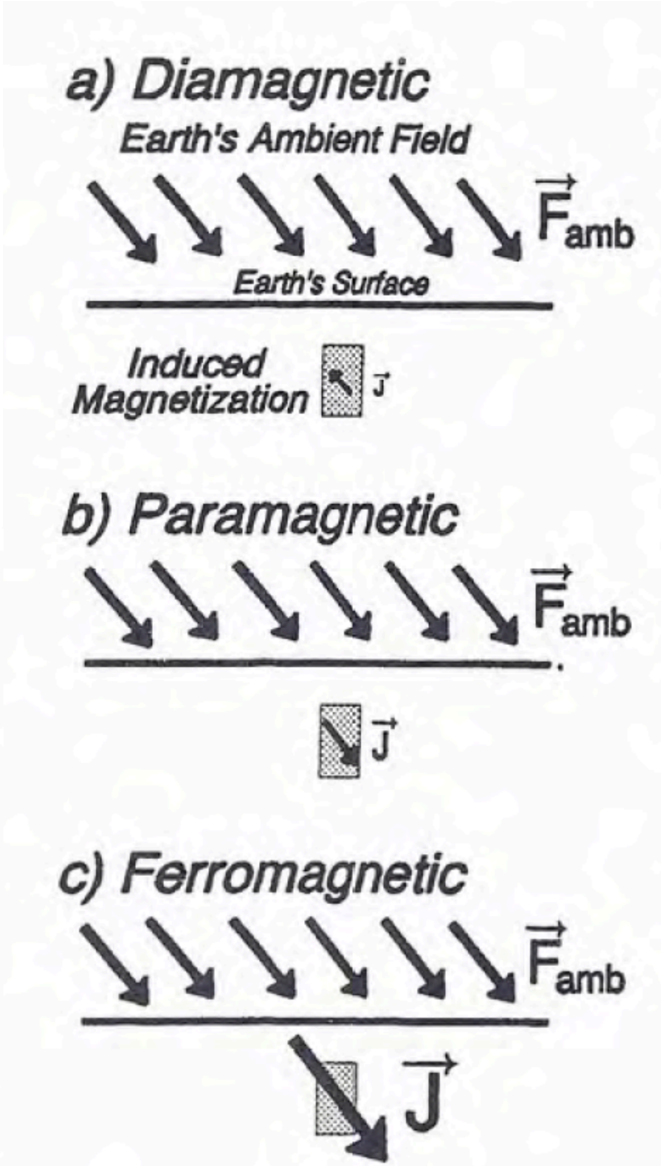
Magnetization

$$\vec{J} = \chi \vec{F}_{amb}$$

$\vec{J}$ = induced magnetization of the material
χ = magnetic susceptibility of the material
$\vec{F}_{amb}$ = magnitude and direction of the ambient field.

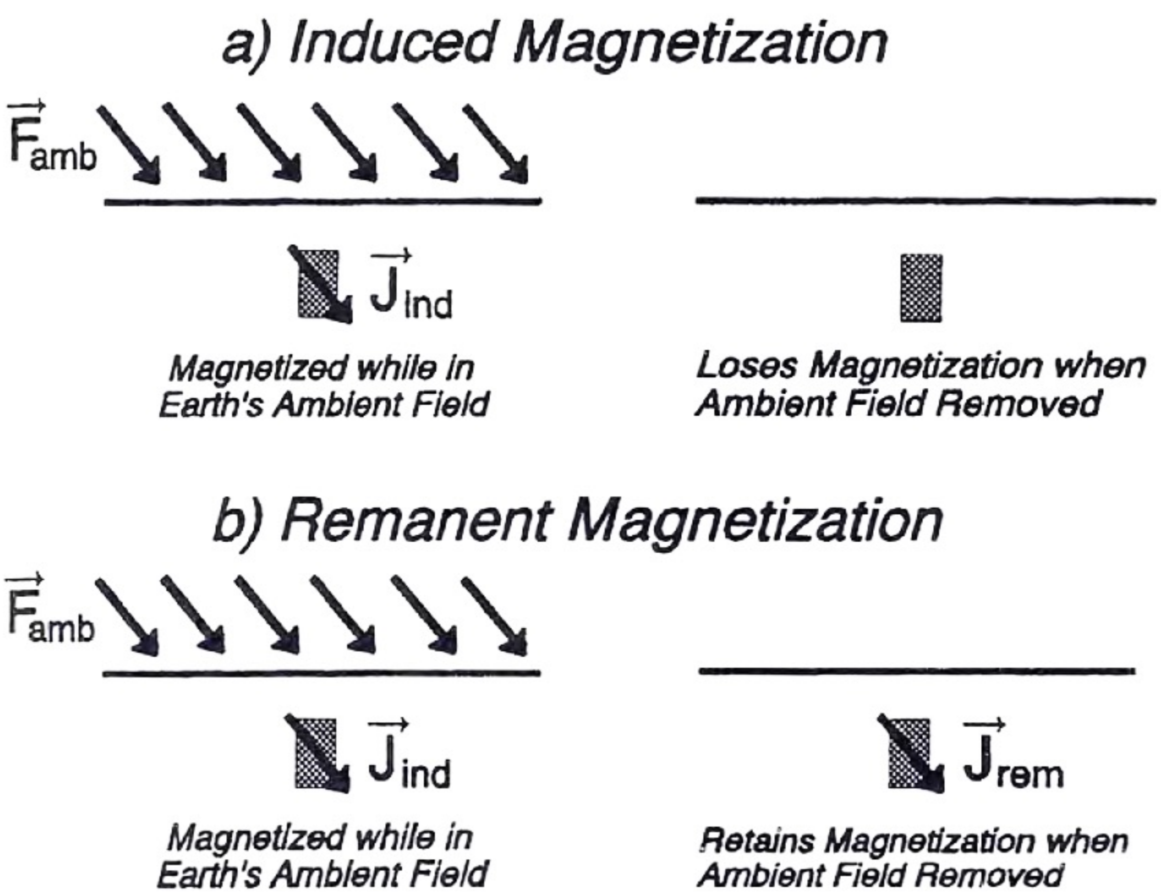
TABLE 9.1 Typical magnetic susceptibilities of some common Earth materials.

Material	Magnetic Susceptibility
Magnetite	10000×10^{-5}
Peridotite	500×10^{-5}
Basalt/Gabbro	200×10^{-5}
Diorite	20×10^{-5}
Sandstone	10×10^{-5}
Granite	1×10^{-5}
Salt	-1×10^{-5}



Magnetic Anomaly

Magnetization



Magnetic Anomaly

$$\vec{\mathbf{F}} = \vec{\mathbf{F}}_{amb} + \vec{\mathbf{F}}_{ind}$$

$$\vec{\mathbf{F}}_{ind} = \vec{\mathbf{F}} - \vec{\mathbf{F}}_{amb}$$

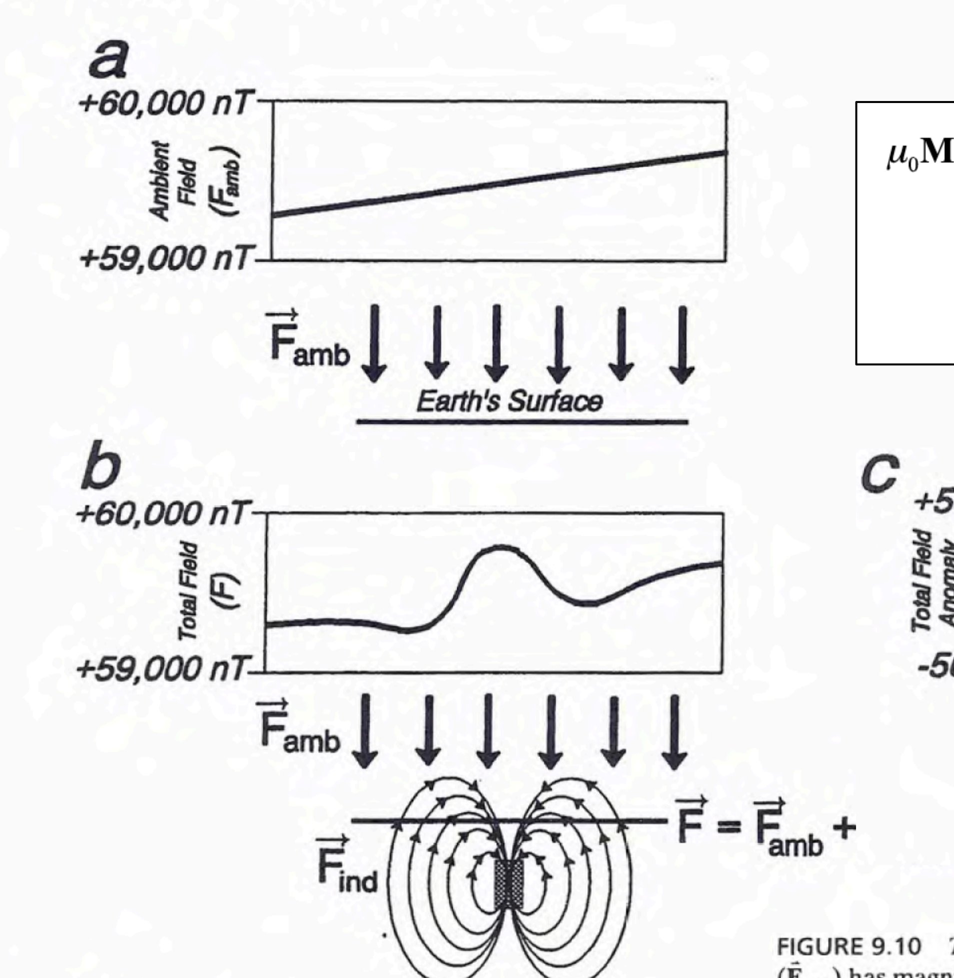
$$\Delta \mathbf{F} = \mathbf{F} - \mathbf{F}_{amb}$$

How to get real world $\mathbf{F}_{amb}$?

Magnetic Anomaly

$$\mu_0 \mathbf{M}(\mathbf{r}) = \chi \mathbf{B}(\mathbf{r})$$

$\mathbf{M}(\mathbf{r})$	Induced magnetic field
$\mathbf{B}(\mathbf{r})$	Earth's magnetic field
μ_0	Magnetic permeability
χ	Magnetic suceptibility typically 10^{-4} to 10^{-1} for basalt



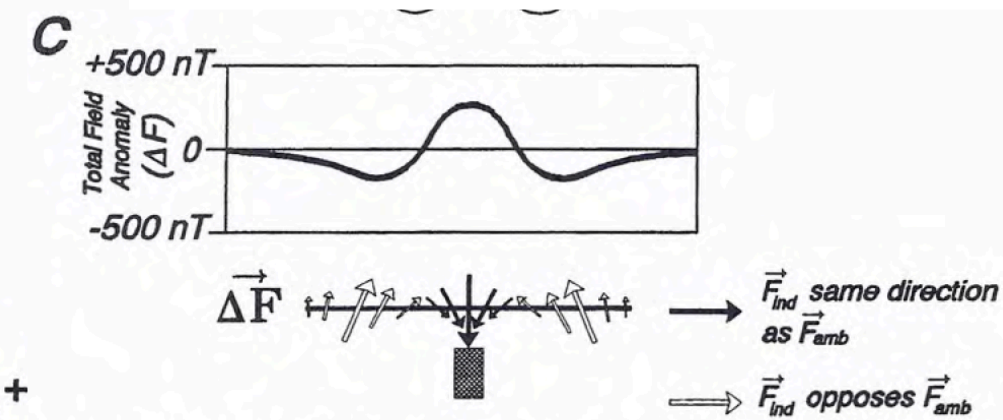
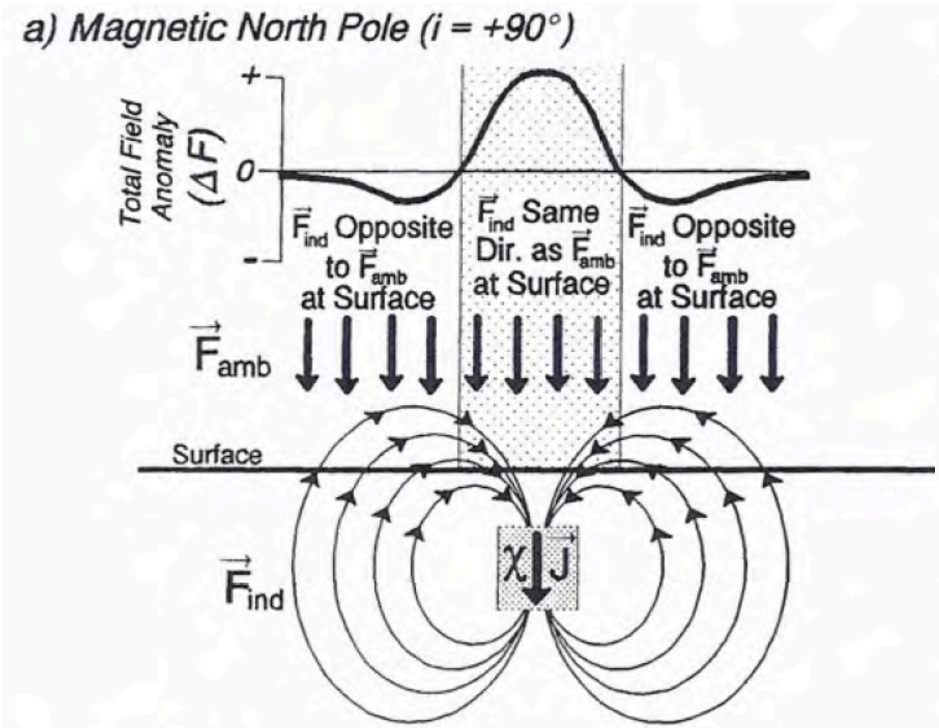


FIGURE 9.10 *Total field magnetic anomaly produced by local magnetic body.* a) Earth's ambient field ($\vec{F}_{amb}$) has magnitude of several thousand nT, with very long wavelength changes. b) A body of magnetization ($\vec{J}$) is surrounded by an induced magnetic field ($\vec{F}_{ind}$), with amplitudes of perhaps a few hundred nT occurring over much shorter wavelengths. The total magnetic field ($\vec{F}$) that results is the sum of the ambient and induced fields. c) Subtracting the magnitude of the ambient field (F_{amb}) from that of the total field (F) yields the total field anomaly (ΔF). A profile of ΔF thus reflects the effect of the induced field.

Magnetic Anomaly



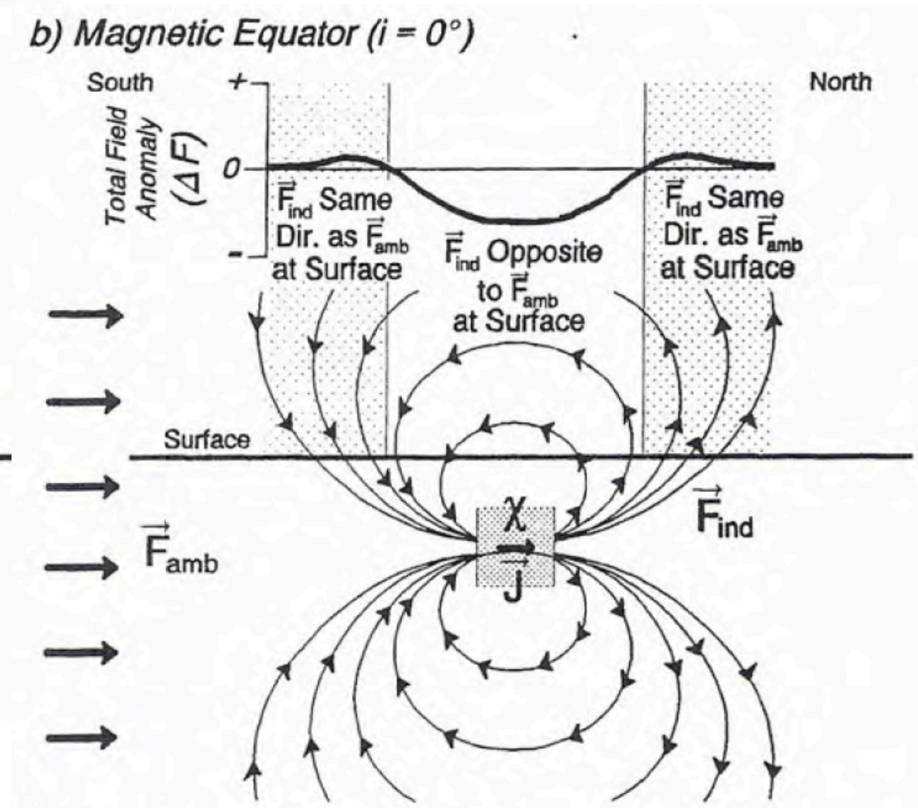
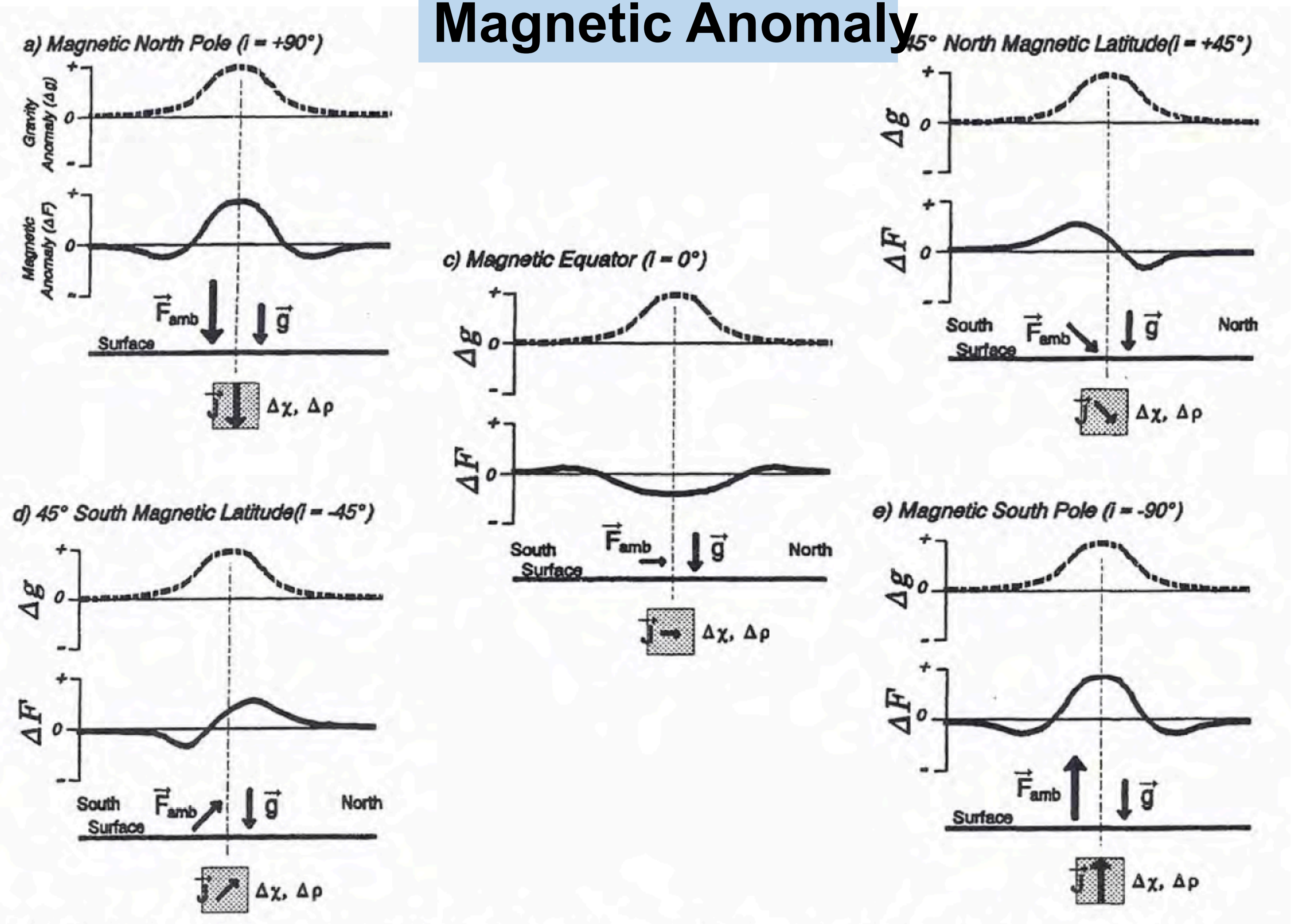


FIGURE 9.11 At different magnetic latitudes, magnetic anomalies from the same magnetic body (that is, a body of exactly the same shape, size, depth, and magnetic susceptibility, χ) are quite different. a) At the magnetic north pole, Earth's ambient field ($\vec{F}_{amb}$) is strong ($\approx$ 60,000 nT) and points downward (magnetic inclination $i = 90°$). Where the induced field ($\vec{F}_{ind}$) points in the same direction as $\vec{F}_{amb}$ (gray shading), the total field anomaly (ΔF) is positive. Negative total field anomalies occur where the two fields oppose one another. b) At the magnetic equator, $\vec{F}_{amb}$ is horizontal ($i = 0°$) and weaker ($\approx$ 30,000 nT). The magnetization ($\vec{J}$) is smaller, leading to a weaker induced field. The total field anomaly is thus lower amplitude than in (a). $\vec{F}_{ind}$ opposes $\vec{F}_{amb}$ over the body, leading to negative ΔF values. (Modified from R. F. Butler, personal communication, 1996).

Magnetic Anomaly

Magnetic Anomaly



Magnetic Anomaly

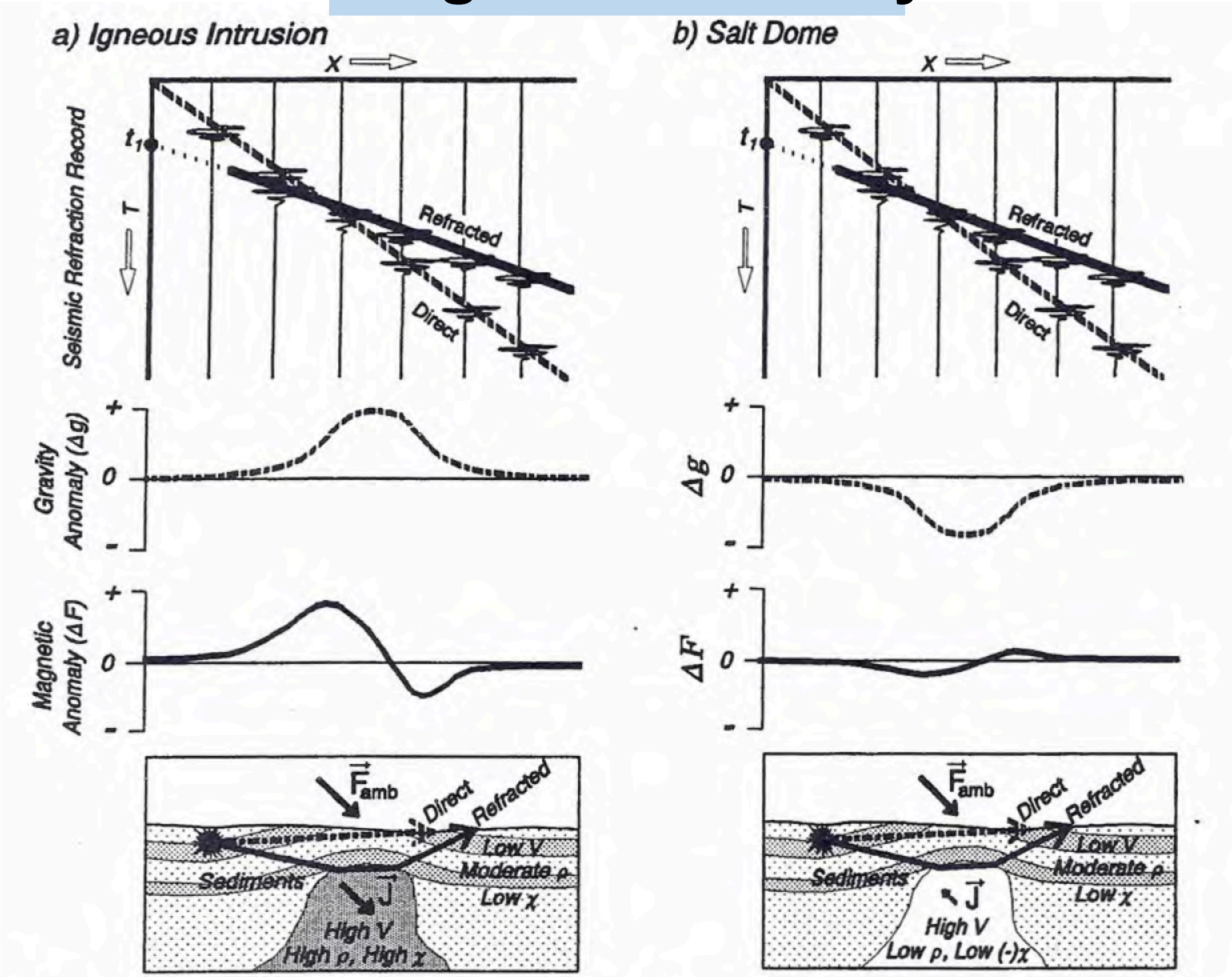
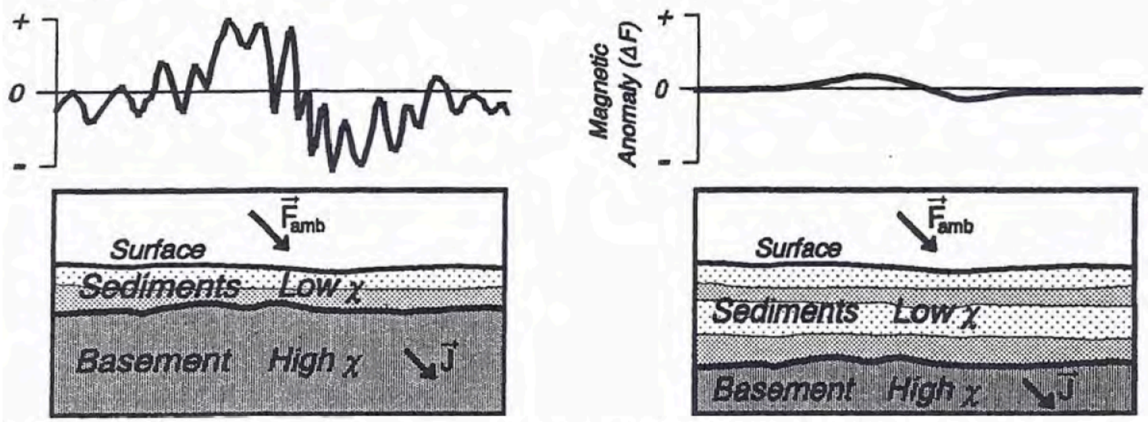
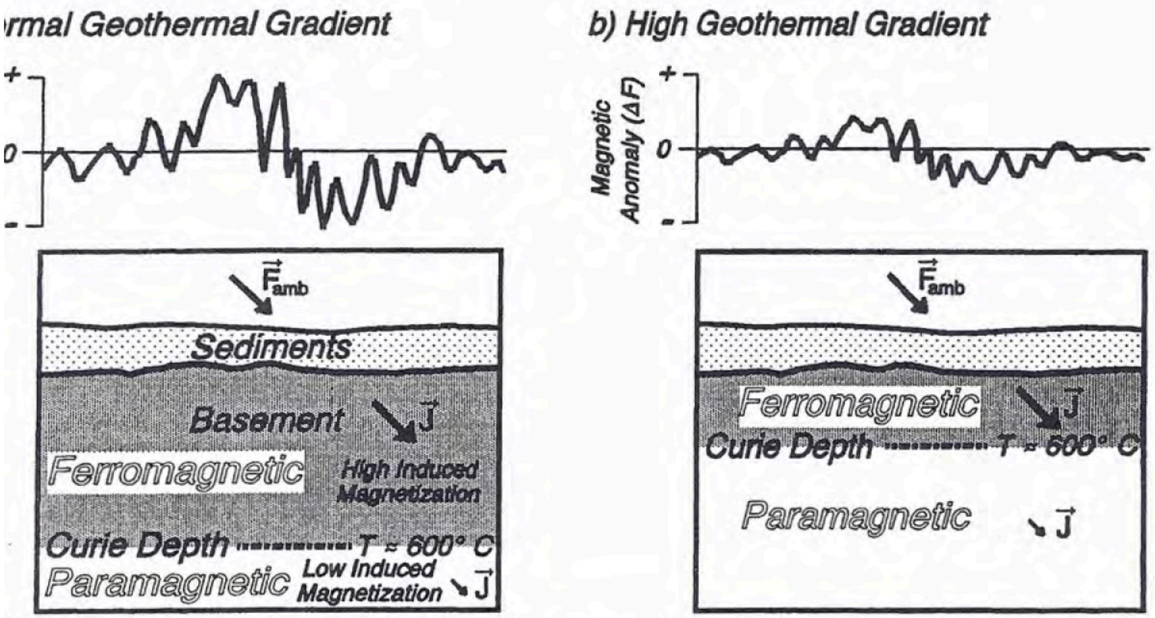


FIGURE 9.13 An igneous intrusion and salt dome might both be recognized as high-velocity material (V), leading to a

Magnetic Anomaly



9.14 *Depth to magnetic basement.* Magnetic anomalies measured at Earth's surface depend on the depth of the magnetic commonly located within crystalline basement. a) Where basement rocks are shallow, short-wavelength anomalies, with plitudes and steep gradients, occur. b) Basement buried deeply beneath sedimentary cover results in longer wavelength es with smaller amplitudes and gradients.



9.15 *Curie depth.* a) Regions with a normal geothermal gradient reach 600°C at depths of about 20 to 30 km. Their