<u>Magnetic Method</u>

<u>Introduction</u>

The Earth is principally made up of three parts: **core, mantle and crust** (Fig. 1).
The hard of the Earth is **solid,** inner core composed primarily of **iron**. At 5700°C, this iron is hot as the **Sun's surface**, but the **pressure** caused by gravity **prevents** it becoming **liquid**.
The outer core at 2000 km thick of **iron, nickel, and small quantities of other metals**. **Lower** pressure than the inner core means the metal here is **fluid**.

Differences in **temperature, pressure and composition** within the outer core cause **convection currents**, dense matter **sinks** while warm, less dense matter **rises**. This **flow** of liquid iron generates **electric currents**, which in turn produce **magnetic Earth's fields**.

These convection currents in the liquid part of core (outer core) give a **dipolar** geomagnetic field that resembles that of a large **magnet bar** aligned approximately along the Earth's **rotational axis.**

The mantle plays **little part** in the Earth's magnetism, while interaction of the **past and present** geomagnetic field with the rocks of the crust produces **magnetic anomalies** recorded in surveys are carried out on above the Earth's surface.

The **magnitude** of the Earth's magnetic field averages to about **(50, 000 nT**). Magnetic **anomalies** as small as **0.1 nT** can be **measured** in continental magnetic surveys and may be of geological significance.

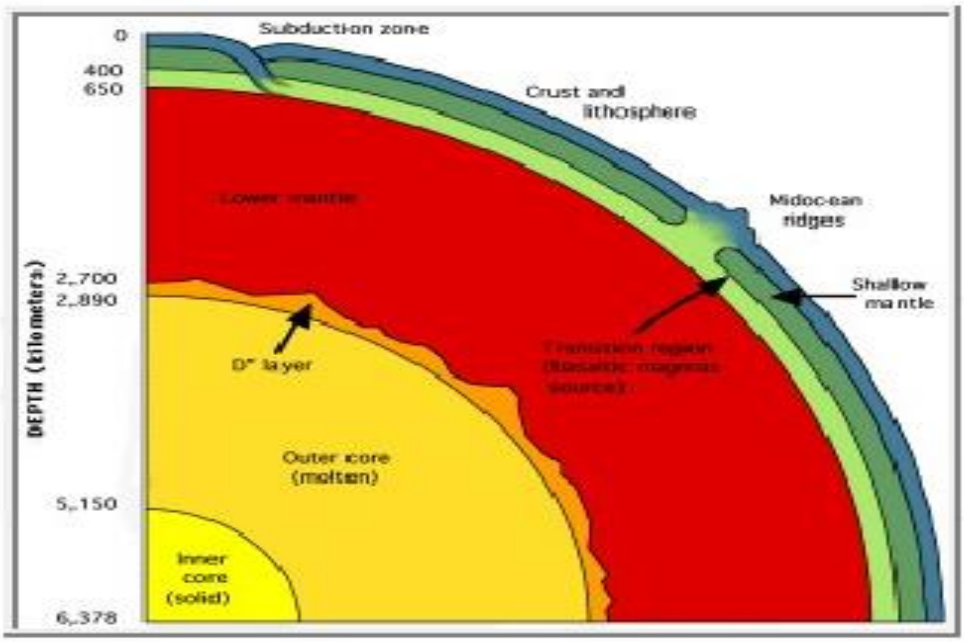

Figure (1) internal structure of the Earth

<u>Magnetic methods are used to solve various problems</u>

<u>Such as</u>:

1-Mapping the basement surface and sediments in oil/gas exploration.

2-Detecting different types of ore bodies in mining prospecting

3-Detecting metal objects in engineering geophysics.
4-Mapping basement faults and fractures.
5-Studying the magnetic field of the Earth and its generators.

Similarities and differences with gravity methods

Magnetic method	Gravity method
Passive and is a potential field bearing all the consequence	**Passive** and is a potential field bearing all the consequences
Mathematical expression for the force field is that of the inverse square law relation	**Mathematical expression** for the force field is that of the inverse square law relation
Force between monopoles can either be attractive or repulsive	**Force** between masses is always attractive
A monopole cannot be **isolated**. Monopoles always exist in pairs (dipole)	A single point mass can be **isolated**
Magnatic earth field has variation due to variation in induced magnetization of susceptible rocks and remnant magnetization	**Earth gravity field** has variation due to density variation in rocks
Field **changes** significantly over time (secular variation	Field does **not change** significantly over time

Table (1): Similarities and differences with gravity methods

Basic geomagnetic concept

1- Pole strength (m.)

Around a bar magnet, a magnetic flux exists, as indicated by the flux lines in Figure 3.1, and converges near the ends of the magnet, which are known as the magnetic poles.
North- poles are +ve, and are south poles- ve. Poles always occur in **pairs**, but sometimes one (monopole) is a very long distance from the other and can be **ignored** in modelling.

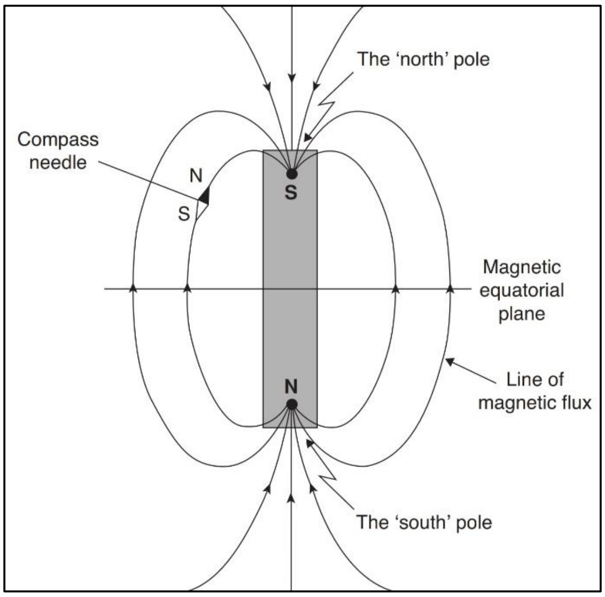

Figure (2) lines of magnetic flux around a bar magnet

2- intensity of magnetization (J)

Is induced by the magnetizing force, H. the intensity of magnetization is to examine a bar magnet of length I and cross-sectional area A which is uniformly magnetized in the direction of the long axis.
or pole strength m per unit area, is a measure of the intensity of magnetization J
$J = m / A$

3- flux density (B)

The closeness of the flux lines shown in Figure 3.1, the flux per unit area, is the flux density B (and is measured in weber/m^2 =teslas), (nT=10^{-9} T), the former c.g.s. units of flux density were (gauss, equivalent to 10^{-4} T). where 1 nT is numerically equivalent to 1 gamma in c.g.s.

4-magnetizing field strength H
The field strength at the center of a loop of wire of radius r through which a current is flowing such that H=1/2r. Consequently the units of the magnetizing field strength H are amperes per meter (A/m).

5- Magnetic permeability (μ)
The ratio of the flux density B to the magnetizing field strength H is a constant called the absolute magnetic permeability (μ).

6- Magnetic susceptibility (k)
This is the degree to which a body is magnetized.

The Earth's geomagnetic field

The Earth's magnetic field is more complicated than a simple dipole. It **consists of:**

1- **The main field**

Represent the **main** earth`s geomagnetic field, have **slowly changing with time**. The variations called **Secular variations**. A simple dipole is a good approximation for **80%** of the Earth's field. The remainder can be modelled as dipoles distributed around the core/mantle boundary
The **origin** of the Earth's field is known to be generated by convection in the liquid outer core, which drives electric currents. It **cannot be** due to magnetized rocks because it must be **deep**, and rocks **lose** all magnetization above the Curie

temperature. The Curie temperature for magnetite is **578˚C,** whereas the temperature of the core is probably~ **5,000˚C.**

2- the external field

This accounts for the other 1% of the Earth's field. It is caused by electric currents in ionized layers of the outer atmosphere. It is very variable, and has an 11-year periodicity which corresponds to sunspot activity. There is a diurnal periodicity of up to 30 γ,

Magnetic storms are random fluctuations caused by solar ionospheric interactions as sunspots are rotated towards and away from the Earth. They may last a few days and have amplitudes of up to 1,000 γ within 60˚ of the equator. They are more frequent and of higher amplitude closer to the poles. The possibility of magnetic storms must be taken into consideration in exploration near the poles, e.g., in Alaska.

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3- local anomalies

These are caused by magnetic bodies in the crust, where the temperature is higher than the Curie temperature. These bodies are the targets of magnetic surveying.

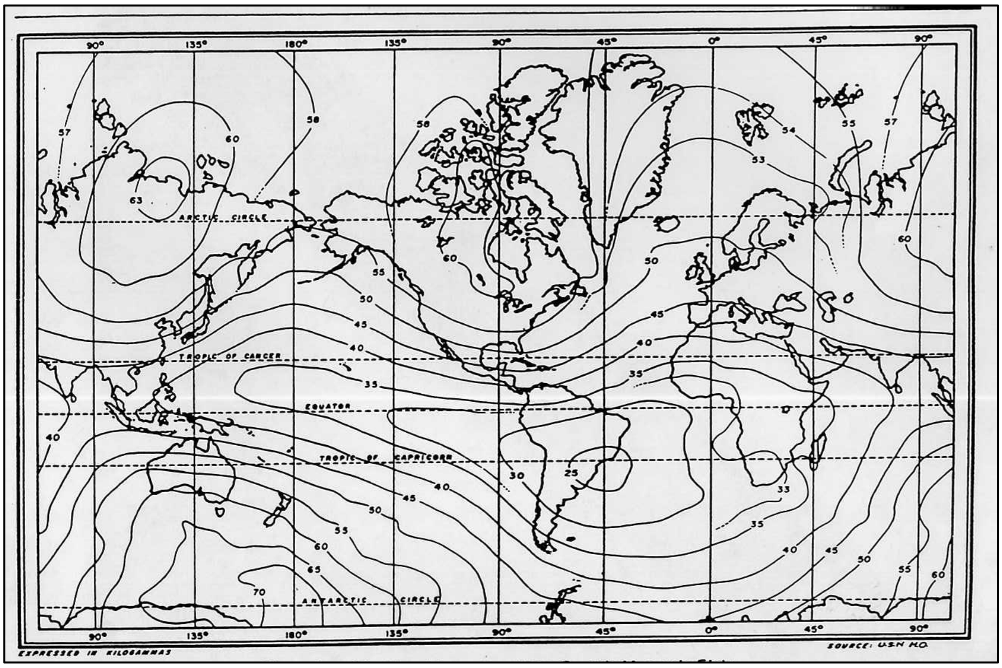


Figure (3): map of the total intensity Erath's magnetic field

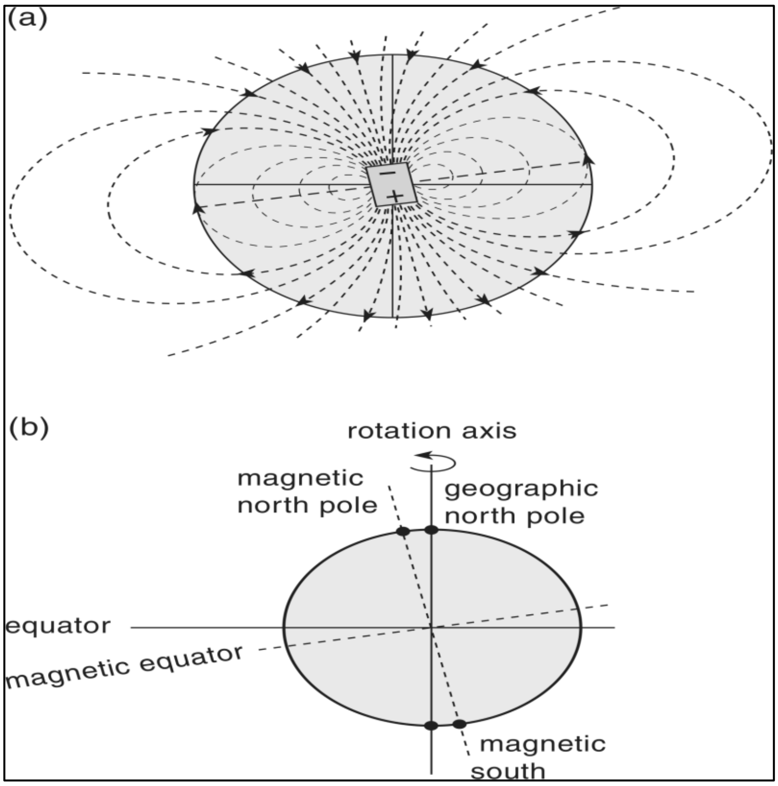


Figure (4): The Geographic and Magnetic Erath's poles

F = total field
H = horizontal component
Z = vertical component
I = inclination
D = declination

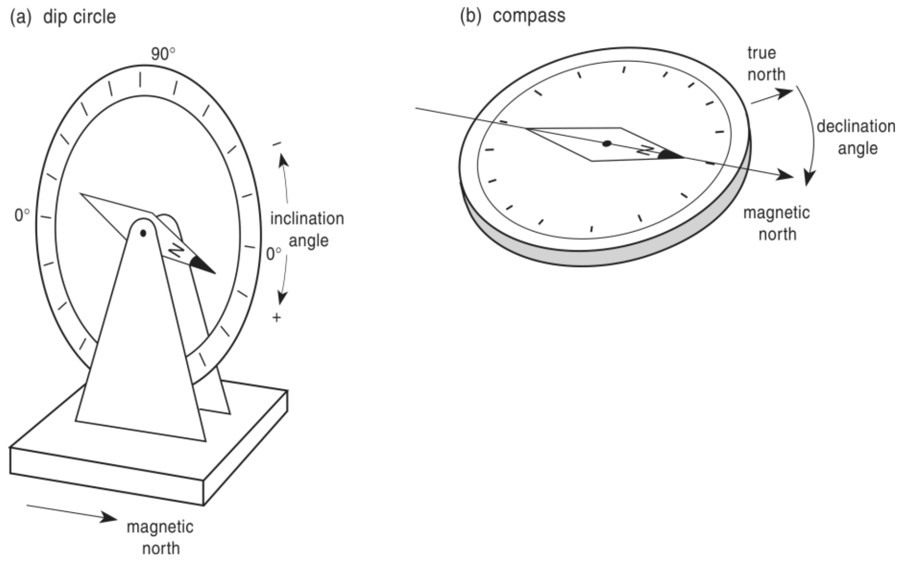


Figure (5): Declination and inclination of the Earth's magnetic field

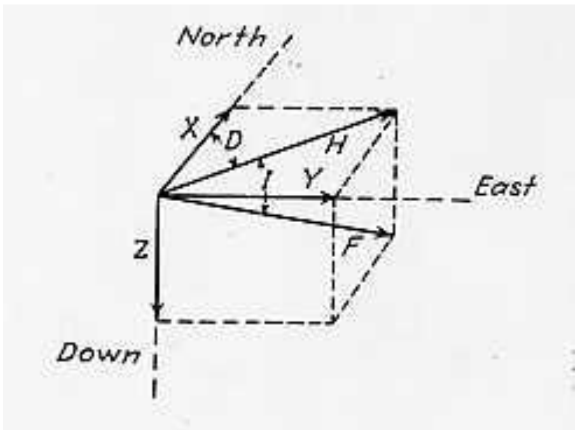
<u>Mathematical terms of main field</u>

The terms used are:

$$H = F\cos I \qquad Z = F\sin I = H\tan I$$

$$X = H\cos D \qquad Y = H\sin D$$

$$X^2 + Y^2 = H^2 \qquad X^2 + Y^2 + Z^2 = H^2 + Z^2 = F^2$$



Measurement of H and Z is now mostly confined to observatories. In surveying, H, Z or Φ can be measured. It is most common to measure Φ.

Secular variations in the main field

Monitored by measuring changes in **I, D** and **F** at observatories These are **very long period changes** that result from **convective changes in the core**. The Earth's field is also subject to reversals, the last of which occurred at 0.7 Ma (They are million years ago). They appear to be **geologically sudden**, not gradual, and their **frequency is very variable**. They are used for **paleomagnetism dating**. This is done by comparing the sequence of reversals in the field area of interest to the known, dated, geological record of reversals.

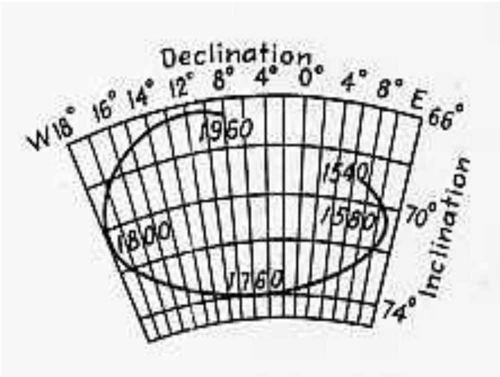


figure (6): Secular Changes in Declination and Inclination at London since 1540.

Rock magnetism

Kinds of magnetism in minerals

1 Diamagnetism

In diamagnetic minerals, all the electron shells **are full**. The electrons spin in **opposite senses** and the magnetic effects **cancel**. Examples of such materials are anomalies. **Quartzite and salt.**

2 Para magnetism

In Paramagnetic minerals the electron shells are **incomplete**. They generate weak magnetic fields as a result, i.e., k is **positive**. Examples of materials that are paramagnetic are the **20Ca - 28Ni element series**.

.3 Ferromagnetism

Ferromagnetic minerals have **groups of atoms align to make domains**. They have much **larger k** values than paramagnetic elements. There are only **three** ferromagnetic elements – **Iron, Cobalt and Nickel.**

<u>Induced and remnant magnetism</u>

Induced magnetism is due to induction by the Earth's field, and is in the same direction as the Earth's field. Most magnetization is from this source.
It is important to appreciate that since the Earth's field **varies** from place to place.
Remnant magnetism this is due to the previous history of the rock.
The true behavior of **induced magnetization** may be investigated by placing a sample in a coil, until the sample is saturated, reducing increase in H. When H is returned to zero, some magnetization still remains. After the magnetizing force is gone. This is called **remnant magnetization**.

The **direction and strength** of the present Earth's field is known. However, we may **know nothing** about the remnant magnetization of a rock. , it is often assumed that all the magnetization is induced. The **true** magnetization is the **vector**

sum of the induced and remnant components, however. The remnant magnetization be **measured** using an Astatic or Spinner magnetometer, which measure the magnetism of samples in the absence of the Earth's field.

Measurement of magnetic field

Magnetometers measurements can be made of the Earth's total magnetic field or of components of the field in various directions.

Instruments for measuring magnetism

1-Observatory instruments magnetic compass.

2- Flux-gate magnetometer.

3-proton-precession or optical-pumping magnetometers.

The **most used** instruments in modern magnetic surveys are the **proton-precession** or optical- pumping magnetometers and these are appreciably more accurate and all of these instruments give absolute values of field.

It must be found the **different** between the observed magnetic value in **station** and that in **base station** to found the **relative** magnetic value that necessary in **magnetic interpretation**.

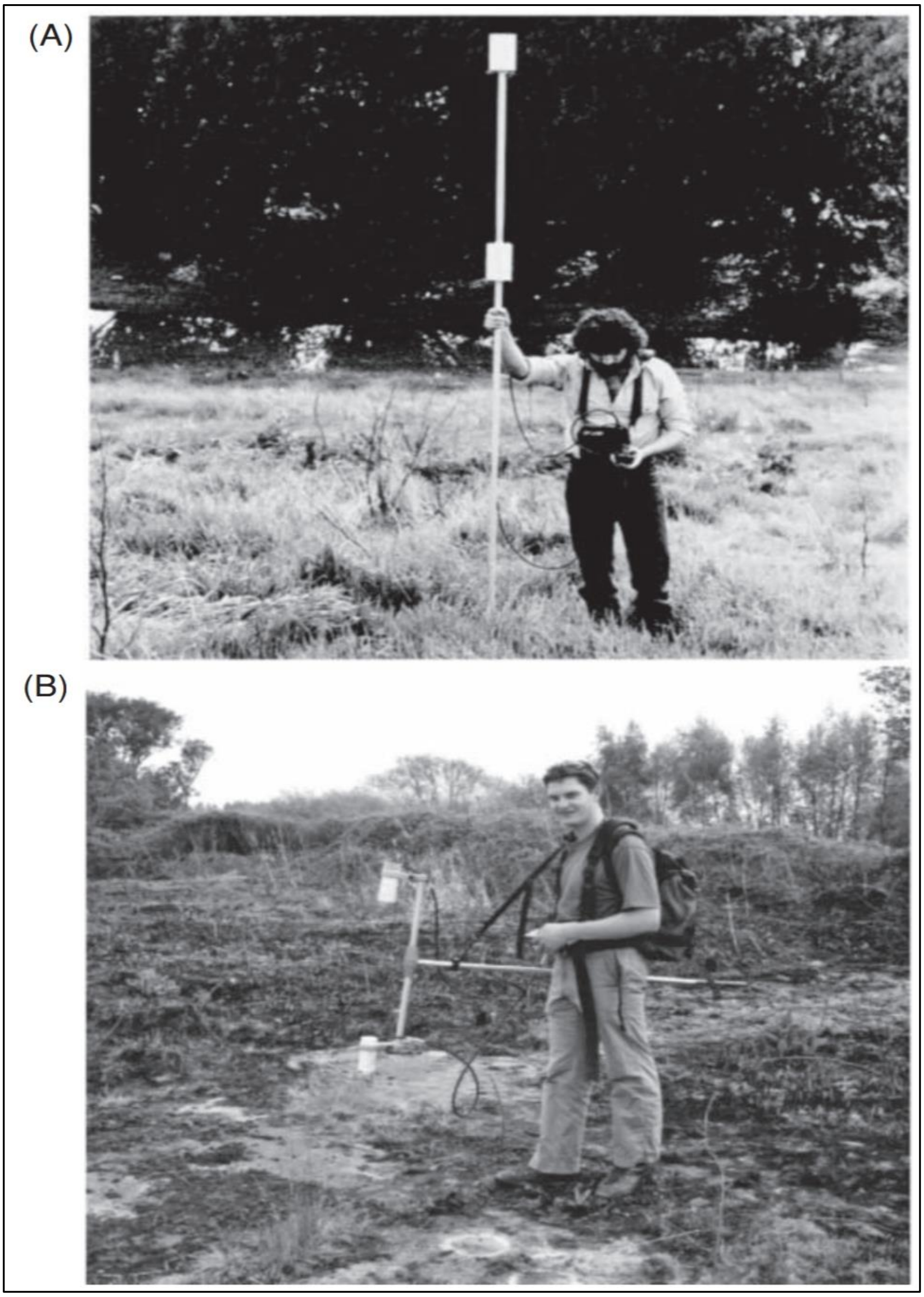


Figure (7): nuclear proton precession magnetometer

Magnetic surveys

Magnetic surveys either directly seek **magnetic bodies** or they seek **magnetic material** associated with an **interesting target**. For example, magnetic minerals may exist in **faults or fractures**.
These surveys are usually done with portable **proton precession** magnetometers. Profiles or networks of points are measured in the **same way** as for gravity. It is important to survey **perpendicular** to the **strike** of an elongate body or two-dimensional modelling. The geomagnetic field is **variable** and **changing with time**, so that, It is necessary **return** to the magnetometer in **base station** at 2-3 hour intervals that take **systematic** readings of magnetic with time. This will give **diurnal drift** and detect **magnetic storms**.

The **operator** must:

- record the **time** at which **readings** were taken, for **drift** correction,
- stay **away** from sensor the interfering objects that makes magnetic noise, e.g., car, power line, wire fences, railway lines, roads,
- Not carry **metal objects** e.g., mobile phones, ring, belts.
- Take multiple readings at each station to checking.

Corrections of Magnetometer observations

Reduction of the observations is much simpler than for gravity:
1. **The diurnal correction**
It’s like drift correction in gravity method. It’s done by put magnetometer in **base station** and take **periodic readings** every one or two hours through the survey time, besides the reading in stations.

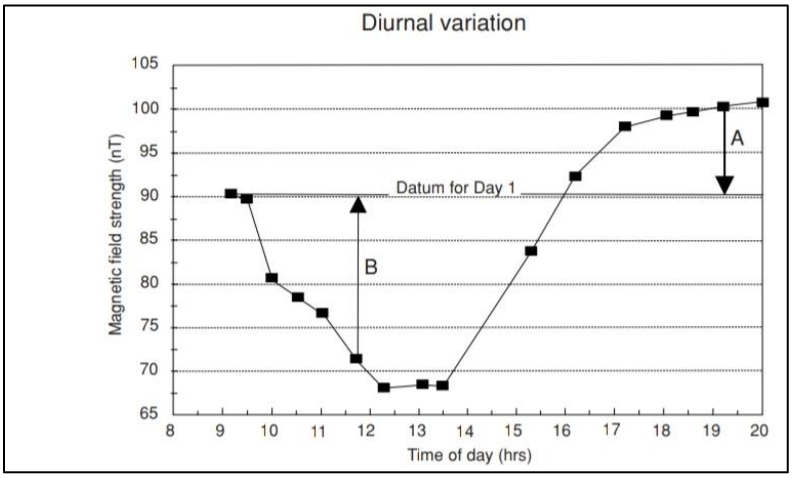


Figure (8) :Diurnal drift curve

3- The magnetic storm correction

A magnetic storm happened **suddenly and grievously**, its makes variations in geomagnetic earth field and affecting on magnetometers during survey makes the data useless. Detecting it in observing data by experience of geophysics, so, he **must stop** the field work.

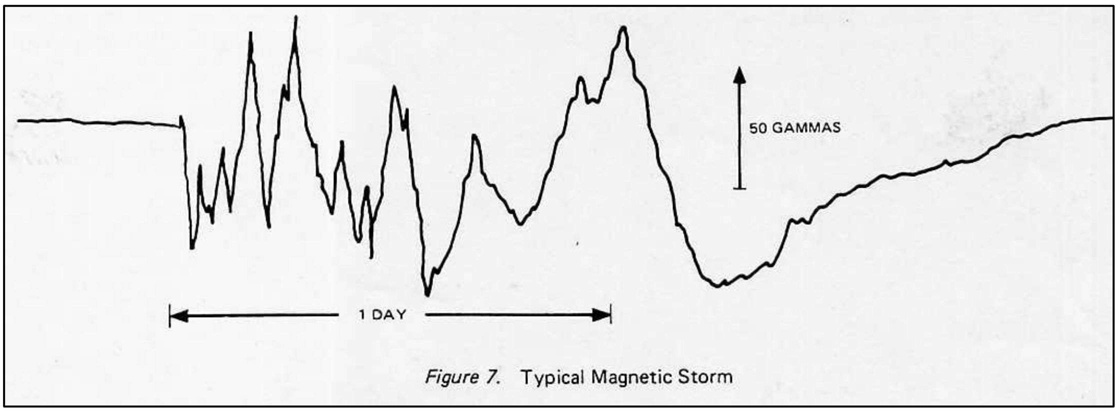


Figure (9): Typical Magnetic Storm

3. Regional trends

These are corrected in the **same way** as for gravity, a linear gradient surface is fit to regional values, and **subtracted**.

Another method is to **subtract** the predicted **IGRF** (International Geomagnetic Reference Field) which is a mathematical description of the field due to the Earth’s core.

The Zero Level

To detect the **magnetic anomaly** it should be **determined** the **zero level** which is the level were the values on it affected with the **natural geomagnetic earth field** and **don't have** any deformation or diffraction from **subsurface geologist bodies**. So it's used as a reference surface (**datum plane**) for the magnetic values, the correcting is by **add or subtract** from this surface and the **difference value** will representing the **magnetic anomaly** of the interests **goal** for geophysics.

The **interpretation** of magnetic anomaly basically **depends** on chose the **zero level**, because its **effects** on calculating the **depth, extension and size of body**.

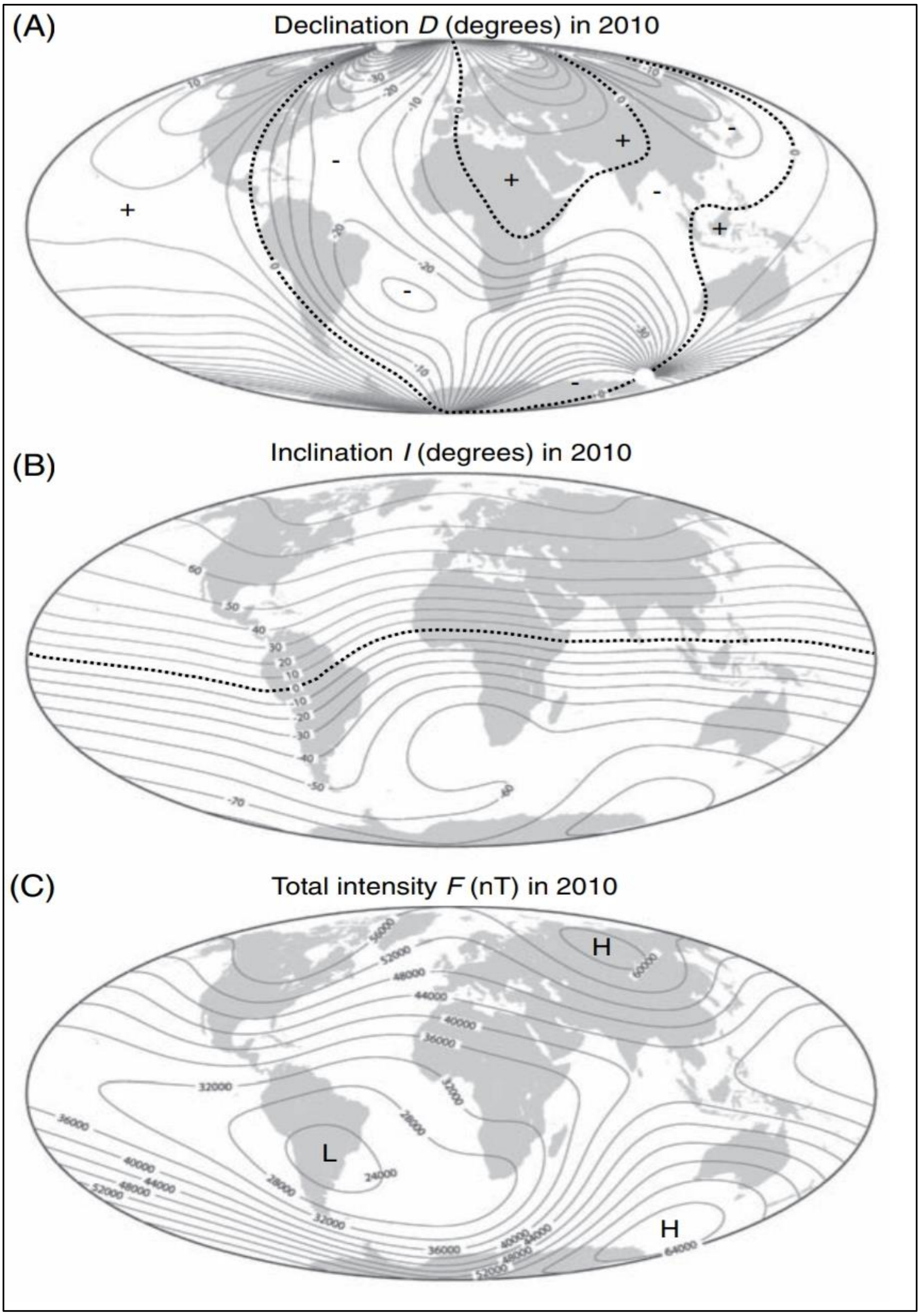


Figure (10); map of the magnetic declination D & inclination I & the zero level & the total intensity F at earth's surface in 2010

Magnetic anomalies

Magnetic effects **result** primarily from the **magnetization induced** in susceptible rocks **by** the Earth's magnetic field. Most **sedimentary** rocks have **very low** susceptibility. Accordingly, the sedimentary rocks are used **negatively** in petroleum magnetics exploration.

Magnetics exploration are **used** for **mapping** features in igneous and metamorphic rocks, possibly faults, dikes, or other features that are associated with mineral concentrations.

Data are usually displayed in the form of a contour map of the magnetic field, but interpretation is often made on profiles.

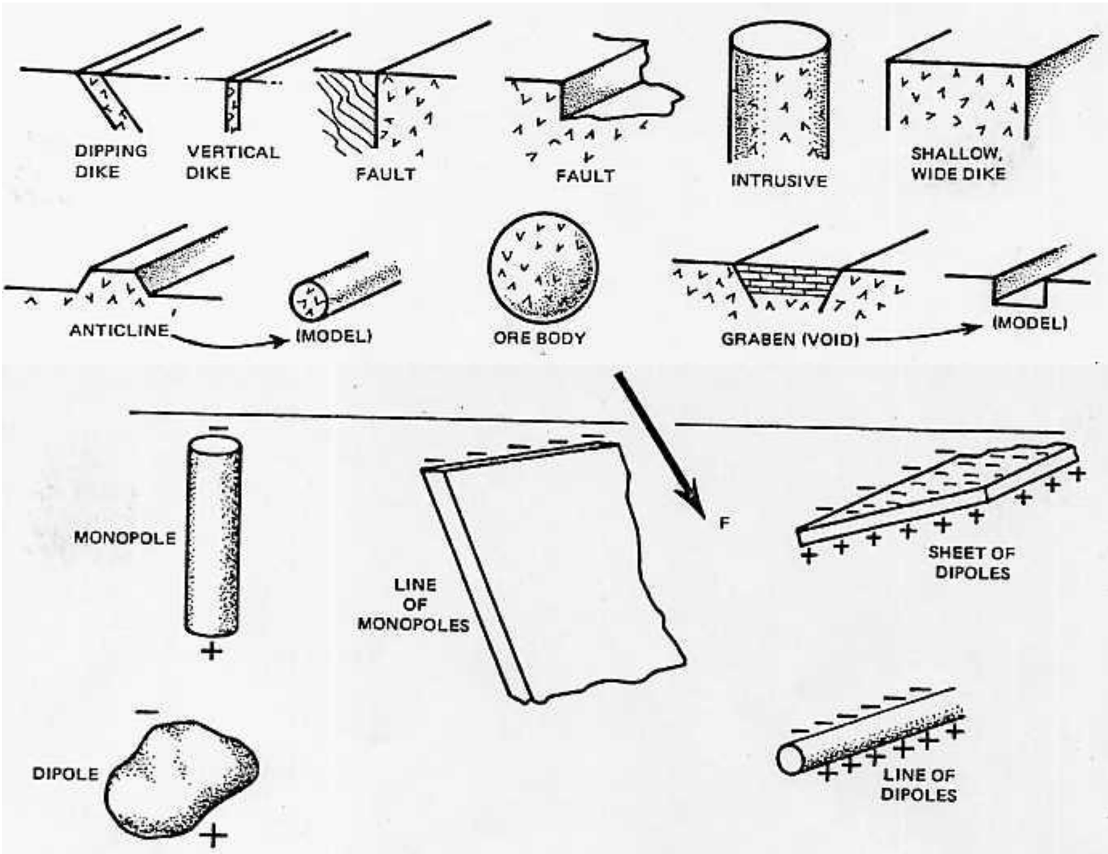


Figure (11): Geological model representations of common magnetic anomaly sources.

<u>**Magnetic field over simple geometrical bodies**</u>

The **form** of magnetic anomaly from a given body is **complex** and generally **depends on** the following factors:
1- The geometry of the body.
2- The direction of the Earth’s field at a location of the body.
3- The direction of polarization of the rocks forming the body.
4- The orientation of the body with respect to the direction of the Earth’s field.
5- The orientation of the line of observation with respect to the axis of the body.

Thus the computations of models to account for magnetic anomalies are **much more complex** than those for gravity anomalies.

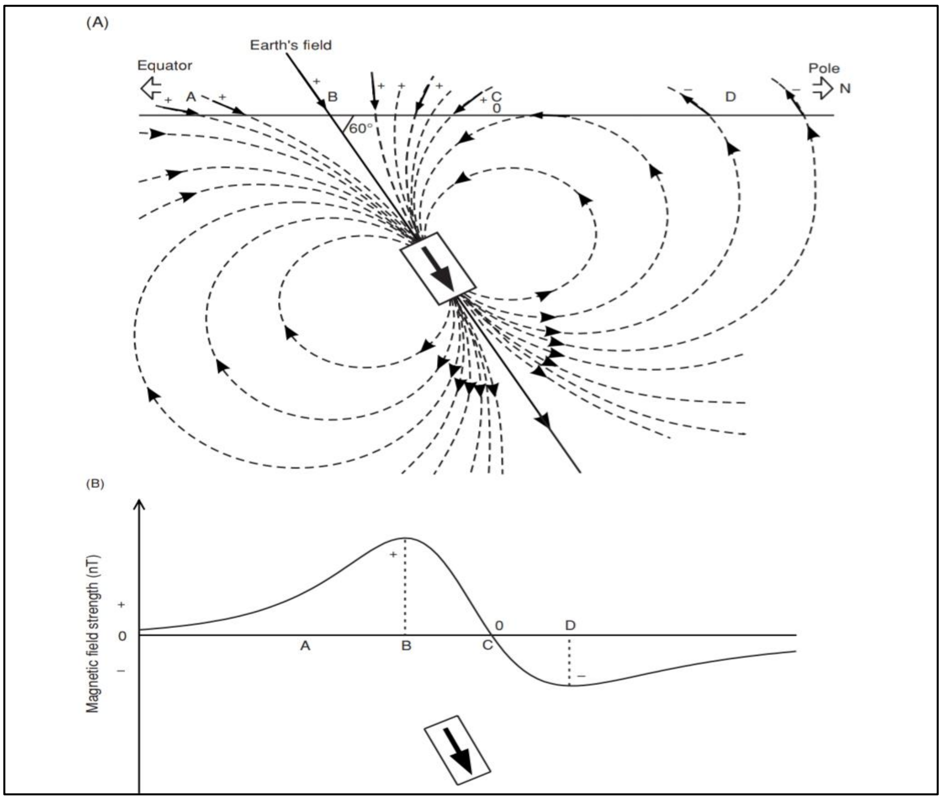


Figure (12): Magnetic field generated by a magnetized body inclined at 60 degree parallel to the Earths field

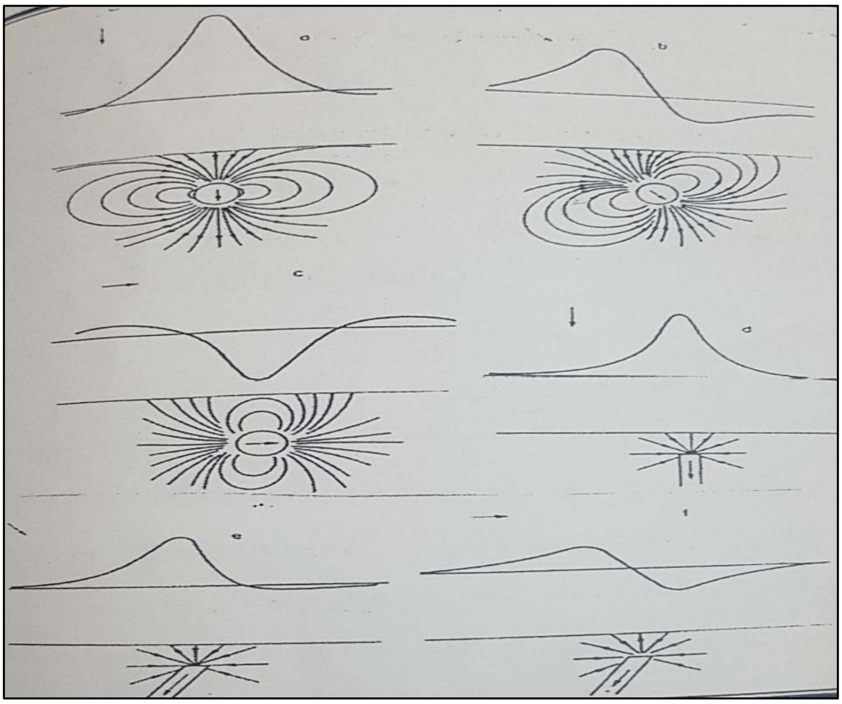


Figure (13): The direction of polarization of the rocks forming the body

Magnetic data processing and interpretation

Magnetic data **processing** includes everything done to the data between acquisition and the creation of an interpretable profile map or digital data set.
The **main goal** of magnetic anomaly interpretation is to estimate the magnetic intensity, shape, size, and depth to upper & lower surfaces body, length and extension of subsurface body which causes this anomaly.

Interpretation of magnetic anomalies has to do with:

1- **Qualitative Interpretation**
   it's done with **visual interpretation** to the magnetic anomaly **map** for location, direction, amplitude for negative or positive anomalies on the map.
   Describe the distribution of magnetic contours line and matching it with geological map of the area.

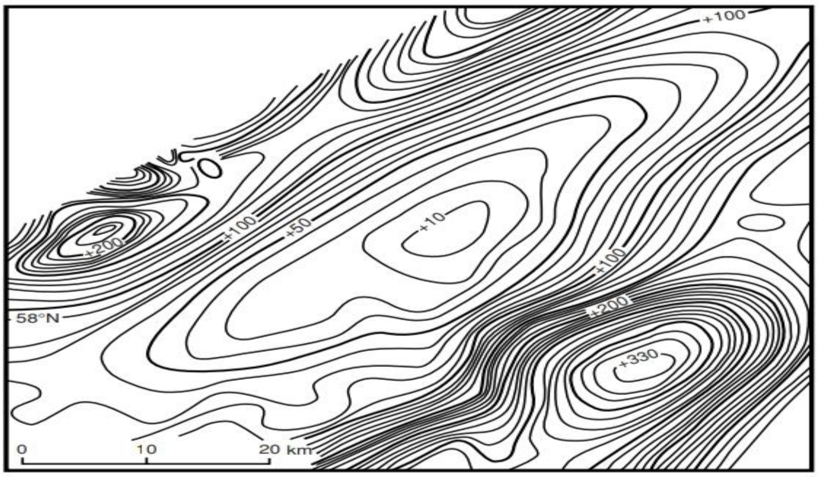


Figure (14): Magnetic anomaly map

2- Quantitative Interpretation

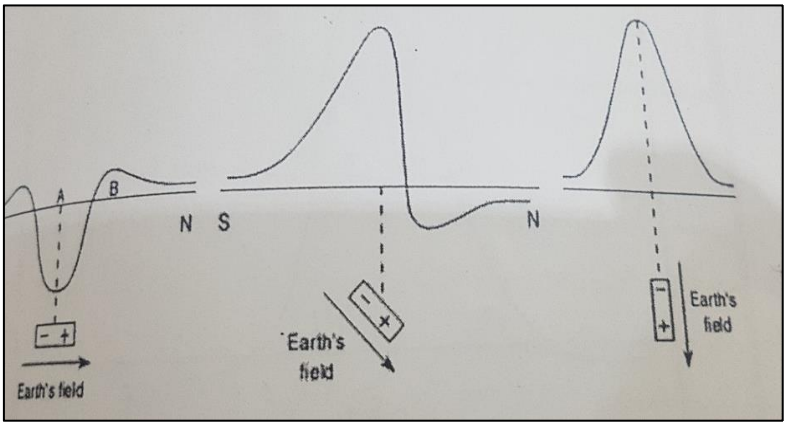
There are **two ways** to reduce the quantitative interpretation.one by **matching** the magnetic **observed** curves (profile) with **stander** curves group to estimate size and depth of anomaly body, the other one is to use the **mathematical ways**.

a- Calculate depth using half width.

b- Strick length.

c- Dip of ore body.

d- Depth extension.



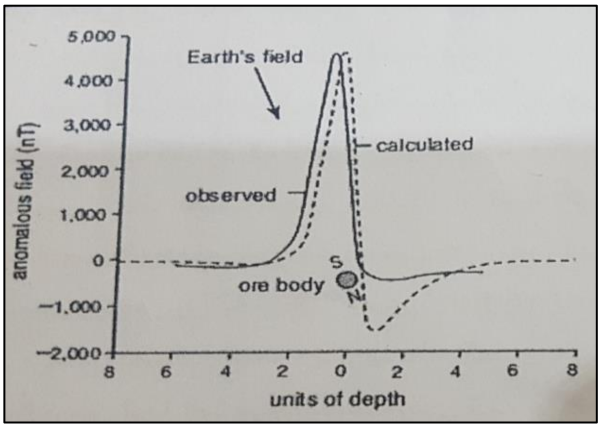


Figure (15): Quantitative Interpretation