المغناطيسية الأرضية و تطبيقاتها

1427 هـ

INTRODUCTION

Magnetometer surveys measure small, localized variations in the Earth's magnetic field. Strong local magnetic fields or anomalies are produced by steel objects buried in the ground, such as tanks, drums, piles and reinforced concrete foundations. Naturally occurring magnetic materials such as basic igneous rocks, and magnetic ore bodies can also be located and mapped by magnetic surveys.

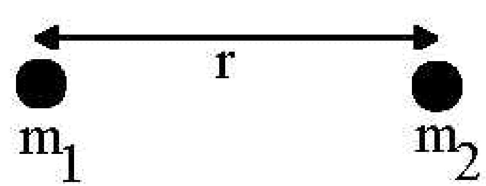
Earth's Magnetic Field

The earth's magnetic field can be separated into three parts:

- **The main magnetic field**: which is produced in the outer core and accounts for the very large regional variations in the field intensity and direction.
- **The external magnetic field**: which is produced by electric currents in the earth's ionosphere.
- **The anomalous magnetic field**: which is produced by ferromagnetic minerals in the earth's crust.

Magnetic force

- analogous to gravitational force
- μ is magnetic permeability (=1 for vacuum, air)



$$F = \frac{1}{\mu}\frac{m_1 m_2}{r^2}$$

- m is magnetic pole strength

<u>Magnetic field strength</u>

- analogous to gravitational acceleration
- force per unit pole strength (force exerted on unit magnetic pole)

$$\vec{H} = \frac{\bar{F}}{m_1}, \text{ or } \vec{H} = \frac{m}{\mu r^2} \text{ (analog: } \vec{g} = \frac{Gm}{r^2}\text{)}$$

<u>القوة المغناطيسية</u>

إذا ما فصل قطبان لهما شدة P_O , P على التوالي بمسافة r فإن القوة F

$$F = 1/\mu \ (P_o P / r^2) \qquad \textbf{(Coulomb Law)}$$

μ : النفاذية : يعتمد على الخواص المغناطيسية للوسط الذي وضعت فيه الأقطاب.

$\mu = 4 \pi \times 10^{-7}$

شدة المجال المغناطيسي **(H)** هي القوة لكل وحدة من شدة القطب التي سوف تبذل على قطب صغير ذي شدة P_O إذا وضع عند هذه النقطة.

$$H = F / Po = P / \mu r_2$$

ووحدتها أورستد واحد O_e **(Oersted)**

* المجال المغناطيسي الكلي للأرض يكون عادة حوالي $\frac{1}{2} O_e$ أو **50.000** جاما مكافئة للنانوتسلا nT في نظام mksg

nT = 10^{-9} Tesla
1 tesla = 10^{4} oersted

1 gamma = 10^{-5} oersted = 1 nT

في حالة وجود مجال خارجي متجانس **H** يصنع زاوية **θ** مع العمودي على سطح المادة القادرة على التمغنط فإن شدة القطب المستحث : $I = KH \cos \theta$

أو المجال عمودي على السطح $I = KH$

الحث المغناطيسي

الأقطاب المغناطيسية المستحثة في مادة ما بواسطة مجال خارجي **H** سوف ينتج مجالاً خاصاً بها **H`** والذي يكون مرتبطاً بشدة التمغنط **I**.

$$\mathbf{H}^{`} = 4\pi I$$

التدفق المغناطيسي الكلي داخل المادة ، مقاساً في تجويف ضيق ذي محور عمودي على المجال يسمى بالحث المغناطيسي (مجموع المجالات الخارجية والداخلية)

$$B = H + \mathbf{H}^{`} = H + 4\pi I = H + 4\pi K H$$

$$\mathbf{B = (1 + 4\pi K) H = \mu H}$$

$$B = \mathbf{\mu H}$$

النفاذية ثابت التناسب $\mathbf{4\pi K + 1}$ **يكافىء النفاذية μ الداخلة ، لذلك :**

$$\mathbf{\mu = B/H = 1 + 4\pi K}$$

لو رفعنا المجال المغناطيسي عن الصخر سنجد أن بعض التأثير سيبقى بالرغم من زوال المؤثر.

Magnetic Elements

Three magnetic quantities:

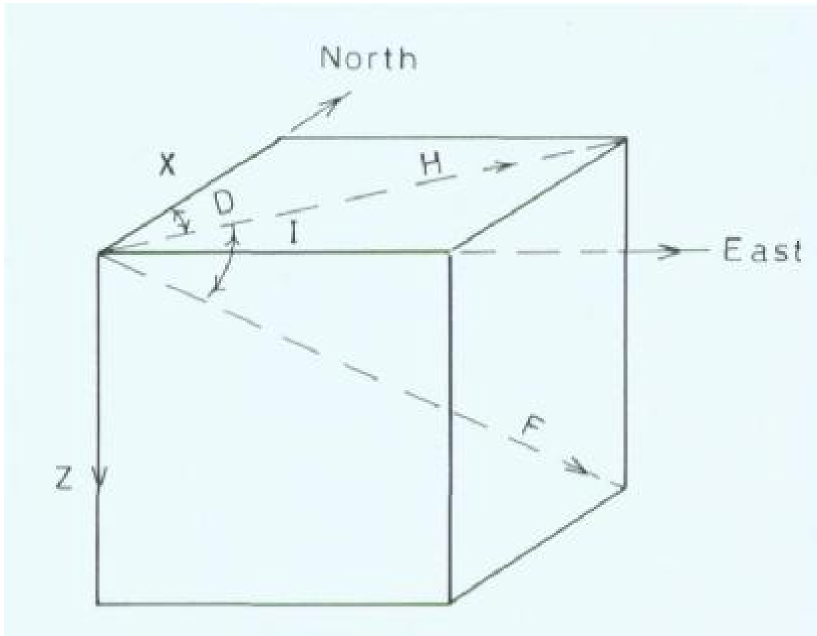
1- **Magnitude.**

2- **Magnetic inclination (I):** Direction with respect to horizontal.
$I = 90^o$ at N. poles, $- 90^o$ at south pole.
I = Ø at the equator.

3- **Magnetic Declination** (Direction with respect to geographic north).

The lines of force are directed outward from positive North (N+) pole and inward to a negative (S-) pole.

الإبرة المغناطيسية عند القطبين	**عمودية**
الإبرة المغناطيسية عند خط الإستواء	**أفقية**



The total field F is resolved into its horizontal components H (x , y) and it vertical components Z. The angle which F makes with its horizontal components H is the inclination (I), and the angle between H and X (points North) is the declination (D).

$\mathbf{F^2 \quad = X^2 + y^2 + Z^2}$

$\mathbf{F^2 \quad H^2 + Z^2}$

$\mathbf{H \quad = F \cos I}$

$\mathbf{Z \quad F \sin I}$

$\mathbf{X \quad = H \cos D}$

$\mathbf{Z / H = \tan I}$

Tan I = 2 tan Ø → Latitude

F at North Pole = 60,000 nT
F at South Pole = 70,000 nT
F at equator = 30.000 nT

$\mathbf{F_{pole} = 2 \ F_{Equator}}$

Basic Field Procedures

Variations of Time in the Earth magnetic field :

a- **Secular variation** : slow change in I , D over a period of time.
b- **Diurnal variation** : every day $\rightarrow \pm$ 30 nT
c- **Lunar variation** : every 25*y* $\rightarrow \pm$ 2 nT
d- **Magnetic storms** : changes with latitude $\rightarrow \pm$ 1000 nT

Diurnal corrections

- drift correction, identical to gravity:

$$F_{dc} = F_{obs} - \frac{F_{Base2} - F_{Base1}}{t_{Base2} - t_{Base1}} \times (t_{obs} - t_{Base1})$$

- re-occupy every hour or two
- recording base-station magnetometer
- must avoid magnetic storms

Reduction of Magnetic Data

Secular variation

- drift correction takes care of short-term secular variation
- main field varies significantly over years
- must adjust surveys to match them up
- International Geomagnetic Reference Field (IGRF)
    - computed every 5 years
    - based on spherical harmonic expansion of field

EQUIPMENT

Magnetometers are highly accurate instruments, allowing the local magnetic field to be measured to accuracies of 0.002%. The proton precession, caesium vapour and gradiometer magnetometer systems are used for commercial applications. The systems operate on broadly similar principles utilizing proton rich fluids surrounded by an electric coil. A momentary current is applied through the coil, which produces a corresponding magnetic field that temporarily polarizes the protons. When the current is removed, the protons realign or process into the orientation of the Earth's magnetic field.

Gradiometers measure the magnetic field gradient rather than total field strength, which allows the removal of background noise. Magnetic gradient anomalies generally give a better definition of shallow buried features such as buried tanks and drums, but are less useful for investigating large geological features. Unlike EM surveys, the depth penetration of magnetic surveys is not impeded by high electrical ground conductivities associated with saline groundwater or high levels of contamination.

Flux-gate magnetometer

- relative instrument
- can be used to find vector components, direction of field
- portable instruments usually set up to read H_Z (vertical component)

Proton-precession magnetometer

- simple, inexpensive, accurate, portable instrument
- measures absolute, total value of field
- 1 nT precision
- susceptible to strong magnetic gradients

Magnetism of Rocks and Minerals

The intensity of magnetization

$I = M / V$

M = magnetic moment = $m L$

V = Volume

m = pole strength

L = length

Intensity of magnetization ∞ H and has the same direction.

Magnetic susceptibility (K) : It is the degree to which the material is magnetized. $I \infty H$ OR $I = KH$

$$K = I / H$$

- K is directly proportional to Fe %.

$$I = \frac{M}{volume} = \frac{ml}{volume} = \frac{m}{area}$$

- magnetic moment is extensive quantity (like mass),
- intensity of magnetization is an intensive quantity (like density)

Magnetic Susceptibility K is dependent on :

1- The state of magnetization.
2- Intensity of saturation magnetization.
3- Grain size.
4- Internal stress.
5- Shape
6- Mode of dispersion.

Magnetism of Rocks and Mineral According to K Values

1. Diamagnetic , weakly magnetic, K is negative $K < o$
   a. Ex. gypsum, quartz, graphite, salt domes.

2. Paramagnetic weakly magnetic, small positive K, $K > o$,
   a. Ex. Common silicate minerals pyroxene, olivine.

3. Ferromagnetic : have positive and relatively Large
   K ($K >> O$) Iron, Nickle.

   a- Ferrimagnetic, in which the induced magnetic is in two opposite directions, like the magnetite **$Fe_3 O_4$**, but with different values.

   b- Antiferrimagnetic in which the induced magnetic is in two opposite directions as in Hematite **$Fe_2 O_3$**, but with same values. (Zero).

Mineral and rock susceptibilities

Mineral	Formula	k (emu)	Curie T, oC
magnetite	Fe_3O_4	0.3 - 0.8	580
hematite	Fe_2O_3	0.0006	680
ilmenite	$FeTiO_3$	0.135	50 - 300
pyrrhotite	FeS	0.125	320
maghemite	Fe_2O_3	variable	545-675
Typical Rock Susceptibilities			
Sedimentary rocks	0.00005 cgs emu		
Metamorphic rocks	0.0003 cgs emu		
Granites and rhyolites	0.0005 cgs emu		
Gabbros and basalts	0.006 cgs emu		
Ultrabasic rocks	0.012 cgs emu		

<u>Remanent Magnetization in Rocks</u>

- Remanent field (remains even after external field removed)
  - thermoremanent
  - detrital remanent
  - chemical remanent

Total magnetization (J) = Remanent (Jr) + induced (Ji)

intensity of Jr is large in igneous and thermally metamorphosed Rocks.

Koenigsberger ratio. Q = Remanent (Jr) / induced (Ji)

Q > 1, Jr of sediments is smaller than Ji.

<u>Magnetic Anisotropy of Rocks</u>

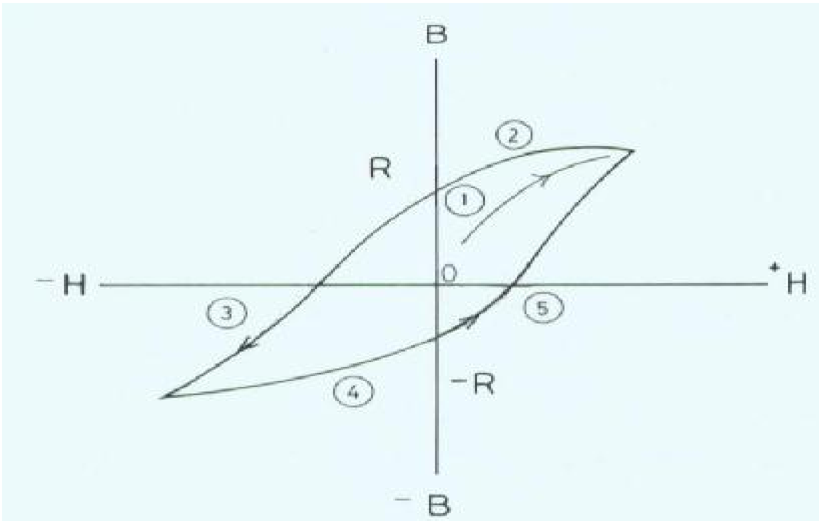
<u>Two types anisotropy</u>

1- When the shape of the magnetically isotropic grains in a rock is elongated along a special direction, K may become anisotropic. This is called the shape anisotropy and dominates in <u>magnetite</u>.

2- In some rocks, the major ferromagnetic minerals themselves have a marked magneto crystalline anisotropy depending on the direction of Hex (ex. Ilmenite - hematite series, pyrohotite).

Hysteresis Loop for Ferromagnetic Material

يمثل هذا المنحني : كيف يمكن لجسم ذو تأثرية مغناطيسية K أن يبقى ممغنطاً بعد زوال قوة التمغنط الأصلية.
التناسب المباشر بين H & B ينهار هذا التناسب كلية في المواد ذات المغناطيسية العالية



1. التمغنط يبدأ بإدخال تيار في ملفات المغناطيس H > O.
2. تتمغنط العينة إلى درجة التشبع وعندها يقترب المنحني من الخط الأفقي وعندئذ يعود المجال الخارجي إلى الصفر. ولكن B لا تعود إلى الصفر. وبدلاً من ذلك تأخذ القيمة R والتي نسميها بالمغناطيسية المتبقية .Remanent mag.
3. إذا ما عكس الآن التيار فإن B سوف تقل حتى تنعكس أيضاً. وفي نهاية الأمر تقترب من التشبع في الإتجاه السالب.
4. النقص في المجال المعكوس إلى الصفر سوف يحضر B إلى `R-.
5. تطبيق مجال التمغنط الموجب سوف يعكس إتجاه B مرة أخرى وينتج طور ثاني للتشبع الموجب.

Processes of acquisition of Natural Remanent magnetization (NRM)

1- Thermo-remanent mag. (TRM).

2- Chemical Remanent mag. (CRM). During crystallization of fine magnetic grains at temp. below curie points. (Red sandstone beds).

3- Depositional remanent mag. (DRM) : acquired during the deposition of very fine magnetized grains which fall down through water. (Varved clays).

4- Isothermal Rem. Mag. (IRM).

5- Viscous Rem. Mag. (VRM).

6- Self-reversed mag (SRM) acquired in a direction opposite to that of the field acting during acquisition of NRM.

7- Piezo-remanent magnetization. (PRM) acquired by applying and releasing mechanical stresses in an ambient field at a constant temperature.

Applications of Rock magnetism in paleomagnetism :

a- Reversals of the earth's field. (most recent reversal about 20.000 y. ago., 50/50 N/R.

b- Sea floor spreading.

c- Secular variation and paleo intensity of the earth field.

d- Polar wander and continental drift.

e- Paleo climatology.

f- Magnetic dating of rocks by :

- secular variation 10^3 y.
- polarity zones $10^4 – 10^6$ y.
- average paleomagnetic pole positions $10^7 – 10^9$ y.
- Q ratio.

g. Tectonic movements involving rotation. Ex. Japan. By NRM.

GENARAL APPLICATIONS

- Finding buried steel tanks and waste drums
- Detecting iron and steel obstructions
- Accurately mapping archaeological features
- Locating unmarked mineshafts
- Mapping basic igneous intrusives & faults
- Evaluating the size and shape of ore bodies

Similarities Between Gravity and Magnetics

$$\vec{F} \propto \frac{m_1 m_2}{r^2}$$

- conservative, ***therefore*** potential field ***therefore*** LaPlace's Equation
- natural source methods, non-invasive
- small anomalies in large total field
- vary in time and space
- used as reconnaissance tools in exploration

Differences Between Gravity and Magnetics

- mass is monopolar, magnetism dipolar
- all matter has mass *therefore* contributes to g; main magnetic field sourced in core, altered by upper crust
- g always vertical *therefore* only measure $|\vec{g}|$; $\vec{B}$ is vector
- g requires 0.1 ppm accuracy, m > 10 ppm
- gravimeter is relative instrument; magnetometer absolute
- densities vary from 1 to 4; susceptibility over several orders of magnitude
- g anomalies smooth, regional; m sharp, local
- tides are only external g effect, can be corrected; effect of magnetic storms cannot be removed
- g corrections: drift, latitude, free air, Bouguer, terrain, etc.; m corrections: ± drift, IGRF
- g surveys slow, expensive; m costs about 1/10 of g

PROBLEMS

IF THE MAGNETIC SUSCEPTIBILITY OF A SPHERICAL PLUTON IS 0.0003 AND THE EARTH'S MAGNETIC FIELD (B) IS 0.0006 TESLA. THE RADIUS OF THE PLUTON IS 1 KM AND THE MAGNETIC PERMEABILITY IS $4\pi \times 10^{-7}$.

COMPUTE :

1. **THE MAGNETIC FIELD STRENGTH (H)**
2. **THE INTENSITY OF MAGNETIZATION (I)**
3. **THE MAGNETIC MOMENT OF THE PLUTON (M).**