COURSE GUIDE

PHY 261
GEOPHYSICS I

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CONTENTS **PAGE**

Introduction

Geophysics 1 (PHY 261) is a 2 credit unit second semester course available to all student offering Bachelor of Science (B.Sc.) Physics Geophysics is a unit in physics department in which any one can specialise as an area of research interest. It is an area where physics principles are employed to study the earth in its entirety. That is, geophysics can be seen as an area where physics principles are employed to explore the liquid, solid and gaseous part of the earth.

This course concerns with application of physics principles to studying the solid earth.

Requirement for this Course

To adequately comprehend this course you will require sound knowledge of basic principles in physics, at least up to the second year level at University. Sound footing in mathematics is necessary to be able to comprehend the mathematical relations involved in the treatment of this course; this is in addition to high commitment to learning. The course must be handled by a trained applied geophysicist, with sound knowledge of physics of the solid earth and geophysical methods such as Gravity and magnetic.

What you will learn in this Course

The course is treated under 21 units, sectioned into 4 modules. You are fully informed on every subtopic for further readings peculiar to each unit are provided under each unit. Guidance to solutions to the tutor-marked assignments is provided in the assignment file name TMA solution. You are strongly advised to attend the regular tutorial classes on the course. The course will provide you with information to face the challenges in the area of introductory geophysics regarding geomagnetism, magnetic and gravity methods.

Course contents

For proper understanding, this course is structured as followed:

The earth: internal structure and constitution, Density of rocks and ores. Geomagnetism: Origin, properties of rocks. Gravity methods: Newton's gravitation, Application, instruments, Zero-length spring gravimeter, Field works, data processing and interpretation. Magnetic methods: Definitions, concepts, instrument, fieldwork, data processing and interpretation.

Course Aims

This course aimed at acquainting you with knowledge on meaning and sources of geomagnetism, gravity and magnetic methods of geophysics prospecting.

Course Objectives

In order to achieve the aims of this course each unit has specific objectives to be achieved at the expiration of studying every unit. Below are the comprehensive objectives of this course you should be able to:

- Explain the theoretical background of gravity methods
- Describe the working principles of zero-length gravimeter
- Explain the gravity field procedure, data processing and interpretations.
- Describe density determination and variations within the solid earth
- Explain the origin and properties of geomagnetism
- Discuss the working principle of proton magnetometer
- Explain the magnetic field procedure, data processing and interpretations.

Working through this Course

To complete this course you will need to read every unit, related texts and other materials which may be provided by the National Open University of Nigeria (NOUN).

Each unit contains self assessment exercise that will test your comprehension at certain stages of the unit. You will be required to submit assignment for assessment purposes. At the end of the course there will be a final examination.

The course will take about 17 weeks to complete. Below, you will find what to do, how to do and suggested time allocations to each unit for successful completion of the course. You will need to engage in a serious personal reading and to attend tutorial sessions where you could validate some of your personal findings.

The course Materials

The main components of this course are:
(a) Course guide
(b) Study modules
(c) Assessments
(d) Presentation Schedule.

Course Guides

This presents you all-round in formations such as the course content, aim and objectives, requirement for successful execution of the course including time management assessment procedure etc. you are advised to read the course guide carefully as it will serve as your road map into mastery of the course.

Study Modules

The content is sectioned into 4 modules. Each module contains series of units of related concepts. The details of the modules are shown below:

Unit 5: Quantitative interpretation of magnetic data

You should be able to exhaust about 2 units within a week in order to work ahead of time. Each unit contains subtopics related to the main topic of the unit in question as shown above. As main headings, each unit includes; introduction, objectives, subtopics, reading materials, self-assessment exercises, conclusion, summary, Tutor marked assignment and references and other resources.

Assessments

There are three main aspects for the assessments of the course.

(a) Self-assessment exercise: This is done by yourself on yourself to access your progress and give directions for improvement in subsequent studies.

(b) Tutor marked assignment: This serves as a recapitulation on your understanding of the unit which will concretise your understanding in a convincing way to the facilitator in charge.

(c) Written Examination: This comes up once at the end of the course for the purpose of quantification of your comprehension the whole course at a sitting.

You are strongly advised to attempt all the assessments. The works you submit to the facilitator will count 30% marks and the end of course examination will stand for 70% marks of the total score for the course
You are advised to always submit the tutor marked assignment to the facilitator as scheduled. It must be noted that evidences of independent readings outside the written course materials given attract much marks from the facilitator in the submitted assignments.

You must note that course materials given have important dates for the timely completion. Thus, prompt attendance of tutorials and timely submission of assignment are imminent for the successful completion of the course. You should guide against falling behind in your works.

Preparations for End of Course Examination

As parts of preparation, through revision of all the units is necessary within the gained time at the end of the study time. You would find it helpful to review all the self-assessment exercise as the examination covers the whole course unit. The examination could be for 3 hours and could not be unrelated to self-assessment and tutor marked exercises. The skeletal course marking scheme for the final examination is shown in table1.

Table: PHY 261 marking scheme

Exercise	Scores
Assignment 1-4	Four assignments, 75% each, totalling 30%
End of course examination	You will attempt all the questions given for 70%
Total	100% of course materials

Facilitator – Student Interactions

You have 16 hours of tutorials with the facilitator. You will be notified informed of the dates, times and location of tutorials as soon as you are allocated a tutorials group. Your facilitator will always mark and comment on your submitted assignments. You are expected to submit the assignments in time rather than on time. You are free to register complaints, should you not contented with the markings of the assignments as soon as possible preferably, before the submission of the next assignment. You can always prepare lists of questions before the next tutorial.

Conclusion

Geophysics 1 is a course that acquaints you with basic theoretical background of gravity and magnetic geophysical prospecting methods. Instrument, survey techniques, data acquisition, processing and interpretation are dealt with in the course.

MAIN COURSE

CONTENTS **PAGE**

Module 1: Earth: Internal Structure and Constitution, Densities: Rocks And Ores

Unit 1: Origin of the Earth

1.0 Introduction

Earth is a terrestrial body whose solid surface, abundant water and oxygen - i.e. rich atmosphere - have combined to create conditions suitable for life to develop on it. The earth exists in the form of three states of matter-the solid rocks on which we stand, being the SOLID, ocean is the LIQUID and atmosphere depicts the GAS. Understanding of the structure, origin and nature of the solid earth is imperative for a meaningful study of the solid part of the earth. This unit deals with the formation theories of the earth, differentiating characteristics of the earth as well as causes and effects of earth zoning.

2.0 Objectives

At the end of this unit you should be able to:

(a) Relate cold and hot theories of the earth formation.

(b) State at least three characteristic that differentiates the earth from other planets

(c) Enumerate at least three conditions that make the earth a congenial place for life to develop

(d) Explain the cause and after mat effects of IRON CATASTROPHE.

(e) Explain the formation of the three states of matter components of the earth.

3.1 Early Theories on the Origin of the Earth

The theories explained the formation of the planet including the earth.

3.1.1 Cold Origin Theory

Nebula hypothesized that a primeval rotating cloud of dust and gas filled the universe initially. Kant explained further that the denser centre of the rotating dust in the Nebula’s hypothesis formed the sun. The less dense side portion of the rotating dust broke into pieces to form the planets which the earth is one of them. However, this theory failed to explain angular momentum observation in the solar system whereby sun alone constitutes 99.9% mass of the solar system but 99% of the angular momentum of the solar system is concentrated in the large farther planets from the sun.

3.1.2 Hot Origin Theory

The theory holds that gravitational attraction between the sun and the preexisting passing stars caused violent collisions and materials were turn off from the colliding stars. The turn off particles joined in parts and formed the planets in which the earth is a part.

The weaknesses of this theory are:

- Angular momentum observation about the solar system was not explained.
- Why has the collisions happened once, is ambiguous.

- Why the collision is perfectly elastic? The materials could have scattered.

3.2 Peculiar Features of the Earth

The planet earth possesses some distinguishing features that differentiated it from other planets. Some of the features suit the development of lives in it. Some of the characteristics are:

- High gravitation field, that keeps objects on its surface
- Uniform motion such as rotation, revolution and wobbling that causes day and night and seasonal changes.
- Presence of enough water for activities such as agriculture.
- Balanced distance from the sun, not too short nor too far
- Presence of rich atmosphere in gaseous form and contains ozone layer.

3.3 Sources of Earth's Zoning

About 4.7 billion years ago there was an accretion of conglomeration of unsorted particles scattered in the universe forming the earth as one of the planets. The earth became warmed up as a result of the following processes:

- **Particle acceleration :**The kinetic energy of the particles coming together turned To heat energy
- **Gravitational pull between the particles:** The pulls resulted in high pressure which raised the heat energy.
- **Radioactivity:** Heat evolved during disintegrations of radioactive elemental components of the earth's particles.

The heat from the above sources raised the temperature of the earth to the melting point of iron which melted the whole earth – the event called **IRON CATASTROPHE**.

3.3.1 Zoning of the Solid Earth

The molten earth that resulted during Iron catastrophe settled such that lighter particles like silicon etc floated, cooled and formed the outer crust and mantle. The heavier particles like iron etc settled beneath the crust forming the core. Hence, iron formed $\frac{1}{3}$ of the earth mass (Fig.1) Water containing particle in the earth went through chemical changes and released water which settled on the surface to form the ocean. Gas containing particles also went through chemical changes releasing gasses to form the lightest atmosphere which is located on top of the liquid and parts of the earth.

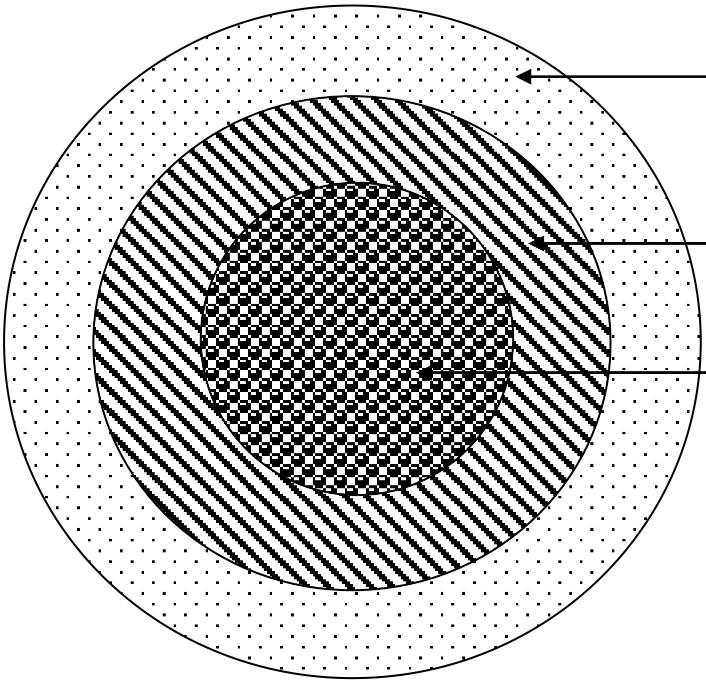

Fig.1: Simplified Model of the Solid Earth

3.4 Self Assessment Exercise

(a) The earth is formed from the remnant particles of what heavily bodies, according to the hot origin theory?
(b) List the source of the heat that caused iron catastrophe.
(c) Which part of the solid earth is densest?
(d) Why is the ocean located on the surface of the earth?

4.0 Conclusion

Earth originated from preexisting entities in the universe, be it particles or parts of heavenly bodies. The internal and external parts of the earth are in a regular zone that conformed to scientific reasoning.

5.0 Summary

I this unit you have learnt the following:

(i) Cold and hot origin theories of the earth
(ii) The characteristics of the earth that suit the development of life on it.
(iii) Iron catastrophe was caused by heat from particle accretion, gravitational pulls and radioactive decay, the aftermath of which is earth zoning.

(iv) The solid earth has three basic sections V_{13} :crust, mantle and core

(v) Over 33% of the earth's mass is iron

6.0 Tutor Marked Assignment

(1) List 5 conditions that make the planet earth a congenial place for living things to survive.

(2) Explain the effects, if the distance of the earth from the sun were less or more than what it is now.

(3) Justify the formations of ocean and atmosphere above the solid earth.

(4) Mention one weakness each of cold and hot origin theories of the earth.

7.0 Further readings and other resources

1. Dunlop, David J.; Özdemir, Özden (1997). Rock Magnetism: Fundamentals and Frontiers. Cambridge Univ. Press. ISBN 0-521-32514-5.

2. Hunt, Christopher P.; Moskowitz, Bruce P. (1995). "Magnetic properties of rocks and minerals". In Ahrens, T. J. (ed.). Rock Physics and Phase Relations: A Handbook of Physical Constants. Vol. 3. Washington, DC: American Geophysical Union. pp. 189–204.

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4. Jeffreys, Sir Harold (1959). The earth: its origin, history, and physical constitution. Cambridge Univ. Press. ISBN 0-521-20648-0.

5. McCabe, C.; Elmore, R. D. (1989). "The occurrence and origin of Late Paleozoic remagnetization in the sedimentary rocks of North America". Reviews of Geophysics. **27** (4): 471–494. Bibcode:1989RvGeo..27..471M. doi:10.1029/RG027i004p00471.

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8. Stacey, Frank D.; Banerjee, Subir K. (1974). The Physical Principles of Rock Magnetism. Elsevier. ISBN 0-444-41084-8.

Unit 2: **Motions of the earth**

1.0 Introduction

The non- stability of the planet earth is exemplified in various events such as occurrence of day and night, seasonal variation as well as annual irregular length of days and night are some of the evens that exemplified the movement of the earth. This unit examines the various modes of motion like rotation, revolution, wobbling and their effect such as centrifugal sorting and oblate nature of the earth.

2.0 Objectives

By the end of this unit you should be able to:

(a) Describe the three main types of motion of the earth
(b) State the effect of each of the three motions.
(c) Show diagrammatically the two hypotheses of earth's rotation
(d) Explain the cause of the density variation of the solid earth
(e) Relate the centrifugal sorting to the density variation of the solid earth

3.1 Types of motion of the earth

The earth, in order to maintain celestial dynamic equilibrium with other planets and other heavenly bodies, is under going series of complex motions. The three major types of the motion whose effects are observable in our daily life are discussed ahead.

3.1.1 Revolution

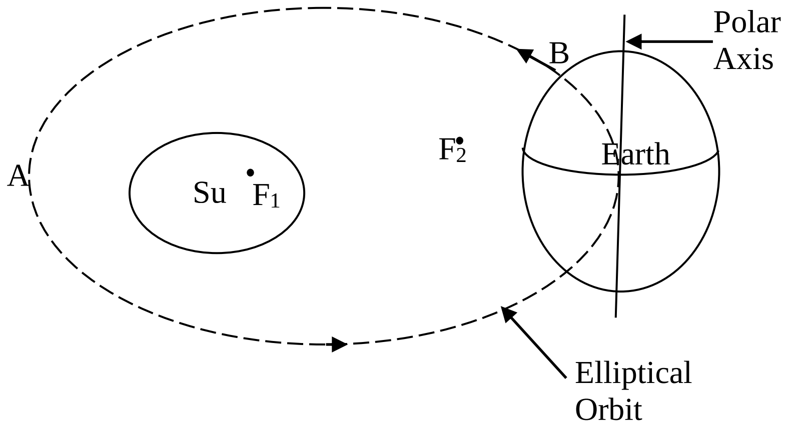

Fig.1: Revolutionary motion of the

The earth moves along an elliptical orbit whose plane is fairly perpendicular to the polar axis of the earth. F_1 and F_2 are the foci of the orbit with sun at one of the foci. This motion has a periodicity of 31557600 seconds (i.e. a year) and determines the global season. The seasonal change is brought about as a result of earth distance from the sun at each location on its orbit. For instance, at location B the earth is far from the sun, so the sun's heat may not be much to cause enough evaporation for much rain. At location A the earth experiences much heat of the sun rays. This causes intense evaporation, leading to rain possibility.

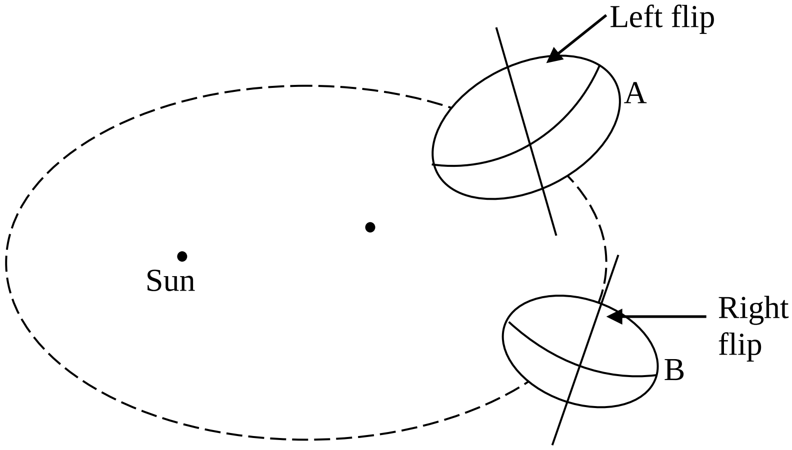

Fig. 2: Flip-flop Motion of the Earth

3.1.2 **Wobble**

The earth exhibits Flip-flop (wobble) motion about its equator as it is revolving round the sun. It should be noted that northern hemisphere is closer to the sun than southern hemisphere. Thus, northern hemisphere experiences longer day and shorter night at this time; But reverse is the case at the location B.

3.1.3 **Rotation**

This is a rotation about polar axis from west to east in an anticlockwise direction, viewing from the tip of the northern pole. The average period of earth's rotation is
86400 seconds. (i.e. a day). Hence, rotation of the earth:

- determines the length of the day and night
- causes its ellipsoidal/oblate shape i.e. equatorial radius being longer than the Polar radius
- results in density variation from the surface to the centre of the earth

3.2 **Hypotheses about the Rotation of the Earth**

3.2.1 **Cassini's hypothesis**

He proposed that the earth is rotating about the equator with the polar axis perpendicular to the axis of rotation. If this is true then the earth will assume <u>prolate ellipsoid shape</u> and one side of it would be experiencing permanent day light while the other side would be in darkness permanently.

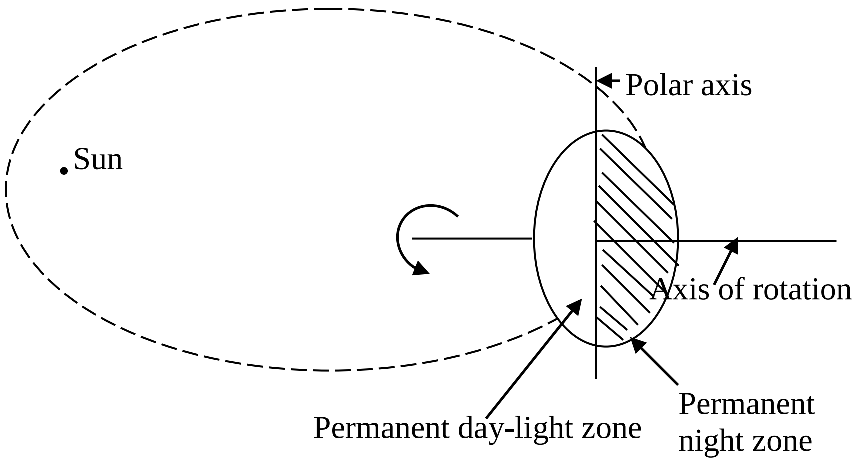

Fig.3: Cassini's Prolate Ellipsoidal earth

3.2.2 **Newtonian Hypothesis**

Newton hypothesised that the earth is rotating about the polar axis which lead
to the oblate ellipsoidal shape of the earth.

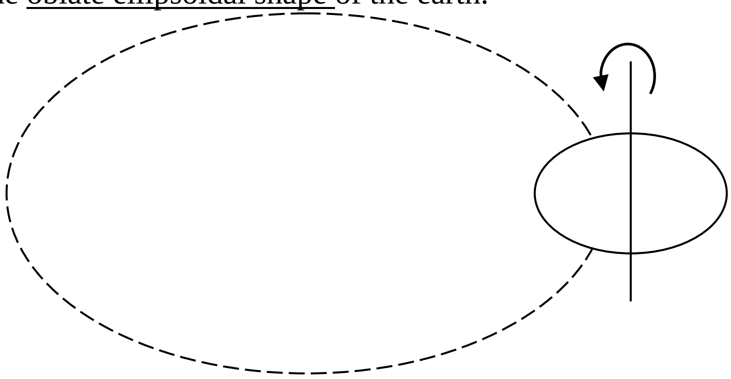

Fig.4: Newtonian Oblate Ellipsoidal Earth

The geophysical evidence such as longer equatorial radius than the polar radius, centrifugal sorting of the earth into its density regimes in which the density increases from the surface towards the centre and occurrence of day and night support Newtonian hypothesis.

3.3 Self-Assessment Exercise1

(i) Draw a wobbling earth with its poles in a vertical position.
(ii) What would be the length of days and nights when the earth wobbles to the position you draw above?
(iii) List the practical experiences on the earth that negate Cassini's hypothesis on the rotation of the earth
(iv) Mention the practical experiences on the earth that supports Newtonian hypothesis about the rotation of the earth.

3.4 **Effect of rotation on the internal structure**

Given the fact that the earth was initially melted, a state attained during Iron Catastrophe, as the earth rotates it behaves like a centrifuge, sending the lighter materials of crust to the flanks while the denser and homogeneous mantle and core materials remain closer to the centre of the earth. Geophysical studies have confirmed the inhomogeneous crust, denser and homogenous mantle (Fig.5)

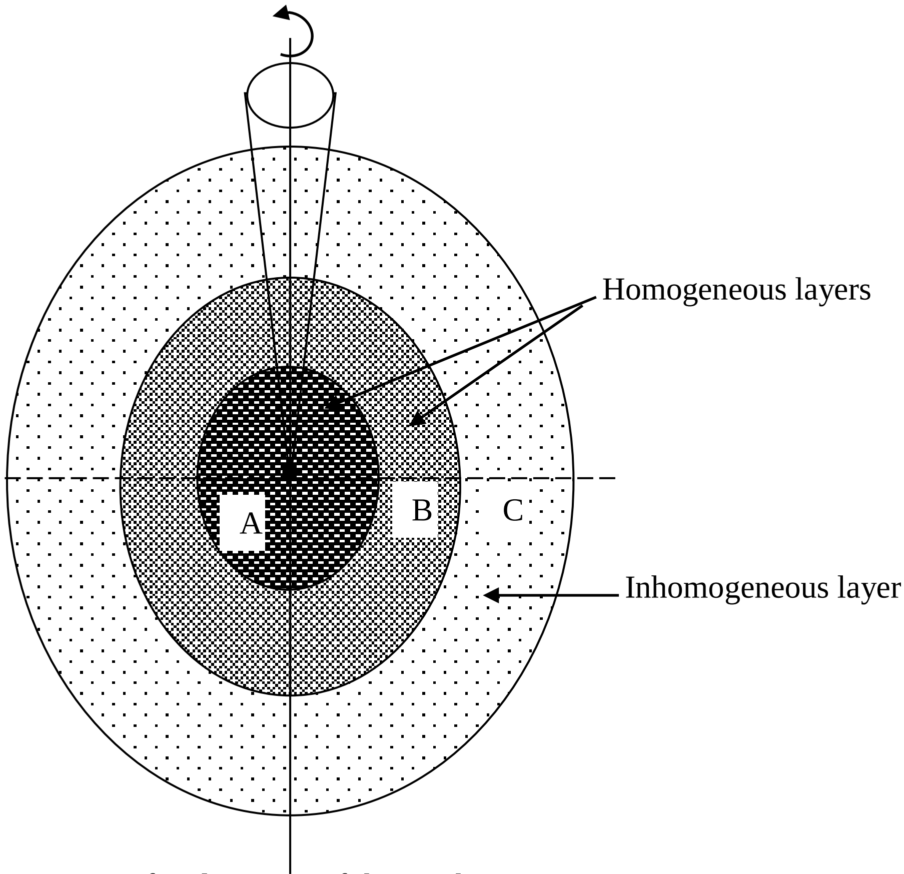

Fig.5: Centrifugal Sorting of the Earth Interior

3.5 Earth Shaping due to its Rotation

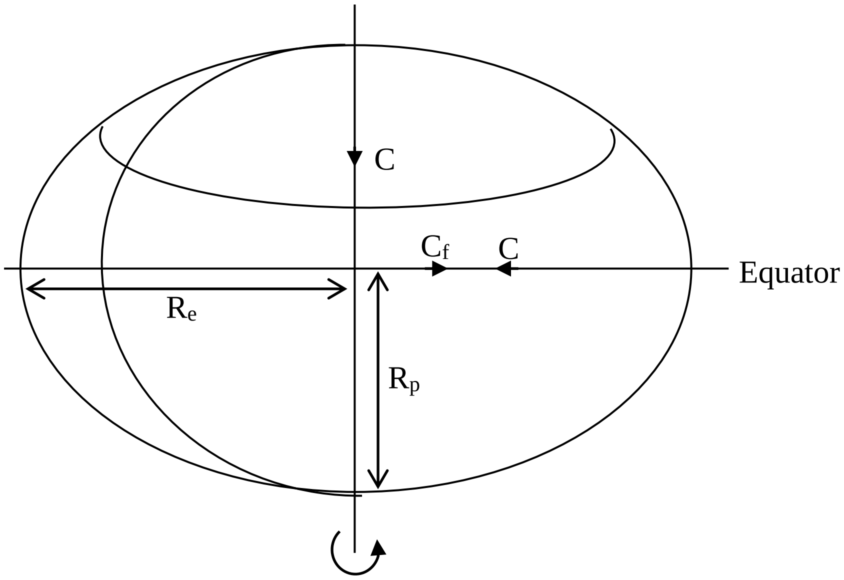

Fig.6: Deviation of the Earth Shape from a Perfect Sphere

The earth rotates about its pole with angular velocity of $7.292\times10^{-5}\, rad/s$ .As the earth rotates centrifugal and centripetal forces (C_F and C_P) cancelled out and net force is zero. Thus, no deformation is caused along the equator. The centrifugal force decreases towards the pole from the equator. Thus there is net force towards the centre of the earth which increases in magnitude as we move further from the equator. C_F decreases to zero at the equators and a maximum centripetal, i.e. net force, directed to the centre is obtained at the poles. Consequently the Polar Regions are flattened and the equatorial region bulges outwards. Hence, the earth assumes the oblate spheroidal nature. Geophysical studies have confirmed this when the equatorial radius is longer than polar radius.

Earth flattening f = $\dfrac{R_e - R_p}{R_e}$.

3.6 Factors Responsible for the Sculpture of the Earth Surface

The surface of the solid part of the earth is not smooth; it exists with wrinkles of hills, valleys, plateaus etc. Some of the causes of the surface shapes are:

(a) Gravitational pulls: After iron catastrophe side particles experiences gravitational pulls from the interior of the earth. Since the pull is from all the directions round the solid earth. Hence, the earth appears fairly spherical (Fig.7). However the in homogeneity of the crustal layer varies the magnitude of the gravitational pulls from place to place depending on the density of the area concerned. Hence, areas with denser crust appear lower (i.e. low land like valley) than those areas that have light crusts beneath.

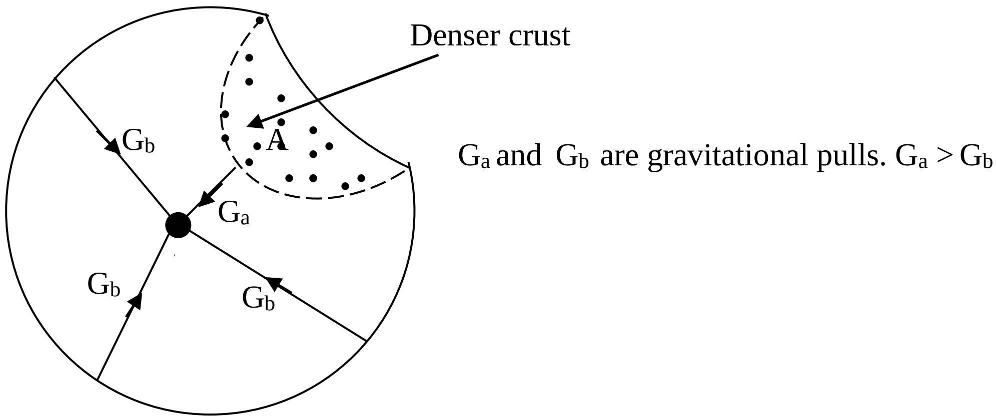

Fig.7: Earth's surface sculpture by the gravitational pull.

(b) Volcanic eruption: Sporadic volcanic eruption from the interior of the earth sometimes protrudes to the surface and form high-rise land such as continental platform and mountain.
(c) Interaction between lithosphere and the two fluid envelops (i.e. atmosphere and hydrosphere). The fluids wear down the volcanic (igneous) rocks. Wind and water erosions transport the loose rock materials to another place to form sedimentary and metamorphic rocks.
(d) Plate tectonics: This refers to the significant movements noticeable on earth's layer called Plates. Some of the processes of plate tectonics are: Sea-floor spreading, earth quake, continental drift, fault etc.

3.7 Self-assessment Exercise 2

i Given that equatorial and polar radii to be 6378.388 km and 6356.912 determine the flattening of the earth

ii Give a condition for gravitational pull to give rise to a valley on the earth's surface

iii Explain the cause of the oblate spheroid shape of the earth

4.0 **Conclusion**

The earth experiences three main motions whose effects are observable on earth. Most of the internal structure and constitution the geophysical studies have direct links with the rotation of the earth.

5.0 Summary

In this unit we have learnt that:

(i) The earth experiences three types of motion

(ii) Rotation f the earth is responsible for the internal density distribution and oblate spheroidal shape of the earth.

(iii) Newtonian hypothesis is most acceptable about the rotation of the earth

(iv) The four factors that is responsible for the shape of the earth's surface.

6.0 Tutor marked assignment

i List the three (3) types of earth's motion and mention one effect each of the motion.

ii Sketch a diagram that can be used to explain Cassini's hypothesis and mention one weakness of the hypothesis as regards our daily experiences on the earth's surface.

iii How did the earth assume its fairly spherical shape?

7.0 Further readings and resources

1. Dunlop, David J.; Özdemir, Özden (1997). Rock Magnetism: Fundamentals and Frontiers. Cambridge Univ. Press. ISBN 0-521-32514-5.
2. Hunt, Christopher P.; Moskowitz, Bruce P. (1995). "Magnetic properties of rocks and minerals". In Ahrens, T. J. (ed.). Rock Physics and Phase Relations: A Handbook of Physical Constants. Vol. 3. Washington, DC: American Geophysical Union. pp. 189–204.
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Unit 3: **The internal and external structures of the earth.**

1.0 Introduction

The internal structures of the solid earth are probed using some geophysical methods. The information obtained are utilised to draw model of the pictures about the interiors of the solid earth. Further, most of the features existing on the earth surface are consequences of the events which either took place around the time of formation of the earth or after mat effects of other event taking place with time. This unit deals with the models of the interior structure of the earth based on the scientific facts. The causes and structure of the external features of the solid earth are treated.

2.0 Objectives

By the end of this unit you would learn the following:

(a) Earth models based on the chemical composition and ability of the material to flow.
(b) Evidence of in homogeneity of the earth crust
(c) Formation of three states of the earth.
(d) Global distribution and surface sequences of the ocean and continent.

3.1 Evidences of the Inhomogeneity of the Solid Earth

The crust is the layer closest to the surface of the solid earth. It is the layer that shows high level of structural variations within the rock layers. The inhomogeneity of the earth is shown in the following.

(1) Density variation: The surface density of the solid earth has been found to be about $2.67g/cm^{3,}$ but the average density of the earth is $5.5g/cm^{3.}$ This implies that deep beneath the earth's surface is denser, i.e. density increases with depth.

(2) Rotational Analogous of mass is Moment of inertia (I). That is, as I is a measure of resistance of a rotating body to changing its angular velocity (ω) mass is the measure of resistance of a body to change its initial states. So, I depends on mass and the distribution of mass in a body. So, for a sphere with uniform density,

$I = bma^2$, where $b = {}^2/_{5,}$ Now, for earth model $I = b = ma^2$, If b is greater than ${}^2/_{5,}$

density decreases with depth and if b is less than ${}^2/_{5,}$ density increases with depth. But for planet earth b has been found to be 0.3308 which is less than 2/5; hence density increases with depth in the earth.

3.2 Internal Models of the Solid Earth

The nature of the solid earth's interior is obtained using various criteria,
based on the available scientific information. Two models are discussed below.

3.2.1 Earth's Model based on chemical composition

The solid earth is oblate with equatorial and polar radii approximately equal to 637.8388 km and 6356.912 km respectively. Based on the chemical compositions seismological evidence gave the following subdivisions

(a) Crust: There is continental and oceanic crust and it is a solid layer. Continental crust is basically solid, 30 – 40 km thick, mostly granite rocks and Gabbro with seismic primary wave velocity of 6 – 7 km/s. It is basically in three forms based on their geologic history of formation over the last 100 million years

(i) Stable region (cratons)
- Little evidences of vertical or horizontal movement but with evidences of
close warping of few minor faults

(ii) Semi-mobile region
- Characterised by differential vertical movement and formation of
Sedimentary basin

(iii) Mobile belts
- Characterised by young mountain ranges
- Strong deformation
- Strong vertical and horizontal movements

Oceanic crusts are mostly basalts and Gabbro, 5 – 11 km thick and they mostly exist in three layers namely:

(i) Layer 1
- It is a non consolidated sediment
- It has seismic velocity of between 1.5 – 1.8 km/s
- It is 0.3 to 0.8 km thick

(ii) Layer 2
- It is 1 – 2 km thick
- It has seismic velocity of 2.1 – 5.5 km/s

(iii) Layer 3
- It is a basaltic layer
- It has seismic velocity of between 6.5 and 7.0 km/s
- It is 5 km thick

(b) Mohorovicic Boundary: It is chemical boundary separating silicic crustal rock with high Feldspar content from underlying Ultramafic rocks of mantle.

(c) Mantle: It is a solid layer and is about 2900 km thick. It is the largest of all the subdivisions, 84% by volume and 69% mass of the entire earth and divided into 3 zones namely:

(i) Upper mantle
- Mineralization of upper mantle is approximately 40% Olivine, 50% Pyroxene and 10% Garnet

(ii) Transition layer
- It is characterised by abrupt increase in seismic velocity which is attributed to phase change

- It is iron rich

(iii) Lower Mantle
- Seismic velocity and density increase steadily with depth
- It has velocity homogeneity

(b) Gutenberg Boundary: It is a discontinuity between the mantle an the core

(c) Core: It is 16% and 13% by volume and mass of the earth. It is about 3470 km thick extended to the centre of the earth and is in 3 zones namely:

(1) Outer core
- It is about 2080 km thick
- It is believed to be in liquid form because seismic S – Wave cannot pass through it
- Earth's magnetic field originates from it
- The response of the earth to tidal forces which affects axis of rotation and the centrifugal force that counter the centripetal force along the equator, which is responsible for the bulginess of the earth at the equator, are associated with the liquid nature of the outer core

(ii) Transition zone
It is a slightly rigid shell (140 km thick) surrounding the solid inner core
with temperature of about 3000 kelvins which is about the melting point of iron.

(iii) Inner core
It is 1250 km thick, solid and with P – wave velocity increase inward,
which implies density increase.

3.2.2 **Earth's Model based on Ability to flow**

Earth model can be drawn based on the ability of its layer to flow. The layers are:

1 Lithosphere- cold and brittle.

$$\begin{matrix} 2 & Asthonosphere \\ 3 & Rheonosphere \end{matrix}\Bigg\} capable\ to\ flow$$

It was reported that towards the centre it becomes hardened again as a result of pressure.

3.3 **Self – Assessment exercise 1**

(i) What is the source of the centrifugal force that is responsible for the bulginess of the earth?

(ii) How does the density vary from the crust to the core?

(iii) Briefly discuss the evidences to confirm that the earth crust is density in homogenous

3.4 Surface Structure of the Solid Earth

The surface of the solid earth witnessed series of features such as oceans and continents which are consequences of geological events that took place over a long period of time; some of the features are explained below.

3.4.1 **Formation of Continents, Ocean and Atmosphere**

(i) Continents: Lava flows as a result of volcanism from the interior to the outer layer cooled and became continent.

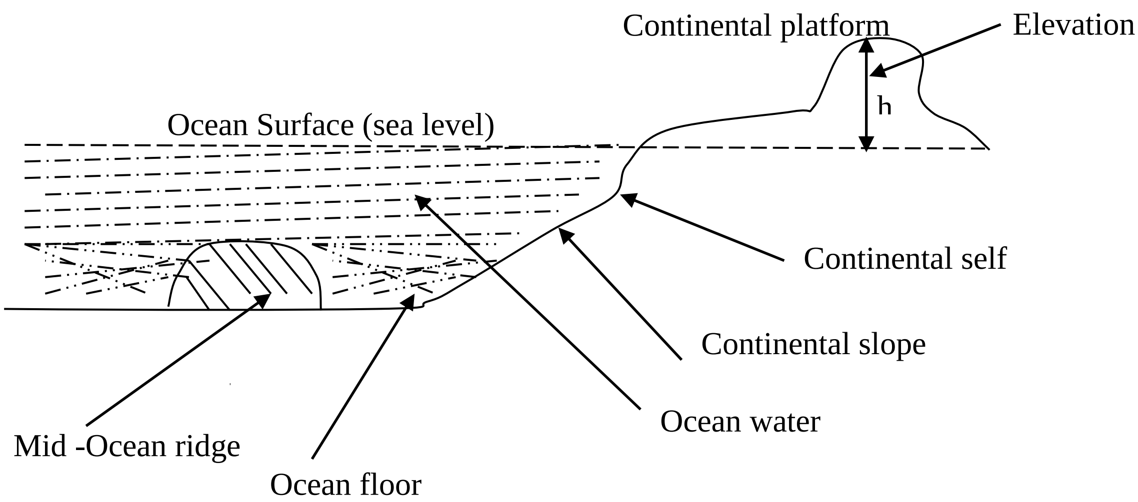
(ii) Oceans: From the interior of the solid earth as a product of the Process of heating up and differentiation, some water bearing elements released their water molecules which accumulate on the surface to form the oceanic water.

(iii) Atmosphere: Out-gassing , resulting from differentiation and some gas releasing chemical reactions brought about much gasses that accumulated above the solid earth.

3.4.2 **Global distribution of continents and oceans**

About 45% of the earth surface has sea-sea antipodal and 1.4% has land-land antipodal. Northern hemisphere has 60% land and 40% water, while southern hemisphere has 61% water and 39% land. In general, earth's surface has 29% continent and 71% is covered by ocean. The total world area is approximately $510 \times 10^6 \, km^2$.

3.4.3 **Significant Surface Features of Oceans**.



Elevation h is the height relative to see surface on the continent. Average elevation of continents is 0.88 km. Average depth or ocean floor is 3.8 km. Continental rocks are lighter than oceanic rocks. There is world wide mountain range that crosses the ocean basin 1000 km wide and 65,000 km long across the world.

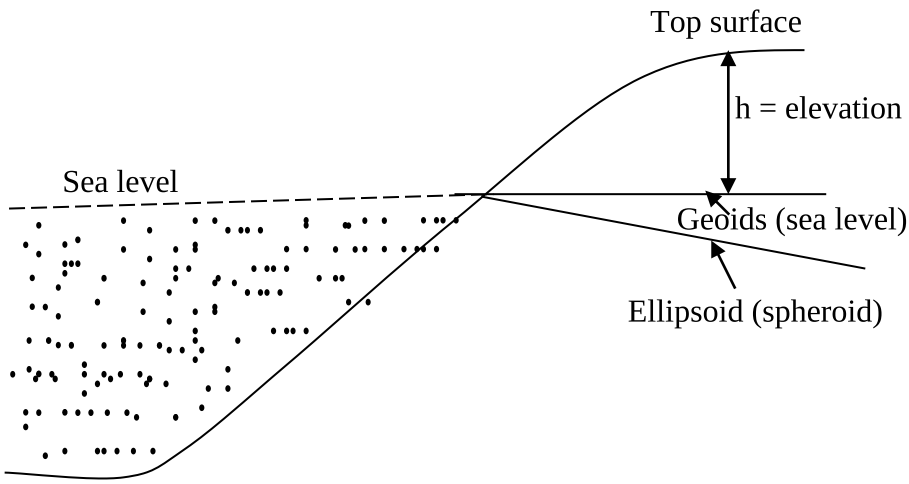


Fig.2: Sequence of the Earth's surface

3.5

Sequence of the Solid Earth's Surface

The earth's surface is basically viewed in three forms:

(i) The top surface is the continental platform wrinkled in nature.

(ii) Geoids is the sea level, where sea water will flow to if the continent were

to be tunnelled. In other word, geoid is the equipotential surface to which direction of gravity field is everywhere perpendicular. The vertical separation between the geoids and a point on the earth's surface is

the elevation.

(iv) Ellipsoid is the ideal smooth surface of the earth in its oblate form. It

sometimes coincides with geoids, but sometimes not.

3.6 Self-assessment Exercise 2

(1) What percentage of the earth's surface is not covered by ocean water?

(2) Define ellipsoid

(3) What other name can you call a geoid?

(4) How did the ocean form?

4.0 Conclusion

The interior of the earth compose of crust, mantle and core where the characteristics of each layer varies based on scientific evidences. Most of the surface structures of the earth are consequences of events that originated from the solid earth.

5.0 Summary

In this unit you have learnt:

(i) The two models of the solid earth drawn from the chemical composition

information and ability of the materials to flow.

(ii) That earth crust is not homogeneous based on evidences such as density
Variation.
(iii) The formations of the continent and as major surface features of the solid
Earth.
(iv) The global distributions of the continents and ocean.
(v) The meanings of ellipsoid, geoids and elevation, the major sequence of the earth's surface.

6.0 Tutor Marked Assignment

(i) Sketch a model of the solid earth based on the chemical composition showing the 5 major internal features, thickness and an ocean.
(ii) Explain three major significant effects of the outer core to the scientific observations on the earth.

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Unit 4: **Variation of some physical properties within the solid earth**

1.0 Introduction

Some parameters vary with depth (i.e. radius of earth).Measurement of these on the surface gives due to the structure of the underlying interior of the earth. The deals with variation of density pressure, gravitational field, Velocity and temperature with depth within the earth's rocks.

2.0 Objectives

At the end of this unit you should be able to:

(1) describe the trend of variation of pressure, density, gravitational field, and seismic velocity as well and with depth in the solid earth.

(2) derive the mathematical relations for the variation of parameter itemised in (1)

(3) Apply the mathematical formula to real life events

3.1 **Variation of Density ρ with depth**

Consider density dependent on pressure P and temperature T. That is

$$\rho = \rho(P,T) \qquad (1)$$

Assuming that the stress in the earth's interior is equal to hydrostatic pressure $(h\rho g)$, then pressure gradient towards the centre of the earth.

$$\frac{dp}{dr} = -\rho g \qquad (2)$$

r is the radius of the earth. The negative sign implies pressure increase with decrease in radius. Consider a homogeneous layer in which the t temperature variation is adiabatic then.

$$\frac{dp}{dv/v} = \frac{dp}{dp/p} = \kappa \; i.e$$

$$\frac{\kappa}{\rho} = \frac{dp}{dp/p} \qquad (3)$$

But

$$\frac{dp}{dr} = \frac{dp}{d\rho} \bullet \frac{dp}{dp} \qquad (4)$$

Use (2) and (3) in (4)

$$\frac{d\rho}{dr} = \frac{-\rho g}{\varphi} \qquad (5)$$

But

$$g = \frac{GM}{r^2}, so$$

$$\frac{d\rho}{dr} = -\frac{GM}{\kappa r^2} -----------------------------------(6)$$

Equation (6) is applicable to region of uniform composition within the earth, which is, starting from mantle down. It shows uniform density increase (Fig.1)
Where
κ = adiabatic incompressibility (i.e. bulk modulus)
M = Mass of the region of the earth with the earth less by the mass of the crust
r = radius of the earth's region with uniform composition
G = Gravitational constant

3.2 **Variation of Pressure P with Depth**

This has to do with the pressure distribution and variation of acceleration due to gravity.

$$\text{Re}\,call\,that\,g = \frac{Gm}{r^2} ----------------------------------(1)$$

$$and\,P = r\rho g -----------------------------------(2)$$

So pressure gradient

$$\frac{dp}{dr} = \frac{-Gmp}{r^2} -----------------------------------(3)$$

Equation 3 shows that pressure decreases with depth, i.e. as r decreases (Fig.1) Also; it shows that pressure has direct relation with the density.

3.3 **Variation of Acceleration due to gravity with depth**

Recall that $g = \frac{GM}{r^2}$. So, variation of g with depth can be calculated using the relation above. Its value does not differ by more than 1% from 990 km until a depth of 2400 km is reached where it decreases to zero (Fig.1)

3.4 **Variation of Pressure P and S waves with Depth**

In seismology P and S waves are used to study the interior of the solid earth. P- Wave is a longitudinal wave that can pass through liquid, solid and gas. S- Wave is a transverse wave that can travel vertically and horizontally and can not pass through fluids. P and S- waves are called body waves because they can pass through the earth's interior. They however possess different velocities while passing through an earth material. usually P- wave is always faster than S- wave. Let α and β be the P and S waves Velocities. It has been proved that:

Bulk modulus $\kappa = \lambda + \frac{2\mu}{3}$ ---------------------------- (1)

$$\alpha = \sqrt{\frac{\lambda + 2\mu}{\rho}} \quad \text{-----------------------------------} (2)$$

$$\beta = \sqrt{\frac{\mu}{\rho}} \quad \text{-----------------------------------} (3)$$

Using 1, 2 and 3, we can show that

$$\alpha = \sqrt{\frac{\kappa + \frac{4\mu}{3}}{\rho}}$$

Also $\kappa = \alpha^2 \rho - \frac{4\rho\beta^2}{3}$

Where λ and μ are called Lamês consonants. The relations of α and β with depth are shown in (Fig.1

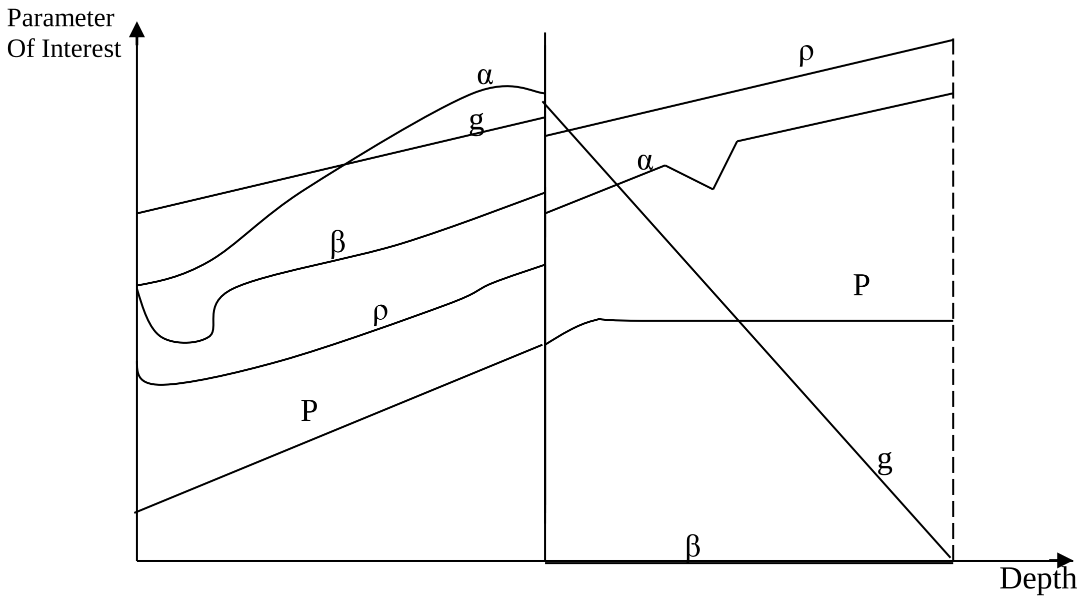

Fig.1: Variation of α ,β, ρ and P with depth in the solid earth.

3.5 **Self assessment Exercise**

(1) State the mathematical relation for hydrostatic pressure.

(2) What is the implication of the negative sign in the density gradient expression in equation (6)?

(3) Sketch the variation of pressure and density with depth, state one similarity and difference each.

4.0 Conclusion

It has been established that density, pressure, and seismic velocities, vary differently with depth within the solid earth. The models developed are easily applicable to layer below the crust where there is some element of homogeneity than in the crust that is characterised by inhomogeneity.

5.0 Summary

At the end of this unit you have learnt that:

(i) density is directly proportional to depth,

$$as\ show\ in\ \frac{d\rho}{dr}=-\frac{Gm}{r^2}$$

(ii) Pressure is inversely proportional to depth,

$$as\,show\,in\,\frac{dp}{dr}=-\frac{Gm\rho}{r^2}$$

(iii) Acceleration due to gravity increases with depth up to a point when it then decreases to zero

(iii) Seismic waves vary differently with depth.

6.0 Tutor Marked Assignment

Given that:

(1)

$$\kappa=\lambda+\frac{2\mu}{3},$$

$$\alpha=\sqrt{\frac{\lambda+2\mu}{\rho}}\quad and$$

$$\beta=\sqrt{\frac{\mu}{\rho}}$$

$$\text{Prove that}\ \alpha=\sqrt{\frac{\kappa}{\rho}+\frac{4\mu}{3\rho}}$$

(2) With the aid of a diagram, describe the variation of S- wave velocity in a homogeneous part of the solid earth.

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Unit 5: **Rocks and Minerals**

1.0 **Introduction**

The solid part of the earth is made of rocks in various forms and quantities. The rocks are made of minerals which are crystallised since the rocks formation periods. The crust and mantle are made up of rocks. This unit examines the rocks and minerals formations, characteristics and properties.

2.0 **Objectives**

At the end of this unit you should be able to:

(i) Define Rock and Minerals.
(ii) Classify rocks based on origin, Mineral contents porosity and consolidation.
(iii) List the characteristics of rocks.
(iv) Derive mathematical relation of porosity using diagrams.
(v) Classify porosity based on factors such as origin and degree of connectivity of the pores.

3.1 **Minerals**

Geologic minerals are the inorganic substances that are naturally present in the earth in crystal form. They are mostly formed together with the host rocks at the inception of rock formation. Examples are: Feldspar, Quartz, Calcite, Olivine, Biotite, Apatite, Amphibole, Iron ore etc. They mainly reside in the crust and mantle.

3.2 **Rocks**

Rocks are group of natural minerals crystallised by rock forming processes. Rocks form the crust and mantle. The boundaries of rocks in the earth are formed by distinct chemical composition which varies density and thermodynamic conditions. In broad sense all rocks can be considered as minerals. Examples of rocks are Gabbros, Diorite, Granite, etc.

3.3 **Classes of rocks**

Rocks are classified based on various conditions as mentioned below:

(a) Rock type based on origin and composition
- (i) Igneous rocks.
- (ii) Sedimentary rock.
- (iii) Metamorphic rock.

(b) Rock type based on mineral content
- (i) Monomineralic rocks.
- (ii) Polymineralic rocks.

(c) Rock type based on pore space
- (i) Nonporous (dense) rocks.
- (ii) Porous (fractured) rocks.

(d) Rock type based on bonding or cementation at the point of contact between their solid components.
- (i) Consolidated rocks.
- (ii) Unconsolidated rocks.

3.3.1 Igneous rocks

They are a group minerals formed from molten magma which crystallised. They are in three groups:

(i) Volcanic rocks – When the magma reaches the surface to form out crops

(ii) Plutonic rocks – When the magma did not expose but crystallises at depth.

(iii) Dike and sill rocks – When the magma crystallised in pipe-like form, standing straight between a large rock body, dike is obtained and when, during dike formation, the magma came across a weak zone above and spread horizontally to form a dike with wide top, sill is obtained.

3.3.2 Sedimentary rock

They are formed from the deposition of remnants of the weathered igneous, metamorphic and sedimentary rocks which are moved away by processes such as erosion. There are two types:

(i) Classic (fragmental) sedimentary rock e.g. Sandstone, shale.

(ii) Chemical and biochemical sedimentary rock e.g. carbonate rock. Over 50% of the earth surface is covered by thin sediments.

3.3.3 Metamorphic Rock

Metamorphic rocks are formed by chemical conversion of sedimentary rocks due to pressure and temperature in the presence of water. During metamorphic rock formations pre-existing minerals can be converted into new ones; that is, new minerals are formed in the presence of suitable thermodynamic conditions. Examples of metamorphic rocks are Schist, Gneisses etc.

3.4 Physical Characteristics of Rocks

(a) Homogeneity and In homogeneity

A rock chunk is homogeneous if the property considered such as density,

conductivity etc is the same at every point, the opposite is inhomogeneous

(b) Isotropy and Anisotropy

Rock chunk is isotropy when the property considered is equal in all directions; that is when the property is independent of direction. The opposite is Anisotropy. That is, a rock property is anisotropic when change in direction causes changes in its value.

(c) Structure and Texture

Structure refers to the 3-dimentional internal arrangement of the constituents of the rock. Texture of a rock refers to size, sorting, shape and packing arrangement of its solids.

3.5 Pore Space in Rocks

Pore space is a space within a given volume of solid rock that is not occupied by the solid constituents. It can be caused during rock formation, by geologic processes like earthquakes, cracks, tectonics, etc, by chemical processes, and by physical processes. There are two major types *viz*:

(i) Primary pore space- Formed during the rock formations.

(ii) Secondary pore space –Formed from other sources aside from during rock formation.

3.6 **Porosity**

Porosity is the ratio of total volume of pore space to the total/bulk volume of the rock in question (Fig 1)

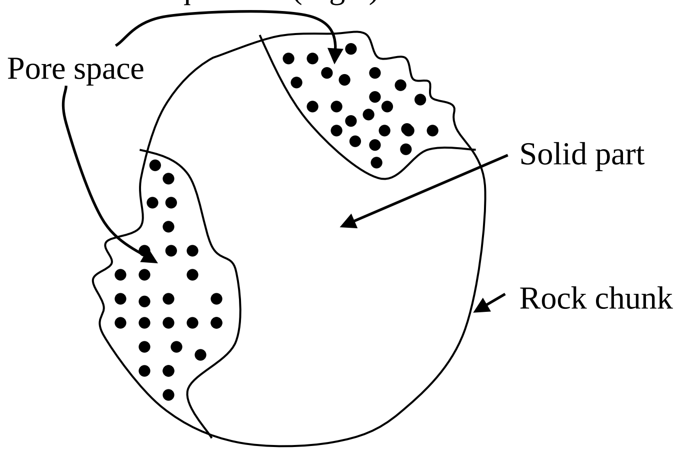

Fig.1: Derivation of Porosity

Let the:

Bulk/total of the rock be V_t,

Total volume of the pore space be V_p and

let the volume of the solid/matrix rock be V_b

So porosity $\Phi = \frac{V_p}{V_t}$

In the same way, porosity can be classified based on the period of formation as:

- primary porosity and
- secondary porosity.

Also porosity can be classified based on the mode of formation *viz*:

(i) Intergranular porosity: Theses are the pores between grains of the rock loosely packed right from formation

(ii) Intragranular porosity: These are pores created by contracting rock grains.

(iii) Fracture porosity: Are caused by mechanical and chemical actions

(iv) Vugular porosity: May be caused by organizations during rock formation or by chemical actions at later time.

3.7 **Total porosity**

This refers to all the pores between the solid chunks of rock.

$$\varphi_{total} = \varphi_{primary} + \varphi_{secondary}$$

3.8 Intercontinental porosity

This refers to pores that linked with spaces through which fluids can pass.

3.9 Potential porosity

This refers to the interconnected pores in which the connectivity is large enough for fluids to flow.

3.10 Effective porosity

This refers to the interconnected pores that contain fluids.

3.11 Specific Internal Surface

This refers to the ratio of total surface area of the pores and the pore volume or rock mass.

3.12 Pore Permeability

This is the measure of the ability of fluids to flow through rock pores.

3.13 Self Assessment Exercise

(1) Differentiate minerals from rocks
(2) Use diagram of a rock block to define porosity
(3) Explain isotropy and inhomogeneity of rocks
(4) Describe the formation of a sedimentary rock.

4.0 Conclusion

Rocks are composed of minerals which are mostly formed within the crust. The pore spaces are the empty space existing within the solid rocks which are obtained either during or after the rocks are formed. Pore may or may not contain fluid within the rocks in the subsurface.

5.0 Summary

At the end of this unit you have learnt that:

(i) Rocks are made up of minerals which are crystallised
(ii) Rocks are formed from magma resulting in igneous rocks, from which other rocks are obtained.
(iii) Rock can be homogeneous or otherwise and isotropic or otherwise, depending on the behaviour of the rock property considered within the region in question.
(iv) That pore space is the empty space within the solid rock in the solid earth.

6.0 Tutor marked assignment

(1) Classify inter-grnular, intragranular fracture and vugular porosities into primary and secondary porosity.

(2) Given that: total/bulk volume of a rock is V_t , total pore space in the rock is V_p and the volume of the solid part of the rock is V_s, derive the expression for the porosity φ in terms of V_s and V_t

(3) Draw diagrams to represent the formation of plutonic and sill rocks.

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Unit 6: Density

1.0 Introduction

The knowledge of density of rocks and their components is of immense importance to knowing other parameters of the rocks. These parameters such as gravity field, which are very important in geophysical exploration of the substances of the earth, are greatly affected by the density variation of the rocks formed in the crust and mantle. This unit, therefore, deals with the meaning and measurement of density as related to various rock components.

2.0 Objectives

By the end of this unit you should de able to:

(a) Define and lime types of density
(b) Calculate density using its mathematical
(c) Explain laboratory measurement of density of rocks
(d) Differentiate densities based on the rock constituents

3.1 Definition of Density (ρ)

Basically, density can be defined and classified based on the parameters compared with the mass.

(a) Linear density ρ_L = Ratio of mass of an object and its length.
SI unit = kg/m
(b) Surface/superficial/area density ρ_s = Ratio of mass of an object and its
surface area. SI unit= kg/ m^2
(c) Cubical//volume density ρ_v = Ratio of mass of an object and its volume
SI unit = kg/m^3

Cubical density ρ_v is mostly used in the area of geophysics, So cubical density is usually addressed 'density' in most geophysics write-ups. Other smaller unit of density is 1g/cm^3 = 10^3kg/ m^3

3.2 Classification of Density Based on Rock Components

Density of rocks ρ_v can be classified based on their components.

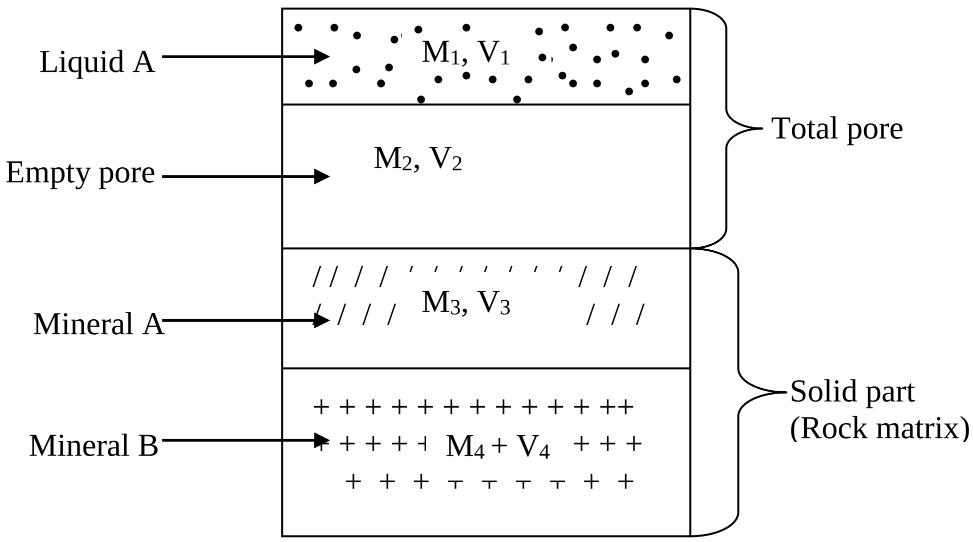
(a) Bulk density ρ_v : This refers to the mean density of the whole rock chunk
considered including pores and mineral contents.
(b) Mean component density ρ_c : This refers to the density of each component
that makes up a rock. eg. Density of each mineral in a rock, density of
pore.
(c) Mean solid Matrix density ρ_m : This refers to the density of the solid part

of a rock chunk excluding the pores

(d) Mean pore-fluid density: This refers to the density of liquids contained in
the rock pores.

3.3 Model for Density of Rock and its Constituents

Consider the rock chunk with the constituents shown (Fig.1)



(Fig. 1): Volumetric Rock Model

$$\rho_v = \frac{M_1 + M_2 + M_3 + M_4}{V_1 + V_2 + V_3 + V_4}$$

$$density\,\rho_c\ of\ liquid = \frac{M_1}{V_1}$$

$$density\,\rho_c\ of\ Empty\ pore = \frac{M_2}{V_2}$$

$$density\,\rho_c\ of\ Mineral A = \frac{M_3}{V_3}$$

$$density\,\rho_c\ of\ Mineral B = \frac{M_4}{V_4}$$

$$Matrix density\,\rho_m = \frac{M_3 + M_4}{V_3 + V_4}$$

Volume fraction of a component is the ratio of the volume of the component to the total volume (bulk volume) of the rock. E.g. Volume fraction of $\text{Mineral A} = \frac{V_3}{V_1 + V_2 + V_3 + V_4}$

Pore saturation of a fluid is the ratio of the volume of the fluid to the whole pore volume containing the fluid the fluid in the rock considered.

$$e.g\ water\ saturation = \frac{Volume\ of\ water}{total\ pore\ volume}$$

$$= \frac{V_1}{V^1 + V_2}$$

3.4 Determination of Density of Solid Minerals

Cubical density is given by $\frac{Mass}{Volume}$

3.4.1 Regular Shape Solid

If the body is a regular 3-dimensional body density can be determined by direct measurement of length L, Breadth b and height h; and mass can be measured using beam balance.

$$Hence\ Density = \frac{M}{L \times b \times h}$$

3.4.2 Irregular Shape Solid

For an irregularly shaped, the mass can be obtained by direct weighing using beam balance. The volume can be obtained by immersing the body in water to sink completely in a graduated cylinder.

The initial and final volumes are obtained as V_1 and V_2 (Fig.1a)

Thus, $\text{Density} = \frac{M}{V_2 - V_1}$. Alternatively, overflow can, can be used and the volume of the displaced liquid is measured as V. (Fig.1b) Thus, density = $\frac{M}{V}$

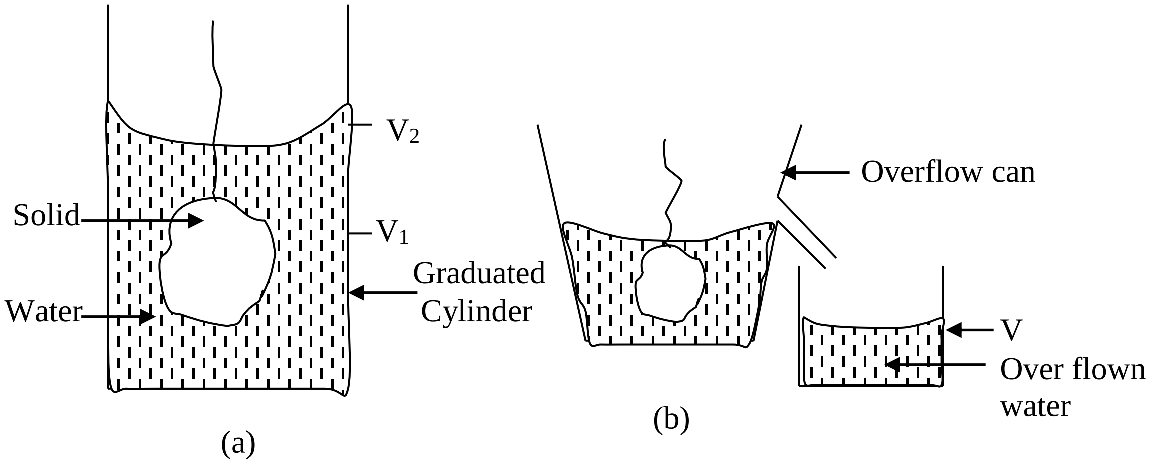


Fig.2: Determination of volume of irregular shape solid

3.4.3 Solid Density Measurement using Archimedes' Principle

The solid is weighed in air using a spring balance as M_a. It is then immersed completely in water with the spring hanging it, but without touching the sides and bottom of the container. Then, the weight in water is then read as M_w

$$Now, mass\ of\ water\ displaced = Ma - Mw = Upcrust$$

$$Density\ of\ water\ displaced = \frac{Mass\ of\ water\ displaced}{Volume\ displaced}$$

But density of water is a constant of 1g/cm^3

So, volume of water displaced = (M_a - M_w) (in g/cm^3)

But volume of water displaced = Volume of the solid immersed

That is volume of object = M_a - M_w

So density of the solid = $\frac{\text{mass of solid}}{\text{volume of solid}}$

That is, density of the solid minerals = $\frac{M_a}{M_a - M_w}$

It should be noted that weight can replace Mass M_a and M_w in the latter expression.

3.5 Self-assessment Exercises

(1) Define bulk density of a solid rock

(2) Draw any suitable diagram that you can use to measure the volume of a
specimen of granite rock.

(3) List all the appropriate instruments you would need to obtain the density
of crystal of a mineral in cube shape.

4.0 Conclusion

Density of solid minerals can be determined in the laboratory irrespective
of their shapes. What requires is their specimen, appropriate apparatus suitable for
the measurement and professional competence for the mathematical calculations.

5.0 Summary

In this unit you have learnt that:

(1) There are 3 classes of density namely: linear, surface and cubical density.

(2) Density of rocks can be classified based on pore content and minerals.

(3) Archimedes' principle can be used to determine the solid density in the
Laboratory using

$$\frac{\text{Mass of solid in air}}{\text{Mass difference of solid in air and when Immersed in water.}}$$

6.0 Tutor Marked Assignment.

(i) A block of quartz weight 14g in air and 12.5n when immersed in water, calculate its density.

(ii) Use a volumetric model diagram of a rock sample to explain pore saturation of the rock.

(iii) A block of rock sample contained the component show in the table below.

Component	Mass (g)	Volume (cm^3)
Quartz	5	3
Natural gas	0.15	5
Iron ore	25	16
Water	2.5	1.5
Amphibole	14	8

Calculate:

(a) Bulk density of the rock

(b) Matrix density of the rock

(c) Volume fraction of mineral amphibole

(d) Pore saturation of Natural gas

7.0 **Further Readings and other Resources**

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Module 2: GEOMAGNETISM: ORIGIN, PROPERTIES OF ROCK

Unit 1: Basic facts in magnetism

1.0 Introduction

Magnetism is an attractive property experienced by some type of metals when brought near another metal which has magnetism in it initially. The latter is regarded as a permanent magnet. Actually, all matters-solid, liquid and gas- exhibit some characteristics of magnetism which is expressed in different forms. Some become more magnetic while some become less magnetic when exposed to permanent magnetic field. Hence, matters are classified on this basis. There are various parameters whose understandings aid comprehensions in the area or magnetism. This unit acquaints you with understandings of basic phenomena and parameters employed in the area of magnetism as well as various methods of producing permanent magnets.

2.0 Objectives

At the end of this unit you should be able to:

(i) Define magnetic field

(ii) List three mutually dependent parameters in magnetism

(iii) List at least three each of characteristics of magnet and magnetic field flux

(iv) Explain the three methods of producing magnet.

3.1 Magnetic field

This is the space surrounding a permanent magnet in which magnetic force is exerted. This force is due to the field around the magnet. For instance, when an iron needle is left freely near permanent magnet it is attracted towards the magnet by the magnetic force in the field around the magnet. You can demonstrate this.

3.2 Magnetic flux

This is the line used to represent the magnitude/strength and direction of the magnetic field surrounding a permanent magnet at any point. Thus, direction of magnetic flux at any point represents the direction of the force on a north pole placed at the point in a field due to a second magnet (Fig.1). In a permanent magnet, the fluxes are directed out of the north pole and directed in to the south pole when observed with magnetic compass. When viewing electric charges with the view of magnetism we know that a moving charge will exert a magnetic field force on another moving chare. This is because the first moving charge tends to set up magnetic field while moving and the second charge experiences such force.

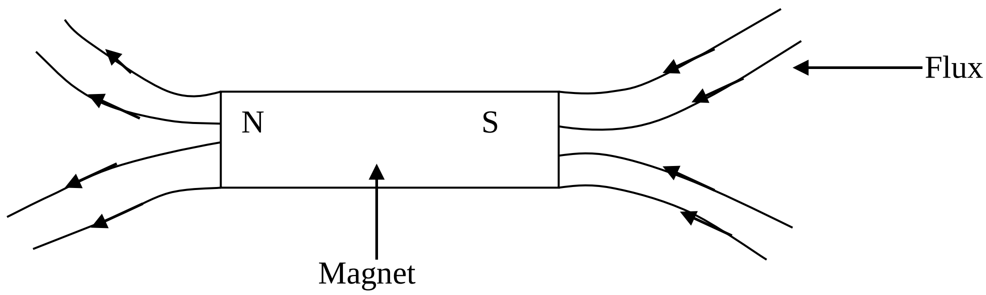

Fig.1: Characteristics of Magnetic flux in a permanent magnet

3.3 Molecular Origin of Magnetism

Basically, Current, Motion and Magnetism are mutually dependent. This implies that existence of any two parameters above induces the third one. All magnetic materials like iron comprise of molecules in which orbiting electrons are found. The motion of electrons develops current. Thus the moving electrons/currents produces magnetic field in molecules making the latter to exist as a tinning magnet. So magnetic material contains series of tiny molecular magnet oriented randomly in a way that their magnetic effects cancel out. This makes the material to appear neutral. Thus, the magnetic effect of an un-magnetised material could not be felt (Fig.2a)

When a magnetic material is brought near a permanent magnet the tiny molecular magnets in it are reinforced in a definite and uniform direction. The direction where all the molecular magnets point to, forms the North pole of the new magnet. This is so because the North pole of the permanent magnet attracts the south poles of the molecular magnets (Fig.2b)

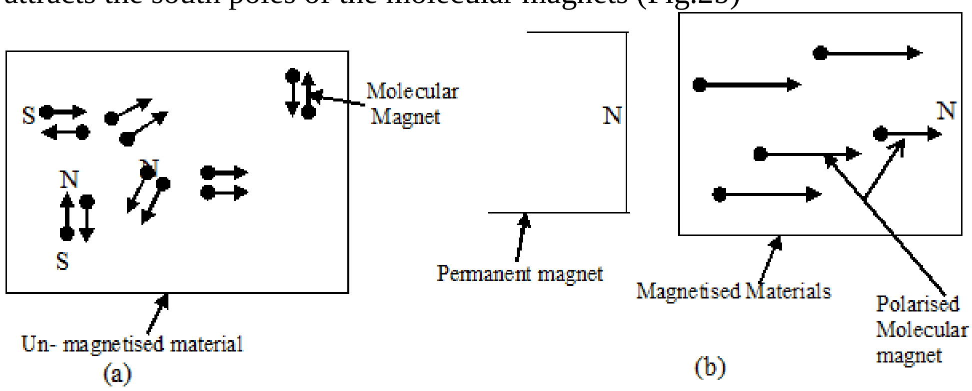

Fig.2: Molecular source of magnetism in magnetic materials

3.4 Basic Characteristics of a Magnet

A permanent magnet exhibits the following characteristics:

(a) Magnetic poles are of two types- North and South

(b) Like poles repel and unlike poles attract each other

(c) Poles always seem to occur in equal and opposite pairs

(d) The magnet lines of force (flux) appear coming out from North pole and entering south pole when traced with a plotting compass.

(e) When no other magnet is near a freely suspended magnet, it will settles so that the line joining its poles is approximately parallel to the earth's geographical north- south axis with its north pointing to the geographical north pole

3.5 **Self Assessment Exercise 1**

(i) Define magnetic flux
(ii) Sketch the flux pattern around a permanent magnet
(iii) Name the three mutually dependent parameters in the area of magnetism
(iv) Draw a diagram to indicate the magnetic property of un-magnetised soft iron bar.

3.6 **Characteristics of magnetic flux**

The basic characteristics of magnetic flux are:

(a) The line gives the direction of the field at the point or the tangent to it, if it is a curve, represents the field direction (Fig. 3)

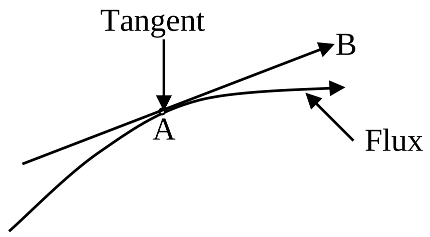

Fig.3: Field direction of a curved flux

(b) The number of lines per unit cross-sectional area is proportional to the magnitude of magnetic field, field induction or simply, field density B. The closer the line the higher is B.

(c) Magnetic flux lines are imaginary (i.e. not real) but just a concept as an aid to visualizing the magnetic field.

(d) It appears emerging from north and ending at South pole of a given magnet (Fig. 4)

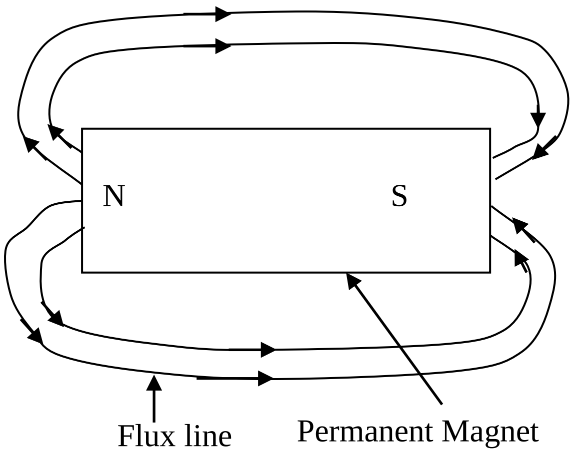

Fig 4: Flux Characteristics around a bar magnet.

(e) Flux lines do not intersect, hence they are vector.
(f) The unit of magnetic flux is Webber (Wb)

3.7 **Production of magnet**

Permanent magnet can be produced in 3 ways namely:

(1) Electrical Method: The magnetic effect around a current carrying wire can be employed to magnetise a magnetic materials (Fig 5)

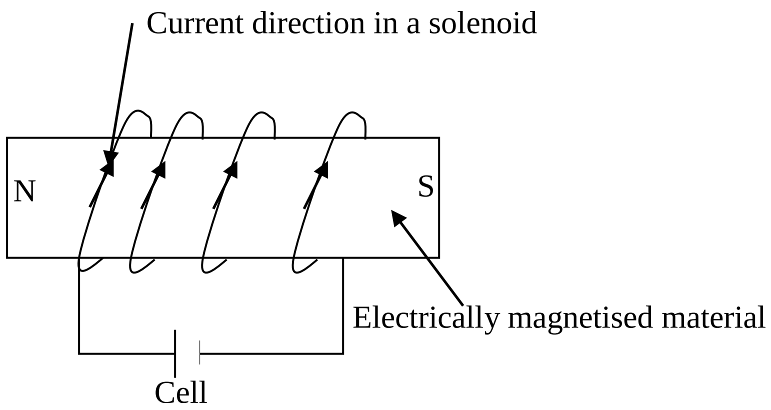

Fig.5: Production of magnet using electricity

(2) Induction method: When a permanent magnet is brought near a magnetic material the tiny molecular magnets in it are aligned making the material becoming magnetic (Fig.6)

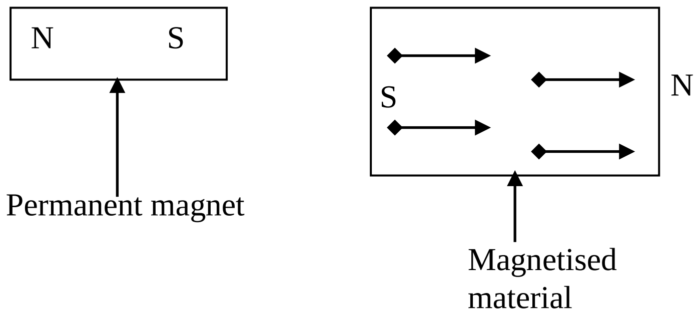

Fig.6: Production of magnet by induction

This method is usually applied in the magnetic method of prospecting.

It should be noted that even if the permanent magnet touches the magnetic material in a regular pattern the same effect will be produced. That is, the magnet may be gently dragged along the length of the magnetic material to induce magnetism in it (Fig. 7)

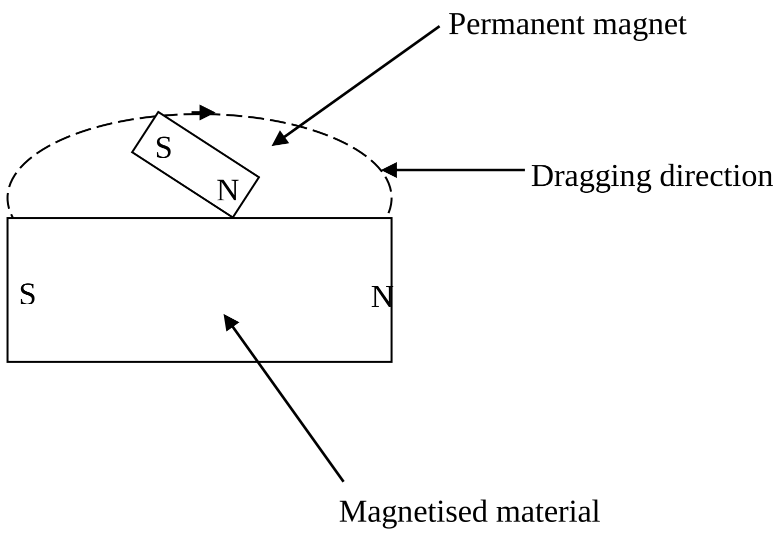

Fig. 7: Production of Magnet by Rubbing to Induce Magnetism

(3) Hammering method: When a magnetic material is oriented at an angle of dip of an area and hammered it is magnetised.

3.8 **Useful magnetic parameters**

Some constantly used parameters in the area of magnetism are shown in the table 1.

Table 1: magnetic parameters

SN.	Parameter (magnetic)	Relation	Unit
1	Flux φ		Webber (w)
2	Density or induction	B= $\beta = \frac{\varphi}{A}$	w/m^2 or Tesla (T)
3	Strength/Intensity (H)	H = I/L	A/m
4	Inductance L or M	L= $\frac{\mu \circ AN^2}{L}$	Henry (H), W/A
5	Permeability (μ)	μ = β/H	H/m
6	Susceptibility φ	φ = $\frac{Magnetisation}{strenght}$	Unit less

3.9 **Self- Assessment Exercise 2**

(i) Define magnetic density

(ii) Mention any two characteristics of magnetic flux.

(iii) Sketch the electrical setup usable to produce a magnet.

4.0 Conclusion

Electricity, magnetism and motion are mutually dependent parameters. Flux lines are used to depict the characteristics of magnetism around a permanent magnet. Permanent magnet can be produced in three methods. Magnetism in magnetic materials originates from the tiny molecular magnets developed by the orbiting electrons in it.

5.0 Summary

In this unit we have learnt that:

(i) The presence of any two of current, motion and magnetism induces the third parameter.

(ii) The space around permanent magnet where magnetic force is felt can be represented by flux lines.

(iii) Flux lines appear emerging from the north pole and entering south pole.

(iv) Magnetic ability of magnetic materials is a consequence of the presence of tiny molecular magnet in them.

(v) Magnet can be produced by electrical, induction and hammering methods.

6.0 Tutor Marked Assignment

(i) Draw appropriate flux line for the arrangement of the permanent magnets shown

(a) (b)

(ii) A freely suspended bar magnet used to settle with its north pole pointing to the geographical North Pole; with this fact suggest the polarity of the earth's magnetic field.

(iii) Sketch the electrical method of producing magnet and suggest means of increasing the strength of the magnet produced in this way.

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Unit 2: **Characteristics of Magnetism in Rocks' Components**

1.0 Introduction

Strictly speaking, all substances are magnetic but only Ferromagnetic and Ferrimagnetic substances, so called magnetic materials of technology, are capable of being magnetised by relatively weak fields. The greater proportion of materials i.e. solids, liquids and gasses are Paramagnetics. There are various kinds of magnetism and each is characterised by its own magnetic structure. Generally, materials are classified using the relative permeability and susceptibility. The knowledge of these parameters about a material during geophysical exploration could give a clue to detection at a location within the solid earth. It should be noted that magnetic anomaly in a rock matrix is entirely caused by the amount of magnetic minerals contained in the rock. This unit treats the various kinds of magnetism with which rock components could be classified based on their magnetic property parameters. The types of magnetism discussed include Diamagnetism, Paramagnetism, Antiferromagnetism, Ferrimagnetisms, and Ferromagnetism.

2.0 Objectives

By the end of this unit you should be able to:

1. Define magnetic susceptibility and permeability.
2. List types of Rocks' magnetism
3. Differentiate the rocks magnetism using their properties
4. Give examples of the minerals in each class of rocks magnetism
5. Describe Curie temperature.

3.1 Intensity of Magnetisation (M)

When a piece of magnetisable material is subjected to an external magnetic field it becomes magnetised; the extent of its magnetism, which depends on the strength of the external field, is called its intensity of magnetisation M, or simply called Magnetisation.

Consider a bar magnet L long having pole strength P.

Its magnetic moment M = PL

So $M = \frac{PL}{V}$, where V = Volume of the magnetising body.

That is, intensity of magnetisation $= \frac{M}{\mathrm{V}}$

Recall that M = $\frac{PL}{A.L}$

And P = IL, (I in Ampere)

So, unit of M is A/m.

3.2 Magnetic Permeability and Susceptibility

If a rod of any magnetic material is inserted in a current carrying coil, the induction/density B is increased. Thus, the lines of force are due to the applied field (H) and that due to the magnetised material inserted called line of Magnetisation M.

Recall that the unit of H is A/m which is the same as that of magnetisation M, and that $B = \mu_0 H \, in vacuum$

So, the total magnetic induction/density

$B = \mu_0 H + \mu_0 M, where$

μ_0 H = induction due to the applied field and

μ_0 M = induction due to the magnetisation of the materials

$$So, \frac{B}{H} = \mu_0 (1 + \frac{M}{H})$$

$$= \mu_0 (1 + \Psi)$$

$$let\, \mu = \mu_0\, \mu_v, where$$

$$\mu = \frac{B}{H} = Magnetic permeabilty$$

That is, magnetic permeability of a magnetised body is the ratio of magnetic density B of the field induced in the body to the magnetic strength/intensity of the applied field. The unit of permeability is Henry/metre (H/m). Also, $\Psi = \frac{M}{H}$

= Magnetic susceptibility

That is, magnetic susceptibility is the ratio of magnetisation in the body to the magnetic strength/intensity of the applied field.

Further, $\mu_r = \mu/\mu_0$ and $\mu_r = 1+\Psi$, where

μ_r = relative permeability.

Literarily, permeability is the measure of how easy or fast a body get magnetised when subjected to external field. Susceptibility is the measure of how much of the magnetism will be retained having removed the magnetising field.

3.3 Types of Magnetism of Rock Components

Magnetic anomalies of rocks are determined by the magnetic parameters such as susceptibility and permeability of their constituents. Hence, the types of magnetism in rocks are based on those parameters. The classes are as follow:

3.3.1 Diamagnetic materials

These materials have the following characteristics:

- When subjected to magnetisation, they show magnetisation in opposite direction.

  That is, they have negative susceptibility (-Ψ)
- Atomic magnetic moment is zero when H is zero
- Relative permeability μ_r is slightly less than 1 in them
- Their electrons' magnetic moments cancel out because of orbital and spin motions.
- They are temperature independent
- Examples are Neon, Helium, Monoatomic gasses, Bismuth, Graphite, Gypsum, Marble, Quartz and Salt.

3.3.2 Paramagnetic Materials

They have the following characteristics:

- Application of external field produces positive magnetisation, that is, +Ψ
- They show high susceptibility at low temperature, i.e. temperature dependent.
- Atom or molecule has a net magnetic moment in zero external field H
- Relative permeability μ_r is slightly higher than 1
- Their electrons' magnetic moments add up.
- Examples are Aluminium, Rare gasses, Copper and substances whose sub-shells are not filled to the maximum.

3.3.3 **Ferromagnetic Materials**

They have the following characteristics:

- There is strong magnetic attraction between atoms which results in alignments of moments within large region (domain) of the material.(Fig 1a)
- High susceptibility
- Very large permeability
- Strong linkage between neighbouring atoms to form magnetic domain.
- At temperature above Curie point ferromagnetic materials turn to Paramagnetic materials.

3.3.4 **Antiferromagnetic Materials**

They have the following characteristics:

- They are formed when net magnet moments of parallel and anti parallel domain and sub domain cancel each other in a ferromagnetic material (Fig 1b)
- The resultant susceptibility Ψ is small, close to that of paramagnetic materials.
- An example is hematite.

3.3.5 **Ferrimagnetic Materials**

They have the following characteristics:

- Their magnetic domains are subdivided into regions which may be aligned in opposition to one another (Fig.1c), but the net moment is not zero when it is zero
- It is an imperfect anti ferromagnetic materials
- It has high resistivity.
- Examples are Magnetite, Ilmenite, oxides of iron etc. Really, all magnetic materials are ferromagnetic materials.

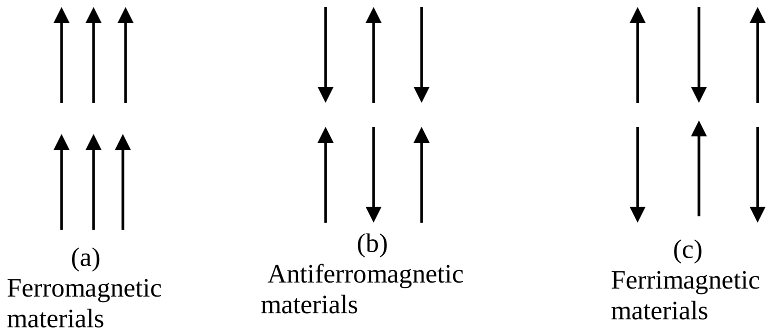

Fig.1: Sketch of Orientation of Magnetic Moment for Ferromagnetic, Antiferromagnetic and Ferrimagnetic Materials.

3.4 Curie Temperature

This is a temperature at which saturation magnetisation becomes zero. That is, at Curie temperature ferromagnetic materials lose their properties and become paramagnetic. This is caused y an extreme increase in the internal energy causing violent vibration of the atoms. This destroys the domain structure.

3.5 Self assessment Exercise

1 List the types of magnetisms in rocks' components.
2 Define Magnetic permeability
3 What is Curie temperature?

4.0 Conclusion

Rocks mineral constituents are classified into five, based on their magnetic properties. Susceptibility and permeability are the important parameters in the area of magnetic prospecting.

5.0 Summary

In this unit you have learnt that:

(i) When a magnetic material is exposed to external field, total magnetic induction in it is the sum of that from the external field and due to the magnetisation of the material.

(ii) Rocks constituents are classified into 5, based on their magnetism.

(iii) Magnetic permeability is the measure of how fast a material could be magnetised.

and susceptibility is the measure of the quantity of the induced field retained in the body after withdrawing the magnetising field.

(iv) Magnetised ferromagnetic materials lose their magnetism at Curie temperature.

6.0 Tutor Marked Assignment

(i) Proof that the unit of magnetic strength H and that of Magnetisation are the same.

(ii) Give one each, similarity and difference between paramagnetic and ferromagnetic materials.
(iii) Give one common characteristics between Ferromagnetic, Antiparamagetic and Ferrimagnetic materials.
(iv) Define relative permeability of a material.

7.0 Further Readings and Other Resources

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Unit 3: **Magnetisation in Earth's Rocks**

1.0 Introduction

Some rocks are naturally behaving like permanent magnet, showing that they must have been magnetised by an external field at one time over geologic period. This unit deals with the sources of the total magnetisation in rocks; the major sources are the ambient geomagnetic field or induced magnetisation and residual or natural/normal remanent magnetisation.

2.0 Objectives

At the end of this unit you should be able to:

(i) Define Palaeomagnetism.
(ii) List the derivations from the palaeomagnetic studies.
(iii) Explain residual magnetism in rocks.
(iv) Mention and explain various mechanisms of remanent magnetism.

3.1 **Definition of Palaeomagnetism**

This is a science that studies the historical background of permanent magnetism found in rocks. The magnetic field found in the rocks is believed to have been formed since the geologic time of formation of the rocks. Some useful in formations derived from palaeomagetic studies, are as follow:

- Permanent magnetisations in some rocks are oriented in directions, different from the present earth's field polarity.
- Earth's field has varied in magnitude and has reversed its polarities severally over time.
- There is evidence of polar wandering and continental drifting.
- Earth's field always exist in dipole form.
- No evidence that earth's field has ever disappeared completely.

3.2 **Total Magnetisation**.

The total permanent magnetism M in rocks can be seen to come from two parts namely:

- Induced magnetisation; this is magnetisation sourced from the earth's external field.
- Remanent/residual magnetisation, this magnetisation formed during the formation of the rocks; that is, independent of present external field but dependent on the magnetic history of the rocks.

3.3 Residual Magnetism

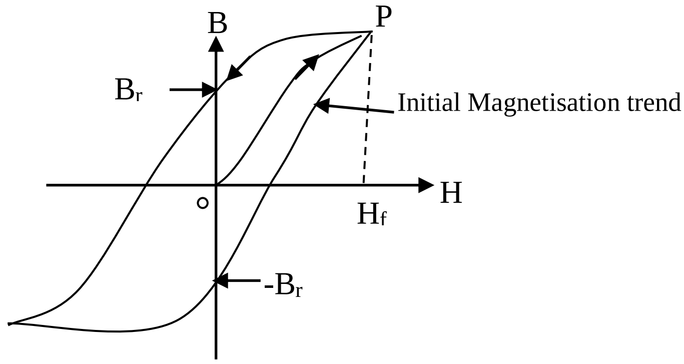

Fig.1: Hysteresis Curve (Magnetisation and Demagnetisation of a Magnetic Material)

Literarily, residual magnetism refers to the magnetism remaining in a substance when the magnetising field has been removed completely. Consider a field with strength H to have magnetised a body to a density B and the field is then removed gradually completely. When H is zero B is found not to be completely zero. The remnant Br after H is zero is called remanent or residual magnetism (Fig.1)

The material is magnetised along OP and demagnetised along PB_r. It is fully magnetised when the field strength is H_f. As H_f. decreases to O along PB_r, the magnetisation B_r still remains in the body. B_r is the remanent/residual magnetisation. This can be adapted to the case of solid earth's rocks. The rocks retained residual magnetisation when the Earth's field is completely removed probably during polar reversal. This residual magnetisation is also called natural remanent magnetisation.

3.4 Remanent Magnetisation

Various mechanical/sources of remanent/residual magnetisation in rocks are as discussed below.

3.4.1 Thermoremanent Magnetisation (TRM)

The earth's rock was believed to have melted completely during iron catastrophe. The molten rock was magnetised by the earth's field present at that time, when the rock cooled below Curie temperature. The direction of magnetism is that of the earth's field during the formation. Pressure and hardness due to cooling make the magnetised rock to retain its direction of polarisation even when the earth's field polarity changes direction. This is common in igneous rocks.

3.4.2 Depositional Remanent magnetisation (DRM)

This is common in sedimentary rocks. When sedimentation is on, particles are free to align and magnetise in the direction of the present earth's field. Further sedimentation pilling on the magnetised sediment raised the pressure. Hence, the magnetised rocks maintained the direction of polarisation during magnetisation.

3.4.3 Chemical Remanent Magnetisation (CRM)

This is common in sedimentary rocks, forming metamorphic rocks, during chemical transformation of some rocks from to another below Curie temperature.

3.4.4 Isothermal Remanent Magnetisation (IRM)

'IRM' is produced from lightening strikes that occur irregularly within a small area.

3.4.5 Viscous Remanent Magnetisation (VRM)

This is produced by build up of the field due to long time exposure to the external field.

3.4.6 Peizo- Remanent Magnetisation (PRM)

This is magnetisation obtained as a result of pressure variation.

3.5 Self-assessment Exercise

1 List any two facts about earth's magnetism obtained from the knowledge of Paleomagnetism

2 Sketch a curve to show residual magnetisation of a demagnetised material.

3 Explain the remanent magnetisation that is common in igneous rock.

4 Explain Isothermal Remanent Magnetisation.

4.0 Conclusion

Total magnetisation in rocks are made up of induced magnetisation from the earth's field and that from remanent magnetisation. Remanent magnetisation is the residual field that remains in the body when the magnetising field has reduced to zero. Remanent magnetisation is from various mechanisms such as TRM, CRM, etc.

5.0 Summary

In this unit you have learnt the following:

(i) Total magnetisation compose of 2 parts which are induced magnetisation from the external field and that from residual magnetism.

(ii) Remanent magnetisation are from mechanisms such as TRM, CRM, IRM, VRM and PRM

(iii) Paleomagnetism has confirmed polar wandering and continental drifting.

6.0 Tutor marked Assignment

1 Briefly discuss the type of residual magnetisation that is peculiar to igneous rocks.

2 Explain the reason why the polarity of a magnetised rock sample picked on the field today defers from the polar direction of the present ambient field.

3 Define Isothermal Remanent Magnetisation.

7.0 **Further Readings and other resource.**

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Unit 4: **Magnetic Measurement**

1.0 Introduction

In magnetic prospecting, susceptibility is a significant variable. Though, it is not possible to measure it directly on the field. However, susceptibility of rock samples from outcrops can be measured using instruments such as Kapameter, variables such as magnetic field strength H and induction/density B are other parameters of interest. This unit discusses elementary parameters such as field strength, density and susceptibility, and their practical units.

2.0 Objectives

At the end of this unit you should be able to:

(i) Explain the following:
- Magnetic force
- Field strength
- Moment
- Intensity of magnetism
- Susceptibility and
- Magnetic induction

(ii) Sketch a uniformly magnetised and polarised body.

(iii) State the practical units of magnetic parameters like susceptibility, intensity and induction.

3.1 Magnetic force (F)

Imagine fictitious unit poles with strengths m_1 and m_2 separated by distance r and $\hat{r}$ is a unit vector direction from m_1, to m_2, using analogy of Newton's law of gravity, magnetic force $F = \frac{m_1 m_2}{\mu r^2} \cdot \hat{r}$, where μ = permeability of the medium surrounding the unit poles. Magnetic force is attractive if the poles are opposite signs, but repulsive if they are the same. The magnetic north poles are always attracted towards the south pole of the earth and the south poles to the North Pole.

3.2 Magnetic Field Strength (H)

It is also called field intensity. It is a point quantity as a result of poles of strength m located at a distance r from it. Field strength is defined as the force per unit magnetic pole strength at a point. That is,

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

m_1 is the fictitious pole at a point in space; in practice, it is the instrument used to measure H. It is taken that m_1 is small that it can not affect the H to be measured. H in the poles of magnetised materials can be measured. H can be produced by current flowing in a solenoid.

3.3 Magnetic Moment

Magnetic dipole consists of two unlike poles with strength +m and -m separated by distance r (Fig.1).Magnetic moment P is defined by P=mr, where m is the strength at a pole.

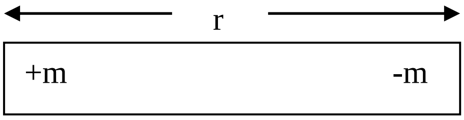

Fig. 1: Magnetic dipole

3.4 Intensity of Magnetisation M

Simply called Magnetisation, it is magnetised moment per unit volume

$$M = \frac{P}{V}.$$

If the dipoles of a magnetic material are line up, we say it has been polarised (Fig. 2a); if the dipoles have the same direction throughout, the body is said to be uniformly magnetised (Fig. 2b)

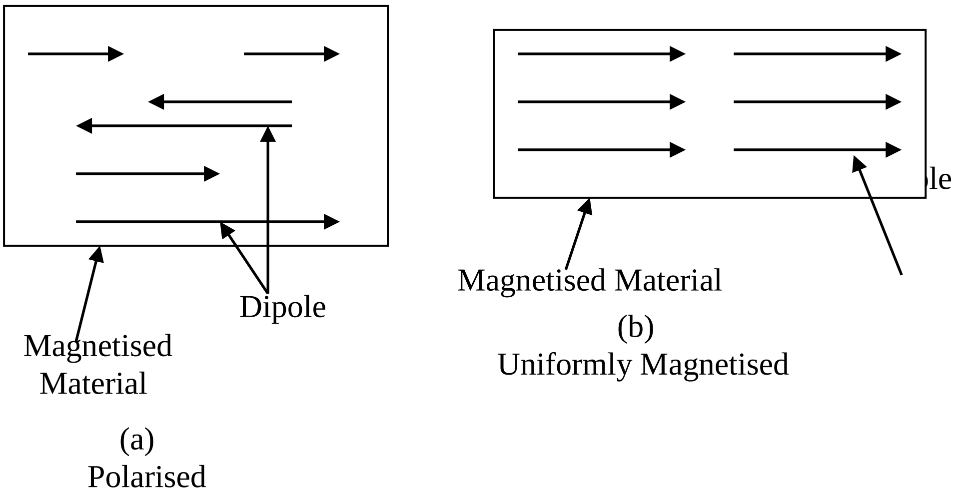

Fig. 2: Sketch of Polarised and Uniformly Magnetised Magnetic Materials.

3.5 Magnetic Susceptibility (Ψ)

The degree to which magnetic material is magnetised is called susceptibility. Mathematically,

$$\Psi = \frac{\mathrm{M}}{\mathrm{H}}$$

Susceptibility is a fundamental parameter in magnetic prospecting.

3.6 Magnetic Induction (B)

This is also called flux density. The strength of a magnetic field H, is also usually measured in terms of magnetic flux density. That is, mathematically,

$$B = \frac{Magnetic\,flux}{crosssectionarea}$$

Also B = μ H, where μ = permeability

$\mu = \mu_o \mu_r$, where μ_o and μ_r are permeability of vacuum and relative permeability respectively.

3.7 **Magnetic Units**

The SI units and equivalent 'cgs' units of useful magnetic parameters, are tabulated below.

Symbol	SI (mks) unit	cgs unit	Conversions
Flux	Webber		
H	A/m, Gamma (γ)	Oersted (oe)	1 oe = 7.6 A/m, 1oe = 10^5 γ
B	Telsa (T), W/M^2	Gauss	IT =1w/m^2, 1 gauss = 10^{-4} T, 1 w/m 10^4 Gauss
M	A/m	Gauss	1 Gauss = 10^3 A/m
Ψ	Unit less		
M	H/m		

For geophysical works, nanoTelsa (nT) is suitable unit for B, i.e. 1nT =10 $^{-9}$ T and suitable unit for H is γ, i.e. 1 γ = 10^{-5} Oersteds.

3.8 **Self-assessment Exercise**

(i) Define magnetic moment
(ii) What is the practical unit of magnetic field strength?
(iii) Sketch a bar of magnetic mineral that is uniformly magnetised.
(iv) What is the unit of magnetic Susceptibility?

4.0 **Conclusion**

Magnetic dipole as obtained when two unlike poles are separated by a distance. Magnetic moment can be obtained only for dipoles. When dipoles line up in the same direction in a magnetised body it is said to be polarised and uniformly magnetised.

5.0 **Summary**

In this unit you have learnt that:

1 A uniformly magnetised body is polarised.
2 Magnetic moment is only obtainable for a dipole.
3 Magnetic field strength and intensity of magnetisation have the same unit
4 The practical units used in the geophysical measurements are nT for B and γ for H.
5 Susceptibility can not be measured in *situ* but can be measured from the samples of rock outcrop.

6.0 **Tutor Marked Assignment**

(a) Differentiate magnetic susceptibility from magnetic permeability.
(b) Sketch a diagram to represent a uniformly magnetised and polarised magnetic material.
(c) How many A/m make 1 γ?
(d) Define relative permeability of a magnetised material.

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Module 3: Gravity Methods

Unit 1: Newton's gravitation and Application

1.0 Introduction

Gravity method is one that is responsive to the density variation in the subsurface rocks. It involves measurement of the lateral variations in the earth's gravitational pull from a point to another, caused by density contrasts within subsurface rocks. The method is a potential field method suitable for the reconnaissance mineral exploration, engineering constructions, geological searches, town planning, geodesic studies etc. This unit deals with the theoretical basis and applications of gravity methods.

2.0 Objectives

By the end of this unit you should be able to:

(i) Differentiate gravitational field from acceleration due to gravity.
(ii) Explain the two ways by which g can be measured.
(iii) State the practical units of gravity field used in geophysical works.
(iv) Determine absolute gravity for a point B, given the absolute gravity at a reference point A and gravity difference measured at B.

3.1 Force of Gravitation

Newton explained the attractive force between two bodies m_1 and m_2 separated by a distance r called force of gravitation. This force is the basis for geophysical gravity works. Newton stated the law that gravitational force F of attraction between two particles with masses m_1 and m_2 is given by;

$$F = \frac{-Gm_1 m_2}{r^2} \text{------------------------------------} (1)$$

The negative sign implies that the bodies' motions are in opposite directions.

G is the universal gravitation constant.

The force F is a gravitational force.

3.1.1 Object on the Earth's Surface

Consider a body of mass m held at the surface of the earth mass M and whose radius is R. m is at distance R from the centre of the earth (Fig.1). Then gravitational force between m and M is

$$F = \frac{-GmM}{R^2} \text{------------------------------------} (2)$$

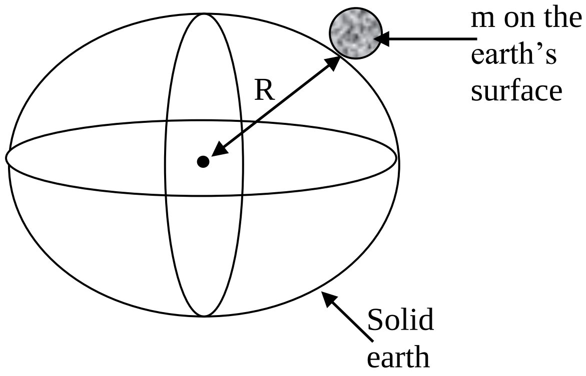

Fig.1: Object on the earth's surface

It should be noted that F is proportional to the magnitudes of mass. That is, gravitational force of attraction by M on m depends on the magnitude of m. And, the larger body is going to attract the smaller one.

3.1.2 **Object a distance r away from the earth's surface**

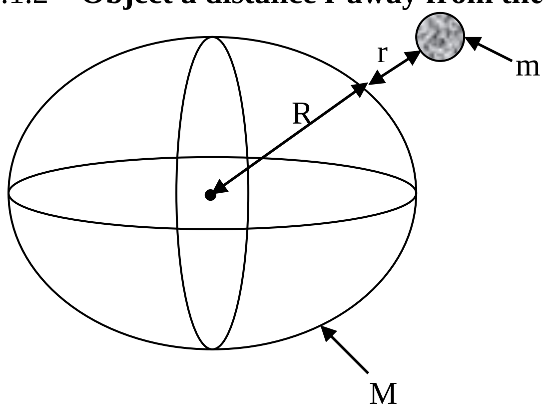

Fig.2: Object in the Atmosphere

Object m is R+r away from the earth's surface as shown in Fig 2 above. Thus, gravitational force

$$F = \frac{-GmM}{(R+r)^2} \quad \text{--} (3)$$

F in equation 2 will be greater than that in equation 3, owing to the inverse square dependent of F on the distance. This implies that the higher the altitude the smaller is the gravitational force.

3.2 **Acceleration due to gravity**

It is a fact that gravitational force F increases progressively as the attracted smaller body moves towards the larger one owing to decrease in their distance apart during attraction. Increase in force, therefore will accelerate the attracted body towards the larger body. Thus, a freely falling object is falling as a result of the gravitational force of attraction by the earth on it. Its acceleration towards the earth is called Acceleration due to gravity (i.e. acceleration caused by the earth). That is, acceleration due to gravity is the acceleration of a freely falling object on the surface of the earth.

$$F = \frac{-GmM}{(R+r)^2}$$

$$\frac{F}{m} = \frac{-GM}{R^2} = g \text{ --- } (4)$$

$$\frac{GM}{R^2} = \textit{Force of attraction by M on unit mass of the attracted body m}$$

$$\textit{i.e. } \frac{GM}{R^2} = \textit{acceleration of m due to gravity/ earth pull on m}$$

$$\textit{But } \frac{F}{m} = \textit{force experienced by unit mass of a body m lying within the force feild of M}$$

$$\textit{Thus, } \frac{GM}{R^2} = \textit{acceleration due to gravity}$$

$$\textit{but } \frac{F}{m} = \textit{gravity feild or gravitational field}$$

Now, recall that $F = ma$, if g is acceleration due to gravity, you then write

$$F = mg \textit{ and}$$

$$F = \frac{GmM}{R^2}$$

$$\textit{i.e. } F = mg = \frac{GmM}{R^2}$$

$$\textit{i.e. } \frac{F}{m} = g = \frac{GM}{R^2}$$

3.2.1 Measurement of g

g can be measured in two basic ways:

(a) Free fall method: When an object is freely falling by the attractive effect of the earth on it, the body experiences acceleration g which is given by

$$g = \frac{GM}{R^2}$$

(b) Field effect method: A stationary object at a point on the surface or at a height about the earth's surface within the attractive force field set up by the earth will experience the attractive effect. g is given by: $g = \frac{F}{m}$ => Force experienced per unit mass m of the body. Such stationary body is designed within an instrument called
Gravity-meter or Gravimeter usually used for measurement of g.

Basically, there are two major types of gravimeters:

(i) Absolute measurement gravimeter. This one measures the true value of g at a point called absolute g

(ii) Relative gravity measurement gravimeter. This one measures the gravity difference between a point of known absolute g and another point of unknown g (Fig. 3)

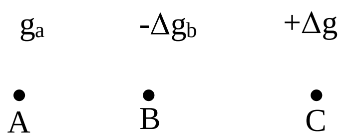

Fig. 3: Relative Measurement of g

If g_a is the absolute value at point A and $-\Delta g_b$ is the gravity difference measured at point B, then absolute gravity at B is $g_B = g_a - \Delta g_b$. If the measurement at point C is $+\Delta_g$, then absolute gravity at C is $g_c = g_a + \Delta g_C$.

3.3 Practical unit of g

The SI unit of g is m/s^2. This unit is too large for geophysical work, in that the gravity difference of interest is very small. Thus smaller units are imperative.

Galileo gave smaller units and the unit are named after him

$1 \text{ cm/s}^2 = 1$ gal, that is,

1000 mgal = 1 gal

3.4 Self- assessment Exercise

1 Explain gravitational field.

2 Differentiate gravitational field from acceleration due to gravity

3 Write the mathematical relation representing the gravitational force for an object at height h from the earth's surface.

4.0 Conclusion

Acceleration due to gravity is the acceleration experienced by a freely falling object above the earth's surface. It can also be explained as the force per unit mass of an object lying within the force field of the earth. Gravimeter is an instrument designed to measure the gravitation or relative field effect at a point. Gravimeter can be designed to measure absolute gravity field or relative difference between a point of known absolute gravity field and the point in question.

5.0 Summary

At the end of this unit you have learnt that:

(i) Gravitational force on an object on the surface of the earth is inversely proportional to the square of its distance from the centre of the earth.

(ii) Gravitational field is the force per unit mass of an object within the effect of the Field.

(iii) The farther an object is from the earth the lower is gravitational field effect on it.

(iv) Gravimeter is the instrument for measuring the gravitational field.

(v) The practical units of gravitational field are gal and mgal.

6.0 Tutor marked assignment

(i)

A $g_{absolute}$ = 980 gal

B Δg = -0.91 gal

C Δg = -0.52 gal

The absolute and gravity differences at point A, B and C are shown above. Calculate the absolute gravities at point B and C.

(ii) Prove that the derived unit of acceleration due to gravity and gravitational field are the same.

7.0 Further Readings and Resources

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Unit 2: **Gravity Instrument**

1.0 Introduction

Gravity work in geophysical endeavour involves measurement of the gravitational field effect on a stationary body at a point on the earth's surface. Gravimeter is an important instrument designed for this purpose; some gravimeter are designed to measure absolute gravity at a point while others are designed to measure the difference within a point of known absolute gravity and others. The point with known absolute gravity serves as the reference point. This unit deals with various types of instrumental need for gravity works.

2.0 Objectives

By the end of this unit you should be able to:

(i) List types of gravimeters.
(ii) Sketch LaCoste-Romberg gravimeter.
(iii) Explain the calibration procedure.
(IV). Describe the daily care of a gravimeter in preparation for a day work.

3.1 Gravimeter

Gravimeter is the major instrument measuring small differences in gravity field between stations. It has two categories namely:

(a) Stable gravimeter: it has responsive element made of spring carrying weight. The element is always at equilibrium. The weight is displaced from its equilibrium position, whenever there is a change in the gravitational pull. Thus, the <u>displacement</u> is a measure of the gravity variation from one observation point to the other. e.g. Askania or Boliden gravimeter (0.1 mgal sensitivity), Gulf or Hoyt gravimeter (0.03 mgal sensitivity)

(b) Unstable gravimeter: It has a hinged beam, spring, weight and adjustable screw. The beam system becomes unstable in response to gravity variation and hence deflected. The <u>angle of deflection</u> at an unstable equilibrium state corresponds to the gravity variation at that instance. e.g. Worden gravimeter (0.02 mgal sensitivity), LaCoste-Romberg gravimeter (0.01mgal sensitivity) The gravity measured from time and length measurements as in the case of pendulum vibration is <u>absolute</u> gravity measurement. But, gravimeter measures only gravity change from stations to stations compared with the absolute value of a station taken as a reference/base station. LaCoste-Romberg gravimeter is most commonly used nowadays, owing to its highest sensitivity.

3.2 LaCoste-Romberg gravimeter

It is unstable gravimeter designed to measure relative changes in gravity field. It has 0.01 mgal sensitivity. It can be used at anytime of the year and at any time on the earth's globe. Absolute gravity can be determined from its measurement by appropriate mathematical procedures using the reference point gravity value and the gravity differences obtained at stations occupied in the gravity works. LaCoste-Romberg gravimetert is also called zero-length spring meter.

3.2.1 Features of the LaCoste-Romberg Gravimeter

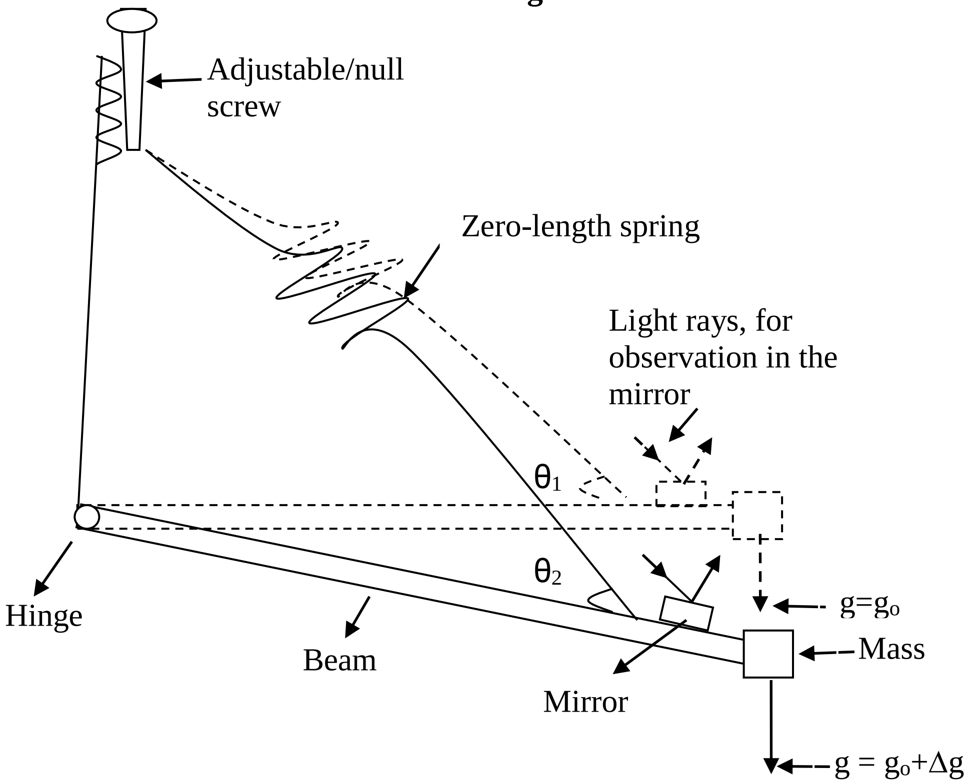

Fig.1: Simplified LaCoste-Romberg gravimeter

The tension in the spring due to the weight of the beam at zero position is made proportional to the actual length of the spring. In theory, it means when all external forces were eliminated the spring would collapse to zero length; hence it is called ZERO LENGTH. So any change in length of spring caused by gravity change will be proportional to the change itself. The limitation of the LaCoste-Romberg gravimeter is that in practice the thickness and weight of the spring will nullify the zero-length expectation. The angular variation θ_2 from what it is at equilibrium is nullified using the screw and the extent of the nullification is taken as the measurement.

3.3 Gravity Measurement

We can measure gravity:

- On land (i.e. land survey)
- On sea (i.e. sea survey)
- In air (i.e. airborne survey)

3.4 Daily Checks on LaCoste-Romberg gravimeter

Prior to a gravity work good condition of the gravimeter must always be checked before commencing a day work. The following steps should be taken:

(i) Take several readings at a spot until the readings becomes constant

(ii) Readings are taken at the same spot in different directions to be sure that its pointer is moving in the same direction and the same distance.

(iii) When transported to the field over a very long distance of several kilometres, it should be allowed to rest for several minutes before the commencement of the work.

3.5 Calibration of Gravimeter

Direct Readings from gravimeter is just the dial/counter readings recorded when null knob is turned. The counter reading is converted to gravity units (e.g. mgal, gal) using calibration constants given by the manufacturers. The constant gives the gravity value per division on the gravimeter. It has been confirmed that the calibration constant changes slowly with time. Thus, it is necessary to check it regularly. Calibration can be done in two ways as shown below.

3.5.1 Tilt Calibration method

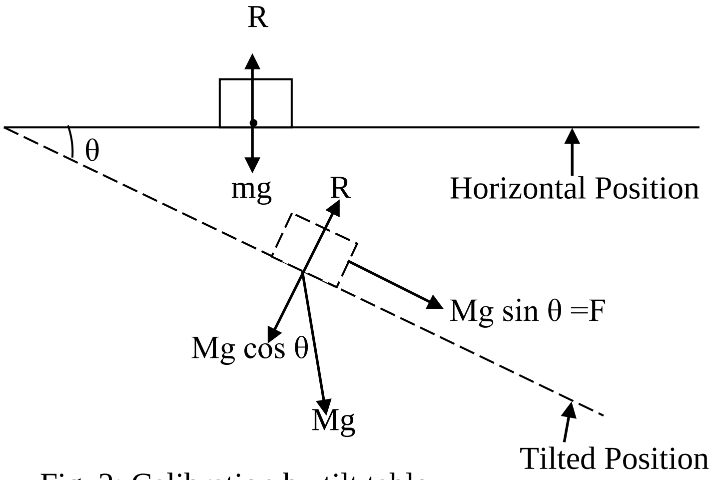

Fig. 2: Calibration by tilt table

The gravimeter is put on a table whose plane surface can be tilted for a very small angle θ about the horizontal (Fig.2)

At horizontal position, the weight is mg. When tilted, the instrument is acted upon by a force given by mgcosθ. Thus, the gravity change is given by $\Delta g = g(1-\cos\theta)$, where g is the absolute gravity of the spot and θ is the angle of tilt. Thus, calibration factor, $\mu = \frac{\Delta g}{g}$.

3.5.2 Two-point Calibration Method

Here two points with known absolute gravity values are occupied with gravimeter to obtain gravity differences. The two points must be about 1 km apart and should have appreciable elevation difference of about 20m. Thus, calibration factor $\mu = \frac{g_{ao} - g_{bo}}{g_a - g_b}$, where g_{ao} and g_{bo} are the observed grarity values at station A and B respectively g_a and g_b are the corresponding absolute gravity values at station A and B.

The calibration factor would serve as the multiplying factor to be applied to the gravimeter readings after conversions. This takes care of any alteration that may have occurred to the scales on the gravimeter.

3.6 Self-assessment Exercise

1. Sketch a simplified zero length gravimeter.
2. Explain the daily checks that must be accomplished on a gravimeter before a day work.
3. Mention the two types of calibration methods.

4.0 Conclusion

Gravimeter is the major instrument for practical measurement of gravity field. There are various types, but the most used one for now is LaCoste-Romberg model that has high precision value of 0.01 mgal. It must be taken care of before, when and after use. There should be calibration check over a period of time.

5.0 Summary

In this unit you have learnt that:

(i) Gravimeter is categorised into stable and unstable classes.

(ii) LaCoste-Romberg is the zero length unstable gravimeter that is used to obtain gravity lateral variations.

(iii) Tilt table and two-point methods are the usual ways to calibrate gravimeters.

(iv) Daily repeated readings of gravimeter at a spot are necessary before a day work, to ensure its good condition.

6.0 Tutor marked Assignment

(1) Convert 1 m/s^2 to mgal unit.

(2)a Use appropriate diagram and mathematical derivation to show that gravity changes on a tilt table method of calibration is given by $\Delta g = g(1 - \cos\theta)$

b Define all the parameters in the equation proved in (a)

7.0 Further reading and Resources

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Unit 3: **Gravity field work**

1.0 Introduction

Geophysical gravity work is basically practical base, involving going to the survey site to make measurements in *situ* Gravity measurement may be on land, in the air or on the sea. Proper planning is very necessary for successful works. This unit deals with the procedures, needs and logistics necessary for proper gravity fieldworks on the land.

2.0 Objectives

By the end of this unit you should be able to:

(i) Demonstrate field observational sequences for gravity survey
(ii) Make proper fieldwork preparation for gravity survey.
(iii) Recommend a suitable field survey that can be used for specific purpose in gravity survey.

3.1 Type of gravity survey

The size of the material of interest could determine the inter-station spacing. For instance an anomaly of size 200 m lengths could be suppressed in a survey with station spacing of 300 m. So, the survey size will determine the details of interest. Typical survey sizes are:

Survey	Station Separation (km)
(1) Trans-continental, geodetic	5 – 10
(2) Regional mapping and structural investigation	1 – 2
(3) Oil exploration	0.5 – 1
(4) Reconnaissance mineral survey	0.2 – 0.5
(5) Detailed structural investigation	0.5 – 0.15
(6) Mineral exploration	0.02 -0.05 or less

3.2 Logistics for Land Measurement

Logistics that will ensure successful work are:

(i) Accessibility to the stations e.g. road network
(ii) Transportation
(iii) Housing, in case of a large scale work that will require staying away from home.
(iv) Reference/Datum Stations
(v) Knowledge of the prevailing local geology of the survey site.
(vi) Adequate map of the area for easy location of stations.

3.3 Requirements for Fieldwork

The materials necessary for gravity fieldworks on land are:

- Field map of the area showing the road network.
- Reference station(s) on or near the area to which measurement will be tied to.
- Field vehicle with effective speedometer/odometer
- Gravimeter
- Instrument to measure elevation e.g. altimeter or Global Positioning System (GPS)

- Hammer and chisel
- Portable power source for charging the gravimeter battery
- Instrument for outcrop specimen density measurement e.g. metler balance.

3.4 Field Observational Procedures

Various procedures of taking measurements are suggested. Let A, B, C and D be gravity stations to be occupied. The field sequences for data collections are:

(1) Leap-frog

A→B→A→B→C→B→C→D→C→D→A→D

(2) Ladder

A→B→C→D→C→B→A→D→A

(3) Double Loop

A→B→C→D→A→D→C→B→A→D

(4) Single Loop

A→B→C→D→A

A new chain method recently developed is shown in (Fig.1)

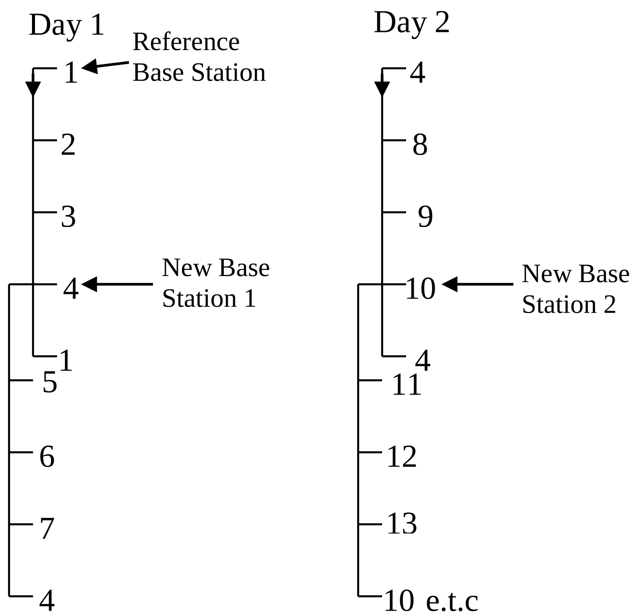

Fig.1: Chain sequence (After Olatunji, 2006)

The repeated stations can be a break time within a day. The work can start from any previous station of the same day and you close back at the station where you started the immediate previous work, e.g. station 4 in Fig .1. Another day work must start from any station with repeated readings in any of the previous day stations. E.g. stations 1 and 4. A station with repeated reading is called base station.

3.5 Instrument Test

It is necessary to ensure a good condition of the gravimeter and the altimeter, prior to the fieldwork. For this, one needs to observe the two instruments hourly at a point for about 48 hours. The responses are plotted against time for each day to detect any regular or irregular characteristics. A typical plot for gravimeter at a time is shown below.

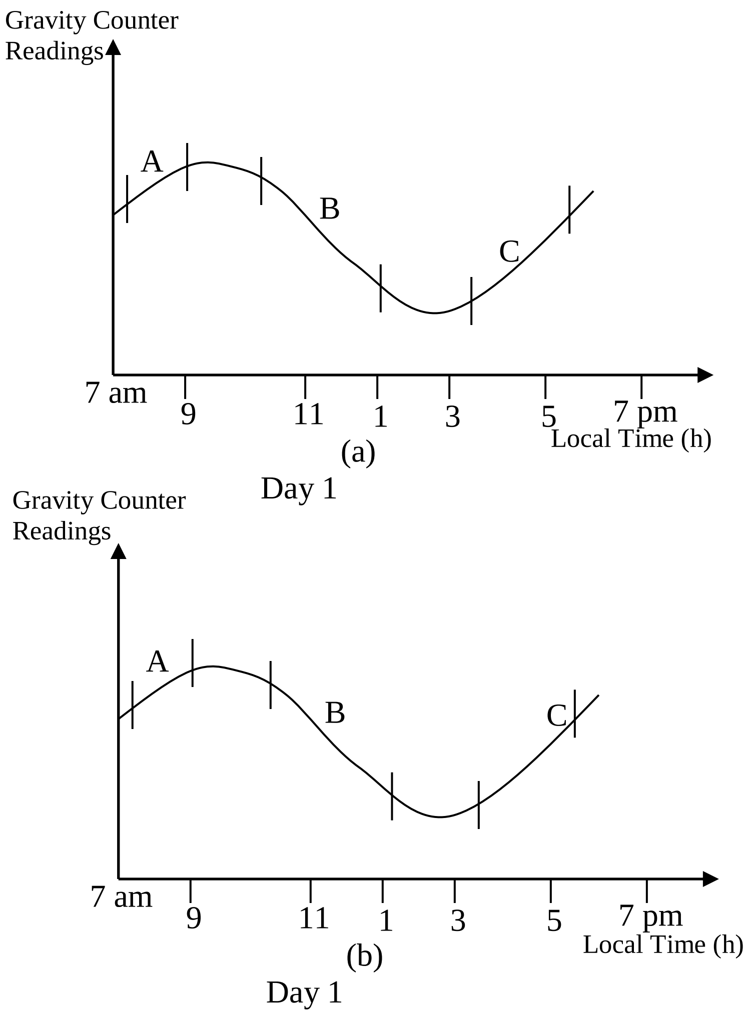

Fig. 2: Pre-fieldwork Gravimeter observed Response (After Olatunji 2006)

The response for the two days shows the same region of linear variation –A, B, C-. This fieldwork could be restricted to those regions of time in other to correct for the irregular variation within the other regions on the graph which may be due to instrument drift and tidal effects.

3.6 **Self assessment Exercise**

(i) List the instruments that can be used to measure elevations at gravity stations

(ii) Mention two logistics when gravity field work is to be accomplished

(iii) Define gravity base station.

4.0 **Conclusion**

Good conditions of gravimeter and altimeter are ensured by taking repeated measurements at a point. The detail size needed in a gravity survey determines the station separation to be used. Various field sequences such as leap, frog, double loop etc are the recommended Procedures for the gravity survey.

5.0 **Summary**

At the end of this unit you have learnt that:

(a) Logistic and required materials must be addressed for successful fieldwork.

(b) There are various field sequences but, in all, each day's work must always commence from base station closest to the starting point.

(c) Instruments must be tested at a point before the fieldwork proper.

6.0 **Tutor Marked Assignment**

(1) Explain how a new base station can be established on the field

(2) Recommend a typical suitable gravity survey spacing suitable to map the detailed structure of a Kimberlite pipe whose lateral extent is 70 m.

(3) Draw a typical 2 day survey using chain sequence if the field man rest 2 times in a day work after every 5 readings

7.0 **Further Reading and Resources**

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Unit 4: **Gravity Data Processing**

1.0 Introduction

Data collected during gravity fieldwork are mostly raw and some contains errors that need corrections. This unit deals with data processing which includes conversion of gravimeter counter reading to mgal, error correction such as Bouguer, Free-air, tidal and drift effects.

2.0 Objectives

By the end of this unit you should be able to:

(i) List steps to be followed in gravity data processing
(ii) Describe various correction procedures in gravimetric works
(iii) Explain gravity anomaly
(iv) Discuss how to obtain absolute and theoretical gravity values

3.1 Major steps in data processing

The procedures to be followed during data processing are:

- Conversion of gravimeter counter/dial reading to mgal unit
- Correction for errors such as Bouguer, Free-air, drift, tidal.
- Determination of observed absolute gravity using the corrected gravity values and the absolute gravity value of the reference station
- Determination of theoretical gravity value using IAG formula
- Determination of gravity anomalies needed for interpretation.
- Humidity corrections using psychrometer data on the altimeter data.
- Conversion of the altimeter reading to m unit.
- Density determination from the fresh rock samples (See module 1, Unit 6 for detailed density determination)

Qualitative and quantitative interpretations can now follow after through accomplishment of the steps itemised above.

3.2 Gravity data

Gravimeters usually give gravity field difference between reference station and the occupied stations. The oblate shapebof the earth contributes uniform gravity variation from equator to the poles. The steps involved in the gravity data processing are discussed bellow.

3.2.1 Gravity Conversion

The counter reading recorded from gravimeter is ordinary number. A table of conversion factor is provided by the manufacturer of the gravimeter used in its manual.

3.2.2 Determination of theoretical gravity values

The oblate shape of the earth gave rise to about 5300 mgal gravity increment from equator to the either pole. Thus, within accuracy of 0.004 mgal International Association of Geodesy (IAG) gave a mathematical model for obtaining theoretical gravity at geoid/sea level, for every latitude increase as

$$g_{th} = 978031.85\,(1+0.005278895 \sin^2\phi + 0.000023462 \sin^4\phi)$$

ϕ = Latitude of the station considered.

If reference plane is chosen above the sea level (e.g. at elevation h), then theoretical gravity is given by

$$g_h = g_{th}\left[1 - \frac{2}{a}\left(1 + f + m - 2f\sin^2\phi\right)h + \frac{3h^2}{a^2}\right], where$$

g_{th} = theoretical gravity at the point, sea level as reference plane.
g_h = theoretical gravity at elevation h, above the sea level
a = equatorial radius
f = flattening factor, given by $\frac{1}{297.000}$
h= elevation of the station
ϕ = latitude of the station

m = $\frac{centripetal\ force at equator}{gravity at equator} = \frac{W^2 a}{g_e}, where$

g_e = equatorial gravity
w = angular relaxity of earth (≈ 0.72921151 x 10^{-4}/s)

3.2.3 Determination of Absolute gravity values

Absolute gravity value is the ideal/actual value of gravitational field obtained at a point. This is obtained using theoretical and the gravimeter measured values at a point after all corrections have been effected. The various corrections that could be effected are discussed below.

3.2.4 Free-air Correction

From $g = \frac{GM}{r^2}$ we can see that g reduces with elevation increase. Free-air effect is therefore the elevation reduction effect on the gravity. Thus, to correct this we add the free-air correction term above the sea level or subtract it below the sea level. This brings the measured value to the sea level provided the sea level is the reference datum.

Free-air correction term = 0.3086h
So, free-air gravity $g_{fg} = g_0 \pm 0.3086$ h, where
h = elevation
g_{fg} =observed gravity value after free-air correction
g_0 =observed gravity value from the field.

3.2.5 Bouguer Correction

Bouguer effect is the gravity field increase caused by the rock slab between the station and the sea level (Fig.1)

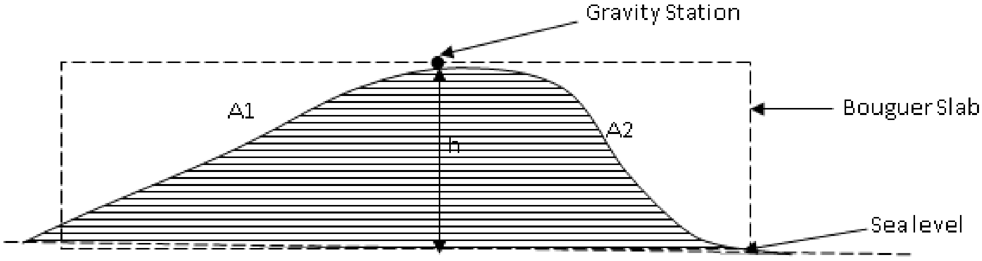

Fig.1: Rock slab for Bouguer Correction

Thus, to correct this we subtract the Bouguer correction term above the sea level or add it below the sea level. This brings the measured value to the sea level

Bouguer correction term =$2\pi\rho Gh$.

So, Bouguer gravity $g_{bg} = g_{fg} \mp 2\pi\rho Gh$, where

ρ = density of the rock within the slab

G = Universal gravimeter

h = elevation

3.2.6 **Bullard Correction**

Bullard effect is the gravity field decrease caused by the empty spaces A1 and A2 added during Bouguer correction (Fig.1) Thus; Bullard involves addition of the correction term.

3.2.7 **Tidal Correction**

Tidal effect is the gravity change caused by attraction of sun and moon on the earth. Global tables covering given time are available. Also, pre-field observation of the gravimeter to obtain daily linear variation time windows where counter reading vs. time is plotted, can take care of tidal effect. This is done by restricting field work to the time window epochs.

3.2.8 **Drift Correction**

Drift effect is caused by creeping of the spring in the gravimeter due to frequent stresses during uses. The correction term is subtracted from the absolute gravity value. For corrections, drift is considered to be a linear function of time. To obtain drift rate between two stations with known absolute gravity values we observe the gravimeter at the two stations. The rate is then

$$R = \frac{(g_{a2} - g_{a1}) - (g_{02} - g_{01})}{t_2 - t_1}.$$

The computations could be done for the stations with the first station as the reference station. Thus, drift correction at any time is $d_c = R\,(t_s - t_i)$ where t_i and t_s are the initial and subsequent times of measurements and s is the occupied station number. This correction adjusts all readings to the initial time, so that all readings look like they were taken at the same time. Hence, observed gravity value is given by

$g_{ob} = g_{ai} + k\,[\,(g_{os} - g_{oi}) - R(t_s - t_i)\,]$, where

g_{ai} = absolute gravity at first station

k= meter constant

g_{oi} and g_{os} = readings at time t_i and t_s in the first and subsequent stations.

3.2.9 **Gravity anomalies**

Gravity anomaly is the departure of the observed absolute gravity, after corrections, from the theoretical value for instance;

Free-air anomaly $g_{fa} = g_{fg} - g_{th}$

Bouguer anomaly $g_{ba} = g_{bg} - g_{th}$

3.3 **Self-assessment Exercise**

(a) List the first 3 steps in gravity data processing

(b) Explain the source of tidal effect

(c) Define gravity anomaly

4.0 Conclusion

Gravity field data processing involves corrections such as Free-air, Bouguer, tidal, drift, and Bullard effects. The absolute gravity value is obtained using theoretical and corrected observed gravity values. The gravity anomaly is the difference between the theoretical and the observed gravity values after all necessary corrections.

5.0 Summary

In this unit you have learnt that:

- Gravimeter counter data must be converted to mgal unit and corrected for various errors.
- Some of gravity corrections are Bouguer, Free-air, drift, tidal and Bullard effects
- Gravity anomaly is the departure of the theoretical value from observed gravity value.

6.0 Tutor Marked Assignment

(i) Sketch the full mathematical expression for g_{bg}, hence mathematical expression for $g_{ba.}$

(ii) Explain Bouguer effect

(iii) Draw a diagram for Bullard effect on gravity field

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Unit 5: Gravity Data interpretations

1.0 Introduction

Gravity data, even after processing, are mere figures which may not be meaningful unless further works are done on the data for them to then depict true representations of the causatives bodies. This unit deals with procedure for qualitative and quantitative interpretations in gravimetric works.

2.0 Objectives

At the end of this unit you should be able to:

(1) Differentiate qualitative from quantitative interpretation.
(2) Explain map contouring.
(3) Define gravity total field.
(4) Describe gravity profiling.

3.1 Qualitative interpretation

Interpretation of the gravity field measurement made involves derivation of meaningful reasoning to the cause of anomalies obtained. This will necessitate further data processing, the result of which can be used to produce maps. Physical view of those maps could depict some meaningful inferences. The first-hand information in this case can aid quantification (i.e. quantitative interpretation) of the causative bodies into 2 and 3 dimensional structures. Thus, qualitative interpretation requires production of Free-air and Bouguer anomaly contour maps. Gravity field of Bouguer can also be separated into Regional and residual fields. The field data are then contoured and profiles are taken across prominent anomalous closures.

3.1.1 Map Contouring

A contour map is one that shows the plots of all points with similar values. Data to be contoured must be in three columns. The first two columns are the (x,y) coordinates of the data points while the third column contains the field data. In gravity works the coordinates is the latitude and longitude of each corresponding gravity field measured at a gravity station. Plotting can be done manually or using computer program called ‘surfer’.

3.1.2 Gravity total field

The measurement made contains the part which is an effect of the local bodies i.e. the wanted part and the part which is an effect of deep-seated bodies which is unwanted part. The gravity value resulting from deep-seated structures which may not be of interest and whose effect can mask the required anomalies is called regional field. The remaining part of the measured gravity field, which is an effect of the local bodies, is called Residual field. The residual field is simply the field due to bodies of interest. In electric filtering fallacy, regional field corresponds to high frequency filter while residual corresponds to low frequency filter. For interpretation purpose, we need to separate total field into regional and residual fields.

3.1.3 Regional-Residual field Separation

There are various methods developed for this purpose, they are:

(a) Empirical gridding
(b) Second derivative

(c) Polynomial fitting

The resulting data of regional and residual fields are contoured.

3.1.4 Profile Taken

Profile is a straight line on earth's surface along which measurements are taken. Really, we can not get such line due to surface wrinkles. To do this we identify prominent closures/anomalies on our contour maps and draw such lines across the preferred directions on the anomalies. We then digitise along the line to get contour values per unit length of the profiles. The plot of distance against gravity value will show the anomaly's structure along the line. The length of the line is referred to the scale of the map itself.

3.2 Quantitative Interpretation

This involves 2 and 3 dimensional quantification of the bodies that caused the gravity anomalies obtained during qualitative interpretation. This is mainly done by inverse modelling. This involves assuming a hypothetical regular body of known parameters to have intruded into the host rocks with different density. The residual gravity field obtained is then compared with that calculated for the hypothetical body. The calculated value is then adjusted until the difference between it and the observed residual field is as small as possible. The assumed body at this time is the model representing the causative body, considered to be responsible for the observed residual field. Thus, the parameters of the body constitute possible representation of the mass distribution of rock unit in the area in question. Surface geological information is usually used to guide decision to be taken pertaining to the rock type.

3.3 Self-assessment Exercise

(i) Define qualitative interpretation

(ii) Explain the data format for a set of data to be contoured

(iii) What is the essence of quantitative interpretation?

4.0 Conclusion

Gravity interpretation entails qualitative and quantitative interpretations. Qualitative involves physical description of the physical features of the maps while quantitative entails quantification of the causative bodies. The measured field is a total field that compose of regional and residual components

5.0 Summary

In this unit you have learnt that:

1 Contour and linear maps of the gravity field are necessary for qualitative interpretation

2 Quantitative interpretation involves 2 and 3 dimensional quantifications of the causative bodies

3 Regional field is due to deep-seated bodies while residual field is due to local bodies of interest

6.0 Tutor Marked Assignment

1. Explain gravity field contour line
2. Compare and contrast regional and residual gravity field
3. Explain field constraints in taken gravity profiles in *situ*

7.0 Further Reading and Resources

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Module 4 **Magnetic Methods**

Unit1: **Theory, concept and instruments**

1.0 **Introduction**

Magnetic prospecting is on of the oldest geophysical methods. In the past compasses were used to get dip I and declination D and at later time dip-needles were developed for use to measure were the magnetic force component Z, H and F. Modern instrument are fluxgate, nuclear precision, rubidium vapour and proton magnetometers. This method is a potential field method suitable for mineral explorations. This unit deals with major theory concept and instrument used for magnetic prospecting.

2.0 **Objectives**

At the end of this unit you should be able to:

(i) Explain the working principle of proton magnetometer

(ii) List advantages of proton magnetometer

(iii) State the practical units employed in magnetic prospecting

(iv) State the frequency-total field, relation for a working proton magnetometer.

3.1 **Theory**

A bar magnet with length L usually set up a force field round itself in form of flux. A magnetic material brought in contact with this field will experience this force. Let m_1 and m_2 be the strengths of the poles of the magnet. The magnetic force F is given by

$F = \frac{Km_1m_2}{L^2}$, where constant of proportionality $K = \frac{1}{\mu}$, and μ is called magnetic permeability. The strength of this field given by

$$H = \frac{F}{m_1} = \frac{m_2}{\mu L^2}.$$

That is, H is the force per unit strength of a pole m_1 from pole with strength m_2; that is, L metres away from m_1. Hence, in practice m_1 can be made an instrument to measure H of m_2. Summary of the useful parameters in the area of magnetic prospecting is given in the table below.

Parameter (Magnetic)	**Geophysical unit**
Field/strength/intensity (H)	Gamma (γ)
Density/induction (B)	nanoTesla (nT)
Susceptibility (Ψ)	Unit less
Permeability (μ)	H/m

In geophysical prospecting susceptibility is not measured in *situ*, but the outcrop
sample can be measured using equipment called kapameter. H and B can be measured in *situ.* Any force field measured usually has three

components at a point: Horizontal H, Vertical Z and total field F. We usually measure total field. We also know that the magnetic field measured at a point is in three parts: (a) main field, sourced from the solid earth (b) external field, sourced from the electric currents in the ionised outer layer of atmosphere and (c) part from local magnetic anomalies in the near-surface crust as a result of the amount of the magnetic minerals contained in the rocks. The last one is the field of interest in the area of geophysical prospecting. We equally know that Magnetisation of a rock is due to two major components (a) the induction in the earth's field which depends on the susceptibility of the rock and (b) the permanent (remanent) magnetisation which depends on the geological history of the rock (i.e. the strength and direction of the earth's magnetic field as at the formation time of the rock)

3.2 Instruments

Magnetometer is the major instrument for magnetic prospecting.
Magnetometers are in two categories:

(1) Those that measure only intensity of the combined (geomagnetic and anomalous) fields.

(2) Those that resolve the total field into vertical and horizontal components.

The first type can be operated on the air and on ground e.g. Fluxgate and proton magnetometer. The second category works with balanced-torque of a freely pivoted magnetic needle in the earth's field. Instruments in this group work in a level position to measure horizontal or vertical component of the magnetic field. Balanced-Torque magnetometers generally work on the fact that suitably balanced magnetic needle at a reference station deflect on the being taken to another station. The compensating force to restore the needle to its reference position or the angle of deflection could be used as a measure of the field.

3.3 Proton Magnetometer

It is a total field instrument i.e. measuring intensity of earth's total field (i.e. geomagnetic and anomalous fields.) It uses the precession of spinning proton or nuclei of the hydrogen atom in a sample of hydrocarbon fluid to measure the total field. Its sensor consists of a bottle containing a low freezing-point hydrocarbon fluid e.g. water, kerosene, alcohol etc. about which solenoid is wound. Current passing through the wire creates magnetic field which is parallel to the alignment of the proton moments in the fluid (i.e. protons are polarised) As soon as the current is removed the spins begin to precess round the direction of the earth's magnetic field (Fig. 1). A small signal is then generated by the precessional protons in the coil. Thus, the frequency f of the signal generated is proportional to the total earth's magnetic field F that is,

$$f = \frac{\gamma_p F}{2\pi}, \quad \text{where}$$

γ_p = a constant called gyromagnetic ratio of the proton

Frequency f is independent of the orientation of the coil (i.e. sensor of the magnetometer)

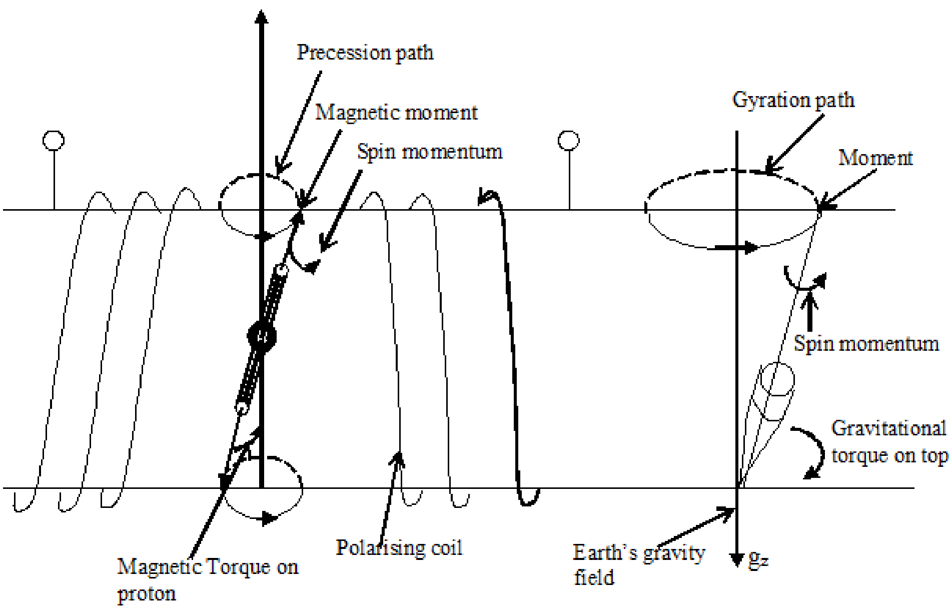

Fig.1: Proton Precision and the Spinning-top Anomaly
(After: Telford, Geld art, Sheriff and Keys, 1976)

3.3.1 Distinct Advantages of Proton Magnetometer

1 It requires no levelling
2 Sensor and recording system can be widely separated with a cable
3 No problem of drift.

3.3.2 Disadvantages of Proton Magnetometer

1 Interpretation is difficult since total field is measured
2 Measurements are affected by magnetic materials around such as power line, metals in the operator's body.

3.4 Self-assessment Exercise

1 Give a practical unit each of magnetic induction B and magnetic intensity H
2 Give an example of total field magnetometer
3 Mention two liquids that can be used in a proton magnetometer
4 Name the constant of proportionality in an expression of magnetic force within two monopole magnets separated by a distance.

4.0 Conclusion

The practical units of magnetic induction and intensity are nT and γ. Magnetometer is a major instrument for magnetic prospecting. Magnetometers are classified into the one that measures total field and that which measures horizontal and vertical field separately

5.0 **Summary**

In this unit have learnt that

(i) nanoTelsa (nT) and Gamma (γ) are the practical units in magnetic prospecting.

(ii) Magnetic susceptibility is usually measured from rock samples

(iii) Magnetometer is the major instrument for magnetic measurements

(iv) Proton magnetometer is most commonly used for air and ground works.

6.0 **Tutor Marked Assignment**

(i) What are the differences between the two categories of Magnetometers?

(ii) What are the limitations of proton magnetometer?

(iii) Explain the source of magnetic anomalies

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Unit 2: **Magnetic Survey**

1.0 **Introduction**

Magnetic survey can be done on land, in air and in the sea using suitable magnetometer. This unit deals with various types of magnetic surveys and the field work requirements.

2.0 **Objectives**

At the end of this unit you have should be able to:

1 Discuss the types of magnetic surveys

2 Mention the necessary instruments and materials needs in readiness for the field works

3 Explain pre-field determination and detection of geomagnetic variations.

3.1 **Pre-Field Work Preparation for Magnetic Variations**

In readiness for magnetic survey it is necessary to prepare for magnetic variations such as diurnal variations and magnetic storm. Diurnal variation has a period of about 24 hours and it occurs on daily bases. Its period decreases from equator to the poles. Magnetic storm has a period of about 27days and last for few days. Its effect is higher toward the poles. Readings can be taken at a point hourly for few days to a day before the commencement of the work. Plot a graph of γ against time. Time windows of linear variation could be restricted to (Fig.1) For instance; portions A, B and C are linear variation windows. Also, any suspiciously high response may depict magnetic storm. When this is seen the fieldwork should be postponed. This could be repeated intermittently during the field work, especially when the field reading is outrageously high.

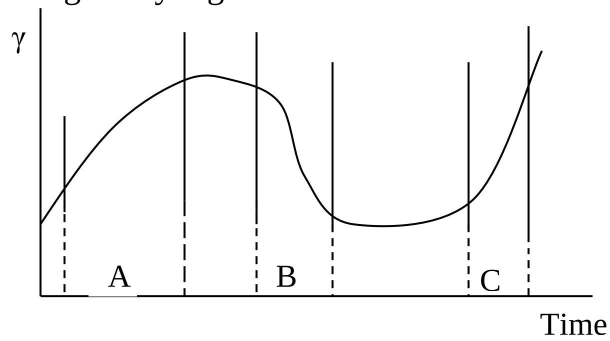

Fig.1: Daily variation of earth's magnetic field

3.2 **Land measurement**

Land survey involves measuring absolute field or variation of field compared to the absolute value of a reference station. The intensity of total, horizontal or vertical field could be measured. Proton magnetometer is designed to measure total field which is a combination of geomagnetic field and anomalous field due to the magnetic field of the rocks around the location surveyed.

3.2.1 Requirement for Fieldworks

- Two field men are ideal: one to carry the sensor and the other to mount the sensor, the sensor should be about 5 m away from the console about 2.5m above the ground
- Observer carrying the sensor must be free of magnetic materials such as key, buckled belt, shoe with metals, metallic wrist watch etc.
- Power lines, cars, railway etc. should not be less than 25 m away from the sensor
- The sensor should be at right-angle to the direction of the earth's field to obtain maximum amplitude.
- Measurement intervals may be between 2 and 200 m, depending on the anomalies, the field and type of information required.

3.2.2 Field Data

The data to be recorded from the field are:

- Intensity, in γ, from the recorder of the magnetometer
- Stations coordinates from GPS
- Ambient time from GPS

3.3 Aeromagnetic Survey

This is a survey carried out using aircraft proton magnetometer is suitable in this area. This survey is necessary in rugged terrain, jungle and for a large work like several square kilometres.

3.3.1 Advantages of Aeromagnetic (Airborne) Survey

- Suitable in rugged topographies
- Suitable for large works
- Time economical
- No problem of accessibility to stations
- No problem of noise from surface conductors.
- Data are conducive to analytical techniques since data are recorded in form of continuous line profiles rather than in form of isolated scattered point readings
- High speed of reading reduces the effect of magnetic variations and storms

3.3.2 Shortcomings of Airborne Survey

- Balancing of torsion types of instruments will suffer from vibration of the aircraft
- It is cost intensive.

3.4 Aeromagnetic Map

A comprehensive contour map of the data can be drawn with reference to the longitude and latitude of every station; this map is called Aeromagnetic map. A more comprehensive magnetic data can be obtained from aeromagnetic maps by interpolation methods using the nearest two data as distributed over the area of interest within the map; this method is also called digitisation.

3.5 Ship-borne (Marine) Survey

This is a survey in which the sensor is lowered into the large body of water e.g. ocean. Proton magnetometer is most suitable in this area is of almost cost density with air-borne survey.

3.6 Self-assessment Exercise

(i) What are the limitations of airborne magnetic survey?
(ii) Which instrument is most suitable for land survey?
(iii) Sketch a typical diurnal variation when proton magnetometer is observed at a point for about a day.
(iv) How many people can conveniently carry out land magnetic survey?

4.0 Conclusion

Magnetic survey can be done on land in the air and in the water. The suitable equipment is proton magnetometer. Variation of total field from stations to stations as well as absolute total field can be measured in magnetic surveys using proton magnetometer

5.0 Summary

In this unity you have learnt that:

- There are 3 magnetic survey methods – land, marine and airborne
- Proton magnetometer is suitable for land, marine and airborne magnetic surveys
- Airborne survey is the fastest and most suitable to cover a very large area of all the three methods
- Pre-field work observations of the magnetometer will to detect occurrence of magnetic storm

6.0 Tutor Marked Assignment

1 Write two each advantages and disadvantages of ship borne magnetic

2 With the aids of any suitable diagram, discuss a way by which the effects of metallic body of the aircraft can be prevented from interfering with the signal obtained from the sensor of a magnetometer during airborne survey.

7.0 Further Reading and Resources

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Unit 3 **Magnetic Data Processing**

1.0 Introduction

Magnetic field data are usually affected by activities such as magnetic variations, magnetic storm vertical and horizontal gradient .etc. This necessitates effection of corrections either practically or analyticaly. This unit discusses the types of sources of errors and how to correct for them as the process of data processing in magnetic prospecting.

2.0 Objectives

By the end of this unit you should be able to:

1 Identify sources of errors to magnetic field data
2 Explain ways for correcting the errors identified in 1
3 Describe continuation processes on potential field

3.1 Sources of Errors

Apart from human causes, other sources of errors in magnetic data colleted are:

- Magnetic variation such as diurnal and magnetic storm can contribute to
erroneous data
- Presence of magnetic materials such as buried pipe, power line etc. could disturb measurement.
- Loss of the actual location of the base/reference station can equally affect reading especially during data reduction.
- On local scale, there is regional horizontal gradient of geomagnetic intensity ranging from 0 to 10 γ per km from equator to poles.
- On local scale, there is regional vertical gradient of geomagnetic intensity of -0.03 γ per m at magnetic poles and about half of this amount at the equator.
- Anomalies of interest are usually superimposed by much broader anomalies or regional gradient due to earth's field or deep-seated sources.

3.2 Corrections

No very serious data reduction is carried out in magnetic data processing i.e. only rudimentary reductions are done.

A first good step to correcting for errors is the pre-field work observations to monitor diurnal and possible occurrence of magnetic storm. Strict adherent to the recommended outcome of such observation takes care of diurnal and magnetic storm disturbance.

Repeating readings by returning to base station analogous to gravity tying takes care of possible drift error.

Error due to horizontal gradient is negligible. Error due to vertical gradient is seldom done too, except for stations located in areas of very high mountains.

To correct for regional gradient, shallow anomalies must be enhanced by various method such as downward continuation method. By this, the remaining anomalies will be from the local/residual sources which are the anomalies of interest.

3.3 Continuation of Potential Field

Magnetic field is a potential method which can be subjected to the process of
continuations. There are two methods: Downward and Upward continuations.

3.3.1 Downward continuation

Here, potential field like magnetic field data from one datum plane are mathematically projected downward to a level below the original surface such that the shallow anomalous bodies are enhanced, that is we are making the image sharper. This case is always of interest.

3.3.2 Upward Continuation

Here, the data from a reference datum are projected upward above the reference plane i.e. into the air. This enhances anomalous bodies at deeper level. That is, we are smoothing in upward continuation.

3.4 Self-assessment Exercise

1. Describe any two sources of errors during land magnetic prospecting
2. Explain how you can take care of magnetic storm before going to the field.
3. Define downward continuation.

4.0 Conclusion

Magnetic data collected on the field are usually affected by sources such as magnetic storm, regional horizontal and vertical gradient of magnetic fields. However, error corrections in magnetic methods are rudimentary.

5.0 Summary

At the end of this unit you have learnt that:

(i) On local scale there are horizontal and vertical gradients of earth's magnetic
Intensity, varying from equator to poles

(ii) Pre-field observation of magnetometer takes care of magnetic variations

(iii) Repeated readings at station aids correction for magnetic variations and possible
Drift errors

(iv) Potential field such as magnetic field can be continued downward to correct for
regional gradient of the field data.

6.0 Tutor Marked Assignment

1. Differentiate between upward and downward continuation
2. Describe how you can effect diurnal variation correction using suitable diagram
3. On what condition must we correct for vertical gradient effect?

7.0 Further Reading and resources

30. Christine Fichler (2017). "Magnetics for Hydrocarbon Exploration." GEOExPro, 13(6). [5]

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Unit 4: **Qualitative Interpretation of Magnetic Data**

1.0 **Introduction**

Magnetic interpretation can be qualitative as well as quantitative. The erratic and complex character of magnetic anomaly map makes the interpretations difficult. However, visual judgement of the contour maps is a prominent endeavour in magnetic interpretation. This unit deals with qualitative interpretation procedure for magnetic data.

2.0 **Objectives**

By the end of this unit you should be able to:

(i) List the required in formations necessary for qualitative interpretation of magnetic anomaly

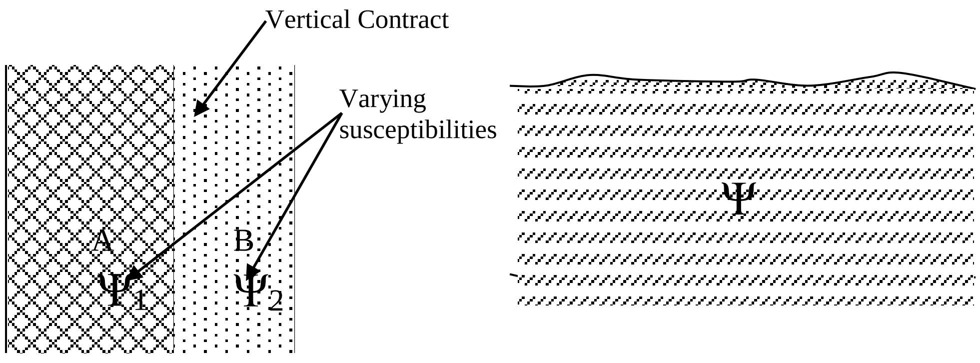
(ii) Mention the geologic features that can be mapped using magnetic survey

(iii) Derive useful information from magnetic anomaly maps

(iv) Describe the resolution dependence on flight height in aeromagnetic survey

3.1 **Preliminary Information**

For meaningful magnetic interpretation geologic information of the area is necessary. Geological structures and surface features can be visualised in the magnetic maps. Larger magnetic anomalies are caused by susceptibility variation rather than topographic relief in the basement. Implying from this, also, is that vertical contact between two slabs of different susceptibility will show larger lateral anomaly than when we consider vertical step in the basement (fig.1a and b). This is also because of the fact that susceptibility may not vary considerably at vertical step within the same basement complex in a locality.



(a)
Vertical contact between slabs A and B giving large lateral variation

(b)
Uniform formation showing smooth Lateral variation

Fig.1: Effects of Lateral and Vertical Susceptibility variations within Formations

Consequently, magnitude of the anomaly may not be of much value in finding basement depth, instead, anomaly shape, especially sharpness, may be used for depth estimation.

In conclusion, large anomaly could mean:

- Basement complex, and rich magnetic mineral.
- Also areas with igneous and metamorphic rocks at near-surface location usually camouflage basement by showing higher magnetic variations.
- Vertical contacts also show large variation. The sharpness of the anomaly map could also indicate vertical contacts.

So, magnetic data can be valuable tools in structural mapping especially when geological information is not available.

3.2 Dependence of Magnetic Interpretations on Geomagnetic Field Types

Magnetic works may involve measuring total, vertical or horizontal field. Remanent magnetisation of rocks in a locality causes high disturbance and almost masks the earth's field of interest. Hence, its effect should be separated from the measured field.

It should be noted that total field is almost equal to the horizontal field at equator where vertical component is zero and inclination is zero too. The higher the latitude the smaller is the horizontal component. At high latitude, vertical component is high and is almost equal to the total field at the pole where horizontal component is zero and inclination is $90^{0.}$ By induction therefore, for buried sources having induced magnetism, total-field anomalies at high altitude should be at least qualitatively similar to vertical anomalies from the same sources. Similarly, total-field anomalies at low altitude should be similar to horizontal anomalies from the same sources.

3.3 Nature of Contour Map in Magnetic Interpretations

Visual observation of contour map is used to take some decisions in magnetic works. Some useful information is given below.

- A basin is characterised by smooth contours and low magnetic relief, while the surrounding platform areas will show steep gradients and high relief in the magnetic contours
- Sharp degrees of magnetic relief that indicates boundaries between zones could denote fault. It could as well mean vertical instructive body such as dyke.
- Magnetic relief over sedimentary basin areas could indicate lithological variation of the basement rather than its topography
- Lineation in magnetic contours could mean structural trend of surface geology. Sometimes, lineation could mean the strike lines of

elongated instructive body or surface of large faults reflected in the basement topography or lithology.

3.4 Effects of Flight Elevation on Airborne Fields

Data obtained at the lower altitude show better resolution of magnetic anomalies than at high altitude. As the flight elevation increases the anomaly from a buried body is attenuated in amplitude and spread out over a wider area. Thus, resolution of individual anomalies from separate bodies depends on the height of the flight line (Fig.2.) At greater height two bodies appear as one, but properly resolved at minimal height.

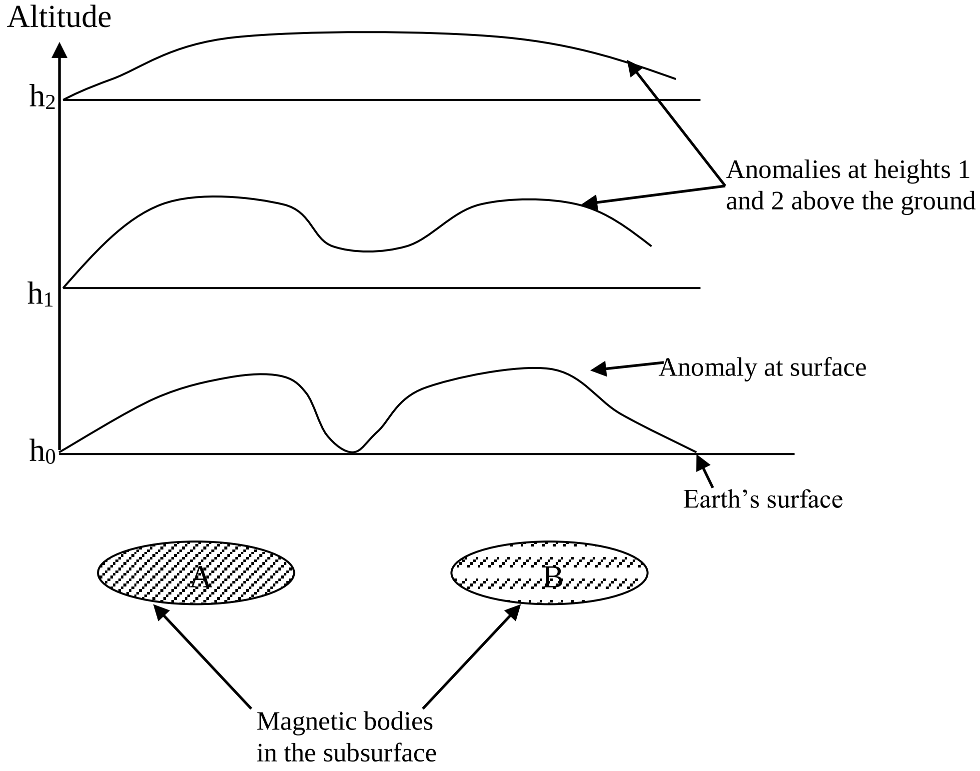


Fig.2: Resolution Dependence on Flight Height

3.5 Self-assessment Exercise

1. Explain the dependence of magnetic data on the susceptibility
2. How could the depth of causative body of magnetic anomaly be determined?
3. Sketch the diagrams to explain the resolution dependence on flight height during air borne magnetic survey.

4.0 Conclusion

Qualitative interpretation is most important in magnetic works. This is mostly done by visual judgements on the contour and linear diagrams obtained from the magnetic data. Magnetic resolution is enhanced by closeness to the source body. Total field at high latitude close to poles is almost equal to the vertical field while it is almost equal to the horizontal field at low latitude, close to equator.

5.0 Summary

At the end of this unit you have learnt that:

(i) Magnetic anomaly is caused by susceptibility variations
(ii) Magnitude of anomaly depicts variation of the susceptibility which indicates a source body and the shape of the anomaly map represents the depth
(iii) Lateral magnetic anomaly can best identify fault and vertical intrusive bodies.
(iv) Flight height in airborne survey affects resolution of the nature of the source
bodies.

6.0 Tutor marked Assignment

1. Mention the major parameter that is responsible for magnetic anomaly
2. Explain the possible implications of lineation observed in magnetic anomaly contour.
3. Why is it proper to measure horizontal field in a magnetic survey of an area closed to latitude 2^0 S?

7.0 Further Reading and Resources

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