GRAVITY AND MAGNETIC DATA REDUCTION SOFTWARE (GraMag2DCon) FOR SITES CHARACTERIZATION

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by

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Lots of love,

Noer El Hidayah Ismail

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LIST OF SYMBOLS

F	Force of attraction between two mass bodies
m	Mass
r	Distance between the centre of mass
G	Universal Gravitational Constant
a	Acceleration of object with mass due to the gravitational attraction of the object with mass
g	Gravitational acceleration
M	Mass of the Earth
R	Distance from the observation point to Earth's center of mass
~	Approximately
≈	Approximately
±	Plus-minus
h	Thickness/elevation
ρ	Density
mGal	milliGal
nT	Nano Tesla
T	Tesla
B	Flux density
H	Magnetizing field strength
I	Current
μ	Magnetic permeability
N	Absolute magnetic permeability
J	Intensity of magnetization
θ	Angle (theta)

k	Constant
i	Magnetic inclination
δ	Magnetic declination
κ	Magnetic susceptibility
π	Pi (3.14159265358979323846)
%	Percent
°	Degree
Δg	Delta g
$Base_f$	Base final
$Base_i$	Base initial

LIST OF ABBREVIATION

IP	Induced Polarization
SP	Self Potential
GPR	Ground Penetrating Radar
2-D	Two Dimensional
3-D	Three Dimensional
4-D	Four Dimensional
SI	The International System of Units
m	meter
m^3	cubic meter
m^2	meter squared
BC	Bouguer Correction
c.g.s	Centimeter-gram-second
emu/g	Magnetization unit in Gaussian & cgs emu
NW	Northwest
SE	Southeast
N	North
SW	Southwest
NE	Northeast
ERT	Electrical Resistivity Tomography
m/s	Unit meter per second
mGal/m	Unit milliGal per meter
mGal/ hour	Unit milliGal per hour
FAC	Free-air Correction
IGRF	International Geomagnetic Reference Field

Obs	Observe
USM	Universiti Sains Malaysia
Sg.	Sungai
GUI	Graphical User Interface

PERISIAN PENAPISAN DATA GRAVITI DAN MAGNETIK (GraMag2DCon) UNTUK PENCIRIAN KAWASAN

ABSTRAK

Perisian kaedah medan keupayaan masa kini lebih menumpukan kepada pentafsiran dan analisis data yang menyebabkan kurangnya perisian kaedah medan keupayaan untuk pemprosesan data. Ini telah menyebabkan pemprosesan data untuk kaedah graviti dan magnetik menjadi satu tugas yang renyah kerana perlu memilih samada untuk memproses data secara manual atau menggunakan perisian yang rumit yang memberi tumpuan lebih kepada pemodelan data dan penapisan data. Dengan membangunkan perisian baharu yang dinamakan GraMag2DCon di mana kombinasi pemprosesan data kedua-dua graviti dan magnetik dimasukkan, pemprosesan data untuk kaedah medan keupayaan akan menjadi lebih mudah. Perisian GraMag2DCon merangkumi pengimportan dan pengeksportan data, dan juga mampu mengubah sebarang data semasa pemprosesan data. Perisian ini juga mampu untuk memberi isyarat kepada pengguna sekiranya berlaku kesilapan atau kesalahan semasa pemprosesan data yang boleh menjimatkan banyak masa. Sebagaimana objektif kajian ini adalah untuk mengenalpasti dan mencirikan nilai graviti dan magnetik untuk tetapan geologi yang berbeza, perolehan data menggunakan kedua-dua kaedah graviti dan magnetik telah dilakukan di kawasan granit (Universiti Sains Malaysia, Pulau Pinang), kawasan sedimen (Kaki Bukit, Perlis), kawasan batu kapur (Batu Caves, Kuala Lumpur), tapak arkeologi (Lembah Bujang, Kedah) dan kawasan impak meteorit (Bukit Bunuh, Perak). Menggunakan perisian GraMag2DCon, semua data yang dikumpul telah diproses supaya nilai graviti dan magnetik untuk pelbagai jenis kawasan geologi boleh dikenalpasti dan dicirikan. Secara teorinya, kawasan

granit akan memberikan nilai graviti dan magnetik yang lebih tinggi kerana batuan granit adalah lebih padat berbanding dengan batuan sedimen dan batuan kapur di samping mempunyai kandungan magnetit yang tinggi di dalamnya. Keputusan yang dicapai daripada kawasan kajian adalah sama dengan teori, di mana sebarang kawasan kajian dengan kawasan granit memberikan nilai Bouguer anomali dan sisa magnet yang tinggi. Tambahan pula, faktor-faktor seperti struktur purba yang wujud di Lembah Bujang, Kedah dan kawasan impak meteorit di Bukit Bunuh, Perak juga mempengaruhi nilai graviti dan magnetik. Patahan batuan dan peleburan batuan juga turut memberi kesan kepada nilai graviti dan magnetik kerana ia akan mengubahsuai geologi di kawasan ini.

GRAVITY AND MAGNETIC DATA REDUCTION SOFTWARE (GraMag2DCon) FOR SITES CHARACTERIZATION

ABSTRACT

Present potential field methods software are focuses more on data interpretation and analysis which resulted in the lack of data processing software for potential field methods. This caused processing gravity and magnetic methods become a tedious task as one will opted either to manually process the data or used the complicated software which focuses more on data modeling and filtering. By developing new software named GraMag2DCon which include the combination of both gravity and magnetic data processing, data processing for potential field methods will be much easier. GraMag2DCon software includes importing and exporting the data, as well as able to edit any data during data processing. This software also able to alert the user if any error or mistakes occur during data processing which can save a lot of time. As the objectives of the study is to identify and characterized gravity and magnetic values of different geological settings, data acquisition of both gravity and magnetic methods are done in granitic area (Universiti Sains Malaysia, Pulau Pinang), sedimentary area (Kaki Bukit, Perlis), limestone area (Batu Caves, Kuala Lumpur), archaeological sites (Lembah Bujang, Kedah) and meteorite impact region (Bukit Bunuh, Perak). Using GraMag2DCon software, all of the data collected were processed so that gravity and magnetic values for different types of geological area can be identified and characterized. Theoretically, granitic area will give higher values of both gravity and magnetic values as granitic rocks is much denser compare to sedimentary and limestone rock and has high magnetite contents in it. The results achieved from the study areas are

similar to the theory, where any study area with granitic area gives high values of Bouguer anomaly and magnetic residual. Furthermore, factors such as ancient structures exist in Lembah Bujang, Kedah and meteorite impact region in Bukit Bunuh, Perak also influenced the gravity and magnetic values. Rock fracturing and rock melting also affect the gravity and magnetic values as it will modify the geology of the area.

CHAPTER 1

INTRODUCTION

1.0 Background

Geophysical methods provide a relatively rapid and cost-effective in acquiring information about the subsurface over a substantial area. Geophysics is the application of physics principles to study the Earth subsurface properties. The aim of pure geophysics is to deduce physical properties of the Earth and its internal constitution from physical phenomena associated with it such as gravity force and geomagnetic field (Burger et al., 2006). Geophysics essentially is the measurement of contrasts in physical properties of materials beneath the Earth's surface and attempt to deduce the nature and distribution of materials responsible for these observations. Four types of common geophysical methods and its physical properties are lists in the Table 1.1.

It is proven that geophysical methods are able to detect and delineate local features of potential interest which could not be discovered by any drilling method although sometimes it is prone to major ambiguities or uncertainties of interpretations. The uncertainties can be overcome by having a good geological background and full knowledge of the area. This will lead to correct interpretation and reduced the uncertainties.

Geophysical methods are classified into two types, passive and active methods. Those methods that detect variations within the natural fields associated with the Earth such as the gravitational and magnetic fields are passive methods.

Table 1.1: Common geophysical methods and its physical properties (modified from Robert, 1999).

Geophysical method			Property measured on Earth's surface	Property investigated within Earth
SEISMIC	Natural sources: earthquake		Ground motion (Displacement, velocity or acceleration)	Seismic velocity (V) and attenuation (Q)
	Controlled source	Refraction		Seismic velocity (V)
		Reflection		Acoustic impedance (Seismic velocity, V, and density, ρ)
POTENTIAL FIELD	Gravity		Gravitational acceleration (g)	Density (ρ)
	Magnetics		Strength and direction of magnetic field (F)	Magnetic susceptibility (χ) and remanent magnetisation (J_{rem})
ELECTRICAL	Resistivity		Earth resistance	Electrical conductivity
	Induced Polarization (IP)		Polarization voltages / Frequency-dependent ground resistance	Electrical capacitance
	Self Potential (SP)		Electrical potentials	Electrical conductivity
ELECTROMAGNETIC	Electromagnetic		Response to electromagnetic radiation	Electrical conductivity and inductance
	Ground Penetrating Radar (GPR)		Travel times of reflected radar pulses	Dielectric constant

Contrary, the active methods involve the generation of artificial signals in which then modified the signals in ways that are characteristic of the materials through which they travel after being transmitted into the ground. These altered signals are then measured by appropriate instruments where the output displayed and interpreted (Edet, 2010). Geophysical methods are one of the fastest, most effective, least costly and an indirect method to perform shallow subsurface study for maintaining infrastructure and geo-environment (Muztaza, 2013).

Seismic method commonly applies to determine rock velocities and quality, stratigraphy, general geologic structure, overburden thickness and bedrock depth. It manipulates energy sources created by shot, hammer, weight drop or some other comparable sources by putting impulsive energy into the ground (Burger et al., 2006). Generally, 2-D resistivity method measures an apparent resistivity of subsurface including soil type effects, bedrock fractures, groundwater and contaminants. Ground Penetrating Radar (GPR) provides a cross-sectional measurement of the shallow subsurface and used to pinpoint the location of buried objects as well as mapping stratigraphy. It also allows registration of such fine archaeological objects that are hard to see by naked eye and can be missed during archaeological excavation (Conyers, 2004).

Gravity and magnetic methods also known as potential field method are very useful and popular in geological case studies. By manipulating density variation of subsurface and magnetic susceptibilities, the methods lead to variations in gravitational acceleration at surface instrument stations and produce measurable differences of magnetic field at observation sites (Burger et al., 2006). The methods provide a low cost way to screen large areas as well as construct important alternative models to delineate subsurface structures and reach a better understanding of geology (Rivas, 2009). Mapping the Earth's subsurface using potential field method is common and widely use around the world including in Malaysia. Fault and fractures, basin, bedrock topography, geological structure and boundaries as well as meteorite impact crater can be map by utilizing gravity and magnetic methods.

The gravity method depends on a high-density contrast between the geologic bodies of interest and that of the surrounding sediment (Jacques et al., 2003). Natural variations in subsurface density include lateral changes of soil or rock density, buried channels, large fractures, faults and cavities. A good processing method can provide a good estimate of depth, size and nature of anomaly. Irregular topography will produce artefacts in the data, unless it is accounted for in the processing. As the microgravimeter is very sensitive, interference can be produce by external factors such as local sources of vibrations, wind, storms, atmospheric pressure, station elevation and distance earthquakes (Seigel, 1995). Thus, data assessment is very important to eliminate such artefacts. Gravity method applications include fault mapping, groundwater inventories, basin studies and mineral exploration.

Magnetic data can be analyzed in a number of ways, with enhanced techniques and imaging, hence making it an increasingly valuable tool. The basic geophysical concept behind this is that different rock types having different magnetic responses. The magnetic method does not give exact depth determination (Grauch and Lindrith, 2005). It can be apply to both, deep and shallow structures which measurements can be obtained for both local and regional studies (Burger et al., 2006). This method is typically applied to locate abandoned steel well casings, buried tanks and pipes, map basement faults and basic igneous intrusive, investigate archaeological sites and map old waste sites and landfill boundaries (Mariita, 2007).

Although geophysical methods are useful and provide valuable information about the subsurface, it is important to recognize their limitations (Burger et al., 2006). The lack of sufficient contrast in physical properties is common as one of the limitation and a good instrument can determine the effects. The presence of nearby bodies of great contrasts creates effects that mask those created by the targeted object frequently cause problems. The second limitation is the non uniqueness of the interpretation. For example in gravity method, ambiguity tends to happen when it is often difficult to differentiate the effect of a small body near the surface from that of a larger body at very deep. The third limitation is resolution. All methods are afflicted with this restriction. The last limitation is noise. All geophysical data contain some undesired signal (or noise) to a greater or lesser extent.

Each of geophysical method has its own advantages and disadvantages. The limitations can be overcome by integrating two or more methods for each study/research. A careful survey planning, desk study, a good geological background and knowledge of the area are the key for good data acquisition and essential for good interpretation.

Gravity and magnetic methods need to be corrected for all of its raw data before interpretation step. This step is called processing step and involves a lot of corrections. Most of the software existed in the market are focuses more on interpretation step which involves modeling and more on quantitative interpretations. Most of these software are also very expensive and complicated to use.

1.1 Problem statements

The potential field methods markets are flooded with software that focuses more on interpretations rather than processing step. The lack of data processing software triggered the start of this research. With little choices to choose from the present software, it is best to develop new processing software that are not complicated and focuses on processing step. Data processing plays a very crucial part in geophysics methods especially in potential field methods. It has many corrections to be made depending on the objectives of the survey. The problem lies as different people processed the same data with the same objective but getting different results. It can be consider as systematic error. Having to do all the data correction manually using Microsoft Excel with all hundreds or thousands of data, mistakes are bound to happen. To go through one by one of those hundreds of data to find the mistake is one tedious task and wasting time.

To overcome this problem, it is useful to develop the new processing software. Other additional corrections can be done depending on the objective and types of survey (ground, air or marine) with this basic processing. The new software will be compute in such a way that the final results can be obtain by input or exporting raw data, elevation and coordinates (latitude and longitude) of the survey stations. By computing this new software, it is hoped that it can be beneficiary for basic magnetic and gravity data processing.

1.2 Objectives

The objectives of the research are:

i. To develop a new gravity and magnetic data reduction processing software.

ii. To identify gravity and magnetic values of different bedrock geological settings in Peninsular Malaysia.

iii. To characterize the gravity and magnetic data for different geological settings.

1.3 Significance and novelties

The study mainly aims to produce data reduction processing software for potential field methods since many data corrections/reductions need to be done. Using the newly developed software, systematic error which usually happened during data reduction processing can be minimized. Unlike any other potential software processing, this new software is only for ground survey and is only for data reduction where else other potential field software mainly focus on modelling and filtering. The software will indicate the error or mistake if it encounters any mistakes. Furthermore, the software is time effective, user friendly and not complicated like other existed software. One can operate it without reading the software manual. Thus, by using the software in different geological settings of the study areas, value range for bedrock from different geological settings can be identified and characterized.

1.4 Thesis layout

Chapter 1 introduce background of geophysical methods which focuses more on gravity and magnetic methods, stating problem statements and ways to overcome the problems. Objectives and novelties of the research are also pointed out in this chapter.

Chapter 2 discusses on theory of potential field methods (gravity and magnetic method), the similarities and the differences between the two methods as well as some previous study of both methods and other geophysical methods with application in geological cases, archaeology and meteorite impact. Some previous studies on other existed potential field software are also included.

Chapter 3 focuses on methodology where it discusses on the research methodology of potential field method, geological settings of study areas besides data acquisition execution. The research involves developing processing software for potential field methods.

Chapter 4 elaborate more on the software development. From how it is developed to step by step in using the new software are explained in this chapter.

Chapter 5 discusses on the potential field methods applications in different geological settings. The acquired gravity and magnetic data were processed using the newly developed processing software. Results of the research will be presented in this chapter as well as more discussions on the results and the advantages of the newly developed software.

Chapter 6 as the final chapter in the thesis concludes the findings done including some recommendations for future findings.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Potential field methods measure natural fields of the Earth which are gravitational and magnetic fields. Both methods utilized natural occurring fields and provide information on Earth properties to significantly greater depth. Gravity and magnetic methods detect only lateral contrasts in density or magnetization. Density and magnetization change significantly from one soil or rock types to another. Knowledge of the distribution of any of these properties within the ground would presumably convey information of great potential value about subsurface geology, even if the soil/rocks themselves could not be otherwise identified (Grant and West, 1965).

Both gravity and magnetic methods have been employed in diversified ways for mineral exploration, oil and gas exploration, environmental and engineering, education and research, earthquake prediction, geotechnical and mining related airborne geophysical surveys. Gravity data can be used to model the shape of a basin containing young sedimentary rocks compared to higher density basement rocks.

On the other hand, magnetic data can provide complementary information if there is a magnetic contrast between the sedimentary rocks and the basement. To understand the movement of subsurface water, mapping of sediment/basement is important. By mapping offsets of both gravity and magnetic source bodies faults can be traced (Ken et al., 2001). Dykes, faults and lava flows, finding abandoned wells and buried drum, and locating and mapping waste dumps are amongst the common causes of magnetic anomalies. The survey can be carried out on land, marine and in the air. The methods were widely used as both methods are relatively cheap, non-invasive and non-destructive towards the environment. Potential fields are those in which the strength and direction of the field depend on the position within the field; the strength of a potential field decreases with distance from the source (Robert, 1999). Table 2.1 shows measured parameter and operative physical property to which the potential field methods is sensitive. Furthermore, the methods are passive which no energy is needed to put into the ground. Besides, it also permits walking traverses with the small portable and sensitive instruments.

Table 2.1: Measured parameter and operative physical property of potential field methods.

Method	Measured parameter	Operative physical property
Gravity	Spatial variations in the strength of the gravitational field of the Earth	Density
Magnetic	Spatial variations in the strength of the geomagnetic field	Magnetic susceptibility and remanence

2.1 Gravity method

The force of gravity has always existed in the universe. Prior to the time of Sir Isaac Newton, nobody was aware of the existence of gravity force. It was Newton who proved that falling objects on Earth, moon rotation, motion of planets and other instances of attraction are all subject to a single law, which is the law of universal gravity. This gravitational force is mentioned in the Holy Quran in Surah Ar-Ra'd verse 2 as 'invincible pillars'. The lines of force for the gravity field are simple and directed toward the center of the Earth (Robert, 1999) as shown in Figure 2.1. The Earth's gravity field is radial with the pull being directed towards the center. The strength of the pull increased as objects move closer towards the center.

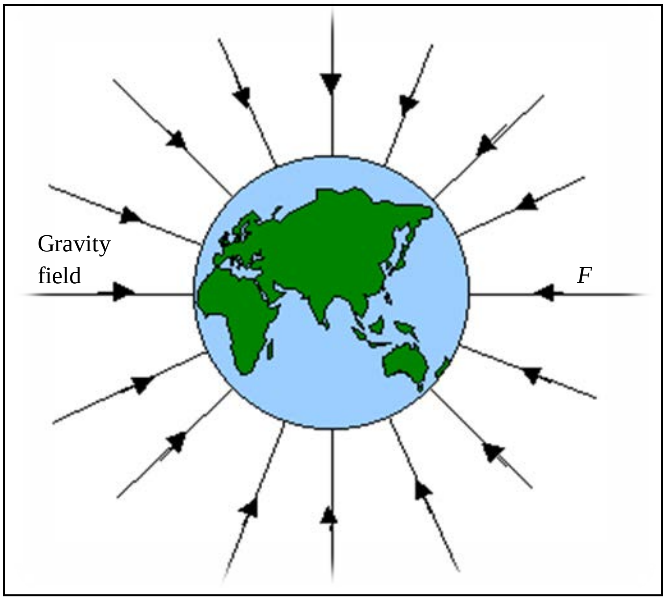

Figure 2.1: Lines of force for the gravity field (modified after Robert, 1999).

Gravity survey is a measurement of the gravitational field at a series of different locations over an area of interest. The objective in exploration work is to associate variations with differences in the distribution of densities and hence rock types (Sheriff, 1994). The gravity method works when buried objects have different masses, which produced by the object having a greater or lesser density than the surrounding material. Following the inverse square law of behaviour, rocks which lie closer to the point of observation will have a much greater effect than those farther away even though all materials in the Earth influence gravity (Grant and West, 1965).

2.1.1 Basic theory

Gravity method basis depends on Newton's Law of Gravitation (Figure 2.2) and Newton's Second Law of Motion.

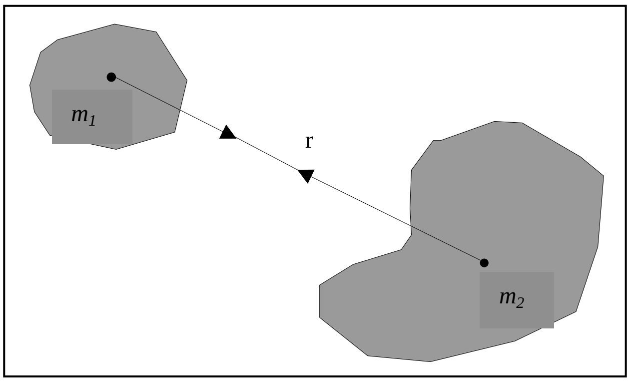

Figure 2.2: Newton's Law of Universal Gravitational Attraction.

Newton's Law of Gravitation states that between two bodies of known mass the force attraction (*F*) is directly proportional to the product of the two masses (m_1 and m_2) and inversely proportional to square of the distance between their centres of mass (r^2) (Burger et al., 2006). The greater the distance separating the centres of mass, the smaller the force of attraction between them (Equation 2.1).

$$F = G\frac{m_1 m_2}{r^2} \tag{2.1}$$

where *G* is the Universal Gravitational Constant. The value of *G* is equal to

6.67×10^{-11} Nm^2/kg^2 in SI units. Newton's Second Law of Motion (Robert, 1999) shows that the force (F) exerted on the object with mass m_1 by the body with mass m_2 (Equation 2.2),

$$F = m_1 a \qquad (2.2)$$

where a is acceleration of object with mass m_1 due to the gravitational attraction of the object with mass m_2 (m/s^2).

The combination of Equation 2.1 and 2.2 produced Equation 2.3.

$$a = \frac{F}{m_1} = \frac{1}{m_1}\frac{Gm_1m_2}{r^2}$$

$$a = \frac{Gm_2}{r^2} \qquad (2.3)$$

If the acceleration (a) is in a vertical direction, then it is due to gravity (g) which gives $a=g$ then it can be write as;

$$g = \frac{GM}{R^2} \qquad (2.4)$$

where M is mass of the Earth ($M = m_2$) and R is distance from the observation point to Earth's center of mass ($R = r$).

If the Earth were a perfect sphere with no lateral inhomogeneties and did not rotate, g would be the same everywhere obeying Equation 2.4. In reality, the Earth is inhomogeneous with an ellipsoid of revolution. This cause the polar radius of the Earth is ~ 20 km less than the equatorial radius, which means that g is less at equator than pole. At the equator, the value of gravitational acceleration on Earth's surface varies from 9.78 m/s^2 to about 9.83 m/s^2 at the poles (Figure 2.3).

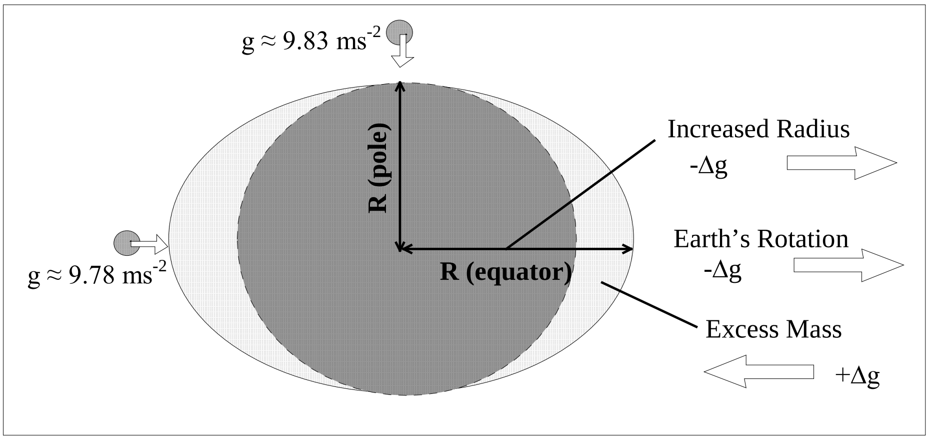

Figure 2.3: Three main factors responsible for the difference in gravitational acceleration at the equator compared to the poles (modified after Robert, 1999).

The smaller acceleration at an equator, compared to the poles, is because of the combination of three factors (Robert, 1999). The first factor is due to outward acceleration caused by rotation of the Earth, there is less inward acceleration. The rotation is greatest at the equator but reduces to zero at the poles. Second factor is less acceleration at the equator because of the Earth's outward bulging, thereby increasing the radius (R) to the center of mass. Third factor is the added mass of the bulge creates more acceleration. Notice that the first two factors lessen the acceleration at the equator, while the third increases it. Gravitational acceleration (gravity) is commonly expressed in miligals (mGal). Gravity increases from about 978 000 mGal at the equator, to about 983 000 mGal at the poles and varies by about 5000 mGal from equator to pole (Figure 2.4).

$$1 \text{ Gal} = 1 \text{ cm/s}^2 = 0.01 \text{ m/s}^2$$

So that:

$$1 \text{ mGal} = 10^{-3} = 10^{-3} \text{ cm/s}^2 = 10^{-5} \text{ m/s}^2$$

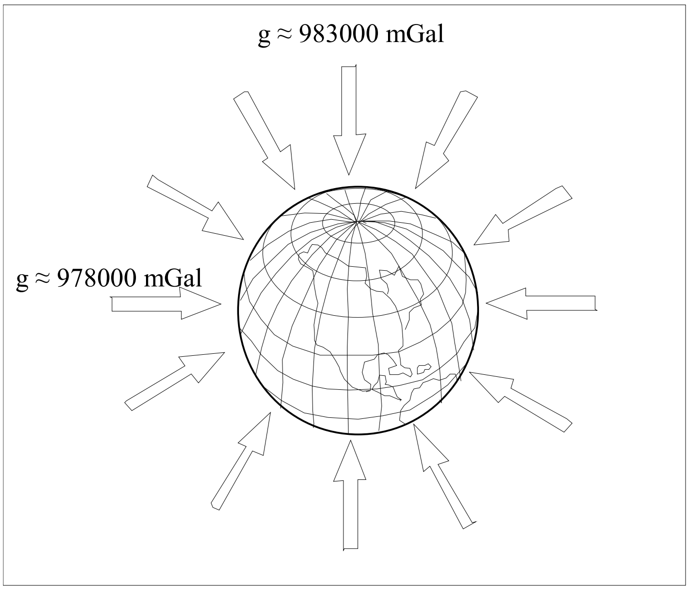

Figure 2.4: Gravity at the equator and pole (modified after Robert, 1999).

2.1.2 Gravity and rock types

Gravity survey is sensitive to variations in rock density. Density is a rock property described by the ratio of mass to volume (Hill et al., 1997a). Therefore, different rock types will affect the results of gravity measurements differently. Based on Table 2.2, granite has the highest range of specific gravity. Sedimentary rocks exhibit the greatest range of density variation due to many factors. The density of sandstones and limestone are increase by infilling of the pore space, not by volume change. For shales, the density is increase by compaction and ultimately re-crystallisation into minerals with higher density.

Table 2.2: Specific gravity of various rock types.

Rock type	**Specific gravity (gm/cc)**
Granite	2.60-2.70
Sandstone	2.00-2.60
Shale	2.00-2.40
Limestone	2.20-2.60

2.1.3 Measuring gravity

Gravity measurements are implemented in studies of the figure, composition and structure of the Earth. The force of gravity is influence by density variations of bedrock and soil in immediate vicinity of measuring points in a discernible way (Elo, 1997). Absolute determinations of gravity can be made by either pendulum or free-fall devices. In applied geophysics, knowledge of absolute gravity is often not of immediate interest. Generally, relative measurements which give the gravity difference between an observation point and a base point is more concerned (Parasnis, 1997). By measuring gravity, it provides information about underground rocks density and thus becoming an important method in geological mapping and mineral resources exploration (Rivas, 2009; Elo, 1997). Gravity anomaly only occurs when there are density contrasts in the Earth. The density contrast between the bodies must be high enough to give an anomaly that rises above the background noise recorded in the survey (Alice and Ray, 2001).

To determine acceleration due to gravity at various sites around the world, instruments are designed and it is called gravity meters, also known as gravimeters. Neither pendulum nor free-fall devices are suitable for field survey as it is not as convenient as gravimeters and both of it measure absolute gravity. The gravimeters are sensitive to 0.01 mGal ≈ 10^{-8} of the Earth's total value. Instruments are designed to measure gravity directly perform absolute measurements (Burger et al., 2006). The field gravity survey conducted using relative gravimeters because it would be impossible to get the accuracy required in absolute gravity measurements quickly with any device. The gravimeter measures relative changes in between two locations (Rivas, 2009).

Gravity prospecting can be conducted over land (ground), water (marine) and air (airborne) using different techniques and equipment. Ground survey conducted by walking traverses or using vehicle while marine survey used the meter onboard ship and an aircraft is used for airborne survey. The airborne survey is always used when confronting an inaccessible terrain and large survey area. The small portable instrument makes gravity method can quickly cover large areas (Rivas, 2009).

2.1.4 Gravity reduction

In reality, the Earth is slightly irregular oblate ellipsoid which means that the gravity field at its surface is stronger at the poles than the equator. The density distribution is also uneven, particularly in the rigid crust, which causes gravity to vary from the expected value as the measurement position changes. These variations are expressed as gravity anomalies. By mapping the gravity anomalies, it gives an insight structure of the Earth (Alice and Ray, 2001). Therefore, it is essential to identify the reasons that gravity varies so it can be corrected while using gravity method in exploring the subsurface (Burger et al., 2006). Gravity observations can be used to interpret changes in mass below different regions of the Earth (Robert, 1999). The observed gravity readings obtained from the gravity survey reflect the gravitational field due to all masses in the Earth and the effect of the Earth's rotation. To interpret gravity data, one must remove all known gravitational effects that are not related to the subsurface density changes (Mickus, 2003). These include latitudinal variations, elevation changes, topographic changes, building effects, the Earth's shape and rotation, and Earth tides (LaFehr, 1991). It is necessary to correct for all of the factors that are not due to density contrasts in the subsurface (Christopher, 2001). Raw gravity data were corrected for drift, height, free-air, Bouguer, absolute gravity, terrain, theoretical gravity correction and finally obtaining Bouguer anomaly value for mapping and interpretation.

2.1.4.1 Drift and tidal effect

If a gravimeter is placed in one position and readings are taken every hour or so, the values obtained would vary. This variation is due to two causes. One is instrument drift, which is caused by small changes in the physical constants of gravimeter components (Burger et al., 2006). Due to elastic creep in the springs, the readings of gravimeters drift more or less with time (Parasnis, 1997). This instrument drift affects cannot be ignored due to an extreme sensitivity of gravimeters (Burger et al., 2006). In order to correct for it, the measurements at a set of stations are repeated after 1 to 2 hour and the differences obtained are plotted against the time between two readings at a station (Parasnis, 1997). This reading sequence is referred to as looping. The other cause is due to tidal effects that are governed by the positions of the Sun and the Moon relative of the Earth. Observed gravity readings at a fixed location will change with time due to the periodic motion of the Sun and the Moon (Christopher, 2001). Tidal variations produce an effect on gravimeter mass that varies by ± 0.15 mGal from a mean value and can have a rate of change as high as 0.05 mGal/ hour. Because there are substantial values relative to the 0.01 precision of most gravimeters, a correction clearly is called for. Tidal effects can be predicted accurately, so it is relatively straightforward to a computer program to produce values for any location at any time (Burger et al., 2006). For Scintrex (gravimeter), software is supplied to automatically remove the Earth tide effect.

2.1.4.2 Latitude effect

The value of gravity increases with the geographical latitude (Parasnis, 1997). Due to the Earth's rotation, the Earth is not spherical but is flattened at the poles. This means that the length of the Earth's radius is greater at the equator than at the poles. This distance factor causes the g value to increase from equator to pole by 6.6 Gals because of the surface is closer to the center of the Earth at the poles (Burger et al., 2006).

2.1.4.3 Free-air correction

Gravity observed at a specific location on Earth's surface can be viewed as a function of three main components which are observation point latitude, station elevation and mass distribution in the subsurface. Free-air correction accounts for second effect, which is the local change in gravity due to elevation difference between station and sea level (Robert, 1999; Hill et al., 1997a). In practice the value of 0.3086 mGal/m is the only value used after deriving from Equation (2.4) and assumed that the Earth is spherical and non-rotating (Equation 2.5). Note that this correction considers only elevation differences relative to a datum and does not take into account that the mass between the observations point and datum, as if the stations were suspended in free air, not sitting on land. This is the reason the correction is termed as free-air correction. Normally the datum used for gravity surveys is sea level and gravity decreases 0.3086 mGal for every meter above sea level (Burger et al., 2006).

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

$$\frac{dg}{dr} = -\frac{2Gm}{r^2} = -\frac{2g}{r} = FAC$$

$$FAC = \frac{2g}{r} = 0.3086 \frac{mGal}{m} \qquad (2.5)$$

where FAC is free-air correction.

2.1.4.4 Bouguer correction

Even after elevation correction, gravity can vary from station to station because of differences in mass between the observation points and sea-level datum

(Hill et al., 1997a). Relative to areas near sea level, mountainous areas would have extra mass, tending to increase the gravity value as seen in Figure 2.5a (Robert, 1999). Figure 2.5b shows the approach for Bouguer correction by assuming each station sit on a slab of material which extends to infinity laterally and to the elevation datum vertically (Burger et al., 2006).

Bouguer correction accounts for gravitational attraction of the mass above sea-level datum. By approximating the mass as an infinite slab with thickness (h) equal to an elevation of the station, the attraction of such slab (Equation 2.6).

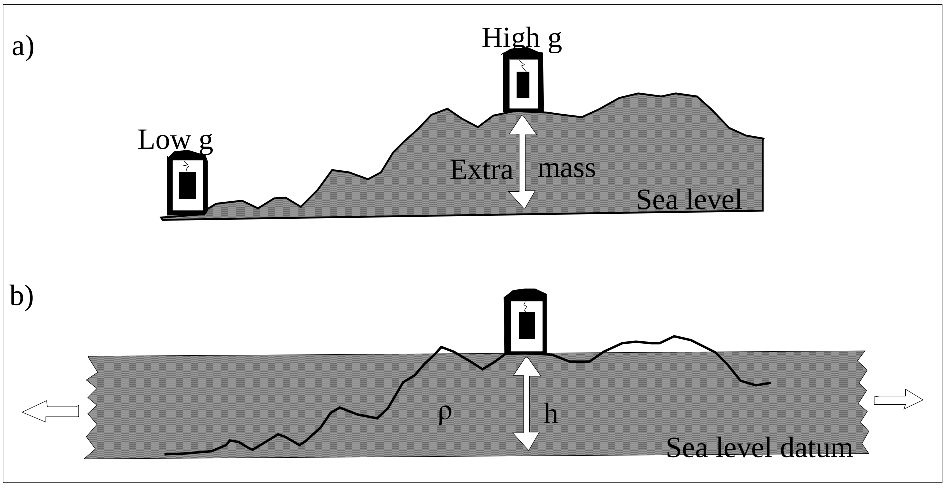

Figure 2.5: Bouguer correction. (modified after Robert, 1999).

$$BC = 2\pi\rho G h \qquad (2.6)$$

where BC is Bouguer correction, ρ is slab density, G is universal gravitational constant and h is thickness of the slab (station elevation). Substituting the values of G and 2π yields an Equation (2.7).

$$BC = 0.0419\rho h \qquad (2.7)$$

where *BC* is in mGal (10^{-5} m/s^2); ρ in g/cm^3 (10^3 kg/m^3); *h* in m.

Using the Nettleton's approach, gravity data were to reduce by using 2.67 g/cm density. This is because this value caused the least influence of relief features which is a few ten meters on the resulting gravity data (Rybakov et al., 2010).

2.1.4.5 Terrain correction

While acquiring field survey, nearby topography such as hills and valleys will attracts the mass in gravimeter and reduces the observed gravity value. With respect to the surrounding rocks, valleys are considered to have negative density. Terrain correction takes into account for undulations of topography above and below the elevation level of an observation point (Burger et al., 2006). Hill will pull up on the mass in the gravimeter while valley is a mass deficiency (Figure 2.6). This correction did not really affect the observed gravity when in flat survey area but it does affect when the survey area has rugged terrain. In mountainous regions, this correction can be as large as 10's of mGals.

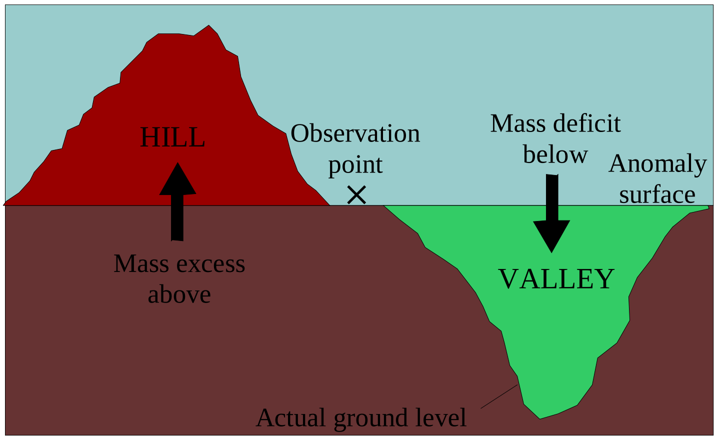

Figure 2.6: Ground above the observation point (hills) tends to attract a mass upwards and lack of ground below the observation point (valley) reduces the downward attraction (modified after Alice and Ray, 2001).

2.2 Magnetic method

Magnetic field observed on Earth's surface varies considerably in both strength and direction. Robert, 1999 stated that unlike gravitational acceleration, which is directed nearly perpendicular to the Earth's surface, magnetic field directions change from nearly horizontal at the equator, to nearly vertical at the poles (Figure 2.7). The magnetic field value at the equator ≈ 30000 nT while 60000 nT at the poles.

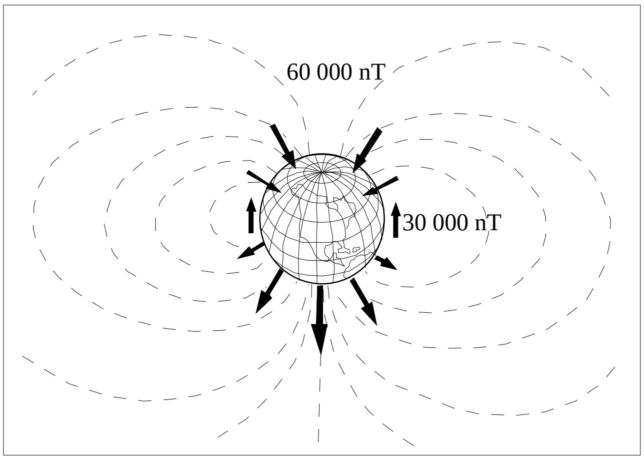

Figure 2.7: Magnetic field shows strong variations in both magnitude and direction (modified after Robert, 1999).

The magnetic method is a very popular and inexpensive approach for near-surface metal detection (Rivas, 2009) where it involves measurements of the Earth's magnetic field intensity using an instrument called magnetometer. It is typically measuring total magnetic field and/or vertical magnetic gradient. The magnetic surveying investigates on the basis of anomalies of the Earth's magnetic field resulting from magnetic properties of underlying rocks (magnetic susceptibility remanence). Magnetic measurements are made more easily and cheaply than most