



**Sudan University of Science & Technology**  
**College of Petroleum Engineering & Technology**  
**Department of Petroleum Exploration**



**The Geometry Configuration of ATBRA Basin**  
**Utilizing Satellite Gravity Measurements**

التراكيب تحت السطحية لحوض عطبرة بإستخدام قياسات جاذبية الاقمار  
الإصطناعية

**This dissertation is submitted as a partial requirement for  
B.sc Degree (honor) in Exploration engineering**

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# الآية

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

{وقل رب زدني علماً}

# DEDICATION

For the man who drinks from empty cup to give me a drop of love ,,for the man who teach me the way of life , happiness and his finger print in my life determine my way . thanks ALLAH because you select for me the best father in world even for short period it is enough for me I am his son forever ,,for the man who want to see me the best one in the world so not just my research is for you but all my steps in the right way is because of you....

♥♥♥♥My Father ♥♥♥♥

For the woman who give me support and love without waiting for price , the woman love my success more than her life ,, the woman who is ready to accept any pain to make me happy and not feel pain for my angel in the life for the meaning of love and smile of life ,, for the woman who her prays is cause of my success and her love is antidote of my sadness , ALLAH blessing you....

♥♥♥♥My Mother ♥♥♥♥

For those who teach me the meaning of responsibility and wisdom, those their smiles make me forget the black dots in my life, for the source of light and nice....

.....My sisters, brothers, friends.....

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First of all to ALLAH the greatest from the start to the end several people have been instrumental in allowing this research to be complete.

We would like to thank our supervisor

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For his encourage, support, correcting our work and advise us Also we would like to thank all the family of petroleum collage for science and technology, a special thanks to exploration department for supporting us.

Thanks continue to our friends and our families for all their encouragement and support throughout our study.

## ABSTRACT

Study area lies in the River Nile state -North Central of Sudan - between latitudes  $17^{\circ} 34'$  - $18^{\circ} 00'$  E and longitudes  $33^{\circ} 55'$  –  $34^{\circ} 43'$  N . The geological settings of the study area are composed of Pre-Cambrian Basement Complex, upper Cretaceous Nubian sandstone formation, Oligocene Hudi Chert , and Quaternary superficial deposits in ascending order.

Atbara Basin represents one of the promising basins in Sudan as far as petroleum is concerned. The previous oil exploration activities have been concentrated in South Sudan basins and little attention was given to Atbara Basin. For this reason, Atbara Basin remained undiscovered and its potentiality is, so far, not fully understood.

The outcome of this study was to generate a structural framework and a depth to basement interpretation for the study area. The Ground Gravity data was originally provided as Bouguer anomaly ( BA) where the satellite gravity data was provided as free air anomaly ( FAA) delivered together with the elevation data for each point. This combination of data was used to compute Bouguer Anomaly (BA) for the study area.

By comparison between ground and satellite gravity data the satellite data were adopted to be used in present study is because the satellite data gives a good coverage, high resolution with relatively low cost. Different derivatives were computed from the Bouguer anomaly values of satellite the Bouguer anomaly and the derived values were interpreted in terms of variations in lithological units, which were constrained by the surface exposures where available.

The average method was used to separating regional from the residual component of the gravity by using mathematical equation. Two profiles were constructed across the residual gravity map in an approximately NW-SE and NW- SE directions cutting the most prominent anomalies in the area. To generate modeling of the subsurface geology of the study area based on the residual gravity map.

## الخلاصة

بحدود ولاية كسلا ومن الغرب تقع منطقه الدراسة في ولاية نهر النيل شمال وسط السودان تحد من الشرق -17° 34' و خطي عرض . 33° 55' – 34° 43' N . تحد بنهر النيل وشمالا بنهر عطبره بين خطي طول 18° 00' E.

التكوين الجيولوجي لمنطقه الدراسة من صخور الأساس والحجر الرملي النوبي و صوان الهودي والرسوبيات الحديثة. يعتبر حوض عطبرة من الاحواض المهمة في السودان ، وقد تركزت عمليات الاستكشاف السابقة في السودان عن النفط في احواض جنوب السودان لذلك اعطي حوض عطبرة القليل من الاهتمام لهذا السبب يعتبر حوض عطبرة غير مستكشف او لم يتم فهمه بالكامل.

مخرجات هذه الدراسة هي تحديد عمق الرسوبيات وانشاء نموذج للتراكيب التحت سطحية لمنطقة الدراسة. بيانات الجاذبية الارضية قدمت في هيئة شذوذ بوقير اما بيانات الجاذبية للأقمار الاصطناعية فقدمت على هيئة شذوذ الهواء الحر التي جمعت مع بيانات الارتفاع لكل نقطة هذه المجموعة من البيانات استخدمت لحساب قيمة شذوذ بوقير لكل نقطة في منطقة الدراسة.

خلال المقارنة بين شذوذ بوقير لبيانات الجاذبية للأقمار الصناعية وبيانات الجاذبية الارضية وجد ان الفرق بينهما بسيط جدا ويمكن اعتماد قيم شذوذ بوقير للأقمار الاصطناعية وذلك لأنها تعطي تغطية اوسع وتكلفة اقل وذات دقة عالية.

العديد من المشتقات تم اشتقاقها من قيم شذوذ بوقير وذلك لتحديد اماكن الفوالق و امتداداتها . استخدمت طريقة المتوسط لفصل الجاذبية الاقليمية من الجاذبية المتبقية باستخدام معادلة رياضية على خريطة الجاذبية المتبقية تم عمل قطاعين وذلك لتحديد عمق الحوض الرسوبي.

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# **CHAPTETR ONE**

# INTRODUCTION

## 1.1 Location and area extend

The study area lies in the River Nile state in the North Central of Sudan. It is bordered by the River Nile in the west and Atbara River in the north and bounded in the East by Kassala state boundary. The study area lies between latitudes:  $17^{\circ} 34' - 18^{\circ} 00'$  E and longitudes  $33^{\circ} 55' - 34^{\circ} 43'$  N. It covers an area of about  $673 \text{ Km}^2$  approximately Figure (1.1). Many paved and unpaved roads were passing through the area; therefore, it is easily accessible to reach any point in the study area.

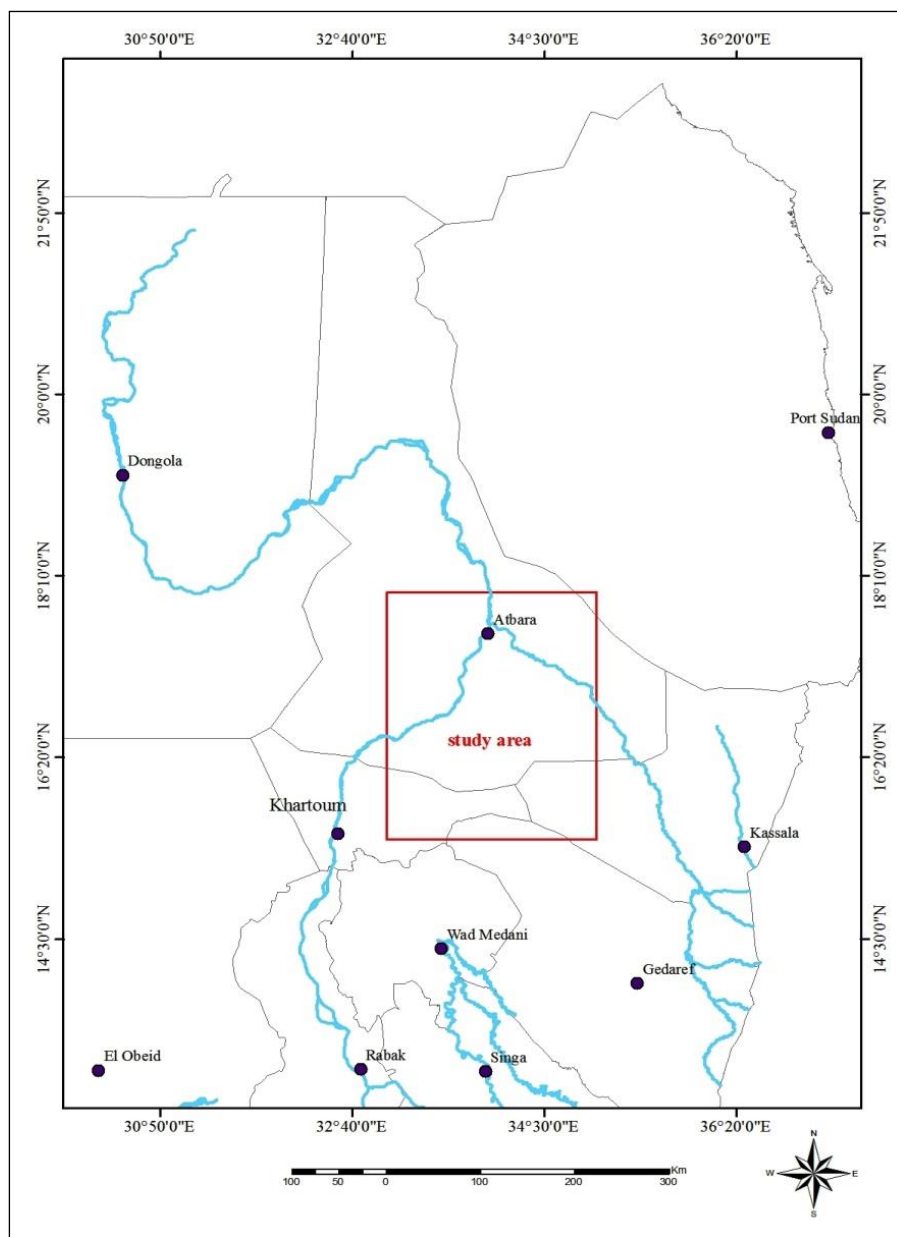
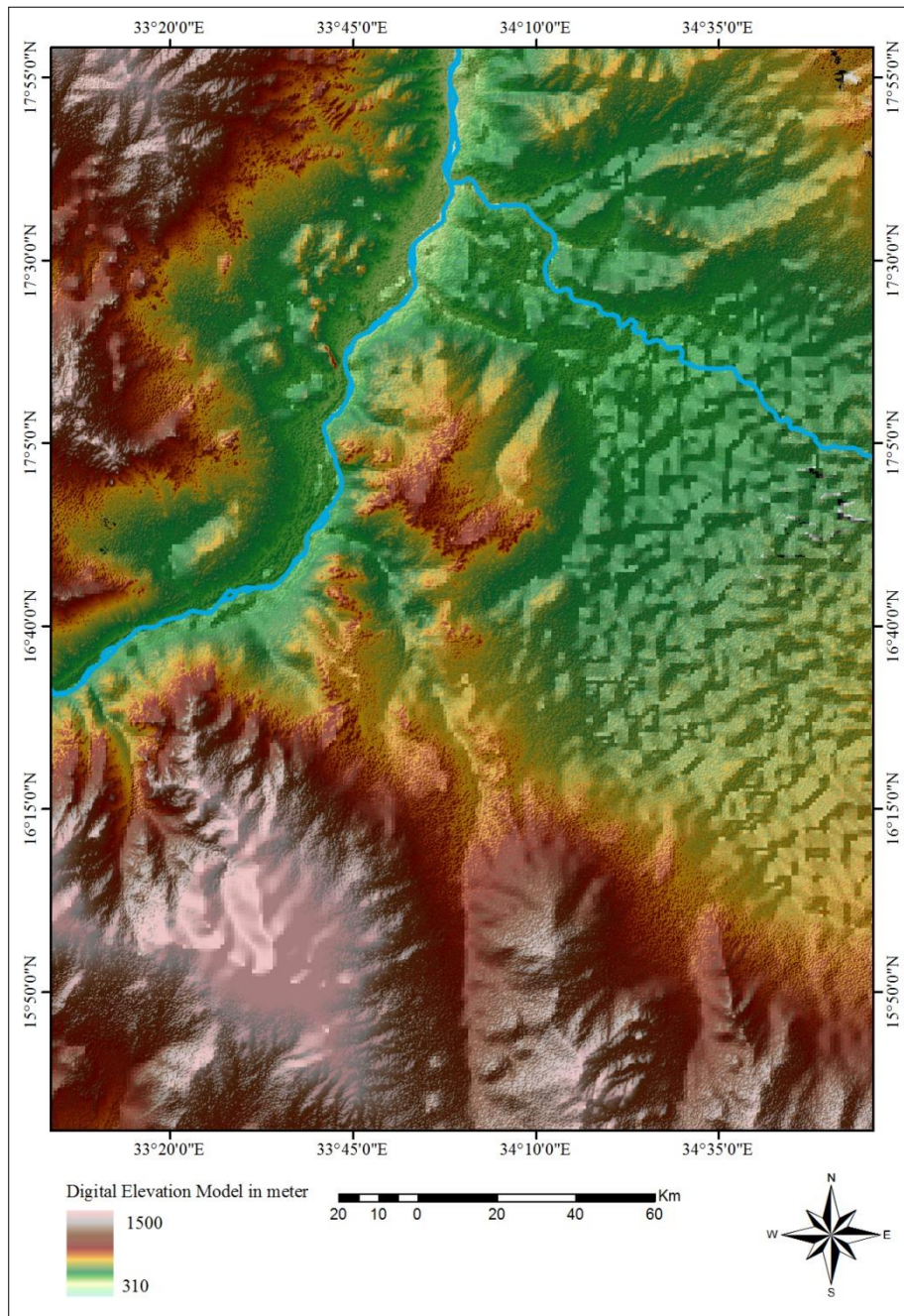


Fig 0.1 : : Location map of the study area.

## 1.2 Topography

The area is extremely flat. The elevation ranges between 330 to 380 meter a.m.s.l . It is dipping gently to the northwest (Figure 1.2). Sand dunes and low ridges with scatter cobble, pebbles and boulders were covering the study area visualizing the undulated surface of the area.

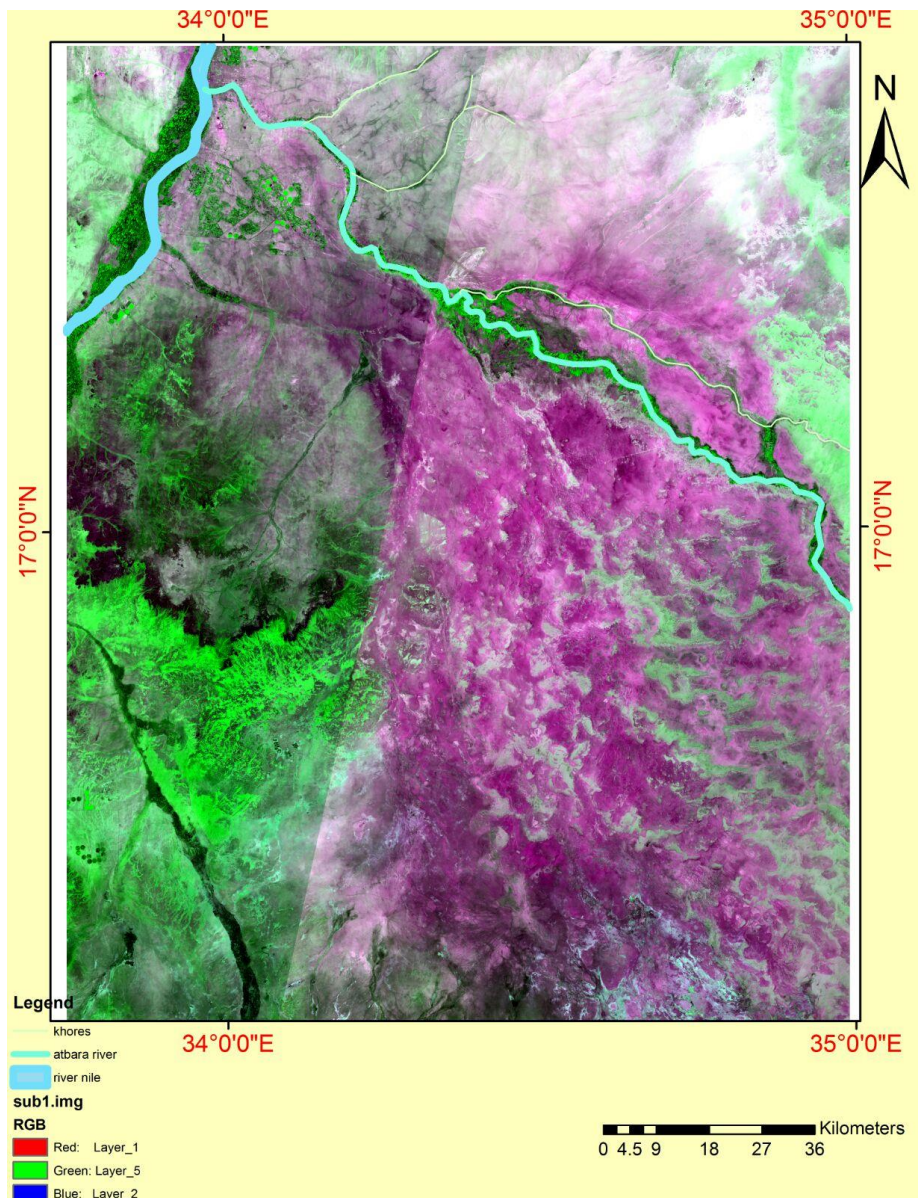


**Fig 0.2 : Digital Elevation Model of the study area showing the main topographic element**



### 1.3 Drainage system

River Nile and Atbara River and seasonal wades are the main geomorphologic features which drain the water to the River Nile and Atbara River which is flowing from south to north (Fig. 1.3). River Atbara is characterized by meandering drainage system depositing huge amount of sediments at the stream valley on the inside of beds. This process is clear in construction and maintaining a flood plain (Mukhtar, 1999).



**Fig 0.3 : Drainage system of the study area superimposed over Landsat image.**

## **1.4 Climate**

The study area is of arid and semi-arid climate, which is characterized by the two main season, winter and summer. The winter season extend from November to March, January represent the coldest month during which a minimum temperature between 15° C to 32° C is recorded. The rest of the year is dominated by a hot summer, May represent the hottest month with maximum Temperature range between 39° C to 43° C. The rainfall in the study is mainly during July to September. Little amount of the rainfall is received during early October. The mean monthly evaporation is about 13 mm/day.

Study area always affected by the wind for most of the year (northern and southwest wind). Sidon station is only one meteorology station in the study area for rainfall intensity mentoring since 1975 to 1995 with an average measurement of 50mm.

## **1.5 Soil and Vegetation :**

The study area is characterized by sandy and clayey soil. it is formed by weathering product of the Nubian sandstone formation and the basement complex some are residual and other are transported by wind and water and the main type of the soil is the alluvial deposit ,sand sheet, flat sand soil.

In the study area the vegetation cover is very poor and trees are scattered along the river banks. Short life grasses cover the plain during the autumn, The study area is considered as Savanna vegetation such as Tabass , and Nal, while the bushes and trees are Tundub, Sunut, Talih ,in addition to date palm along the river and Dom trees. There are also many agriculture projects in the area and agriculture research center such as elhdyba center .

## **1.6 Population**

The population is mainly concentrated along the Nile River and Atbara River , some villages are located far from the river Nile . The people live in small villages and settlement , most of inhabitants on limited agriculture activity depending on limited rainfall during summer , The people living in the Nile valley depend on growing vegetables and fruits using river and ground water for irrigation purposes.

The number of population is not achieved but generally less than half million but now the number of population increased because all the people coming to this area looking for gold mining or working in the cement factories.

### **1.7 Previous works**

The study area has been studied by Sun oil company between (1983-1985) the company carried out geophysical survey lead to the collection of gravity, magnetic and seismic data.

Recently, Sudapak Petroleum Operating Company (SPOC) conducted high resolution airborne gravity and magnetic survey and carried out new seismic investigations with different parameters, one well has been drilled in Atbara Basin.

An interpretation of newly acquired airborne gravity and magnetic data, with seismic and well data supported, over exploration area. There are many researches were performed in the study area concerning different topics in the earth sciences. Kheiralla (1981) has carried out a comprehensive study of groundwater resources of the northern Sudan.

Awad (1982) provided general survey for natural resources including Kenedra basin. Ayed (1994) assess groundwater using electrical resistivity technique to delineate the contact between the Nubian sandstone and the basement.

Ahmed and Abdelrahman (1996) studied the capacity of groundwater wells in the area and the uses of groundwater for different purposes. Mukhtar (1999) carried out a hydrogeological and hydrochemical and geophysical survey, assessing the location capacity geometry. Geophysical survey using resistivity method was carried out as an electrical sounding to delineate the contact between the basement complex and the Nubian sandstone formation and elaborate groundwater assessment of the area.

### **1.8 SCOPE OF STUDY:**

The aim of this study was to generate a structural framework and a depth to basement interpretation for the study area, in order to achieve these aims and airborne & ground gravity survey has been reviewed and merged with existing data . A suite of gravity and "Arc GIS" were tested in a series of 2.5D models . these 2.5D models were used to interpreted subsurface of study area by identifying the faults extension and their orientations also to detect shallow and maximum depth .



## 1.9 statement of study

Atbara Basin represents one of the promising basins in Sudan as far as petroleum is concerned. The previous oil exploration activities have been concentrated in South Sudan basins and little attention was given to Atbara Basin. For this reason, Atbara Basin remained undiscovered and its potentiality is, so far, not fully understood.

## 1.10 Methodology

### 1.10.1 Data type

In order to fulfill the objectives of the present study, different data types have been utilized, these include:

- 53 points of ground gravity that were measured using an auto-gravimeter system.
- Satellite gravity grids covering the area extended between longitudes: 33.45°-34.75° and latitudes: 16°-17.75°.
- Landsat 7 ETM image, path 173 – row 48, in digital format, including seven spectral bands, acquired in the year 2000.
- The data obtained from open file of the Ministry Of Mineral and Energy .

### 1.10.2 Method

The ground gravity data was originally provided as Bouguer anomaly (BA) where the satellite gravity data was provided as free air anomaly (FAA) delivered together with the elevation data for each point. This combination of data was used to compute Bouguer Anomaly (BA) for the study area.

By comparison between ground and satellite gravity data the satellite data were adopted to be used in present study. Furthermore, different derivatives were computed from the Bouguer anomaly values of satellite. The Bouguer anomaly and the derived values were interpreted in terms of variations in lithological units, which were constrained by the surface exposures where available.

The average method was used to separate regional from the residual component of the gravity field. Two profiles were constructed across the residual gravity map in an approximately NW-SE and NE- SW directions cutting the most prominent anomalies in the area to generate models of the subsurface geology of the study area based on the residual gravity map.

### **1.10.3 Software**

Initial efforts were exerted on the assembly and analyses of the large amount of available data in the study area by using ArcGIS program to generate maps used in the interpretation of subsurface structures.

Geosoft OasisMontag was used to obtain first vertical derivative, second vertical derivative and first horizontal derivative for the Bouguer anomaly gravity data.

Gravmodel program was used to generate geological models for two profiles crossing the study area.

# CHAPTER TWO

# Literature Review

## 2.1 Geological setting

The main geological units in the study area are composed of Basement Complex (Pre-Cambrian), Nubian sandstone formation (upper Cretaceous), Hudi Chert (Oligocene) and Quaternary superficial deposit (figure 2.2) in ascending chronological order (Kheirallah 1978, Ayeid 1994 and Mukhtar 1999). These geological units can be described in the following paragraphs:

### 2.1.1. Pre-Cambrian Basement Complex

The basement complex is composed of highly deformed and multi metamorphosed gneisses and schist. The original rock are largely subjected to intensive deformation resulting in different types of structure and fracture systems and followed by erosional period creating of topographical relief (Mukhtar 1999) forming the base over which all other sediment were deposited and generally it appears as low bouldery outcrops at river Atbara (river Atbara bridge). The contact between the basement and Nubian sand stone appear in the Mebireka village north of the study area and in South east near the Umshadida village( Kheiralla, 1966 ).

### 2.1.2. Cretaceous Nubian Sandstone

The Basement rocks are unconformable overlain by the rudaceous and arenaceous beds of the Nubian Sandstone Formation, which are considered to have been deposited mainly in upper Cretaceous time (Edwards, 1926; Kheiralla, 1966; Whiteman, 1971 and Vail, 1978). Many geologists beliefs that Nubian sandstone formation of Sudan and southern Egypt; is of continental origin with marine facies.

The Nubian sandstone is mainly composed of sandstone in different color and cemented materials and it is intercalated by gravel, grits and mudstone which are older than early Tertiary lavas (Mukhtar1999).

Nubian sand stone cover about 40% of Sudan and the bulk of formation is confined to the northern part of Sudan. In the study area the Nubian sandstone formation cover the area between the river Nile and Atbara River and northern part of the delta area.

The Nubian sandstone is continental origin and it is classified into three cycles (Awad 1994) namely; lower, middle, and upper and suggested more than twenty formations and proposed as Cambrian–Ordovician to Tertiary age. The Lower Sandstone forms a

discontinuous. This member of the Nubian Sandstone immediately overlies the basement and igneous ring complexes(basal conglomerates). The Middle Iron-Shale is occurred between the Lower and Upper Sandstone. They are more strongly eroded; giving rise to a plain of denudation covered by gravel and sheets of sand .The Upper Sandstone, forms a more complete escarpment and constitutes the isolated scattered inselbergs. The surface blanket in the study area mainly belong to the upper cycle and consist of fluvial and lacustrine facies (figure 2.2)

This area represent apart of Nubian basin which extend along eastern bank of river Nile. The formation is highly weathered by seasonal stream in the direction of the drainage pattern (east – west).

The Nubian sandstone formation is composed of unconsolidated sand and gravels with mud stone or clay stone intercalation having variable textural grades.

Along river Atbara the Nubian formation are characterized by thick layers of mudstone (300 m) where the total thickness of Nubian formation reached by drilled wells is over 400 m and diminished toward the east and south east (Mukhtar 1999) where the Basement rock are outcropped .

The Nubian formation in the study area extend along the river Nile west of Atbara town they lies uncomformably on basement complex of undulated topographical relief.

The thickness of sediment at east and northeast of the area varies from 90 meter up to 220 meter where the lithology is dominated by sands and gravely sand separated by layers of clay. Kanker nodules occur in the upper zone mixed with gravels and sands particularly in the Middle East part of the area (figure2.2& 2.3).

### **2.1.3. Hudi Chert (Tertiary)**

These rocks are named after the Hudi locality lying on the railway line between Atbara and Port Sudan, the place where they were discovered for the first time. They occur as boulders consisting of fossil ( gastrobods fssils ) and ferrous cherty deposits or as bedded strata.

They are variable in texture, very hard frequently possessing a concoidal fracture, their surface is usually yellowish, brownish to reddish in color and also occur as gravelly and breccias form, which give a reddish brown appearance. Sometimes they occur as small mounds made of Chert, gravels and boulders mixed with quartz

pebbles and reddish clayey sands (Khierallah 1966). The Hudi Chert rock overlying the Nubian sand stone formation covering large area.

In the study area the Hudi Chert appears in the south east of Atbara near the hudi-valley (Mukhtar; 1999; figure2.1) and in the southern bank of Atbara river near Alglaiia village and Omerab and appear in the east river Atbara in Elkwib and Elnikhela villages. Also it is appeared in different massive form and conglomerate (Elsalam factory) and Breccia. In some places out of the study area chert contains gastropods fossils that suggest Oligocene age and shallow environment.

#### **2.1.4. Superficial deposits**

These include silt of the river terraces (Nile river and Atbara river ) and unconsolidated layers of gravel, sand ,clays and sandy clay with kanker nodules as well as extensive sand dunes that almost occupy the southern part of the River Atbara .Near Nile river alluvial deposit is consist mainly of dark clays , brownish pebbly and clayey sand and kanker nodules. Where as at the river Atbara, alluvial deposit are composed of grey clays followed by a layer of sand ,kanker nodules and Hudi Chert fragment are found in some area. The thickness of this group varies between 30 to 70 ft(figure2.2 and 2.3)

#### **2.1.5 The geological structure**

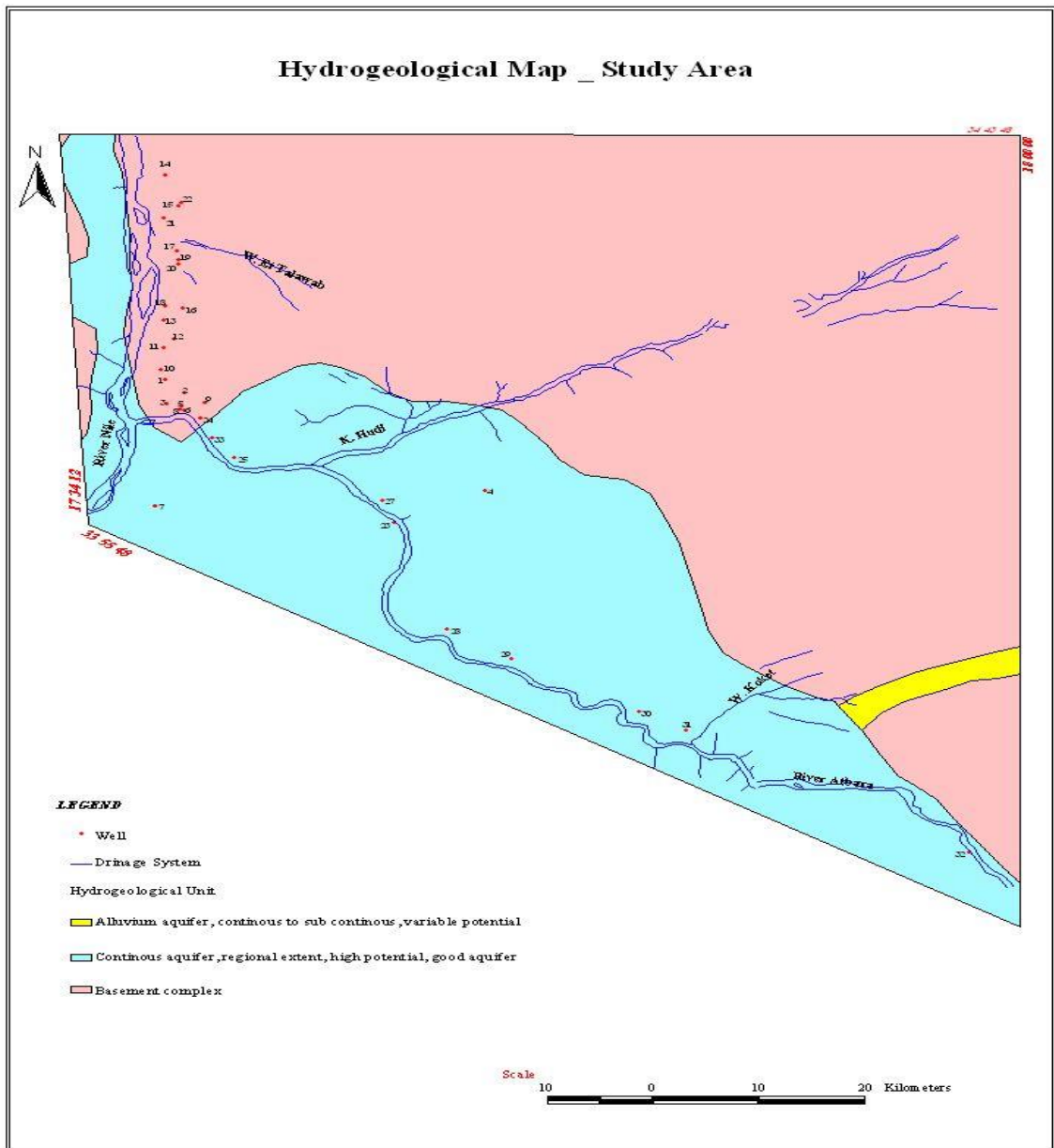
Five NW-SE oriented continental rifts are now known to cross Sudan, defining an extensional province 1000 km wide and with length of at least 800 km parallel to the strike from north to the south. These rifts are Atbara, Blue Nile, White Nile (Melut basin ), Abu Gabra-Muglad and Bahr ElaArab rift are referred to collectively as the south Sudan rift common, such as at Kosti, Umm Ruwaba basins of the White Nile rift and Sag El Naam basin. Generalized geological map in figure (2.1) shows the main lithological units of Sudan and adjacent territories which was modified after Vail (1988). , Sudan's interior basins have been related to the west and central African rift system (CASZ,Schull,1988), formed in the Late Jurassic to Early Cretaceous. The shear stress resulting from the separation of Africa and South America and the subsequent opening of the South Atlantic Basin has been transferred along the Central African Fault Zone.

Atbara basin is controlled with the same orientation of the rift zone but it is comparatively small. The strip along Atbara-Abu hammed, which extends along Atbara river (William; 1980) is one of the major structure passing through the area.

This strip create a fault , trending EW and is bounded from the north by Fadlab-Atbara uplift that extend north parallel to the River Nile east of Atbara (Sones 1994, Mukhtar1999) . The deformation of the basement and the overlying sedimentary sequences are ascribed to faulting and folding activities (Mkhtar; 1999). The depression at Atbara town and center of study area; the confluence of River Nile and Atbara as well as depressions in north (Abu Amar) and south (Alamrab) may be ascribed to the folding activities.



Fig 0.1 : map showing the major rift basins of Sudan and adjacent countries



**Fig 0.2 : Hydrogeological map of the study area.**



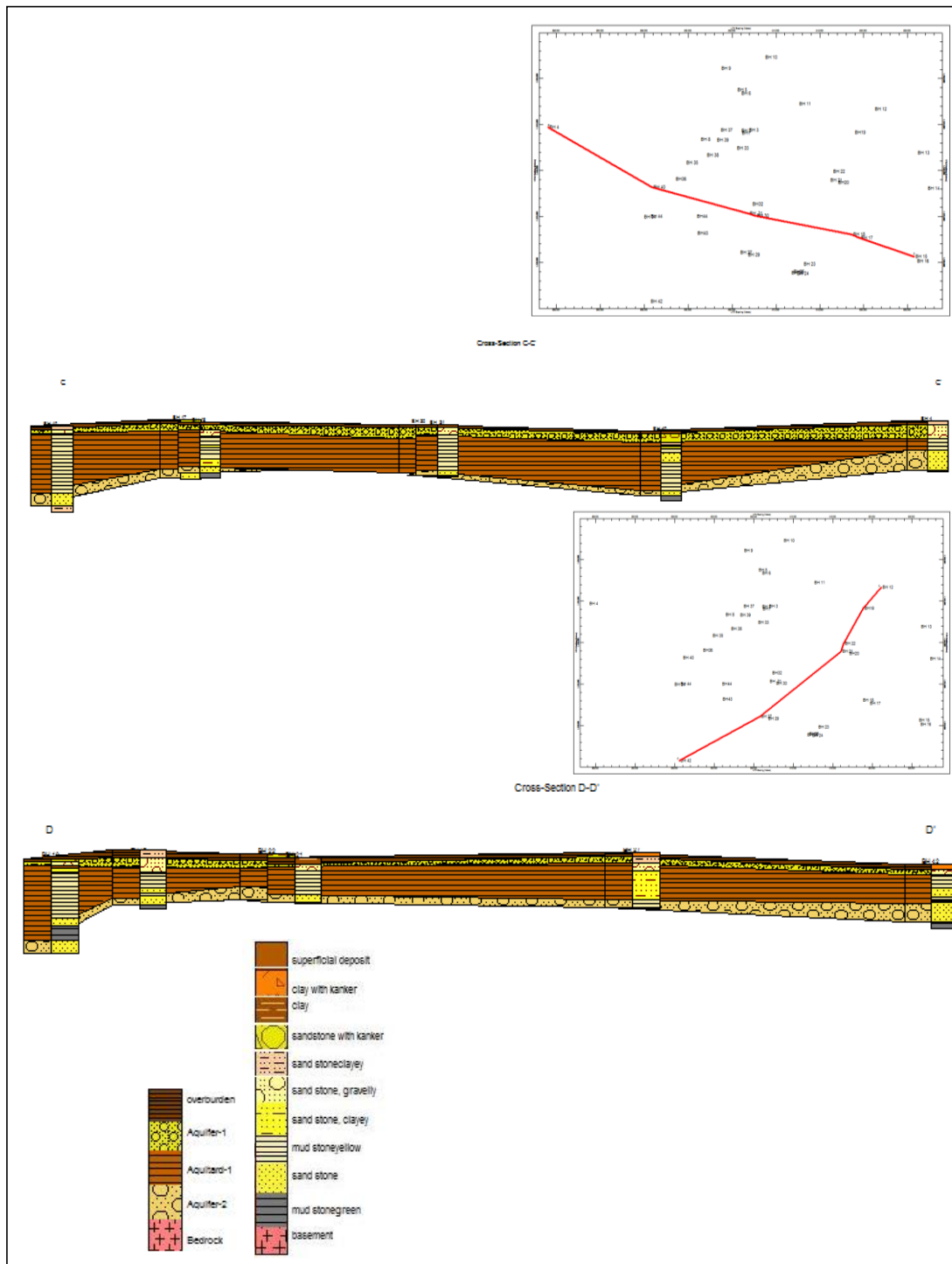


Fig 0.3 : cross section of the study area (C–C) and (D-D).

## 2.2 Gravity surveying

### 2.2.1 Introduction

In gravity surveying, subsurface geology is investigated on the basis of variations in the Earth's gravitational field arising from differences of density between subsurface rocks. An underlying concept is the idea of a *causative body*, which is a rock unit of different density from its surroundings. a causative body represents a subsurface zone of anomalous mass and causes a localized perturbation in the gravitational field known as a gravity anomaly. a very wide range of geological situations give rise to zones of anomalous mass that produce significant gravity anomalies. on a small scale, buried relief on a bedrock surface, such as a buried valley, can give rise to measurable anomalies. on a larger scale, small negative anomalies are associated with salt domes, . On a larger scale still, major gravity anomalies are generated by granite plutons or sedimentary basins. Interpretation of gravity anomalies allows an assessment to be made of the probable depth and shape of the causative body. The ability to carry out gravity surveys in marine areas or, to a lesser extent, from the air extends the scope of the method so that the technique may be employed in most areas of the world.

### 2.2.2 Basic theory

The basis of the gravity survey method is Newton's Law of Gravitation, which states that the force of attraction  $F$  between two masses  $m_1$  and  $m_2$ , whose dimensions are small with respect to the distance  $r$  between them, is given by

$$F = \frac{Gm_1m_2}{r^2} \quad \mathbf{(2-1)}$$

where  $G$  is the Gravitational Constant ( $6.67 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$ ). Consider the gravitational attraction of a spherical, non-rotating, homogeneous Earth of mass  $M$  and radius  $R$  on a small mass  $m$  on its surface. It is relatively simple to show that the mass of a sphere acts as though it were concentrated at the centre of the sphere and by substitution in equation

$$F = \frac{GM}{R^2}m = mg \quad \mathbf{(2-2)}$$

Force is related to mass by an acceleration and the term  $g = GM/R^2$  is known as the gravitational acceleration or, simply, *gravity*. The weight of the mass is given by  $mg$ . On such an Earth, gravity would be constant. However, the Earth's ellipsoidal shape, irregular surface relief and internal mass distribution cause gravity to vary over its surface. The gravitational field is most usefully defined in terms of the gravitational potential  $U$ :

$$U = \frac{GM}{r} \quad \mathbf{(2-3)}$$

Whereas the gravitational acceleration  $g$  is a vector quantity, having both magnitude and direction (vertically downwards), the gravitational potential  $U$  is a scalar, having magnitude only. The first derivative of  $U$  in any direction gives the component of gravity in that direction. Consequently, a potential field approach provides computational flexibility. Equipotential surfaces can be defined on which  $U$  is constant. The sea-level surface, or *geoid*, is the most easily recognized equipotential surface, which is everywhere horizontal, that is, at right angles to the direction of gravity.

### 2.2.3 Units of Gravity

The mean value of gravity at the Earth's surface is about  $9.8 \text{ ms}^{-2}$ . Variations in gravity caused by density variations in the subsurface are of the order of  $100 \text{ mms}^{-2}$ . This unit of the micrometre per second per second is referred to as the *gravity unit* (gu). In gravity surveys on land an accuracy of  $\pm 0.1 \text{ gu}$  is readily attainable, corresponding to about one hundred millionth of the normal gravitational field. At sea the accuracy obtainable is considerably less, about  $\pm 10 \text{ gu}$ . The c.g.s. unit of gravity is the milligal ( $1 \text{ mgal} = 10^{-3} \text{ gal} = 10^{-3} \text{ cms}^{-2}$ ), equivalent to  $10 \text{ gu}$ .

### 2.2.4 Gravity Reduction

Before the results of a gravity survey can be interpreted it is necessary to correct for all variations in the Earth's gravitational field which do not result from the differences of density in the underlying rocks. This process is known as gravity reduction (LaFehr 1991) or reduction to the geoid, as sea-level is usually the most convenient datum level.

### 2.2.4.1 Drift correction

Correction for instrumental drift is based on repeated readings at a base station at recorded times throughout the day. The meter reading is plotted against time. A gravimeter drift curve constructed from repeated readings at a fixed location. The drift correction to be subtracted for a reading taken at time  $t$  is  $d$ .

(Fig.(2.4) ) and drift is assumed to be linear between consecutive base readings. The drift correction at time  $t$  is  $d$ , which is subtracted from the observed value. After drift correction the difference in gravity between an observation point and the base is found by multiplication of the difference in meter reading by the calibration factor of the gravimeter. Knowing this difference in gravity, the absolute gravity at the observation point gobs can be computed from the known value of gravity at the base. Alternatively, readings can be related to an arbitrary datum, but this practice is not desirable the results from different surveys cannot then be tied together.

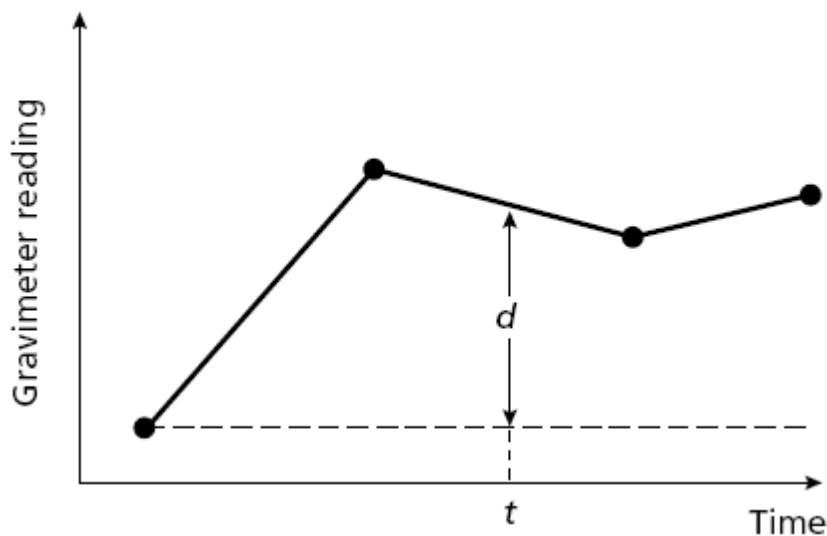
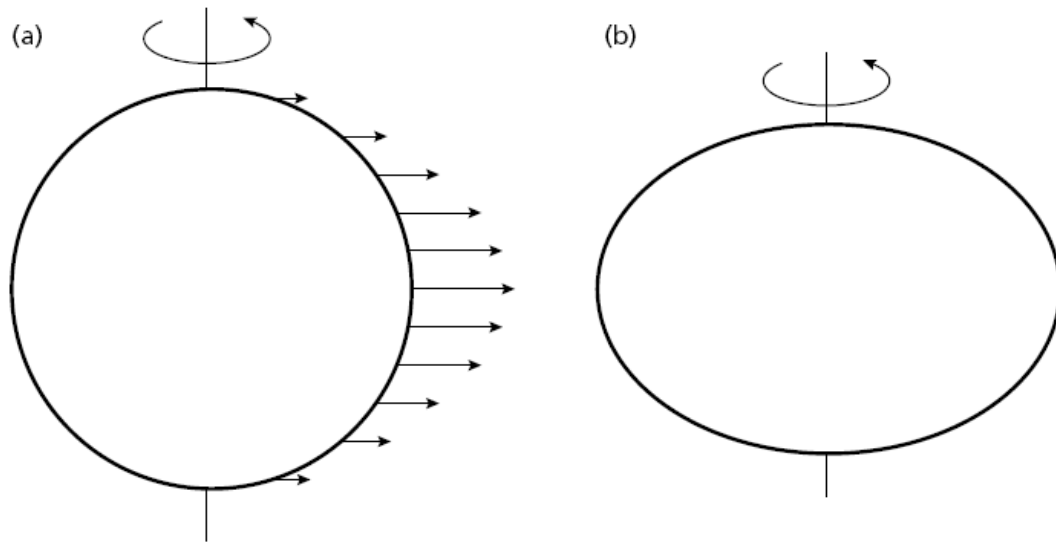


Fig 0.4 : The meter reading plotted against time.

### 2.2.4.2 Latitude correction

Gravity varies with latitude because of the non-spherical shape of the Earth and because the angular velocity of a point on the Earth's surface decreases from a maximum at the equator to zero at the poles Fig.(2.4 (a)). The centripetal acceleration generated by this rotation has a negative radial component that consequently causes gravity to decrease from pole to equator. The true shape of the Earth is an oblate

spheroid or polar flattened ellipsoid Fig. 2.5(b)) whose difference in equatorial and polar radii is some 21 km. Consequently, points near the equator are farther from the centre of mass of the Earth than those near the poles, causing gravity to increase from the equator to the poles. The amplitude of this effect is reduced by the differing subsurface mass distributions resulting from the equatorial bulge, the mass underlying equatorial regions being greater than that underlying Polar Regions.



**Fig 05. : (a) rotation of earth**

**(b) true shape of earth**

The net effect of these various factors is that gravity at the poles exceeds gravity at the equator by some 51860 gu, with the north–south gravity gradient at latitude  $\phi$  being  $8.12 \sin 2\phi \text{ gukm}^{-1}$ . Clairaut’s formula relates gravity to latitude on the reference spheroid according to an equation of the form:

$$g_{\phi} = g_0(1 + k_1 \sin^2 \phi - k_2 \sin^2 2\phi) \quad \mathbf{(2-4)}$$

where:  $g_{\phi}$  is the predicted value of gravity at latitude  $\phi$ ,  $g_0$  is the value of gravity at the equator and  $k_1, k_2$  are constants dependent on the shape and speed of rotation of the Earth. The equation is, in fact, an approximation of an infinite series. The values of  $g_0, k_1$  and  $k_2$  in current use define the International Gravity Formula 1967:

$$g_0 = 9780318 \text{ gu}, k_1 = 0.0053024, k_2 = 0. \quad (2-5)$$

### 2.2.4.3 Elevation corrections

Correction for the differing elevations of gravity stations is made in three parts. The free-air correction (FAC) corrects for the decrease in gravity with height in free air resulting from increased distance from the centre of the Earth, according to Newton's Law. To reduce to datum an observation taken at height  $h$  Fig. (2.6.(a)).

$$\text{FAC} = 3.086h \text{ gu} \quad (h \text{ in metres}) \quad (2-6)$$

The FAC is positive for an observation point above datum to correct for the decrease in gravity with elevation.

The free-air correction accounts solely for variation in the distance of the observation point from the centre of the Earth; no account is taken of the gravitational effect of the rock present between the observation point and datum. The *Bouguer correction* (BC) removes this effect by appro

$$\text{BC} = 2\pi G\rho h = 0.4191\rho h \text{ gu} \quad (2-7)$$

$(h \text{ in metres, } \rho \text{ in Mg m}^{-3})$

imating the rock layer beneath the observation point to an infinite horizontal slab with a thickness equal to the elevation of the observation above datum Fig. 2.6.(b)). If  $\rho$  is the density of the rock

:

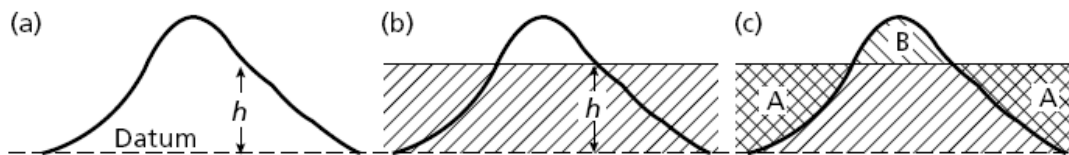
The Bouguer correction must be subtracted, as the gravitational attraction of the rock between observation point and datum must be removed from the observed gravity value. The Bouguer correction of sea surface observations is positive to account for the lack of rock between surface and sea bed. The correction is equivalent to the replacement of the water layer by material of a specified rock density. In this case:

$$\text{BC} = 2\pi G(\rho_r - \rho_w)z \quad (2-8)$$

where  $z$  is the water depth and  $\rho_w$  the density of water.

The free-air and Bouguer corrections are often applied together as the *combined elevation correction*.

The Bouguer correction makes the assumption that the topography around the gravity station is flat



**Fig 0.6 : (a) The free-air correction for an observation at a height  $h$  above datum. (b) The Bouguer correction .The shaded region corresponds to a slab of rock of thickness  $h$  extending to infinity in both horizontal directions. (c) The terrain correction.**

#### 2.2.4.4 Eotvos correction

The Eötvös correction (EC) is applied to gravity measurements taken on a moving vehicle such as a ship or an aircraft. Depending on the direction of travel, vehicular motion will generate a centripetal acceleration which either reinforces or opposes gravity. The correction required is:

$$EC = 75.03V \sin \alpha \cos f + 0.04154V^2 \text{ gu} \quad (2-9)$$

where  $V$  is the speed of the vehicle in knots,  $\alpha$  the heading and  $f$  the latitude of the observation. In midlatitudes the Eötvös correction is about +75 gu for each knot of E to W motion so that speed and heading must be accurately known.

#### 2.2.4.5 Tidal correction

Gravity measured at a fixed location varies with time because of periodic variation in the gravitational effects of the Sun and Moon associated with their orbital motions, and correction must be made for this variation in a high precision survey. In spite of its much smaller mass, the gravitational attraction of the Moon is larger than that of the Sun because of its proximity. Also, these gravitational effects cause the shape of the solid Earth to vary in much the same way that the celestial attractions cause tides in the sea. These *solid Earth tides* are considerably smaller than oceanic tides and lag farther behind the lunar motion .They cause the elevation of an observation point to be altered by a few centimetres and thus vary its distance from the centre of mass of the Earth. The periodic gravity variations caused by the

combined effects of Sun and Moon are known as *tidal variations*. They have a maximum amplitude of some 3 gu and a minimum period of about 12 h.

### 2.3 Geographic Information System

Geographical Information System (GIS) is a new, developing science and technology, which combines the general definitions of Geography, which describes the real world and spatial realities. Information is any type of data and information that have a meaning and can be useful. System defines the computer technology and supporting infrastructures and any hardware that takes share in the process.

GIS is considered as a multidisciplinary, multi-application, multi-purpose, multi technique, and multi-dimensional integrated technology and methodology (El Khidir, 2006). GIS can also defined as " an organized collection of computer hardware and software, with supporting data and personnel, that captures, stores, manipulates, analyzes, and displays all forms of geographically referenced information (Sabins, 2000).

The GIS process consists of the following steps (Sabins, 2000):

- Compile source data and prepare the various original geographic data sets, which may consist of multi-spectral images (Landsat, AVHRR), contour maps, thematic maps (climate, soils, others). At this stage the different data sets are in raster format and cover the same area.
- Geocod source data: This is the process of resampling each data set to a uniform pixel size that is registered to a geographic coordinate system.
- Derive attributes: A data set that is suitable for analysis is called attribute such as land cover maps and each spectral band of multi-spectral image is an attribute. The collection of geocoded attribute data is often called input data.
- Analyze attribute data: the attribute data are digitally processed to produce the desired information.
- Display results: the final display of a GIS session is typically a map with the desired information shown in colors or patterns.

Geographic features can be categorized into two types, the discrete and the continuous data. The discrete data are the distinct features that have a location and shape and



constitute spatially well defined features (e.g. rivers, lineaments, dykes and house). The discrete data are generally represented in the vector format. Continuous data are borderless and non-distinctive values that change gradually (e.g. pollution zone, temperature and rainfall zonation)

## 2.4 Satellite Gravity

The Radar altimeter measurements provided the scientific community with valuable information about the earth interior . From this, the sea-surface topography from radar altimeter data was used to calculate the vertical component of the gravity field. This significantly helped in improving the knowledge of the earth's tectonic , . Consequently, the gravity field measurements were moved from only calculating the marine gravity field from radar altimeter measurements to measuring the global gravity field using new satellite missions. This step led to improving the quality of the available data and also improving our understanding of the overall earth tectonic history ,e.g. . Satellite gravity is gravity field measurements that were available recently in the last decade. Recent satellite missions were launched like CHAMP in 2000, GRACE in 2002, and GOCE in 2009 to map the Earth's gravity field , . The global coverage and the consistent data quality are the most significant advantages of the satellite gravity data . 4.2.3. Satellite

# **CHAPTER THREE**

## Processing and Interpretation

### 3.1 Data preparing

The Ground gravity was measured using auto-gravimeter system for measuring the gravity in the area of study. 53 points have been measured by previous missions. These points are put in to an excel sheet then corrected all of them to get “Bouguer anomaly”. The satellite gravity prepared from satellite covering the area extended between (16-17 and 17-18). After that the data were filtered to over only the study area that is situated between longitudes: 33.45-34.75 and the latitudes: 16-17.75, then the correction was done to those points to obtain the Bouguer anomaly (Table 3.1) using the following equations:

$$BC=0.04193*2.67*elevation \quad (3-1)$$

$$BA=FAA-BC \quad (3-2)$$

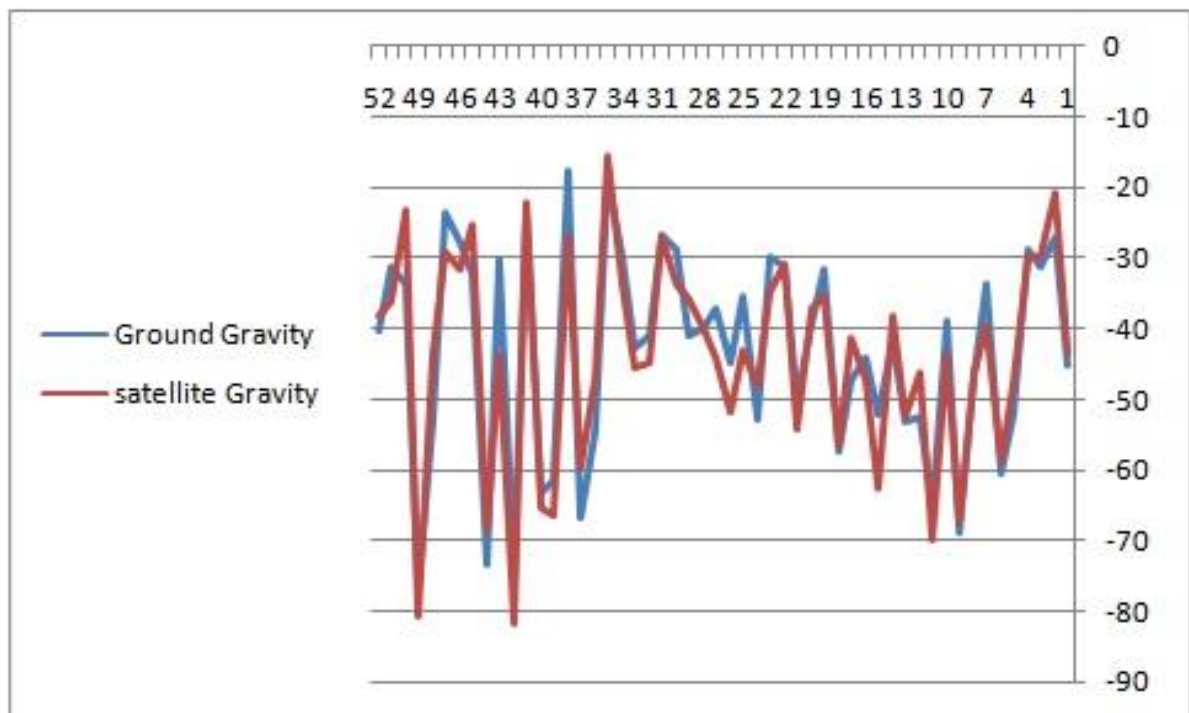
**Table 0.1 : Summary of the important data of gravity points in the study area.**

Long.	Lat.	FAA	elevation	BC	BA
33.4583	17.7349	1.9	447	50.04304	-48.143
33.475	17.7349	0.2	435	48.6996	-48.4996
33.4917	17.7349	-1.3	427	47.80397	-49.104
33.5083	17.7349	-2.5	425	47.58007	-50.0801
33.525	17.7349	-3.2	421	47.13226	-50.3323
33.5417	17.7349	-3.5	419	46.90835	-50.4083
33.5583	17.7349	-3.4	421	47.13226	-50.5323
33.575	17.7349	-3.1	423	47.35616	-50.4562
33.5917	17.7349	-2.7	417	46.68444	49.3844
33.6083	17.7349	-2.2	415	46.46054	-48.6605

### 3.2 Comparison between ground and satellite data

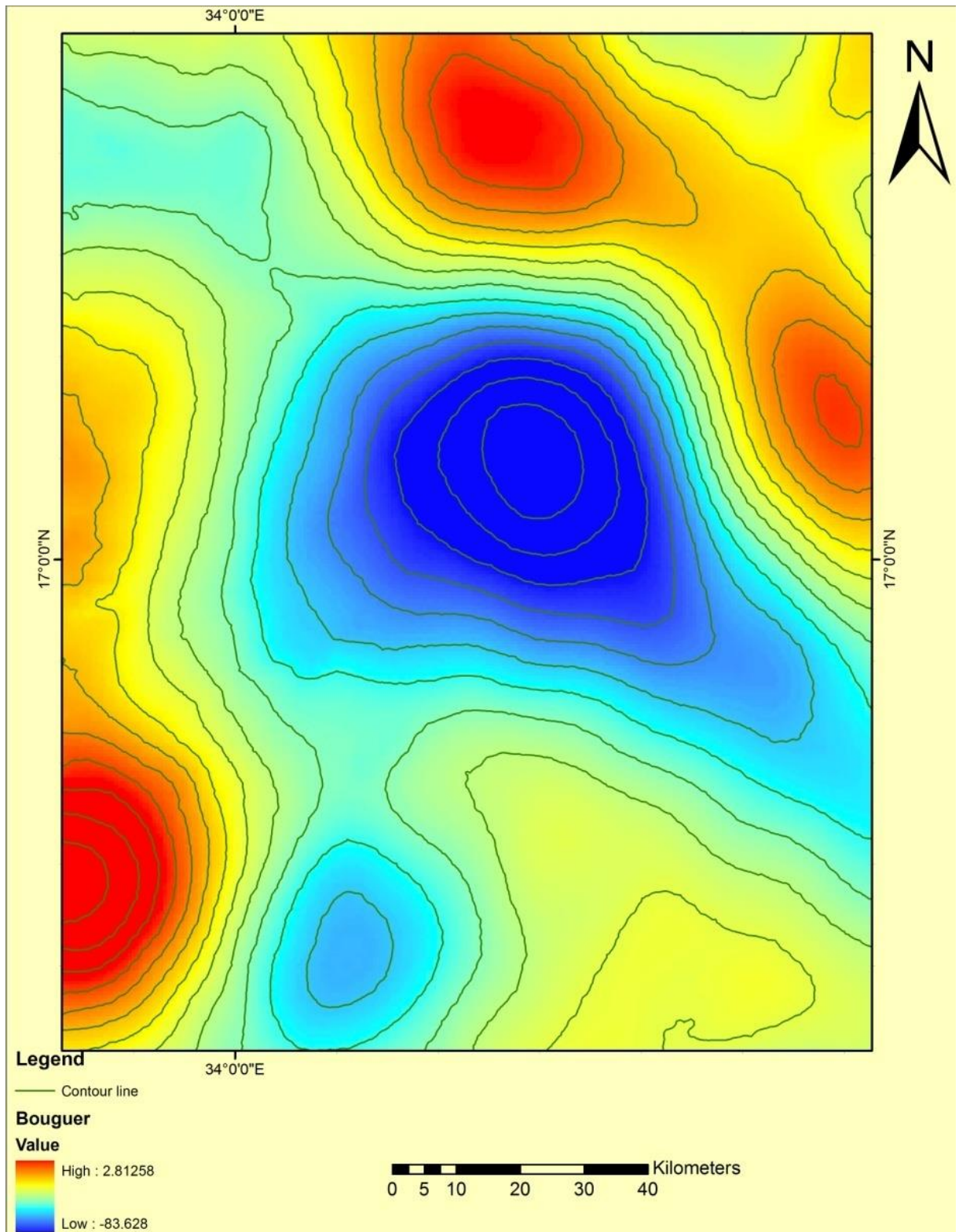
Bouguer anomaly for satellite and ground were exported to “ArcGIS” by using tool called “Export data” and converted into “shape file”, by selecting (X, Y) coordinate system to make comparison between them. The satellite gravity data were interpolated to create a surface covering the whole study area using a tool called "interpolation" by using mathematical equations. Interpolation gives a map, featured by colors – colors refer to the value of Bouguer anomaly. Whereas the red color represents the highest value of Bouguer anomaly, dark blue is the lowest value of Bouguer anomaly and the rest colors represent intervening values.

Then contour lines were generated to separate between low readings and high readings for Bouguer anomaly by using contour tool in the spatial analysis, after that we using tool called “spot” to pick BA from satellite data that corresponds to BA from ground measurements. From attributes of the shape file we are taking BA for ground and satellite together with (X,Y) coordinates. Then, the difference between the BA ground and BA satellite was calculated. Afterthen, statistical analysis for these differences was carried out and the results were presented in Figure (3.1).



**Fig 0.1 : shows the difference between satellite and ground data.**

The outcome of the comparison revealed that ground BA and the satellite BA are more or less similar and their values are approximately closer to each other. Therefore, based on this similarity the satellite gravity data will be used though the rest of the study. This is because the satellite data gives a good coverage, high resolution with relatively low cost. Accordingly, “Arc GIS” was used to input satellite BA and plotted the BA map and create contour lines (Fig. 3.2).



**Fig 0.2 : Bouguer anomaly of the study area , contour interval is 5mGal .**

Color ramp indicate to the value of Bouguer anomaly where the value of Bouguer is higher on red color region and the value gradually decrease until to be the lowest value on the dark blue color region. On this map, the lower values of anomalies appear in the center of the map. The regions that appear on dark blue color represent the sedimentary basin. The qualitative interpretation involves the description of the resulting anomaly of gravity data, and the explanation of the major features revealed by these data in terms of types of likely geological formations and structures.

The main feature of Bouguer anomalies may be summarized as follows:

The gravity gradient increases on the NE part and has a maximum value on the SW part. While the maximum anomaly gradient over the basement is fairly constant ( 2.4 – 2.7 mGal/km).

The map contains big anomalies and others small that indicate the difference on the depth and size of structures which caused the anomalies. The big anomalies indicate the deep structures which may be contact with the basement rocks and the small anomalies may found within the basin coverage.

Many faults were identified from the map Fig(3.2) as indicated by dense gradient belt of gravity anomaly, distortion zone of gravity anomaly contours and borderline of significant positive gravity anomaly and negative one. Some of the identified faults are main faults but some of them are just minor faults with limited effects. The main faults which separate the gravity high area trending NW to SE, the other faults are trending NS.

### **3.3 Regional- residual separation**

The problem of the regional and residual anomalies arises in all geophysical methods which are based on measurements of a potential field. Basically, the question is that of separating a potential field into possible component parts and of ascribing separate geological causes to these parts. The determination of a satisfactory regional is a geological as well as a geophysical problem defined the regional gravity anomaly as "the field that is too broad to suggest the object of exploration and it is generally assumed to be smooth and regular, suggesting characteristically the field due to a deep-seated disturbance". Adopted the following definition: "the regional is what you

take out to make what is left looks like the structures" defined it as "the regional field is the field that would be Produced when local anomalous masses are replaced by masses of the same density as that of the country rocks.

This definition will smooth out the regional field sufficiently and also will signify the residuals as the field due to local mass distributions with densities equal to density contrasts i.e. true densities minus the densities of the surroundings" defined the regional gravity as "the interpreter's concept of what the Bouguer gravity should be if the anomalies were not present" and the residual gravity as "what remains of Bouguer gravity after subtraction of a smooth regional effect". However, the residual can be expressed as follows:

$$\text{Residual gravity} = \text{Observed gravity} - \text{Regional gravity}$$

The Bouguer anomaly map has been divided into grid, by using tool called "fishnet" in the ArcGIS, each cell has the dimensions of 5x5 km. The Bouguer anomaly in centre of each cell has been taken using a tool called "spot". From attribute table the value of Bouguer anomaly which has been taken from the centre of the cell were converted into excel sheet contain three column, the first column represent longitude, the second column represent latitude and the third column represent Bouguer anomaly. To separate the residual from regional component the following equation was used:

$$\text{Reg}_{i,j} = \frac{(\text{obs } i,j-1) + (\text{obs } i,j+1) + (\text{obs } i-1,j) + (\text{obs } i+1,j)}{4 \times d} \quad (2-3)$$

Where:

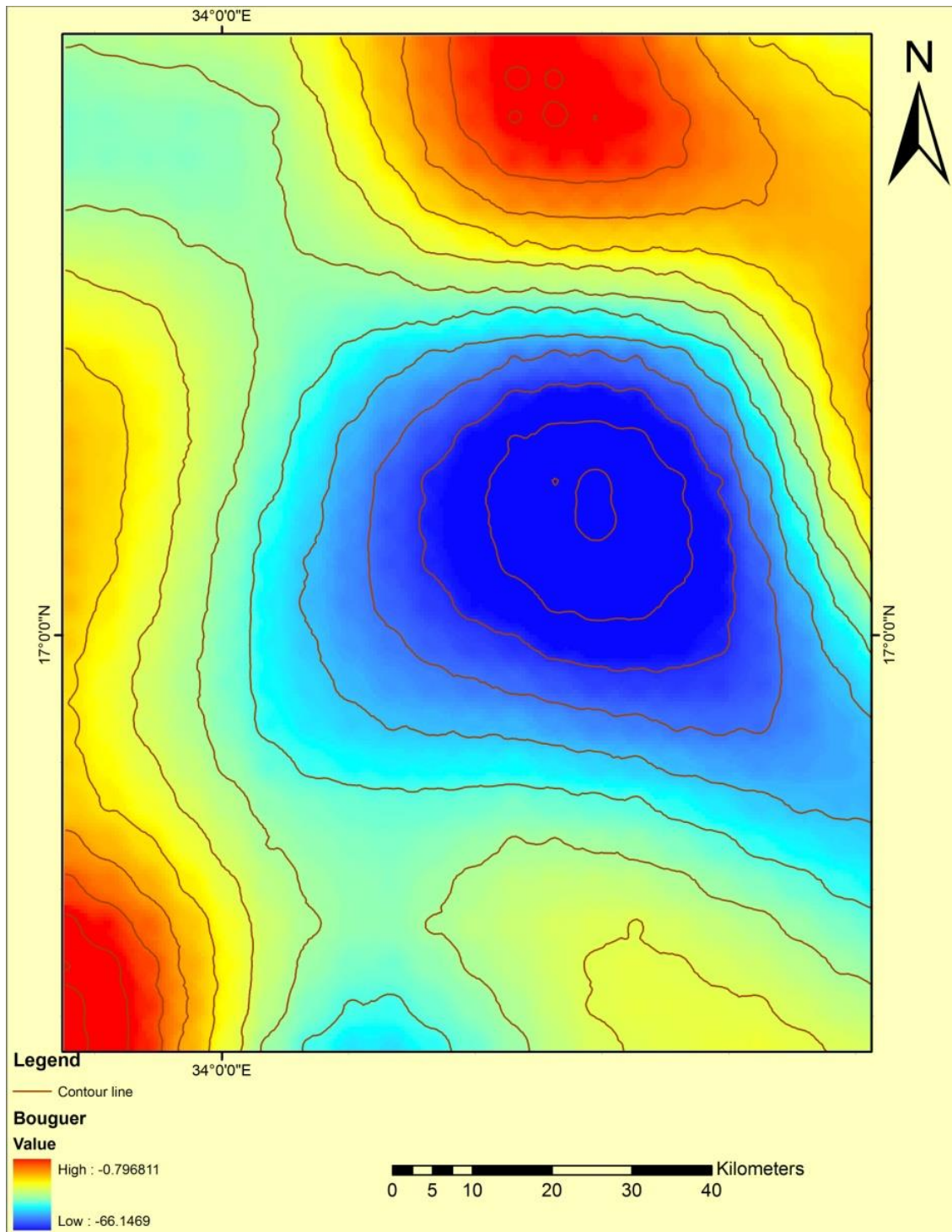
$i \equiv$  longitude.

$J \equiv$  latitude.

$d \equiv$  distance between readings lie in the centre of cells.

Residual Bouguer anomaly data were exported to "ArcGIS" to interpolate the values to obtain a surface, from which contour lines were generated, thus facilitating the production of the residual anomaly map of the gravity field presented in Figure (3.3).





**Fig 0.3 : map showing the residual Bouguer anomaly, contour interval is 5mGal.**

### 3.4 Second Vertical Derivative

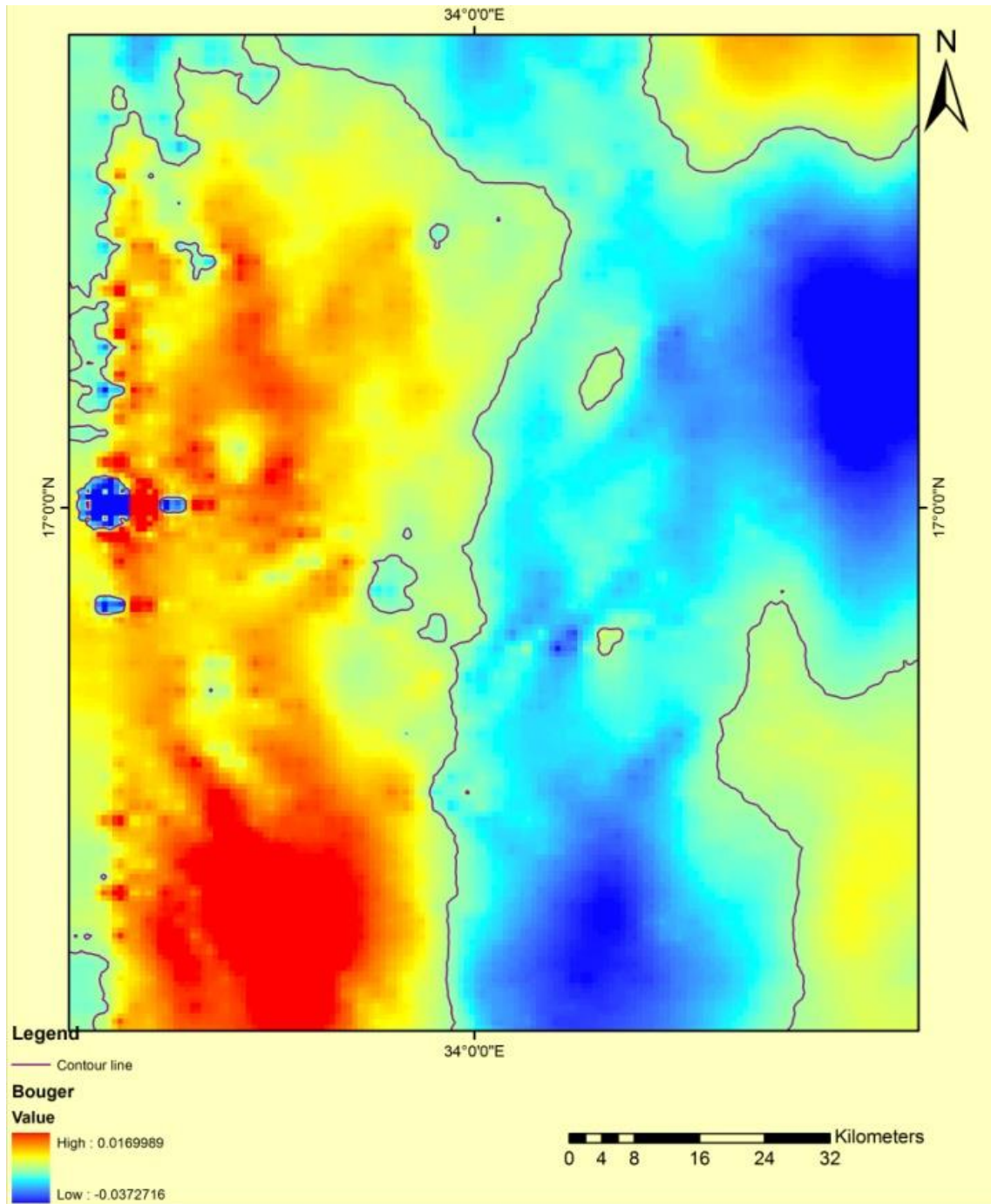
The Second Vertical Derivative technique was used as two dimensional filters for interpretation of potential field data (Henderson and Zietz, 1949; Elkins, 1951; Darby and Davies 1967; Zurfluch, 1967; Mesko, 1965; Dobrin, 1976 and Nettleton, 1976). This technique was developed by Elkins (1951). If we use the symbol ( $g$ ) to represent gravity a choose axes so that ( $z$ ) is vertical downward, then the second derivative is the quantity  $d^2g/dz^2$ .

The importance of the second derivative for potential field interpretation arises from the fact that the double differentiation with respect to depth tends to emphasize the smaller, shallower geological anomalies at the expense of larger, regional feature (Elkins, 1951).

The second derivative of a gravity field can be shown to be a measure of the curvature of the field. Considering a gravity profile, where the curvature of the line is greatest (radius least), the second derivative has its higher value. Where there is no curvature, (radius infinite), the second derivative is zero. If a shallow geological feature of limited lateral extent (like a salt dome) has a gravity anomaly with greater curvature than the regional field on which it is superimposed, the second derivative will be greater over the localized feature than over the part of the area where the gravity variations follows the regional trend. The second derivative accentuates shallow anomalies and suppresses deep seated effects. Points of inflections of the second derivatives, i.e. points where the second derivative value changes its sign, are geologically expressed as faults, since the gravity gradient undergoes its most rapid changes from one level to another in the vicinity of faulted areas (Ibrahim, 1993).

The main objective of applying the derivative in the research study is for the delineation of shallow faults. The derivative has a higher value at the greatest curvature (crest or trough) and has a zero value where there is no curvature i.e. at point of inflection; this phenomenon could geologically represented by the presence of a fault. Therefore, the importance of applying the second derivative technique in this research study is to help fault detection and delineation. The computation of the first and second vertical derivatives was conducted using Geosoft OasisMontag software. The results were imported in ArcGIS, interpolated and maps were prepared (Figs. 3.4 and 3.5).

Zero contours separate between the low and high value of Bouguer anomaly and indicate the fault region. Many normal faults have been delineated in the study area based on the interpretation of the vertical derivatives maps. The delineated faults are presented in Figure (3.6).



**Fig 0.4 : map showing first vertical derivative of the study area.**



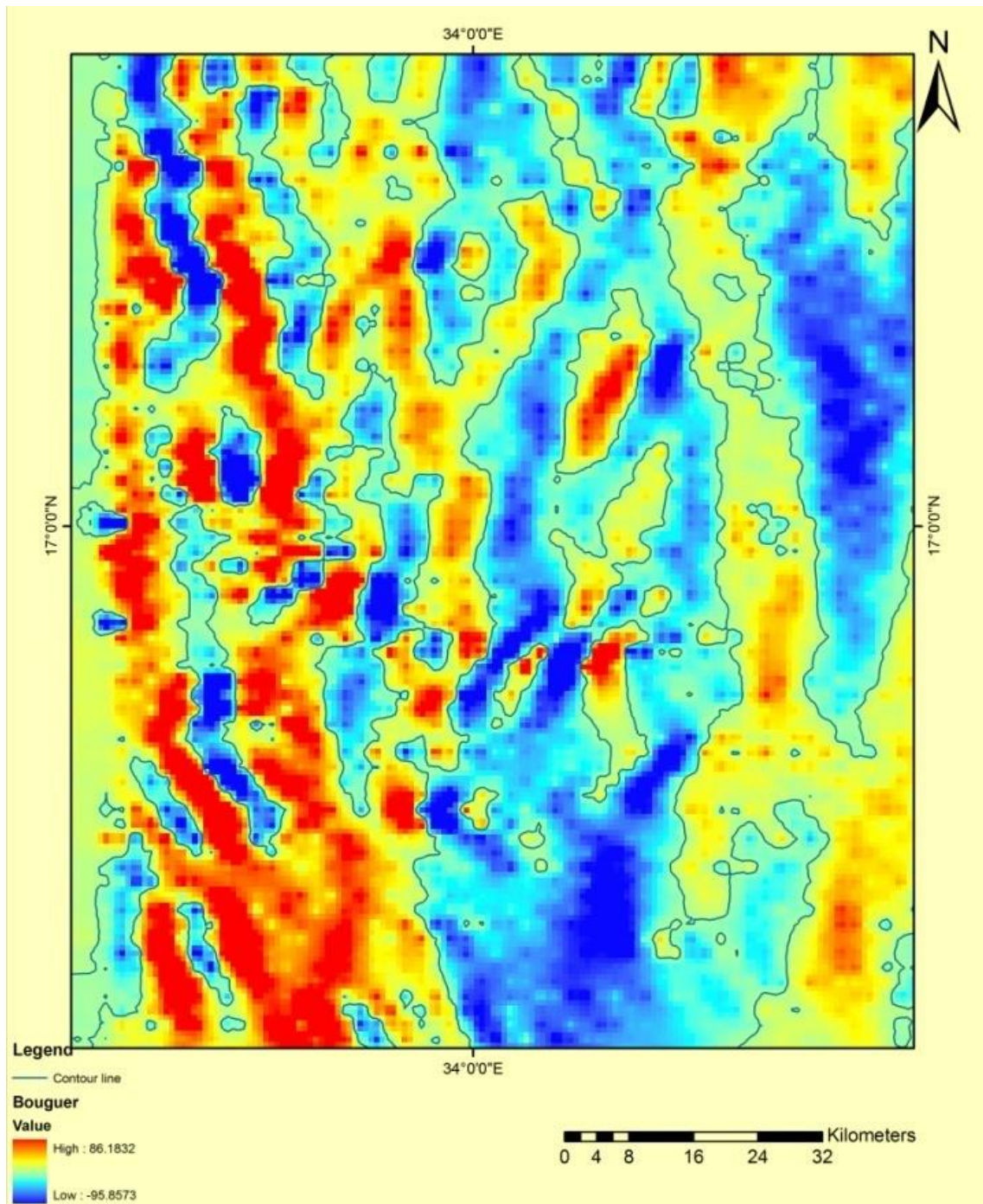
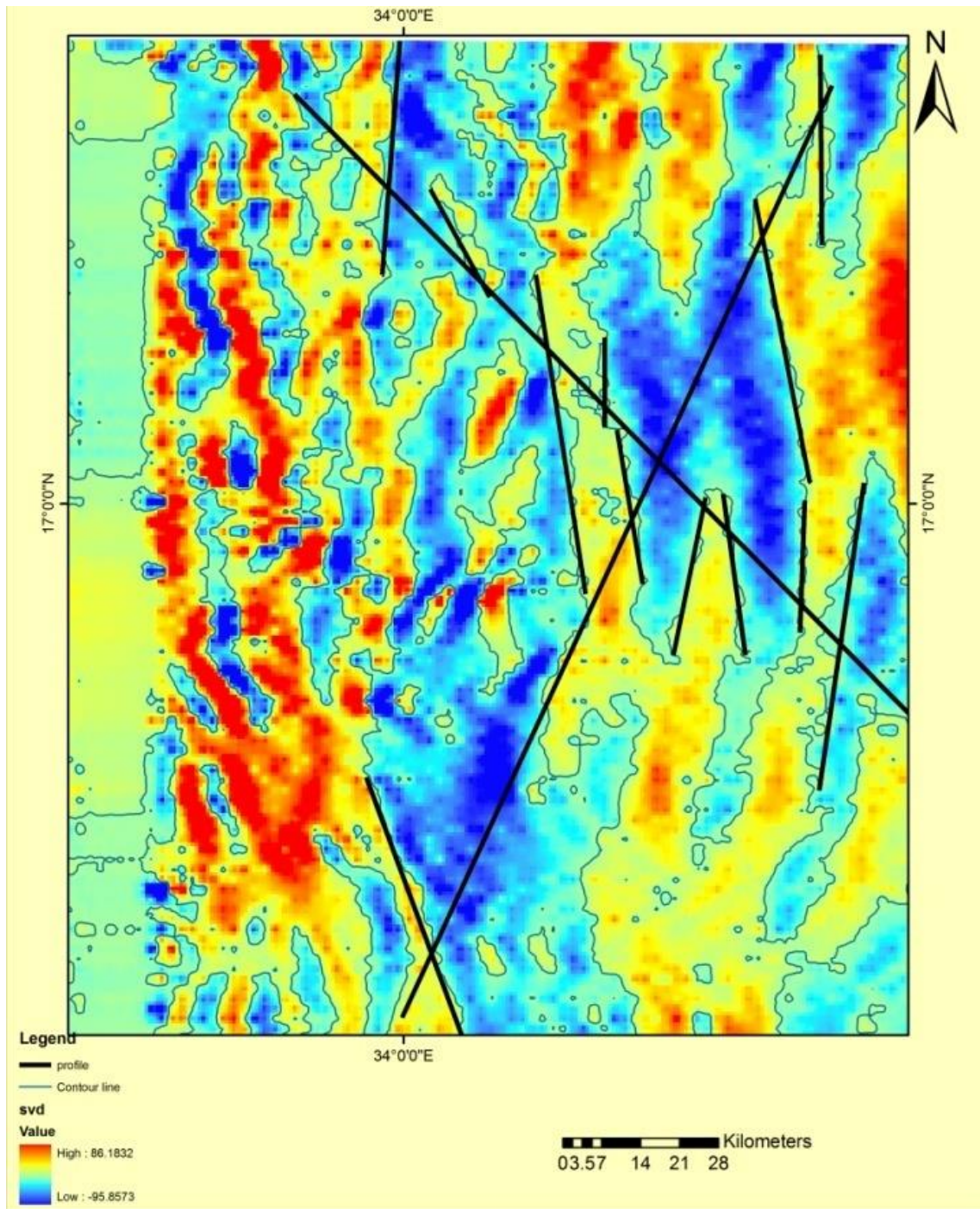


Fig 0.5 : map showing the second vertical derivative of the study area.



**Fig 0.6 : map showing allocation of faults delineated using vertical derivatives as indicated by the inflection points.**

### 3.5 Density Measurements

The interpreter of the gravity data is interested in determining the subsurface variations of mass and this process requires that the density of the material of interest or the density contrast between the surrounding materials be known. For this reason especial attention is paid to the densities and the density contrasts between different representative rock types in the surveyed area. Robertson Research International (1988) provided density measurements for all the sedimentary formations ( $2.4 \text{ g/cm}^3$ ) and the Basement rocks of the area ( $2.7 \text{ g/cm}^3$ ). So the density contrast is ( $-0.33 \text{ g/cm}^3$ ).

### 3.6 2.5D Gravity Modeling

Quantitative interpretation (non-linear method) calls for approximation of the geological bodies, which are considered to be the gravity source, by assuming simple geometric model from which the theoretical gravity effect can be compared with the observed gravity data and the shape of the body can be changed (modified) to minimize the difference between the observed and the computed gravity effects, often by interactive and/or iterative computer inversion methods (Kearey and Brooks, 1988).

The modeling technique calls for approximation of the geological feature considered being the source by assigning it a simple geometrical form for which the gravity field can be computed mathematically by specified dimension and various values can be assigned to the parameters describing the geometry of these bodies. The model is not truly 3D because it is assumed to be uniform in the third dimension, it is more than 2D. Hence the term '2.5D' modeling of the anomalies.

In this study gravity modeling was performed using GravModel program. Two profiles has been created in the study area Profile I is trending in NW-SE direction and Profile II is trending in the NE-SW direction.



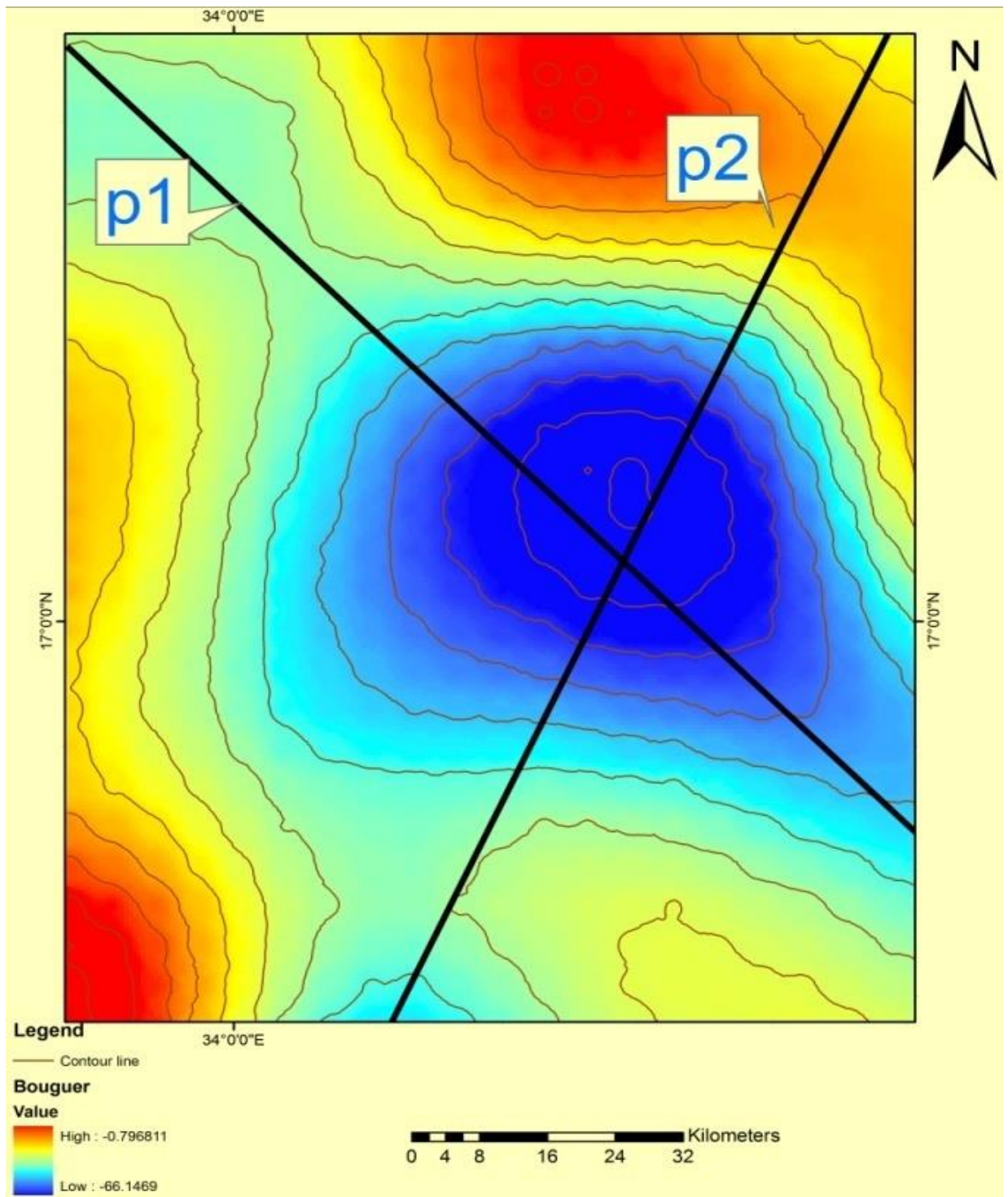
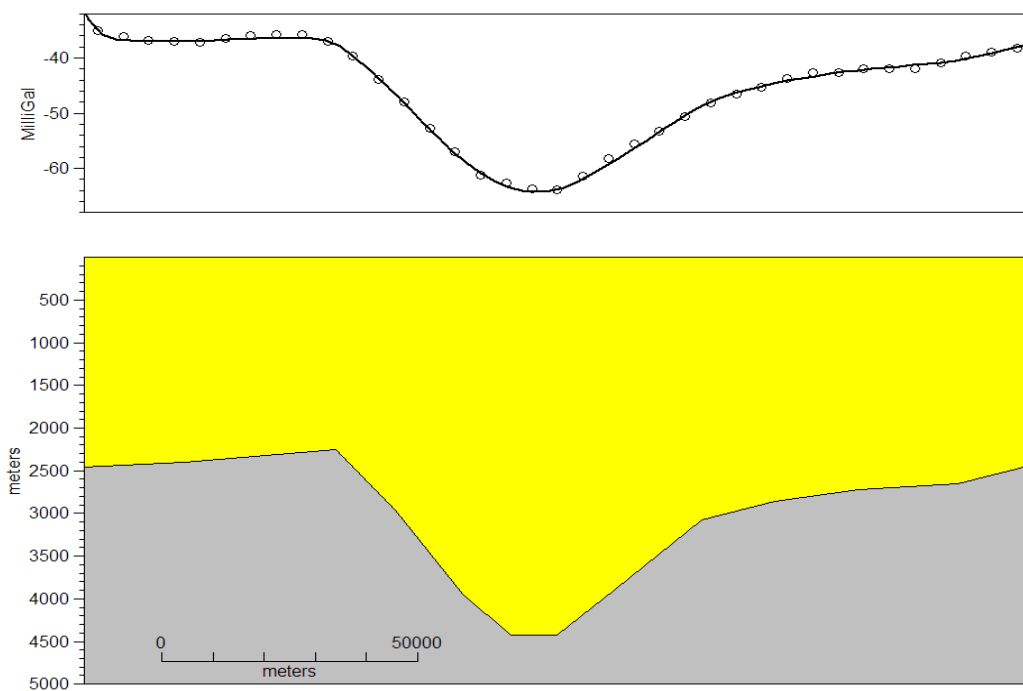


Fig 0.7 : A map showing residual Bouguer anomaly and location of profiles.

### Profile 1

The profile runs in NW-SE, passes across the basinal area and different anomalies area, its length is 170 km containing a number of 34 points, the distance between any point and the next is 5 km. The Gravity field along the profile is characterized by low gravity anomaly in the centre and high gravity anomaly in east and west of the profile. From the modeling of this profile defines two normal faults creating graben structure that delineated by the Residual anomaly as shown in Figure (3.8). The maximum depth shown in the model is about 4500 meters below the ground surface.

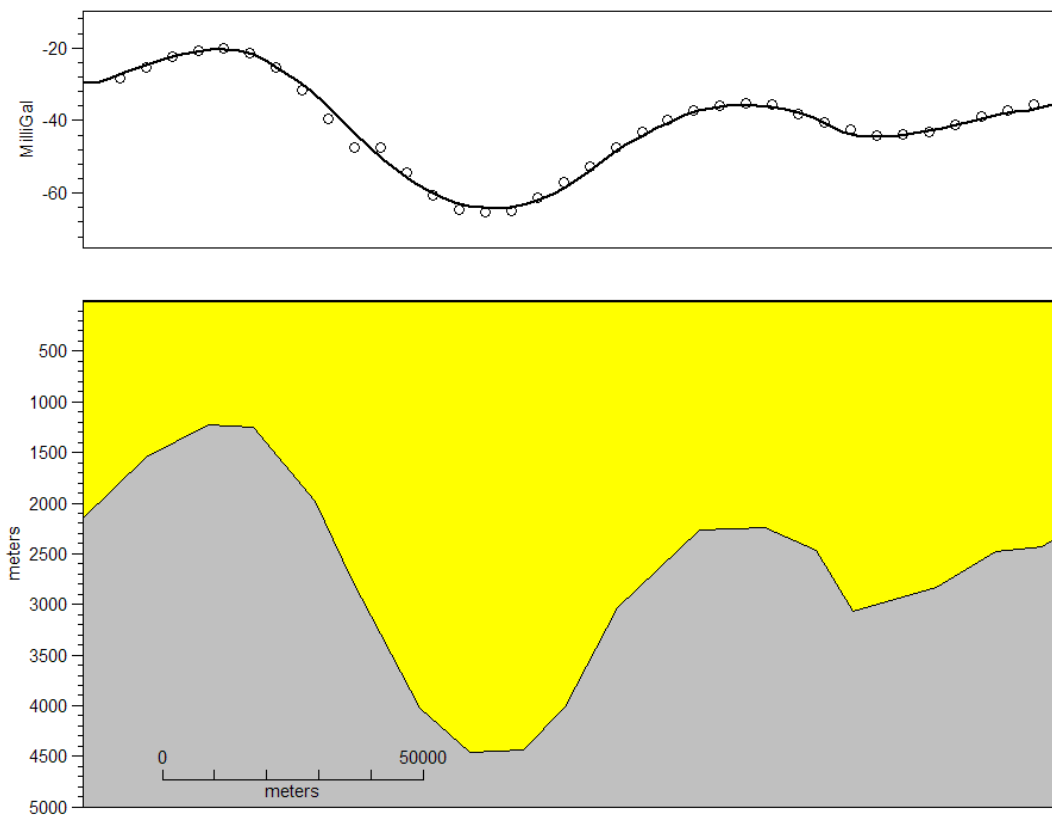


**Fig 0.8 : Geological model of profile I.**



## Profile 2

This profile runs in NE-SW, extending across basin and different anomalies area. Its length is 180 km, involving 36 gravity points. The Gravity field along the profile represent is characterized by high gravity anomaly in western portion of profile, low gravity anomaly in centre and flanked by two high different amplitudes in eastern part. The modeling of this profile defines 5 normal faults as shown in the modeling the shallow depth about 1300 meters and the maximum depth about 4500 meters below the ground surface (Fig. 3.9).



**Fig 0.9 :Geological model of Profile 2**

# **CHAPTER FOUR**

## Conclusion and Recommendation

### 4.1 Conclusion

Study area was carried out in the River Nile state in the North Central of Sudan . The geological settings of the study area are composed of Basement Complex (Pre-Cambrian), Nubian sandstone formation (upper Cretaceous), Hudi Chert (Oligocene) and superficial deposit (Quaternary) in ascending order.

Bogger anomaly for satellite and ground were exported to “ArcGis” to make comparison between them . The outcome of the comparison revealed that ground BA and the satellite BA are more or less similar and their values are approximately closer to each other. Therefore, based on this similarity the satellite gravity data will be used though the rest of the study. This is because the satellite data gives a good coverage, high resolution with relatively low cost.

The average method was used to separating regional from the residual component of the gravity field using mathematical equation .

different derivatives were computed from the Bouguer anomaly values of satellite. The Bouguer anomaly and the derived values were interpreted in terms of variations in lithological units which were constrained by the surface exposures where available.

density measurements for all the sedimentary formations ( $2.4 \text{ g/cm}^3$ ) and the Basement rocks of the area ( $2.7 \text{ g/cm}^3$ ). So the density contrast is ( $-0.33 \text{ g/cm}^3$ ).

For profiles I and II the residual anomaly for a presumed model constrained by the geology of the area is calculated. The residual gravity of this model is subtracted from the observed gravity to obtain the regional anomaly at the control points of the presumed body. A depth to basement is constructed from these models the maximum depth is about 4500 m. The first and second vertical derivatives and the first horizontal derivative were computed in order to study the presence of faults.

Normal fault is the dominant fault type. This intensive faulting can be attributed to the extension forces acting on the stretching crust of the area.

## **4.2 Recommendation**

The sedimentary rocks aren't homogeneous in their properties that required to utilizing other methods of geophysics surveying to make integrated and accurate image of basin, completed by seismic surveying, primary exploration drilling and other methods.

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