UPWARD CONTINUATION AND SPECTRAL ANALYSIS OF AEROMAGNETIC SIGNATURES OVER KALTUNGO AREA AND SURROUNDING CRETACEOUS SEDIMENTS, NORTHEASTERN NIGERIA

The methods of Upward Continuation and Statistical Spectral Depth Analysis were applied on Aeromagnetic data over Kaltungo Area in the Upper Benue Trough, Nigeria and the results are presented in this study. The area is bounded by Latitude 9°00'N to 10°00'N and Longitude 11°00'E to 12°00'E with an area cover of about 12,100 km^2. The Oasis Montaj software was used to isolate the residual field components from the total magnetic field and also to analyse the field at different upward continuation levels. A Slope Plot Program extract from MATLAB was used in determining the spectral depths to recorded magnetic sources in the subsurface while Surfer 8 was used to contour the resultant maps. The TMI/residual magnetic anomalies were found have a dominant SW-NE trend with magnetic high concentrating and stretching along a prominent SW-NE trending- Kaltungo fracture zone flanked on either side by moderately low-low magnetic anomalies. The depth to the shallow magnetic layer ranges from 0.60 to about 1.00 km while that of the deeper source ranges from 2.25 to 3.25 km. The first magnetic layer is attributed to magmatic intrusives which occurred at shallower depths both in the basement inlier and the sedimentary cover. The second magnetic layer is believed to originate from the basement. Since the depth to the basement is an alternative measure of the thickness of the sediments overlying it, it shows that the sedimentary cover in the area is generally thin. The area is unlikely to favour economic concentration of oil and gas due to its limited thickness and size of sediments and secondly due to the Tertiary-Quaternary magmatism in the basin but, may be worthwhile for prospecting some magnetic ore minerals. However, more data are needed for interpretation in order to actually unravel the economic potential of this area.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

The aeromagnetic method of geophysical prospecting plays a distinguished role when compared with other geophysical methods due to its rapid rate of coverage and low cost per unit area explored. The main purpose of magnetic survey is to detect rocks or minerals possessing unusual magnetic properties that reveal themselves by causing disturbances or anomalies in the intensity of the Earth's magnetic field. This research work focuses on the analysis of aeromagnetic data/maps over the Kaltungo area and the surrounding sedimentary formations in the Upper Benue Trough, North-eastern Nigeria. The Kaltungo area is occupied by older rock units (basement rocks) and surrounded by younger sedimentary formations. The basement includes mainly rocks of the ''Older Granites'' series (Carter, Barber and Tait, 1963) emplaced during the Pan-African orogenesis, around 600±70 Ma (Van Breeman, Pidgeon and Bowden, 1977; Tubosun, 1983). The sedimentary series which includes the marine facies exemplified by shale and limestone, and continental series marked by sandstone, mudstone, etc were Cretaceous-Tertiary (146-24 Ma) in age (Whiteman, 1982; Benkhelil and Robineau, 1983). The method employed in this study was the integrated approach where the analysis of the aeromagnetic maps was done with the knowledge of geologic information available from the area. This enables depict accurately the nature, shape and orientations of the anomalies.

The usual problem in magnetic interpretation is the fact that not all the elements of the rock unit are attractive or magnetic unlike in gravity where every element of the rock mass shows or responds to gravitational attraction (Telford, Geldart, Sheriff and Keys, 1976). Besides, the amplitude, direction and sense of the geomagnetic field vary with time and magnetisation direction of rocks is usually complex and difficult to infer while in gravity, the direction of gravitational attraction of all masses is one and everywhere vertical or directed towards the centre of mass of the body in question or towards the centre of the Earth (Kearey and Brooks, 1990). Consequently, the interpretation of magnetic anomalies seems to be more cumbersome than gravity and therefore requires more skills, care and experience than the latter.

The interpretation methods employed in this study are firstly qualitative which focuses on the description of the magnetic anomalies in terms of nature/shape, trends, relief, closures, amplitudes, etc as they occur within the subsurface and lastly quantitative analysis which involves spectral depth determination to get information about depth of the magnetic source rocks. The results from these analyses will find useful applications in many areas, for instance, in the oil industry where the thickness of the sediments within this basin can be estimated from the knowledge of the depth to the magnetic basement. In mineral exploration, structures which control mineralisation such as intrusive bodies, faults, intrusions, folds, etc can be traced out. Finally the lithologic boundaries within the study area are delineated to give a better picture of the geology of the area

1.2 Statement of the Problem

The search for mineral deposits and hydrocarbon (oil and gas) has been a major business challenge in Nigeria since the colonial times and following the discovery of commercial quantity of oil in the 1960s. The bedrock of Nigeria’s economy has been the solid mineral and currently the lucrative oil sector; attention being diverted from the former to the latter because of its high profitability. More than 80 percent of the country’s revenue comes from export and domestic sales of the oil and gas on which the over 140 million growing population depends. As the hydrocarbon potential of the prolific Niger delta becomes depleted, attention needs to be shifted to other sedimentary basins. The Upper Benue Trough in particular, which the study area is a part of, is one of those basins being suspected to have hydrocarbon potential, besides economic mineral deposits.

Therefore, determining the depth to the source of recorded magnetic anomalies is generally equivalent to determining the thickness of the sedimentary section. Since oil occurs only in sedimentary rocks, a reliable determination of the depth to the basement rocks gives a measure of the volume of sediments available in a given sedimentary basin and is a first limitation on its potential as source of oil (Nettleton, 1976). With modern magnetic surveys of high precision and close control, magnetic measurements can be complementary to seismic data in the interpretation of a body of geophysical data in a given area. This is essentially true in complex areas in relatively deep basins, where reflection seismic surveys are subject to alternative interpretations. With a complex pattern, reflections from the basement may be difficult to recognise, and a basement profile from a careful interpretation of magnetic data may be very helpful in identifying a basement reflection.

1.3 Justification of the Study

The petroleum potential of the Upper Benue Trough has been of great interest to geologists and geophysicists in recent times. The Nigerian government through the Nigerian National Petroleum Corporation (NNPC) and many oil companies has invested heavily in this part of the Benue Trough prospecting for oil which remains elusive up to today. SNEPCO, Chevron, Elf have each drilled one borehole which were latter abandoned as dry holes (Nkem, 2002). But SNEPCO’s well, Kolmani-1, was suspended and capped, which was an indication that the company found oil and gas. However, efforts are still on and more money is still being sunk into the area with the hope of finding oil in the near future.

It is believed that this research work on a reconnaissance basis over this area could yield useful information for further assessment of the hydrocarbon potential and economic minerals in the basin. If the information is gainful, huge investment plans can be proposed.

1.4 Aim and Objectives

The main aim of this study is to use the methods of upward continuation and spectral analysis of aeromagnetic fields over the area to differentiate and characterise regions of sedimentary thickening from those of uplifted or shallow basement within the area of study. The results could be used to suggest whether or not the study area has the potential for oil/gas and mineral deposits concentration. The study objectives include:

1. To identify and delineate areas of low/and or high magnetic anomalies within the study area.
2. To delineate the various lithologic boundaries in the area as revealed by the magnetic anomalies.
3. To determine the thickness of the sedimentary formations and the depth to the magnetic Basement

4. To map out the positions and depths of the intrusive rock bodies that characterise the area.

1.5 Location, Extent and Accessibility of the Study Area

The area is bounded by latitudes 9° 00' N to 10° 00' N and longitudes 11° 00' E to 12° 00' E located within the Upper Benue Trough in Gombe/ Adamawa and part of Taraba States, North-eastern Nigeria (Figure 1.1) and covered by four aeromagnetic maps of Kaltungo, Guyuk, Lau and Dong respectively. Each map is 55 km x 55 km giving the total area covered approximately equal to 12,100 km^2. Accessibility in the Upper Benue Trough is difficult and some parts are inaccessible (Jarawa hills, Muri area), particularly during the rainy season.

1.6 Principles of Aeromagnetic Surveying/Field Operations

The vast majority of aeromagnetic surveys are carried out in the air using aircrafts. There are usually two types of aircraft used: the fixed –wing aircraft used for high altitude investigations whereas the rotary-wing aircraft for low altitude.

In aeromagnetic survey, the sensor (magnetometer) is usually quartered in a compartment known as a 'bird' to remove the instrument from the magnetic effects of the aircraft. In the fixed-wing aircraft on the other hand, the sensor can be towed behind the aircraft in an arrangement referred to as a 'stinger'. In this case, inboard coil installations compensate for the aircraft's magnetic field. Aeromagnetic surveys are carried out along specific flight lines at a given interval and spacing depends on the objective of the survey. Since it is not possible to establish base station readings in aeromagnetic surveying, flight lines are usually arranged in a grid-network to allow for diurnal correction using cross-correlation analysis. The flight pattern usually consists of a series of primary flight lines at a fixed spacing, which, ideally, should be about one-half the depth from the height of the airplane to the basement but usually is not changed within a given survey even when it is known that large variations in basement depth may be found. These main flight lines are tied by cross lines at greater distances. Common dimensions of the rectangles formed by the flight lines and tie lines are 1 by 6 miles, 2 by 6 km, 2 by 10 miles (Nettleton, 1976). Aeromagnetic surveying is rapid and cost-effective, typically costing some 40 % less per line kilometre than ground survey (Telford *et al.,* 1976). Vast areas can be surveyed rapidly without the cost of sending a field party into the area and data can be obtained from areas inaccessible to ground survey. The most difficult problem in airborne surveys is position fixing, where available, electronic positioning systems are employed. Without these, it is necessary to use aerial photography. Terrain photographs are taken simultaneously with the magnetic readings so that the location can be subsequently determined by reference to the topographic maps.

1.6.1 Flight-Line Orientation

The principle is that, more closely spaced lines should be oriented roughly perpendicular to the expected geological strike or tectonic trends of the area. These may not be accurately known in advance of planning the survey, but usually they can be determined roughly from regional geologic or tectonic maps. This alignment means that magnetic features of geologic origin are crossed to the best advantage, so that the azimuth corrections, which are part of the basement-depth calculations, are smaller and determined more accurately. When the angle between anomaly trend and flight line becomes less than 60°, the interpretation deteriorates seriously (Nettleton, 1976). In low magnetic latitudes where a simple source produces a complex anomaly with a low on the north side, it may be preferable to fly approximately north-south no matter what the geologic strike because the magnetic character is better determined (Nettleton, 1976). A magnetic east-west line between maximum and the minimum would not reveal the essential nature of the anomaly. Aeromagnetic surveying is employed in mineral and oil prospecting as a reconnaissance tool.

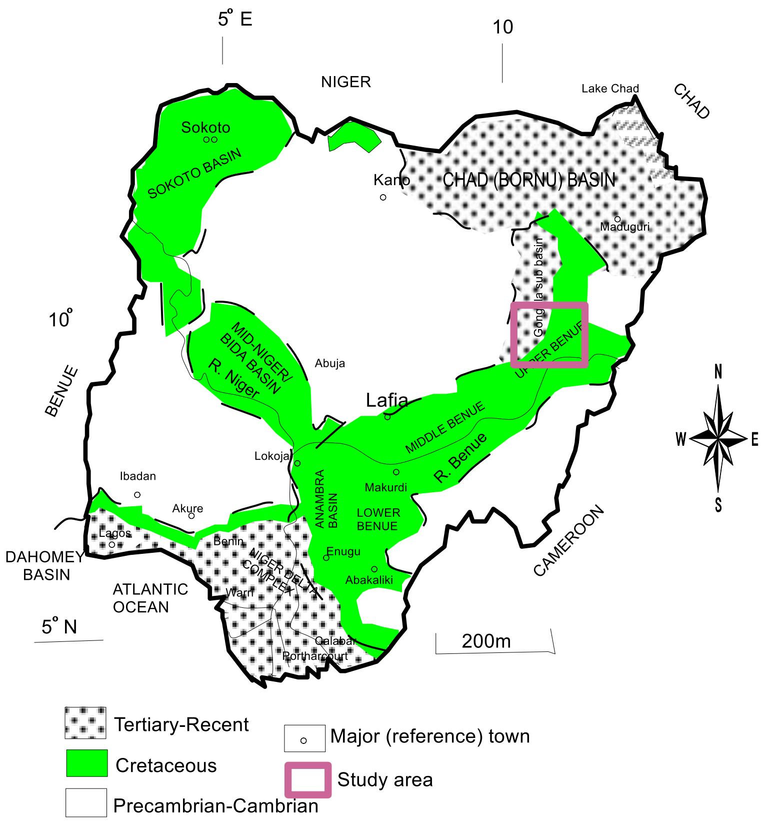


Figure 1.1: Location of the Study Area on the Geological map of Nigeria (Modified after Obaje, 2009)

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Geology of Upper Benue Trough/Study Area

The Benue Trough corresponds to a sedimentary basin which extends for more than 800 km in a NE direction from the Niger delta to the surroundings of the Chad Lake (Figure 2.1). The basin is sub-divided into three units: Lower, Middle and Upper and this has been adopted and used for a long time by many authors, both of geographical and geological orders. The term Upper Benue, is applied to the Cretaceous and Tertiary sedimentary basin which splits into two branches nearly perpendicular: the Yola branch trending E-W and the N-S trending Gongola branch (Figure 2.1). The drainage of this region is realised partly by the Benue river which takes its source eastwards in the Cameroons and for the other part by its main affluent the Gongola river which rises from the Jos Plateau. Regional faults and fracture zones such as the Romanche, Chain and Charcot appear to cut across the Benue Trough (Ajakaiye, Hall, Ashiekaa and Udensi, 1991). The Chain and Romanche in particular pass through the Upper Benue Trough where the study area lies (Figure 2.1). The climate of this region is typically tropical, with a long dry season (6 to 9 months), (Benkhelil, 1986). Vegetation is Savannah grading to desert conditions towards the Chad Lake. The boundary between Middle and Upper Benue is located around 9°N parallel and corresponds to a change in rock lithology resulting in different landscapes.

In the Upper Benue, the Precambrian basement rocks crop out in the Kaltungo area which constitutes an inlier within the Cretaceous sediments. Due to the structural position of this inlier and its important role in the Mesozoic tectonics of the Benue Trough, a more detailed description is necessary and is available in the recent work of Maurin, Benkheli and Robineau (1986). The Older Granites constitute the bulk of the Kaltungo Inlier. The various petrographical types and the chronology of emplacement are the following from the oldest to the youngest: oriented biotite granite, biotite and hornblende porphyroid granite, biotite and muscovite equiangular granite and alkaline granites with sodic hornblende and arfvedsonite. The structural trends within this basement inlier range between N40E and N70E and are dominated by a prominent N50E mylonitic zone about 300 m wide cutting across the massif.

2.1.1 Palaeogeographic Evolution of the Benue Trough/ Upper Benue Basin

The palaeogeographic evolution of the Benue Trough was directly controlled by the South Atlantic opening during the Early Cretaceous, and then was influenced by the Late Cretaceous transgressions. The separation of the African and South American continental blocks occurred from the south as early as the *Berriaisian* (Kogbe, 1976). The first marine influences reached the Gulf of Guinea during the Albian but no communication was established with waters of the North Atlantic. The transgression invaded the Benue Trough for the first time during the Albian and from there; its sedimentary history has been recorded for about 50 Ma. The oldest deposits in the Upper Benue Trough are located at the base of the Bima sandstone and dated Upper Aptian (Allix, 1983). These thick sedimentary deposits being infilling of grabens are isolated attesting the apparition of much localised subsidence zones. The region situated at the transition between the Middle and Upper Benue Trough is marked by a marine sedimentation in a shallow environment (Kumberi Formation). After the deposition of the continental Bima series, the northeast was subjected to transgression from the South Atlantic and the Tethys across the Sahara (Reyment, 1965; 1980). Two main domains are the Gombe and Dadiya-Lau areas, where the deposits display facies and thickness differences are individualised (Grant, 1965, Jones, 1960; Allix, 1983).

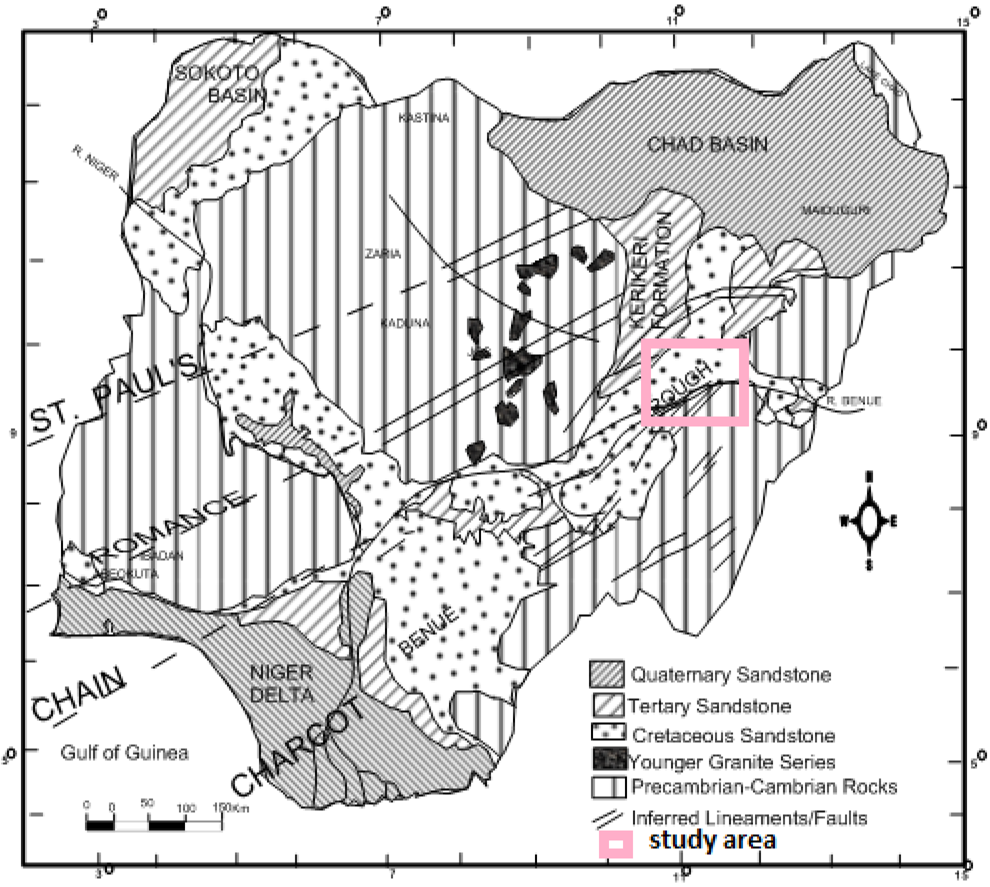


Figure 2.1: Location of the Benue Trough and Regional Faults/ Fracture zones cutting across the Study area (Modified after Ajakaiye *et al.*, 1991)

This transgression determines a shallow-water environment which is widespread during the Lower Turonian with the deposition of Dukul, Gongila and Pindiga Formations. The maximal extension was reached during the Upper Turonian with the deposition of Jessu Formation. In the Gombe basin, Turonian transgression deposited the shale/limestone sequence of the Pindiga of which lower part corresponds to an environment of carbonate platform. During this period, the waters of the Atlantic and Tethys were still in communication across the Sahara, the Niger basin and the Gongola branch (Barber and Jones, 1960). In the Dadiya-Lau basin, the regression started the deposition of the Numanha and Sekule Formations (Enu, 1978; Allix, 1983) of which facies traduced shallow basin conditions with a deltaic tendency. The Gombe and Gongola branch are still under the marine conditions with, however, a clear tendency to regression (Upper part of Pindiga and Fika Formations). These formations contain gypsum indicating hypersaline conditions related to the beginning of regression.

2.1.2 Lithostratigraphy of the Upper Benue Trough and the Study Area

The Cretaceous sedimentary basin of the Upper Benue Trough is centred on the regions of Muri, Lamurde and Kaltungo (Benkhelil, 1982[a]). It is divided into two branches trending N-S and E-W, respectively named Gongola branch and Yola branch. The Yola branch, constituted by sediments of Cretaceous age, forms a narrow band of terrains which stretches eastward to split into small isolated basins in the Cameroons (Cratchley and Jones, 1965). The Gongola branch includes Cretaceous sediments bordered to the west by Tertiary sediments, the whole being concealed by the Quaternary deposits of the Chad Lake basin (Matheis, 1976). The Cretaceous sedimentary cycle is characterised by the deposition of a continental series in which is intercalated a short marine episode (Adegoke, Agumanu, Benkhelil and Ajayi, 1986). A generalised stratigraphic succession in the Benue Trough/Upper Benue Trough/study area is presented in (Figure 2.3) below.

2.1.3 The Kaltungo Fault

The Kaltungo Inlier appears as a basement inlier within a Cretaceous sedimentary basin. Towards the NE, there is a basement horst (Gwol-Gubrunde) limited by a NE-SW trending fault which is in the straight line of the Kaltungo Inlier. A major fault cutting across the Kaltungo Inlier has been observed in the field (Benkhelil, 1982[b]) and mapped in detail (Popoff, Benkhelil, Simon and Motte, 1983) using Landsat and SLAR imageries and field data. The Kaltungo basement consists of two blocks of unequal importance apparently offset in a sinistral manner by a NE-SW trending zone. The Kaltungo Fault, a major feature in the structural evolution of the basin, is a Late Pan-African fault reactivated as a sinistral wrench fault in the Upper Aptian-Lower Albian times and responsible with other similar faults for the formation of sub-basins. The so-called Kaltungo fault is a 1 km wide zone constituted by an anastomosed set of shears of two types: the ductile shears and the cataclasites/breccias.

2.1.3.1 The Mylonites

The ductile shears form a set of mylonitic bands 1 to 5 m wide with a N45E to N50E direction, a N170E trend being recorded too. Only the orthogneiss are affected by the mylonites while in the biotite porphyroid granites only thin bands of protomylonites form a conjugated set with trends ranging from N160E to N180E and from N50E to N70E. A mylonitic band is characterised by a strong orientation whose appearance from the undeformed rock is marked by a progressive reduction of grain size and stretching of the feldspar phenocrysts.

2.1.3.2 The Cataclasites and Breccias

Mylonites are not the single characteristic structures of the Kaltungo Fault. They are cut by bands of cataclasites and tectonic breccias. These structures are stretched along the N50E main trend of the Kaltungo Fault. The cataclasites look like to microbreccias and are formed by angular clasts within a dark and fine matrix. The fault breccias form irregular and heterogeneous accumulations within the Kaltungo Fault zone. The angular clasts, whose size varies from 1 to 10 cm, are constituted by fault rocks (mylonites and cataclasites) and by the orthogneiss which form the country rock.

2.1.4 Economic Geology of the Upper Benue Trough/the Study Area

Deposits of limestone, brick and fire clay, construction stones, laterite and coal, all of economic importance are already known and some are being worked, while others are being investigated and new ones sought (Ford, 1981). Significant occurrences of base-metal sulphides (lead, zinc, with small amount of copper), cadmium and silver, and the associated minerals- barytes and fluorspar are known to occur locally in spatial, and probably genetic, in relation to salt water springs. The possibilities for oil and natural gas are further worth investigation, as is the potential for radioactive minerals within the basin.

Outcrops of volcanic are widespread in the in the Upper Benue Trough, and geophysical (magnetic) data indicate the presence of many more sub-surface igneous masses. These rocks are the main-indeed within the trough almost the only –source of hard rock for stone aggregates. The surface exposures are also widely lateritised, giving a useful source of road-making and building materials. Associated with the escape of magma, and outliving this activity, has been the rising of (juvenile) mineralising waters and volatile materials, leading to the deposition of certain minerals, including sulphides, sulphates, carbonates, fluorides variously of iron, calcium, magnesium, barium and base metals, lead, zinc and copper with associated elements cadmium and silver.

Sulphides of zinc and lead, locally associated with smaller quantities of copper, occur in lodes and veins infilling open fractures in the sedimentary formations. The strike of these mineralised fractures is generally N-S or NW-SE. They vary from a few centimetres to 2 km in length and from a few centimetres to 7 m in width. In all cases, the lodes are steeply dipping and the greatest vertical range proved so far is more than 150 m. Gangue minerals include siderite, pyrite, marcasite (probably secondary after solution and alteration of sphalerite), quartz and barytes, with other secondary minerals, sulphates, carbonates, and oxides in oxidised zone. Occurrences of radioactive minerals are associated with granites, and related rocks of Jos Plateau area, and radioactivity is also scattered more widely in the Basement rocks. The best known is monazite, containing thorium, a resistant mineral which is concentrated in sands of rivers and streams draining into the trough. Since this mineral is only intermittently payable when recovered as a by-product with cassiterite it is very unlikely to be of economic interest in sediments of the Benue Valley.

2.2 Review of Geophysical Work in the Upper Benue Trough/Study Area

Benkhelil, Conodera, Dainelli, Ponsard and Saugy (1985) through the analysis of aeromagnetic anomalies over the Upper Benue Trough were able to differentiate the areas of sedimentary thickenings from areas of shallow basement and localise the volcanic intrusions which affected the trough. Their analyses led to the observations: that the contours of the magnetic basement are in good conformity with the geological boundaries of the basement; and the volcanic bodies are mainly oriented in the SW-NE, SSW-NNE and NW-SE directions forming concentrations localised on the eastern border of the Gongola branch and around the Kaltungo Inlier.

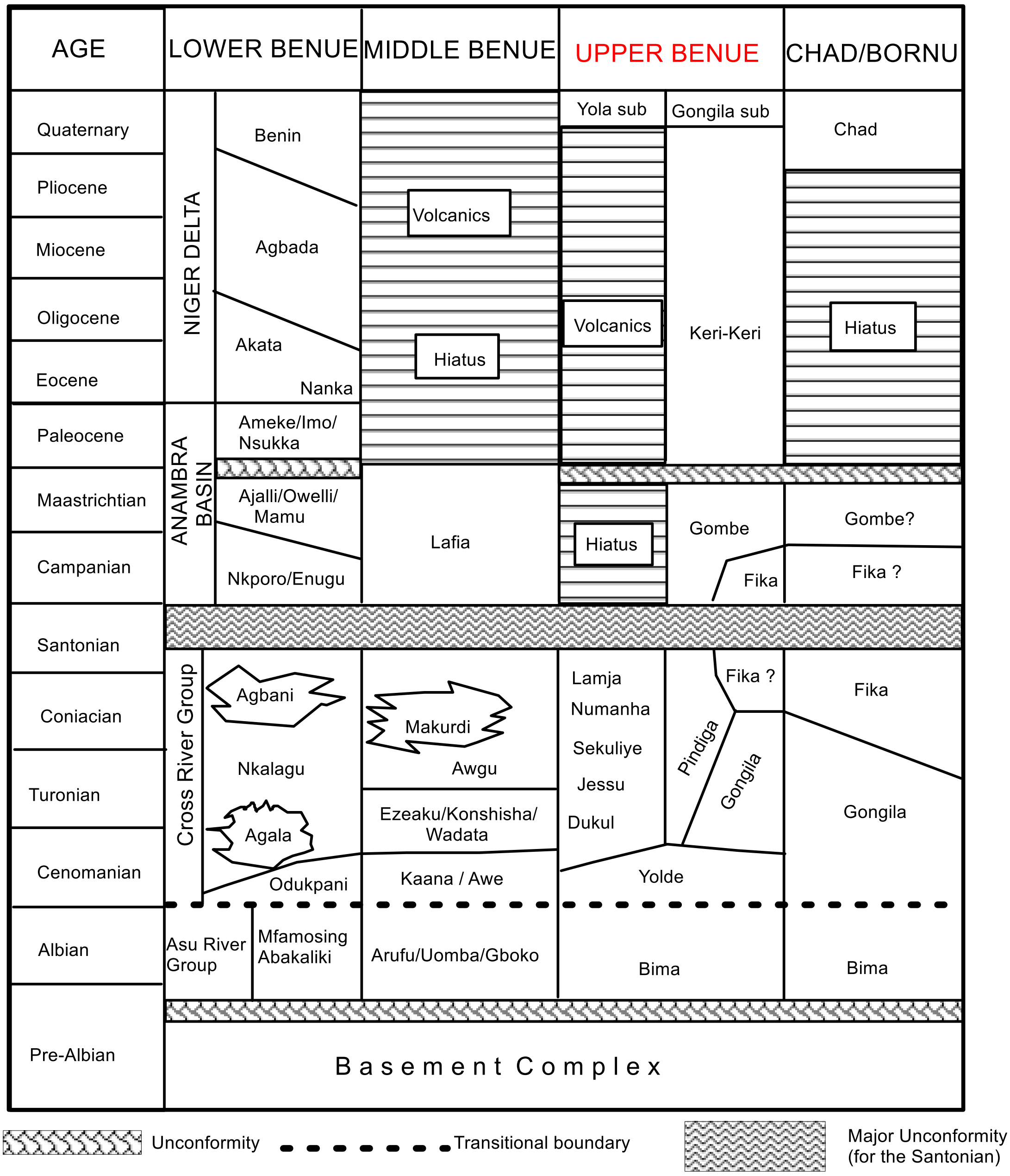


Figure 2.2: **Stratigraphic successions in the Benue Trough/ Upper Benue Trough/Study Area** (After Obaje, 2009)

The thickness of the sedimentary cover was estimated from the computation of about 700 unit depth boundaries of the magnetic basement (half slope method in the case of a horizontal regional).The depth estimation of the magnetic basement shows a distribution of sedimentary basins along the flanks of the basin separated by an ‘’axial’’ zone characterised by an uplift of magnetic basement which does not exceed a depth of 1000 m. In this zone, Ofoegbu (1984) imputes the magnetic anomalies to basic intrusions in the basement and the cover as well as the depth variations of the basement. Two major structures localised in the Upper Benue Trough, were examined: the Kaltungo Fault and the western border of the Kerri-Kerri basin (Benkhelil, Conodera, Dainelli, Ponsard and Saugy, 1988). The magnetic signature of these two structures is particularly clear, especially for the Kaltungo Fault. Around Gwol, the extension of this fault is marked by an alignment in a N50E direction of small elongate anomalies but in trend close to N70E (Ofoegbu, 1988).

The Kaltungo Inlier does not show any peculiar magnetic signature compared to the surrounding Cretaceous deposits. This can be explained by the abundance of the Tertiary intrusions in this area both in the basement and the cover. The magnetic anomalies are very strongly oriented in a N50E direction. The highest densities are located in the basement but surround it forming two pronounced zones. The sharpest, bounding the northern border, coincides with one of the most important lineaments in the Upper Benue Trough detected on the Landsat Imagery (Popoff *et al.*, 1983).

The Kaltungo lineament itself is much less marked relative to the surrounding structures. It is well underlined by sharp variations of curve style and density near Kaltungo town. Its southwestern extension is interrupted near Filiya by a cross fault. The E-W structures situated in the southern block, identical to that of Gwol-Gubrunde, are straddling both the basement and the basin to the north of Kaltungo.

Osazuwa (1978), in his gravity and magnetic data interpretation in the Upper Benue Trough shows that in the Gombe arm of the trough, the thickness of sediments appears to be no greater than 2 km in view of the Kaltungo basement inlier. Shemang, Jacoby and Ajayi (2005) in their gravity anomalies investigation over the Gongola Arm of the Upper Benue Trough concluded from the results of the interpretation that there is existence of intra-basin intrusives of high density in the trough at depth between 0.5 to 2 km while Onuba, Onwuemesi, Anudu, Chiaghanam and Ifelunni (2008) in their interpretation of magnetic anomalies over the Gongola Arm of the Upper Benue Trough show that the deeper magnetic sources range from 2 to 2.8 km.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Magnetic Data Acquisition

The aeromagnetic data were gotten as part of the nationwide aeromagnetic survey sponsored by the Geological Survey of Nigeria (now the Nigerian Geological Survey Agency, NGSA). The data were acquired along a series of NW-SE flight lines with a spacing of 2 km and an average flight elevation of about 150 m while tie lines occurred at about 20 km interval. The geomagnetic gradient was removed from the data using the International Geomagnetic Reference Field (IGRF). The data were made available in the form of contoured maps on a scale of 1:200,000. The component of the field measured during the survey is the total field intensity. The aeromagnetic maps were digitised at 2.9 km interval and the regional gradient was removed from the composite map by fitting a linear surface to the digitised data.

3.2 Data Digitisation and Boundary Merging

The aeromagnetic maps covering the study area were extracted from the block map covering some parts of the Upper Benue Trough. Four maps over Kaltungo (173), Guyuk (174), Lau (194) and Dong (195) each of $1/2° \times 1/2°$ digitised and recorded in a 19×19 coding sheet, were used. A sampling interval of 2.9 km $\times$ 2.9 km for digitisation on a grid system with a sampling frequency of 0.3/km was used and this gives a Nyquist wave number of 0.15/km (Ajakaiye, Hall and Millar, 1981). Previous studies with crustal aeromagnetic anomalies (Hall, 1968, 1974; Udensi, 2004) show that this spacing is suitable for the representation of the continuous data in a discrete form without losing details and equally suitable for the interpretation of anomalies resulting from regional crustal structures, which are larger than 6 km and thus lie below the number range for which computation errors arising from aliasing do not occur.

The composite dataset for the area of interest is the first tool required for the work. The composite map obtained from the composite dataset, represents the entire area of study on which the interpretation is based. To achieve this, a composite dataset for the measured discrete quantities is produced. This was done on a spreadsheet format using Microsoft Excel package. Each coding spreadsheet was arranged into a worksheet placed side by side going by the layout of sheets from the index map.

In adjoining the sheets into one worksheet, it was ensured that all boundaries joining two or four sheets had to be the same. At the boundary of two maps that are supposed to be side by side, the last column of map A and the first column of map B have the same coordinate, which is done by using the average of adjacent values at a particular boundary point. This was also done for maps that lie above the other, with last row of map A having the same coordinate as the first row of map C. In the case of the study area, which is covered by four maps lettered A, B, C and D respectively, the arrangement and joining of boundaries is as shown in (Figure 3.1).

Thus, to have a unified dataset, all data with the same coordinates (latitudes and longitudes) were averaged. Thus a single data entry would take the place of the two or four similar data with the same coordinate. The coordinates were generated by a Fortran Program and were supplied in cognizance to the arrangement of the sheets. The Microsoft Excel software when producing the dataset was used to minimise or eliminate human error. On completion of this process, a dataset of 36×36 (i.e. row X and column Y) was obtained giving a total dataset of 1296 of its unified composite dataset.

3.3 Production of Composite Aeromagnetic Map

The unified composite dataset for the study area was produced from edge-matching to remove duplication of data for corresponding points from adjoining sheet map. The composite dataset was arranged in three columns having fields' northing (latitudes), easting (longitudes) and the corresponding magnetic values extracted from the digitised map. This dataset was then gridded in the Surfer 8 Program environment using the ''Kriging Method'' of data gridding and a composite map is thus obtained. Kriging method is a moving average method popularised by a French geomathematician under the name kriging (in honour of D.G Krige, a notable South African mining geologist and statistician).

3.4 Regional-Residual Anomaly Separation

The residual field(s) due to the residual anomaly of interest of a potential field (magnetic or gravity) must be separated from the background (regional field) before such a field can be interpreted. Two fundamental methods for removing the unwanted regional field from the total field data are:

1. Graphical/visual smoothing
2. Analytical method

3.4.1 Graphical/Visual Smoothing Method

This is the earliest method used for estimating the regional effect by means of smooth curves or profiles. This process works roughly by means of approximations in the following order: the first step is to look for the local undisturbed area(s) on the map; the trend(s) in such undisturbed area(s) is/are projected onto the disturbed area(s) and the points of intersection of the regional curves and the anomalous contours are noted. The regional trend depicted by extrapolation is then subtracted from the observed anomalous

A KALTUNGO SHEET (173)	B GUYUK SHEET (174)
C LAU SHEET (194)	D DONG SHEET (195)

Figure 3.1: Boundary Merging Layout for Composite Dataset

trend at the point of intersection; the result then yields the residual field. The flexibility of this method is an advantage because it allows the interpreter to incorporate into the process his personal judgment or sense of ‘’rightness’’ about the form of the residual anomaly. This method will be effective when the regional trend is fairly evident from the beginning.

The use of this method which is subject to personal bias requires considerable work and can be expensive but it is entirely reasonable (Grant and West, 1965). The inherent subjectivity may either be an advantage or disadvantage depending on the interpreter’s experience and ability to incorporate relevant geological information about the regional field. The smoothing or graphical method cannot be applied under certain conditions, for instance when the ground (topography) is very hilly and the subsurface materials are inhomogeneous; secondly, when the regional trend is very strong the residual anomalies are masked and easily missed by this method; and lastly when the topography is not hilly but the residual anomalies are very strong, the regional trends are often difficult to discern; this is usually very true in large-scale surveys. However, with small amount of data and simple regional trends, graphical/smoothing method has an edge over other methods.

3.4.2 Analytical Method

This method uses numerical operations on the observed data to isolate the anomalies. Techniques of this sort require that the magnetic values be spaced in a regular array. The analytical approaches commonly in use include: determination of second vertical derivatives, direct calculation of residual by techniques such as the centre point and ring method, downward/upward continuation and polynomial fitting.

The polynomial fitting is about the most flexible of all the analytical methods for determining regional fields (Skeel, 1967; Udensi, 2004). In this method, the matching by a polynomial surface of low order exposes the residual features as random error. The observed data are used to compute, usually by least squares, the mathematically describable surface giving the closest fit to the magnetic field that can be obtained with a specified degree of detail. This surface is considered to be the regional field and the residual is the difference between the magnetic value as actually mapped and the regional value thus determined (Udensi and Osazuwa, 2003).

The Least Squares method was applied to the study area as it is handy and adequate because of the simple nature of the geology of the area and its limited spatial extent. It was assumed reasonably that the regional field is a first order polynomial surface. Thus, all the regional were therefore calculated as two dimensional (2-D) first degree polynomial surfaces. The residual and regional anomaly maps/fields from this study were thus obtained by contouring sing the Oasis Montaj and Surfer 8 software.

3.5 Upward Continuation Method

A potential field measured on a given observation plane at constant height can be calculated as though the observations were made on a higher plane (upward continuation). The equation of the wave number domain filter for this function is given by:

$$\boldsymbol{F = e^{-hw}} \qquad \textbf{(3.1)}$$

where **h** is the continuation height, ***w*** the wave number and ***e*** the exponential function. This function decays steadily with increasing height, attenuating higher wave numbers severely, thus producing a map in which regional features predominate.

Upward continuation is used in magnetic interpretation as a filter to remove anomalies from shallow sources (residuals). It has also been used to compare the field upward continued to a higher level with that measured at that level. When the calculation is made from an adequately mapped field, the continued and measured fields at higher level are almost identical (Nettleton, 1976). Deep bodies produce only long wavelengths whereas shallow bodies can produce long or short wavelengths. Shortest wavelength that can be produced at a given depth is due to a point mass or spherically symmetric mass (Kanasewich and Agarwal (1970).

In this study, the basis of upward continuation is to observe and study how the regional field is when the height is increased arbitrarily from the initial observation plane. This is like feeding the total field anomaly into a series of low-pass filters. The short wavelength or high frequency (high wave number) residuals cannot pass through these filters and are consequently sieved off leaving only the long wavelength or low frequency (small wave number) regional to pass through the filters. As the height above a given observation plane is continued upward, the regional field which is broad and deep-seated becomes sharper, smoother and more discernible due to continuous filtering of the residual field. The upward continuation approach employed here is a process aimed at enhancing the regional trends. The total magnetic intensity map was produced using Oasis Montaj software and then continued upward by 2, 5, 7.5, 10, 12.5, 15, 17.5 and finally 20 km respectively in that order. The resultant anomaly fields are displayed in the form of maps according to the different filters through which they passed.

3.6 Spectral Analysis/Magnetic Source Depth Determination

Spectral analysis of residual magnetic field data can be used to determine the depth to the buried magnetic source rock. The residual field intensity values are used to obtain the two-dimensional Fourier series consisting of various wave numbers (frequencies) which characterise the anomalies. It has been recognised that a statistically-oriented approach is preferable because more than one anomaly can be used to determine the depth to the buried magnetic rock and mean depth values to major units of the buried magnetic rocks. This approach has been found to yield good estimates of mean depth to basement underlying a sedimentary basin (Hahn, Kind and Mashira, 1976; Shehu, 2003).

Spector (1968) and Spector & Grant (1970) developed a 2-D spectral depth determination method. Their model assumes that an uncorrelated distribution of magnetic sources exists at a number of depth intervals in a geologic column. The evolution of spectral analysis has some important precursors, by which one tries to present data only in a simple 2-D format. The most important of these precursors is the harmonic analysis or Fourier series expansion of a given time series of data. According to Fourier theorem, any function f(t) satisfying certain restrictions can be expressed as a sum of infinite number of sinusoidal terms. In general case, f(t) can stand for any function such as displacement, particle velocity, acceleration, temperature, rainfall, wind velocity, geomagnetic field intensity, etc.

To study the characteristics of the residual field, the data is first transformed from space to frequency domain and then their frequency characteristics are analysed. For the purpose of analysing aeromagnetic maps, the subsurface is assumed to consist of a number of ensembles of rectangular, vertical-sided parallelepipeds. If there are two sets of sources then they can be recognised by a marked change in spectra decay rate. The energy spectrum of the double ensemble will then consist of two parts. The first which relates to the deeper sources, is relatively strong at low frequencies, and decays away rapidly. The second which arises from the shallower ensemble sources, dominates the high frequency end of the spectrum (Spector & Grant, 1970)

In general case, the radial spectrum may be conveniently approximated by straight line segments, the slopes of which relate to the depths of the possible magnetic layers (Spector & Grant, 1970; Hahn *et al.*, 1976). The power spectrum derived from a 2-D dataset such as a grid of residual magnetic data, also has inherently a 2-D form. If the frequency unit is in radians per kilometre, the mean depth of burial of the ensemble is given by:

$$z = -\frac{m}{2} \qquad \textbf{(3.2)}$$

where m is the slope of best fitting straight line. If however, the frequency unit is in cycles per kilometre, the corresponding relation can be expressed as:

$$z = -\frac{m}{4\pi} \qquad \textbf{(3.3)}$$

The use of the Discrete Fourier Transform introduces the problem of aliasing and the truncation effects (Gibb's phenomenon). The problem of aliasing can be reduced by choosing an appropriate digitising interval. In this study an interval of 2.9 km by 2.9 km on a grid system was used for the map. This spacing imposes a Nyquist frequency of 0.15/km. Thus, the narrowest magnetic anomaly that can be defined by the digitised data has a width of 2.9 km (Ajakaiye *et al.*, 1981).

Previous studies with crustal magnetic anomalies (Hall, 1968; 1974) show that this spacing is suitable for the portrayal and interpretation of magnetic anomalies. The truncation effect arises when limited portion of an aeromagnetic map is subjected to Fourier synthesis; it is difficult to reconstruct the sharp edges of the anomaly with a limited number of frequencies. This truncation leads to the introduction of spurious oscillation around the region of discontinuity. This means that false frequencies will be introduced into the spectrum. The truncation effect can be reduced by applying a cosine tapper to the observed data before Fourier transformation (Kangkolo, 1996; Akanbi and Udensi, 2006). It has been found (Pal, Khuran and Unnikrisnna, 1978) that in the use of spectral approach to magnetic source determinations, the error in depth prediction increases with the depth of source and is also related to the map size. The map size required for adequate results should be much larger, (about 10 times) the required target depth. The low frequency components in the energy spectrum are generated from the deepest layers whose locations are most likely in error thus, it is advisable in the general method here to ignore the first few points in the energy spectrum.

3.6.1 Magnetic Source Depth Estimation of the Study Area

In this study, the area was divided into nine (9) blocks/cells along specific longitudes and latitudes for spectral depth analysis. The choice of nine spectral cells was informed by the fact that the area has limited size (small area) of about 12100 km^2. The residual magnetic data for each cell was gridded using Oasis Montaj and the energy spectrum of each or block/cell was obtained. The logarithm of the spectral energy was then plotted as a function of frequency of the ensemble for each section using Slope Plot Program- a computer program derived from MATLAB. The slopes of the first and second segments of the plot were respectively calculated and displayed automatically based on the best line of fit chosen. From the slopes of the spectral energy-frequency plot, the first and the second layer depth was respectively estimated using the relation below:

$$z_1 = -\frac{m_1}{4\pi} \qquad (3.4)$$

Similarly,

$$z_2 = -\frac{m_2}{4\pi} \qquad (3.5)$$

where m_1 and m_2 are slope of the first and second segment of the plot respectively while z_1 and z_2 are first and second layer depth respectively. The formula $z = -\frac{m}{4\pi}$ applies because the frequency is in cycle/km.

The coordinates of each spectral depth point were obtained by summing the values of the bounding latitude and longitude respectively and averaging it. The first and second layer depths were later contoured respectively using SURFER 8 program.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 The Total Magnetic Intensity Map

A qualitative study of the total magnetic intensity map/field (Figures 4.1a & b) reveals that the dominant trend of the anomalies in the study area is SW-NE. There is a distinct trend of high magnetic anomalies in the SW-NE direction which is flanked on either side by regions low to very low anomalies. Along this SW-NE anomaly trend of high intensity, there are some distinct, sharp, isolated patches of high anomalies with high structural closures. These patches of high closures also dot the two lower magnetic regions flanking the SW-NE high magnetic trend.

The dominant SW-NE trend of the anomaly with high intensity on the map is believed to correspond with the trend of a prominent uplifted basement which crops out in some areas as an inlier within the basin (Kaltungo Inlier). This high magnetic trend is also noticed to extend slightly from SW into the south central portion of the map. The Kaltungo basement which is made up of predominantly older granite (Carter *et al.,* 1963) contains more magnetic minerals responsible for this high anomaly. The two regions of low to very low magnetic amplitudes that flank this dominant SW-NE trend are indicative of deeper basement or thicker sedimentary cover. Those sharp, isolated patches of high magnetic amplitudes are believed to be due to the intrusive bodies which affected the basin during the Tertiary –Quaternary Period; these intrusives invaded both the basement inlier and sedimentary cover.

The high and very high, distinct magnetic anomalies trending approximately SW-NE also suggests a major tectonic/structural trend in this direction. Nsikak, Nur and Gabriel (2000) generally believe that there would always be a magnetic susceptibility contrast across a fracture zone due to oxidation of magnetite to haematite and /or infilling of fracture planes by dyke-like bodies whose susceptibilities are different from those of their host rocsks. Such geological features may appear as thin elliptical closures or nosing on an aeromagnetic map. These assertions corroborate the findings of (Benkhelil, 1982[b]) that a major fault cutting across the Kaltungo Inlier has been observed in the field and mapped in detail (Popoff *et al.*, 1983) using Landsat and SLAR imageries and field data. This tectonic trend aligns neatly with the direction of the Romanche Fracture zone which cuts through the Benue Trough on a regional scale (Figure 2.1).

4.2 The Residual Map

The residual magnetic anomaly map looks very much similar to the total magnetic intensity map. The trends of the anomaly, the shape, closures, reliefs, etc, on both maps only show very slight changes. Since the process of regional-residual separation was done using a first degree polynomial surface, it is evident that the residual field would only be slightly different from the total magnetic field (Figure 4.2a and b).

4.3 The Regional Map

The regional map (Figure 4.3) which represents the background field of broad and deep-seated origin here in the study area has a dominant SW-NE trending which is nearly parallel to the trend of the TMI/residual field. It can be observed that the magnetic contours show values which increase towards the NW flank; this is due to the high basement relief in this area. However, the contour trends show progressive low magnetic values towards the SE portion of the map implying that the basement in this region is much deeper.

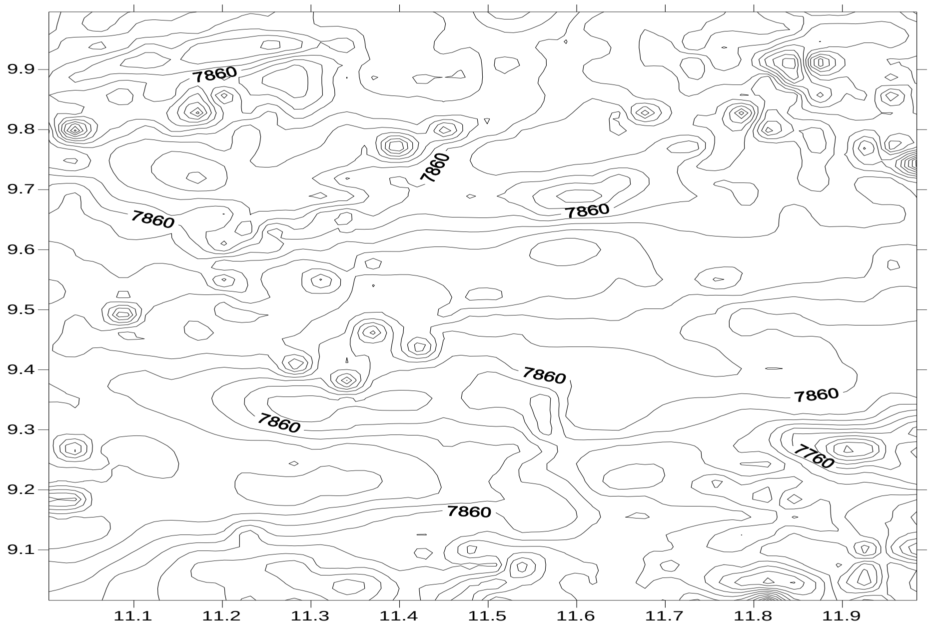


Figure 4.1a: Total magnetic intensity contour map of the study area (Contour Interval = 20 nT)

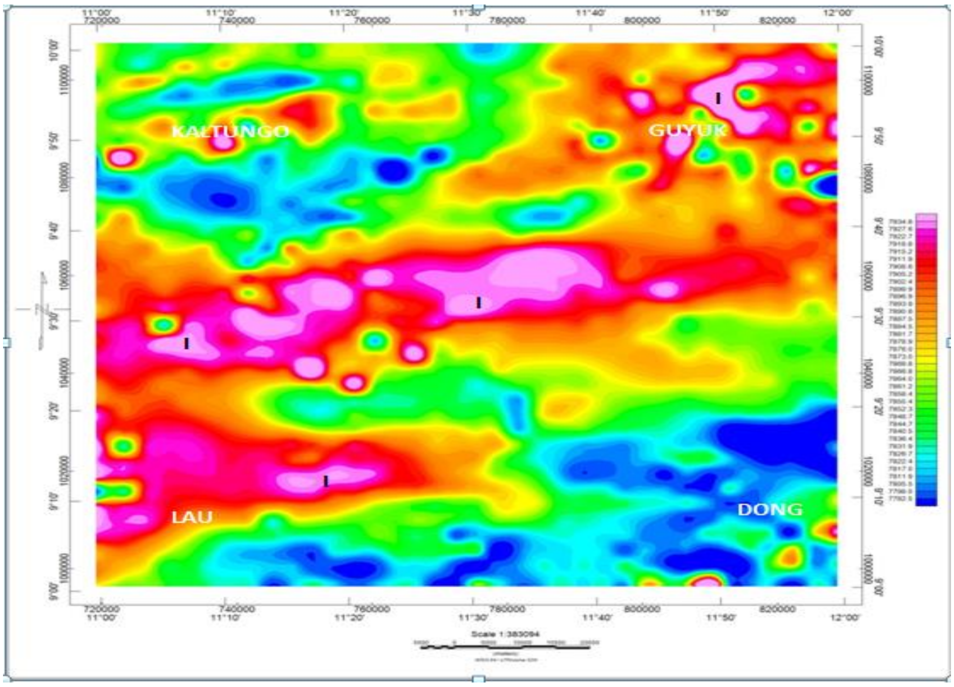


Figure 4.1b: Total magnetic intensity map (Oasis Montaj)

Key: I- intrusive bodies

4.4 The Upward Continuation Maps

The upward continuation maps at various levels (Figures 4.4 to 4.12) show that the regional fields become sharper and smoother with increasing continuation height. This is because of the continuous attenuation of the short wavelength anomalies (residual) from shallow sources leaving only the long wavelength regional fields as output. At 20 km (Figure 4.12) upward continuation, the regional fields become sharpest and smoothest showing a dominant SW-NE trending as observed on the TMI/residual and regional maps respectively. Three to four magnetic sections are observed: the first section occupies the SE extreme of the map and this also depicts the lowest magnetic level. This is interpreted as the area of deeper basement surface. The second magnetic section occupies two different positions namely: one stretching from the SW flank towards the Eastern region of the map while the other lies in the north- central area of the map. These areas depict the next higher magnetic level than the first, where the basement is slightly raised.

The third magnetic region occupies the western part of the map and extends towards the NE flank. This marks a higher magnetic level implying closer-to the surface basement relief. This magnetic region is evidence of the Kaltungo basement rocks which occupy largely this area. There is within this long stretch of higher magnetic section a localised area occupying the western part of the map with the highest magnetic amplitude in the entire area. A smaller portion with similar magnetic signature is also observed in the NE part and NW fringe of the map respectively. The persistence of these anomalies of high intensity even at 20 km continuation is an indication that intrusive bodies giving rise to these anomalies have deeper roots far down in the basement. However, if the height is continued above 20 km up to 40 km, the residual effects of these intrusives may be totally removed and hence the regional trends will become perfectly smoother.

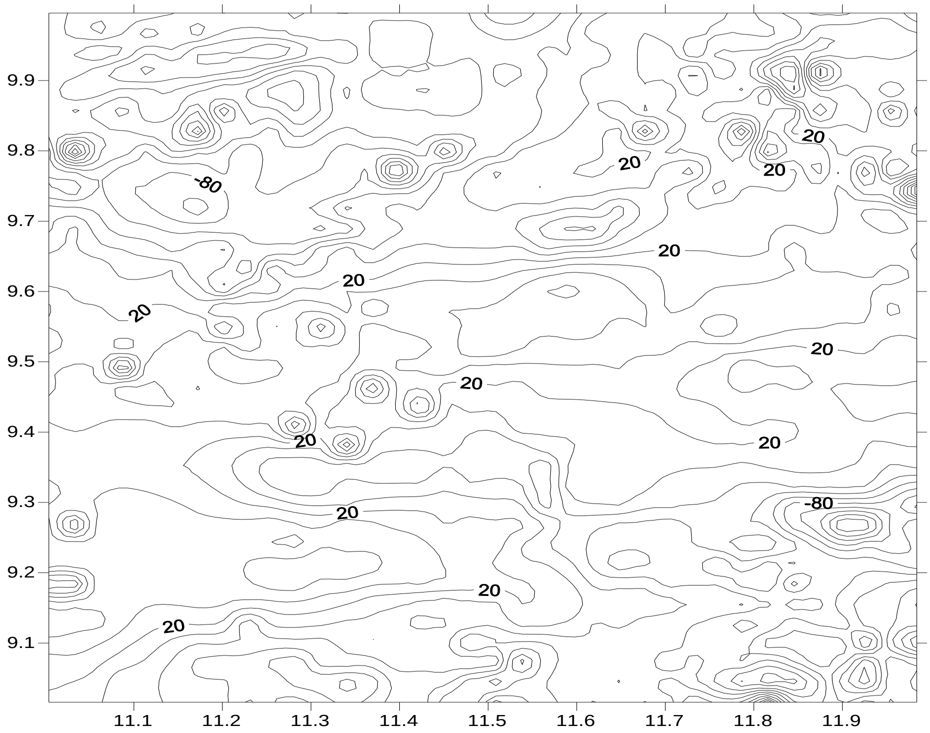


Figure 4.2a: Residual anomaly contour map of the study area

(Contour Interval = 20 nT)

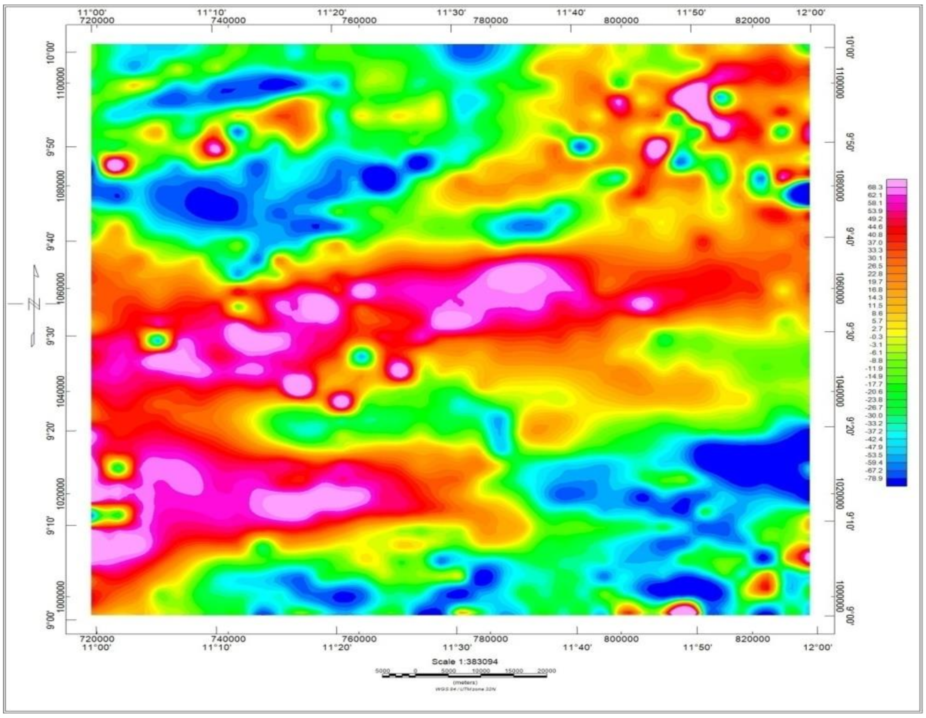


Figure 4.2b: Residual anomaly field of the study area (Oasis Montaj)

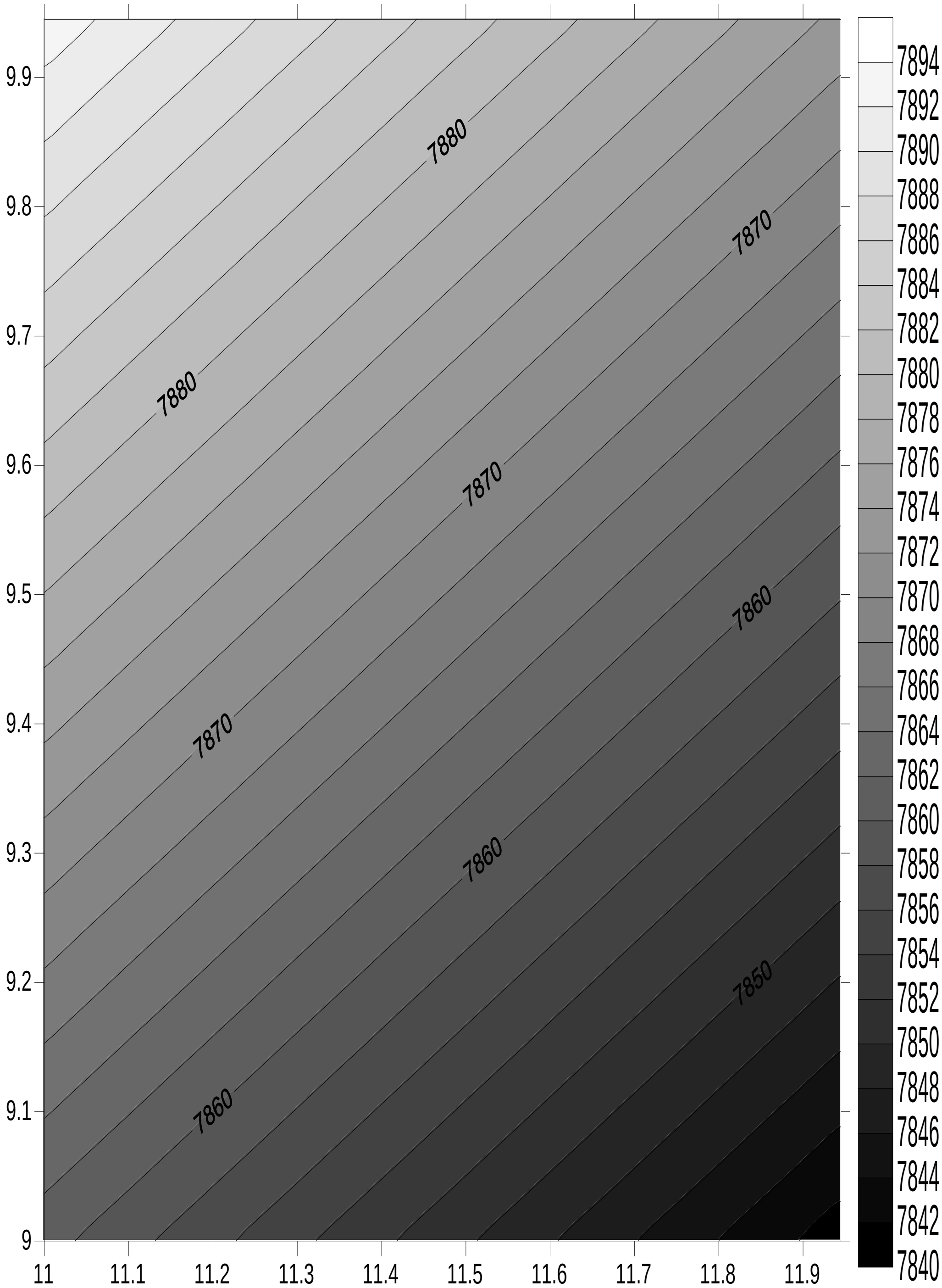


Figure 4.3: Regional anomaly contour map of the study area

(Contour Interval = 2 nT)

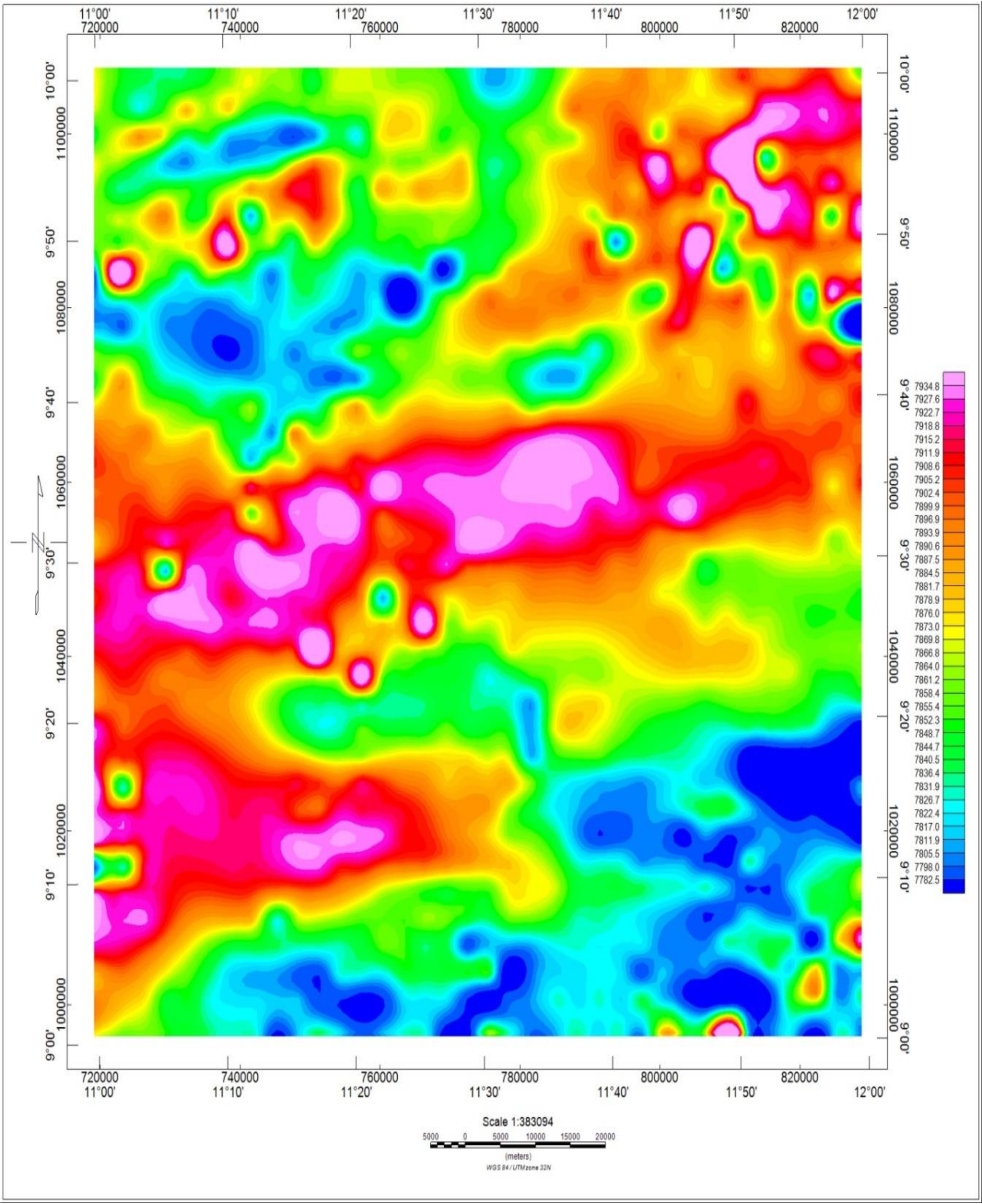


Figure 4.4: Total magnetic intensity field of the area (normal flight height)

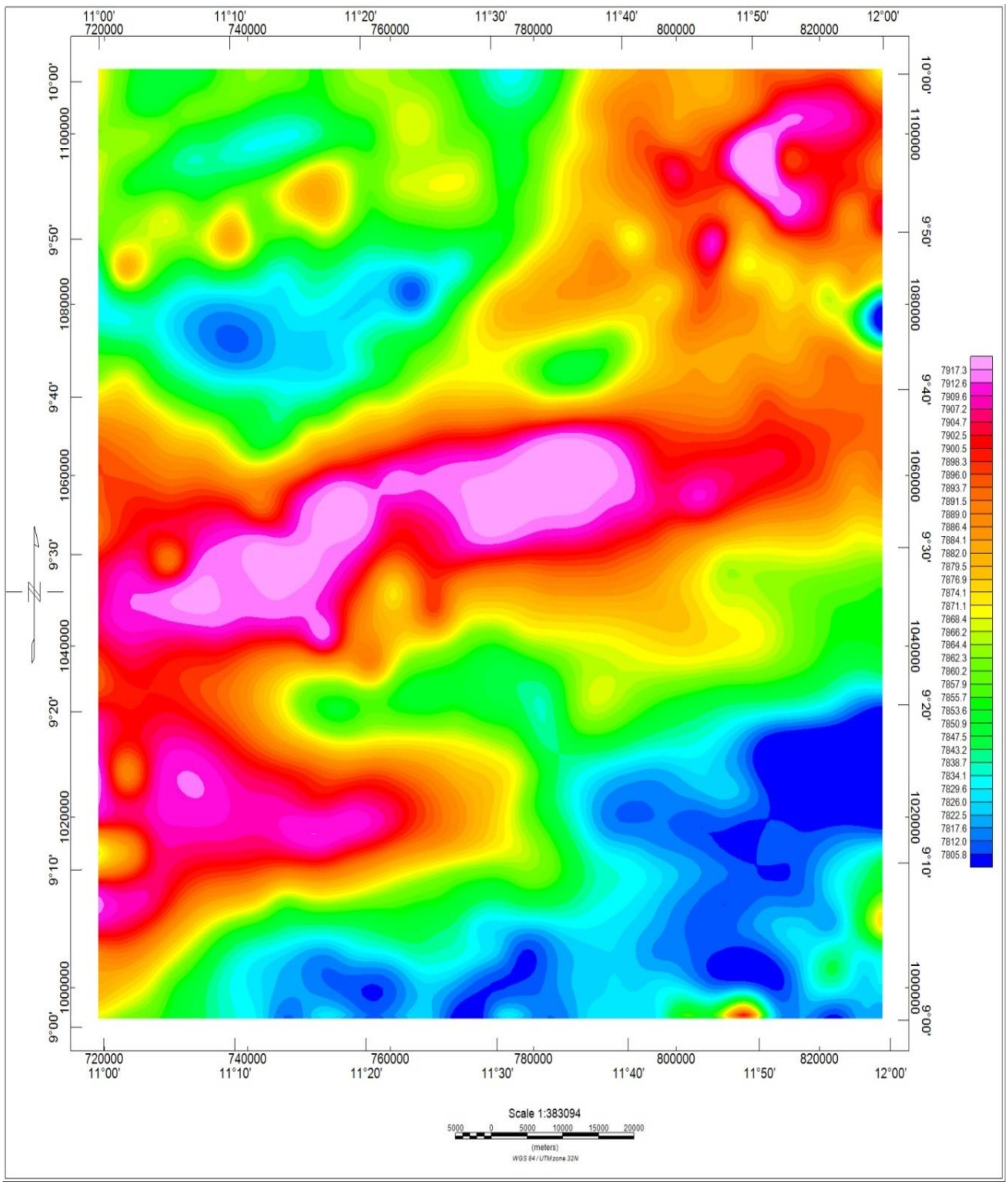


Figure 4.5: Total magnetic field of the study area (2 km upward continued)

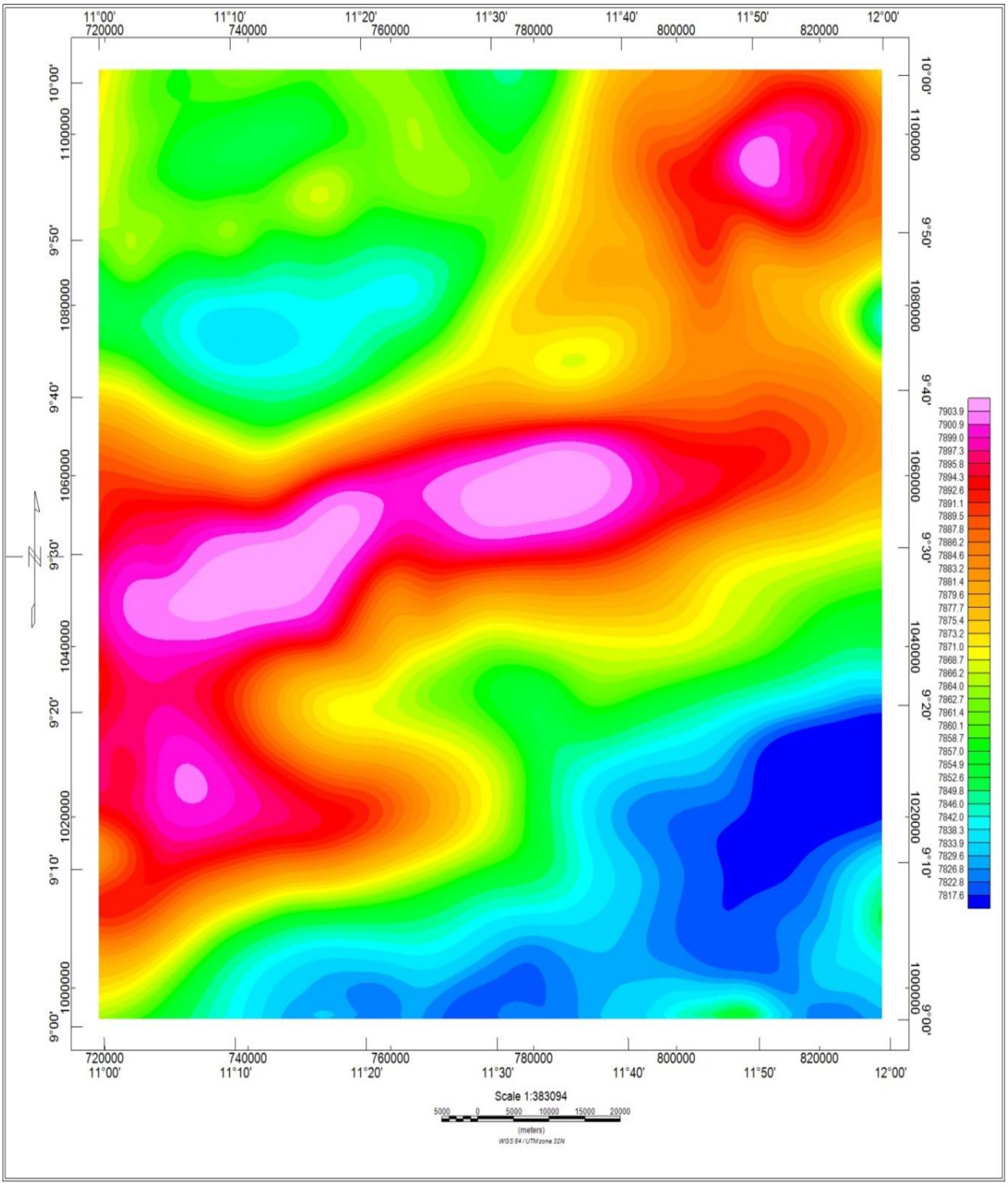


Figure 4.6: Total magnetic field of the study area (5 km upward continued)

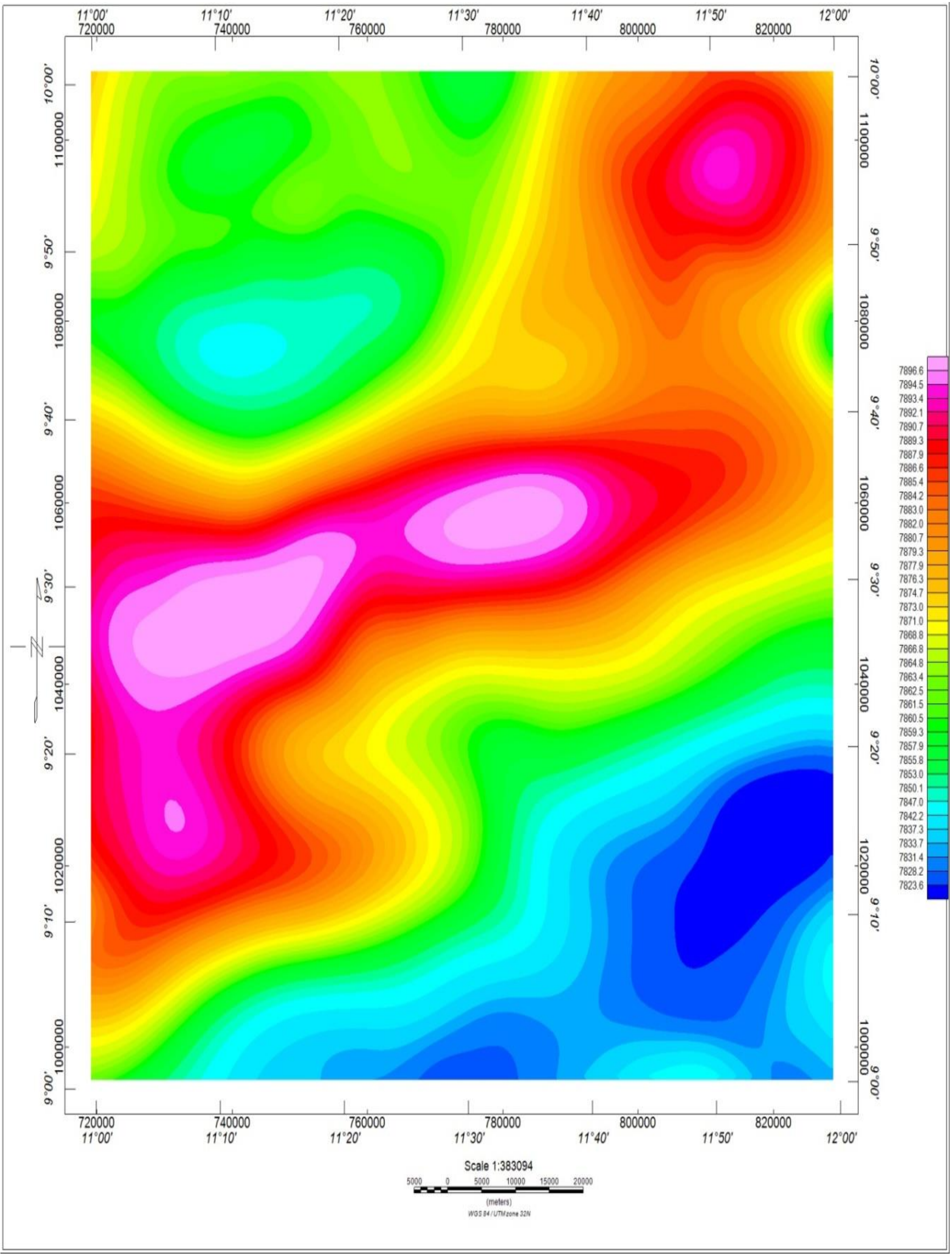


Figure 4.7: Total magnetic field of the study area (7.5 km upward continued)

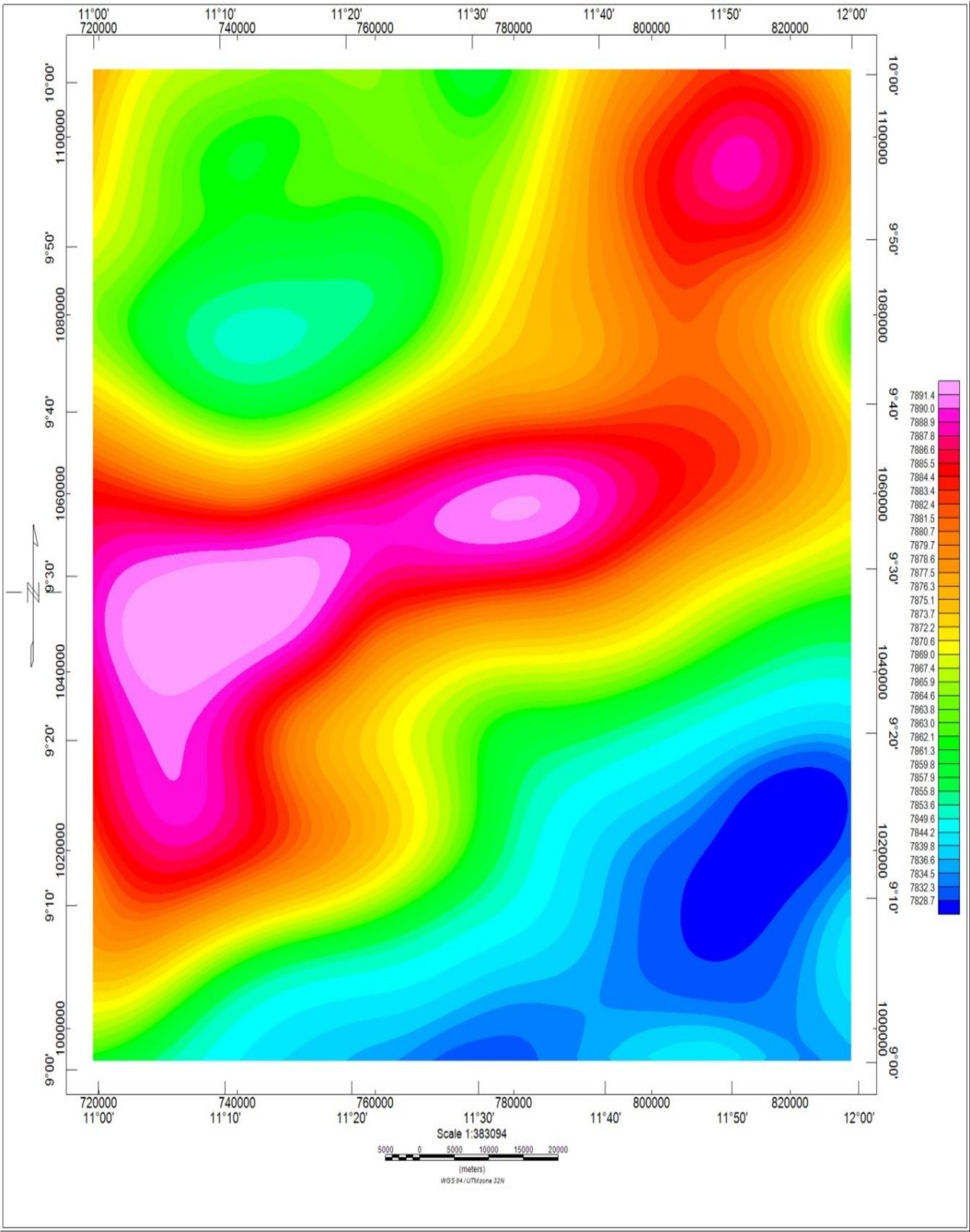


Figure 4.8: Total magnetic field of the study area (10 km upward continued)

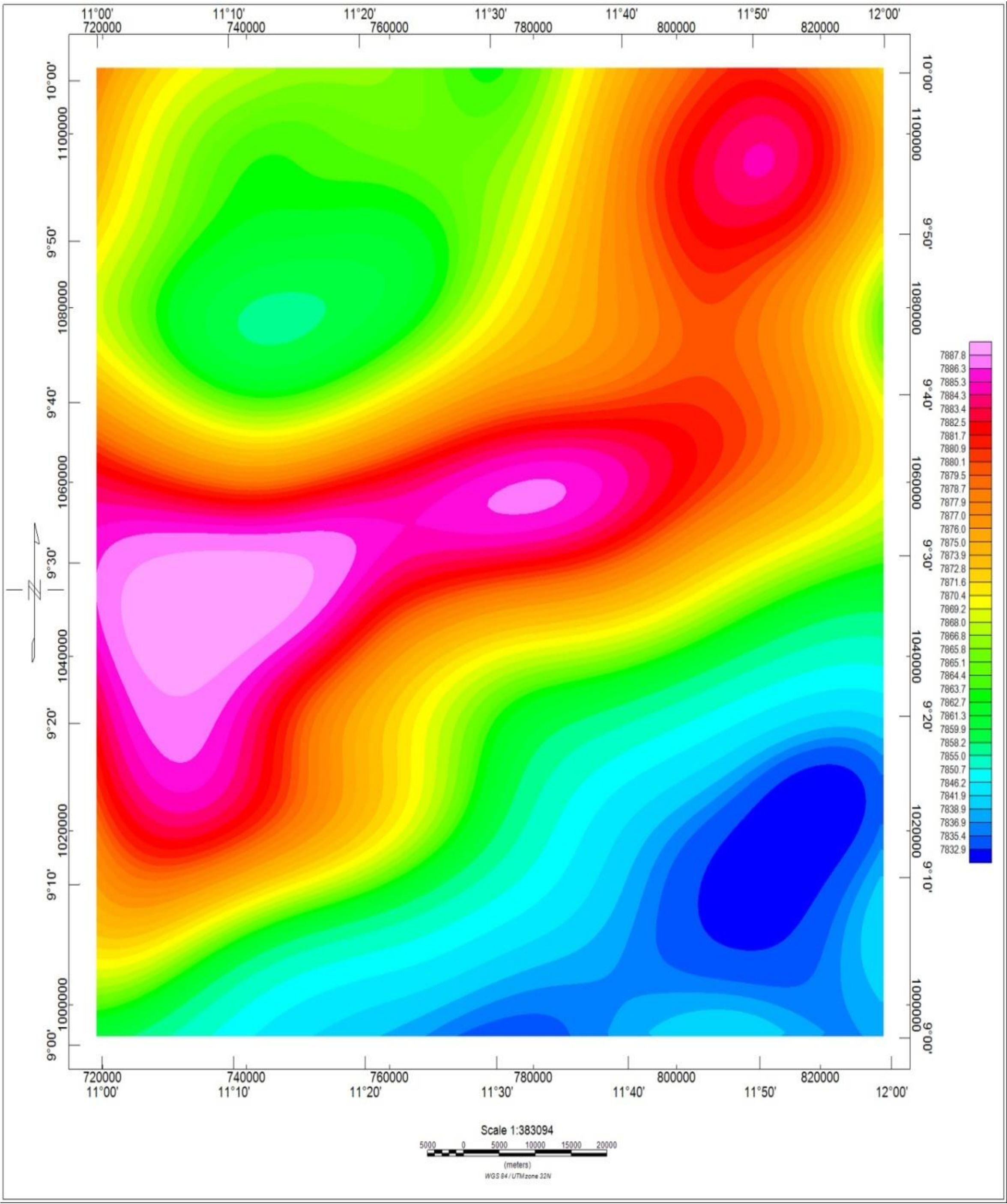


Figure 4.9: Total magnetic field of the study area (12.5 km upward continued)

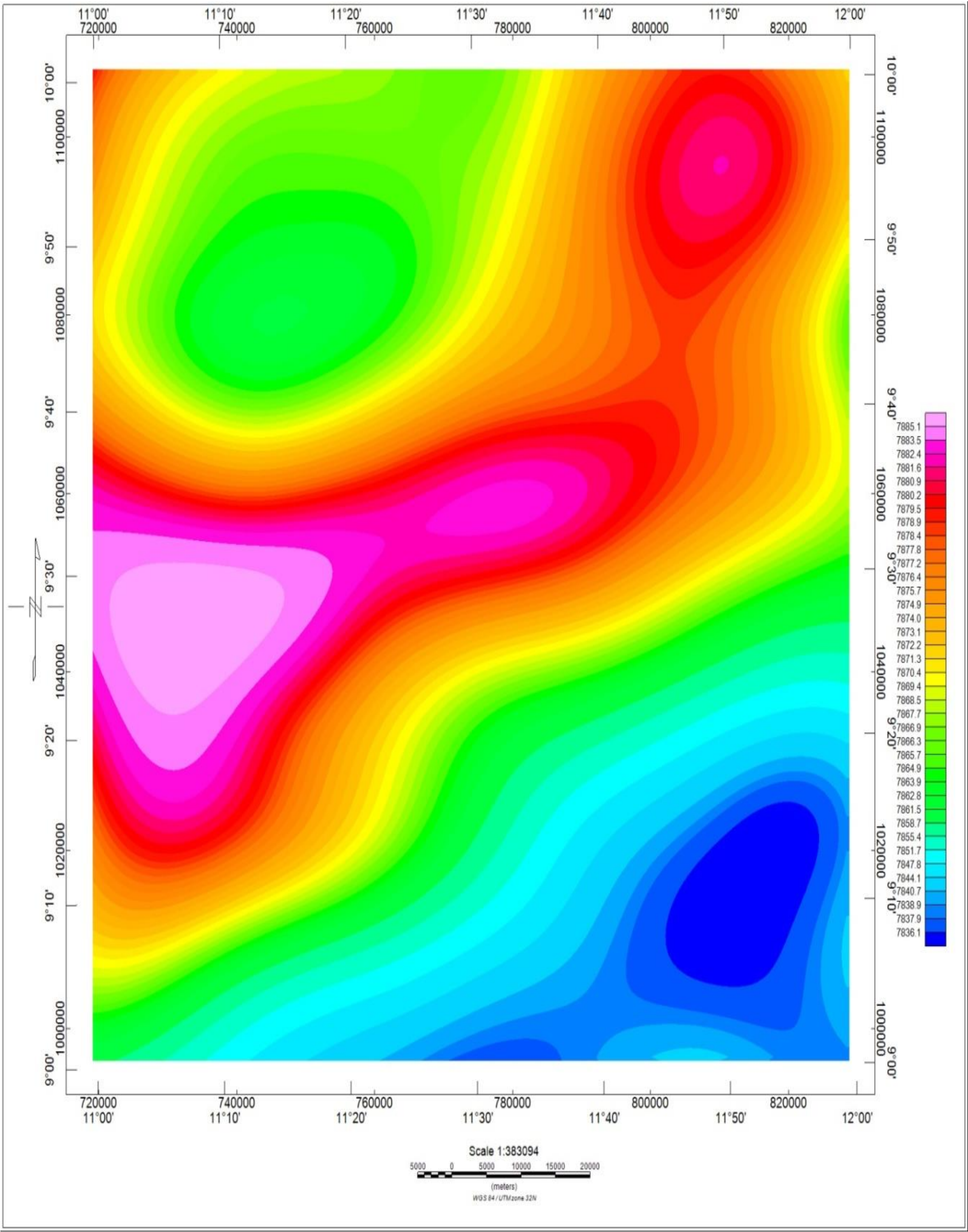


Figure 4.10: Total magnetic field of the study area (15 km upward continued)

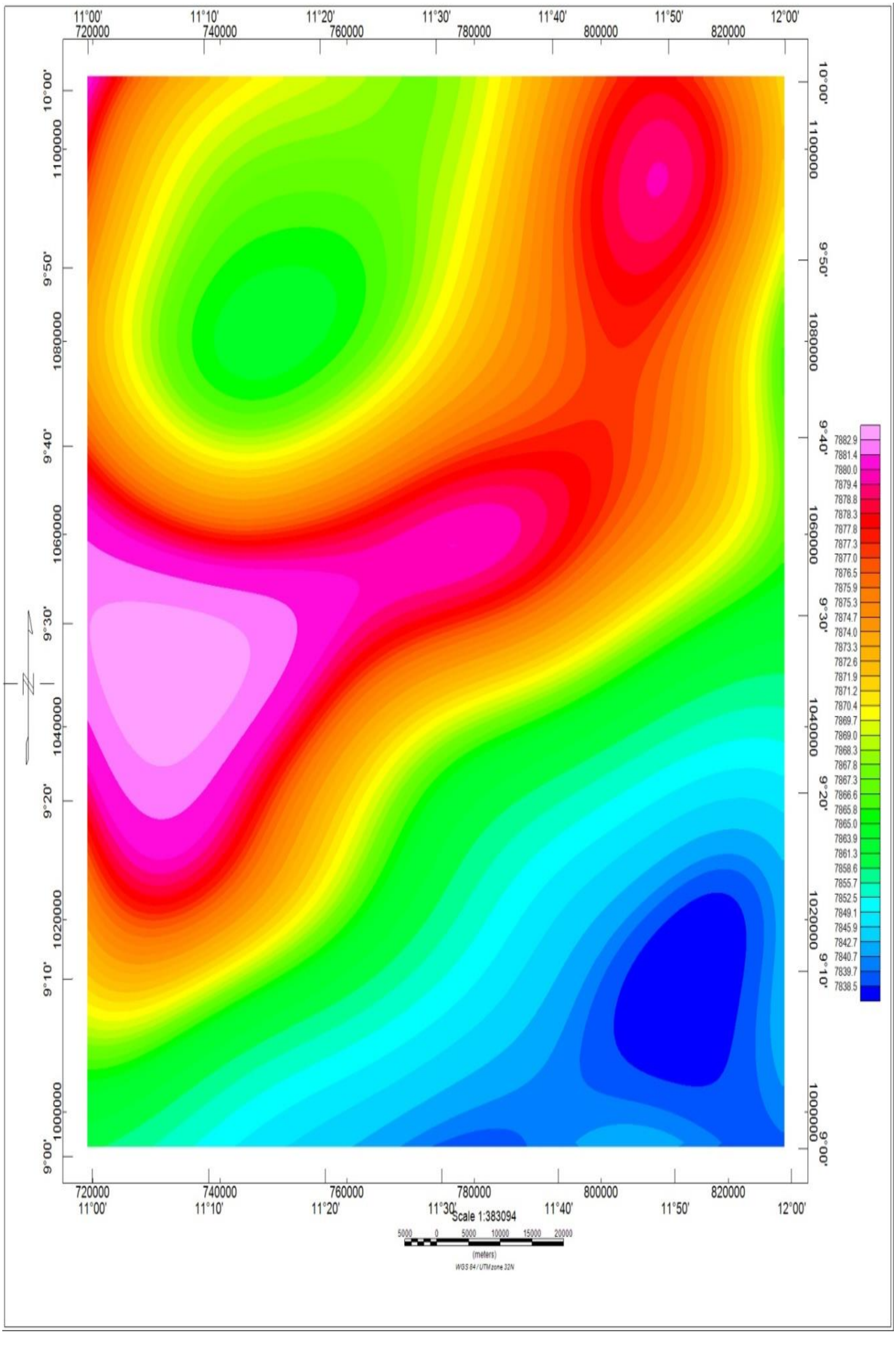


Figure 4.11: Total magnetic field of the study area (17.5 km upward continued)

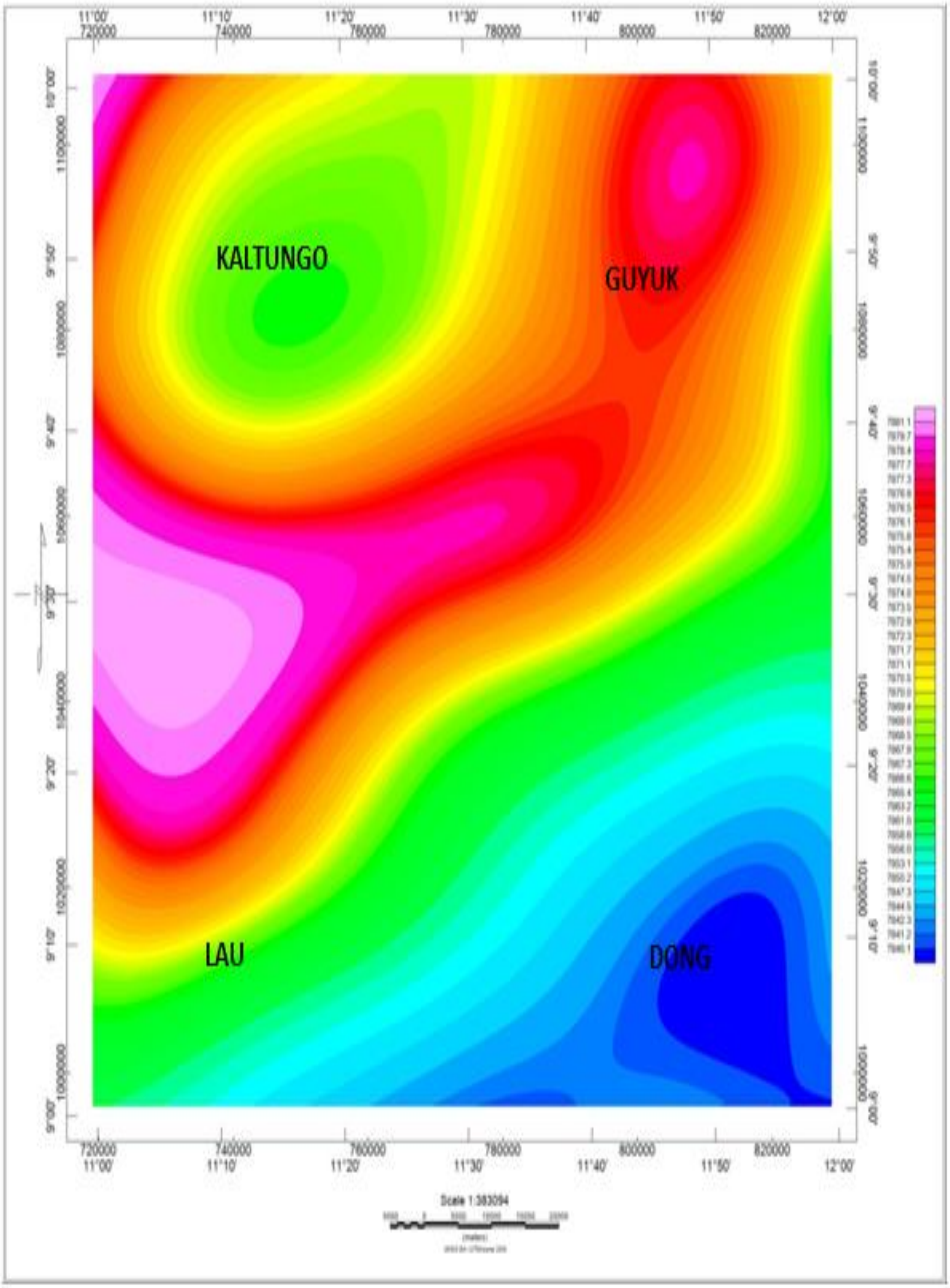


Figure 4.12: Total magnetic field of the study area (20 km upward continued)

4.5 The Spectral Depth Maps

The spectral depth maps (magnetic source depth maps) resulted from the values calculated from the plots of spectral energy against frequency (Figure 4.13) for each spectral cell covering the entire study area. The analysis of these spectral depths reveals that the magnetic anomalies originated from two depth sources (Table 4.1); the first depth ranges from 0.60 km to approximately 1.00 km. The magnetic signatures from this layer depth (shallower sources) are believed to be due to the basic magmatic intrusive bodies that characterise the basin both within the basement and the sediments which occurred during the Tertiary-Quaternary. The second depth ranges from 2.25 to 3.25 km**.** This depth defines and corresponds to the basement surface topography within the basin which varies from one part to the other. This depth to the magnetic basement is a good estimate for the thickness of overlying sedimentary cover. The first depth contour map shows that the intrusive bodies occurred at a much shallower depth not greater than 1.00 km. The bodies appear to be more localised and at shallower depth along an approximately SW-NE trend with a peak in the north-central region than any other area on the map (Figure 4.14a & b). From the second depth contour map, it can be seen that the depth progressively increases towards the far SE extremity of the map (Figure 4.15a & b**).** This means that the depth to the recorded magnetic signatures otherwise called the depth to the basement (in this case), is deeper and this implies that the sedimentary cover in this region is thicker than the rest in the area.

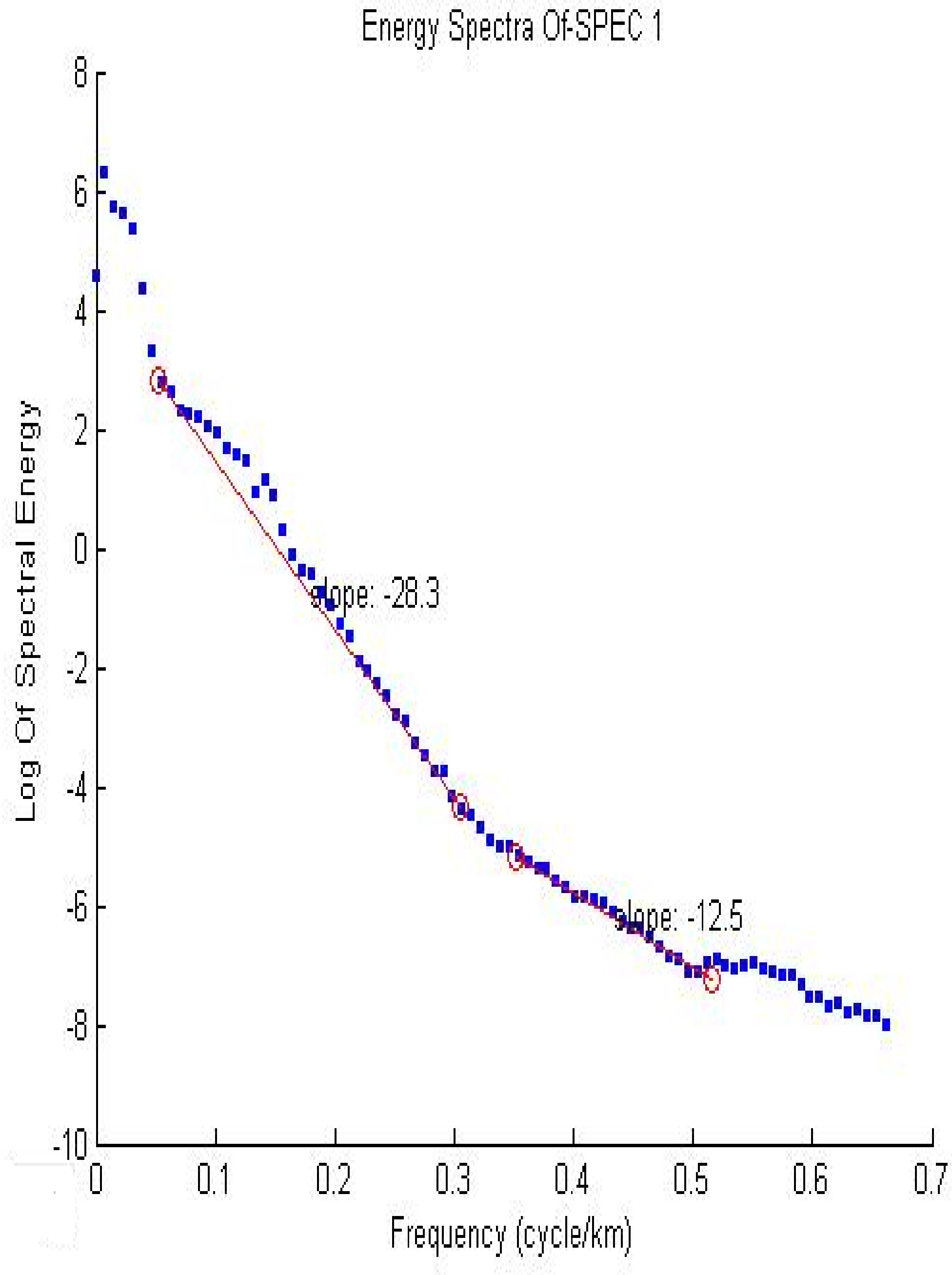


Figure 4.13: Spectral depth plot

Tale 4.1: Magnetic source depth estimates of the study area

Spec No.	Long. (^oE)	Lat.(^oN)	m_1	z_1 (km)	m_2	z_2 (km)
1	11.2500	9.2500	-12.50	0.99	-28.30	2.25
2	11.7500	9.2500	-11.80	0.94	-40.90	3.25
3	11.2500	9.7500	-7.57	0.60	-30.00	2.39
4	11.7500	9.7500	-8.41	0.67	-33.00	2.62
5	11.5000	9.2500	-11.00	0.87	-30.60	2.43
6	11.5000	9.7500	-8.60	0.68	-32.30	2.57
7	11.2500	9.5000	-10.00	0.79	-30.60	2.43
8	11.7500	9.5000	-8.85	0.74	-30.50	2.43
9	11.5000	9.5000	-8.22	0.65	-32.40	2.58
Average				**0.77**		**2.25**

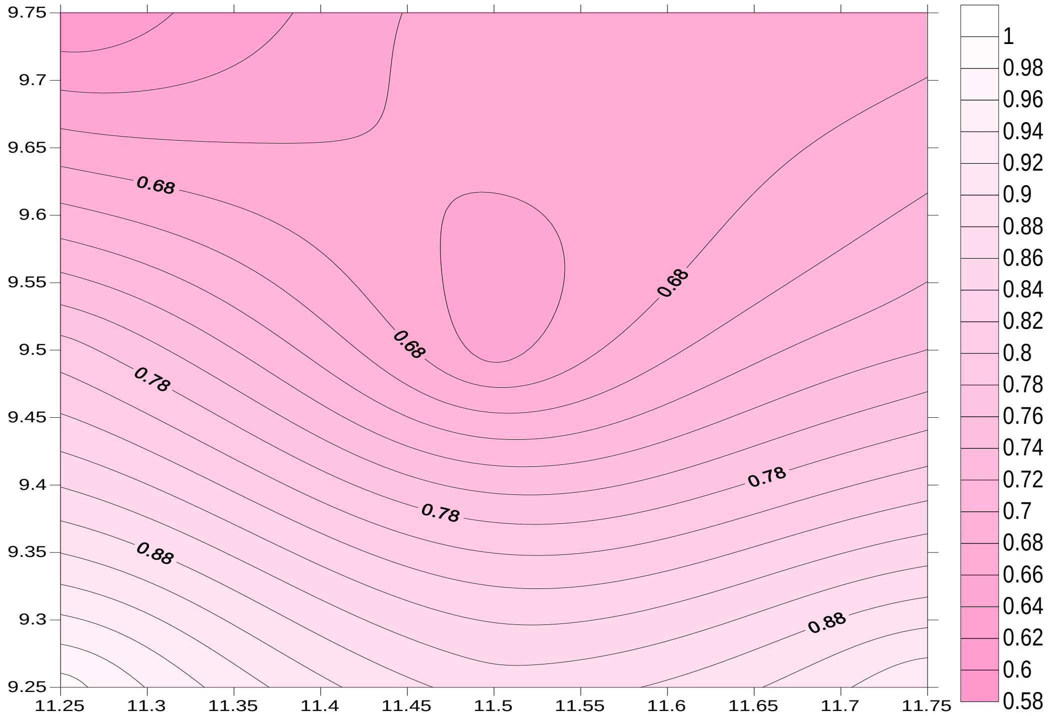


Figure 4.14a: Contour map of first magnetic layer depth of the study area (Contour Interval = 0.02 km)

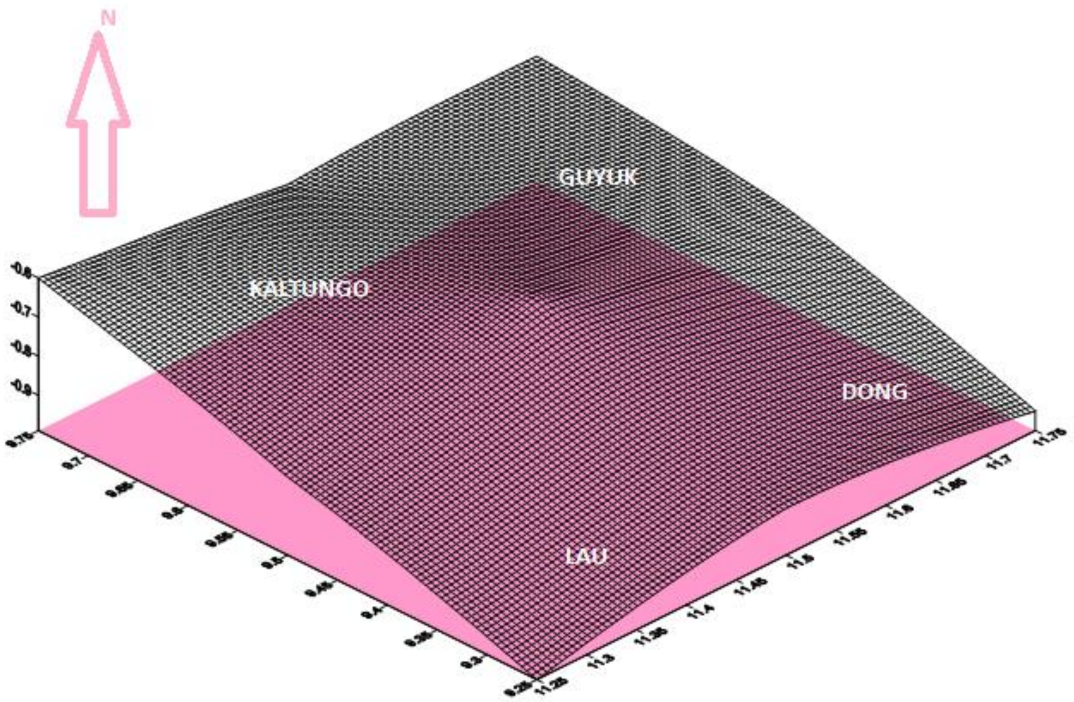


Figure 4.14b: 3-D map of first magnetic layer depth of the study area

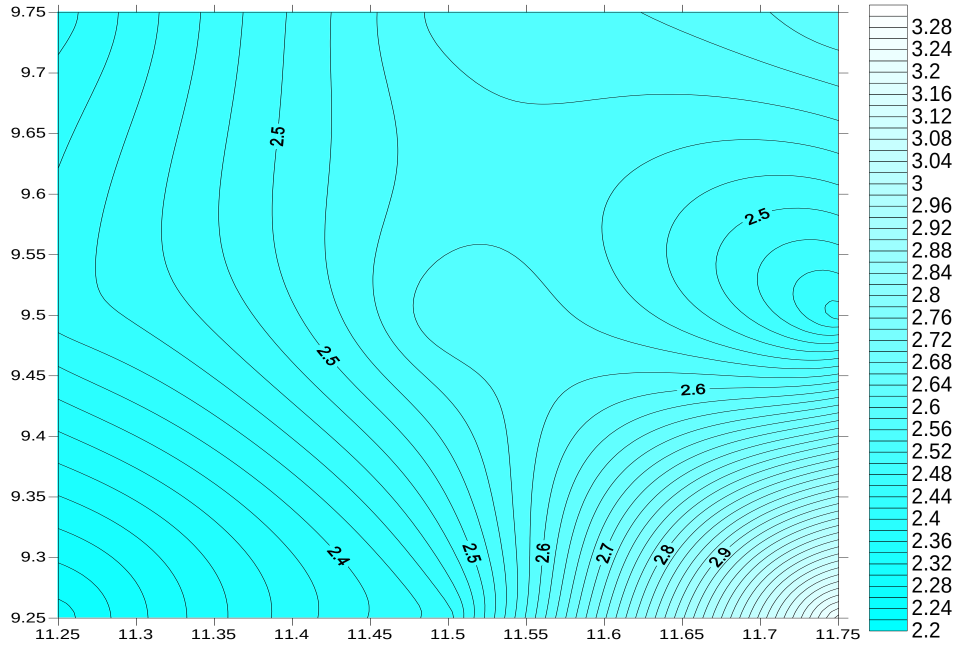


Figure 4.15a: Contour map for second layer depth of the study area (Contour Interval = 0.02 km)

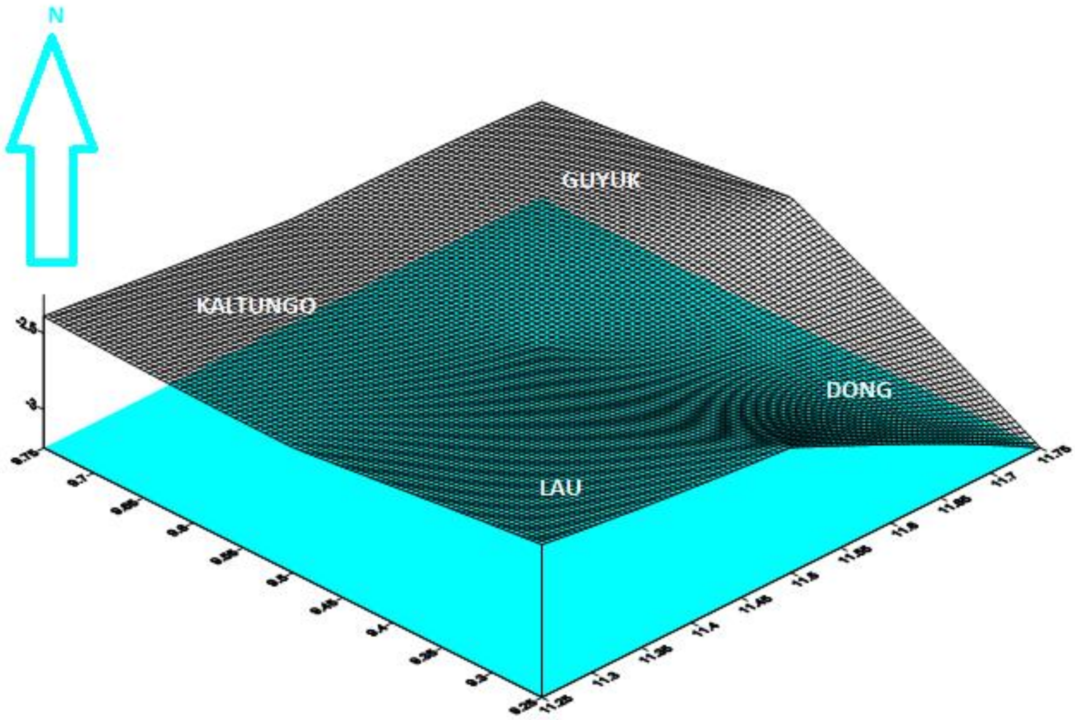
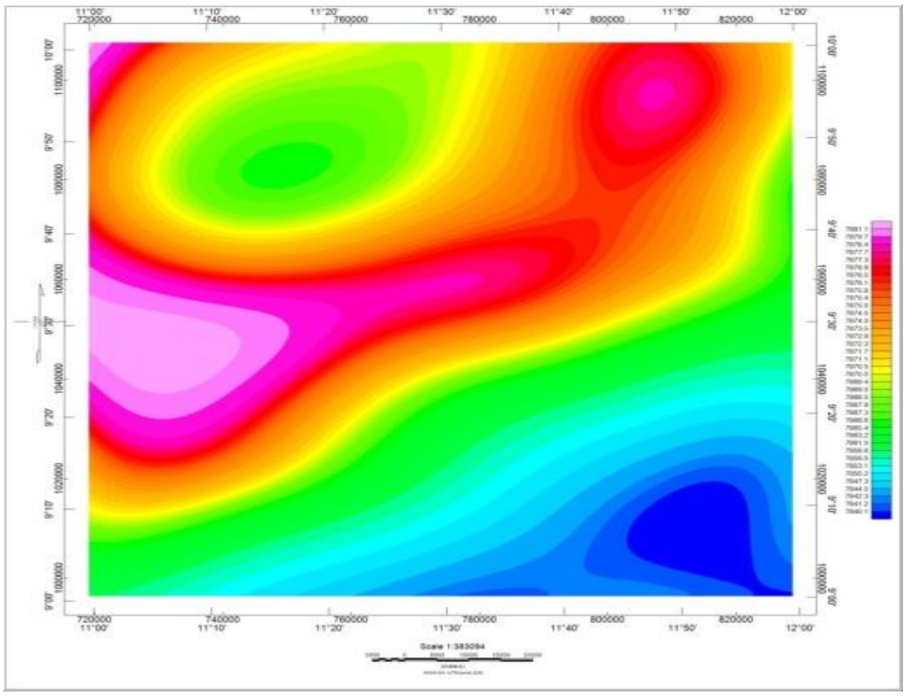


Figure 4.15b: 3-D map of second magnetic layer depth of the study area.

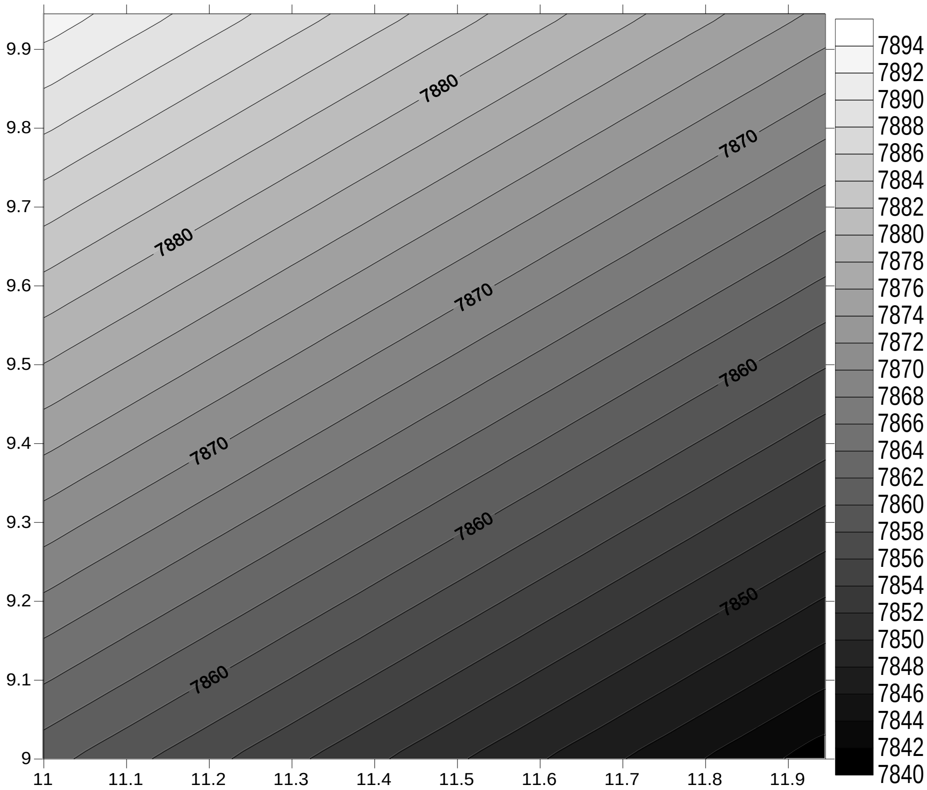
4.6 Comparism between Upward Continuation Map and Regional Map

Looking at the two maps (Figure 4.16) one can observe that the trends for both the regional and upward continuation maps are in approximately SW-NE directions. The trends for the regional map are however smoother and appear straight because all the residual effects have been completely removed by the polynomial fitting method which is an automatic operation. The regional trends for the upward continuation maps on the other hand are not smooth and straight as that of the regional map even at 20 km. In practical sense, the trend directions and smoothness of both the regional map from polynomial fitting and that from upward continuation map are supposed to be similar or the same.

The persistence of high magnetic values in the SW-NE direction on the upward continuation map therefore means that the residual effects have not been completely removed. The high magnetic values persisting in this direction is a clue to the direction of the so-called Kaltungo basement inlier which has been invaded by intrusive bodies which gave rise to these persistent high magnetic values. In addition, these intrusive bodies are believed to be deeply-rooted; hence their residual effects can only be totally removed when the height is continued above 20 km up to say 40 km. When this is done, the two maps (regional and upward continuation) will appear to be similar or the same in terms of smoothness and directions.



4.16a: Upward continuation map (20 km)



4.16b: Regional map

Figure 4.16: Comparism between the Upward Continuation map and Regional map

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The dominant SW-NE trend of high magnetic discontinuities on the shown on the TMI/residual maps indicates the direction of the Kaltungo Fault as reported by Benkhelil (1982[b]) and mapped by Popoff *et al.* (1983). The upward continuation analysis carried out shows that the study area is characterised by basically three distinct regions of magnetic anomalies. The first is an approximately linear trend of high anomalies trending SW-NE. The second and third regions are that of low to very low anomalies flanking the first on the northern and southern sides respectively. This region of high magnetic anomalies is indicative of uplifted basement whose rock types that give rise to these anomalies are mainly migmatite/gneiss and older granites. The region of low magnetic anomalies depicts deeper basement and is confined to the SE part of the map. Occurrences of basic to intermediate intrusive rock bodies both within the sediments and the basement have also been detected with the intrusive bodies more localised along the high magnetic SW-NE basement trend particularly around the SW and NE regions.

The spectral analysis of the residual magnetic field shows that the shallower magnetic sources occurred at depth ranging from 0.60 km and does not appear to exceed 1.00 km while that of the deeper sources range from 2.25 to 3.25 km. The deeper magnetic source depth which corresponds to the basement depth and also equivalent to the thickness of the sedimentary cover does not seem to exceed 2.75 km, and is confined to the SE part of the area.

In the prolific Niger delta with very high hydrocarbon potential, (Evamy, Hamboure, Kamerling, Knaap and Rowlands, 1978) show that the elastic sequence reaches a maximum thickness of 9 to 12 km. Since the thickness of the sediments within a basin is a first limitation to its oil generation potential, the study area may not be favourable for commercial oil/gas accumulation owing to its limited size and thickness. Even if the area were found to have thick sedimentary cover to warrant oil formation, the sporadic magmatic intrusions (Tertiary-Quaternary) which post-dated sedimentation (Cretaceous) in the basin might have interfered with the source sediments or oil in the affected areas. This is because of the general lack of association of hydrocarbon with intrusions due to the tremendous heat of ascent that usually accompany intrusions. Nevertheless, solid minerals such copper, zinc blende, galena, and other base-metal sulphides and ferromagnetic minerals as well as industrial minerals like barytes, limestone, and gypsum may be explored for within the region of the intrusive bodies and as fracture infillings/veins within the sedimentary cover. These intrusive bodies and the associated fractures in the basin are good sites for mineralisation.

5.2 Recommendations

Although the above conclusion is drawn based on the findings from the upward continuation and spectral depth analyses showing that the sedimentary cover is very limited in terms of size and thickness and that there are also occurrences of igneous intrusives within the basin, hence cannot favour commercial concentration of oil as compared to that of the profitable Niger delta, more detailed geological mapping should be carried out to ascertain the existence of hydrocarbon source rock, reservoir rock and other important structures that could favour hydrocarbon accumulation in a basin. Any further exploration work for oil and gas (where need be) should be narrowed towards the SE region where the sedimentary cover is somewhat deeper than the rest of the other part of the basin. Detailed gravity work should be conducted over this area to confirm the positions of the intrusive bodies in the basin, their size and seismic reflection/refraction work should be carried out to unravel the various geologic or lithologic boundaries and confirm the basement depth and structural relief. A fractal analysis should also be run on the data over the area; this can reveal the structural disposition pattern in the area that could favour mineralisation.

REFERENCES

Adegoke, O.S., Agumanu, R.E., Benkhelil, J. and Ajayi, P.O. (1986). New stratigraphic, sedimentologic and structural data on the Kerri-Kerri Formation, Bauchi and Borno States, Nigeria. *Journal of Africa Science 5, 249-277.*

Ajakaiye, D.E., Hall, D. H. and Millar, T.W (1981). Interpretation of aeromagnetic data across the central crystalline shield area of Nigeria. In C.A. Kogbe (Ed), *Geology of Nigeria* (pp. 81-92). Jos, Rock View Publishers (Nigeria) Limited.

Ajakaiye, D.E., Hall, D.H., Ashiekaa, J.A. and Udensi, E.E. (1991). Magnetic Anomalies in the Nigerian Continental Mass based on Aeromagnetic Surveys. *Tectonophysics, 192:211-230*

Akanbi, E.S. and Udensi, E. E. (2006). Structural trends and spectral depth analysis of the residual field of Pategi area, Nigeria, using Aeromagnetic Data. *Nigerian Journal of Physics 18(2), 271-276.*

Allix, P. (1983). Environements me'sozoiques de la partie nord-orientale du fosse' de la Be'noue' (Nigeria). Stratigaphie-Sedimentologie. Evolution ge'odynamique. *Travel Laboratory Science Terre, St. Jerome, Marseille Fr. B21, 1-200*

Barber W.N. and Jones, D.G. (1960). The Geology and Hydrology of Maiduguri, Bornu Province. *Reconnaissance Geological Survey of Nigeria 1958, p. 5-20*

Benkhelil, J. (1982[a]). Benue Trough and Benue Chain. *Geol. Mag. 119, p.155-168*

Benkhelil, J. (1982[b]). Structural map of the Upper Benue valley. *Nigerian Journal of Mining Geology. 18 p.140-151*

Benkhelil, J. and Robineau, B. (1983). Le fosse de la Benoue est-il un rift? *Bulletin Centres Rech. Exploration-Production. Elf Aquitaine 7, 315-21*

Benkhelil, J. (1986). Structure and Geodynamic Evolution of the Intracontinental Benue Trough (Nigeria*). PhD Thesis,* University of Nice. Published by Elf Nigeria Ltd SNEA (P)

Benkhelil, J., Conodera, C., Dainelli, P., Ponsard, J.F. and Saugy, L. (1985). Structural interpretation of the Benue Trough and Bornu Basin. *Geological interpretation of Radar Imagery, Gravity and Aeromagnetic Data and Field Data.* Elf Nigeria Ltd., Exploration Department

Benkhelil, J., Conodera, C., Dainelli, P., Ponsard, J.F., and Saugy, L. (1988). The Benue Trough: Wrench fault- related basin on the border of the Equatorial Atlantic. In

W. Manspeizer (Ed), *Triassic-Jurassic Rifting and the Opening of the Atlantic Ocean*. Amsterdam, Elsevier Pub. Co.

Carter, J.D., Barber, W. and Tait, E.A. (1963). The Geology of parts of Adamawa, Bauchi and Bornu Provinces in North-eastern Nigeria. *Geological Survey of Nigeria, Bulletin 30.*

Cratchley, C.R., and Jones, G.P. (1965). An Interpretation of the geology and gravity anomalies of the Benue valley, Nigeria. *Overseas Geological Survey/ Geophysics, Paper 1, 1-26*

Encyclopaedia Britannica, **(**2005). The Geologic Time scale.

Enu, E.I. (1978). Contribution a' l'e'tude sedimentologique des formations Cretacees dan lahaute vallee de la Benoue. *The'se 3eme cycle Nice, 178p.*

Evamy, B.D., Hamboure, J., Karmerling, P., Knaap, W.A. and Rowlands, P.H. (1978). Hydrocarbon habitat of the Tertiary Niger delta. *American Association of Petroleum Geologists Bulletin U.S.A., 62 (1): 1-39*

Ford, S.O. (1981). The Economic Mineral Resources of the Benue Trough. In C.A Kogbe (Ed), *Geology of Nigeria* (pp. 472-484). Jos, Rock View (Nigeria) Limited.

Grant, F.S. and West, G.F. (1965*). Interpretation Theory in Applied Geophysics.* New York, McGraw Hill Book Co. Inc.

Grant, N.K. (1965). The Geology of part of the Dadiya syncline, Northeastern Nigeria. *Nigerian Journal of Mining Geology 2, p.17-28*

Hahn, A., Kind, E.G and Mashira, D.C. (1976). Depth estimation of magnetic sources by means of Fourier amplitude spectra. *Geophysical Prospecting 24, 287-308.*

Hall, D.H. (1968). Regional magnetic anomalies, magnetic units and crustal structure in the Kenora district of Ontario. *Canadian Journal of Earth Science Pp: 1227-1296.*

Hall, D.H**.** (1974). Long wavelength aeromagnetic anomalies and deep crustal magnetisation in Manitoba and Northern Ontario, Canada. *Canadian Journal of Geophysics 40, 430.*

Jones, G.P. (1960). Deformed cross-stratification in Cretaceous Bima Sandstone. *Journal of Sedimentary Petrology 32, p.231-23911.*

Kanasewich, E. R., and Agarwal, R. G. (1970). Analysis of combined gravity and magnetic fields in wave number domain. *Journal of Geophysical Research, 75, 5702-12*.

Kangkolo, R. (1996). A detailed interpretation of aeromagnetic field over Mamfe basin of Nigeria and Cameroun. *Unpublished PhD Thesis,* Ahmadu Bello University Zaria, Nigeria

Kearey, P. and Brooks, M. (1990). *Introduction to Geophysical Exploration*, (2nd Edition). Blackwell Scientific Publications.

Kogbe, C.A. (1976). Palaeogeographic history of Nigeria from Albian times. In C. A. Kogbe (Ed), *Geology of Nigeria* (pp.237-252). Lagos (Nigeria), Elizabethan Pub. Co.

Matheis, G. (1976). Short review of the Geology of the Chad Basin in Nigeria. In C.A Kogbe (Ed), *Geology of Nigeria (*pp. 289-294). Lagos Nigeria, Elizabethan Pub. Co.

Maurin, J.C., Benkhelil, J. and Robineau, B. (1986). Fractured rocks of the Kaltungo lineament, NE Nigeria, their relationship with the Benue Trough tectonics. *Journal of Geological Society, London 143, 587-599*

Nettleton, L.L. (1976). *Gravity and Magnetics in Oil Prospecting.* International series in the earth and planetary sciences .New York, McGraw-Hill Book Co.Inc.:452pp

Nkem, J. (2002). Politics of Oil Exploration in the North. www.nigerdeltacongress.com

Nsikak, E. B, Nur, A. and Gabriel, I.D. (2000). Analysis of aerial photographic data over Guyuk Area, Northeastern Nigeria. *Journal of Mining Geology 36(2): 145-152.*

Obaje, N.G. (2009). *Geology and mineral resources of Nigeria*. Germany, Springer Publishers, Pages 1-203

Ofoegbu, C.O. (1984). A model for the tectonic evolution of the Benue Trough. *Nigeria Geological Research 73, 1007-1018*

Ofoegbu, C.O. (1988). An aeromagnetic study of part of the Upper Benue Trough Nigeria. *Journal of African Earth Science 7, 77-90.*

Onuba, L.N., Onwuemesi, A.G., Anudu, G.K., Chiaghanam, O.I. and Ifelunni, C.D., (2008). Interpretation of Aeromagnetic Anomalies over Upper Benue Trough Northeastern Nigeria, Nigeria. *Natural and Applied Sciences Journal 9(1). Available online @* www.naasjournalng.org

Osazuwa, I.B. (1978). Gravity and magnetic surveys in the Upper Benue. *Unpublished M.Sc Thesis,* Ahmadu Bello University, Zaria.

Pal, P.C., Khuran, K.K .and Unnikrishnna, P. (1978). Two examples of spectral approach to source depth estimation in gravity and magnetics. *PAGEOPH 117, 772-783*

Popoff, M., Benkhelil, J., Simon, B. and Motte, J.J. (1983). Geodynamic approach to the Benue Trough (NE Nigeria) using field and teledetection data. *Bulletin Centres Research Exploration- Production. Elf Aquitaine 7, 323-337.*

Reyment, R.A. (1965). *Aspects of the Geology of Nigeria:* University of Ibadan Press.

Reyment, R.A. (1980). Paleobiogeography of the Saharan epicontinental transgressions. *Bulletin Department of Geology, 2(2).* Ahmadu Bello University, Zaria, Nigeria.

Shehu, A.T. (2003). Spectral Analysis of the magnetic Residual Anomalies over the Upper Sokoto basin, Nigeria. *Unpublished M.Tech Thesis,* Federal University of Minna, Niger State.

Shemang, E.M, Jacoby, W.R, and Ajayi, C.O. (2005). Interpretation of gravity data over Gongola Arm of the Upper Benue Trough. *Global Journal of Geological Science 3(1): 61-69.*

Skeel, D.C**.** (1967). What is Residual Gravity? *Geophysics 32, 872-876.*

Spector, A. (1968). Spectral analysis of aeromagnetic maps. *PhD Thesis,* Department of Physics University of Toronto.

Spector, A. and Grant, F.S. (1970). Statistical models for interpreting Aeromagnetic data. *Geophysics 35(2), 293-302*

Telford, W.M., Geldart, L.P, Sheriff, R.E. and Keys, D.A. (1976). *Applied Geophysics*. Cambridge, Cambridge University Press: 841pp

Tubosun, I.A (1983). Geochronologie U/Pb Socle Precambrian du Nigeria. *Unpublished 3 eme CycleThesis, Univ. des Sciences et Techniques du Languedoc.*

Udensi, E.E, and Osazuwa, I.B. (2003). Spectral determination of the depths to the buried magnetic rocks under the Nupe Basin, Nigeria. *Nigerian Journal of Physics, 15(1), 51-59.*

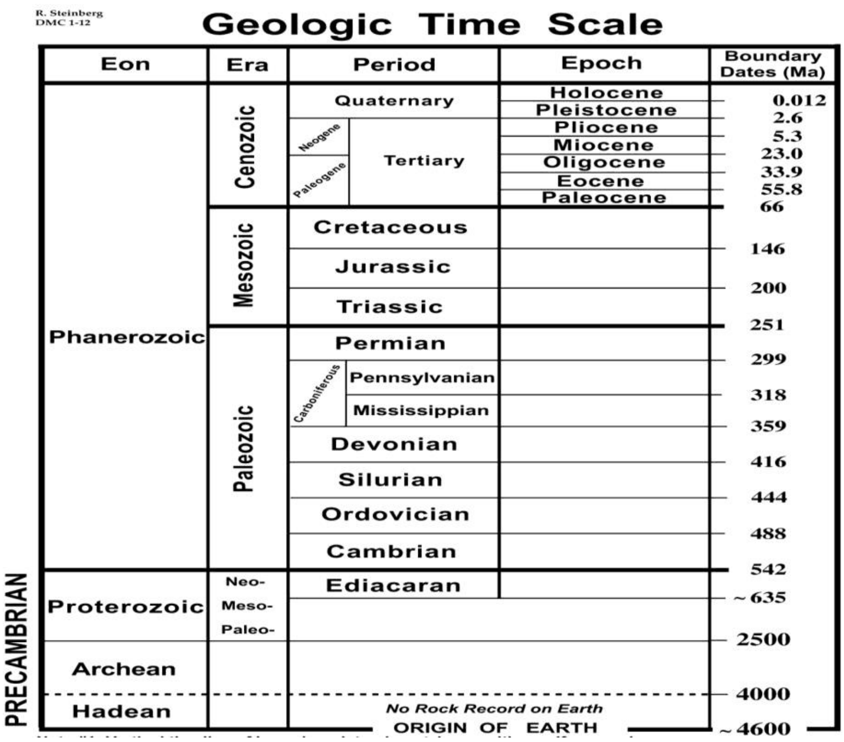
Udensi, E.E. (2004). Two and half dimensional Modelling of the Sandstone Thickness of the Pategi area, Central Nigeria using Aeromagnetic data. *GFF, Journal of Geological Society of Sweden, 126(1), pp.93.*

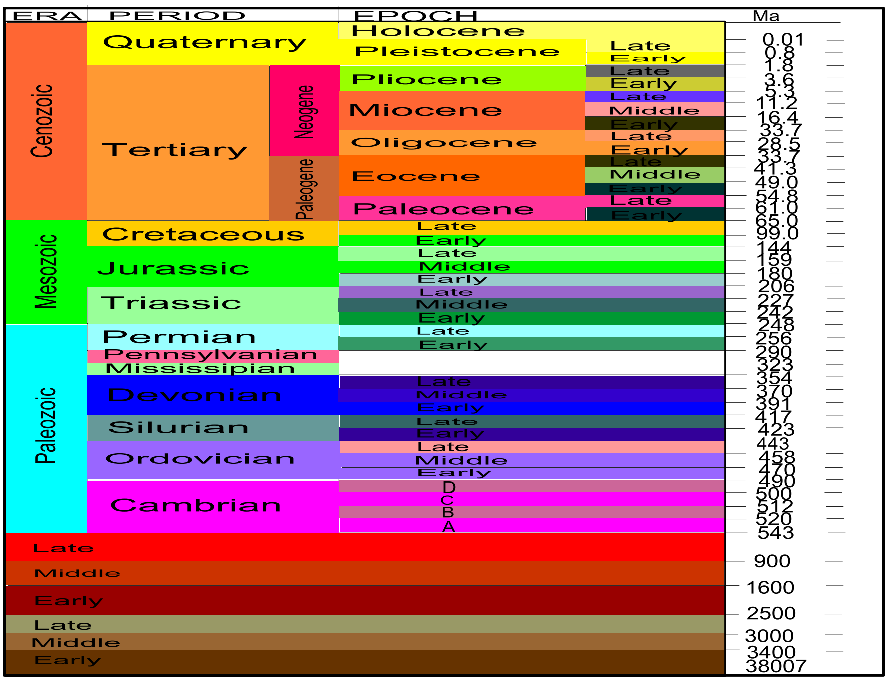
Van Breeman, O., Pidgeon, R.T. and Bowden, P. (1977). Age and isotopic studies of some Pan-African granites from North-central Nigeria. *Precambrian Research 4, 307-319.*

Whiteman, A. (1982). *Nigeria: Its Petroleum Geology, Resources and Potential*. London, Graham and Trotman Pub. Co.

Appendix A

The Geologic Time Scale

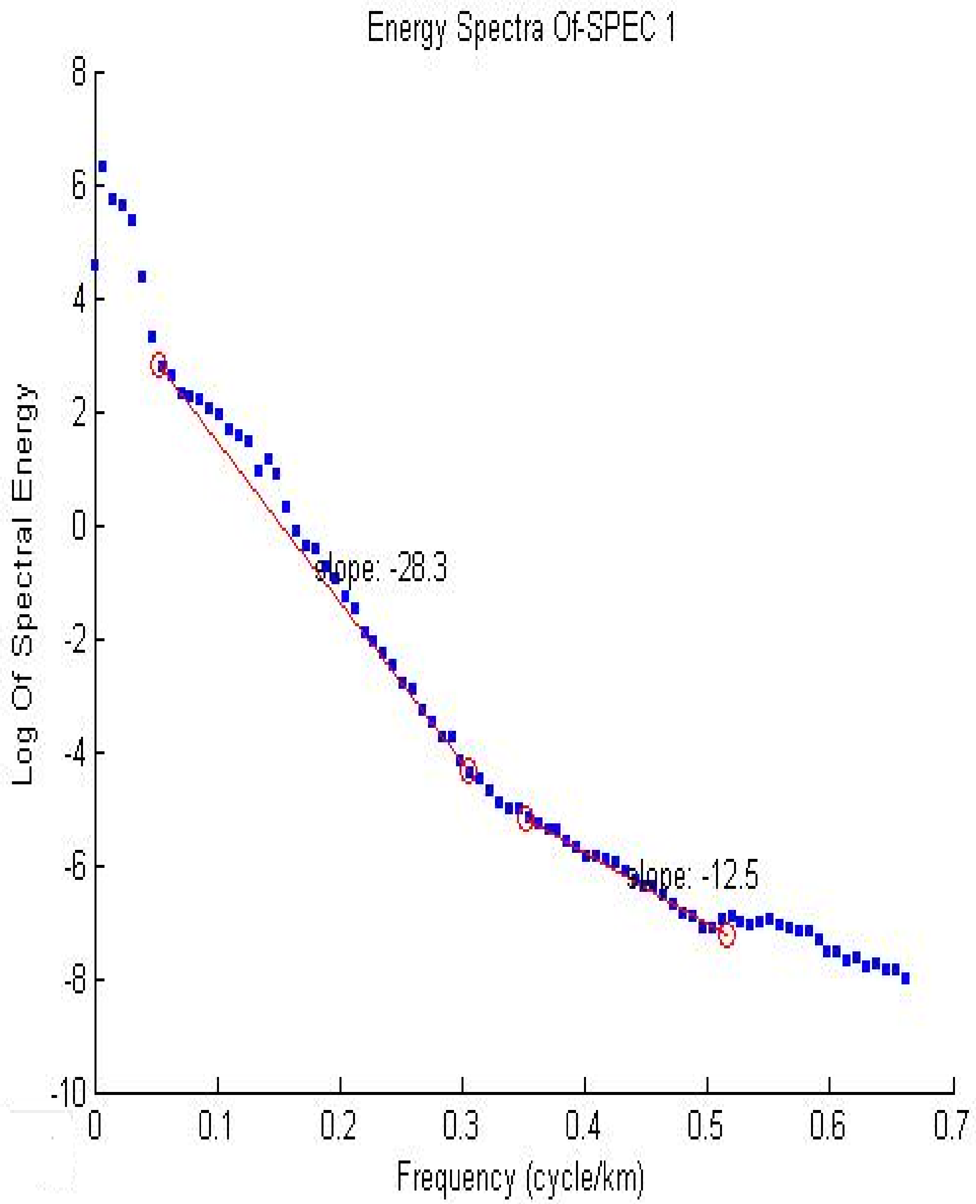




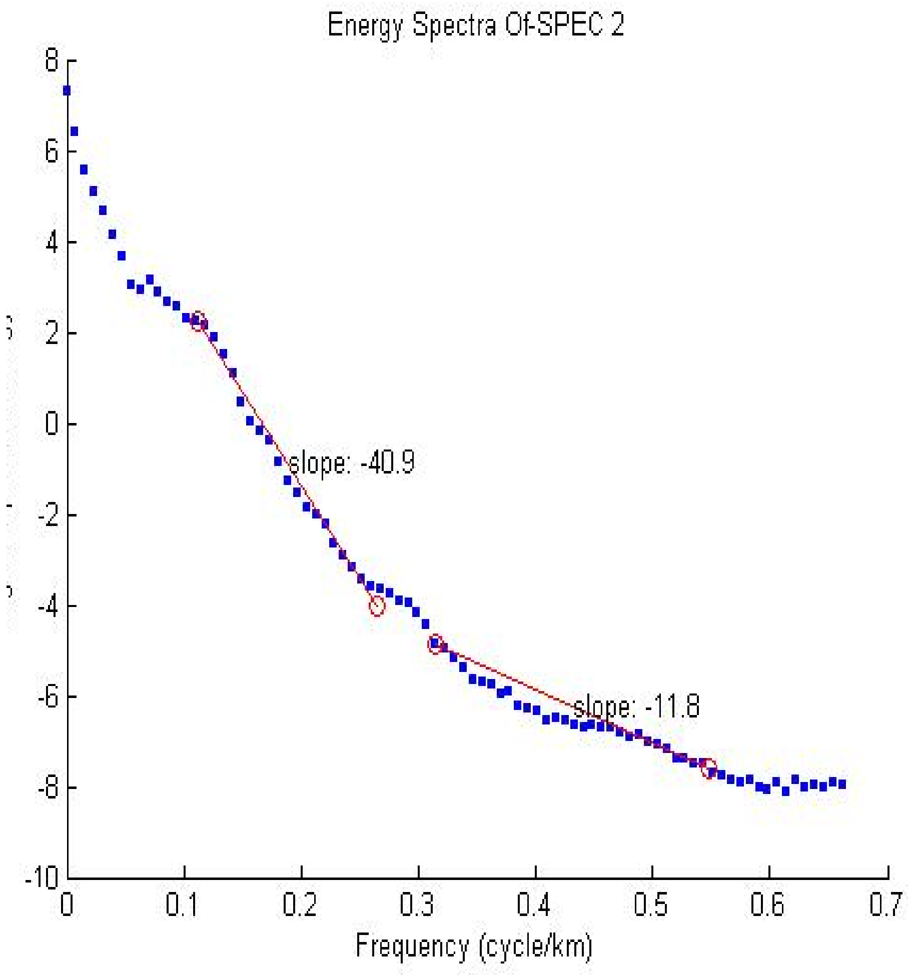
Source: Encyclopaedia Britannica, 2005

Appendix B

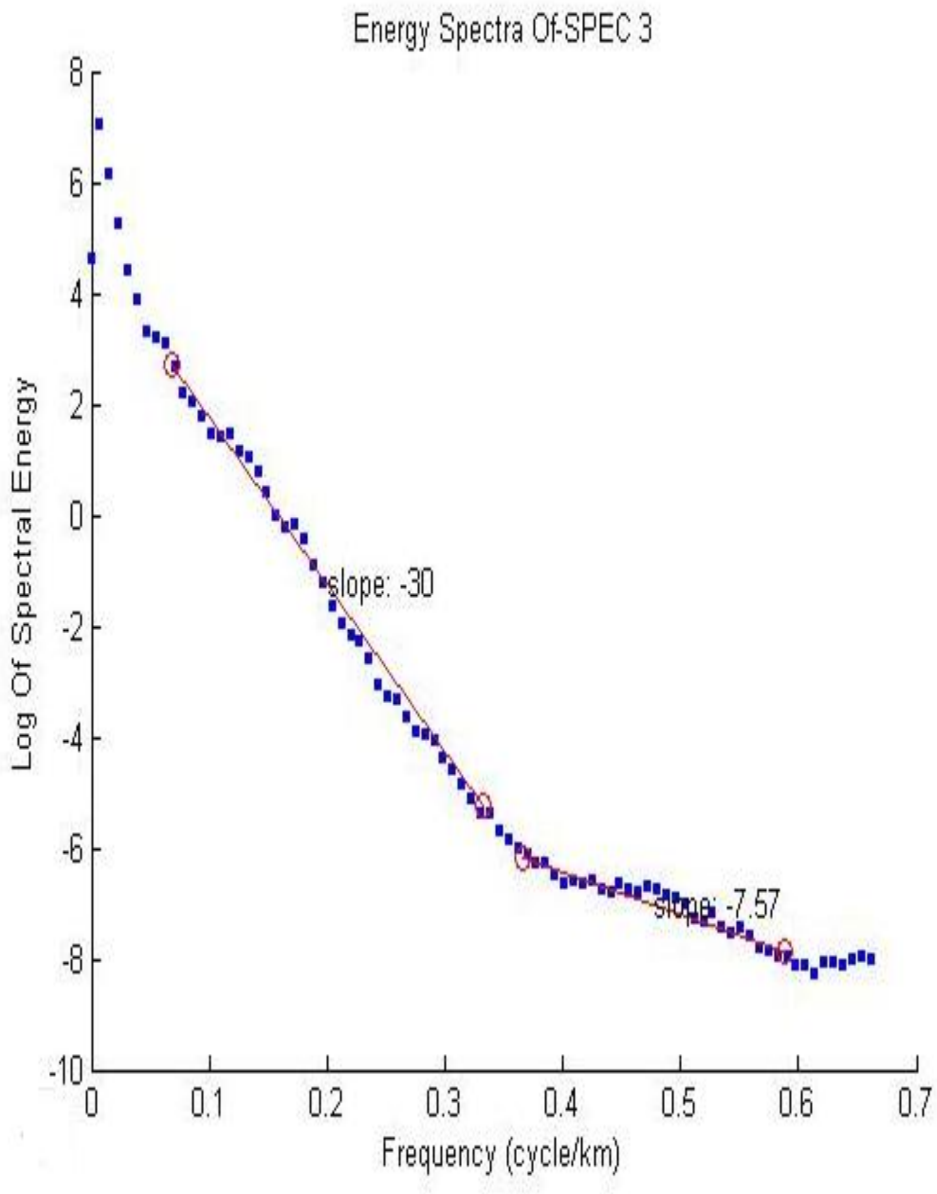
Spectral Depth Plots



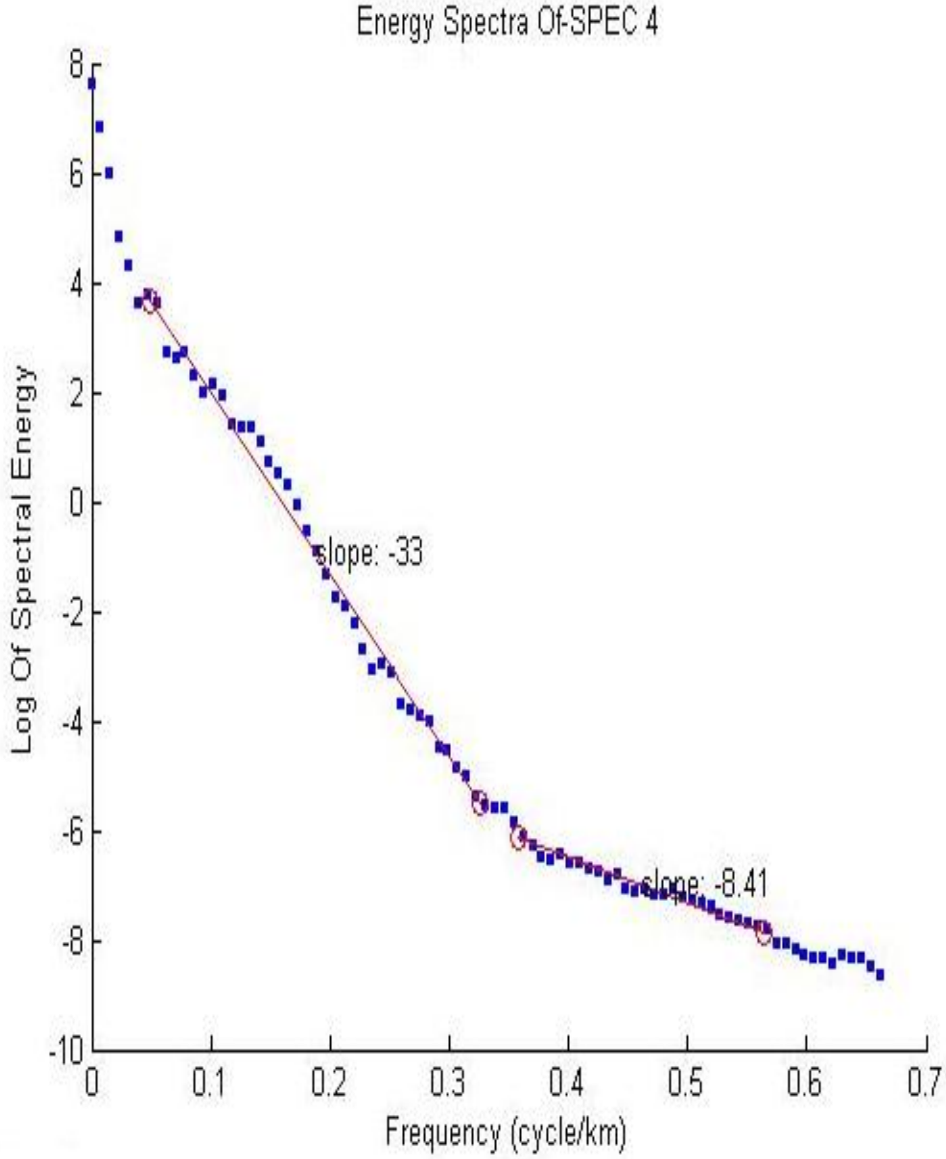
Appendix B Cont'd



Appendix B Cont'd



Appendix B Cont'd



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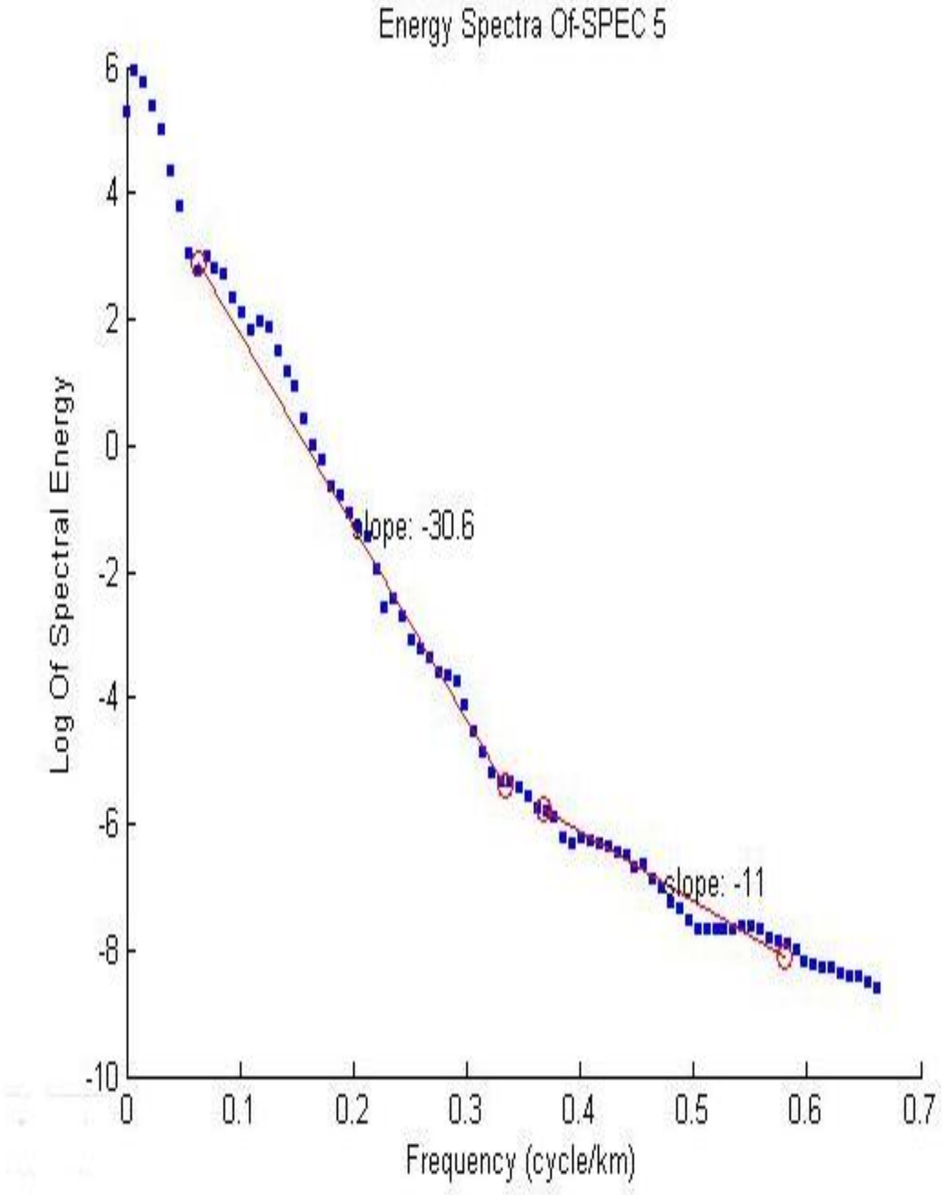

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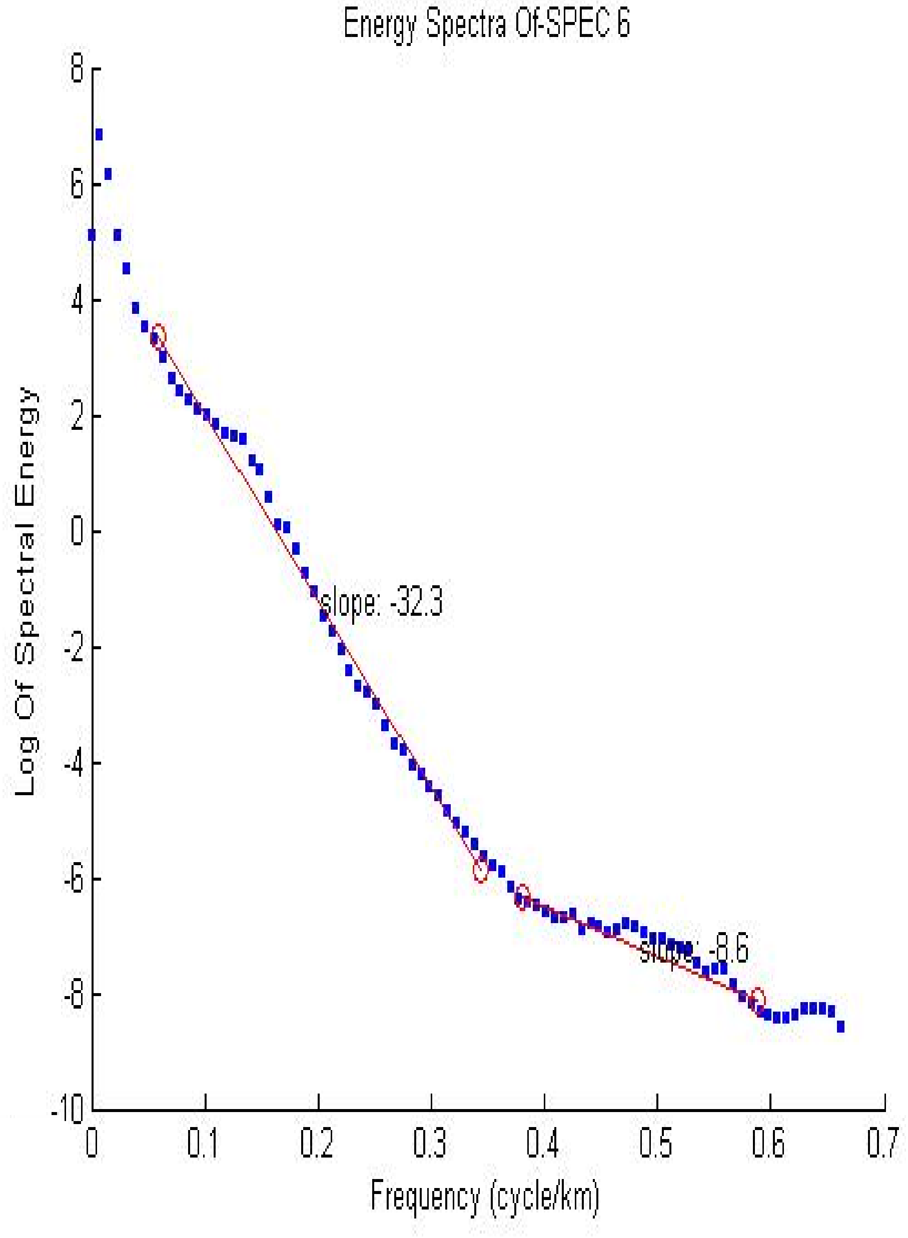

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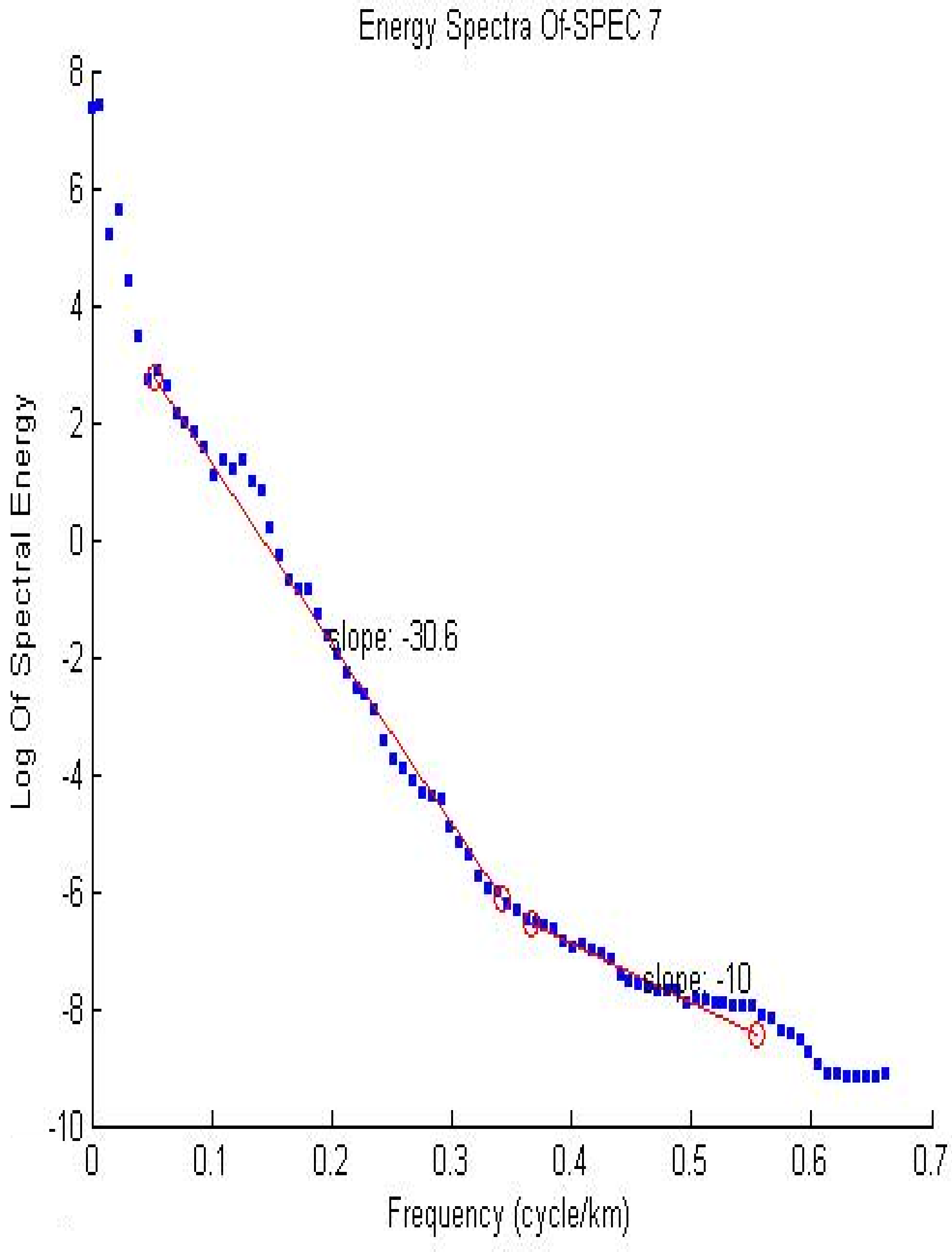

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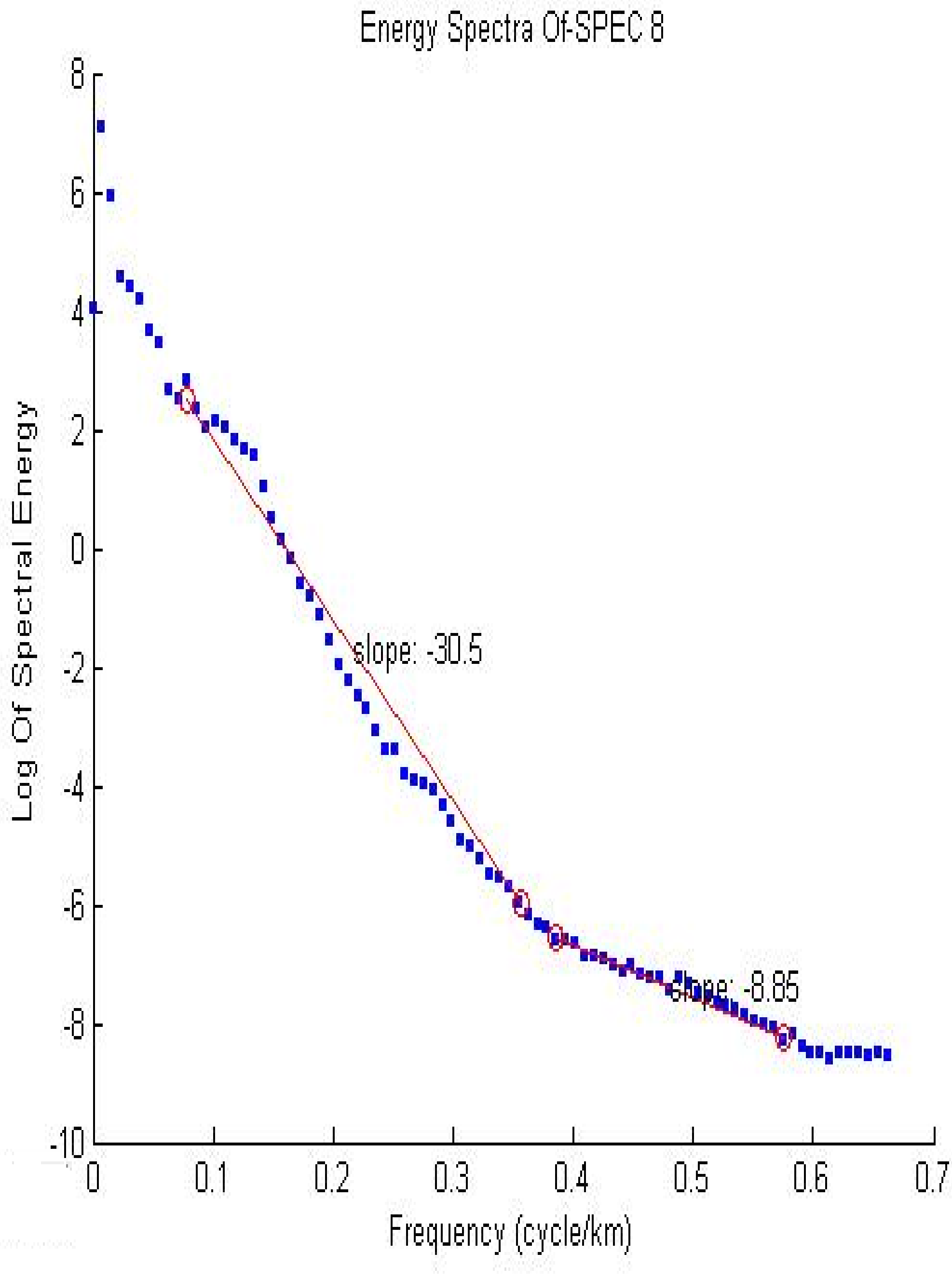

Appendix B Cont'd