Integrated Study of Gravity and Aeromagnetic Data over Malumfashi Area of Katsina State, Nigeria

Gana, Ç. S.,* Udensi, E. E., and * Jonah, S. A.
Department of Science Education, Federal University of Technology, Minna
*Department of Physics, Federal University of Technology, Minna

ABSTRACT
In this study, a geophysical study of the Malumfashi area of Katsina State was carried out using aeromagnetic and gravity data. The objective of the study was to investigate the subsurface geologic structures in the area. A 2½-dimensional model of the subsurface structures showed that the thickness ranges between 3.5 km (for schist) and 8-9 km (for granite) while the width range between 33 km (for schist) and 45 km (for granite). The gravity/magnetic measurements show large negative anomalies, ranging from -33 mGal to -65 mGal for gravity and 0.0 nT to 170 nT for magnetic. A regional anomaly ranging from about -56 mGal in the southwestern part of survey area to about -44 mGal in the northeastern part of the survey area is tentatively correlated with a gradual thinning of the crust from southwest to northeast while the magnetic regional anomaly showed an opposite of the gravity regional anomaly. High-gravity gradients of up to 6mGal at some contact area between the schist and granite bodies are attributed to sharp contact; magmatic stopping is thought to be the most likely mode of emplacement of the granite bodies in the area. The bouguer anomalies observed over the schist have a maximum of only -34mGal. These values are considered to be too low to allow for the existence of more mafic rock at depth and the schist in the area are therefore believed to have evolved in an ensialic environment.

Keywords: Aeromagnetic, gravity, anomaly, modeling, intrusion

1.0 Introduction

The aim of this study is the use of both magnetic and gravity methods to study the subsurface geologic structures in the Malumfishi area of Katsina State. This study is an extension of an earlier work in the area using gravity method (Gandu et al., 1986). The study also represents one of the many attempts to study Precambrian schist belts geophysically. The aeromagnetic residual data from the area would be interpreted alongside the gravity residuals of Gandu et al. (1986). It is believed that the subsurface geological structure and their relationship will be better defined by a combination of magnetic and gravity methods. This study is also concerned with providing more information on the geological history of the area. Prior to this research, few major geophysical surveys have been carried out in the area. Ajakaiye and Verheijen (1977) carried out a regional gravity survey of the former Kano State. The study of Gandu et al (1986) showed that the maximum thickness of the schist over the crust is estimated to be 1.4km. Also thicknesses estimated from two-dimensional modeling were 4km for granites and vary from 4 to 5km for schist.

2.0 Location of Study Area

Malumfashi, lies within the schist belt of northwestern Nigeria in Katsina State. It occupies an area of about 6500km^2 and it lies between longitudes of $7^{0}30^{I}$E and $8^{0}30^{I}$E and latitudes 11^{0} 30^{I}N and $12^{0}30^{I}$N, Fig. 1. The average elevation is approximately 580m above sea level, and the vegetation type is typically savannah with isolated trees amongst stunted shrubs.

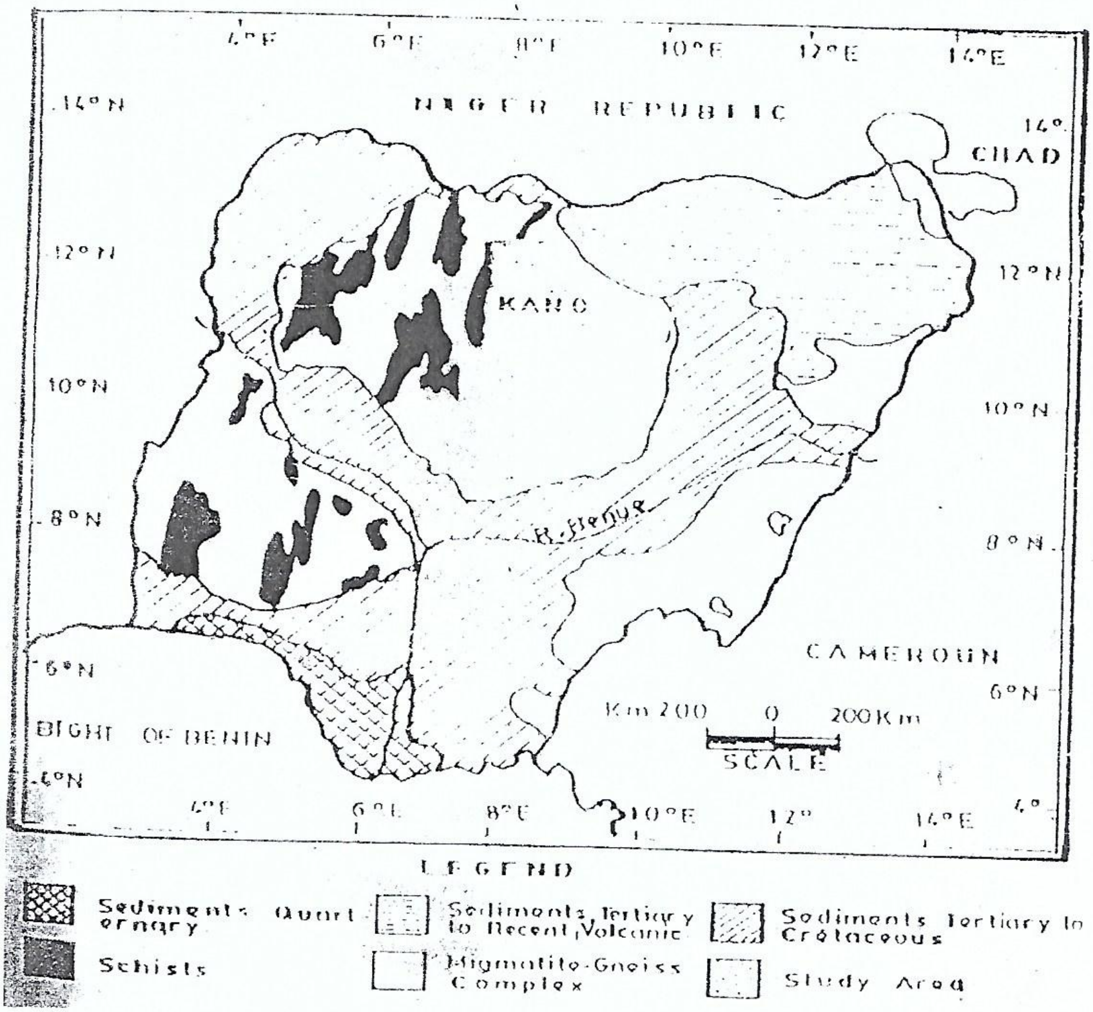

Fig. 1: Simplified Geological Map of Nigeria (Source: Geological Survey of Nigeria)

3.0 Magnetic Surveying Method

The oldest branch of geophysics is the study of the earth's magnetism (Kearey and Brooks, 1988). Investigation of the subsurface geology on the basis of anomalies in the earth's magnetic field resulting from the magnetic properties of the underlying rocks is the sole aim of a magnetic survey. Although most rock-forming minerals are effectively non-magnetic, certain rock types contain sufficient magnetic minerals to produce significant magnetic anomalies. Similarly, artificial ferrous objects also generate magnetic anomalies. Magnetic surveying thus has broad range of applications, from small-scale engineering surveys or archaeological surveys to detecting buried metallic objects, to large-scale surveys carried out to investigate regional geological structures. Magnetic surveys can be performed on land, at sea, and in the air. Consequently, the technique is widely employed and the speed of operation of airborne surveys makes the method very attractive in the search for types of ore deposit that contain magnetic minerals (Kearey and Brooks, 1988). Magnetic anomalies are caused by magnetic minerals (mainly magnetite and pyrrhotite) contained in rocks. It is important to note that magnetically important minerals are surprisingly few in number. Magnetic anomalies caused by rocks are localized effects superimposed on the magnetic field of the earth (geomagnetic field). Consequently, knowledge of the behaviour of the geomagnetic field is necessary in both the reduction of magnetic data to a suitable datum and the interpretation of the resulting anomalies. The geomagnetic field is geometrically more complex than the gravity field and it exhibits irregular variation in both orientation and magnitude with latitude, longitude, and time. A freely-suspended steel needle that is not magnetized will usually assume an orientation which is neither horizontal nor in line with geographic meridian. This orientation is the direction of the total field at a point.

In gravity survey, it is the anomaly caused by subsurface variation in the density of the various subsurface rocks that is measured. This anomaly is usually superimposed on the existing gravity field of the earth at the position in which measurements are carried out (Kearey and Brooks, 1988).

The choice of the use of aeromagnetic data was informed by the availability at the Geological Survey of Nigeria of airborne-conducted aeromagnetic survey data.

4.0 General Geology of the Basement Complex

The basement complex covers more than half of Nigeria. Cretaceous and younger sediments overlie the basement complex in the remaining part of the country. The basement complex is believed to be Precambrian in age. However, it probably contains a number of intrusions of Paleozoic age (Oyawoye 1964). The earliest study of the complex was carried out by Falconer (1911) who identified the age distinction between the Precambrian Older Granites and Jurassic "Younger" Granites of Jos Plateau. The geology of the basement complex is quite complicated. The terrain involved represents a level at considerable depth in the earth which has now been exposed through erosion over several millions years (Russ 1957, Oyawoye 1964). The rock of the basement complex can be divided into three lithological units (Jones and Hockey, 1964; Ajibade, 1980), viz:

1. The migmatite gneiss complex which covers about 70% of the whole basement.
2. The metasediments and metavolcanics which form N-S trending schist belts.
3. The Older Granites which intruded both the migmatite-gneiss complex and schists belt.

The migmatite-gneiss complex is the largest unit in the basements complex and consists essentially of migmatites, quartz perthitic-biotite-hornblende gneiss with relicts of metasedimentary rocks. It is considered to be the oldest unit in the complex and probably evolved from sedimentation followed by successive migmatization, granitization and igneous intrusion (Russ, 1957). Following the formation of the gneisses, a period of sedimentation intervened and predominantly fine-grained rocks were deposited, probably in moderately deep water (Russ, 1957). During the episode of compressions which followed the sedimentation, the sediments were isoclinically folded and largely converted to schists. The metasediments and metavolcanics form the schists belts. They consist of low grade metamorphosed sedimentary rocks and associated metamorphosed volcanic rocks. Their age is believed to be between 800 and 1000 millions years (McCurry, 1976). The metasediments are thought to have once covered the whole basement complex area. They have been removed by subsequent erosion and are now preserved in synclical troughs. After folding and other tectonic deformation and metamorphism of the sediments, there followed a period of granitic intrusion. This was the oldest granitic cycle, known throughout Nigeria (Falconer, 1911; Russ, 1957; Truswell and Cope, 1963). The Older Granites are bodies of igneous rock of various compositions, ranging from true granites to tonalities and charnolcitic rocks, which intruded both the migmatites-gneiss complex and schist belts. They occur as elongated batholiths or small circular plutons. Age determinations on Older Granites all over Nigerian have yielded Pan-African age (600my) (Van Bieemen *et al*, 1976; Grant, 1978). The geological map of Malumfashi Area is shown in Fig.2.

5.0 Data Acquisition

The Geological Survey of Nigeria (GSN) carried out aeromagnetic survey over the entire country between 1974 and 1980. The magnetic information consists of flight lines plotted on continuous strip chart or tape records. To achieve this, the Nigeria landmass was flown at altitude 500ft (152.4m) along N-S flight lines direction spaced approximately 2km apart. The data were later published in the form of $1/2^0$ by $1/2^0$ aeromagnetic maps on scale 1: 100,000. The magnetic values were plotted at 10nT (gamma) interval. The maps were numbered and named according to the places covered for easy reference. The country was divided into a total of 340 block call sheets. The actual magnetic values were reduced by 25,000 gammas before plotting the contour maps

(Huntings, 1976). This means that the value of 25,000 gammas should be added to the contour values so as to obtain the actual magnetic field at a given point.

6.0 Techniques Adopted for Digitization of the Data

The data set used in this study was compiled by digitizing on a 1 X 1 km system using visual interpolation method. This procedure was adopted because the original data recorded on tape during survey could not be obtained. Four aeromagnetic maps cover the study area. They are map numbers 56, 57, 79 and 80. These maps were obtained from Geological Survey of Nigeria. The contour lines in all the maps were dense. Therefore it was easy to adopt the method used with very minimal errors of human judgement. The maps were digitized on a 1 X 1 km grid system. This spacing imposes a Nyguist frequency of 1/4 km^{-1} line. The narrowest magnetic feature that can be defined by the digitized data has a width of 4km. Previous work with crustal magnetic anomalies (e.g. Hall, 1968; 1974 and Udensi, 2001) showed that this spacing is suitable for the interpretation of magnetic anomalies arising from regional crustal structure.

7.0 Contouring of Maps using Surfer-8 Program

Having digitized each aeromagnetic map, the data were stored in 38 by 38 coding sheets, each of which contains records of the boundary longitudes and latitudes, the map number and map sheet name. The data were entered into a computer file. The data file thereafter became the input file for a computer program, which picked all the data points row by row, calculate their longitudes and latitudes and write out the results as columns of x, y, z where x, y, z representing longitude, latitude and the magnetic values for coordinates respectively. Each output file for this operation was given a name for easy identification. The three-dimensional coordinate from x, y, z is the form the data must be so as to be acceptable to a contouring package called Surfer-8. Surfer-8 is a menu driven interactive computer program which places each magnetic data point according to their longitude and latitude bearing and thereafter produces a contour map for each small map.

8.0 Compilation of the Aeromagnetic Map of Malumfashi Area

A composite aeromagnetic map of the study area was produced by joining the four maps covering the study area together. The four maps are map 56, 57, 79 and 80. The adjacent longitudes and latitudes are identical therefore in merging the four maps, the last column on sheet 56 and 79 were added to the first columns of sheet 57 and 80 to give four columns which was then divided by two to obtain two rows. This addition was carried out in Microsoft Excel environment.

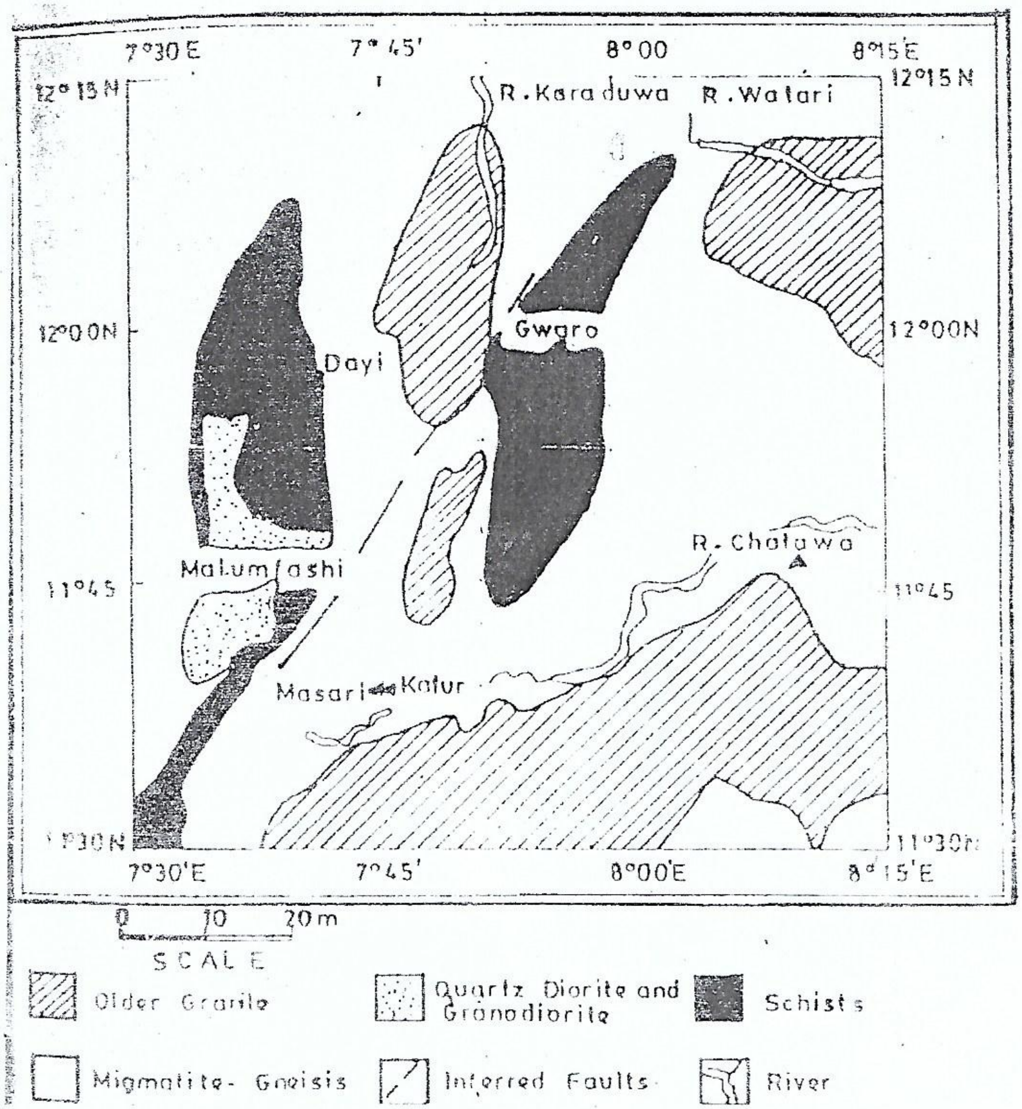

Fig. 2 Geological Map of Malumfashi

9.0 Composite Aeromagnetic Map

9.1 Introduction: In composite aeromagnetic map, the picture that usually emerges is one that shows the superposition of disturbances of noticeably different magnitude. The larger features generally show up as trends, which continue smoothly over considerable distance. They are caused by the deeper heterogeneity of the earth's crust. These trends are called the regional. Superimposed on the regional fields, but frequently camouflaged by them are the smaller, local disturbances, which are secondary in size but primary in importance. These are the residual anomalies, which may provide direct evidence of the existence of reservoir-type structures or mineral ore bodies. For potential field data to be interpreted, the residual anomalies must be separated from the regional background field. In some respects the problem usually conceived is analogous to the filtering in seismic survey. There are several methods of removing the unwanted regional. One approach is entirely graphical. The other one is analytical.

9.2 Magnetic Trends and Structures: Spatial variations in the total magnetic field over an area reflect the variations in the magnetization of the rocks below the magnetometer. The area studied forms part of the Nigerian Basement complex and consists of Older Granite, quartzite and granodiorite, schist and migmatite-gneiss. All measurable features at the surface would result from topographic or lithologic changes associated with the basement rocks. Fig.3 shows the composite aeromagnetic map of the study area. The axes are in degrees and contour interval is 20nT. As expected, in a basement complex area the magnetic map of the study area of Fig. 3 is complex. The gradients are steep, particularly along the central part. The composite aeromagnetic map (Fig. 3) shows that most of the study area is characterized by a NE-SW trend. At the northeastern part of the map it shows a N-E trend which repeats at the central part of the map. The NE-SW trends agree with the opinion of Buser (1966). In the study that covered Nigeria and surrounding countries, he established the existence of paleostructures, which have directed events like tectonic movements, intrusions, metamorphism, sedimentation, mineralization, volcanism and drainage. He identified these paleostructures as striking in a NNE-SSW direction. These structures are in the form of crests and depressions. The closure in the middle part of the map is a major discontinuity comprising of smaller ones as shown in Fig.3. The dominant trends in total magnetic field of an area are usually an indication of the features such as dykes, faults and fractures. In this work, the features are characterized by NE-SW trend. The composite map of the study area displayed a number of faults. Faults are usually identified with discontinuities in magnetic anomaly or intensity maps (Telford et al, 1976; Ajakaiye *et al*, 1985; 1991). The major closures at the central part of the composite map of Fig.3 correlate with schist, which is shallow and likely to be underlain by magnetite-gneiss. The closure at the southern part of the map correlates with granite; another closure at the central part of the map also correlates with schist.

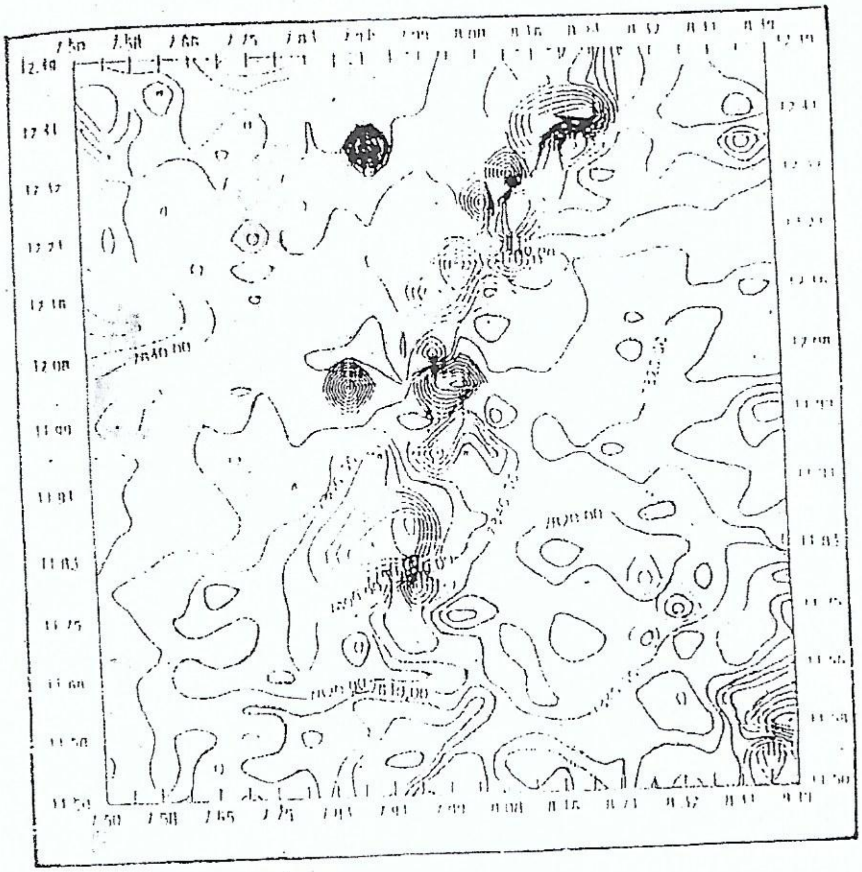

Fig. 3 Aeromagnetic Map of the Malumfashi Area. Axes are in Degrees and Contour Interval is 20nT

10.0 Methods of Regional-Residual Separation

10.1 Analytical Methods: Four analytical approaches are in common use. The direct calculation of residuals by techniques such as the centre point-and-ring methods, the determination of second vertical derivatives, upward and downward continuation, and polynomial fitting. With analytical methods of determining residual anomalies, numerical/operations on observed data make it possible to isolate anomalies without such a great reliance upon the exercise of judgement in carrying out the separations. Such techniques generally require that the magnetic values be spaced in a regular array. Though in this work, the array were irregular so as to be able to represent the superimposed gravity profile without estimation. The polynomial fitting method is about the most flexible and most applied of the analytical methods for determining regional magnetic fields (Skeels, 1967; Johnson, 1969 and Dobrin, 1976). The treatment is based on statistical theory. In this method, matching of regional field by a polynomial surface of low order exposes the residual features as random errors. The observed data arc used to compute, usually by least square, the mathematically describable surface giving the closest fit to the magnetic field that can be obtained within a specified degree of detail. This surface is considered to be the regional field, and the residual is the difference between the magnetic field value as actually mapped and the regional field value thus determined.

10.2 Visual Smoothing: Visually smoothing the contour lines is one of the oldest and most traditional methods of making the regional-residual separation. The process works roughly by successive approximations in the following way. The trend of the regional field is assumed and profiles are drawn along that trend. The set of profiles, which emerge from this exercise, is then examined with a view to further smoothing, and so on until an acceptable regional map is achieved. This method has the merit of being highly flexible, since it allows the interpreter to incorporate into the process his personal judgement or sense of "rightness about the forms of residual anomalies." This method will be satisfactory when the regional trend is fairly evident from beginning. The use of this personal bias is subjective, but it is entirely reasonable (Grant and West, 1965).

This method however fails in surveys with complex geology, and also when the contour maps are complex. Magnetic contour maps are usually complex and thus this method is rarely applied in magnetic survey. The least square polynomial fitting method was adopted in this study. The study area does not have complex geology and it has limited spatial extent, therefore it seemed adequate and reasonable to assume that the regional field is a first order polynomial surface. All the regional fields were therefore calculated as a two dimensional first-degree polynomial surface. The polynomial coefficients were used to compute the regional map of the study area. The regional map is shown in Fig.4. The regional map trends E- W, which agrees with trends in the study area. A computer program was used to subtract values of the regional field from the total magnetic field value at grid points giving the residual map. Fig.5 shows the contour map of the residual magnetic anomaly values; these values range from +60nT to - 170nT. The negative magnetic residual values correlates with schist and positive magnetic values correlate with granite. This result is going to be used for analysis and interpretation in the subsequent chapters.

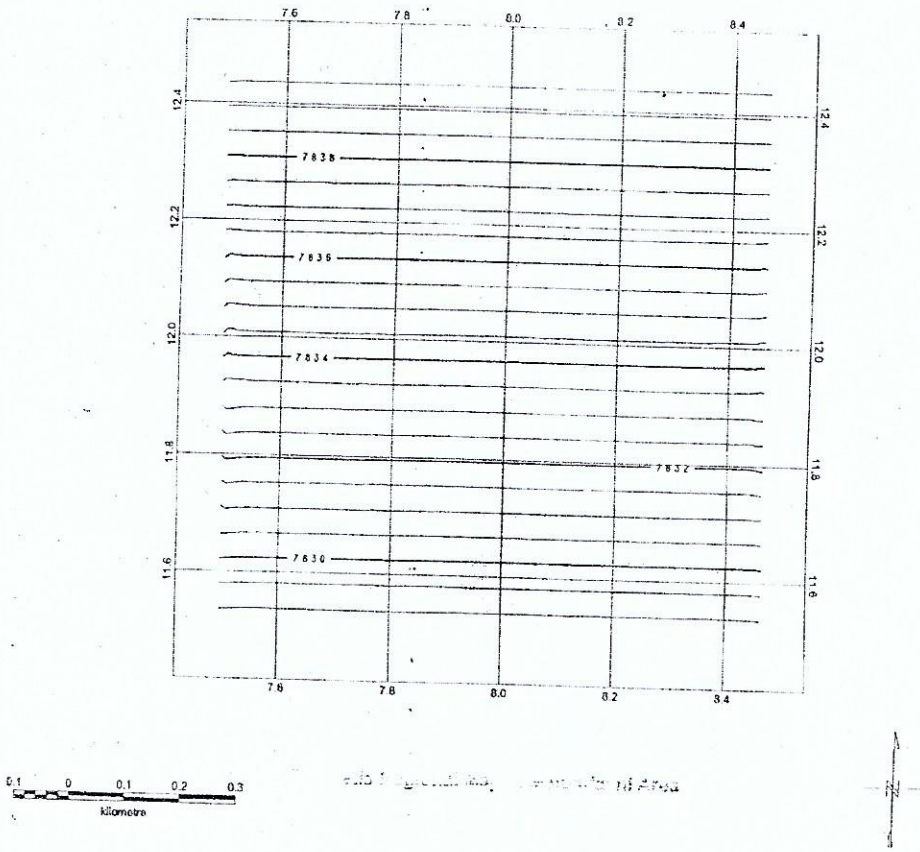

Fig. 4 **Regional Magnetic Map of the Malumfashi Area. Axes are in Degrees.**

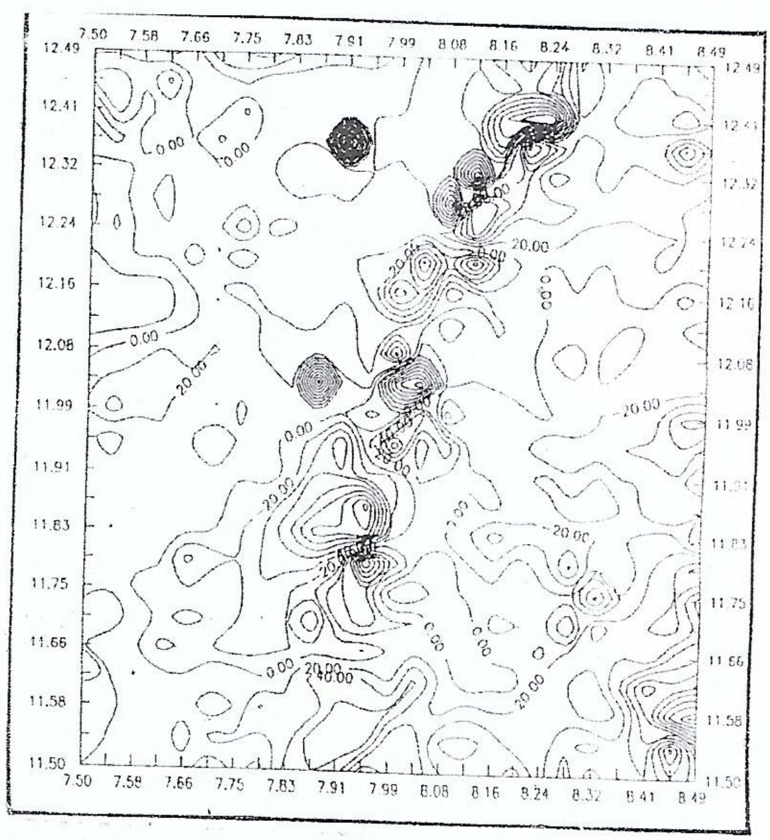

Fig. 5: Residual Magnetic Map of the Malumfashi Area. Axes are in Degrees and Contour Interval is 20nT

11.0 Quantitative Interpretation of Magnetic Residual Anomalies

11.1 Introduction: The interpretation of magnetic anomalies utilizes natural potential fields based on inverse square laws of attraction. The immediate purpose of a magnetic survey is to detect rocks or minerals possessing unusual magnetic properties, which reveal themselves by causing disturbances or anomalies in the intensity of the earth's magnetic field. In this work, four aeromagnetic maps covering the study area were subjected to data analysis so as to achieve the aims and objectives of the project. Bodies were fitted to the anomalies and subsequently adjusted until a good fit was obtained between the calculated anomalies and observed residual anomalies using the available geological information, magnetic susceptibility and gravity density. An infinite number of models are possible in this way, but geological and other constraints would often limit these to only a few acceptable ones.

11.2 Choice of Modeling Technique: The purpose of this research is to model the shape and depth of the structures in the complex and outcrops in Malumfashi area so as to correlate with the gravity work that was done by Gandu et al (1986). There are several methods of modeling bodies. These methods are divided into two- dimensional (2D), three-dimensional (3D), and recently two-and-half-dimensional (2½-D) modeling techniques. The two-dimensional techniques are usually applied in modeling elongated bodies with length to width ratio greater than 10, as in the case of dykes. Thus, the length is assumed to be infinite. In 3-D technique, many simple geometric forms have been used to model magnetic anomaly fields. Some of these forms, such as the vertical and inclined prisms, have been particularly successful, especially in near surface exploration work. The 2½D modeling technique is an improvement of the 2-D and an approximation of the 3-D model. Here, the length is made finite though considerably longer than the width of the body. The technique applied in any survey depends on the structures intended to model and the purpose of the survey. Two-dimensional technique will readily be used to quantitatively model dykes since their length to width is usually greater than 10. Three-dimensional modeling techniques are easily used in modeling batholiths while moderately elongated slabs can be modeled using the 2-D method (Talwani, 1965; Gemerle et al., 1991). The modeling method used for this work was adopted because it is a schist belt.

11.3 The GM-SYS Computer Modeling Techniques: GM-SYS, written by Gemerle et al (1991) is a program used for easy interactive modeling of a 2-D and optionally 2-½D geological cross section with the ability to quickly calculate and display thé gravity or magnetic response from the cross section. The

2-½D method was adopted in this research. The method used for calculating the magnetic response and model is based on the methods of Talwani et al (1959) and Talwani and Hertzler (1964). It made use of the algorithms described in Wen and Bevis (1967). The 2-½ calculations are based on Rasmussen and Pedersen (1979)..

12.0 Discussion, Conclusion and Recommendation

12.1 Discussion: Fig.6 shows the residual map superimposed on a simplified geological map of the area. There is remarkably good correlation between the major anomaly (1) which is a positive anomaly of magnitude + 13mGal that occurs over the mapped schist body near Gwarzo. To the northwest of anomaly (I), a negative anomaly (2) with a magnitude of -10mGal occurs over a granite intrusion, while the positive anomaly (3) with a magnitude of about 8mGal also occurs over schist and quartz diorites. Since these bodies and the anomalies associated with them are distinctly elongated in a general direction which varies from north-south to northeast-southwest, a two-dimensional interpretation of a profile A - A' which runs across the centre of anomalies (I) and (2) from the northwest to southeast was carried out. The method of interpretation adopted employs a simple computer program to determine the gravitational/magnetic attraction over a body whose section is approximated by a polygon, and which is assumed to extend infinitely in a direction perpendicular to the cross section. Using the available geological information and density/magnetic contrast (Gandu et al, 1986) bodies were fitted to the anomalies and subsequently adjusted until a good fit was obtained between the computed anomalies and observed residual anomalies. An infinite number of models are possible in this way but geological and other constraints would often limit these to only a few acceptable ones. The result of this survey shows that geologically, Bouguer anomalies in the range of +30 to I 80m Gal which have been associated with and interpreted as being due to essentially ensimatic processes were not observed in this survey. It is therefore concluded based on the interpreted magnetic/gravity residuals that the schists in the Malumfashi area evolved in an ensialic environment and also the acidic nature (i.e. low density) of the Older Granites suite and the large negative Bouguer anomalies strongly indicate a granitic parent magma for the suite in the granites with the surrounding rocks also suggest that magmatic stopping is the most likely mode of emplacement.

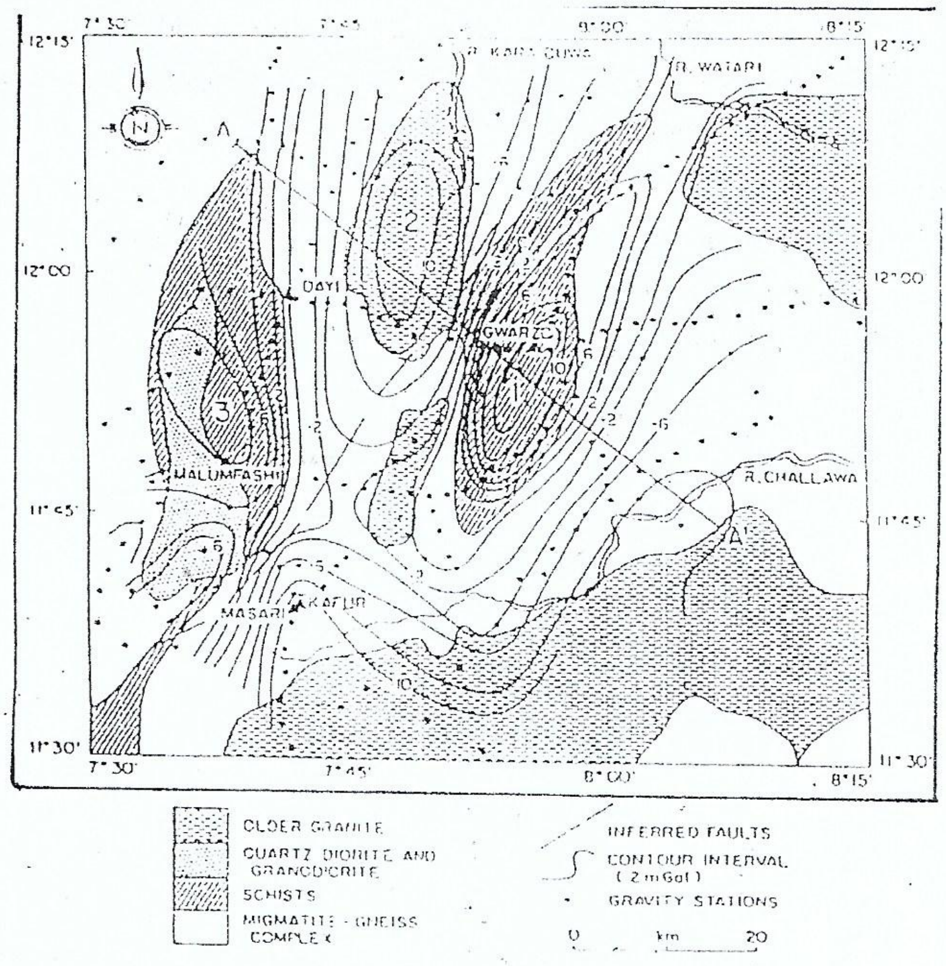

Fig. 6 Residual Gravity Anomaly Contours Superimposed on the Geological Map of the Area

The observed values of the gravity and magnetic data from the residual map of the Malumfashi area were used to remodel the profile A-A^1. The magnetic residual map (Fig. 7) of the study area is as complicated as expected in magnetic studies. The previous method of extracting observed values from residual maps was that of regular array which allow for interpolation and extrapolation, but in this modern method the array are irregular which allow the observed values to be picked according to the correct representation of the anomalies on the ground. The Gandu's profile was supperimposed on the magnetic residual map (Fig.6) in order to model these major anomalies. Four different models of the profile A - A^1 were taken using the GMS computer program, so as to estimate the width and thickness of the Precambrian rocks. No magnetic susceptibility data exist for the Malumfashi area. However, Udensi (200I) used a value of 0.008 Gaussian units for schist and 0.0013 Gaussian units for basement rocks. Gandu et al (1986) used value of -70kg/m^3 density units for granite, 80kg/m^3 for schist and 0.0000kg/m^3 for basement rock that is for gravity data. Granites are believed to intrude the migmatite - gneiss complex beneath

Malumfashi (Gandu et al, 1986). The susceptibilities used in this research were 0.0008, 0.00933 and 0.0000 Gaussian units for schist, granite and basement rock, while -0.07 g/cm^3, 0.08g/cm^3 and 0.00g/cm^3 were the density differentials used for granite, schist and basement rocks respectively. The average ambient magnetic field, Azimuth, magnetic inclination and declination values used for this study were 33000nT, 70^0, 2^0, 5^0, respectively. The anomalies shown along the profile are believed to be older granites and the schists were suspected to be of low susceptibility.

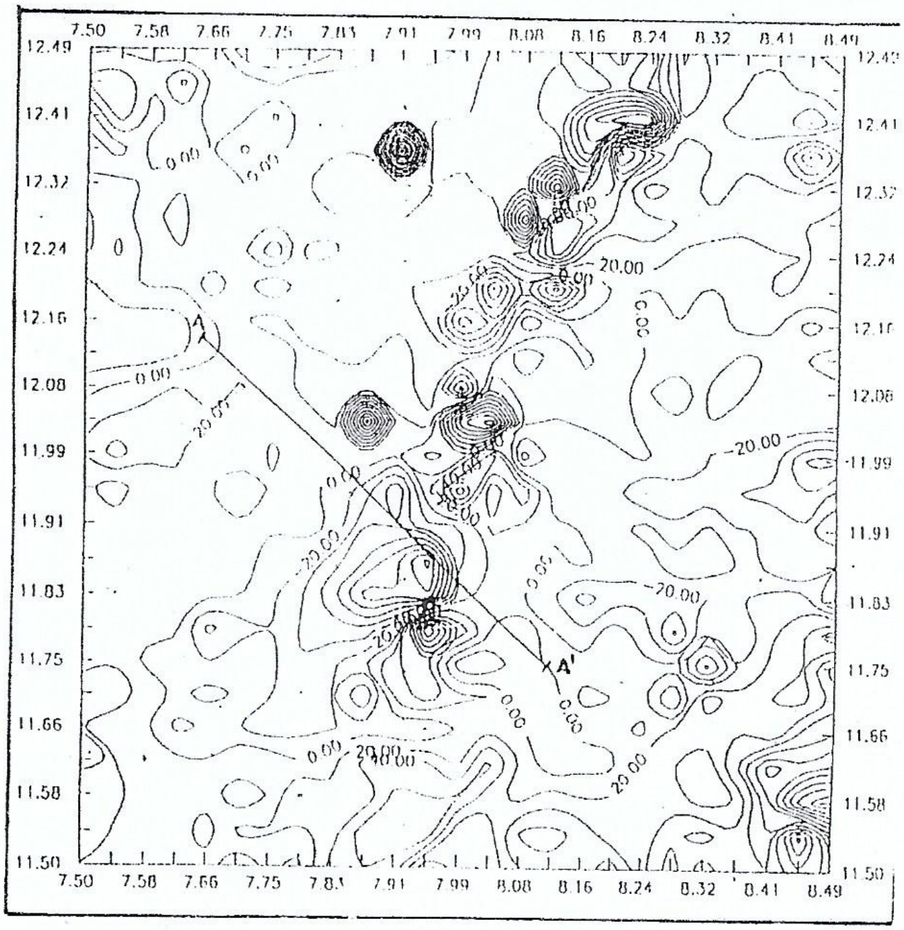

Fig. 7 **Residual Magnetic Map of the Malumfashi Area. Axes are in Contour Interval of 20nT**

Four different possible models were shown, Figs 8 to 11. This shows two granite bodies and a schist body. The thickness of the granite ranges from 8km to 9km and the width ranges from 37km and 51km. The thickness of the schist body is 3.5km and the width is 23km at the surface. Fig.12 represents the model where only gravity method was used.

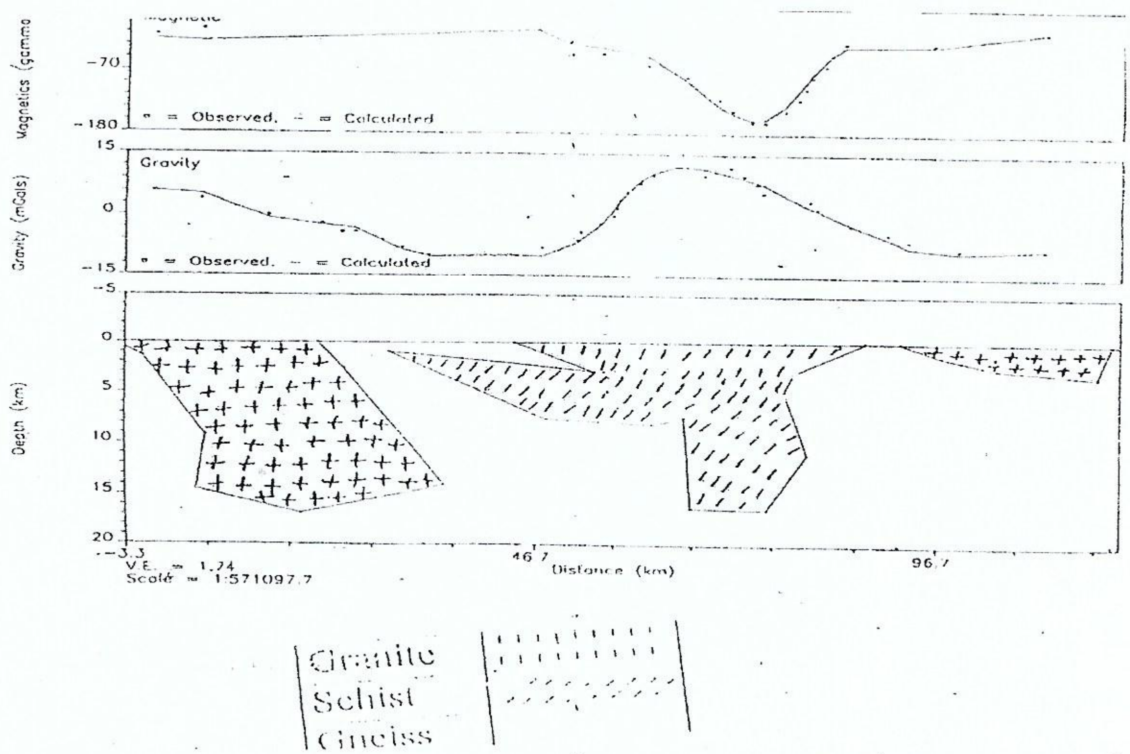

Fig. 8: 1st Model of A – A[1]

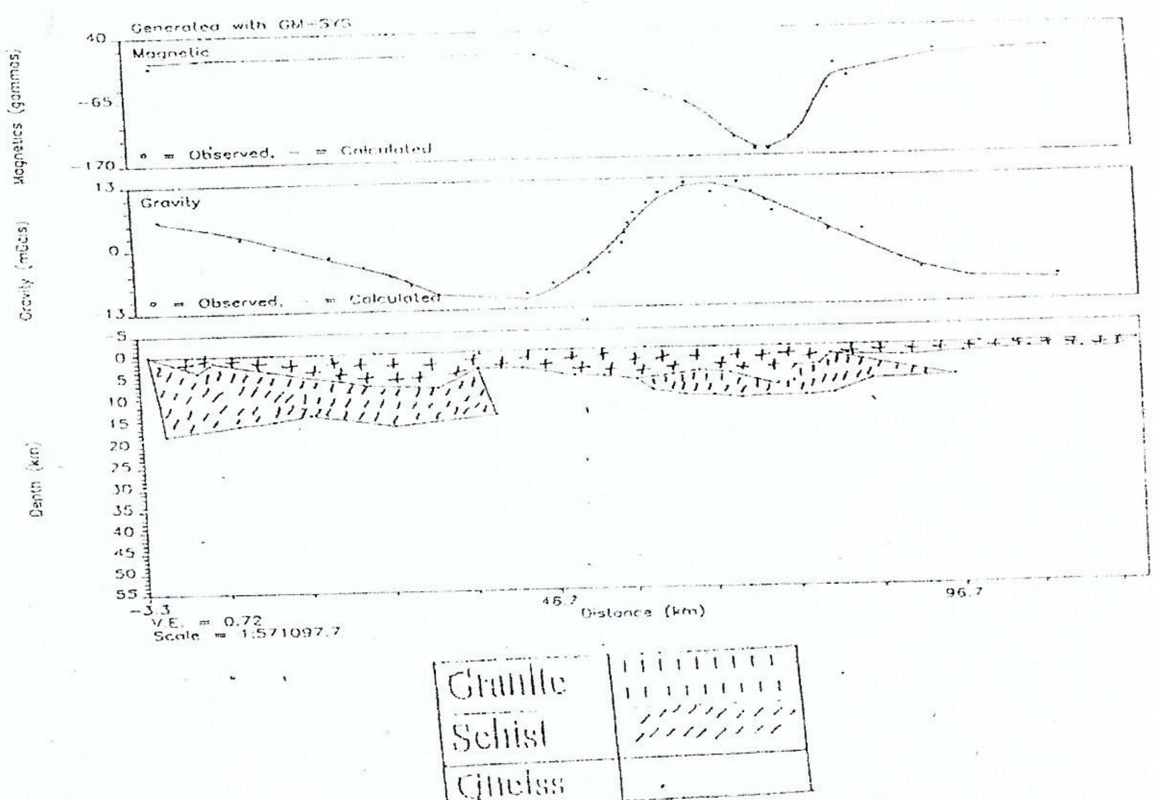

Fig. 9: 2nd Model of A – A[1]

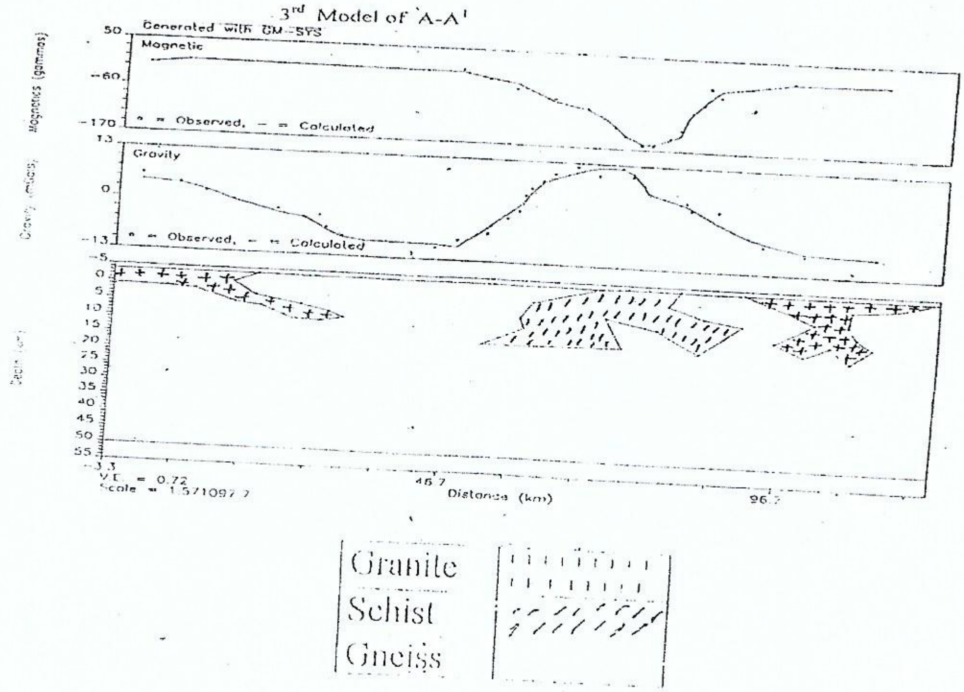

Fig. 10: 3rd Model of A – A1

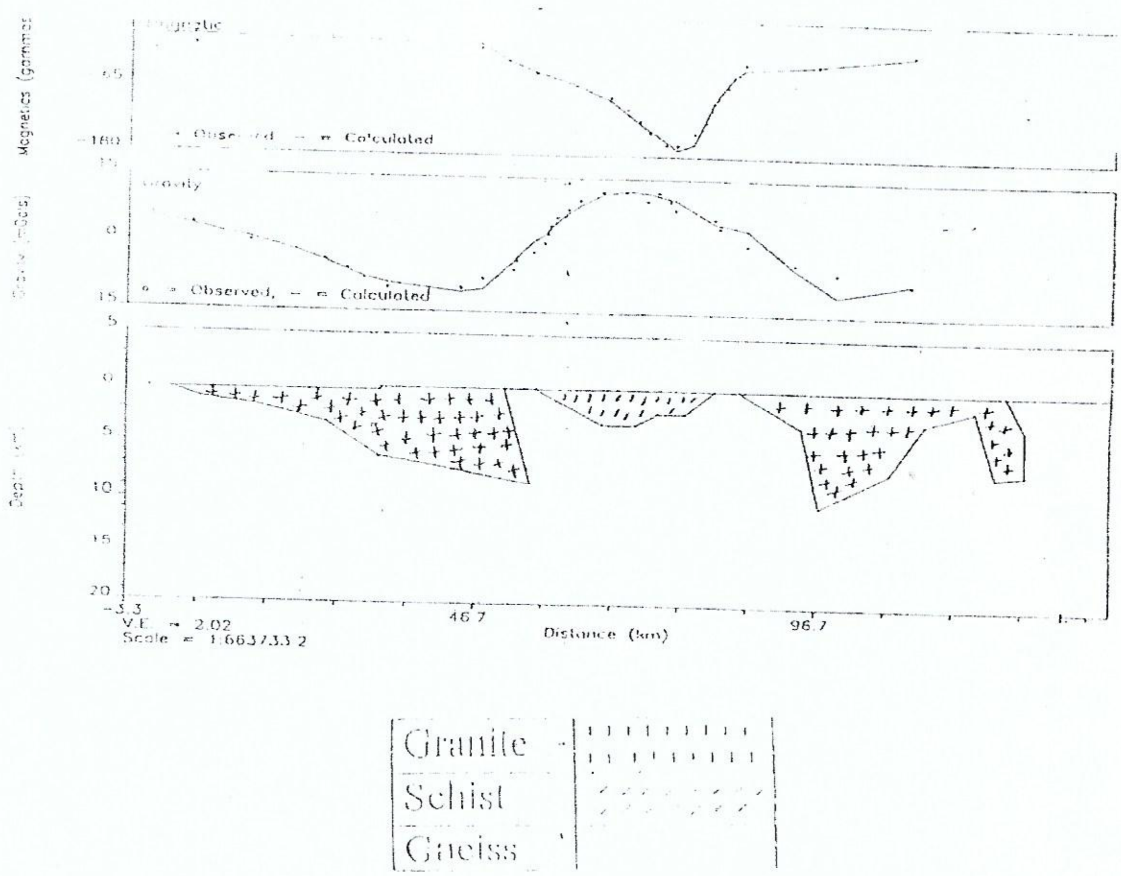

Fig. 11: 4th Model of A – A1

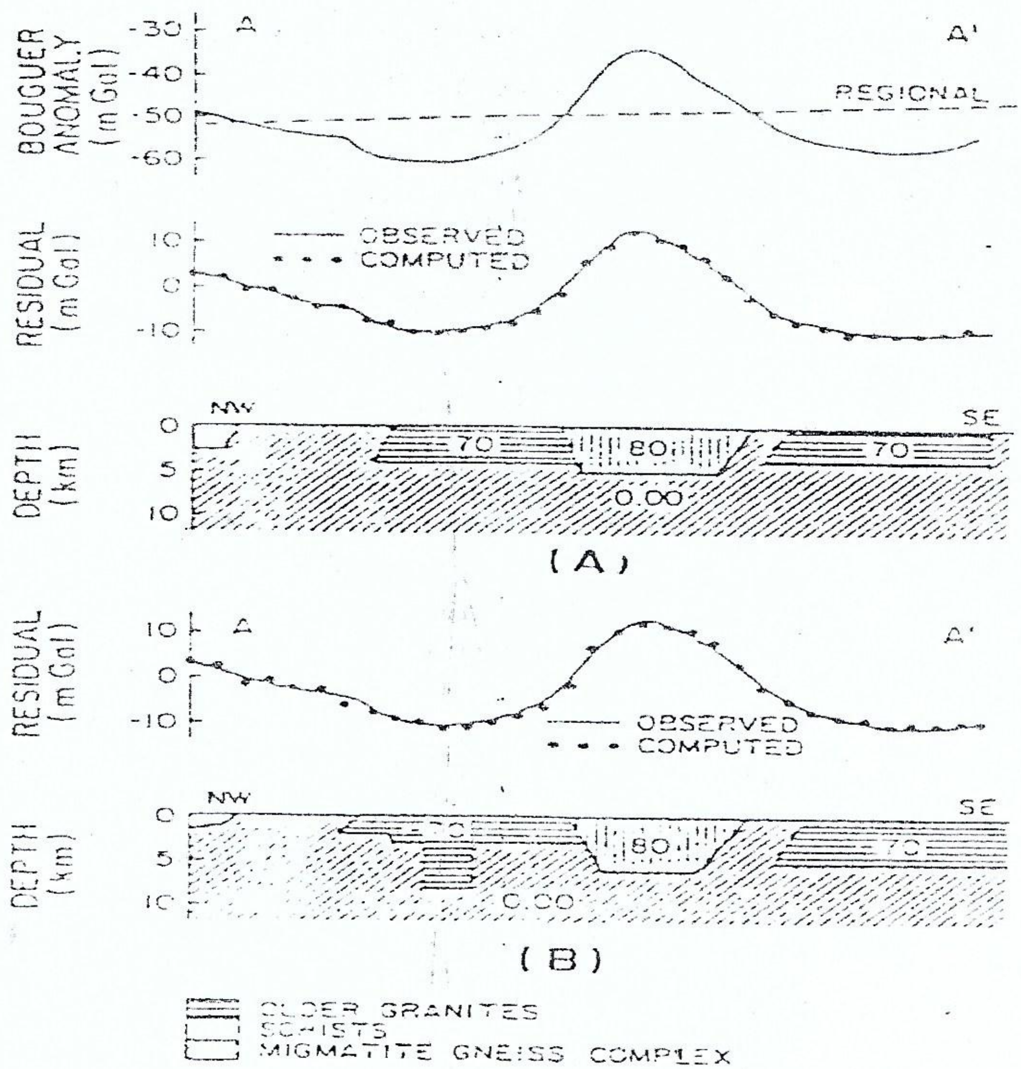

Fig. 12: Best Fit Two-Dimensional Model Interpretations for Profile A – A^1 Density Contrasts in kg/m^3

12.2 Conclusion: Results of Figs 8 to 11 correlate favourably with the results of gravity study in the area by Gandu et al (1986). The thickness of the schists was found to be 3.5km while the thickness of the granite bodies is of order 8km to 9km. The depths determined from the study area are below the estimated values of depths to the bottom of the earth's magnetic crust, which are 18 to 25km (Vanquier and Afleck, 1941) and 17,7km to 24km (Bhattacharyya and Morley, 1965). The overburden rock was considered to have a relatively very low density and susceptibility which account for the drop in both gravity and magnetic values. The NE - SW lineament at the central part of the area is a major fault line which was not clearly indicated by Gandu's gravity work in Gandu (1986) but, this work has brought the fault line clearly and it is probably the suspected kimberlite pipe that has been the concern for researchers.

12.3 Recommendation: Studies on the magnetic susceptibilities of the rocks in the area should be carried out, as these will enhance the results of the further studies. To the Government of Katsina or Federal Government of Nigeria, drilling of five well-positioned holes to a depth of about twenty meters each on the suspected pipe area, might confirm the nature of the suspected pipe whether or not to be of economic value. Alternatively sinking of about sixteen 16 numbers of trenches of dimensions 2x2x20m at intervals of four meters along the suspected orientation of the body, could also be undertaken.

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