A GEOPHYSICAL INVESTIGATION OF THE SUBSURFACE STRUCTURES BETWEEN RISHIWA AND GESHERE RING COMPLEXES USING MAGNETIC METHOD

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AHMADU BELLO UNIVERSITY, ZARIA

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BY

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June, 2015

DECLARATION

I declare that the work in this Thesis entitled "Ageophysical investigation of the subsurface structures between Rishiwa and Geshere Ring Complexes using magnetic method" has been carried out by me in the Department of Physics. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other Institution.

Yusuf Ayoola BELLO …… ……..

Signature Date

CERTIFICATION

This thesis entitled "AGEOPHYSICAL INVESTIGATION OF THE SUBSURFACE STRUCTURES BETWEEN RISHIWA AND GESHERE RING COMPLEXES USING MAGNETIC METHOD" by Yusuf Ayoola BELLO meets the regulations governing the award of the degree of Master of Science in Applied Geophysics of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

To my parents, Alh.AbdulGaniyuOlanrewajuAjala BELLO and Alh.KhadijatOluwakemi BELLO

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ABSTRACT

In this research, the 'surface gap' between Rishiwa and Geshere Younger Granites was investigated using both ground and airborne magnetic survey. This was informed by the suspicion of Geshere Younger Granite being an extension of Rishiwa Younger Granite. The effects of both diurnal and secular variations were removed from the magnetic data - both airborne and ground. Power spectrum analysis was used to investigate the likely noise level in the aeromagnetic data by calculating the cut off wavelength, 6 km, and this noise level was filtered out using low-pass filter. The data set was subsequently subjected to appropriate enhancement and interpretation techniques. Qualitative interpretations including second vertical derivative and analytic signal defined distinct pattern of the magnetic signatures. The second vertical derivatives of the aeromagnetic map revealed the presence of a boundary within the gap which coincided with abrupt change in the magnetic contrast observed on analytic signal map of the aeromagnetic data. Euler solution of the aeromagnetic data with structural index of zero (SI = 0 for contact) revealed the presence of a major contact between the two Younger Granites with a depth ranging from 0.3 to 1.1 km, some unexposed part of Rishiwa, and also indicates the possibility that both Younger Granites may be a single Younger Granite that might have been separated by plate movement aided by fault.The analytic signal of the ground magnetic data delineates boundaries in between the two Younger Granites and finally 2D Werner solutions of the ground magnetic data produced more contact than dyke solutions with depth range of 15 m to 150 m.

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LIST OF ABBREVIATIONS AND SYMBOLS

μTmicrotesla

∇ The gradient operator

° Degree

☎ Minute

✐ Seconds

2D Two-Dimensions

3D Three-Dimensions

DC Direct Current

E East

e.g.Example

eq. Equation

et al. and others

Fig.Figure

GPS Global Positioning System

km kilometre

m metre

Ma Million years

N	North
N – S	North-South
NE – SW	Northeast-Southwest
NNE	North Northeast
NNPC	Nigerian National Petroleum Commission
NNW –SSE	North Northwest-South Southeast
nT	nanotesla
NW – SE	Northwest-Southeast
NYG	Nigerian Younger Granite
SSW	South Southwest
WSW	West Southwest

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Introduction

The magneticmethod involves the measurement of theearth'smagneticfieldintensity. Magnetometer surveys indicate that there are many unexpected variations in themathematical model for the earth's magnetic field, i.e., its shape and intensity across the surface of the earth, called "magnetic anomalies". Anomalies in the earth's magnetic field are caused by induced or remanent magnetism. Induced magnetic anomalies are the result of secondary magnetization induced in a ferrous body by the earth's magnetic field. Theshape,dimension,andamplitudeofaninducedmagnetic anomalyis afunctionofthe orientation,geometry,size,depth,andmagneticsusceptibility ofthebodyaswellastheintensity andinclinationoftheearth'smagneticfieldinthesurveyarea (Hinze, 1990). Magnetic prospecting looks for variations in the magnetic field of the earth that are caused by differences in the magnetic properties of near-surface rocks or by changes in the subsurface geologic structure. For example, the magnetic materials within the weathered zones are reduced as a result of the weathering processes during the geological time (Nabighian *et al.,* 2005). Hence, the depletion of the magnetic materials in the altered zones would reduce the susceptibility, i.e. the inherent magnetism of rock, which is a measure of the extent to which a material may be magnetized.Possible causes for magnetic highs include the presence of magnetically charged rocks in the subsurface.

Groundand airbornemagnetic surveys are used atjustabout every conceivable scale and for awiderange ofpurposes. Aeromagnetic maps in Nigeria have helped in revealing unexposed rocks (e.g. Raimi *et al.,* 2014) and the ground magnetic survey is known to better discriminate the shallow and more intense anomalies because it is closer to them.An economically important use of themagnetic methodisthemappingofburiedigneousbodies (such as Younger Granites). Younger Granites generallyhavehighersusceptibilitiesthantheBasement rocks theyintrude yielding lateral magnetization contrasts, i.e. contacts, soitisofteneasytomapthemin2 D plane-view (Obaje, 2009).

The Nigerian Younger Granites (NYG) Ring Complexes are a series of petrologically distinctive crystalline igneous rocks of granitic composition. Several individual complexes (fifty two in number) have been identified with varying sizes and named after their localities, individual massifs range from 640km^2 to less than 1680km^2. Ogezi (1986) referred to them as Cenozoic (Jurassic) igneous granitic rock suites that occur in a north–south trending belt, restricted to the northern part of the country, indicating that the suites extend from Afu (near River Benue) in Central Nigeria to Zinder and A'ir in Niger Republic and covers an area of about 1300km^2 within Nigeria – enclosing parts of Plateau, Bauchi, Kano and Kaduna states. They are emplaced as non-volcanic intrusions from high level magmatic activities and controlled by ring fracturing, faulting and cauldron subsidence (Turner, 1971).

1.2 Description of the study area

The study area is located in Geshere, Kauru local government, Kaduna State, Nigeria. It is approximately3 hours drive via Zaria-Panbeguwa Road (215 km) and it is flanked at the north and south by Rishiwa and Geshere Ring Complexes respectively. The area lies between latitude 10^{0}9☏22.32✐N and 10^{0}10☏24.78✐N, and longitude 8^{0}20☏45.36✐E and 8^{0}20☏9.14✐E. There are settlements within the study area and the inhabitants are Surubus. Hausa is the general language spoken in the area though they have their local language. They are mainly farmers and their main food/cash crops include maize, corn, yam, soya bean, sugar cane, rice and groundnut.

1.3 Statement of problem

Fifty twoYounger Granites Ring Complexes have been identified with varying sizes and named after their localities, individual massifs range from 640km^2 to less than 1680km^2. Studies have suggested that some of the Younger Granites are extension of others. In the work of Aina and Olarewaju (1992) it was reported that 'the nature of the magnetic

contour patterns suggests that Gamawa complex probably is an extension of Ririwai complex but separated by a linear pattern of discontinuous magnetic contours trending NW-SE and stretching right across the sheet. The gap between Ririwai and Gamawa Younger Granites is wider than that of Rishiwa and Geshere Younger Granites (see Figure 1.1). Therefore, there is the possibility of Geshere Younger Granite(also known under the name Kerku in older compilations) as being an extension of Rishiwa.

This research therefore employs the use of magnetic method (airborne and ground survey) to investigate the surface gap between Rishiwa and Geshere younger granites for the presence of contact.

1.4 Justification

Geshere ring complex, about 1 km southward and about one-fourth the size of Rishiwa Ring Complex (a deduction from the Google map image in Figure 1.2) is suspected to be an extension of the Rishiwa Ring Complexes, at the same time the surface gap in-between both Younger Granites (see Figure 1.3) is composed mainly of outcrops of the Basement complex of Nigeria thereby necessitating a detailed investigation.

Although, this is not the first case of a Younger Granite been claimed to be an extension of another (e.g. Aina and Olarewaju, 1992), but, to the best of the knowledge of the author, this will be the first geophysical investigation carried out to verify the claim in Nigeria.

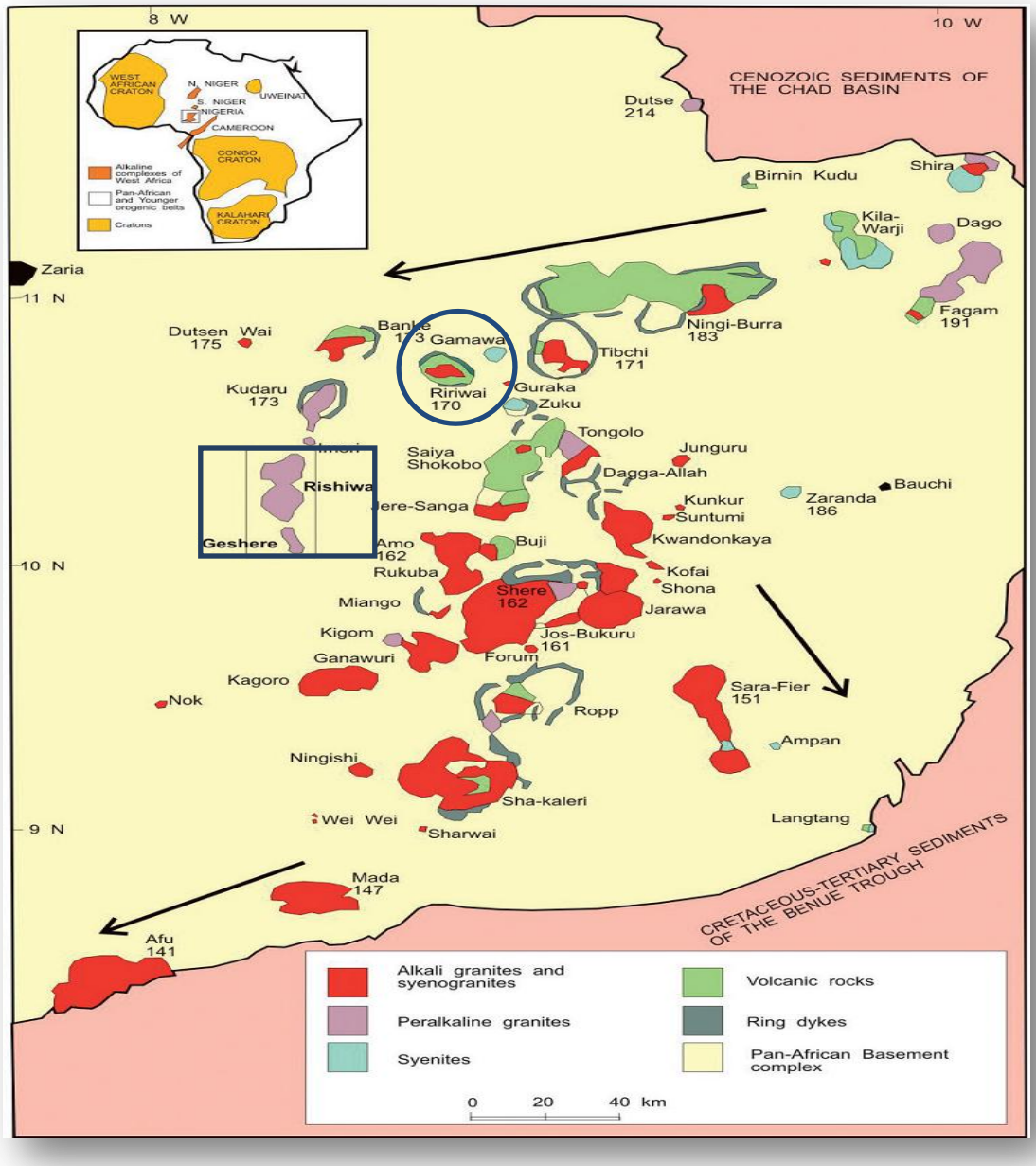


Figure 1.1.SimplifiedgeologicalmapoftheNigerianYoungerGranite(NYG)complexes(afterKinnaird,1985) showingthelocationoftheGesherecomplex;arrowsindicatethedirectionofmigrationofagesofMesozoic magmatic centres. Inset is a map ofAfrica (after Bowden et al., 1987), with location of the NYG province. The blue rectangle isolates the Younger Granites of interest while blue circle isolates the Younger Granites of interest in Aina and Olarewaju's (1992) work.



Fig. 1.2: Google map image of the two ring complexes.



Fig. 1.3: Google earth image of the study area

1.5 Aim and Objectives of the study

Theaim of the present study is to investigate in detail the subsurface structures between Rishiwa and Geshere ring complexes using magnetics method to verify the probable connection between them.

The specific objectives are to:

1. delineate the boundaries of anomalies using various data transformations such as vertical derivatives and Analytic signal technique.

2. identify the likely subsurface structure within the area of study using Werner and Euler deconvolutions.

1.6 Research questions

I. Can the boundaries of the anomalies be delineated using the selected data transformations?

II. Can the subsurface structure be identified using Werner and Euler deconvoultion?

CHAPTER TWO

LITERATURE REVIEW

2.1 Definitionsandbackground

Johnson *et al*. (2002) reported in their work that thebest-knownringcomplexes occurintheTertiaryplutonicdistricts oftheBritish Isles,whichincludespectacularexamplesofmultiply- intrusive and nestedcomplexes(Richey,1932,1948; Walker,1975).Other examplesinclude thoseinthe YoungerGranitecomplexesofnorthernNigeria(Jacobson*etal.*,1958;Turner, 1963;Bowdenand Turner,1985),thePeruvian Coastal Batholith(CobbingandSpencer,1972;Myers,1975;Bussell*et al.*,1976),theOsloregionofNorway(Oftedahl, 1953,1978),theWhiteMountainsandWinnipesaukee batholithsinNewHampshire,USA(Billings,1943, 1945),theMediterraneanislandofCorsica(Bonin, 1986),theGeorgetownInlierofQueensland,Australia (Branch,1966),andthewesternPRB (Peninsular Ranges batholith)inBajaCalifornia,México(Gastiletal.,1975;GrometandSilver, 1977;Gastil,1990;Delgado-Argote*etal.*,1995;Johnson*et al*.,1999a,b;Tate*et al*., 1999; Johnson *et al.*, 2002).

Sincethefirstdocumentationofa ringdikein relation toacollapsedcauldronatGlenCoe, Scotland(Clough *etal*.,1909) nomenclatureusedtodescribe magmaticringstructures hasbecomecomplex,with severaltermsbeingusedloosely orinterchangeably. Examplesofthesetermsinclude‘‘caldera’’, ‘‘cauldron’’,‘‘ringstructure’’,‘‘ringcomplex’’, ‘‘ringzone’’, ‘‘ringdyke’’,‘‘ring-dykecomplex’’and‘‘conesheet’’. A‘‘caldera’’ isalargevolcanicdepression thatismoreorlesscircular,hasadiametermanytimes thatofincludedvents,and formsby roofcollapseinto anunderlyingmagmachamber(Lipman,2000).‘‘Ring complex’’ isageneraltermusedtodescribeanintrusivecomplexthatcontains conesheetsand/orring dykes,althoughtheterm canbeusedlooselytodescribeanyintrusivecomplexwithcircular,oval,polygonalorarcuateintru

sionsinplanview (Johnson *et al.*, 2002).A‘‘conesheet’’ isadiscordant intrusionthatcanbecircular,oval, polygonalorarcuateinplanandhasgently tosteeply inward-dippingcontacts(Harker,1904wasapparently thefirsttodocument conesheets,butthetermwas apparentlyfirst usedbyBaileyetal.,1924).Sheet thicknessesarevariable,butseldomreachmorethana fewtensofmeters.Rock types canbemafic,intermediateor felsic(lesscommon),and commonlyshow quenchtextures.A‘‘ringdyke’’isadiscordant intrusionthatcan becircular,oval,polygonalorarcuatein planandhasnear-vertical tosteeplyoutward-dipping contacts. Dykethicknessesarevariable,butcanreach uptoseveralkilometers. Rock-types aregenerally felsicanddonottypicallyshowquenchtextures.

Implicitinthepublisheduseofsomeoftheabove termsisthenotionthattheydescribedifferent structurallevelsinvolcano-plutonic subsidencesystems; plutonsliebelow ringcomplexes,which liebelow calderas(Richey,1932,1948;Williams, 1941; Billings,1945;Reynolds,1956;Jacobsonetal.,1958; Smith andBailey, 1968;CobbingandSpencer, 1972; Busselletal.,1976;Oftedahl,1978;Bonin,1986, 1996).Thus,theterm‘‘ringcomplex’’ iscommonly reservedforrelativelydeeplyerodedsubsidencesystems,eventhoughconesheetscanbe foundrelatively highinvolcanicedifices(Schirnicketal.,1999).

Goussev and Pierce (2000) defined contact as a boundary (often, a fault) between two blocks of differing susceptibility/density values or rock types. Correlating the analytic signal amplitude maxima and computation of analytic derivatives is used for delineating geologic boundaries in the subsurface.

2.2 Geology of the area

The area comprises of Precambrian to Lower Paleozoic Basement Complex rocks into which the Younger Granite suites are emplaced (Figure 1.1).

The rocks of the Basement in the region, which is part of the metamorphic rocks of northern Nigeria, consist of the Migmatite Gneisses Complex, the Older Granites and the charnockitic rocks.The western domain of Northern Nigerian (area of study inclusive) is floored by Archean tonalite-trondhjemite-granodiorite-type gneisses of early Archean age (Dada *et al.,* 1993; Braguier *et al*., 1994), while the cover is assumed Proterozoic age, has been preserved in N-S trending schist belts (Turner, 1983). Zircons from orthogneisses in

Kaduna area (study area inclusive) have given U-Pb ages of 3040-3050 Ma for the emplacement of Archaean granodioritic magma (Bruguier *et al*., 1994). These authors recognized from their data lack of Palaeoprotozoic or Mesoproterozoic tectono-metamorphic events. A U-Pb age of 618 Ma from a monazite indicates that the Archaean basement of the Neoproterozoic Belt of northern Nigeria probably underwent high-grade metamorphism and anatexis during the Pan-African orogeny ±10 Ma (Dada *et al.*, 1993).The migmatite-gneiss complexes constitute the oldest rock group of presumably Eburnian age and have been greatly reactivated during the Pan-African plutonic activity of about 600 Ma (Aina and Olarewaju, 1992). It was during the Pan-African Orogeny that suit of intrusive granites (Older Granites) and the charnockitic rocks were emplaced in a magmatic phase within country rock migmatite-gneisses (Olarewaju, 1976, Olarewaju and Rahaman, 1982). ThemajorPhanerozoiceventwastheintrusionof numerousJurassicanorogenicgranitessharplycuttingallpreviousstructuresinthewesternhalfof northern Nigeria. The latest event in the area is represented by ring structure formation and subsequent intrusion of Younger Granite Complexes around 160-170 Ma (Turner, 1976). These are discordant, high level intrusions of granite massifs which cut across all units of Basement Complex (Macleod *et al.,* 1965: Jacobson *et al*., 1958). Cone sheets and ring dikes are widely distributed in the Younger Granite Province. Ring dykes show outward dips both on the inner and outer contacts but some have steep or vertical contacts (Jacobson *et al*., 1958, Turner, 1989 and MacLeod *et al.,* 1965).

The Younger Granites have a clear topographical definition and there is usually a close coincidence between the geologic and topographic boundaries at the margins of the granites. They form continuous ranges and plateaus, which rise between 91 and 305 m above the surrounding level plains (MacLeod *et al*., 1965). The Younger Granites intruded through the Older Granites, migmatites and meta-sediments of the basement complex.

There are two Younger Granite Complexes outcrops in the region and these comprises the Rishiwa, which is located in the northern flank of the study area and Geshere which is located towards the south of Rishiwa.

2.2.1 Outcropping conditions

In the basement portions of the region outcrops are scarce and only low-lying exposures are encountered especially the migmatite-gneisses. The outcrops of these rocks are generally of small sizes. The exposures are mainly low-lying smooth rounded boulders derived from the massif rocks of spheroidal.

The Younger Granites show great superior resistance to erosion in comparison to the rocks of continuous ranges and plateaux which rise between 300 – 900 m with striking escarpments above the surrounding level plains. The rocks are homogeneous and relatively fresher than the Basement rocks.

2.2.2 Structural trends

The regional north-south basement trend which indicates the final imprint of the Pan-African Orogeny is apparent especially in the migmatite-gneisses. There is some striking concordance between the photogeological trends and some observed north-south measurements (Olarewaju, 1976).

The Younger Granite Complexes trend in an N-S belt with the ages of complexes decreasing southwards (Alkali, 2013). Rahaman *et al.* (1984) showed that the major local magmatic activities were concentrated along ENE and WSW zones. The age pattern suggests that the parent magma were locally derived from several simultaneous high level magma chamber connected to a common deeper source. The emplacement of these ring complexes was controlled by fracture systems in the basement (Alkali, 2013).

2.2.3 Mineralization

Unlike the Basement Complex rocks, the Younger Granite emplacement was associated with phase of mineralization. Economic mineral deposits alluvial cassiterite and associated minerals like arsenopyrite (FeAs S), chalcopyrite (CuFe S_2), columbite and tantalite (Fe, Mn) Nb_2O_6- (Fe, Mn) Ta_2O_6 occur within and around the Younger Granite Complexes.

2.3 Stages of development of Younger Granite

The main phase of acid magmatism in Nigerian Younger Granite province commenced during Triassic times and continued to migrate in a generally southerly direction until the close of the Jurassic (Bowden *et al*., 1971). The cessation of magmatism might have been synchronous with the initiation of the South Atlantic.

Bowden *et al.*, (1971) proposed three stages of development of the Nigerian ring complexes:

1. Early stage of a large rhyolite volcano which prior to the end of its stage, large amount of magma accumulated in the synvolcanic reservoir about 5 km beneath the surface.

A mass of granite (see the shaded area in Fig. 2.1a) rises high into the crust (basement gneisses, migmatites and granites), supplied ring fracture below. Emplacement is accompanied by doming or swelling of the overlying crust and by initial subsidence of the underlying crustal block. Cone sheet (C) may be emplaced. Predominantly rhyolitic magmas are erupted, mainly as ignimbrites, from acuate vents along the ring fracture and also from central vents (illustrated in Fig. 2.1a).

2. Caldera and ring dike stage when the centre of the volcanic structure within a ring fault collapsed, magma arose along the fault and crystallized as granite porphyry which was extruded into the caldera rocks.

Rapid eruption of ignimbrites empties the magma chamber so that the overlying crustal cylinder breaks up and collapses into the resulting void, and there may also be further subsidence of the crustal block beneath. Early volcanic are downfaulted into the surface calders, which is filled by eruptions of later rhyolites in the form of both ignimbrites (see the dashes in Fig. 2.1b) and viscous lava masses (black). These are mainly supplied by magma rising along the ring fractures. Caldera subsidence continues during the eruptions of the rhyolite (illustrated fig. 2.1b).

3. Intrusive stages were the warming phase of igneous activity when smaller granite intrusions were emplaced at increasing depth levels. The magma evolved and crystallized

at lower temperatures and as lower assemblages. Their rocks are composed of biotite granite.

Eruptions cease and the ring fractures are filled with granite porphyries to form marginal ring dikes (black). Emplacement of granites (crosses) occurs by subterranean cauldron subsidence: intermittent large-scale sinking of the roughly cylindrical crustal block beneath. The granites are emplaced into the upper crust, intruding and sometimes doming the earlier volcanic. The heavy bricken lines indicate approximate upper and lower limits of present-day levels seen in complexes in different places (illustrated in fig. 2.1c).

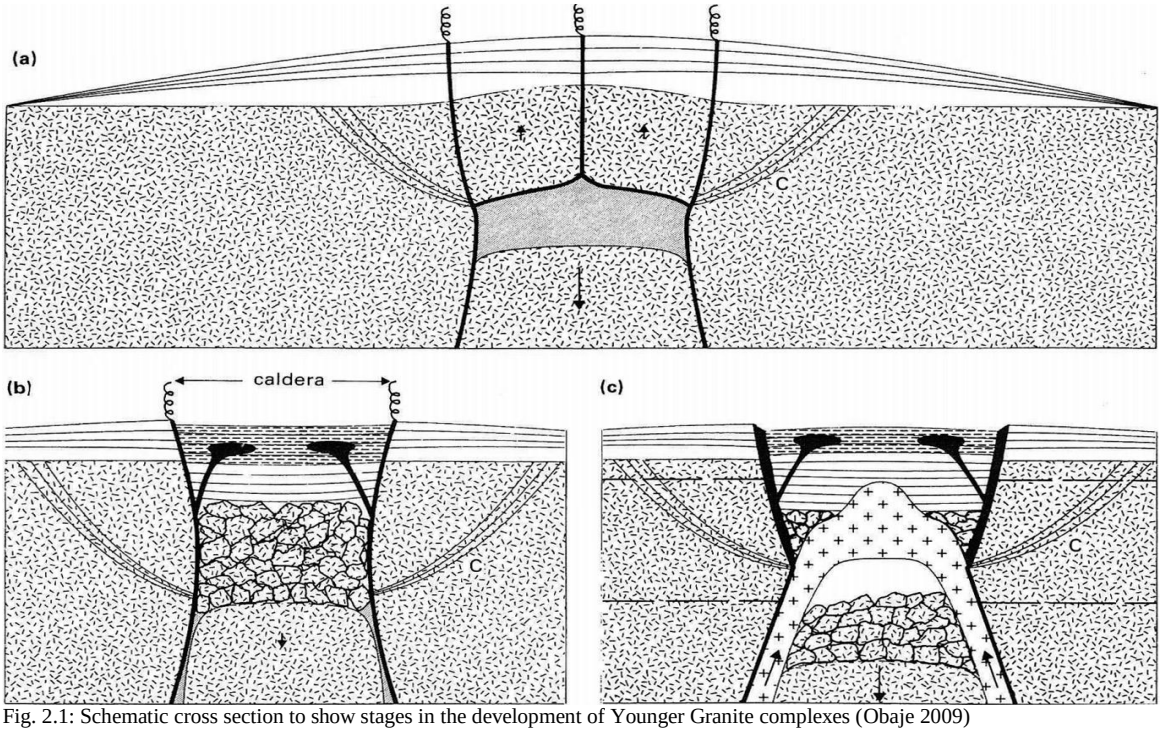


Fig. 2.1: Schematic cross section to show stages in the development of Younger Granite complexes (Obaje 2009)

2.4 Source of Younger Granite magmatism

A lot of propositions have been put forward by many geologists to account for the origin of the Younger Granite magma. Two of the most recent theories are summarized here.

The first, suggests that peralkaline silicic magma generated within the lower crust on the upper mantle, are contaminated while ascending into the upper mantle to yield non-peralkaline magma (Bailey and Schairer, 1966). The other theory, states that the peralkaline magma was generated in the upper crust from some basement rocks and that on further progressive melting and cooling, yield the non-peralkaline magma of metaluminous and peraluminous trends (Bowden, 1970).

While both theories agree on peralkaline liquid as the source liquid, the point of disagreement lies on the source region for the generation of peralkaline magma and how the associated non-peralkaline granite was derived. Evidence from the gravity survey carried out in the Younger Granite suite of Nigeria by Ajakaiye, (1974) indicates granitic parent magma for the suite due to the predominant acidic low density rocks and large Bouguer anomalies over the area. This result agrees with Bott (1953) who has earlier pointed out that large negative Bouguer anomalies over granites would suggest a magmatic origin either by direct intrusion from the 'granitic layer' or possibly by melting, differentiations and intrusion of the "metamorphic layer" (Ekwue, 1994).

In fact, a magmatic origin has since been proposed for the Younger Granite suite (Falconer *et al*., 1926; Jacobson *et al*., 1958; Turner, 1963) and was re-emphasized later by Bowden, (1970) who suggested that the absence of contact metamorphism around the Younger Granite ring complexes indicated that granitic magma was intruded into the preheated rocks (Ekwue, 1994).

Another issue, concerning the emplacement of the Younger Granite has also remained an unresolved problem. However, concerning the general sequence in the emplacement of the Younger Granite, it is believed that, there was usually a volcanic phase during which volumes of rhyolite were intruded from ring fractures, followed by the emplacement of a peripheral ring dyke, then series of granite and syenites by cauldron or block subsidence (Jacobson *et al*., 1958; Turner,1963, 1969; Jacobson and Macleod, 1972).

2.5 Some previous geophysical works on NYG province

There was no knowledge of any geophysical survey been carried out at the present place of study, but some geophysical works have been doneat other places within the Younger Granite province.

Ajakaiye *et al*.,(1991) carried out an analysis of the aeromagnetic data (7°00 - 12°00N and 7°00 – 12°00 E) from Nigerian continental mass (covering the Younger Granite Province of Nigeria) which revealed magnetic lineations and regions of distinct magnetic character and field level which are interpreted as expressions of tectonic features related to igneous intrusives of various ages. The results also revealed aspects of the regional tectonics framework of West Africa and its relationship with the major structures in the adjacent Atlantic basins.

A gravity investigation of the younger granites (10°00 - 10°30N and 8°30 – 9°00 E) in Saminaka area, Kaduna state carried out by Ekwue (1994) indicated, among others, that a number of unexposed intrusions exist. Ajakaiye *et al.*, (1991) opined that the proposed unexposed complexes, strongly favours the opinion that the ring complexes originated in relation to a deep-seated pre-drift megacontinental fracture system (shear zones and

transcurrent faults). Furthermore, that the fracture zones and complexes are related suggests that there was serial reactivation of the megacontinental faults, because the alkaline ring complexes have different ages.

A gravity study which was intended to delineate new structures and extend known ones and also with the anticipation to help in gaining better understanding of the structural set-up of Jos-Buruku Younger Granite complex of North Central Nigeria was carried out by Alkali and Yusuf (2010) and it was observed that the Jos - Bukuru Younger Granite Complex is characterized by negative Bouguer anomalies that conform to the regional,two and a half dimensional gravity models of the subsurface structures identified prominent deep seated faults along the profile sections in the area (the gravity models revealed that the fault attained maximum depth of 18.75 km and the steepness of the gravity contours supports possible relative displacement of the rocks of the intrusive bodies of that magnitude), the faults correlate with Romanche fracture zone which, if extrapolated into the Nigerian landmass will cut across the Jos – Bukuru complex.

Alkali and Gaiya (2011) in their effort to delineate linear structures from digitized aeromagnetic data of the western part of the Younger Granite complex of North Central Nigeria observed that the Younger Granite complex of North Central Nigeria (9°00 - 10°00N and 8°00 – 9°00 E) is characterized by five main directional lineaments. The NE – SW linear structures belong to fractures associated with major movement produced by previous tectonic forces. Pegmatite and quartz zones are associated with the NNE – SSW linear structures. NNW – SSE and NW – SE structural lines are probably produced by ductile and brittle deformational events that affected the Nigerian basement rocks.

Lawal *et al.,* (2012) interpreted aeromagnetic data over the Younger Granite complex of the northern Nigeria (9°00 - 9°30N and 10°00 – 10°30 E) and observed that the isolated magnetic anomalies of geological interest by the regional-residual separation technique revealed that there were three major magnetic regions in the area, that are regions of positive anomaly which could be due to the rock rich in ferromagnetic minerals, regions of intermediate which are found to be lying over the undifferentiated basement complex and region of negative anomalies which could be due to acidic rocks.

An interpretation of high resolution aeromagnetic data (10°30 - 11°00N and 8°30 – 9°00 E)carried outby Raimi *et al*., (2014) revealed previously unknown folds and magnetic anomaly with a signature that is similar to those associated with ring complexes,qualitatively interpreted to be unexposed ring complex.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Instrumentation

Two magnetometers (Proton-Precession Magnetometer and Earth Magnetometer Model EM2) and a GPS were used for the ground magnetic survey.

3.1.1 Earth Magnetometer Model EM2

The Earth Magnetometer Model EM2 (figure 3.1) measures the Earth magnetic field with a resolution of 1nT (1 gamma). This resolution is about 0.002% of the typical Earth field strength. It is used to locate buried magnetic objects or materials.



Fig. 3.1:Earth Magnetometer Model EM2(Courtesy: AlphaLab)

Product Description:

The Earth Magnetometer Model EM2 measures small variations from location to location in the Earth magnetic field associated with buried magnetic masses. Unlike metal detectors, a magnetometer signal is not attenuated by rock, dirt, mud or water, so targets can be detected at great depth (If D is the diameter of a mass of magnetizable material, the

EM2 can detect it as deep as 40 times the diameter D, whether the mass is specifically magnetized or not). It is the lightest weight and lowest cost magnetometer available which can reliably measure differences down to 1 nT from point to point (Because of random fluctuations in the Earth field due to the ionosphere, 1 nT is about the finest usable resolution)

Applications

- Determines both the location and depth of a buried target of magnetic material.
- Measures the presence (and amount) of certain minerals such as black sand (associated with gold deposits)
- Measures inside DC Solenoids (probe is bent into "L" shape to measure this).
- Can in some cases locate voids or caverns in a given stratum if at least a trace of magnetic mineral is normally present.

To use the equipment,assemble the three-segment black stick into a single stick. The plastic point (nearest the white sensor cube) should be on one end of the stick, and the small "L" shape should be on the other end. When using this meter, the plastic point is normally placed on the ground. Then the azimuth and elevation angles of the stick are adjusted to find the maximum value for displayed field strength. But after consulting the manual on several occasions and implementing the instruction, it was observed that the white cube should be placed at the free end of the "L" shaped part of the stick to find the maximum value – Earth field – because of the proximity of Nigeria to the Equator.

Typical Earth field is between 30 and 60 μT. The field is not exactly horizontal in most locations on the Earth's surface. In fact, it is nearly vertical (downward) in Northern Canada and upward at a corresponding region in the Antarctic (AlphaLab).

To make measurements, place to stick on the ground vertically with the point (at bottom) downward. Press "Reset" for at least 1/2 second. Start tipping the stick toward the horizontal; this reduces the stick's elevation angle (which is something like latitude on a globe). Continue tipping to find the elevation of maximum field. When you have gone too far, the white circle will become big. Tip back upward a little to return to the relative maximum field, then rotate the stick in the azimuthdirection (like longitude) to find a new, higher maximum. Then change the elevation and then azimuth again to find theabsolute maximum. This is displayed as PEAK and it is the field at that location. Walk to the next location and press "Reset" for the next measurement. Each measurement should require 10 seconds or less (with practice).

The most direct way to use the meter is by finding the orientation of the stick that yields the highest "FIELD" reading, andthat displayed (maximum) number is the correct field strength. This can be done by orienting the stick in various directionsuntil the direction with the highest FIELD value is found. If done carefully, the field can be repeatedly measured down to the last digit (0.001 μT = 1 gamma or 1 nT). In order to obtain the precision, the stick must be pointed to within 0.4° of the actual field direction. If the stick is 0.45° off, the display will read about 0.001 μT low; if it is 0.9° off, it will have four times the error (i.e., it will read 0.004 μT low). Additional features of the meter allow this "maximum" to be determined more easily, as is explained below.

The top number (PEAK) shows the highest field that the sensor experienced since the most recent time that the Reset button has been pressed. This peak-capture function updates much more rapidly than the display does. If at any time the stick was briefly pointed to within 0.4° of the correct direction for at least 10 milliseconds, the PEAK value displayed will be the true field strength at that location. This number is repeatable; that is, re-measuring at that location later will give the same result down to 0.001nT (unless the field has changed). The upper right corner of the display is a circle which helpsvisualize whether the stick is pointed close to the correct direction. It becomes a small circle whenever the actual (FIELD)value is within a few counts of the PEAK value. (Remember that the PEAK by definition will never be less than the presentFIELD value. Therefore it is always true that FIELD ≤ PEAK.) In areas close to civilization or vehicle traffic, the size of the circle may fluctuate significantly (AlphaLab).

Features

- Displays field strength up to 199.999 micro teslas
- A relative zero mode subtracts the background field from all subsequent readings so there is only a 1- 2- or 3- digit number to watch.
- Backlit display can be turned on.
- Lightweight with long battery life (see specifications below).
- This is a vector magnetometer so the direction of the field (as well as strength) can be determined (but see full description; this feature requires a longer time per measurement).

3.2 Theories of the interpretation techniques

3.2.1 Theory of Analytic signal technique

The analytic signal technique is based on the use of the first derivative of magnetic anomalies to estimate source characteristics and to locate positions of geologic boundaries such as contacts and faults. The forward and inverse 2-D Fourier transform g and *f* respectively of the magnetic field anomaly, **M**, is given by:

$g(k_x, k_y) = F[f(x, y)]$

$$= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f\ (x,y)e^{-i(k_x x + k_y y)}\,dxdy \qquad 3.1$$

$f(x, y) = F^{-1}[g(k_x, k_y)]$

$$= \frac{1}{4\pi^2}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} g(k_x + k_y)e^{i(k_x x + k_y y)}\mathrm{d}k_x\mathrm{d}k_y,$$

wherek_x and k_y are the wave numbers in the x- and y-directions respectively.Using equation (3.1), wave number domain relations can be derived between the Fourier transforms of a magnetic anomaly *M* and of its horizontal and vertical derivatives, as well as relations between the different derivatives, as well as relations between the different derivatives of a potential field anomaly (Nabighian, 1972, 1984; Nelson, 1988; Pedersen, 1989).

The three-dimension (3-D) analytic signal (A) of a potential field anomaly M (magnetic field or vertical gradient of gravity), can be defined as a complex vector

$$AS(x,y) = \frac{\partial M}{\partial x}\hat{x} + \frac{\partial M}{\partial y}\hat{y} + i\frac{\partial M}{\partial z}\hat{z} \qquad 3.2$$

where$i$ is the complex number $\hat{x}$, $\hat{y}$, and $\hat{z}$ are the unit vectors in x,y,and$z$ directions, respectively (Nabighian, 1972; Roest *et al*, 1992: Debeglia and Corpel, 1997).

Equation (3.2) satisfies the basic requirement of the analytic signal (Nabighian, 1972, 1984), that its real and imaginary parts form a Hilbert transform pair. This can be achieved by transforming equation (3.2) into the frequency domain and expressing it in terms of the gradient of the Fourier transform of the magnetic field (Roest *et al*., 1992) which is equivalent to equation (3.2) in the space domain (Debeglia and Corpel, 1997):

$$\hat{t} \cdot F[\boldsymbol{AS}(x,y)] = \hat{h}\nabla F(M) + i\hat{z}\nabla F(M) \qquad 3.3$$

The real and imaginary parts of eq. (3.3) being the horizontal and vertical derivatives respectively, form a Hilbert transform pair and are related by the 3D Hilbert transform operator $i(\hat{h} \cdot \boldsymbol{k})/|\boldsymbol{k}|$ as follows:

$$\hat{h} \cdot \nabla F[M] = ih \cdot kF[M]$$

$$= i\frac{\hat{h}\cdot k}{|k|}|k|F[M] \qquad 3.4$$

$$= i\frac{\hat{h}\cdot k}{|k|}\hat{z} \cdot \nabla F[M]$$

where $\nabla = ik_x\hat{x} + ik_y\hat{y} + |k|\hat{z}$, represents the gradient operator in the frequency domain, $\boldsymbol{k}$ = (k_x, k_y) the wavenumber, $\hat{h} = \hat{x} + \hat{y}$ and $\hat{\imath} = \hat{x} + \hat{y} + \hat{z}$.

According to Roest *et al.*, (1992), equation (3.4) is equivalent to the scalar equation (17) of Nabighian (1984) and represents a means of calculating the vertical derivative when horizontal derivatives in two perpendicular directions are available.

The absolute value (amplitude) of analytic signal (**AS**) is defined as the square root of the squared sum of the vertical and the two horizontal first derivatives of magnetic field anomaly M is given by:

$$|\boldsymbol{AS}(x,y)| = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2 + \left(\frac{\partial M}{\partial z}\right)^2} \qquad 3.5$$

The shape of the absolute value of the analytic signal is used for interpretation; the amplitude of the analytic signal shows maxima over boundaries/edges.

For the 2D case, this equation is simplified to

$$|\boldsymbol{AS}(x)| = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial z}\right)^2} \qquad 3.6$$

Using eq. (3.6) Nabighian (1972) showed that for a thin sheet-like body (dyke), the location of the source in the horizontal plane can be deduced from the positive peaks of the amplitude of the analytic signal and the source depth can be estimated as the half width at half maximum of the amplitude of the analytic signal over a thin dyke is independent of the angle of inclination and declination of the magnetic field vector and the magnetization vector.

This is not the case when prismatic 3D bodies are encountered, especially if their extents are close enough to produce interference effects and thereby affect the shape of the analytic signal amplitude.

Roest *et al.,* (1992) determined the analytic signal over a vertical magnetic contrast at a depth d, given by:

$$|A(x)| \propto \frac{1}{x^2+d^2} \qquad 3.7$$

Equation (3.7) indicates that amplitude of the analytic signal has a bell shaped function; with half-maximum half-width that equals the depth to the magnetic source (Nabighian, 1972; Roest *et al.*, 1992).

The absolute value of the analytic signal is often referred to as the energy envelope of a signal (Oppenheim and Schafer, 1975). The absolute value of the analytic signal is the envelope of all possible phase shifts of an observed anomaly. The absolute value of the analytic signal in three dimensions is also envelope over all possible directions of magnetization and inducing field (Roest *et al.*, 1992). The envelope has a maximum that is located over the magnetic contrast. The locations of these maxima thus determine the outlines of magnetic sources.

3.2.2 Theory of Werner deconvolution

Werner (1953), introduced Werner deconvolution technique, he realized that the greatest need was for a method to separate an anomaly from the interference caused by adjoining anomalies and to consider the entire anomaly in the analysis rather than just a few parameters such as maxima, minima, or inflection points, which can be greatly affected by type of interference. With Werner's method, it is necessary still to assume the type of source configuration, e.g. dykes, and to process the interference correctly. Also, the method assumes initially that the data are perpendicular to geologic strike.

The equation in the total field for a dyke with infinite strike length and depth extent can be written in the form,

$$F(x) = \frac{A(x-x_0)+Bz}{(x-x_0)^2+z^2} \qquad 3.8$$

where*x* represents distance along a profile and *F* is the total magnetic field intensity at *x*. The *A* and *B* are functions of the field strength, susceptibility, and the geometry involved (dip, strike, magnetic inclination, declination, etc.); x_o is the horizontal distance along traverse to the point immediately above the top of the dyke; and z is the depth to the top of the dyke. There are four unknown quantities - *A, B,* x_0*, z*.

Werner points out that in the simple case where observations are made in a level plane over level bounded bodies whose length and depth are infinite and whose strike is perpendicular to the direction of the profile, the equation for a dyke can be cast into the following interpretation equation:

$$a_o + a_1 x + b_0 F + b_1 xF = x^2 F \qquad 3.9$$

In this equation, *x* and *F* are the same as in equation (3.8). It follows that

$$a_0 = -Ax_0 + Bz, \qquad a_1 = A,$$

$$b_0 = -x_0^2 - z^2, \text{ and} b_1 = 2x_0. 3.10$$

Conversely, the depth and horizontal position of the top of the dyke are functions of the parameters of the interpretation equation (3.9):

$$x_0 = \frac{1}{2} b_1 \text{and} \pm\sqrt{-4b_0 - b_1^2} 3.11$$

Since there are four unknowns, simultaneous solution of the interpretation equation (3.9) at four x values and their corresponding *F* values will yield solutions for a_l, b_o, andb_l, and, from equation (3.11), for x_0 and *z*. In the simple case, the geometric solution is complete. The depth to the top of the dyke (thin sheet) has been determined.

If we now admit the possibility of interference and assume that the interference can be represented by a polynomial of some degree, we can add the interference polynomial to equation (3.8).

$$F(x) = \frac{A(x-x_0)+Bz}{(x-x_0)^2+z^2} + C_0 + C_1 x + \cdots + C_n x^n, \qquad 3.12$$

Where *n* is the order of the interference polynomial and the C's are the coefficients. We now have a total of (*n* + 5) unknowns and therefore (*n* + 5) points are required to solve for the unknowns. In practice, a first or second order polynomial is generally sufficient, so that 6 or 7 points are required for solution. Werner also presents a simple method of solving the simultaneous equations which amounts to multiplying the data points by a set of linear operators, thus greatly reducing the labour involved. Although this represents the first attempt to deal automatically with interference, with Werner's method it is necessary still to assume the type of source configuration, e.g., dykes, and to process the interference correctly. Also, the method assumes initially that the data are perpendicular to geologic strike.

Werner's theory is valid for all semi-infinite, homogenous, thin-sheet bodies, whatever their strike, dip, or remanent magnetization, and at any magnetic latitude.

Werner's theory was extended to incorporate another geometric form (contact) (Hartman *et al.*, 1971). Thin-sheets are actually bounded by two planes called interfaces. In the case of thin sheets, the individual interfaces are too close together for their anomalies to be separately distinguishable. In general, this is true if the width of the sheet is less than the depth to the top edge of the sheet. By the integration of a sufficient number of thin sheets, a body can be made broad enough so that the magnetic anomaly from each of the interfaces is distinct. This extension of a thin sheet theory results from the fact that the magnetic

anomaly for a thin sheet is precisely the same as the derivative of an anomaly for a similar positioned interface.

Therefore, by applying Werner's formulas to the total field and to the two gradients, Hartman *et al.*, (1971) were able to identify and calculate the pertinent characteristics of thick sheets and individual interfaces, as well as those of thin sheets. Solutions are found from any set of equally spaced points, and these points need not be predetermined or critical points along the profile, such as inflection points, maxima, or minima.

3.2.3 Theory of Euler deconvolution

Thompson (1982) showed that Euler's homogeneity relation could be written in the form

$$(x - x_0)\frac{\partial T}{\partial x} + (y - y_0)\frac{\partial T}{\partial y} + (z - z_0)\frac{\partial T}{\partial z} = N(B - T), \qquad 3.13$$

where (x_0, y_0, z_0) is the position of a magnetic source whose total field T is detected at (x, y, z). The total field has a regional value of B.

The degree of homogeneity N may be interpreted as a structural index (**SI**) (Thompson, 1982), which is a measure of the rate of change with distance of a field. Sources are simple geometrical object such as a homogenous point source N = 3, a linear source (line of dipoles or poles, and for a homogenous cylinder, rod, etc.) N = 2, for extrusive bodies (thin layer, dyke, etc.) N = 1, for a contact, vertex of a block and a pyramid with a big height N = 0. The choice of a proper SI is a function of the geometry of causative bodies. Estimation of the correct structural index is crucial for the successful application of the Euler deconvolution method (Reid *et al.*, 1990). And this is achieved by using the index that produces the best clustering of solutions (Reid, 1995).Incorrect choice of structural index

leads to errors in estimated source depths (Ravart, 1996). Euler deconvolution used the magnetic field and its three orthogonal gradients (two horizontal and one vertical) to compute anomaly source locations (Keating and Pilkington, 2004).

3.3 Data acquisition

Two sets of data were acquired for this study: aeromagnetic data and ground magnetic data.

The high resolution aeromagnetic (HRAM) data of the study area and beyond (Fig. 3.2), named Geshere sheet 146, was sourced from the Nigerian Geological Survey Agency (NGSA). The data, covering half-degree sheet (10°00 - 10°30N and 8°00 – 8°30 E) and in scale of 1:100,000, were acquired at a flight altitude of 80 m, along NE-SW flight lines that were spaced at 500 m. The total magnetic field intensity range between 32600 and 33350 nT. Most of the anomalies trend NE–SW including a big anomaly located almost at the centre of the map (see fig. 3.2). Passing through this anomaly is a conspicuous linear anomaly (may be a lineament) extending NW–SE. Analyzing the aeromagnetic data is essential forunderstandingthe tectonic setting about the survey area.

The ground magnetic survey data of the study area (10°8.9 - 10°10.4N and 8°20.2 – 8°20.8 E) was acquiredusing two magnetometers. One magnetometer was stationed at a point within the area of survey to take base station readings at 10 minutes interval to correct for diurnal variations while the other was used to measure total magnetic field intensity along the profiles.The survey was conducted along seven profiles along NE-SW direction, the distances of the profiles are between 800 m and 900 m, and both the inter-station and inter-profile spacing was 20 m. The stations' coordinates was taken using aGPS

and it was recorded with the corresponding total magnetic field readings. Maps of aeromagnetic and ground magnetic data were plotted using SURFER 11. The total magnetic field intensity of the ground magnetic survey range between 33000 and 35000 nT, the lower section of the map (see fig. 3.3) is characterized by high intensities which may be due to the presence of settlement and NNPC pipeline buried therein.

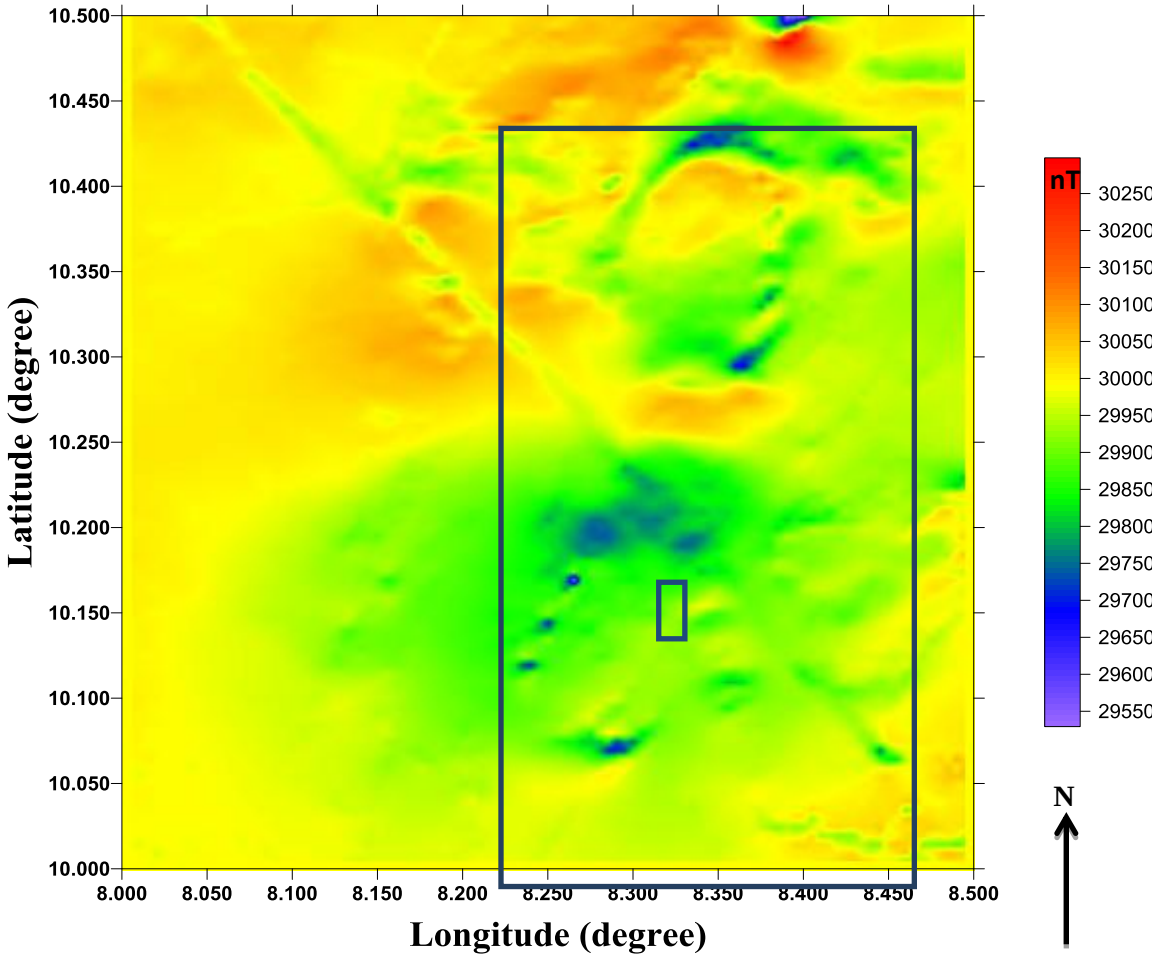


Figure 3.2: Total intensity aeromagnetic data of the Geshere area. Big rectangle is the location of the two Younger Granites while the small rectangle is the location of the gap between them.

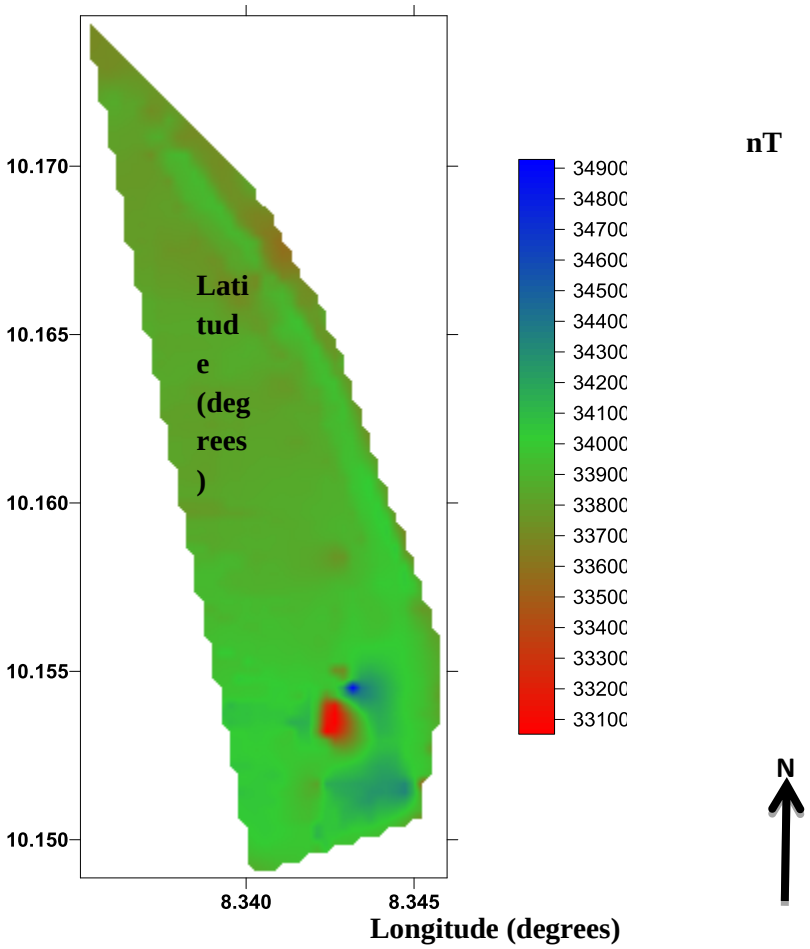


Figure 3.3: Total intensity map of the ground magnetic data of the gap between the two Younger Granites.

3.4 Data processing

Magnetic observations are affected by a number of sources in addition to signature of subsurface magnetic polarization effects which we are interested in mapping. However, for most geological applications the corrections that are applied to the observed data are fewer in number (Hinze, 1990).

Data processing is the series of steps taken to remove both signal and spurious noise from the data that are no related to the geology of Earth's crust. This process thereby prepares

the dataset for the interpretation by reducing the data to only contain signal relevant to the task and these steps include:(i) Data checking, (ii) Diurnal correction, (iii) Regional-residual separation, and (iv) Low-pass filtering.

3.4.1 Data checking and editing

This involves the removal of spurious noise and spike from the data. Such noise can be caused by cultural influences such as powerlines, metallic structures, radio transmission, fences, computation of wrong data and various other factors. This step will ideally involve systematic and detailed viewing of data by sorting to observe erroneous values and verification of the computed ground data.

3.4.2 Diurnal correction

Earth's magnetic field has day-night variations associated with interactions between the solar wind and ionosphere: they can be removed using concurrent observations at a base station.

Fluctuations within a period lasting of several hours to one day are called diurnal variations (as shown in Figures 3.4a-c). These can be considered much like tides that ebb (recede) and flow during the course of a day. This diurnal drift can cause a variation of the order of 50 nT per hour. The following figures illustrate typical diurnal variation of total field in the survey area.

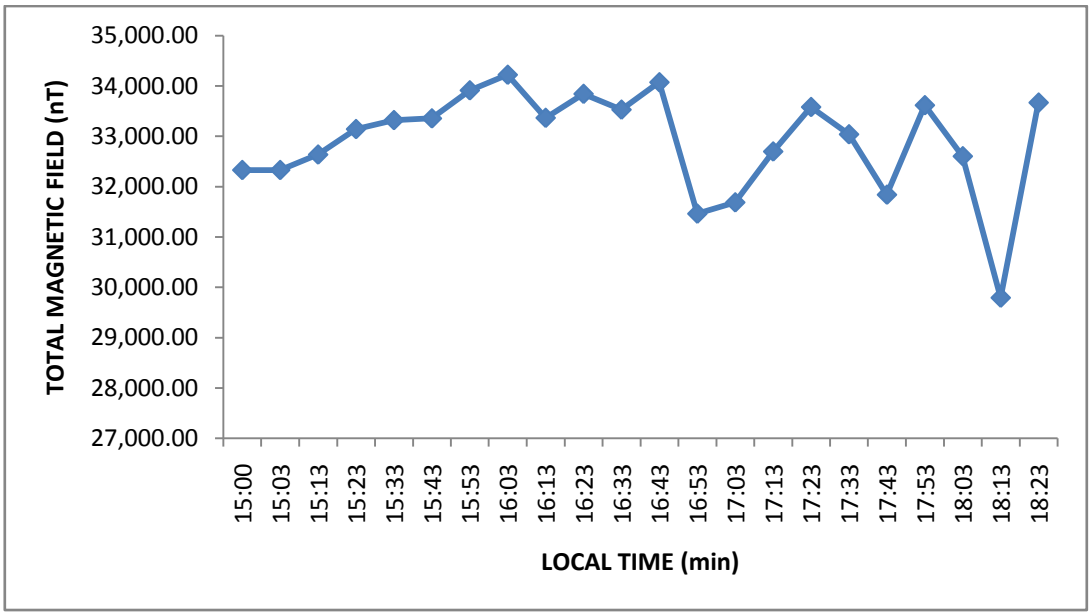


Fig. 3.4a: Magnetic variation recorded at the base-station for day1

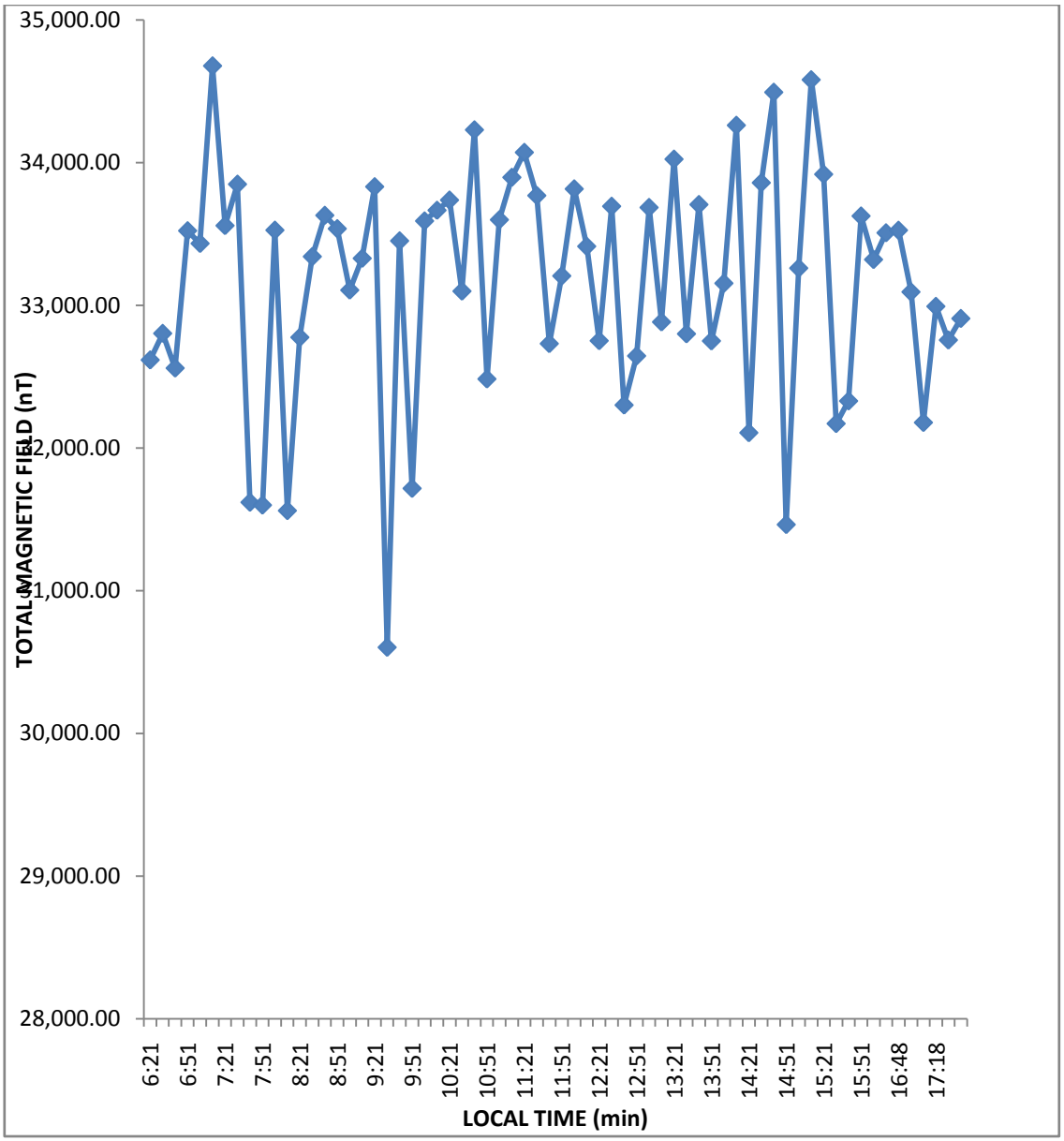


Fig. 4.3b: Magnetic variation recorded at the base-station for day2

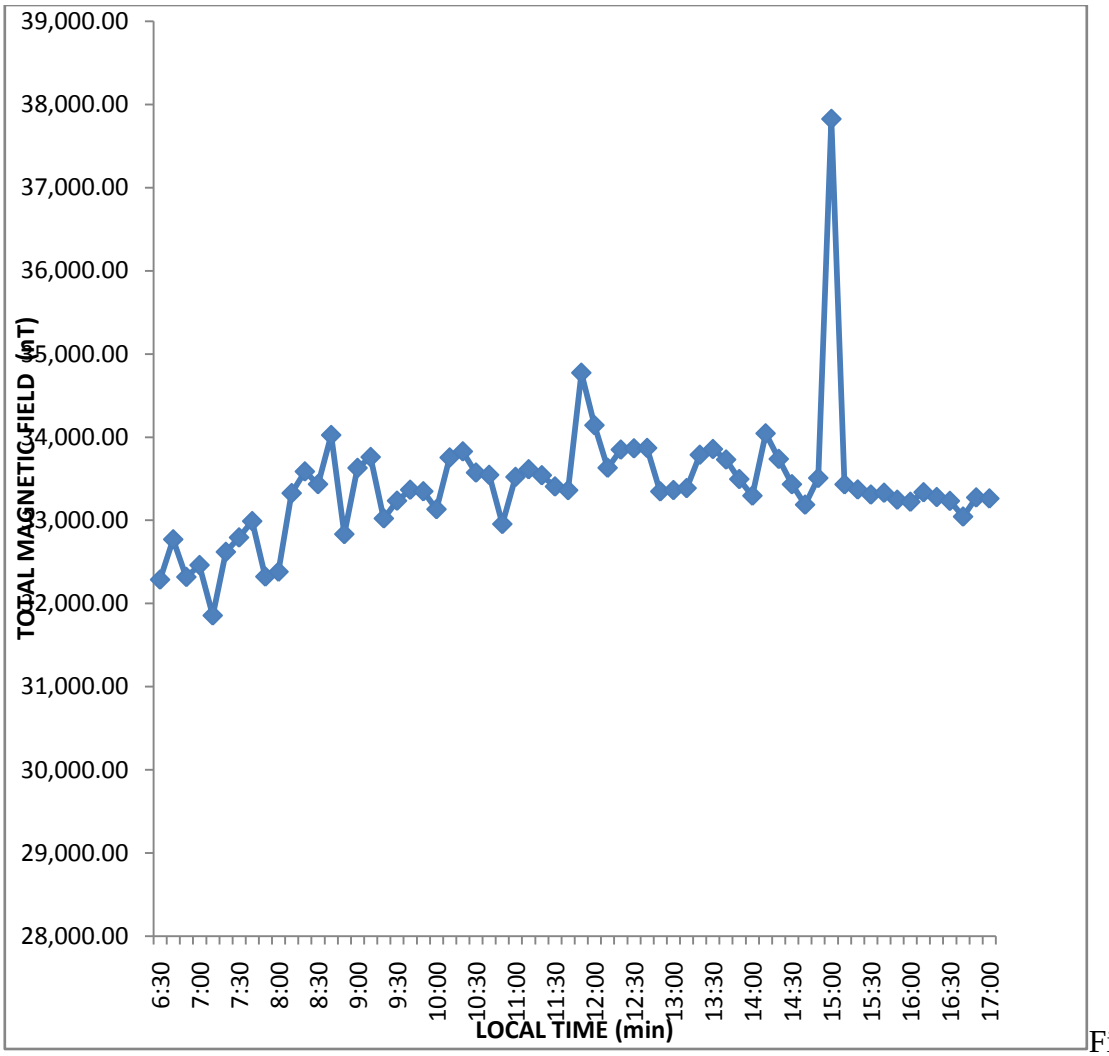


Fig. 3.4c: magnetic variations recorded at the base-station for day3

Temporal variations - diurnal variations - are primarily caused by particles and electromagnetic radiations from the sun acting upon the external field of the earth. Lesser effects are caused by tidal effects of the moon perturbing the ionosphere of the earth, and thus the geomagnetic field, and lastly magnetic field from electrical currents induced in the earth (Hinze, 1990). Because these variations have a wide range of period and amplitude: diurnal variation of the earth's magnetic field may have an amplitude as great as 100 gammas, significant effects are observed in magnetic surveying and it must therefore be

taken into account with field magnetometer and consequently must be eliminated in most applications.

Out of several techniques by which diurnal effects can be removed, the use of two magnetometers was employed in this work. The total magnetic reading of a selected station (base station) within the survey area was taken at every 10 minutes with the base station magnetometer (Proton-precision magnetometer). The first base-station reading was taken before the actual commencement of the field survey every day. Data from the base station magnetometer was used in the reduction of the survey data according to Hinze, (1990) the inherent drift of magnetometer is negligible under most survey condition.

The drift rate was calculated using

$$\text{Drift rate} = \frac{Change\ in\ magnetic\ intensity\ of\ the\ base\ station}{change\ in\ time\ of\ the\ base\ station} \qquad 3.14$$

Therefore, the drift was removed from the field data by

$$\text{Reduction} = \text{Total field data} - (\text{Drift rate x Time of field data acquisition}) \qquad 3.15$$

3.4.3 Regional-residual separation

Magnetic anomaly field combine the effect of the horizontal variation of magnetic polarization within the earth, and thus the anomaly of interest in a particular geologic application is commonly distorted by overlapping anomalies. The geomagnetic anomaly fields include effects of deeper, broader sources called regional anomalies: local sources which are considered noise as well as the anomalies of interest – the so-called residual anomalies. The definition of residual anomaly is not very precise, but perhaps can best be

defined as the anomaly of geologic interest in a particular study. Broader anomalies than the residual are regional and much smaller anomalies can be reproduced as noise.

Over the years numerous graphical and numerical techniques (which are in reality filters) have been devised to focus on particular anomaly types, of specified characteristics, within a field of superimposed anomalies of varying properties (Hinze, 1990).

Elimination of the regional and noise from potential field is a filtering process. The ideal residual determination method will 'pass' without distortion only those anomalies which are significant to the particular problem and will attenuate all others. Properly selected methods have very useful filtering characteristics, but the cutoffs are seldom sharp and can lead to both amplitude and phase distortions. This is complicated by the wide spectrum of frequencies that may be present in an anomaly.

Furthermore, the filters can be applied on both profile (one-dimensional) and map (two-dimensional) cases. The anomaly characteristics of interest in filtering can be used in an inspection interpretation, but as the residual anomaly become similar to regional and /or noise it is helpful to utilize arithmetic filters based on one or more of the anomaly characteristics.

3.4.3.1 Techniques for regional-residual separation

Of all the techniques for isolating the residual anomalies, the simplest and most effective is the geologic method. In this method, the anomalous effect of known geology is computed and subtracted from the observed anomaly. It is best to eliminate all known effects in this way, but geologic and physical property information is seldom sufficiently complete to warrant this computation (Hinze, 1990).

A widely used approach to isolation of residual anomalies includes variety of techniques that are variations on graphical procedure. These techniques are empirical and mostly satisfactory for simple regional anomalies which are markedly different from residuals (Nettleton, 1954). In the profile method, smooth regional curves are visually estimated and drawn through the profiles and this smoothed profile is subtracted from the observed anomaly to obtain the residual. In turn, the observed anomaly can be smoothed to eliminate noise in the data. A degree of control can be imparted to this subjected process by establishing a network of intersecting profiles and requiring the smoothed regionals to be equal to at intersecting points. Another graphical method employs smooth contours of the gravity or magnetic fields to obtain the residual anomalies. Also, parallel profiles drawn perpendicular to the strike of the regional anomaly pattern can be stacked together by averaging values located at the same position on parallel profiles to obtain the mean regional anomaly, which can be subtracted from the observed anomalies to isolate the residual anomalies. This method assumes that the regional is constant in amplitude and phase from one profile to another and the residual anomaly values show a normal distribution about the regional (Hinze, 1990).

The use of non-linear filters was proposed by Naudy and Dreyer (1968) to remove noise from magnetic profiles. The basic idea is that anomalies that are to be removed should be totally removed and those to be kept should remain unchanged. The parameter which guides the filtering is the maximum width of the anomalies to be removed. As such, it closely mimics a graphical determination of the regional without the disadvantage of being time consuming; its disadvantage is that it cannot take geological constraint other than the width of the anomalies account (Keating and Pinet, 2011).

Trend-surface analysis (Agocs, 1951; Oldham and Sutherland, 1955) is a variation on the graphical procedure which minimizes the subjective nature of the process. In this method the regional is approximated from the observed values by least-squares method. The regional is subtracted from the observed value to obtain the residual anomaly. Furthermore, the anomaly field may be closely approximated by least-squares to eliminate noise. Thus, two equations, one approximating the regional and the other the original function, may be subtracted from one another to obtain an effective bandpass filter (Hinze, 1990).

In the least squares method, we are interested in the general tendency of the data, this tendency is used to interpolate between data points, extrapolate beyond the data sequence, infer the presence of trends, or estimate characteristic that may be of interest to the geologists and geophysicist (Davis, 1973).

The least squares criterion regional-residual separation is such that the residual is the square of the deviation of the regional from the observed (measured). The regional uses a polynomial surface to expose the residual features as deviation from the observed field. The separation of a data into two component is done by fitting a trend (plane) surface, which may be defined as a linear function of the geographic coordinates of a set of observations (in this case, total magnetic field data) so constructed that the squared deviations from the trend are minimized.

The definition above may be explained in three parts:

1. It is based on geographic coordinates: this means that an observation (the total magnetic field data) is considered to be in part a function of the location of the observation.

2. The surface is a linear function: it has the form

$Y = b_0 + b_1X_1 + b_2X_2 \ldots$, where the b's are coefficient and the X's are some combination of the geographic coordinates.

3. The specific linear functions chosen for the trend must minimize the squared deviation from the trend.

Hence, a linear function is an equation of this type:

$$Y = b_0 + b_1X_1 + b_2X_2 \qquad 3.16$$

where the b's are coefficients and the X's are some combination of the geographic coordinates.

Equation (3.16) thus yield values ($\hat{Y}$) which are the regional components of the observation, which may be regarded as a linear function of some constant value b_0 related to the mean observations, plus an east-west (b_1) component (in this case, the latitudes) and north-south (b_2) components (that is, the longitudes).

Hence, we obtain the three normal equations:

$$\sum Y = nb_0 + b_1\sum X_1 + b_2\sum X_2$$

$$\sum X_1 Y = b_0\sum X_1 + b_1\sum X_1^2 + b_2\sum X_1X_2 \qquad 3.17$$

$$\sum X_2 Y = b_0\sum X_2 + b_1\sum X_1X_2 + b_2\sum X_2^2$$

In matrix form, equation (3.17) becomes:

$$\begin{bmatrix} n & \sum X_1 & \sum X_2 \\ \sum X_1 & \sum X_1^2 & \sum X_1 X2 \\ \sum X_2 & \sum X_1 X2 & \sum X_2^2 \end{bmatrix} \times \begin{bmatrix} b_0 \\ b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} \sum Y \\ \sum X_1 Y \\ \sum X_2 Y \end{bmatrix} \quad 3.18$$

3.4.3.2 Application and Results

The least square method was adopted in this work. The solution to equation (3.18) for both aeromagnetic and ground survey data were obtained solving the series of simultaneous equation that evolved from the substitution of the sums, sums of powers, and sums of cross-products required in equation (3.17)

The coefficients b_0, b_1, and b_2 were found by solving the resulting set of simultaneous normal equations and the coefficients of the plane surface determined are then substituted into equation (3.18) and evaluated to obtain the regional surface ($\hat{Y}$). The differences between the measured or observed field data (Y) and the regional field data ($\hat{Y}$) gives the residual field data. The residual obtained normally consist of positive and negative values. The regional fields for both ground and aeromagnetic were presented in figure 3.5 and 3.6 below and it was observed that their trend pattern (NE-SW) is in conformity with most tectonic structures.

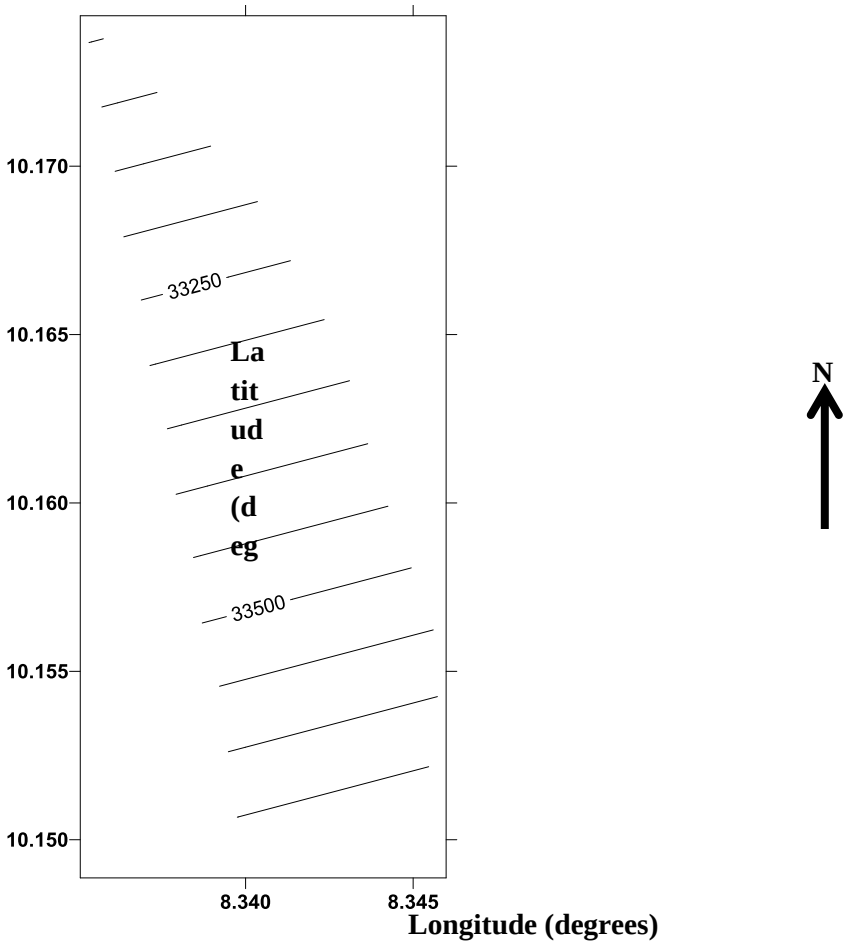


Figure 3.5: Regional contour map of the ground data (contour interval: 50 nT).

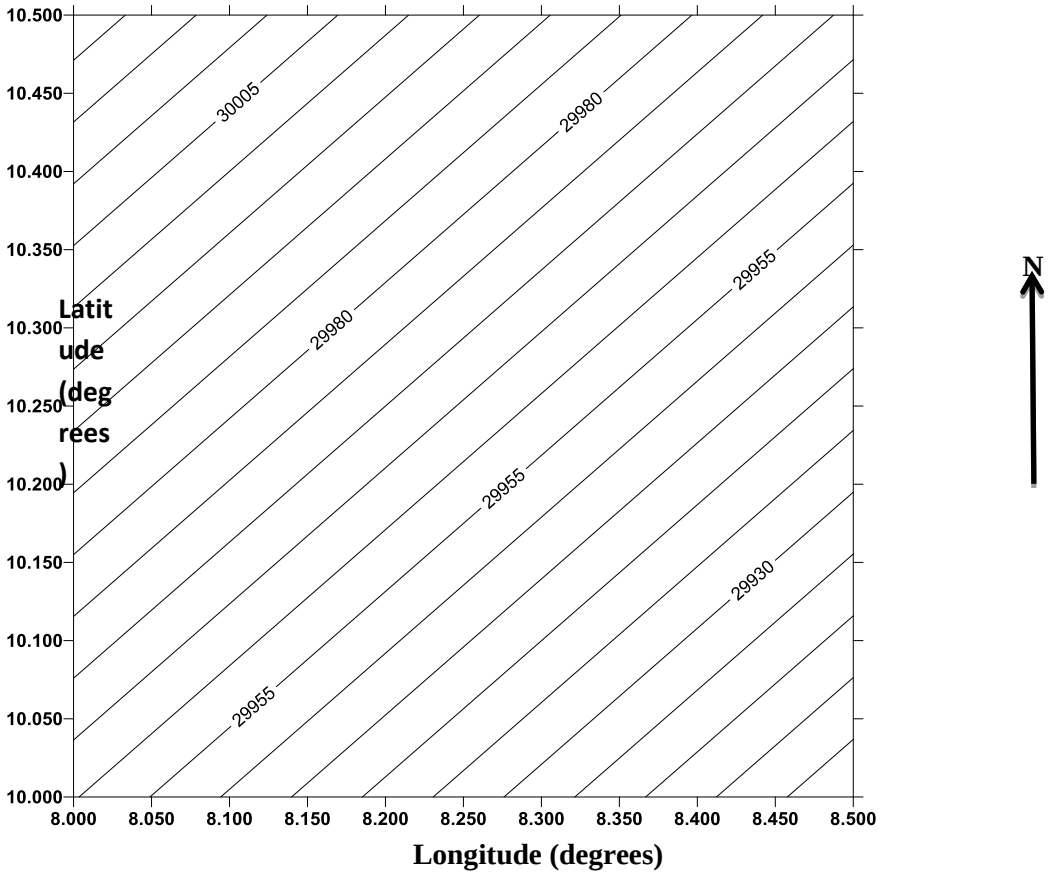


Fig 3.6: Regional contour map of aeromagnetic data (contour interval: 5 nT).

The values of the regional field of the ground magnetic data in figure 3.5 increases gradually from the NW to SE section and that of the aeromagnetic data in figure 3.6 increases from the SE to the NW section of the study area.

Both corrected data, aeromagnetic and ground magnetic data, were presented in grid for visualization and further enhancements as shown in figures 3.7 and 3.8 respectively. The aeromagnetic data were gridded using minimum curvature gridding method. Five profiles were extracted from the corrected ground magnetic map as shown in figure 3.9 with the plot of their magnetic field in figures 3.10 a – d which was later subjected to various interpretation techniques. For effective interpretation of the obtained aeromagnetic data, further enhancements were carried out using various filtering techniques.

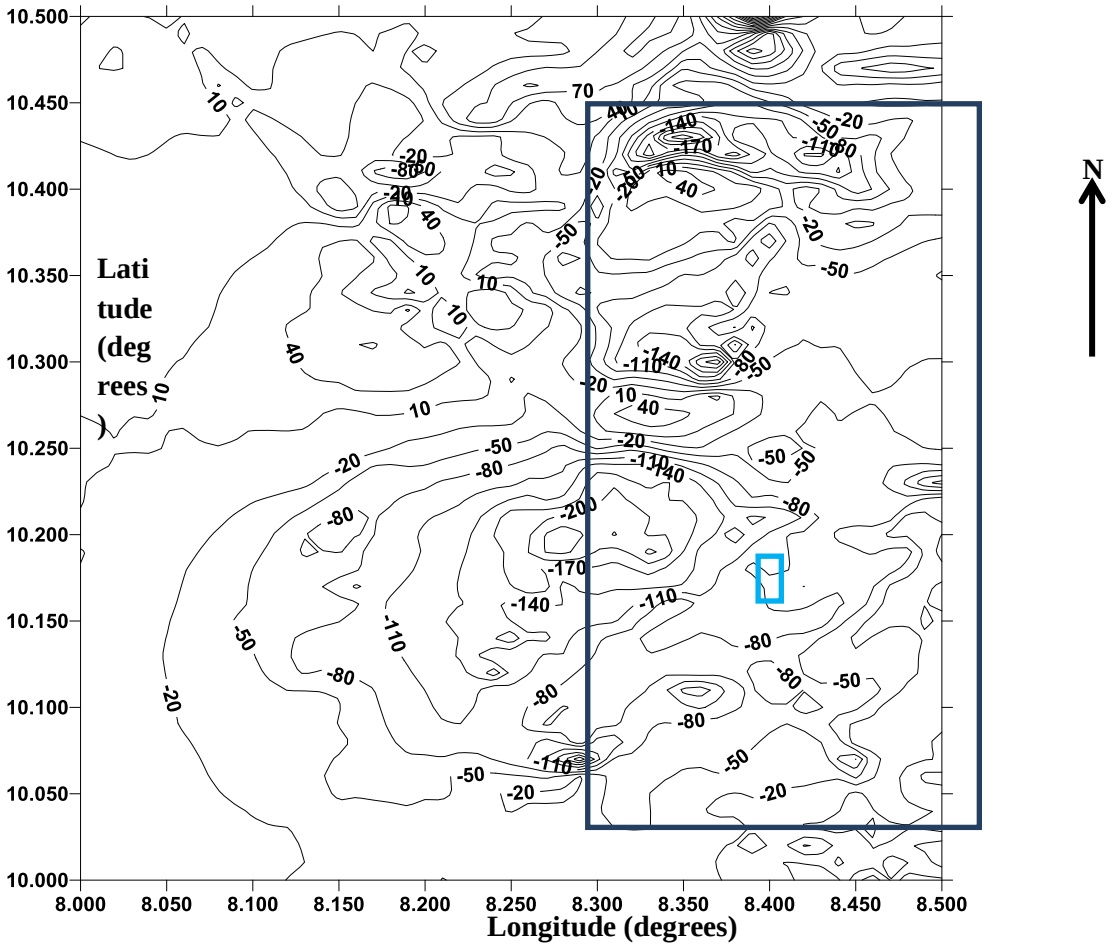


Figure3.7: Residual contour map of aeromagnetic data. Big rectangle is the location of the two Younger Granites while the small rectangle is the location of the gap between them (contour interval: 30 nT).

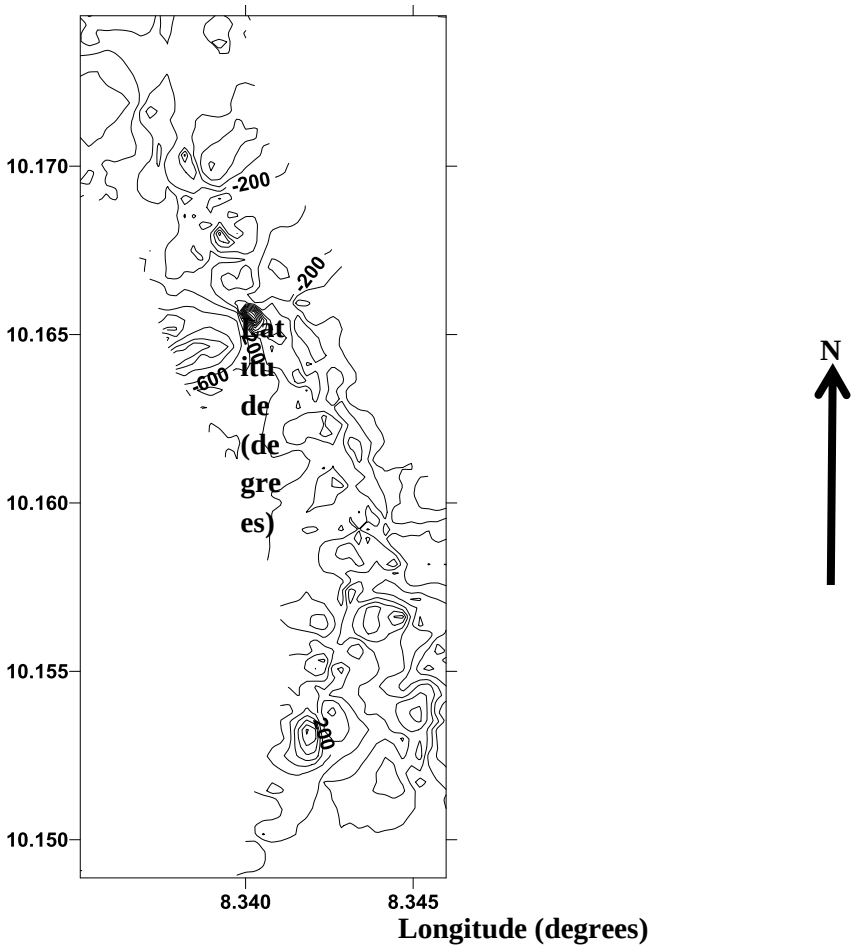


Figure 3.8: Residual contour map of ground survey data (contour interval: 600 nT).

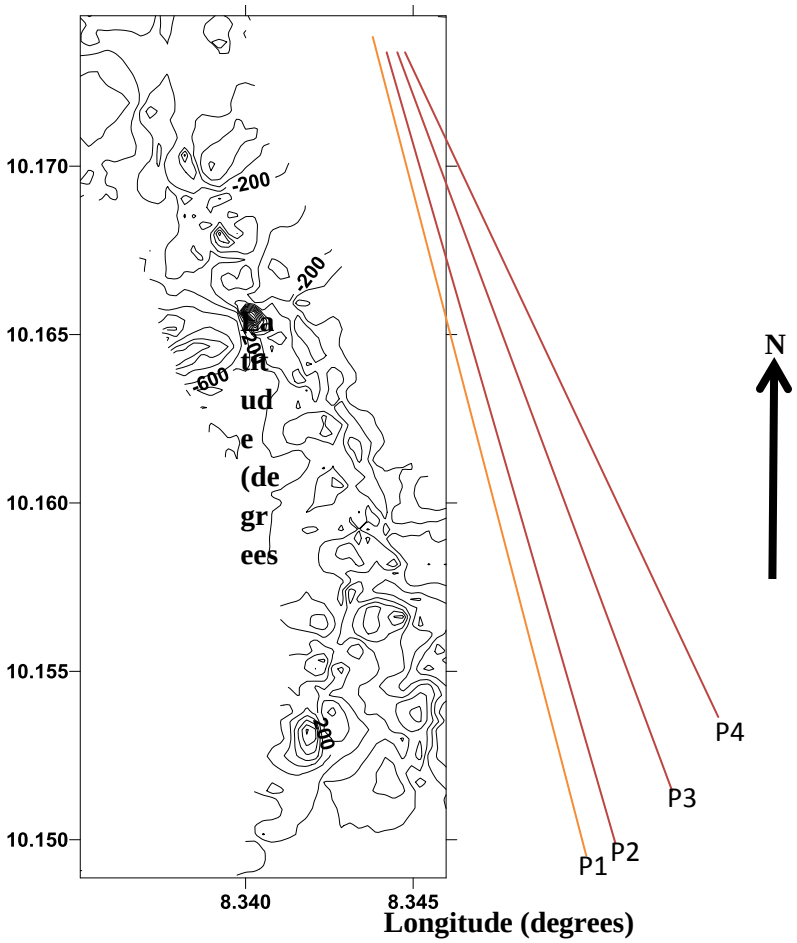


Fig. 3.9: An overlay of the profiles on total ground magnetic field.

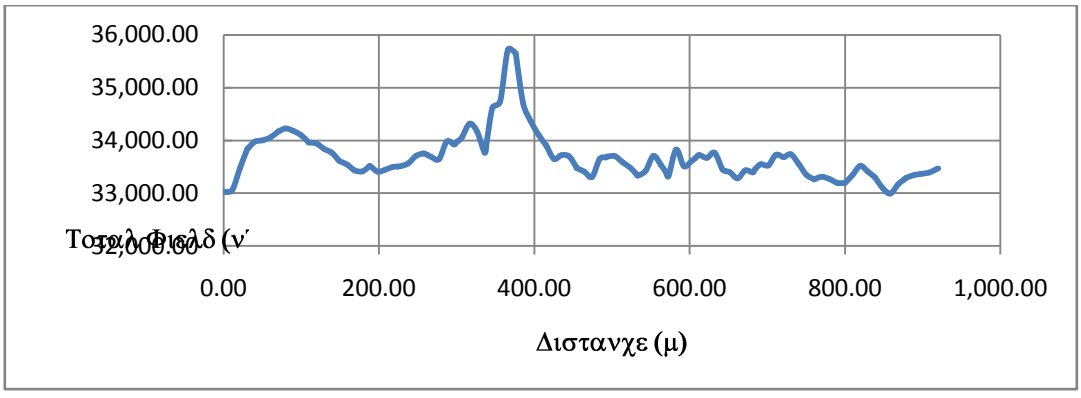


Figure 3.10 a: Total field of profile one selected from the ground magnetic data.

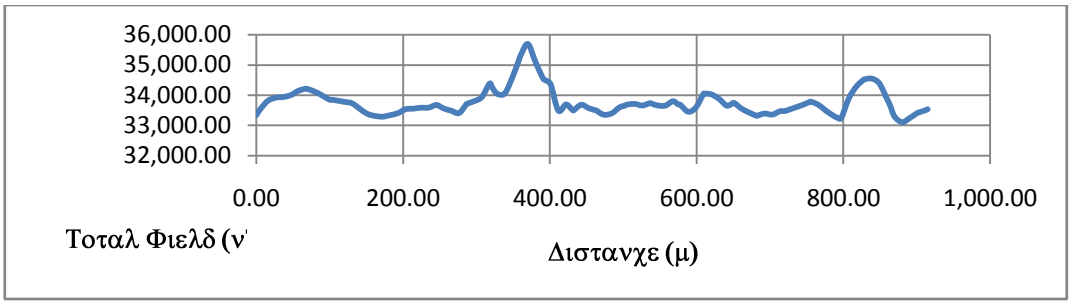


Figure 3.10 b: Total field of profile two selected from the ground magnetic data.

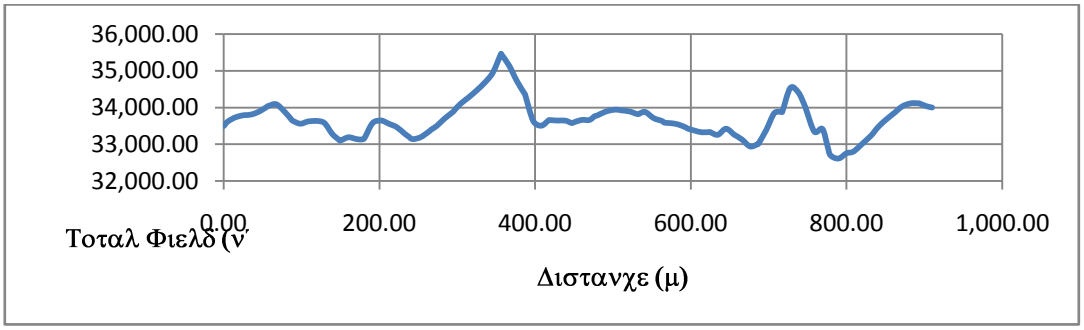


Figure 3.10 c: Total field of profile three selected from the ground magnetic data.

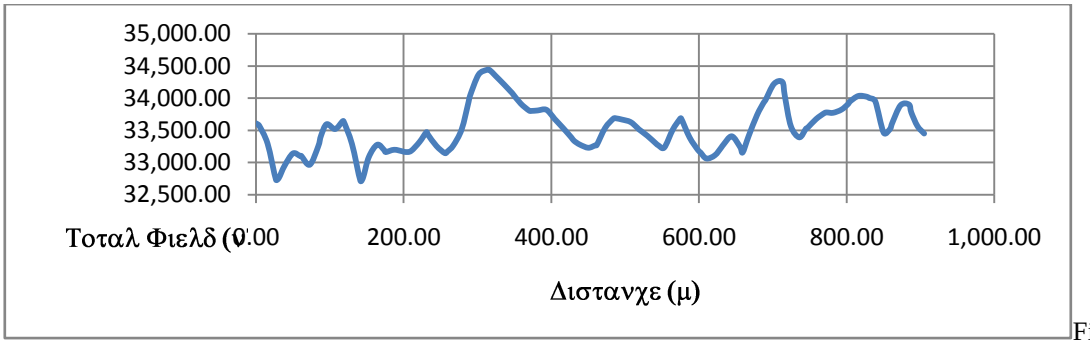


Figure 3.10 d: Total field of profile four selected from the ground magnetic data.

3.5 Data enhancement

Data enhancement techniques such as filtering, continuations, computation of derivatives, etc. are used as interpretational aids in potential field studies. The purpose of enhancement is to accentuate certain characteristics of anomalies to increase their perceptibility. The

enhanced potential field anomalies are primarily used in qualitative visual analysis to infer approximate shape outlines of anomaly sources of interest which may be localized features at relatively shallow depths, or large scale structures at greater depth (Sharma, 2002).

3.5.1 Low-pass filtering

It is essential to reduce the effect of noise in the data because most of the techniques adopted for interpretation involve derivative process (both vertical and horizontal) which even though enhances the shallow anomalies, can also enhance noise in the data.

The low-pass filtering of cut-off wavelength of 6 km was applied to residual total magnetic field of the aeromagnetic data. The choice of the cut-off wavelength was guided by the plot of the logarithm of the spectral energies against wavenumber obtained for the area (seefig. 3.11)

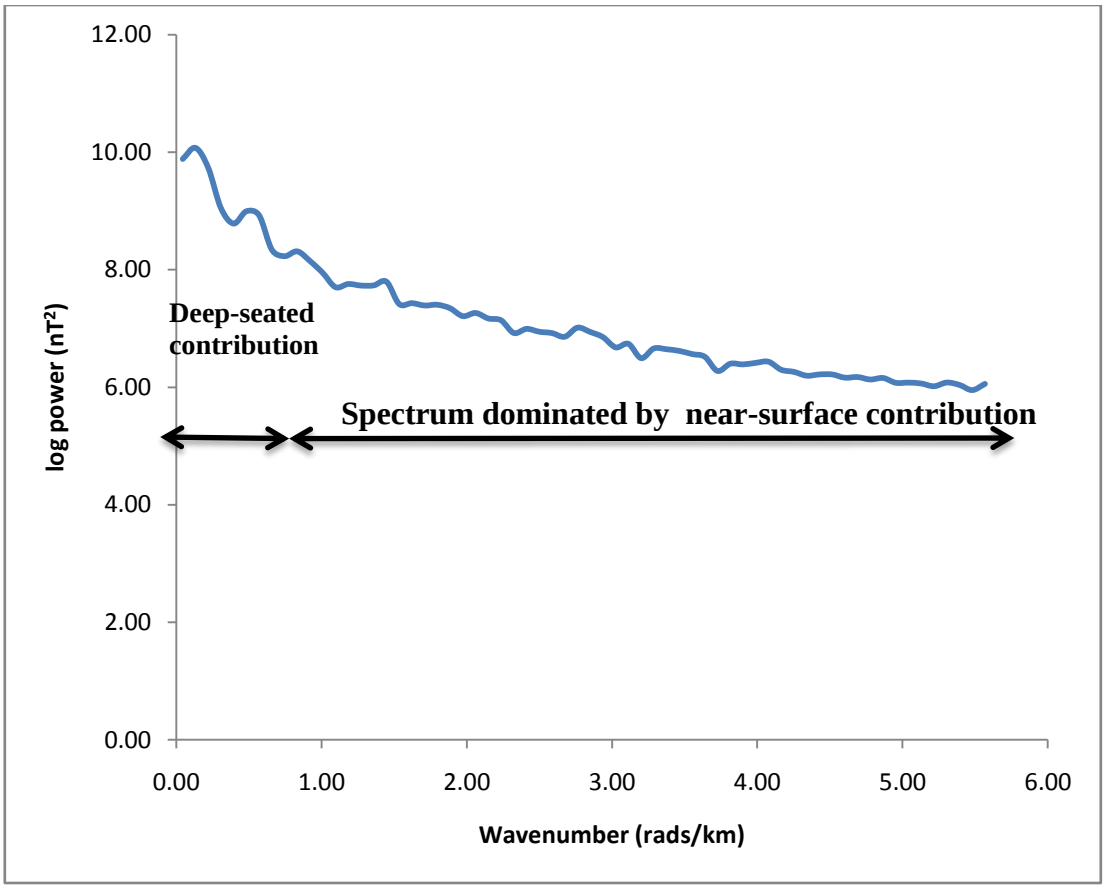


Figure 3.11: Energy Spectrum of the study area

Two spectral (magnetic) layers are distinguished from the plot above: the first segment of the energy spectrum (low frequency component of the plot), is ascribed to contributions from deep-seated magnetic sources; while the second segment (high frequency component of the plot), represent magnetic anomalies attributed to near surface sources and cultural noise.

The low-pass filtering implies that magnetic effects with wavelength range from the minimum to the cut-off wavelength result largely from source at depths from which materials intrude the surface.

Frequencies ranging from the minimum value to the cut-off are passed without modification. The noise in the residual of total magnetic field was hence removed by the low-pass filtering; the contour map of low-pass filtered residual data is much smoother and shows clearly the alignments and boundaries of the anomalies (Fig. 3.12).

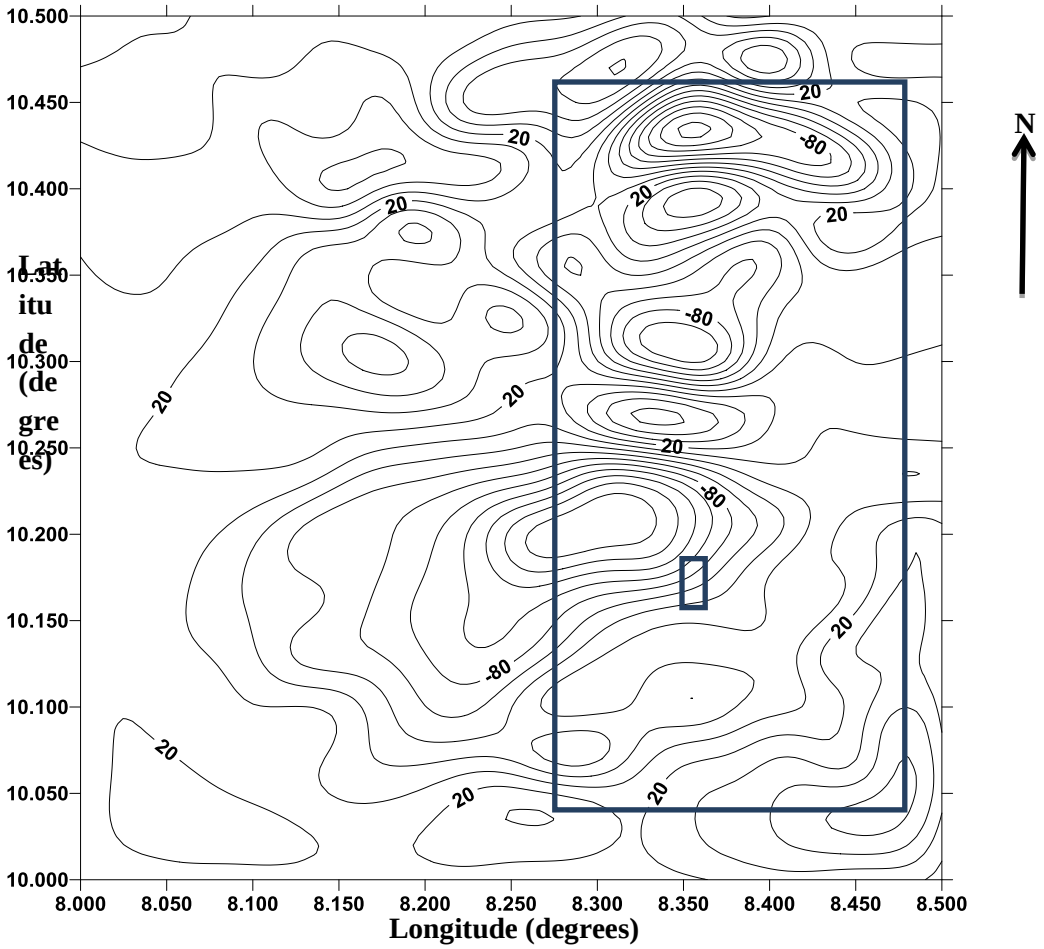


Figure 3.12: Low-pass filtered aeromagnetic map. Big rectangle is the location of the two Younger Granites while the small rectangle is the location of the gap between them (contour interval: 20 nT).

CHAPTER FOUR: DATA INTERPRETATION

4.1 Second vertical derivatives

Vertical gradient (Vertical derivative) can be thought of as component of the rate of change of the anomaly values as the potential-field data are upward continued. Nonetheless, vertical-gradient maps help highlight the details, discontinuities and breaks in anomaly texture. Derivatives are intended to outline boundaries.

Second vertical derivatives $\left(\Delta T'' = \frac{\partial^2(\Delta T)}{\partial Z^2}\right)$, given that ΔT and Z are change in magnetic field and vertical displacement respectively, are conventionally used to enhance near-surface effects obscured by the regional trends and also as aid in the definition of the edges of source bodies. The second vertical derivative has even more resolving power than the first vertical derivative, but its application requires high quality data as its greater enhancement of high frequencies result in greater enhancement of noise. It was shown by Hood and McClure (1965) that second vertical derivative is zero and rapidly changes sign at a point vertically over the contact.In magnetic data interpretation, second vertical derivatives are used to delineate the plain-view boundaries of intra-basement anomaly sources and are also found to be effective for enhancement of magnetic anomalies(Sharma, 2002).

From the second vertical derivatives map which outlines the edges of the anomalous bodies, the depth to the top of a body is estimated to be half the width of the distance between the zero contours (Dobrin, 1976). The second vertical derivatives of the low-pass filtered aeromagnetic data was derived using Geosoft oasis montaj software as shown in figure 4.1 while the zero contours of the second vertical derivatives were obtained using

Surfer software and this is shown in figure 4.2. The red lines indicate the zeros of the contour that delineate the spatial locations of the magnetic source edges which in effect outline anomalous areas.

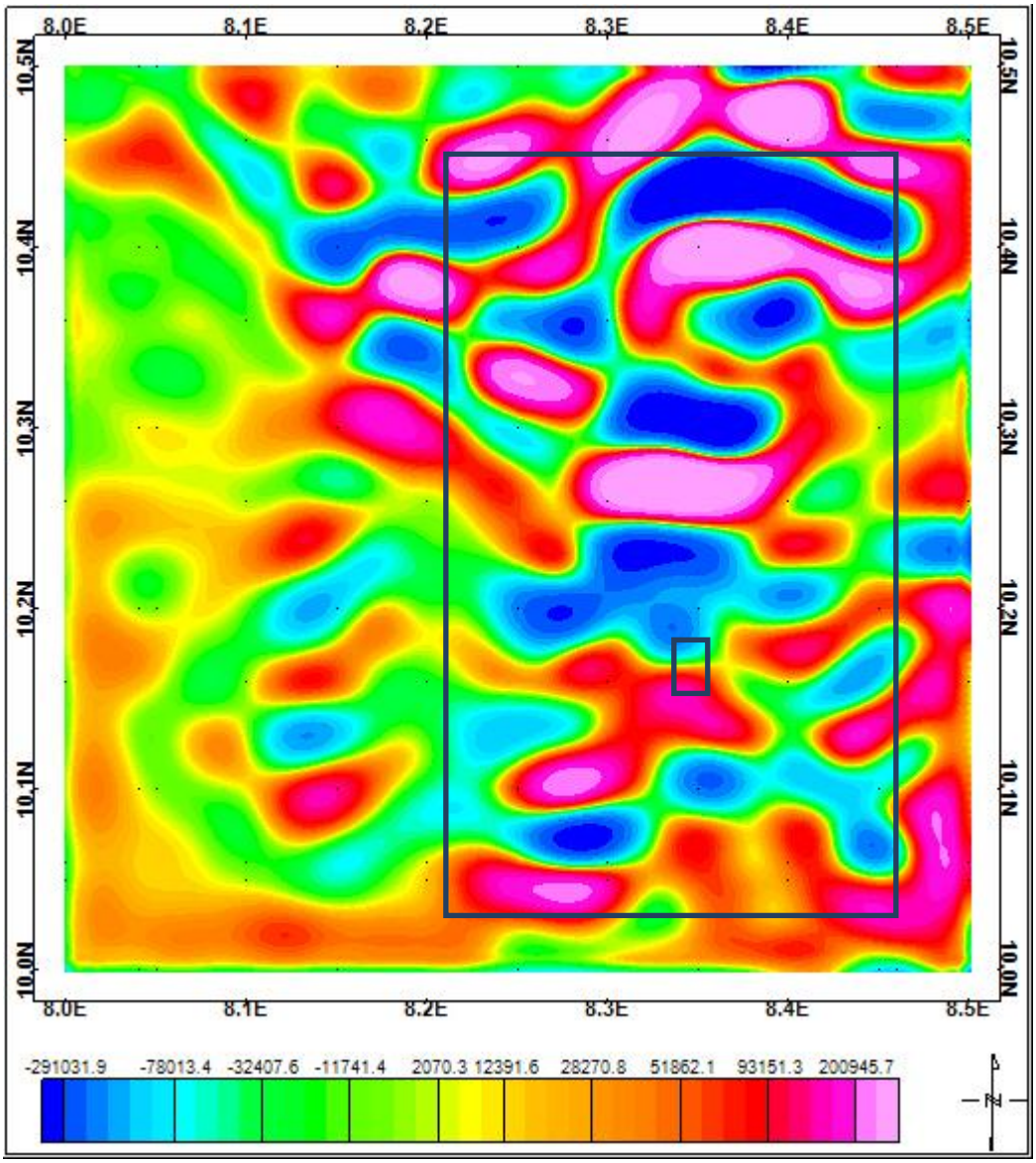


Figure 4.1: The second vertical derivative of the filtered aeromagnetic map. Big rectangle is the location of the two Younger Granites while the small rectangle is the location of the gap between them.

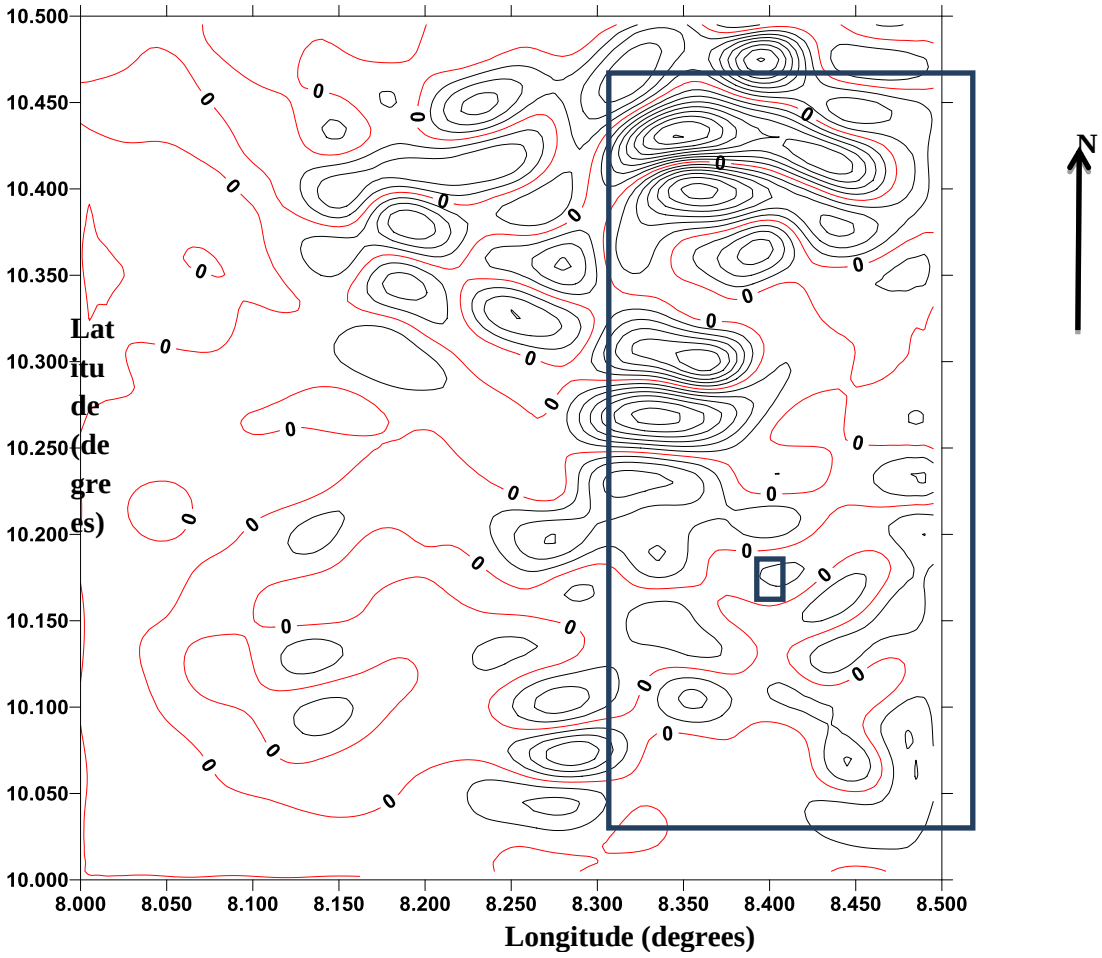


Fig. 4.2: Second vertical derivative contour map (contour interval of 100,000 nT) with red line indicating the zero contours. The big rectangle indicates the boundary of Rishiwa and Geshere Younger Granites and the small rectangle indicates the boundary of the gap between the two Younger Granites.

4.2 Analytic signal technique

The analytic signal (or total gradient) is the combination of vertical and horizontal gradients. It is based on the calculation of the first derivative of magnetic anomalies to estimate source characteristics.

This is a filter applied to magnetic data and is aimed at simplifying the fact that magnetic bodies usually have a positive and negative peak associated with it, which in many cases make it difficult to determine the exact location of the causative body.

Nabighian (1972, 1974) suggested the concept of analytic signal (AS) and proposed that in the 2-D case, the horizontal and vertical derivatives of gravity and magnetic fields satisfy the Hilbert transform, thus can be regarded as analytic signals. The amplitude of the analytic signal is the same as the total gradient, independent of the direction of the magnetization, and represents envelop of both the vertical and horizontal derivatives over all the possible directions of the earth's field and source magnetization. In 1984, Nabighian extended this theory to three dimensions the 2-D Hilbert transform relations between potential field components. In 1992, Roest *et al*., introduced the 3-D analytic signal of magnetic data as an extension to the 2-D case and pointed out that the signal exhibits maxima over magnetization contrasts, independent of the ambient magnetic field and source magnetization directions. Qin (1994) also suggested a similar view, he claimed that the amplitude of the analytic signal is independent of the inclination of the field in 3-D case. Some workers (Agarwal and Shaw (1996); Guan and Yao (1997); Haung *et al*. (1997); Haung and Guan (1998)) argued the conclusion that the shape of the analytic signal over 3-D bodies is independent of inclination of magnetization and that the analytic signal response always produces symmetrical anomalies.

Nabighian (1972), shows that the shape of the analytic signal of contacts and sheets is independent of the directions of the magnetization and the local geomagnetic field. In addition, Roest *et al*. (1992) showed that this is true for any 2D magnetic anomaly (Keating and Sailhac, 2004). Such is not the case for 3D anomalies. Nevertheless, the

shape of analytic signal is still nearly independent of the directions of magnetization and of the earth's field. Agarwa and Shaw (1996) calculated the analytic signal of a single magnetic pole anomaly and concluded that, in general, the analytic signal is not symmetric for arbitrary values of inclinations and declination. A circular symmetry is observed for a field inclination of 90^o, and at an inclination of 0^o the anomaly is symmetric along the axis of the declination. In general, the anomaly is nearly circular or slightly elongated along the geomagnetic field declination. Therefore two advantages exist in using the analytic signal to identify magnetic anomalies: first, it is independent of remanence; second, as it will be shown, it performs well at low magnetic latitudes.

4.2.1 Application

The analytic signal of the low-pass filtered aeromagnetic data was computed and the map was subsequently plotted (see fig. 4.3) using OASIS MONTAJ^{TM}. The zero contours of the aeromagnetic data were overlaid on the analytic signal of the low-pass filtered data using SURFER 11 (see fig. 5.4). Also, the analytic signal of profiled ground data were computed and plotted (see fig. 4.5a- d)

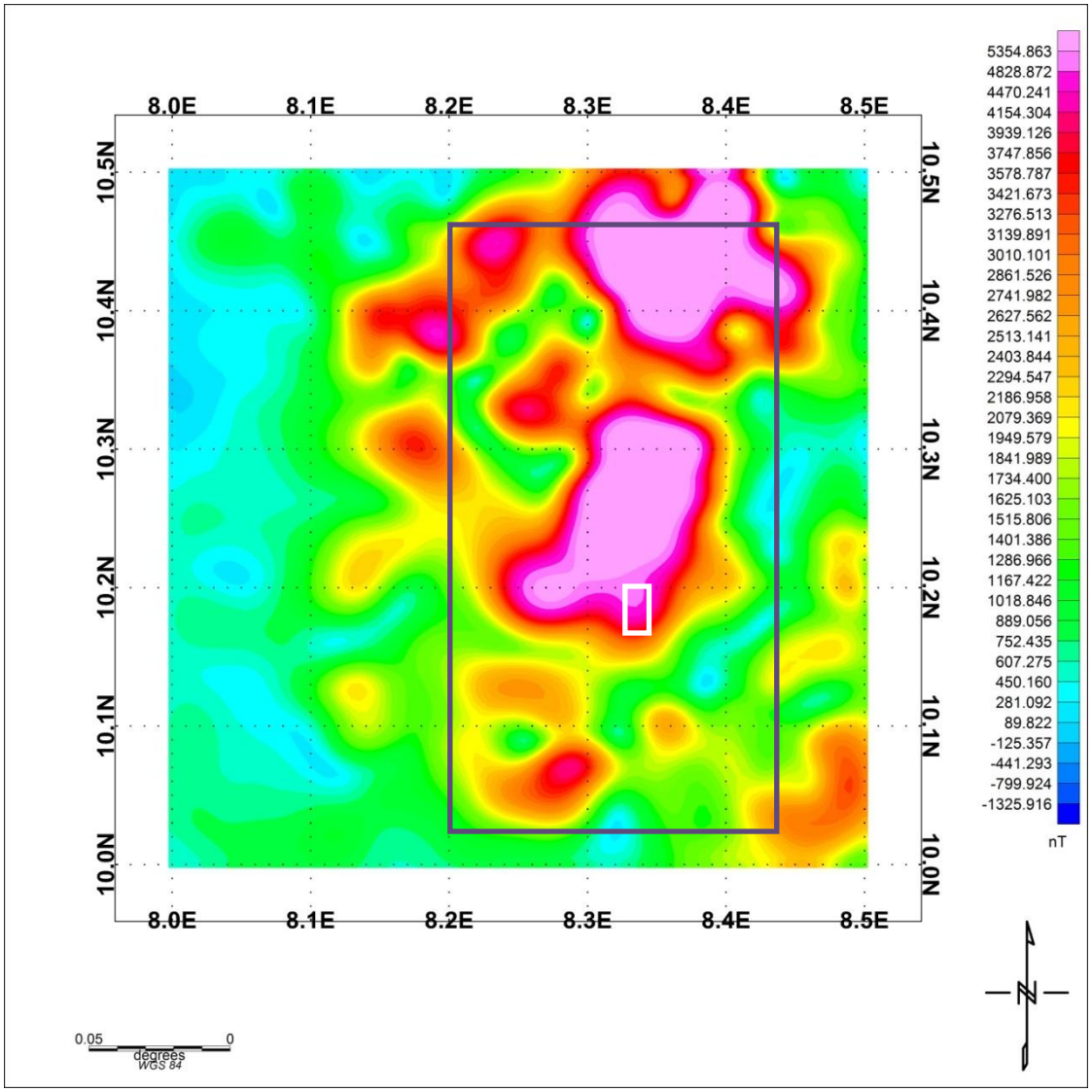


Figure 4.3: Analytic signal of the aeromagnetic map. Big rectangle is the location of the two Younger Granites while the small rectangle is the location of the gap between them.

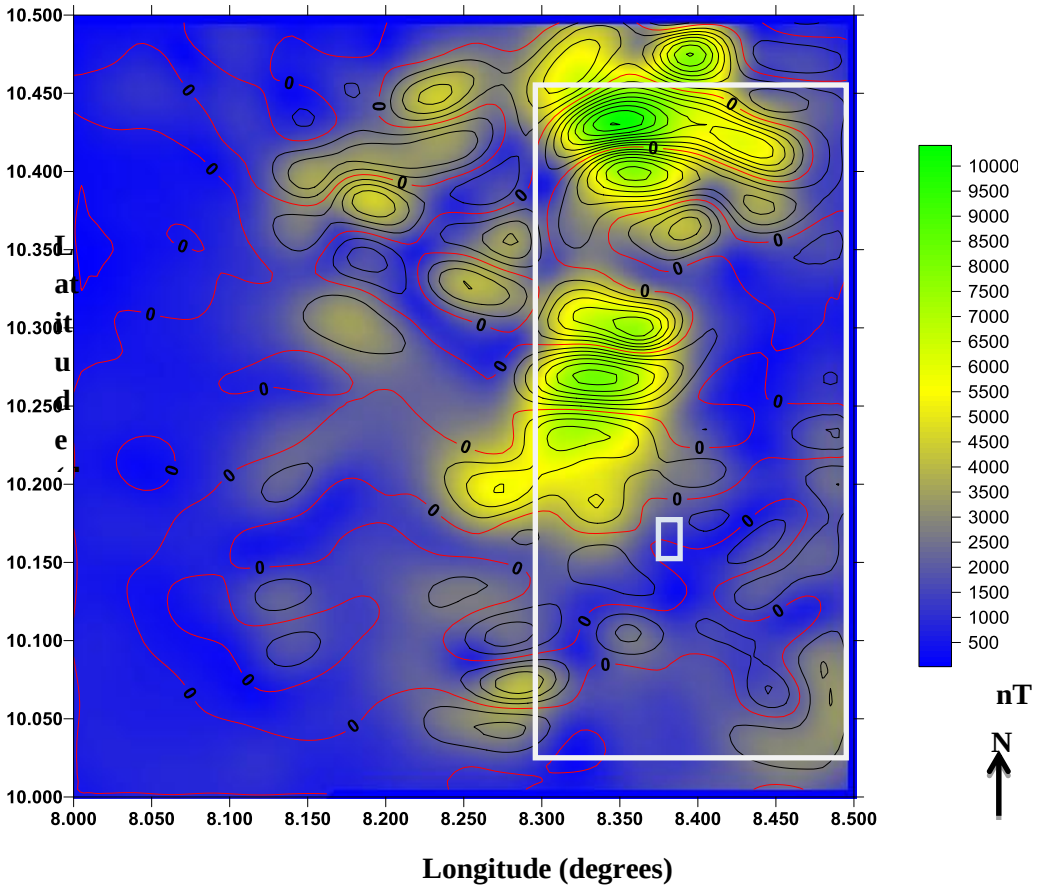


Figure 4.4: Overlay of analytic signal over second vertical derivative map. Big rectangle is the location of the two Younger Granites while the small rectangle is the locationof the gap between them.

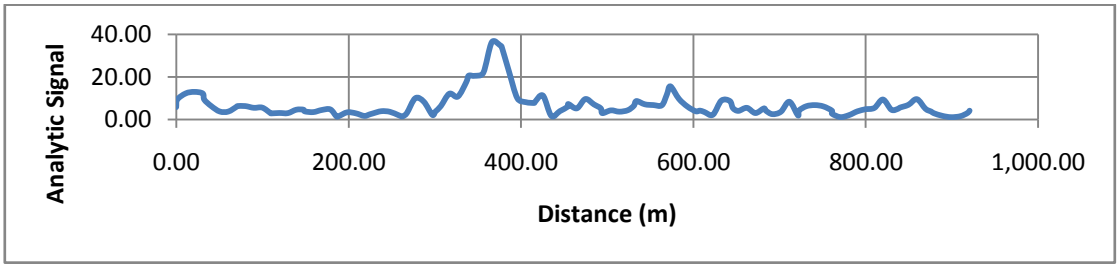


Figure 4.5a: Analytic signal for profile one.

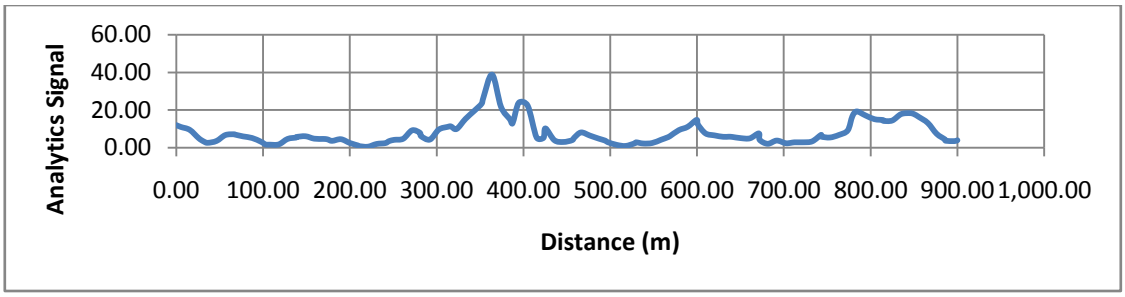


Figure 4.5b: Analytic signal for profile two

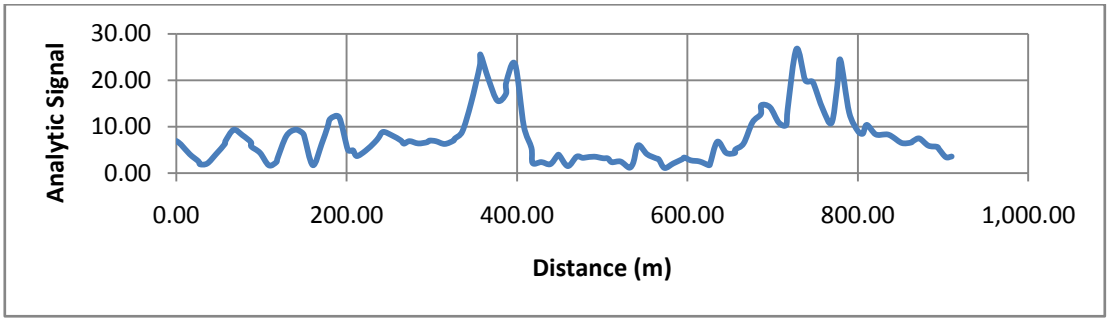


Figure 4.5c: Analytic signal for profile three

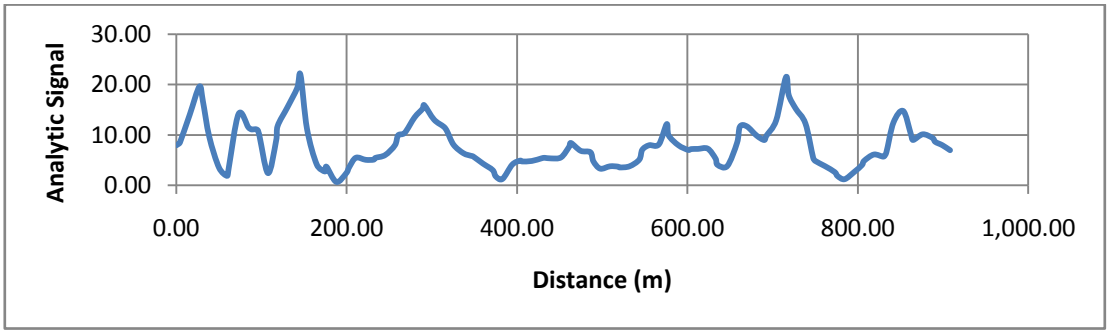


Fig. 4.5d: Analytic signal for profile four

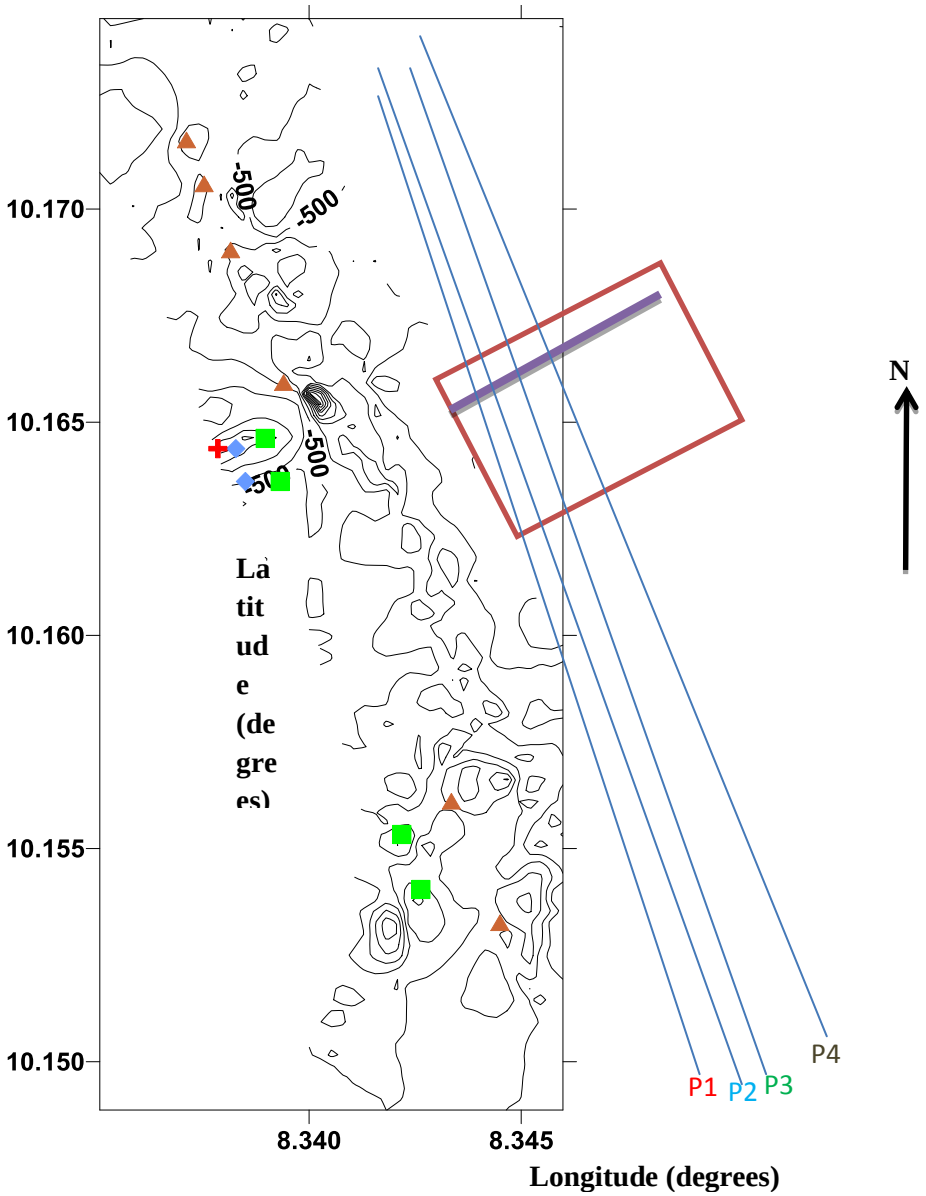


Figure 4.6: Plot of the locations of peaks of 2D analytic signals on the ground magnetic map; profile one (red), profile two (baby blue), profile three (green) and profile four (brick red). The thick purple line represents the location of the zero contour of second vertical derivatives.

4.3 Werner deconvolution

In practice, measurements of the magnetic field are made along a profile at equal linear intervals (Hartman *et al.*, 1971). The sensitivity of the operator for the detection of an anomalous geologic source will be strongly related to the horizontal distance subtended by

the array: the broader a given anomaly, the larger must be the dimension of the array required to recognize it. For this reason, the computation sequence described above is repeated a number of times, with the operator length (distance between points in the array) increased each time.

If thin sheets (dykes or sills) are present, their anomalies are recognized and analyzed from the total field data, while interfaces (dipping contacts or changes in slope of a particular surface) are analyzed from the measured vertical gradient data and the computed horizontal derivative of the total field. Typically, an anomaly will produce both a thin-sheet solution and an interface solution.

In practice, a scatter of solutions is obtained and virtually all anomalies are interpreted as both thin dykes and edges. Considerable skill appears to be required to use the results in a meaningful way. The concept, however, seems fundamentally sound (Gunn, 1997). Jain (1974), using model data, has shown that the accuracy of the depth determinations is approximately 10 per cent. The Werner deconvolution of the four profiles from the ground magnetic data which solves for contact and dyke were computed using OASIS MONTAJ^{TM} (see fig. 4.7a-d) and the overlay of plot of the locations of the solutions on the total field of the ground magnetic data was shown in figure 4.8.

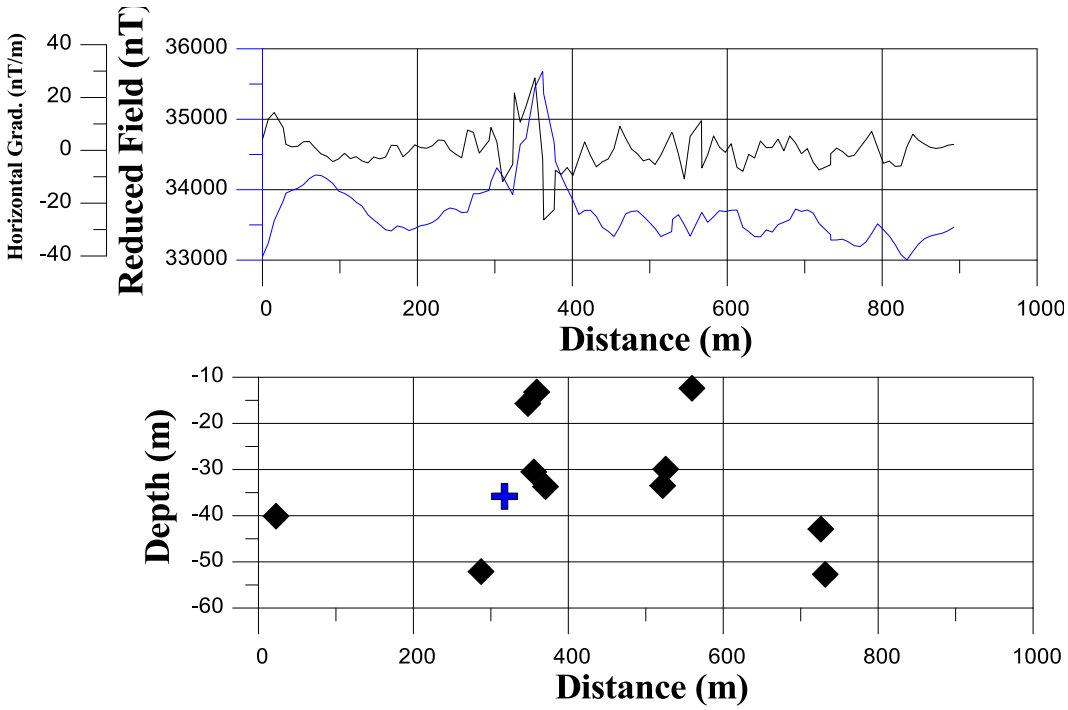


Figure 4.7a: Werner solution for profile one.

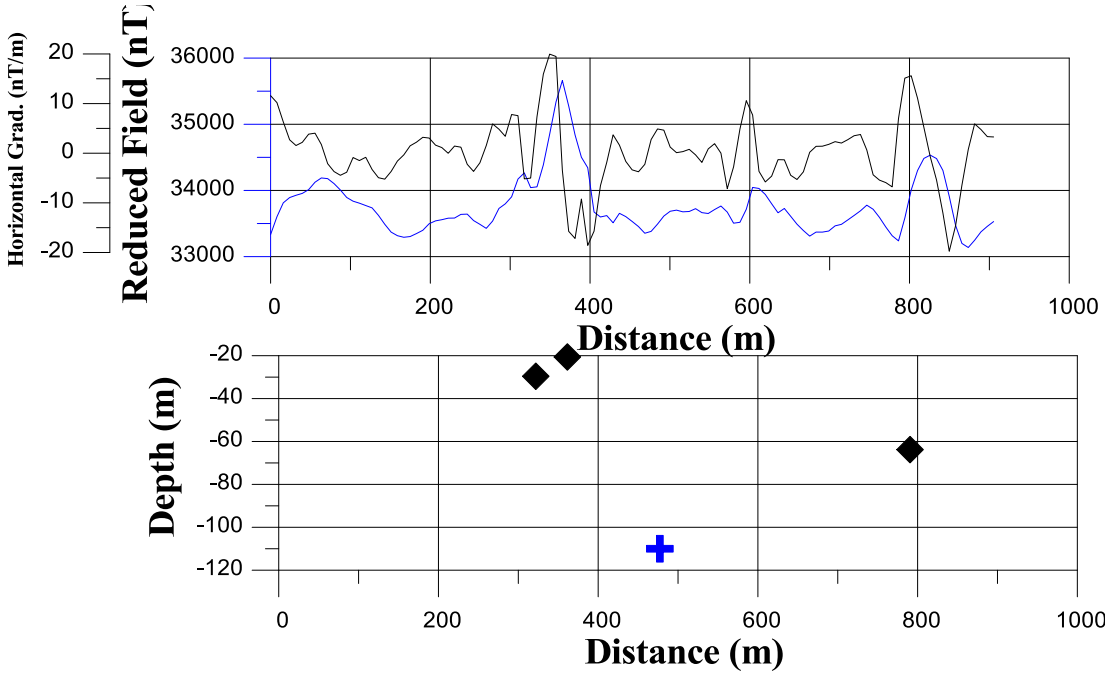


Figure 4.7b: Werner solution for profile two.

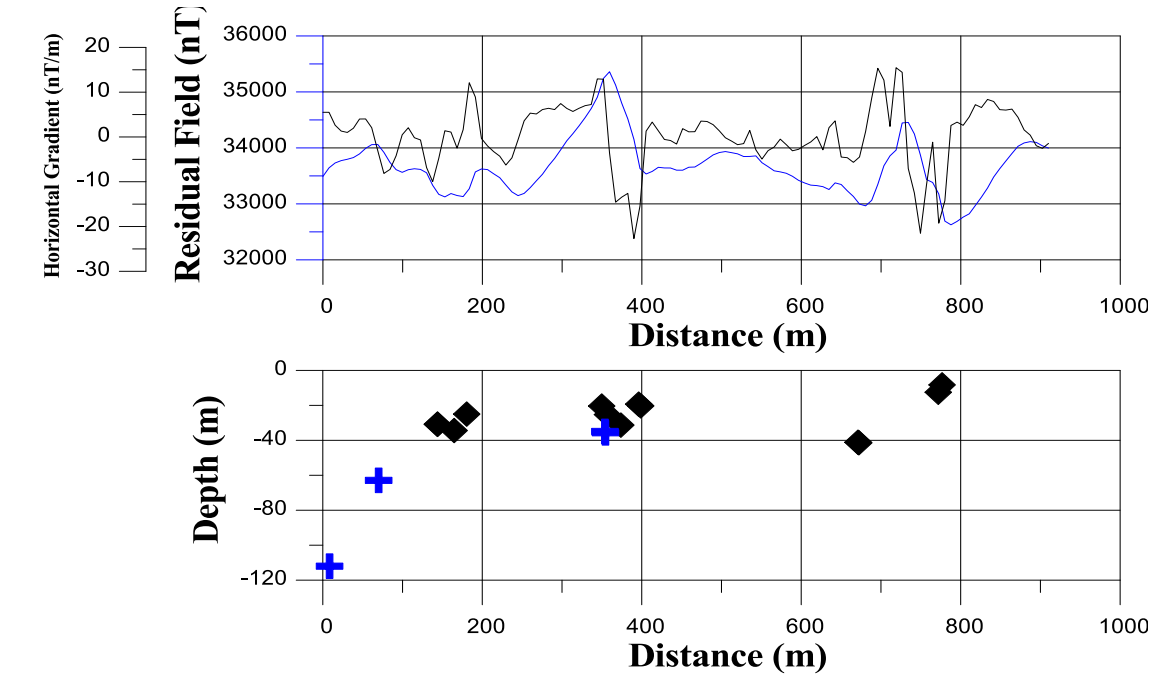


Figure 4.7c: Werner solution for profile three.

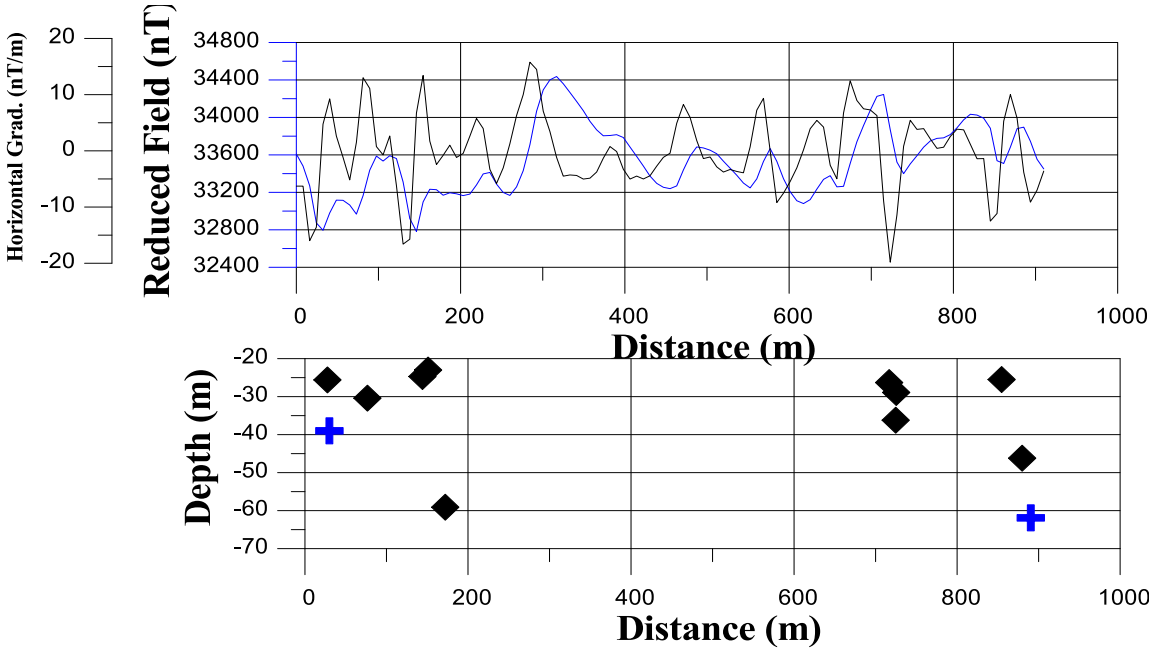


Figure 5.7d: Werner solution for profile four.

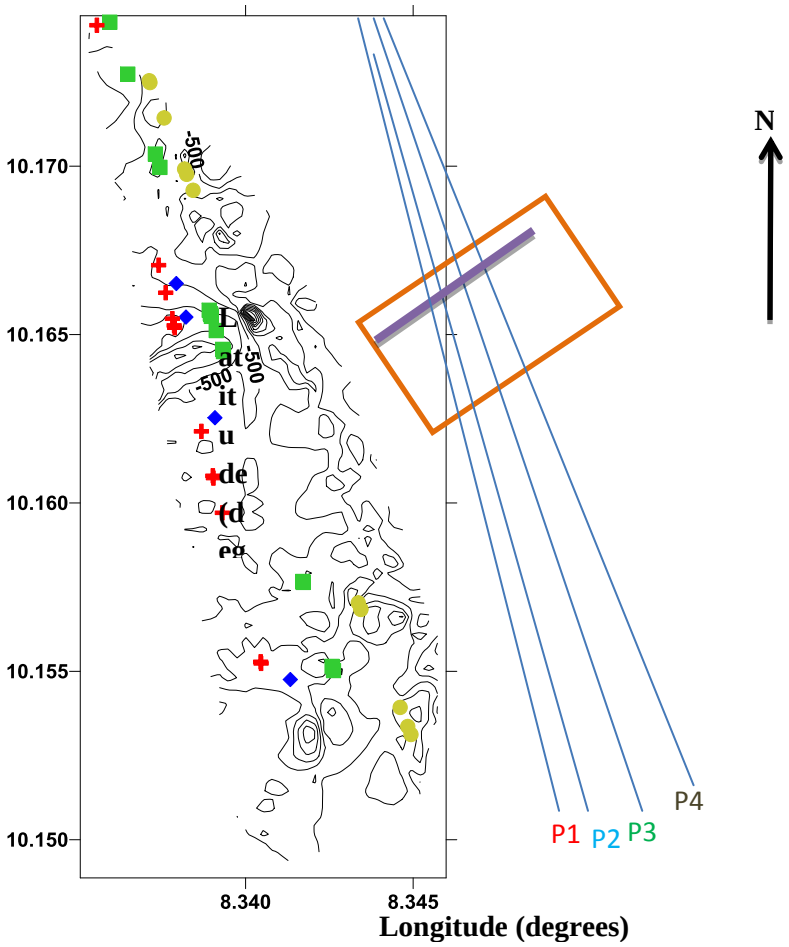


Figure 5.8: Plot of the locations of Werner solutions of the profiles on the ground magnetic map; profile one (red), profile two (blue), profile three (green) and profile four (banana yellow). The thick purple line represents the location of the zero contour of second vertical derivatives.

5.4 Euler deconvolution

Euler's homogeneity relation has attracted sporadic interestfrom geophysicists over the yearsbecause it serveas a fast means of processing a magnetic grid to derive trends and depth estimates in an automatic or semiautomatic manner (Reid *et al.*, 1990). Thompson (1982) suggests in passing that a 3-D implementation of EULDPH algorithm could be used to analyze mapped magnetic data. It solves for source position, and obtains an indication of source type.

This methodology utilizes the total potential field and its related gradients (X, Y, and Z components) to derive the rate of change of potential field with respect to distance from the source location and depth. The degree of homogeneity of the rate of change of the three gradient components is directly related to geometry of the source body and is commonly referred to as the structural index or SI (Thompson,1982).

Most implementations of Euler involve the sequential movement of predefined window across the gridded data resulting in the generation of a large number of solutions form broad clouds rather than dense clusters, making it difficult to outline side boundaries of causative sources.

In general, the desired structural indices are chosen with the window size for depth determination. This is set based on the anomaly of interest. In this research, 3D Euler deconvolution was adopted for the aeromagnetic data.

3D Euler deconvolution was performed on the low-pass filtered aeromagnetic grid data using standard Euler deconvolution. This was done to locate depths to locate depth to the lithology contacts on the gridded map. The best clustering solution was achieved using; 0.0 structure index (for contact) and 15% depth tolerance for fewer solutions (i.e. the most likely solution). The results were plotted on the analytical signal map for effective correlation (see Figure 4.9).

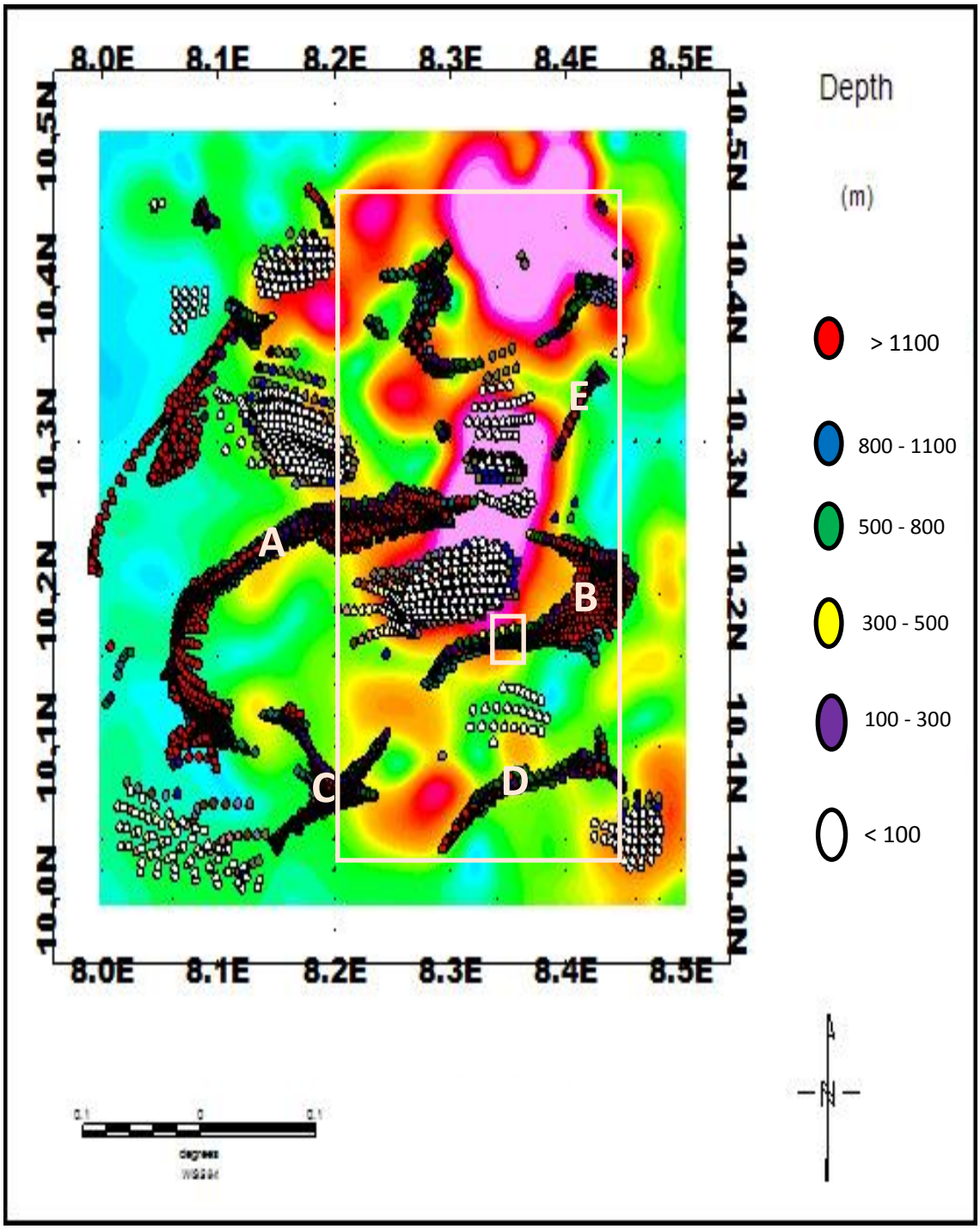


Figure 4.9: Map of Euler solutions of the aeromagnetic data overlay on the 3D analytic signal map. Big rectangle is the location of the two Younger Granites while the small rectangle is the location of the gap between them.

CHAPTER FIVE: DISCUSSIONS

5.1 Discussions

The magnetic method is a powerful tool that can be successfully applied in structural studies. Since magnetics –airborne and ground- provide a relatively direct mapping of the abundance of magnetic minerals, it also serves as a useful indicator of lithology, structure, weathering and alteration processes.

Airborne magnetic is utilized to delineate the subsurface structure which controls the anomalous mineralization zones while ground magnetic resolves shallow source anomalies better.Therefore,the use of airborne and ground magnetics gives detailed information of the study area.

In this study, aeromagnetic data and ground magnetic data are used in order to achieve the primary aim of the study which is to investigate whether or not the two Younger Granites namely Geshere and Rishiwa Younger Granites are extensions to each other. Necessary data corrections were carried out on both the aeromagnetic data and the ground magnetic data covering the two Younger Granites.

Visual inspection of the aeromagnetic data showsthe presence of a strong conspicuous linearanomaly that extends NW-SE,encompassing the two Younger Granites. This suggests probably that they come from the same source (see small rectangle in figure 3.2).

The Power spectrum of the aeromagnetic data (as shown in figure3.11) revealed that the shallow anomalies and noise can be characterized by wave numbers higher than 1 rad/km. Hence, a low-pass filter was appliedto the data in order to attenuate the noise effects and thereby produce a smooth contour map shown in figure3.12 as compared to the map shown in figure 3.7.

Second vertical derivative calculations were performed on the aeromagnetic data shown in figure 4.1. The second vertical derivative analysis providesa means of discriminating local features while suppressing broad and regional structures. The zero contours of the second vertical derivative map (which indicates the presence of a boundary) passes in between the two Younger Granites as shown in figure 4.2.

The analytical signal technique was applied to the low-pass filtered aeromagnetic data and the result is shown in figure 4.3. The resulting analytical signal map (figure 4.3) shows that the zone, which appears to have the highest amplitude-signals (indicated with pink) is located in the Rishiwa Younger Granite, but the intensity keep decreasing southwards towards Geshere Younger Granite.This indicates that the locations of the observed variation in amplitude are similar to that of the zero contour of the second vertical derivatives within the small rectangular box.An overlay of the 3D analytic signal map and the second vertical derivatives made aforementioned observation obvious (see figure 4.4).
Euler deconvolution technique was applied on the filtered aeromagnetic data of Geshere area to delineate contact (with S.I. = 0) within the gap between the two Younger Granites and determine its depth. The solutions were plotted on the 3D analytic signal for correlation. Figure 4.9 shows that the solutions plotted clustered around the regionwhere the estimated boundary is located on the analytic signal map within the gap (small rectangular box),it also indicates that there are some unexposed parts of the Rishiwa Younger Granites and with depthsranging between 300 m and 1100 m. A thorough examination of the solutions at regions A, B, C and D shows that they (i.e. the regions A, B, C and D) can fuse together thereby suggests that the two Younger Granites were initially one single unit but were separated by plate movement due to the presence of fault

E (see the fragment E in figure 4.9). The direction of the so-called fault E is in conformity with the major fault pattern in Nigeria which is NE – SW.

The 2D analytic signal amplitude was applied on the ground magnetic data and figure 4.6 shows the locations of peaks posted on the map of the ground magnetic data. It can be observed in profiles one, two and three that the peaks consistently occur within a particular region (indicated by the rectangular box in the figure. This coincides with the region where the zero contour in the second vertical derivative map pass through (see the thick purple line in figure 4.6) and also with the sharp contrast observed on the 3D analytic signal map.

Finally, the Werner deconvolution method was applied along profiles 1 to 4 on the ground magnetic map and this revealed that all the profiles are mostly composed of interfaces (contacts) with few dyke solutions having depth ranging from 15 to 150 m (see figures 4.7 a - d). The outcome was achieved by applying high residual cut-off which is variable required to generate few solutions of Werner deconvolution. In addition, the Werner deconvolution solution also revealed that the region indicated by a rectangular box in figure 4.6 is characterized by contacts (see figures 4.7 a - c and the rectangular box in figure 4.8).

CHAPTER SIX: CONCLUSION ANDRECOMMENDATION

6.1 Conclusion

In this research, both aeromagnetic and ground magnetic maps have been used to investigatethe subsurface structure within the study area. The presence of contacts between the two Younger Granites would imply that Geshere Ring Complex is separated from Rishiwa Ring Complex.

Both qualitative (second vertical derivative and analytic signal) and quantitative (Werner and Euler deconvolutions) interpretation techniques were chosen to achieve the outlined objectives of this research.

The second vertical derivatives and analytic signal of the aeromagnetic data delineate a boundary between the two Younger Granites apart from other boundaries delineated. The Euler deconvolution solution of the aeromagnetic data clearly revealed the presence of an extended contact between Rishiwa and Geshere Younger Granites with depths ranging between 300 and 1100 m.

A careful holistic analysis of the Euler solution of the aeromagnetic data points to the possibility of a single body (i.e. Rishiwa-Geshere Younger Granite), that might have been shifted due to the presence of fault by plate movement making them to appear as separate bodies. The Euler solutions also revealed some unexposed part of the Rishiwa Younger Granite.

The analytic signal of the ground magnetic data delineates boundaries in between the two Younger Granites while Werner deconvolution solutions of the ground magnetic data indicates that the nature of the boundary between them is more likely a contact to dyke.

6.2 Recommendation

Based on the results obtained from this research the following is recommended:

1. Another imaging technique like seismic method should be employed across the gap between the two Younger Granites to confirm the findings in this research.

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