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# Aeromagnetic Anomalies Modeling and Their Tectonic Implications in the Middle Benue Trough, Nigeria.

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**ABSTRACT**
The middle Benue Trough has been studied on a reconnaissance stage, no detail subsurface modeling to reveal basin configuration has been undertaken. Twelve(12) Aeromagnetic maps on a scale of 1:100,000, covering the middle Benue Trough were digitized and processed using computer techniques which include; map merging, polynomial filtering, power spectrum, forward and inverse modeling. Eight (8) profiles were modeled to determine the structure of the basin and the presence of possible intrusives. The results indicate the presence of twenty three (23) intrusives; seven (7) are basaltic while sixteen (16) are rhyolites. The Saki model configuration reveals average sediment thickness ranging between 0.5 – 4.0km, these represent horst and graben structures. These variations are also revealed in the power spectrum depth estimate, which shows a range between 1.2 – 2.7km. The Doma and Agana areas have the largest accumulations of sediment thickness (0.5 – 4.0km) covering about 40km, other areas have shallow depths (0.5 – 2.0km), and cover distances between 19.5 – 23.8 km, these later areas are less favorable for hydrocarbon accumulation. The Doma and Agana areas remain the most favorable areas for hydrocarbon exploration based on their thick sediment accumulation. However, these areas reveal the presence of seven (7) intrusives; this may cause high geothermal temperatures that may not be favorable for hydrocarbon accumulation.

## INTRODUCTION

The area of study is the middle Benue Trough which links the upper and lower Benue Trough. It is delimited by latitude $7^0 30^1$ and $9^0 00^1$N and longitude $8^0 00^1$ and $10^0 00^1$E and covers an area of 142,992 sq km (fig. 1). The area forms part of the Benue Trough which is a linear cretaceous sedimentary basin that extends towards the north from the east. It is approximately 1000 km long and 2.5 – 4.5 km thick (Ojoh, 1992, Fairhead and Ofoegbu, 1990, Benkhelil, 1988, Burke, et. al 1972, and Obi et, al 2008).

The cretaceous rifting of the Benue Trough initiated different cycles of depocenters which were influenced by subsidence and sea level changes as South America drifted away from Africa (Ojoh, 1992, Grant, 1971). The area of study has not been extensively studied geophysically. Although, earlier works (Okereke and Ofegbu, 1989, Murat, 1972, Ofoegbu, 1985, Nur, 2000, Osazuwa, et. al. 1981 and Adighije, 1981) highlighted the stratigraphy, tectonics and basin thickness in general. This study is aimed at providing a detail subsurface model of the basin configuration, possible types of intrusives and sediments thickness.

## GEOLOGY

The Benue aulacogen has four main stages that represent the evolutionary trend of this basin (Ojoh, 1992). During these stages of development different sedimentary cycles prevailed. The middle Benue Trough experienced two major types of sedimentation cycles. The first sedimentary cycle deposited shales and limrstones (albian - cenomenian) along Wukari and Akwana (fig. 2.0). These sediments lie unconformably on the Precambrian basement rocks (biotite granites, hornblende gneiss). Along Makurdi areas turonian sandstones also overlie the basement directly. The second sedimentary cycles started from the upper coniacian to late maestrichian depositing shales, limestones, sandstones and ironstone around Lafia, Agana and parts of Shendam (fig. 2.0). Other areas around Wamba, Akwanga (Garakili, Waiye), Shendam (Peshiep, Kuragwi) and Lafia (Dudugu), are characterized by undifferentiated granites, migmatites, gneisses and tertiary – recent volcanics.

## MATERIAL AND METHODS

Twelve aeromagnetic maps on a scale of 1:100,000 were acquired from the Nigerian Geological Survey Agency, Kaduna. The survey was conducted along E-W profiles with a flight line spacing of 2.0 km and a tie line spacing of 20 km. all the maps were based on data acquired at a norminal flight elevation of 0.5126 km above mean sea level. The geomagnetic gradient was removed using the International Geomagnetic Reference Field (IGRF) formula of 1st January, 1974. Also, about fifteen software programs obtained from United States Geological Survey (USGS) potential field version 2.2 were used in this study (Phillip, 1997). A hard copy of the geologic map of Nigeria was obtained from the Nigerian Geological Survey Agency, this map was digitize with the Arc GIS software using the coordinates of the study area to produce the geologic map of the study area (fig.2)

The first step in the data analysis was to digitize the maps at 1.0 km interval to avoid the problem of frequency aliasing. The digitized data was in the x, y, z format where x is the latitude, y the longitude and z the total magnetic field. Batch software program (A2XYZ, DETOUR, GEOCON, P2GRD, and CONTOUR) was used in gridding and contouring the data to obtain the total magnetic field of each of the digitized map. Since all the maps were obtained at the same flight elevation, there was no continuation method applied. Map merging of all the twelve sheets was accomplished using the following software: Addgrd and Gmerge where the individual grid outputs of each sheet was added along rows to produce single grids output for Gmerge to sum gridded outputs and merge them with no interpolation (Phillips, 1997). The output of Gmerge grid file is contoured using another software (PC contour) to produce the total magnetic field intensity map of the study area (fig. 3). The power spectrum technique and forward and inverse saki modeling techniques were used in this study. Details of the theoretical background of these techniques are better explained in Obi et, al 2008, Olagundoye, 2004 and Phillip 1997.

Anomaly separation into regional and residual components was carried out using the polynomial fitting technique software SURFIT (Phillips, 1997) which is a polynomial fitting algorithm to produce the residual maps fig.4 which was then used for depth estimation and P-depth and SAKI software for modeling. The batched software programs (mfnit, mfdesign) were used in the power spectrum analysis. The residual grid was used as the input to mfinit which is accessed by the mfdesign which produces cut off filters and produces an output file accessed by mffilter to generate the average power spectrum depths of the various layers. Layer one is usually the depth to the sediment thickness. The procedure described above was applied to the residual gridded data; this data was subjected into blocks of $0.5^0$ x $0.5^0$ and $0.25^0$ x $0.25^0$ sizes in overlapping positions to produce over ninety (90) grid cells vis-à-vis ninety depth points. These depth points were then positioned in their actual positions as in the residual map and then contoured to get the power spectrum depth map of the study area (fig. 5).

The forward and inverse modeling was done by using the residual grid of fig. 4.0 where eight (8) profiles were extracted in perpendicular direction to observed magnetic anomalies. The extraction was done by using a software (PROFILEX),, this was then used as an input file to the Pdepth program which does the forward modeling. The modeling parameters include; inclination, declination, total field Azimuth, no of bodies, magnetic susceptibility and assumed depths of placed bodies (table 1). These parameters are used to generate a calculated curve that best fit the observed curve and when the root mean square error (RMS %) is less than 5 % a forward model profile is created prior to the inverse SAKI modeling (table. 2.0). the inverse modeling program (SAKI) utilizes the forward model file from Pdepth and with input parameters same as in forward modeling. A series of mathematical iterations are made and with several iterations the RMS error reduces to a minimal 1% indicating an almost perfect model of the subsurface.

## RESULTS AND CONCLUSION

Magnetic source depth determination through power spectrum analysis over the middle Benue Trough (fig. 5) indicates a thick pile of sediments (2.5 – 2.7km) around Doma and Agana areas, also the area around Wukari has a thick pile of sediments (2.0 – 2.4km). Other areas around Wamba, Shendam, Akwanga and Akari have less sediment accumulations (1.2 – 1.6km). These areas with less sediment accumulation are not favorable target for hydrocarbon exploration, while those areas with thicker sediment accumulations remain the favorable sites for further hydrocarbon exploration activities.

Modeling of local anomalies using the SAKI forward and inverse modeling software was performed on eight profiles (A- H) along prominent anomalies. Along each profile the structure and the type of anomaly in the study area was determined.

Profile A-A$^1$: this profile is about 22.8km (fig. 6) and runs NW-SE along Kwola. There are two intrusives with susceptibilities value of 0.025 and 0.0045 S.I towards the NW end of the profile with a possible sediment thickness of 2.0 – 2.2 km and extends for a distance of 5km. The areas around the SE cover a distance of about 17.0km and have depths between 0.5 – 1.0km.

Profile B-B$^1$: this profile runs in the NW-SE orientation and is 19.2km long (fig. 7). It has only one intrusive with susceptibility value of 0.025 towards the SE end. The sediment thickness (0.5 – 1.5km) covers a distance of about 15km. Towards the SE end sediment thickness of about 2.0km is reached. This area covers only a small distance of about 2.5km.

Profile C-C$^1$: this profile runs in the NW-SE orientation and is 23.8km long (fig. 8). The area has five intrusives with susceptibilities of 0.0035, 0.003, 0.002, 0.003 S.I. The sediment thickness is between 0.5 – 1.0km. This area is less attractive for further hydrocarbon exploration.

Profile D-D$^1$: this profile runs in the NE-SW orientation and is about 27.0km long (fig. 9). The area has three intrusives with susceptibilities of 0.0025, 0.0025 and 0.0025 S.I. The area has a thin sediment accumulation of about 0.5 – 1.2km. The area is not a good target for hydrocarbon exploration.

Profile E-E$^1$: this profile runs in the NW-SE orientation and is 26.0km long (fig. 10). The area has five intrusives with susceptibilities values of 0.0025, 0.0075, 0.015, 0.0095, and 0.0085 S.I. A thick sediment pile covering a distance of about 5km with a depth range of 2.2 – 2.4km is attained. The area has good prospects for accumulation of hydrocarbons but the large number of intrusives may introduce high geothermal temperatures that may hinder hydrocarbon accumulations.

Profile F-F[1]:this profile runs in the NW-SE orientation and is 48.0km long (fig. 11). It has two anomalies with susceptibility value of 0.0025 S.I. The sediment thickness (2.5 – 3.5km) is the highest in the study area. This thick pile of sediment covers a distance of about 10km. The two intrusives are about 15.0km apart and are situated in areas of 2.0 – 2.2km depths, so their effects may be minimal on the sediments which range between 2.5 – 3.5km. This area remains the most prospective area for further hydrocarbon exploration activities.

Profile G-G[1]: this profile runs in the NE-SW orientation and is 27.0km long (fig. 12). The area has two intrusives with susceptibilities values of 0.015 and 0.025 S.I. the profile is characterized by horst and grabens. The sediment thickness range between 1.5 – 2.0km within the grabens and 0.5 – 1.0km within the horst areas. This area is not attractive for further hydrocarbon exploration because of its shallow depth of sedimentary rocks.

Profile H-H[1]: this profile runs in the NW-SE orientation and is 27.0km long (fig. 13). It has three intrusives with susceptibility values of 0.020, 0.025, and 0.0075 S.I. The sediment of 2.0km is extensive for about 10km. Other shallow areas with sediment thickness between 0.5 – 1.0km are at the flanks of the profile. The three intrusives are sitting directly on the sediment pile (2.0km), also these shallow depth may not support the favorable conditions for hydrocarbon accumulations.

The modeling susceptibility value used indicates that the intrusives were mostly basalts and the extrusives were rhyolites in the study area. This modeling has been done in other areas (Obi, et. al 2007, Olagundoye, 2004, Shemang, 1998, Philips, 1997). In conclusion, basement depth to the source magnetic anomalies has been determined using the power spectrum and the forward and inverse modeling. These techniques identified the areas around Doma towards Agana as potential targets for further hydrocarbon exploration activities, based on their sediment thickness (2.0 – 3.5km). However, modeling of local anomalies revealed the subsurface configuration to be that of horst and graben structures. The twenty three intrusives identified in the study area reveals the tectonic activities that followed the rifting processes during the formation of the Benue Trough. About seven intrusives were found (probably basaltic) within these Doma and Agana areas, this makes the area susceptible to high geothermal temperatures and may cause over-maturity of the sediment producing more gas than oil.

**REFERENCES**

Adighije, C. I. (1981): A gravity interpretation of the Benue Trough. Nigeria *Tectonophysics*, 79, PP 109 – 128.

Benkhelil, J., 1982: Benue trough and Benue chain. *Geological Magazines* 119;115-118

Benkhelil, J., 1988: Structure et Evolution Geodynamique du Basin Intracontinental. Bull Centres Reach. *Explor. Prod. Eu Aquitain*. 1207: 29 – 128.

Burke, K. C., Dessauvagie, T. F. J. and Whiteman, A. T. (1972). Geologic history of the Benue valley and adjacent areas. – In: Dessauvagie T. F. J. and Whiteman, A. J. (eds): *African Geology, Univ. Ibadan press, Nigeria* PP. 187 – 206.

Geological Survey of Nigeria (1994). *Geology of Nigeria,* scale 1:2,000,000.

Grant, N. K. (1971). South Atlantic, Benue Trough and Gulf of Guinea triple junction-Bull geol, *Soc. Amer*., 82, PP 2295 – 2298.

Murat, R. C. (1972). Stratigraphy and Paleogeography of the Cretaceous, and Lower Tertiary in Southern Nigeria. In: Dessauvagie, T. F. J. and Whiteman, A. J. (eds): African geology. *Univ. Ibadan press,* Nigeria PP 251 – 266.

Nur, A. 2000. Analysis of Aeromagnetic data over the Yola Arm of the Upper Benue Trough, *Nigeria. Jour. Mining and Geol* Vol 36 (1): 77 – 84.

Obi, D. A., Okereke, C. S., Obi, E. O. and George, A. M. (2008). Mapping depth to the crystalline basement in the lower Benue Trough (Nigeria) using Power Spectrum and horizontal gradient magnitude techniques on aeromagnetic data. *International journal of Natural and Applied Sciences (IJNAS),* vol. 3, Nos. 102 P. 69 – 74.

Obi, D. A., Okereke, C. S., Egeh, U. E. and Olagundoye, O. O. (2008). Aeromagnetic modeling in evaluating the hydrocarbon potential of the basement of the Calabar Flank, Southeastern Nigeria. *Journal of Mining and geosciences Society* vol 44 (2) PP. 151 – 160.

Ofoegbu, C. O. and Onuoha, K. M. (1990). Analysis of magnetic data over the Abakaliki Anticlinorium of the Lower Benue Trough, Nigeria. *Marine and petroleum Geology*. 8: 174 – 181.

Ofoegbu, C. O. (1985). A review of the Geology of the Benue Trough. *Jour. Afr. Earth Sci.*, 3, 283 – 291 PP.

Okereke, C. S. and Ofoegbu, C. O. (1989). Gravity and magnetic data over the Yola arm of the upper Benue Trough (1989). *In C. O. Ofoegbu (Ed) The Benue Trough, Structure and Evolution* (PP. 161 - 169). Braun schwelg. Vieweg and Sohn.

Ojoh, K. A. (1992). The Southern part of the Benue Trough (Nigeria) Cretaceous stratigraphy, Basin analysis, Paleo-oceanography and Geodynamic Evolution in the Equatorial domain of the South Atlantic. *Nigerian Association of Petroleum Explorationist* vol. 7. No. 2. P.131-152

Olagundoye, O. O. (2004). Geophysical study of the basin structure of the Anambra Southeastern basin, Southeastern Nigeria. *Unpublished PhD thesis, University of Calabar, Nigeria*.

Osazuwa, I. B., Ajakaiye, D. E. and Verheijin, P. J. T 1981. Analysis of the structure of part of the Benue valley on the basis of new geophysical data. *Earth Evol.* Sci., 2: 126 – 135.

Phillips, J. D. (1997). Potential field geophysical software for the PC, version 2.2 *U.S. Geological survey open file report* 97 – 725: 1 – 32.

Shemang, E. M. Ajayi, C. O. and Umego, M. N. (1988). The structure of the Gongola arm of the upper Benue Trough as revealed by gravity and magnetic studies: *NAPE Bulletin*, 13 (1) 50 – 69.

TABLE 1: Magnetic susceptibility of common rocks and ores (SI units)

| **COMMON ROCKS** | **MAGBETIC SUSCEPTIBILITY** |
|---|---|
| Slate | 0 – 0.002 |
| Dolerite | 0.01 – 0.15 |
| Greenstone | 0.0005 – 0.001 |
| Basalt | 0.001 – 0.1 |
| Granulite | 0.0001 – 0.05 |
| Rhyolite | 0.00025 – 0.01 |
| Salt | 0.0 – 0.001 |
| Gabbro | 0.001 – 0.1 |
| Limestone | 0.0000 – 0.0001 |
| **ORES** | |
| Hematite | 0.001 – 0.0001 |
| Magnetite | 0.1 – 20.0 |
| Chromite | 0.0075 – 1.5 |
| Pyrrhotite | 0.001 – 1.0 |
| Pyrite | 0.0001 – 0.005 |

After John Milson 2003

**TABLE 2.0: MODELING STASTISTICS**

| **Towns** | **No of Bodies** | **No of Intrusives** | **Depth of sediment thickness** | **Magnetic susceptibility of intrusives** | **Type of intrusive** | Max/Min amplitude of profile nT | **Distance of profile (km)** |
|---|---|---|---|---|---|---|---|
| Wamba | 14 | 5 | 1.0 – 1.2 | 0.003<br>0.002<br>0.003<br>0.0035<br>0.002 | Gneiss/ Rhyolites<br>“<br>“<br>“<br>“ | 68/20 | 23.8 |
| Akwanga | 8 | 1 | 1.5 – 2.3 | 0.025 | Basalt | 62/-15 | 19.2 |
| Lafia | 10 | 3 | 0.8 – 1.6 | 0.0025<br>0.0025<br>0.0025 | Gneiss/Rhyolites<br>“<br>“ | 74/21 | 27.0 |
| Wukari | 11 | 3 | 1.0 – 2.2 | 0.020<br>0.025<br>0.0075 | Basalt<br>Basalt<br>Gneiss/Rhyolites | -62/-166 | 27.0 |
| Doma | 10 | 5 | 0.5 – 2.4 | 0.0025<br>0.0075<br>0.0095<br>0.15<br>0.0085 | Gneiss/Rhyolites<br>“<br>“<br>“<br>Basalt | -30/-85 | 26.0 |
| Agana | 9 | 2 | 2.2 – 4.0 | 0.0025<br>0.0025 | Gneiss/Rhyolites<br>“ | 8.8/-3.3 | 40.0 |
| Makurdi | 10 | 2 | 0.5 – 2.3 | 0.015<br>0.025 | Basalt<br>“ | -10/-78 | 27 |
| Kwola | 10 | 2 | 0.5 – 2.2 | 0.025<br>0.0045 | Basalt<br>Gneiss/Rhyolites | 79/-155 | 22.8 |

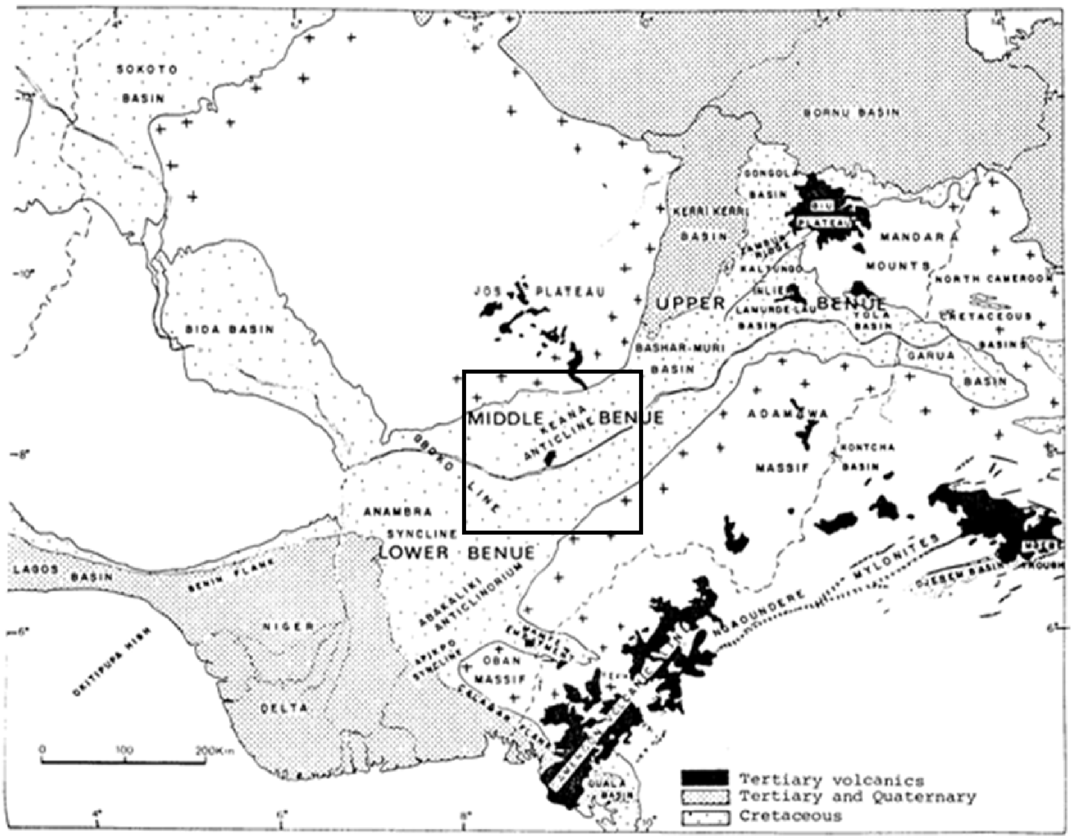



Fig 1: Map showing location of the study area (modified from Benkelil 1982),

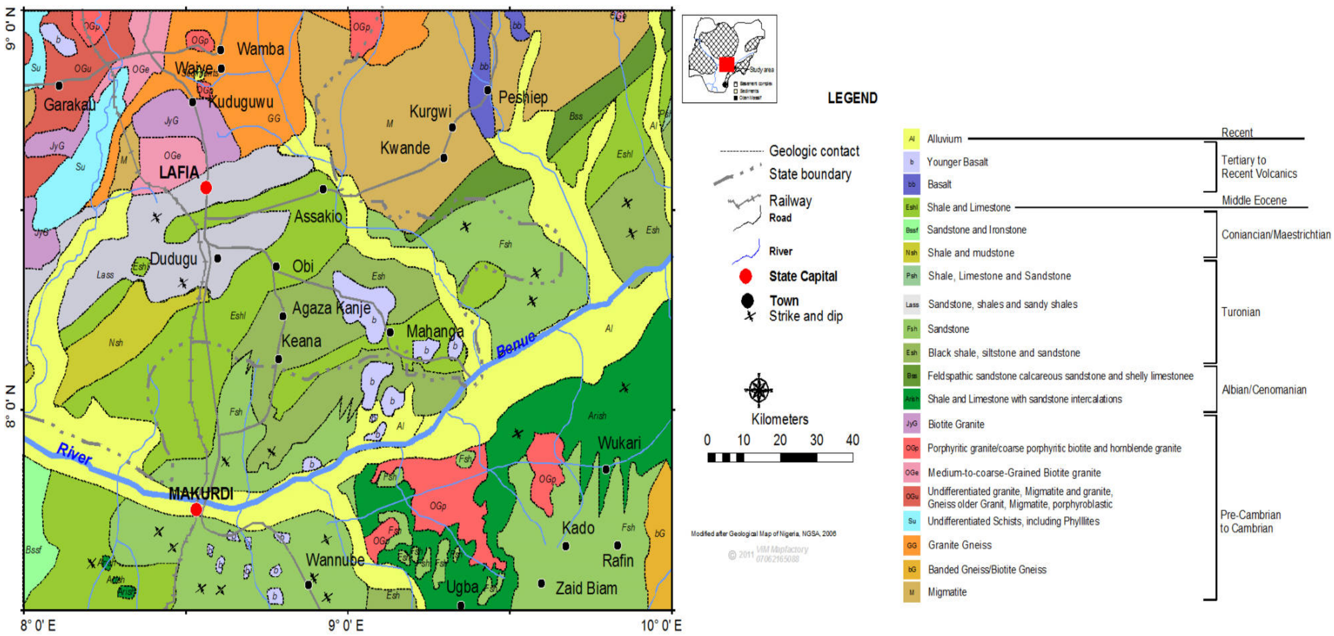



Fig.2 Geology map of study area based on map by Geologic Survey Agency of Nigeria (1994)

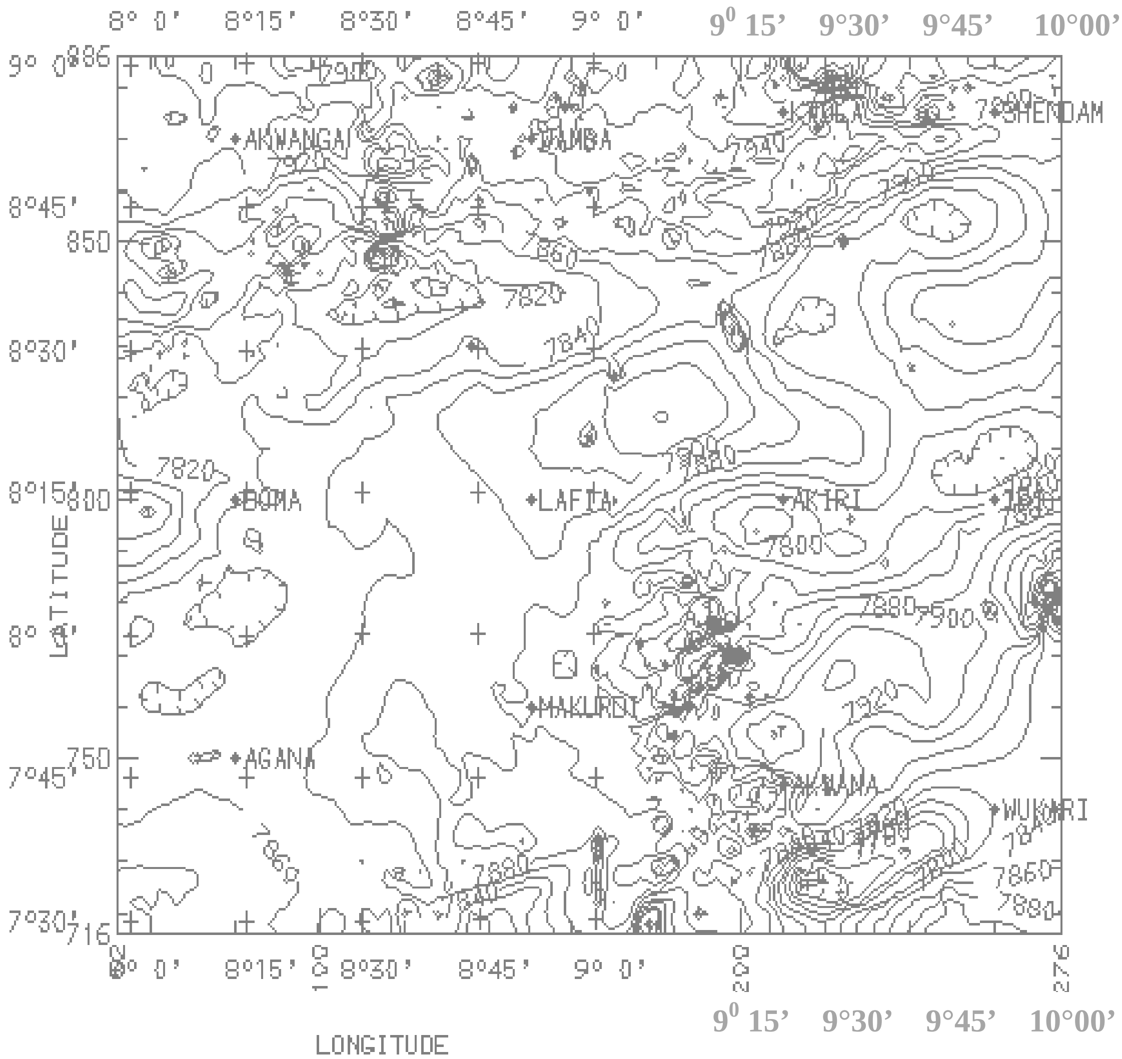



Fig. 3 Composite map of total magnetic field intensity (+25,000nT) contour interval = 20nT

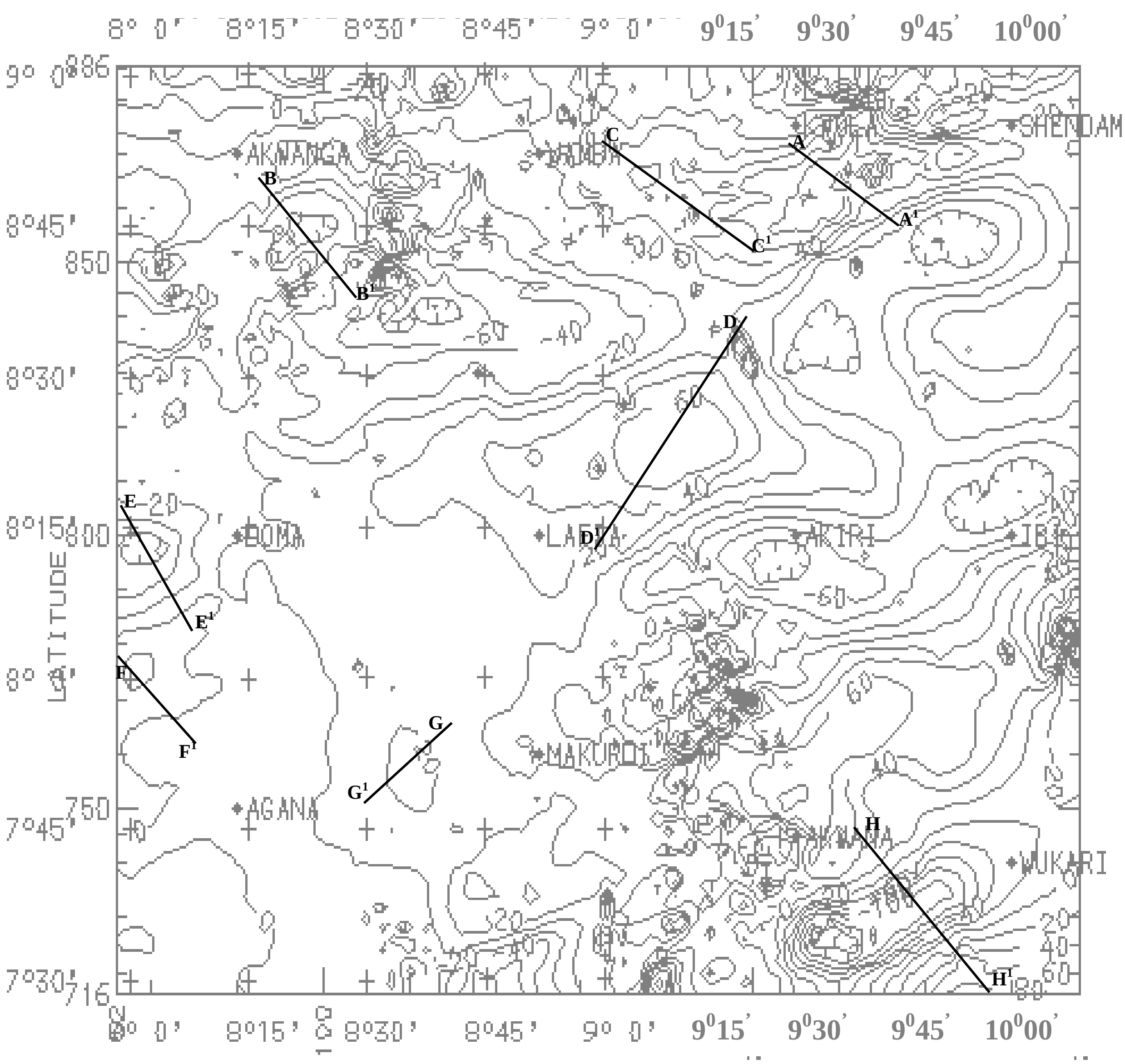



Fig. 4 Residual magnetic anomaly map based on polynomial fitting method. Contour interval=20nT

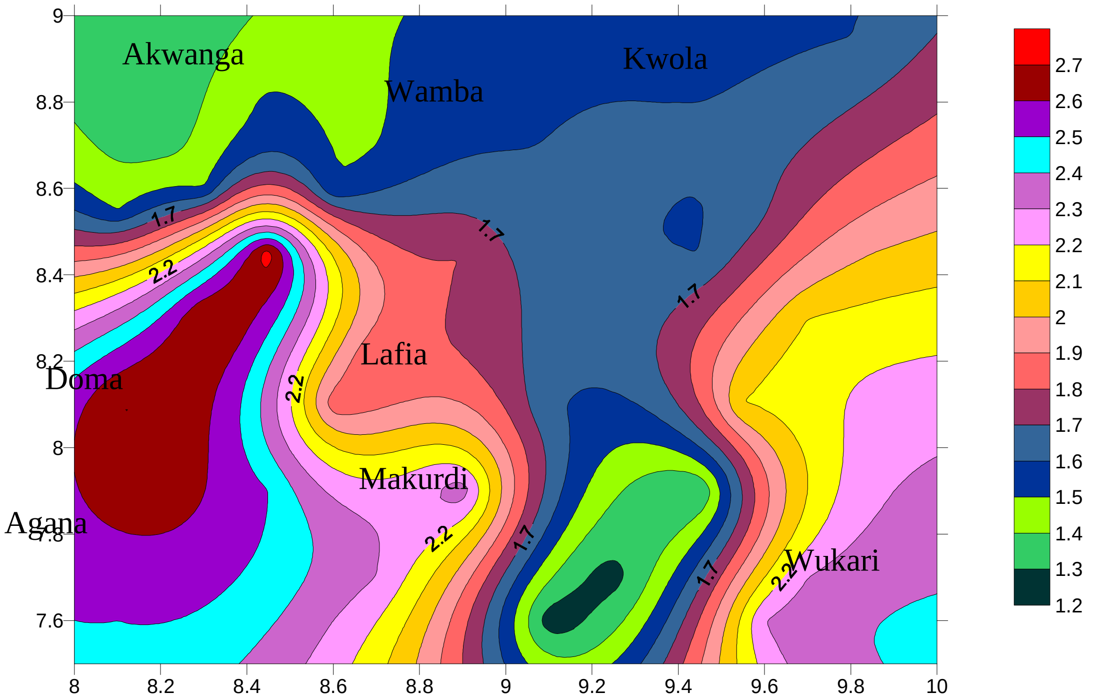



Fig. 5 Power spectrum depth map of the study area (contoured at 0.2km interval)

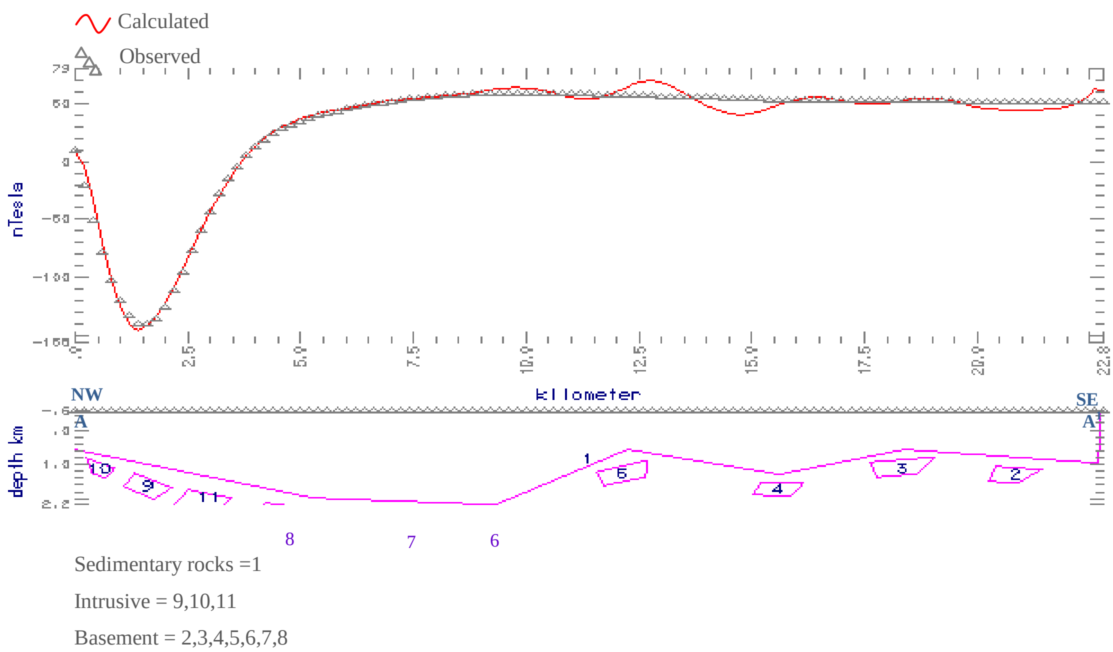



Fig. 6 Forward and inverse model interpretation of residual magnetic anomalies along profile A-A[1] (Kwola)

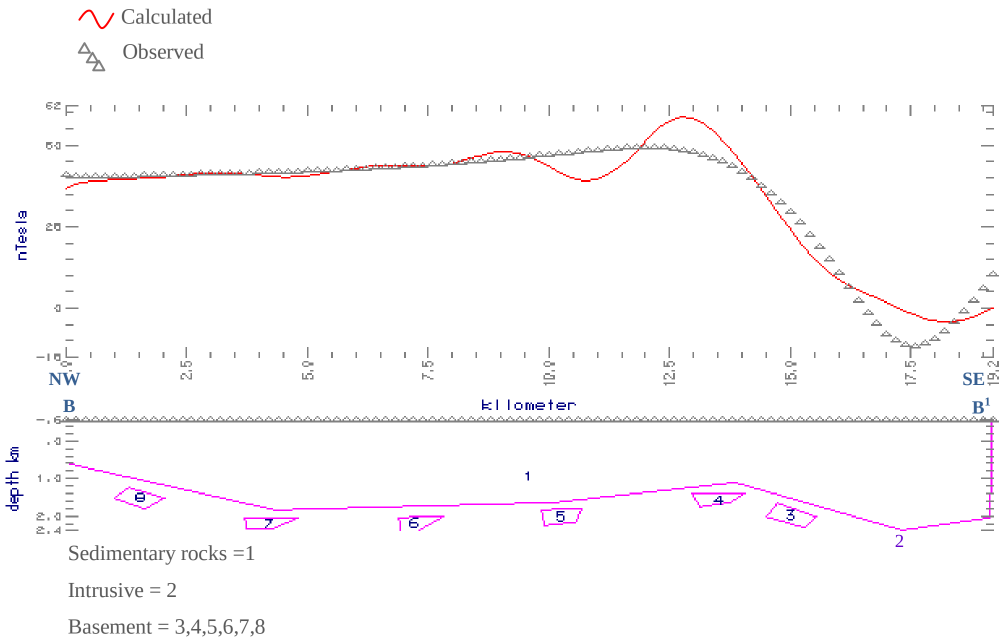



Fig. 7 Forward and inverse model interpretation of residual magnetic anomalies along profile B-B[1] (Akwanga)

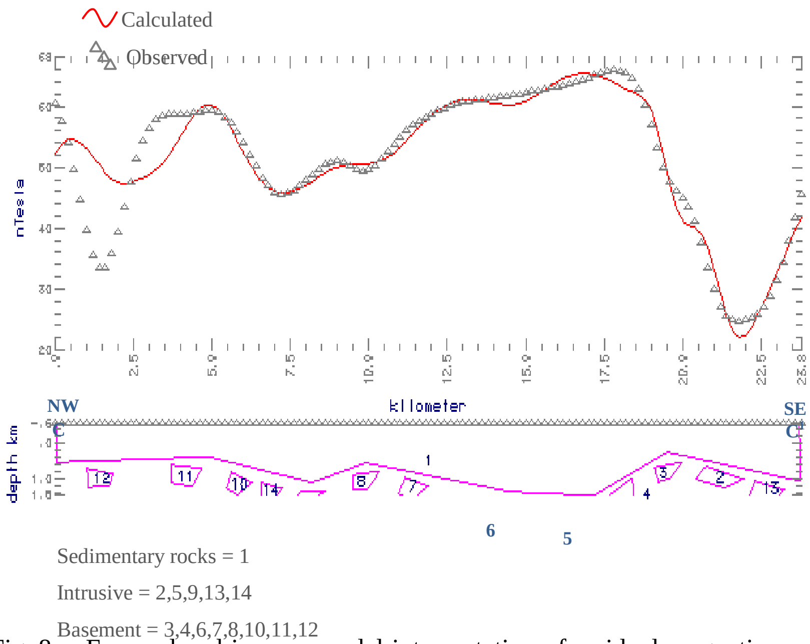
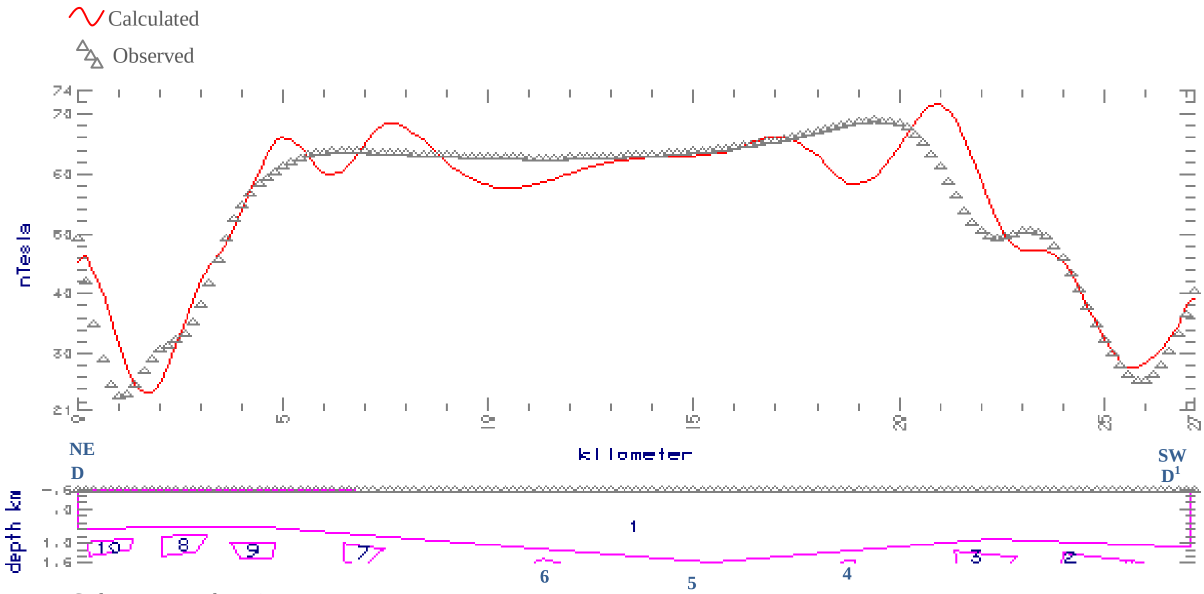



Fig. 8 Forward and inverse model interpretation of residual magnetic anomalies along profile C-C[1] (Wamba)

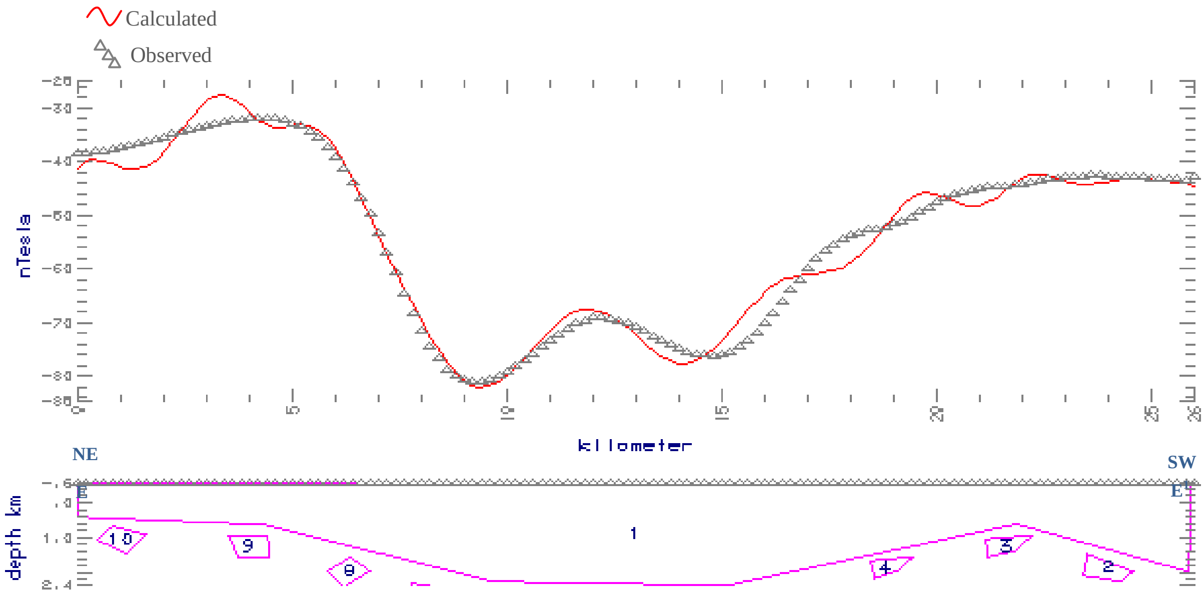



Sedimentary rocks = 1

Intrusive = 2,3,10

Basement = 4,5,6,7,8,9

Fig. 9 Forward and inverse model interpretation of residual magnetic anomalies along profile D-D[1] (Lafia)




Sedimentary rocks = 1

Intrusive = 3,4,5,6,7

Basement = 2,8,9,10

Fig. 10 Forward and inverse model interpretation of residual magnetic anomalies along profile E-E[1] (Doma)

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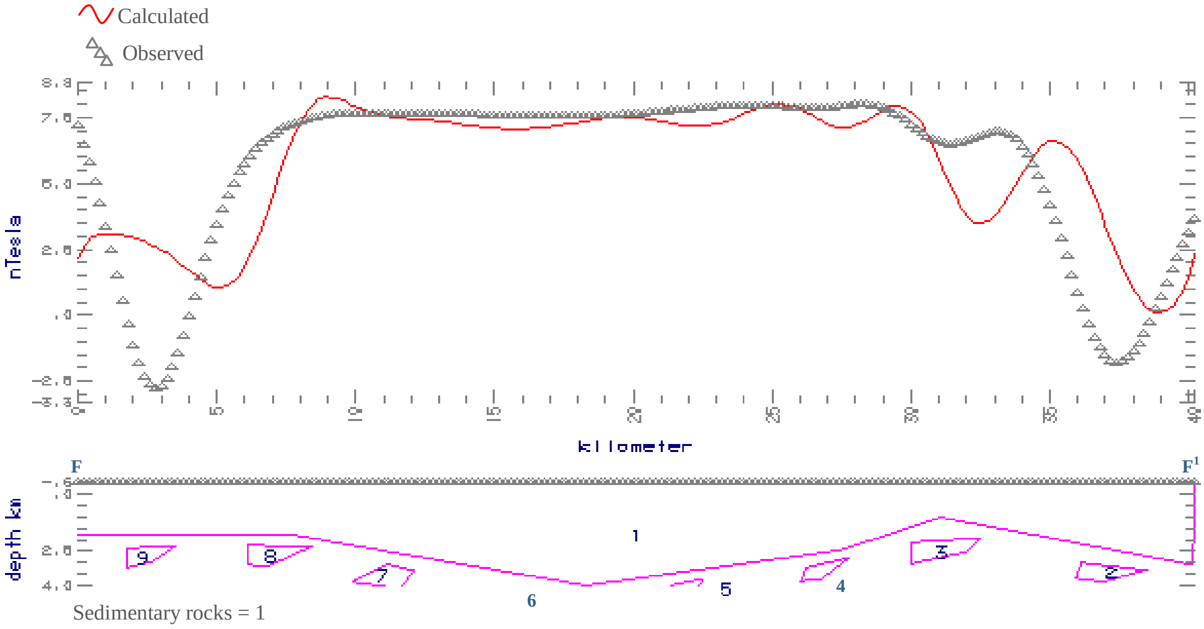
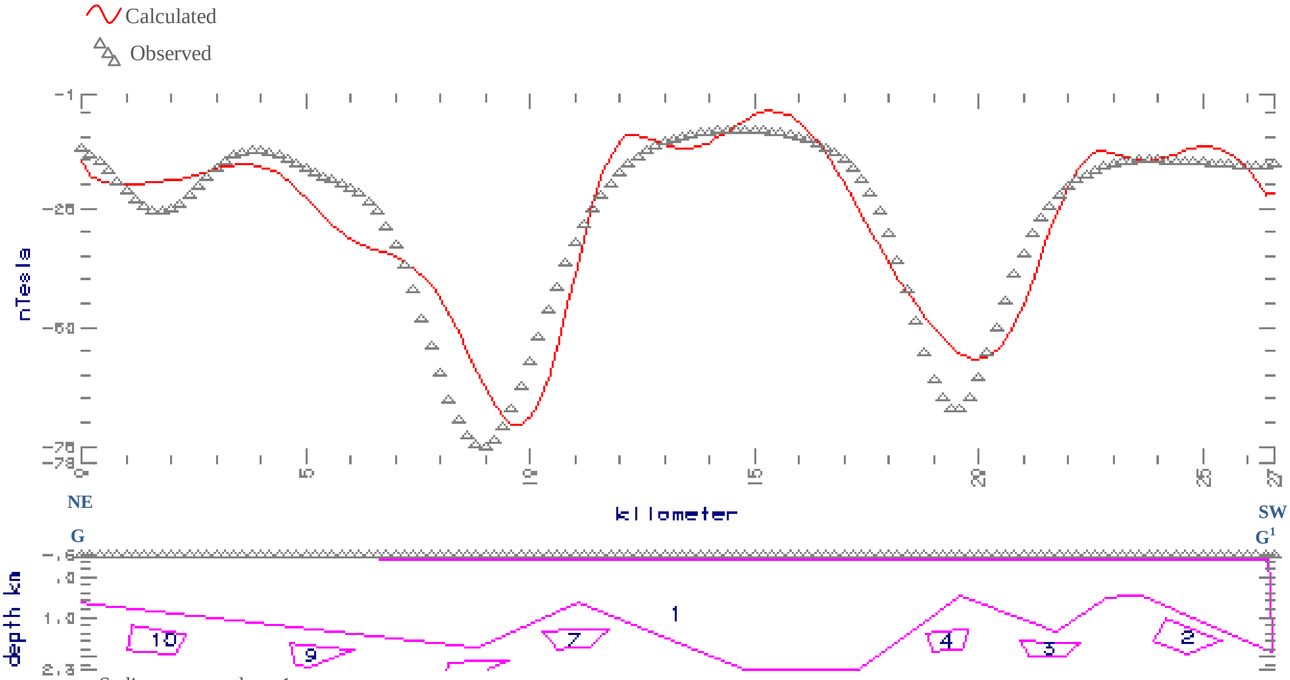



Sedimentary rocks = 1

Intrusive = 2,9

Basement = 3,4,5,6,7,8

Fig. 11 Forward and inverse model interpretation of residual magnetic anomalies along profile F-F[1] (Agana)




Sedimentary rocks = 1

Intrusive = 5,6,7

Basement = 2,3,4,8,9,10,11

Fig. 12 Forward and inverse model interpretation of residual magnetic anomalies along profile G-G[1] (Makurdi)

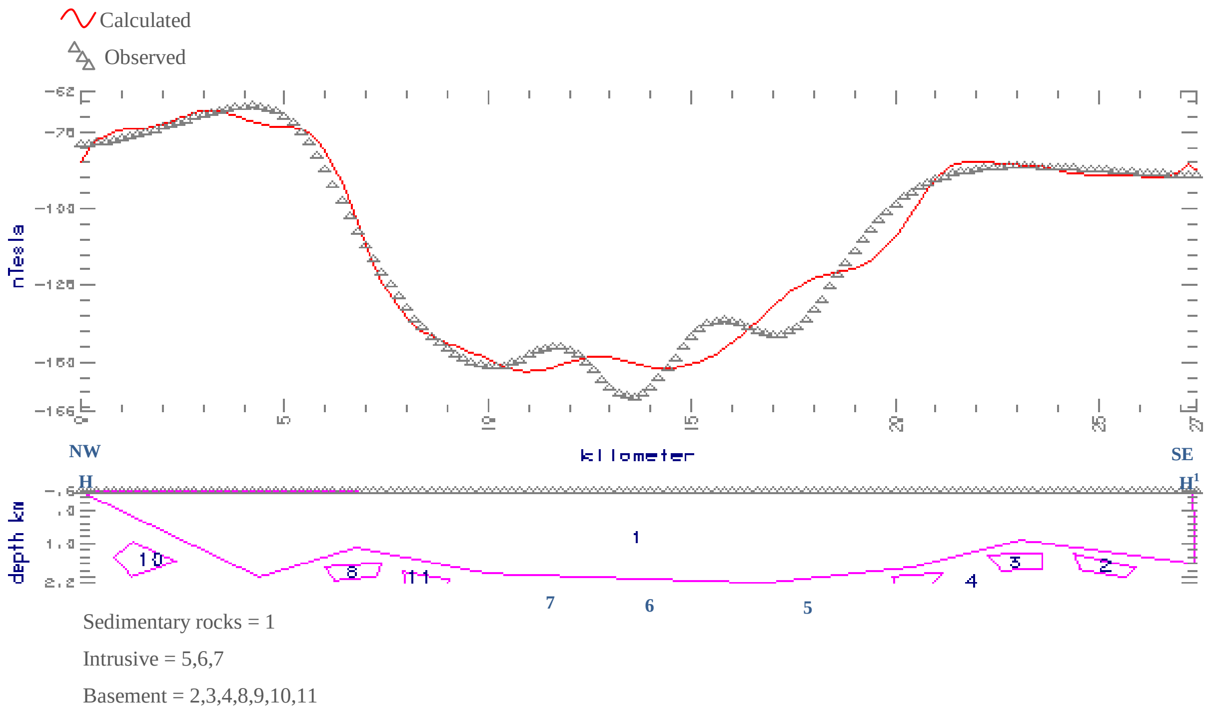



Fig. 13 Forward and inverse model interpretation of residual magnetic anomalies along profile H-H[1] (Wukari)