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Interpreting High Resolution Aeromagnetic Data to Determine Petroleum Potential of Matto and Environs Using Source Parameter Imaging, North Central Nigeria

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Abstract: *Interpretation of high resolution aeromagnetic data was used to carry out to determine the petroleum potential of Matto and environs Northcentral Nigerian, Using Source Parameter Imaging (SPI).Oasis Montaj software was used to carry out the analysis. From the contour residual contour map the magnetic signatures over the study area consist of short, medium and long magnetic anomalies. The short and medium magnetic anomalies are as a result of adjourning basement terrain. While the long wavelength magnetic anomalies at the central part of the study area, is as a result of the deep basement under thick sedimentary cover. The result obtained from the analysis of SPI Profile indicates two source depths. The shallow sources and the deeper sources. From profile 1 the depth to magnetic sources (sedimentary thickness) are shallow and deep, the shallow sources varies from 10 to 1500 m, while the deeper sources varies from 2000 to 6000m. From profile 2 the shallow sources varies between 5 m to 1000 m, while deeper sources varies between 2000 to 8000 m. The result obtained indicates that the study area is a potential site for hydrocarbon exploration especially in the central part where the sedimentary cover is thick.*

Keywords: *Matto, Benue rift, Source Parameter imaging, Profiles, Petroleum and North central*

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I. Introduction

The aim of a magnetic survey is to investigate subsurface geology on the basis of anomalies in the Earth's magnetic field resulting from the magnetic properties of the underlying rocks. Although most rock-forming minerals are effectively non-magnetic, certain rock types contain sufficient magnetic minerals to produce significant magnetic anomalies. Similarly, man-made ferrous objects also generate magnetic anomalies. Magnetic surveying thus has a broad range of applications, from small scale engineering or archaeological surveys to detect buried metallic objects, to large-scale surveys carried out to investigate regional geological structure.

An aeromagnetic as the name implies is a type of geophysical survey carried out using a magnetometer board or towed behind an aircraft. The principle is the same to a magnetic survey carried out with hand-held magnetometer, but they are mounted on different platform. The former allowed large area of the earth's surfaces to be covered quickly for regional reconnaissance and the latter is mostly on microscopic scale. For aeromagnetic survey the aircraft typically flies in a grid like pattern with height and line spacing determining the resolution of the data.

Aeromagnetic survey are mostly used to aid in the production of geological maps and are also commonly used during mineral exploration. Some minerals deposits are associated with an increase in the abundance of magnetic minerals, and occasionally the target may itself be magnetic (e.g. iron ore deposits), but often the elucidation of surface structure of the upper crust is the most valuable contribution of the aeromagnetic data.

Aeromagnetic data was once presented as contour plots, but now is more commonly expressed as thematic (colour i.e. high resolution) and shaded computer generated pseudo-topography images. The apparent hills, ridges and valleys are referred to as aeromagnetic anomalies. A geophysicist can use mathematical modelling to infer the shape, depth and properties of rock bodies responsible for the anomalies. In a high resolution aeromagnetic map, the colour patterns represent total magnetic intensity and can be used to interpret lithology, alteration, and structure in the survey area. Airplanes are normally used for high-level reconnaissance surveys in gentle terrain, and helicopters are used in mountainous terrain or where more detail is required

Many authours have worked on this area or close to it, author such as Wright et al, (1985), Ofoegbu and Odigi, (1989) , Ahmed, (1991), K. A. Salako (2014), Nwosu O.B and Anuba (2013) etc

According to Nwosu O.B and Anuba, (2013) the SPI of the aeromagnetic data over some part in the middle Benue trough has revealed two main magnetic anomaly sources depth represented by the long spikes and the short spikes .The long spikes represent areas with deep lying magnetic bodies hence with thicker sedimentary cover and ranges from 2000 to 6291.5m with an average depth of 3245m and could be viewed as the magnetic basement depth of the studied area. The magnetic basement depth gotten from this SPI has been validated using spectral analysis and slope techniques each yielding 3.65km and 3.70km respectively. This magnetic basement depth is synonymous to depth of over-burden sediment which has a very important significance as regards to the hydrocarbon generation potential. The short spikes show areas of shallower sediment ranging from 159.067m to 2000m with an average depth 1079.5m and may be regarded as magmatic intrusions into the sedimentary basins and these may be responsible for the Lead-Zinc mineralization found in the area.

The work of Wright et al, (1985) reported that the minimum thickness of the sediment required to achieve the threshold temperature of 115^{0}C for the commencement of oil formation from marine organic remains would be 2.3km deep when all other conditions for hydrocarbon accumulation are favourable and the average temperature gradient of 1^{0}C for 30m obtainable in oil rich Niger Delta is applicable. Previous study showed the geology of the area to be associated with the marine AlbianAsu River Group which commenced sedimentation in the middle Benue Trough, therefore the calculated average depth of 3.25km from the study area is sufficient for oil to generate if other conditions are met.

Salako K. A and Udensi E.E(2013) worked on upper Benue trough using source parameter imagine estimate depth to sedimentary/basement interface varies between 0.96 km and 5.862 km. The highest depth can be found at the south-central part to the north-eastern part. However, relatively higher depth scattered around northern and southern parts. Avbovbo et al (1986) found out that thickness of over 10km was obtained around Maiduguri depression, but less than 5km was later proved from seismic reflection data.

Nur, Onuoha and Ofoegbu (1994) obtained 1.6km to 5km for deeper source around middle Benue, while 60m to 1.2km was obtained for shallow magnetic source; Nwogbo (1997) got 2 km to 2.62km for deeper source and 70m to 0.63km for shallow source from spectral analysis of upper Benue trough; Udensi and Osazuwa (2003) obtained a maximum depth of 3.39km at Nupe Basin; Nur (2000) obtained depth range of 625m to 2.219km for deeper source and an average of 414m for shallow source at upper Benue trough; Nur (2001) got a depth range of 420m to 8km southwest of Chad basin..

This paper aimed at interpreting high resolution aeromagnetic data using Source parameter Imaging (SPI) over Matto middle Benue Trough and its environs with the following objectives:

- **i.** To determine the depth to magnetic source using source parameter imaging (SPI).
- **ii.** To locate area with potential hydrocarbon potentials.

Location and acessibility

The study area lies between latitude $8^0$0'00''N - $9^0$0'00"N and longitude $9^0$30'00"E – $10^0$0'00"E in North-central Nigeria and covers an area extent 6,050km^2 landmass. The study area lies within Middle Benue Trough. It consist of the following prominent town and village Ibi, Urotukun, Gindiwaya, GidanMasu, Shemankar, Kalong, Gerkawa, Dutsen and Rimi. These town are highly accessible by major road such as Jos – Taraba road and minor road which links the villages (Fig.1).

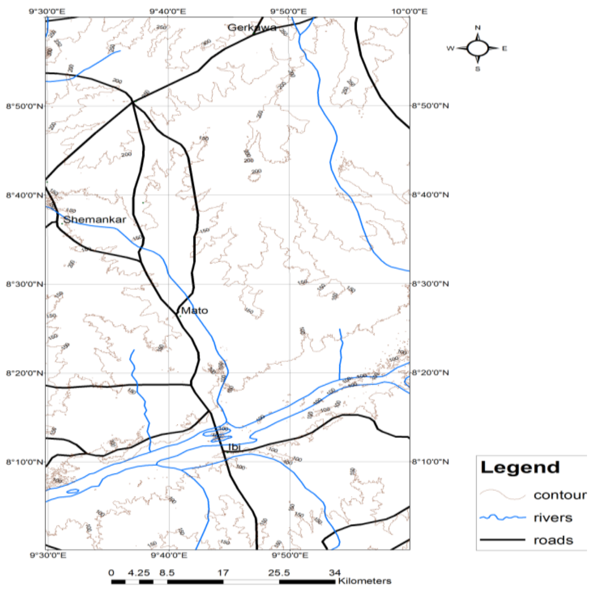


Fig.1 Location map of the study area. (Modified from USGS,2015).

Geology of the Study area

The geology of study area is consisting of gneiss, migmatites older granite and volcanic basalts on the adjourning side of the middle Benue, and the cretaceous sedimentary rock (Fig.2). The Benue trough is part of the long stretch arm of the Central African rift system originating from the early Cretaceous rifting of the central West African basement uplift (Obaje, 2004). The tectonic evolution of Benue trough originated from the separation of the African Continent from the South American continent in the Aptian (Grant, 1971). This trough is divided into the Lower Benue Trough at the southern part, the Middle Benue Trough at the centre while the Upper Benue Trough is at the Northern part, Samuel et.al, (2011).

In the Middle Benue Trough, the sediments thickness is about 4,000 m. The stratigraphic succession in this part of the Trough begins with the basal AlbianArufu, Uomba, Gboko Formations, generally referred to as the Asu River Group. These are overlain by the CenomanianKeana and Awe Formations and the Cenomanian–Early TuronianEzeaku Formation. The Late Turonian–Early SantonianAwgu Formation lies conformably on the Ezeaku Formation. The Late Santonian–Early Cenomanian was a period of folding and uplift.Volcanic (Basalts)**:** No Post-Cretaceous sediments, apart from superficial deposits, occur in the Middle Benue Trough. Volcanic activity was relatively minor in scale and was concentrated in its southern part. Carter *et al.,* 1963 reported several volcanic plugs and basalt flows from south eastern Nigeria with similar occurrences found in the Upper Benue Trough.

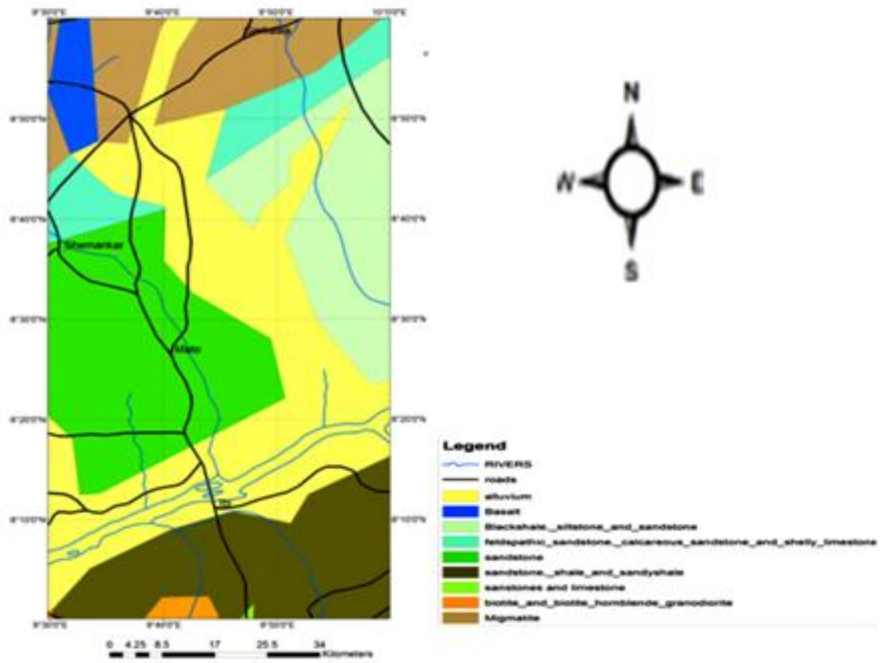


Fig.2 Geologic map of the study area. (modified from NGSA 2006)

II. Material and Methods

The aeromagnetic data used for this study, was obtained digitally from The Nigerian Geological survey Agency (NGSA), Abuja. Geosoft Oasis Montaj was used to get both the Regional-Residual Map (using first order polynomial fittings Regional-Residual separation method) and both the Source Parameter Imaging (SPI) and Analytic Signal (A.S) of the study area were derived from the TMI map (Total Magnetic Intensity map).

Data acquisition

The map of the study area was acquired digitally from the Nigerian Geological Survey Agency (NGSA). The data was part of the new survey which started in 2006 was awarded to Messrs Fugro. The survey was carried at 0.05 seconds magnetic data recording interval, at 80m terrain clearance; flight line spacing was 500 meters at 135 degrees flight line trend. Tie line spacing was 5 000 meters at 225 degrees tie line trend. Cesium vapour SCINTREX CS2 magnetometer was used for the survey. The data was generally plotted using Universal Transverse Mercator (UTM) projection method. WGS 1984 Spheroid and WGS 1984 datum were also used. Grid mesh size was 125 meters.

Data processing

Total magnetic intensity

Total magnetic intensity (TMI) is the measurement from the magnetometer after a model of the earth's normal magnetic field is removed. It is generally reflection of the average magnetic susceptibility of broad, large scale geologic features. Magnetic variation or susceptibility may be analyzed using either total intensity or residual maps. Magnetic residual maps reveal much more detail geologic in particular, the geometry and configuration of individual basement blocks. They bring out the subtle magnetic anomalies that result from change in rocks type across basement block boundaries. Total intensity map shows large scale geologic features, such as basin shape or anomalous rock types deep within the basement(Fig.3).

Regional residual Separation

Residual anomaly is what is left after regional magnetic trends are removed from the total intensity. Gaussian Regional Residual separation method was used. Residual maps showed local magnetic variations, which may have exploration significance. The regional trend of the total intensity can be calculated using a number of techniques, including running averages, polynomials, low-pass filters or upward continuation techniques(Fig.4).

Analytic Signal

The analytic signal is formed through a combination of the horizontal and vertical gradients of a magnetic component. Analytic signal (AS) requires first-order horizontal and vertical derivatives of the magnetic field or of the first vertical integral of the magnetic field. The horizontal derivative of magnetic field is a measure of the difference in magnetic value at a point relative to its neighbouring point whereas the vertical derivative is a measure of change of magnetic field with depth or height. These derivatives are based on the concept that the rates of change of magnetic field are sensitive to rock susceptibilities near the ground surface than at depth. The first vertical derivative is an enhancement technique that sharpens up anomalies over bodies and tends to reduce anomaly complexity, thereby allowing a clear imaging of the causative structures. The transformation can be noisy since it will amplify short wavelength noise i.e. clearly delineate areas of different data resolution in the magnetic grid. The application of analytic signals to magnetic interpretation was pioneered by Nabighian, for 2D case, primarily as a tool to estimate depth and position of sources. More recently the method has been expanded to 3D problems as a mapping and depth-to-source technique and as a way to learn about the nature of the causative magnetization. The analytic signal of potential field data in 2- D could be written as,

$$A(x) = \varphi_x \ {}_{+} i\varphi_z \qquad 4$$

Where the 2-D analytic signal amplitude (ASA) of potential field is

$$/A(x)/ = \sqrt{\varphi_x^2 + i\varphi_z^2} \qquad 5$$

Roest et al. (1992) write the analytic signal in 3D as a vector encompassing the horizontal derivatives and their Hilbert transform and the 3D analytical amplitude of the potential field measured on a horizontal plane as Ø (x, y) measured on a horizontal plane as

$$/A\ (x, y)\ / = \sqrt{\varphi_x^2 + \varphi_{y+}^2\varphi_z^2}$$

Source Parameter Imaging (SPI)

The source parameter imaging (SPI) is a quick, easy, and powerful method for calculating the depth of magnetic sources. Its accuracy has been shown to be +/-20% in test on real data sets with drill hole control. This accuracy is similar to that of Euler deconvolution however, source parameter imagine has the advantages of producing a more complete set of coherent solution points and it is easier to use. Stated the goals of the source parameter imagine method is that the resulting images can be easily interpreted by someone who is an expert in the local geology. The SPI method estimates the depth from the local wave number of the analytical signal. The analytical signal A1(x,z) is defined as.

$$A1(x,z) = \frac{\partial M(x,z)}{\partial x} - j\frac{\partial M(x,z)}{\partial z} \qquad 7$$

Where m(x,z) =magnitude of the anomalous total magnetic field, j=imaginary number z and x = Cartesian coordinates for the vertical direction and horizontal direction respectively. From the work of Nabighian (1972), he shows that the horizontal and vertical derivatives comprising the real and imaginary parts of the 2D analytical signal arerelated as follows.

$$\frac{\partial M(x,z)}{\partial x} = -j\frac{\partial M(x,z)}{\partial z} 8$$

Where equation 8denotes a Hilbert transformation pair. The local wave number k1 is defined by Thurston and Smith (1997) to be

$$K1=\frac{\partial}{\partial x}\tan^{-1}\frac{\partial M}{\partial z}\Big/\frac{\partial M}{\partial x} \quad 9$$

III. Results

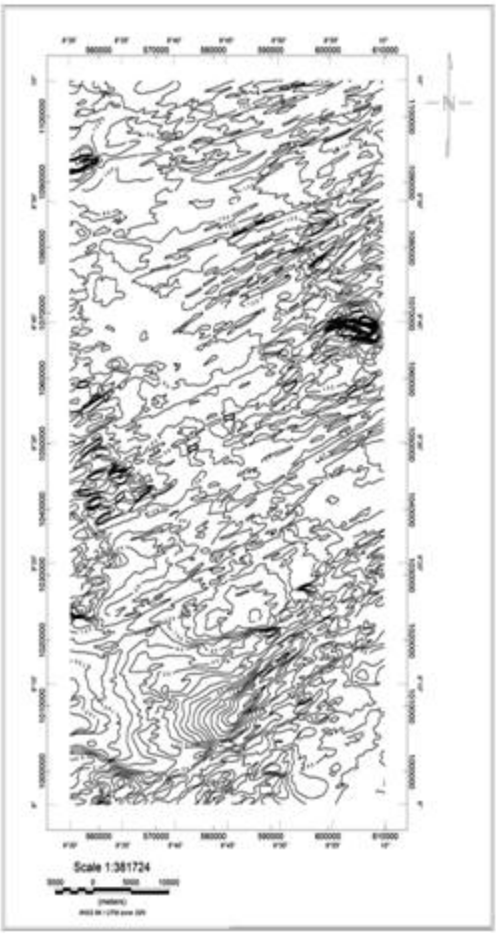


Fig .3. Total magnetic Intensity map (TMI) of the study area

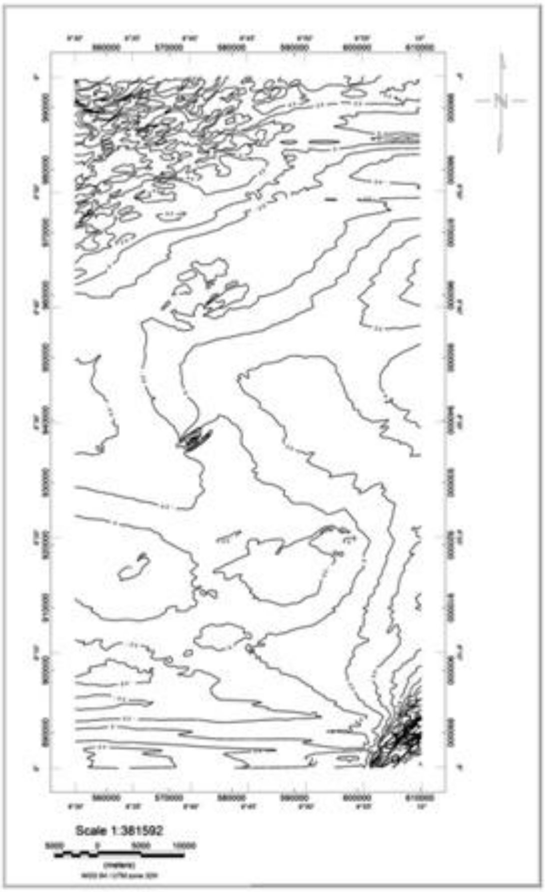
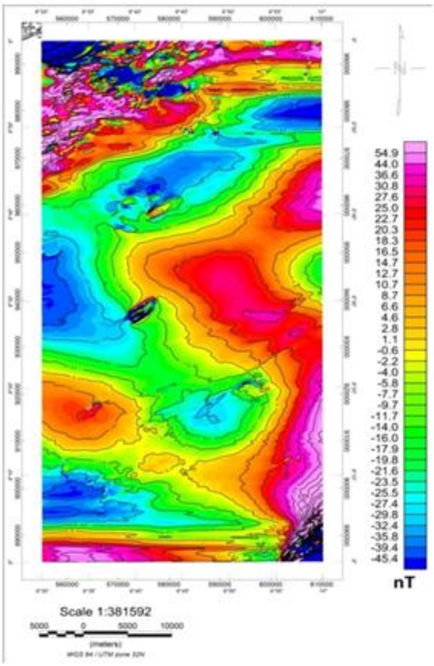


Fig. 4.Residual contour map of the study area



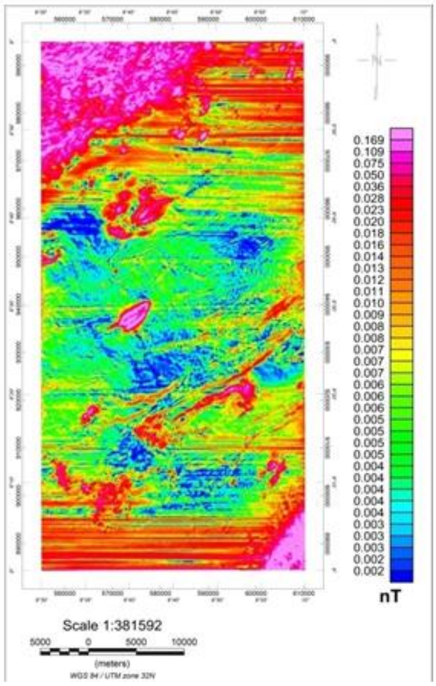


Fig.5. Residual map with contour*Fig .6.analytical signal of the area*

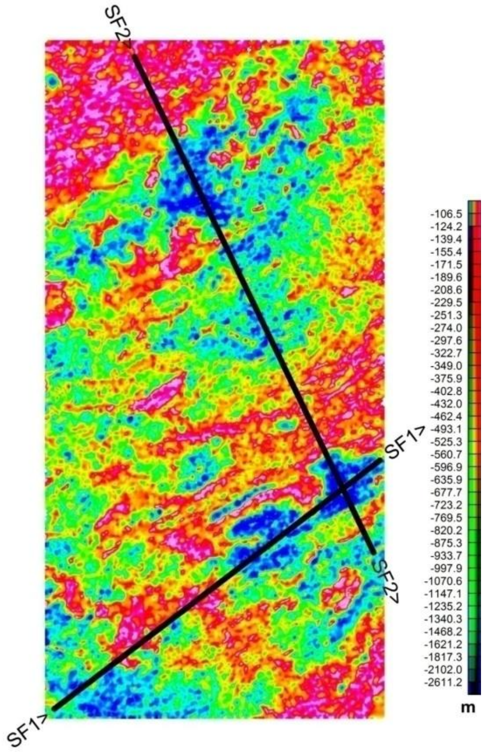


Fig .7 SPI profile of the study area

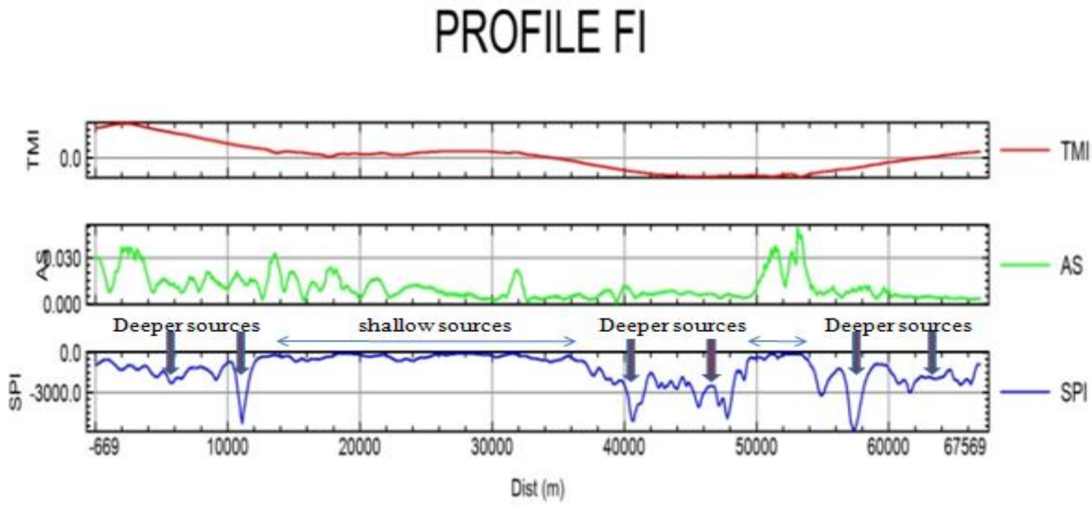


Fig.8. SPI profile along F1

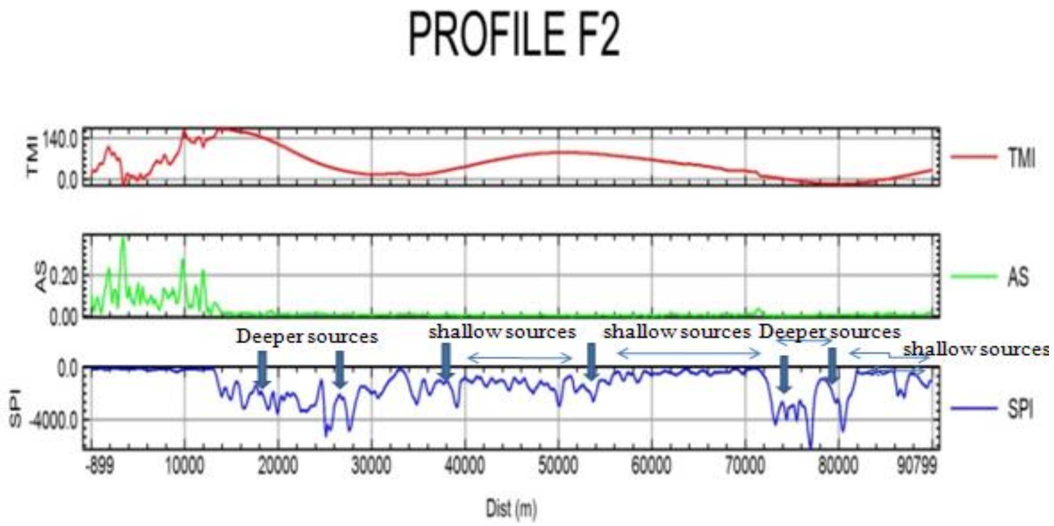


Fig.9. *SPI profile along F .*

IV. Discussion of results

The interpretation is done both qualitative and quantitative. The qualitative interpretation is carried out by visual inspection of the total magnetic intensity contour map (Fig.3), residual map (Fig.4), analytical signal(Fig.6) and SPI profile(Fig.8&9).

Having examined both the TMI contour and the residual contour map of the study area, it is observed that the study area consist of three magnetic anomaly signatures, these are the short wavelength, medium and the long wavelength which is typical of sedimentary environmentwith adjoining basement terrain. The short and medium magnetic anomaly is indicated by nosing and elliptical closurewhich are concentrated at the NW and extremes parts of the SE, is an indication of thin sedimentary cover and the localised short wavelength that are found scattered within the study area could be as a result of intrusive body such as dyke and sills in the area. The long wavelength indicated by long wavelength contour lines is an indication of thick sedimentary cover. Both the short and long wavelength magnetic anomaly can be enhance or eliminated either by upward or downward continuation depending on the target.

Analytical signal map of the study area enhances magnetic intensity over magnetic bodies and it contacts regardless of the direction of magnetization. It is always positive which can be seen on the analytic signal map in (Fig.5), the magnetic intensity of the study area ranges from 0.002nT – 0.169nT, the higher magnetic intensity which are concentrated in the NW and extreme ends of SW are depicting higher magnetic susceptibility which can be related to major tectonic activities such as fracture, faulting and intrusion. The analytical signal profile also show area of major intrusion, on both A.S profile 1 & 2 various magnetic intrusive body can be seen clearly on the profile represented by high peak in analytic signal.

Quantitatively, the interpretation is done using the SPI profile, thegenerated SPI profile shows different magnetic susceptibilities contrast within the studied area as well as showing sedimentary thickness and the configuration of the basement surface. The sedimentary thickness can always be calculated from the SPI profile which varies from the beginning of the profiles to the end. From profile 1(Fig.8) the depth to magnetic sources (sedimentary thickness) are shallow and deep, the shallow sources varies from 10 to 1500 m, while the deeper sources varies from 2000 to 6000m. from profile 2 it the shallow sources varies between 5 m to 1000 m, while deeper sources varies between 2000 to 8000 m. The shallow sources of profile 1 could be as a result of basic intrusion such as dykes or sills that form during the active magmatism as early reported in the work of Ofoegbu and Odigi (1989) within the Benue Valley. While the shallow source sources on profile 2(Fig.9) could be as a result of combine effects of basic intrusive as well as the basement terrain in the Northern part of the study area. While the deeper sources on all the profiles could be as a results of thick sedimentary cover within the Benue valley occurred during rifting and it make the study area a potential site for hydrocarbon exploration which correlate with the work of Nwosu (2014). As reported early by Wright*et al*(1985) that the minimum thickness of sediment required to achieve the threshold temperature of 115^0C for the commencement of oil and gas formation from marine organic remain would is 2.3km deep, there for the marine AlbianAsu river group has the potential to generate hydrocarbon in the area if all other condition for hydrocarbon generation are meet and the average geothermal gradient of 1^0C for 30m obtainable in the oil rich Niger Delta is applicable in the study area.

V. Conclusion

The result of the analysis indicates that the study area is a potential site for hydrocarbon exploration. This is due the facts that thedeeper sources varies between 2000 to 8000 mthat the minimum thickness of sediment required to achieve the threshold temperature of 115^0C for the commencement of oil and gas formation from marine organic remain which is 2.3km deep, there for the marine AlbianAsu river group of the study area has the potential to generate hydrocarbon as all other condition for hydrocarbon generation are meet and the average geothermal gradient of 1^0C for 30m obtainable in the oil rich Niger Delta is applicable in the study area.

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