Source Parameter Imaging (SpI) Interpretation of Aeromagnetic Data over the Younger Granite Rocks around Amper and Environs, North Central Nigeria

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ABSTRACT

Source Parameter Imaging (SPI) was used to interpret high resolution aeromagnetic data in anOasis montaj Software environment in order to determine the depths to magnetic source over Amper and Environs in the North Central Nigeria.The results suggest the existence of shallow and deeper magnetic sources at depths between 10 to 1490 m and 1500 to 4000 m respectively. The shallow sources are interpreted as consisting of volcanic intrusive within the Younger Granite while the deeper sources resulted from thick weathered overburden materials within the craters in the ring complexes. The thick overburden in the southern part of the calderas is considered a recharge zone for ground water exploration around Amper community. The study area can also be further investigated for potential targetssuch as mineral exploration since the Younger Granite are associated with minerals of economic importance.

KEYWORDS: Source parameter imaging, calderas, ring complexes, Younger Granites and crater

Introduction

Aeromagnetic survey is one of the common types of geophysical survey carried out using a magnetometer aboard or towed behind an aircraft. The principle is similar to that of magnetic survey carried out with a hand-held magnetometer, but allows much larger areas of the earth’s surface to be covered quickly for regional reconnaissance. The aircraft typically flies in grid-like pattern with height and line spacing determining the resolution of the data and the survey of the cost per unit area. Survey along a profiles or grids determine the strength of the geomagnetic field at particular points by measuring spatial variation in the Earth’s magnetic field (Onwuemesi, 1995).

As the aircraft flies, the magnetometer records any variations in the intensity of the ambient magnetic field due to the temporal effects of the constantly varying solar wind and spatial variations in the earth’s magnetic field; the latter being due to both the regional magnetic fields and the local effects of magnetic minerals in the earth’s crust. By subtracting the solar and regional effects, the resulting aeromagnetic map gives the magnetic anomalies due to the spatial distribution and presence of minerals (iron oxide minerals) in the upper levels of the crust. Because different rock types differ in their content of magnetic minerals, the magnetic contour map allows a visualization of the geological structure of the upper crust in the subsurface, particularly the spatial geometry of bodies of rock and the presence of faults and folds. Ofoegbu (1988) reported that roughly about 60 percent of magnetic surveys are carried out for regional geological mapping and mineral exploration. The main purpose of magnetic survey is to detect rocks or minerals possessing unusual magnetic properties that reveal themselves by causing disturbances or anomalies in the intensity of the earth magnetic field. Aeromagnetic data is commonly expressed as shaded computer generated map. From regional aeromagnetic data sets, information such as tectonic frame of the upper crust can be obtained.

Quantitative interpretation is to obtain information about the depth to the magnetic source, its shape and size, and details of its magnetization. This is done either by direct method, where the field data are interpreted to yield a physical model or by inverse method, where models are generated from which theoretical anomalies are generated and fitted statistically against the observed data

The Nigerian Younger Granites ring complexes are a series of petrologically distinctive crystalline igneous rocks of granitic composition. Several individual complexes have been identified with varying sizes and named after their localities. Individual massifs range from 640 km^2 to less than 1.68km^2. Ogezi (1986) referred the massif as Cenozoic (Jurassic) igneous granitic rocks suites that occur in a north – south trending belt and are restricted to the northern part of the country. The suites extend from Afu (near River Benue) in Central Nigeria to Zinder and Air in Niger Republic and cover an area of about 1300 km^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 and hence, their evolution as near ring (circular) complexes. They are however, known to be associated with earlier acid volcanoes such as rhyolite, gabbros and syenites (Elebe, 1990).

The Nigerian Younger Granite complexes are known to be mineralogically heterogeneous with variations in their textures that are attributable to the proximity of the roofs of the batholiths. They are composed of a wide variety of rock types. Individual Younger Granite suites are known to contain different rock types in the various sub provinces. Their age differences decrease towards the south, suggesting that their emplacement was fundamentally controlled by thermal anomaly in the mantle or lower crust but not related to any orogenic activity (Garba, 1988). This is also supported by their non-foliated and un-fractured surfaces (Idumah, 2005), in contrast to the foliated calc-alkaline Older Granites.

The aim of this work is to analyse the aeromagnetic data over the study areain order to determine the depths to magnetic sources using Source Parameter Imaging (SPI).

MATERIALS AND METHOD

The study area is located between latitude 9° to 10° N and longitude 9° 30′ to 10° E (Figure 1.). It covers, Dull, Amper, Tafawa Balewa and Langtang areas. It has an approximate area of 6,050 km^2 and embraces a number of farm lands, settlements, and towns. The area is endowed with a range of hills, the most prominent of these hills are found in the northern and central part of the study area. The hills are underlain by pre-Cambrian Basement Complex rocks. The area is characterized by rugged terrain, The rugged terrain forms part of the Younger Granites of North-Central Nigeria and the crystalline pre-Cambrian basement block.

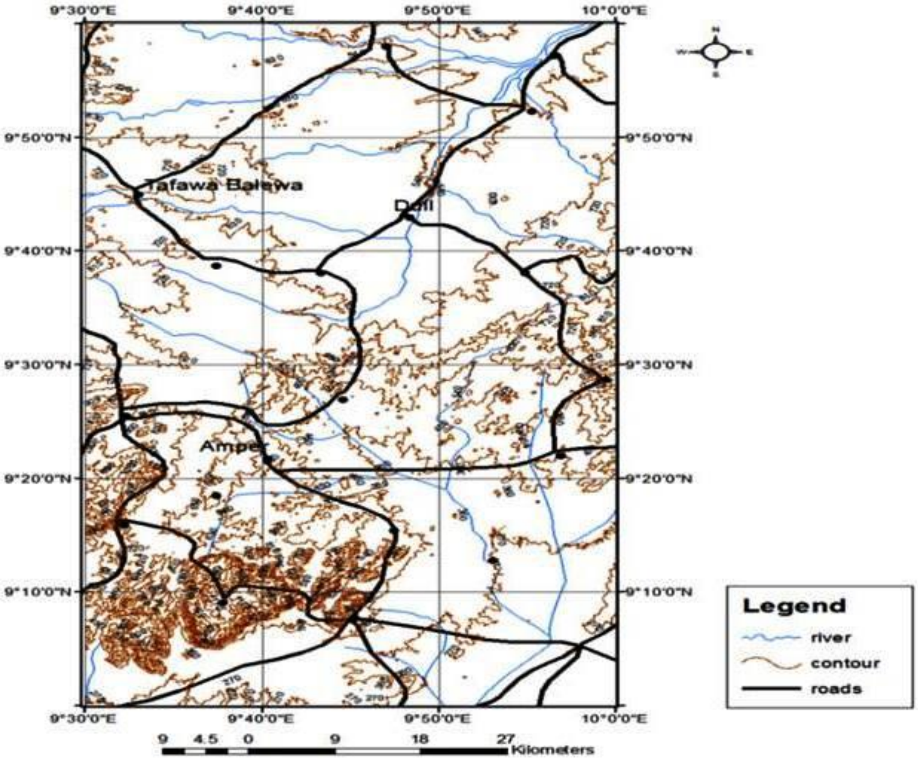

Figure 1: Location map of the study area (USGS, 2015)

The geology of the area is dominated by Older Granites which dated to the late Cambrian and Ordovician. The distinct phases of volcanic activities led to the intrusion of Younger Granites into the Older Basement rocks. In Nigeria, about fifty separate Younger Granites complexes are recognized with a total area of 7511 km ^{2}. The individual massifs display circular or elliptical outlines and range in size from 1036 km^2 to smaller stocks of less than 2.59 km^2. Several cycles of intrusion occur within one complex and the sizes of many of the structures are due to overlapping and superposition of separate intrusive cycles. These Younger Granites are emplacements that are dated to the Jurassic and forming part of a series that includes the Aiir Massif in the Central Sahara.

There are also many volcanic and sheets of basalt that extruded since the Pliocene. The phases of volcanic activities resulted in the formation of Plateau State which made it one of the mineral rich States in the country. There are great peaks like the Shere Hills, extinct volcanoes and crater lakes on the Jos Plateau which is also the source of great rivers like those of Kaduna, Hadeja and Yobe. Volcanic rocks in most of the complexes have either been obliterated by later granite intrusions or eroded to an extent that their original pattern of distribution is conjectural. Where the lavas are preserved, they are confined within the major peripheral ring faults. The early groups are products of vent intrusion from groups of vents aligned along ring-fractures. The fractures extended to the surface and provided zones of weakness that facilitated the upward passage of the magma.

In the northeastern part and a little portion around the central part, there is alluvium which is of variety of materials including fine grain particles of silts and clays, and large grain particles of sand and gravel. Thereexist basalts in the southwestern part, a little ignimbrite in most easterly part and biotite granite covering a considerable portion near the central part. Dominantly, biotite and biotite hornblende Granodiorite, meta conglomerate and migmatites cover the area. There are also some disseminations of pophyroblastic gneiss, granite gneiss and biotite muscovite granite (Figure 2)

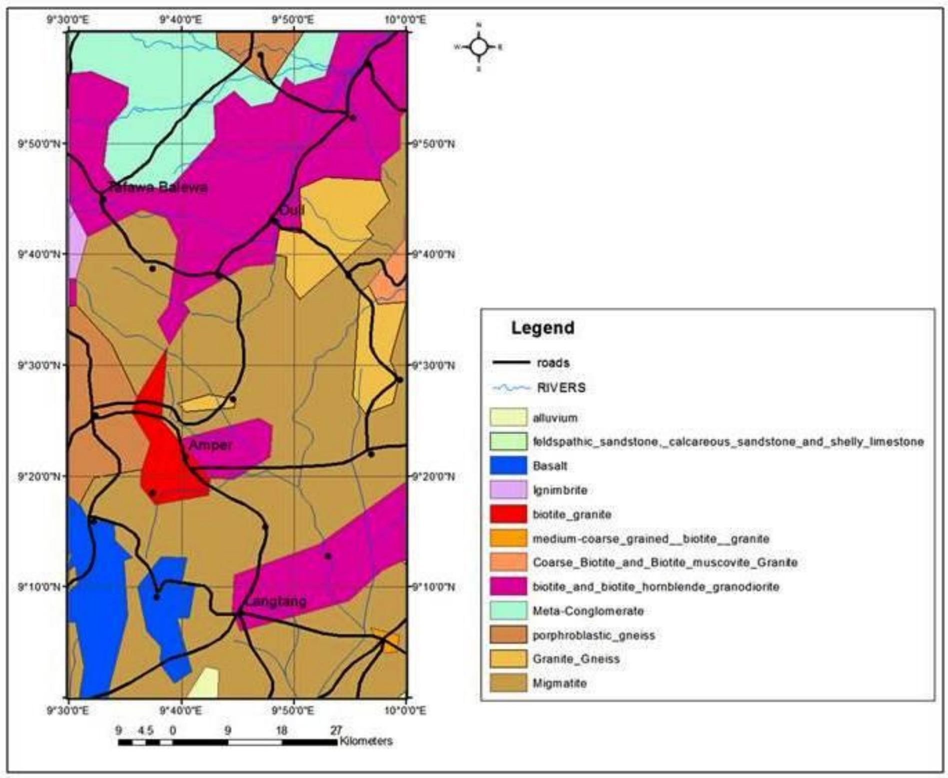

Figure 2: Geological map of the study area (Modified from NGSA 2006)

The aeromagnetic data used for this research work, were obtained as high resolution aeromagnetic data from Nigerian Geological Survey Agency (NGSA) in 2010 by Messrs Fugro. The survey was carried at 0.05 seconds magnetic data recording intervals, at 80 m terrain clearance; flight line spacing of 500 meters at 135 degrees' flight line trends. Tie line spacing are 5000 meters at 225 degrees tie line trends. Caesium vapor SCINTREX CS2 magnetometer was used for the survey.

The data was plotted using Universal Transverse Mercator (UTM) projection method. WGS 1984 Spheroid and WGS 1984 datum were also used. Grid mesh size was 125 meters.

The data used for this research was delivered as total magnetic intensity map in Oasis montaj format (Fig.3).

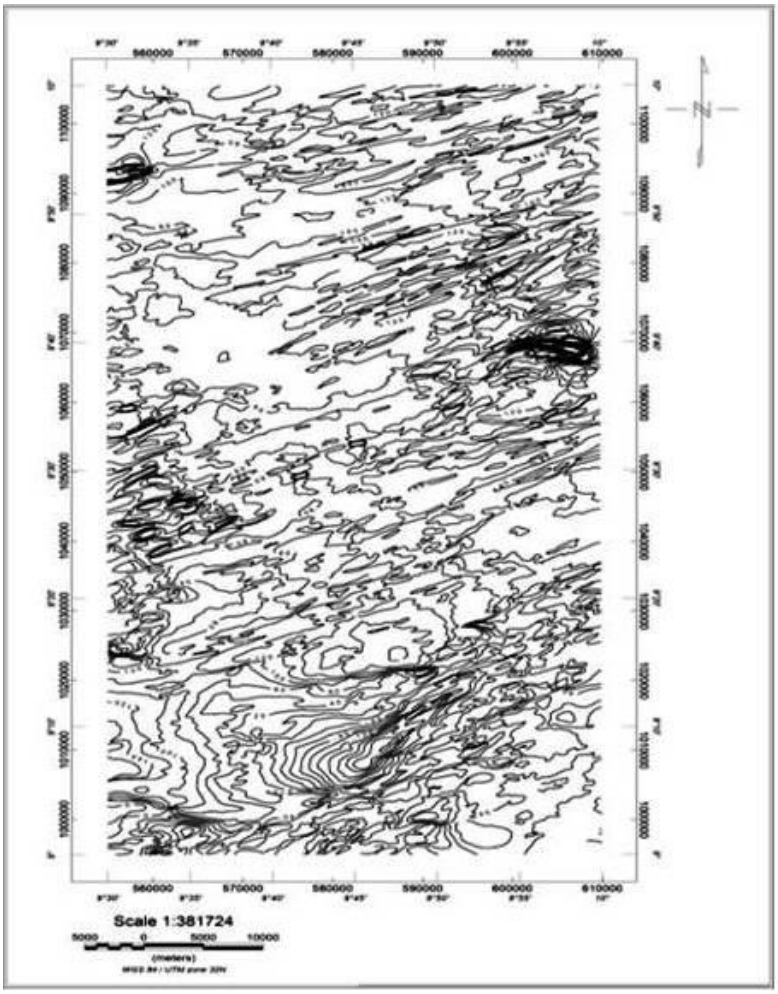

Figure 3: Total magnetic intensity contour map.

Source Parameter Imaging

The Source Parameter Imaging (SPI) method uses the local wave number from an analytical signal to calculate depth to magnetic sources. The SPI function is a quick, easy, and powerful method for calculating the depth of magnetic sources. SPI has the advantage of producing a more complete set of coherent solution points and it is easier to use. The resulting images of SPI method can be easily interpreted by someone who is an expert in the local geology (Thurston and Smith, 1997).

The analytical signal A(x, z) is defined by Nabighian (1972) as:

$$A(x,z) = \frac{\partial M(x,z)}{\partial x} - j\frac{\partial M(x,z)}{\partial z} \qquad 1$$

Where M(x, z) is the magnitude of the anomalous total magnetic field, j is the imaginary number, z and x are Cartesian coordinates for the vertical direction and the horizontal direction respectively. Nabighian (1972) showed that the horizontal and vertical derivatives comprising the real and imaginary parts of the 2D analytical signal are Hilbert transformation pair given by

$$\frac{\partial M(x,z)}{\partial x} \Leftrightarrow \frac{\partial M(x,z)}{\partial z} \qquad 2$$

Where ⇔ denotes a transformation pair.
Thurston and Smith (1997) define the local wave number k (in radian per ground unit) for this analytical signal to be

$$K = 2\pi f_0 \qquad 3$$

and

$$f_0 = \frac{1}{2\pi}\frac{\partial}{\partial x}\tan^{-1}\left[\frac{\partial M(x,Z)}{\partial z} \Big/ \frac{\partial M(x,z)}{\partial x}\right] \qquad 4$$

where f_0 is cycles/ground unit and K is the wave number in radian per ground unit.

$$K = \frac{\partial}{\partial x}\tan^{-1}\left[\frac{\partial M(x,Z)}{\partial z} \Big/ \frac{\partial M(x,z)}{\partial x}\right] \qquad 5$$

Nabighian (1972) gives the expression for the vertical and horizontal gradient of a sloping contact model as:

$$\frac{\partial M(x,z)}{\partial z} = \frac{2\chi Mc\sin\beta \cdot x\cos(2I-\beta-90^{\circ}) - h\sin(2I-\beta-90^{\circ})}{h^2+x^2} \qquad 6$$

And

$$\frac{\partial M(x,z)}{\partial x} = \frac{2\chi Mc\sin\beta \cdot h\cos(2I-\beta-90^{\circ}) - x\sin(2I-\beta-90^{\circ})}{h^2+x^2} \qquad 7$$

where χ is the susceptibility contrast at the contact, M is the magnitude of the earth's magnetic field (the inducing field), $c = 1-\cos^2 i\sin^2\alpha$, α is the angle between the positive x-axis and magnetic north, *i*is the ambient-field inclination, tan i = sini/cosi, β is the dip (measured from the positive x-axis), *h* is the depth to the top of the contact and all trigonometric arguments are in degrees. The coordinate system has been defined such that the origin of the profile line (x = 0) is directly over the edge. Substituting equations 6 and 7 into 5 gives the wave number for a contact profile as:

$$K_{max} = \frac{1}{h} \quad 8$$

And

$$\text{Depth (h)} = 1/ K_{max} \quad 9$$

Where K_{max} is wave number of the analytical signal
h is depth to the point of contact

Using the concept of Hsu *et al.* (1996) for an analytic signal comprising second-order derivatives of the total field, a second wave number can also be generated.

From equation 6, it is evident that wave number is independent of susceptibility contrast, the dip of the source and the inclination, declination, and the strengthof the earth's magnetic field.

Equation 7 is the basis for SPI method (Adetona and Abu, 2013). It utilizes the relationship between source depth and the local wave number of the observed field, which can be calculated for any point within a grid of data through horizontal and vertical gradients (Thurston and Smith, 1997). For vertical contacts, the peaks of the local wave number define the inverse of depth. The depth is displayed as an image (in color aggregate). Image processing of the source-parameter grids enhances detail and provides maps that facilitate interpretation by non specialists (Ojoh, 1992).

Analytic signal

The analytic method gives the amplitude response of an anomaly. These filter applied to magnetic data is aimed at simplifying the fact that magnetic bodies usually have positive and negative peaks associated with it, which may make it difficult to determine the exact location of causative body. For two dimensional bodies a bell shaped symmetrical function is derived and for three dimensional bodies the function is amplified by analytical signal. This function and its derivatives are independent of strike, dip, magnetic declination, inclination and remnant magnetization.

The analytic signal or total gradient is formed through the combination of the horizontal and vertical gradients of the magnetic anomaly. The analytic signal has a form over causative body that depends on the locations of the body (horizontal coordinate and depth) but not on its magnetic direction. This quantity is defined as a complex function that its real component is horizontal gradient and its imaginary component is vertical gradient. Nabighian, (1972,) was able to prove that the imaginary component is Hilbert transform of real component.

Consider M(x, z) to be 2-D magnetic field that was measured along x-axis, then the analytical signal, a(x,z) can be expressed in terms of vertical and horizontal gradient of M(x, z) with respect to x and z directions in Cartesian coordinates as Blakely, (1995) put it as:

$$a(x,z)=\frac{\partial M}{\partial x}+i\frac{\partial M}{\partial z} \quad 10$$

where $\frac{\partial M}{\partial x}$ and $\frac{\partial M}{\partial z}$ are Hilbert transform pair. The amplitude for the 2D signal is giving by:

$$|A(x, z)| = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2+\left(\frac{\partial M}{\partial z}\right)^2} \quad 11$$

For the 3-D case, the analytic signal is given by:

$$a(x,z)=\frac{\partial M}{\partial x}+\frac{\partial M}{\partial y}+i\frac{\partial M}{\partial z} \quad 12$$

The amplitude of the analytic signal in the 3-D case is given by:

$$|A(x, z)| = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2+\left(\frac{\partial M}{\partial y}\right)^2+\left(\frac{\partial M}{\partial z}\right)^2} \quad 13$$

Where M = magnetic field

The analytical signal can be calculated with commonly available computer software. The x and y derivatives can be calculated directly from total magnetic field grid using a simple 3×3 filter, and the vertical gradient is routinely calculated using Fast Fourier Transform (FFT) techniques.

Some of the properties of the analytic signal are:

i. Its absolute value is symmetric; it is independent of body magnetization direction and ambient geomagnetic field and is only relevant to body location.
ii. It can be employed to causative body depth estimation.
iii. Its maximum value lies over the body directly.

Results and Discussion

The results for the interpretation of aeromagnetic data over the study area are presented in figures and are discussed. Fig 4 shows the SPI map displaying various depths to magnetic sources while Figs 4, 5, 6 and 7 show the SPI map on which the profiles were drawn.

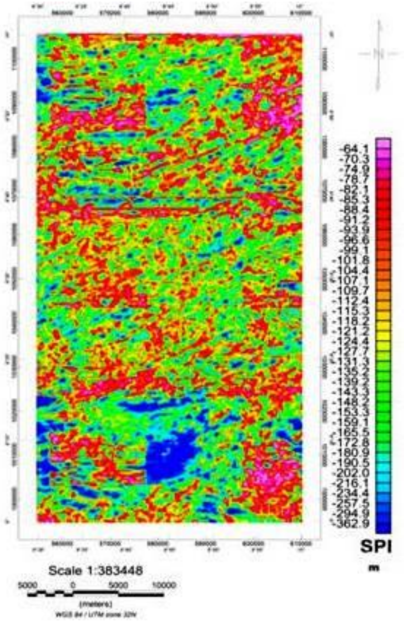

Figure 4: SPI map

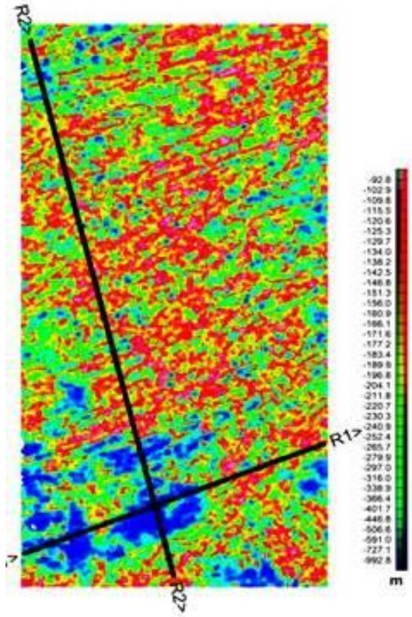

Figure 5: SPI map with profiles

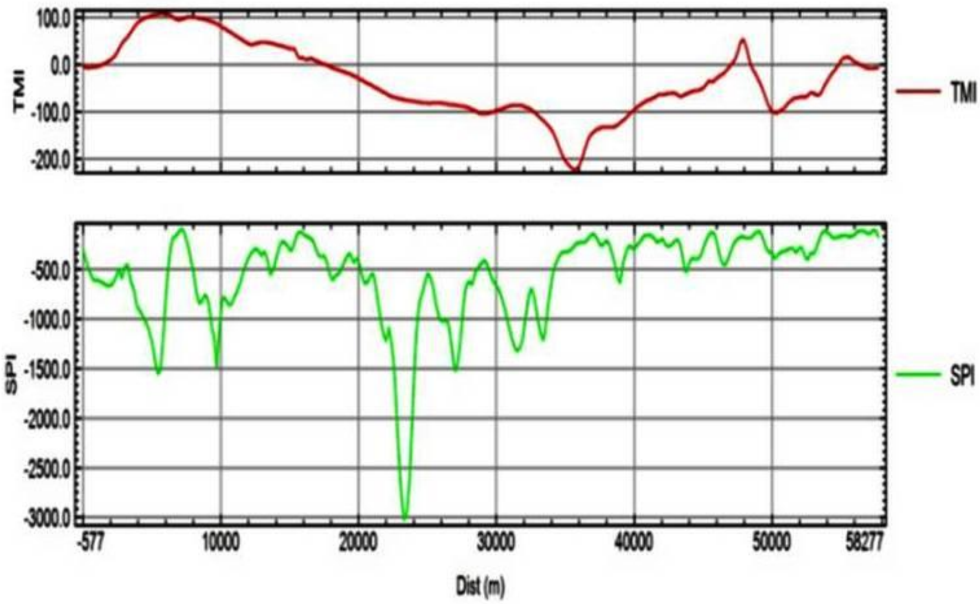

Figure 6: SPI profile of R1

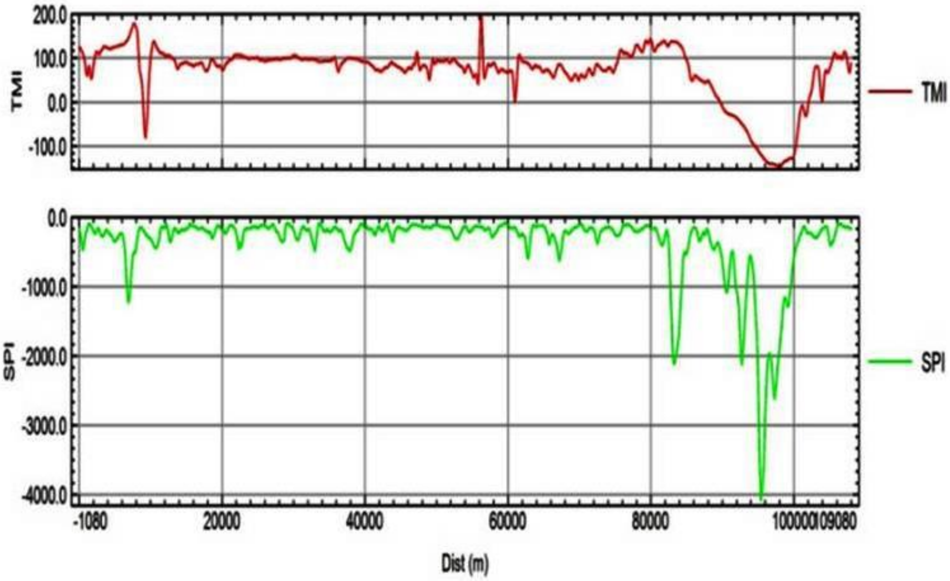

Figure 7: SPI profile of R2

The total magnetic intensity map (Fig. 3) over the study area consists of short, medium and long wave magnetic anomalies. The short and medium wavelength magnetic anomalies correspond to shallow magnetic sources, while the long wavelength magnetic anomalies correspond to deeper magnetic sources resulting from the Precambrian Basement Complex rocks. The magnetic signatures over the study area correspond well with the geology (Fig. 2). Fig. 5 shows that the southern part of the study area has deeper sources. This are suspected to contain a crater lake around it.

The depths to magnetic source based on the SPI results (profiles) suggest the existence of two magnetic sources, the shallow source and the deeper sources. The depth to the shallow sources on profiles 1 and 2 (Fig. 6 and 7) ranges between 10 m to 1490 m, while the depth to deeper sources varies between 1500 m to 4000 m. These results are consistent with those obtained by other authors using spectral analyses. This deeper source is typical of crater lakes which might have influenced deep weathering. The shallow sources indicate the existence of series of volcanic plugs within the Younger Granites.The ring complexes and calderas were also responsible for the deeper magnetic source with thick sedimentary covers. The results thus suggest the Younger Granite complex of North Central Nigeria to be potential targets for ground water and mineral exploration due to series of volcanic activities, which led to the emplacement of minerals of economic importance.

Conclusion

The Younger Granite complex of North Central Nigeria is characterized by series of ring complexes evident from the variation in depths to magnetic sources using Source Parameter Imaging (SPI). Areas of deeper magnetic sources are associated with deep weathering due to formation of Crater Lakes, while the shallow depthsconstitute series of intrusive. The craters in this area serve as recharge zones for boreholes located around them. This study thus illustrated that; surface magnetic data can be used to produce depths to magnetic sources in areas where borehole data are lacking,

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References

Adetona, A. A. and Abu, M. (2013). Estimating the thickness of Sedimentation within Lower Benue Basin and Upper Anambra Basin, Nigeria, using both Spectral Depth Determination and Source Parameter Imaging. Hindawi Publishing Corporation ISRN Geophysics. Pp, 1-10.

Blakely, R. J. (1995). Potential theory in gravity and magnetic applications. Cambridge University press. New York, 435p

Elebe, B. O. (1990). Geology and Mineral processing of Alluvial Deposits, 'Columbite', Jos Plateau. B. Sc Thesis. University of Jos, Nigeria.

Garba, I. (1987). Introduction to Geology and Mineral Deposits of Nigeria. Ganuwa Publishers series, Zaria.

Hsu, N. C., Herman, J. R., Bhartia, P. K., Seftor, C. J., Torres, O., Thompson, A. M., Gleason, J. F., Eck, T. F., &Holben, B. N., (1996). Detection of biomass burning smoke from TOMS measurements. *Geophysics. Res. Lett., 23*. Pp745–748

Idumah, O. (2005). Geology and Geochemistry of Tailings from Tin Mining (A case study of BarkinLadi and its Environs). Naraguta sheet 168 SW. B. Sc Thesis. University of Jos, Nigeria.

Nabighian, M. N. (1972). The Analytic Signal of two dimensional magnetic bodies with polygonal cross section: Its properties and use for automated anomaly interpretation. Geopgysics. 37(2). pp. 507-517

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

Ogezi, A. E. (1986). Mineral Raw Materials and the Nigerian Economy. Unpublished post graduates Open Lecture University of Jos. Plateau State.

Ojoh, K. (1992). The Southern part of the Benue Trough Nigeria Cretaceous Stratigraphy, Basin analysis, Paleoceanography and Geodynamic evolution in the equatorial domain of the South Atlantic. NAPE Bulletin 7, Pp, 131-152

Onwuemesi, A. G. (1995). Interpretation of magnetic anomalies from the Anambra Basin of Southeastern Nigeria. Ph. D Thesis, NnamdiAzikiwe University, Awka. Anambra State. Pp, 12-55

Thurston, J. B. and Smith, R. S. (1997). Automatic conversion of magnetic data to depth, dip and susceptibility contrast using the SPI^{TM} method. Geophysics, 62, pp, 807-813

Turner, D. C. (1989). Structure and petrology of the Younger Granite Ring Complexes. In Geology of Nigeria, Kogbe, C. A (ed). Rock View International, France, Pp, 175-190

United State Geologic Survey, (2015). United State Geological Survey geographic information data base.