ISSN 2055-009X(Print),
ISSN 2055-0103(Online)

Review: Spectral Analysis of Aeromagnetic Data Interpretation

[1]Sunday Ayigun., [2]Hamid K. Y and [3]Omoniyi O. Titilola

[1,2&3]Department of Pure and Applied Physics, Federal Polytechnic Mubi, Adamawa State, North Eastern Nigeria

Citation: Sunday Ayigun., Hamid K. Y and Omoniyi O. Titilola (2022) Review: Spectral Analysis of Aeromagnetic Data Interpretation, *International Research Journal of Pure and Applied Physics*, Vol.9 No.1, pp.1-11

ABSTRACT: *Spectral analysis of aeromagnetic data interpretation method is a vital tool in the field of geology and geophysics for solid minerals, groundwater, hydrocarbon and geothermal energy exploration. Human existence depends on availability of mineral and their explorations for daily activities in every part of the world. In order to reduce the scarcity of minerals and problems associated with minerals exploration, this paper reviews shed more light on source of data acquisition, data processing and interpretation in respect to the subject matter. Two case studies were considered, the first case study was on the spectral analysis method of aeromagnetic data interpretation in Longuda Plateau and its environs in Adamawa state North Eastern Nigeria. The data of the study area was divided into 16 x16 data points; the data was subjected to 2D Fourier transformation. After the spectral analysis the depth to magnetic sources were discovered ranging from 1900 m to 2620 m at the basement and shallow depth was ranging from 512 m to 670 m magnetic sources. The second case study was on magnetic data processing for hydrocarbon exploration in the Pannonian Basin, Yogoslavia, from the magnetic data analysis, hydrocarbon potential zones were identified.*

KEY WORDS: spectral, analysis, aeromagnetic, exploration, interpretation, data, minerals

INTRODUCTION

Spectral analysis is the process of breaking down a signal into its components at various frequencies, and in the context of acoustics there are two very different ways of doing this, depending on whether the result is desired on a linear frequency scale with constant resolution (in Hz) or on a logarithmic frequency scale with constant percentage resolution. The fundamental connection between the time domain and the frequency domain, the Fourier transform, is most easily interpreted in terms of linear time and frequency scales, at least in the practical version now used to calculate it, the FFT (Fast Fourier transform).However, expressing a spectrum on a linear scale automatically restricts its frequency range, since the upper frequency decade occupies 90% of the scale and the upper two decades 99% of the scale. The human ear has a frequency range of three decades (20Hz–20kHz) which can only be expressed on a logarithmic frequency scale with constant percentage bandwidth, i.e., where the bandwidth of a filter at any frequency is a fixed percentage of its center frequency (Randall, 2001).

ISSN 2055-009X(Print),
ISSN 2055-0103(Online)

The use of aeromagnetic survey in the sedimentary basins dates from the late 1940s when magnetometers that had been used in aircraft for hunting submarines were adapted to map magnetic basement in the petroleum exploration sector. Conventional use of aeromagnetic surveys, commonly in association with ground gravity surveys has helped to delineate basin architecture via depth to basement studies. This has evolved to the point where such work is integral in the early in the early stages of basin exploration, frequently preceding and guiding the acquisition of seismic data. The speed and uniformity of coverage plus the relatively low cost of aeromagnetic surveys have consolidated their role in this application (David and Leigh, 2013).

Magnetic surveying is a geophysical method focused on the mapping of the magnetic field produced by rocks of the Earth's crust. It allows inferring location, shape and depth of crustal magnetic sources and, combined with geologic information; it can yield an unprecedented geological interpretation of the target area. With respect to the measurement carried on land, airborne magnetic measurements have the advantage of being rapid, of covering areas otherwise difficult to access(e.g. rugged and/or inaccessible volcanic areas (Paolettiet *et al.*, 2005, 2016), and of being much less disturbed by ground-level sources (both natural and anthropogenic). Aeromagnetic surveys are largely applied in subsurface exploration (ore and oil exploration), environmental and ground-water investigation, and geological mapping.

Minerals are key element to nations building and require several methods to recognize its areas of deposit. The deposition of these minerals can be in tabular or shell-like form, filling a fracture in a host rock controlled by hydraulic of magmatic water that carries large amount of dissolved minerals which it deposits in veins as it travels to the earth surface (Richard, 2001; McGraw, 2003). However, minerals are not easily determined except with the expertise of geologists and application of geophysical tools. Geophysical method such as aeromagnetic data has been chiefly used for geologic structural mapping and mineral exploration (Moghaddam, 2015; Oladunjoye, 2016). The elementary geophysical understanding behind this is that; different rock types host different magnetic responses and as a result several analytical data processing tools is needed to enhance the output images of these magnetic responses for better geologic interpretation.

The magnetic method is one of the best geophysical techniques used for determining depth to magnetic source bodies (and possibly sediment thickness) and delineating subsurface structures Large-scale aeromagnetic surveys have been used to locate faults, shear zones and fractures Such zones may serve as potential hosts for a variety of minerals and may be used as guidance for exploration of the epigenetic, stress-related mineralization in the surrounding rocks (Paterson and Reeves, 1985) Sediment thickness required for hydrocarbons (oil and/gas) to form or be generated varies from place to place The minimum sediment thickness required for producing oil usually varies from 2km to 4km, compared to 3 km to 7 km for gas production/formation (Dow, 1978; Cornford, 1990; Gluyas and Swarbrick, 2005).

Aeromagnetic maps usually reflect variations in the earth's magnetic field resulting from the underlying rocks' magnetic properties (e g magnetic susceptibilities) Sedimentary rocks have the lowest magnetic susceptibility, whereas metamorphic and acidic igneous rocks intermediate and

Vol.9 No.1, pp.1-11, 2022
ISSN 2055-009X(Print),
ISSN 2055-0103(Online)

basic igneous rocks have the highest magnetic susceptibility (Kearey *et al.*,2002). The largest proportion of a magnetic signal or anomaly is thus generated at crystalline (igneous or metamorphic) basement level (GETECH, 2007). Magnetic anomalies are caused by magnetic minerals contained in rocks; such anomalies are usually caused by underlying basement (igneous and/or metamorphic) rocks or by igneous features such as intrusive plugs, dykes, sills, lava flows and volcanic centres when magnetic anomalies are observed over sedimentary terrain (Gunn, 1997) Nevertheless, high sensitivity measurements could also be associated with cultural iron contamination and authigenic alterations in sedimentary rocks, possibly caused by hydrocarbon migration (Costanzo-Alvarez et al., 2000; Aldana *et al.*, 2003).

The role of aeromagnetic method in mineral exploration varies from delineation structures like faults, folds, contacts, shear zones and intrusions to automated detection of porphyry and favorable areas of ore deposits. These structures play important roles in the localization of mineralization. There are various enhancement techniques that can help achieve objectives. These include Horizontal gradient magnitude “HGM”(Cordell and Grauch, 1985), Tilt derivative “TDR”(Miller and Singh, 1994), A directional filter (Cooper, 2003), Theta derivative (Wijns *et al.*, 2005) and normalized standard deviations “NSTD”(Cooper and Cowan, 2008). Also, there are automated methods that can locate porphyry magnetic signatures and delineate lineaments that used to identify favorable areas of ore deposits (Macnae, 1995; Holden *et al.*, 2008; *Core et al.*, 2009).

A lot of research work has been carried out on the interpretation of aeromagnetic data for the purpose of delineating solid minerals, ground water potentials and geothermal energy exploration. Ajakaiye *et al.,* (1986) studied the Benue Trough’s tectonic framework and that of parts of the adjoining Nigerian basement complex using aeromagnetic maps, delineating NE-SW and ENE-WSW directions as being the dominant aeromagnetic lineament trends. They stated that these aeromagnetic lineaments depicted a possible continental continuation of the four Atlantic fracture zones (St Paul’s, Romanche, Chain and Charcot) abutting the West African coast into the Nigerian basement complex According to Olasehinde *et al.*, (1990), analyzing aeromagnetic data over central Nigeria’s basement complex has shown that the Nigerian basement complex’s structural and tectonic framework comprises NE-SW and NW-SE lineaments superimposed over a dominant N-S trend Overall NE-SW aeromagnetic lineaments of the Benue Trough and Atlantic fracture zones apparently signified an ancient zone of weakness in the Nigerian basement complex According to Nur *et al.,* (1994), depths to magnetic basement in the middle Benue Trough varied from 0 066km to 4 938km, whereas Onyedim *et al.,* (2006) have stated depth values ranging from 0 11 km to 5 5 km.

Ikumbur *et al*. (2019) conducted research to Determine Curie-Temperature Depth and heat flow deduced from spectral analysis of aeromagnetic data over the southern Bida Basin, West-Central Nigeria. and find out that the area under study is good for exploration of an alternative source of geothermal energy, especially at Gulu and Kirri areas. The spectral analysis data shows that the heat flow information revealed an almost linear relationship between heat flow and Curie depths.

Vol.9 No.1, pp.1-11, 2022

ISSN 2055-009X(Print),

ISSN 2055-0103(Online)

Adewumi and Salako (2018) carried out qualitative analysis of aeromagnetic data of part of Nasarawa State Nigeria, in order to delineating mineral potential zone. They were able to identify the potential zone for mineral exploration in the area under study.

Oke *et al*. (2018) worked on Interpretation of high resolution aeromagnetic data to determine sedimentary thickness over part of Bida Basin, North Central Nigeria. Spectral depth analysis showed a maximum sedimentary thickness of 3.50 km. It was found that the maximum depths obtained might probably be sufficient enough for hydrocarbon maturation and gas accumulation Adelusi *et al*. (2013) carried out Interpretation of aeromagnetic anomalies and electrical resistivity mapping around Iwaraja area Southwestern Nigeria. Qualitative interpretation of the aeromagnetic and ground magnetic profiles suggests varying magnetic intensities from different sources producing the anomaly. And they were able to identify some geology features of the area under study.

Olasunkanmi *et al*.(2018) worked on the Interpretation of high resolution aeromagnetic data for mineral prospect in Igbeti-Moro area, Southwestern Nigeria. They were able to establish significant geologic features associated with occurrence of marble, gabbro and muscovite mineralization in the area. The geologic feature in the area shows that the solid minerals that can be of social-economic benefit.

Anudu *et al.* (2012) carried out research on Analysis of aeromagnetic data over Wamba and its adjoining areas in north-central Nigeria. They were able to determine the depths to magnetic sources in two models and their magnetic intensities.

The Curie point depth is known as the depth at which the dominant magnetic mineral in the crust passes from a ferromagnetic state to a paramagnetic state under the effect of increasing temperature (Hisarlis, 1996; Nwankwo, *et al.*, 2011; Kasidi and Nur, 2012; Megwara, *et al*., 2013, Anakwuba and Chinwuko, 2015, Abraham and Nkitnam, 2017). For this purpose, the basal depth of a magnetic source from aeromagnetic data is considered to be the Curie point depth (Kasidi and Nur, 2012). This depth can be approximated from aeromagnetic survey data through spectral analysis.

The aim of this paper is to review spectral analysis of aeromagnetic data interpretation. The objectives are; to review the impact of spectral analysis of aeromagnetic data interpretation in the field of geology and geophysics, to unveil the significant of aeromagnetic data interpretation in search for solid minerals, groundwater exploration, hydrocarbon and geothermal energy exploration.

Methods Involve in Spectral Analysis of Aeromagnetic Data Processing

The resolution of the magnetic data, incorporating the measured horizontal gradients, affords a range of processes that highlight the high-frequency responses. These are useful for accurately locating contacts, tracing horizons and delineating structure. Vertical derivatives, horizontal gradients, the analytic signal amplitude, tilt derivative and filter have all played a role in the

Vol.9 No.1, pp.1-11, 2022
ISSN 2055-009X(Print),
ISSN 2055-0103(Online)

interpretation, and contributed to semi-automated techniques for tracing contacts and anomaly peaks (Stephen,James, Paterson, Watson, Hernan, Ugalde, McMaster, Jacob and Olaniyan, 2010)

Horizontal gradient

In the spontaneous potential field, the horizontal gradient is an important parameter. During field surveys, because of the influence of regional background fields such as power networks, industry and civil buildings, topography, and geologic structure, anomalies of horizontal potential gradients produced by local geologic bodies tend to be shifted or masked. Therefore, the interpreted position of the geologic body is deviated from its true location. To remove such influence and highlight local anomalies, this work introduces the first-order difference method, which allows the separation of these anomalies from regional background fields, thus enhancing survey results (Du, Chen, Zhou and Cheng, 2010).

Vertical derivative filters

The vertical derivative is commonly applied to total magnetic field data to enhance the most shallow geological source and can be calculated either in space or frequency domain. The enhancement sharpens anomalies over bodies and tends to reduce anomaly complexity, allowing a clearer imaging of a causing structure. The transformation can be noisy since it will amplify short wavelength noise. First vertical derivative data have become almost a basic necessity in magnetic interpretation projects. The second vertical derivative has more resolving power than the first vertical derivatives (Milligan, 1999).

Downward continuation

Downward continuation is used to enhance features at a specified depth/elevation, lower than the acquisition level. This procedure accentuates near surface anomalies and can be used as an interpretation tool to determine the depth to a causative body. The filter can be applied to both gravity and magnetic data. Down-ward continuation is done using the expression (Geosoft Inc 1996)

Analytic signal

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. Two-dimensional bodies, a bell-shaped symmetrical function can be derived which maximizes exactly over the top of the magnetic contact. The three-dimensional case was derived in 1984 also by (Nabighian, 1984). This function is the amplitude of the analytical signal. The only assumptions made are uniform magnetization and that the cross section of all causative bodies can be represented by polygons of finite or infinite depth extent. This function and its derivatives are therefore independent of strike, dip, magnetic declination, inclination and remnant magnetism (Debeglia, 1997). The 3-D analytical signal, A, of a potential field anomaly can be defined (Nabighian, 1984).

Vol.9 No.1, pp.1-11, 2022
ISSN 2055-009X(Print),
ISSN 2055-0103(Online)

Tilt derivative analysis
The tilt derivative and its total horizontal derivative are useful for mapping shallow basement structures and mineral exploration targets (Geosoft Inc,1996) where VDR and THDR are first vertical and total horizontal derivatives, respectively, of the total magnetic intensity T.

Filters
The concept of filtering in any form of Data processing involves retention and / or enhancement of the desire position of the signal and eliminate or suppression of unwanted part. In aeromagnetic surveys, filtering is usually aimed at separating the deeper and shallower components in the data and sharpening the clarity with which these components can be observed by the interpreter. The two main classes of filter noted are high filter and low pass filter (David and Leigh, 2013). Higher pass filters are so aimed because they retain the higher frequency content in the data. Higher frequencies have shorter wavelengths: These in simple terms will have shorter straight slope distance; the high pass filters will emphases shallower sources in aeromagnetic data. Conversely, low pass filters retain low frequencies which have long wave lengths and therefore long straight slope distances which relate to deeper source (David and Leigh, 2013).

Spectral Analysis Method of Aeromagnetic Data Interpretation

Longuda Plateau and its environs Adamawa State North Eastern Nigeria
Kasidi and Ndatuwong (2008) acquired contoured aeromagnetic data over the Longuda Plateau, Guyuk area from the Geological Survey of Nigeria (GSN) as part of the Nigeria wide geological survey data. The data acquired were along a series of NE-SW with a flight line spacing of 2km, average flight elevation of 150m above terrain and a nominal tie line spacing of 20km. The geomagnetic gradient was removed using the International Geomagnetic Reference Field formula (IGRF). The map was published on the scale of 1:1000.

This average amplitude fully represents a spectrum form which the depth to magnetic sources can be estimated. (Kasidi and Ndatuwong, 2008) carried out spectral analysis, the area under study was divided into blocks of 16 x 16 data points; the essential part of an anomaly contains more than one maximum or minimum. The data for each block was subjected to 2-D Fourier transformation.

The average amplitude Spectrum all waves falling within a given frequency range was then computed by summing the Fourier amplitudes and dividing by the sum of the number of frequencies. These average amplitudes are then plotted against the frequency on a semi-log scale. Straight lines of best fits are drawn through the different segments of the spectrum. The depths to the magnetic source are related to the slopes of the lines segment by the relation.

Kasidi and Ndatuwong (2008) determined total intensity of magnetic field, depth to magnetics sources; from their findings, total magnetic field map was along NE-SW and E-W lineaments. NE-SW lineaments meets with Longuda basalts and that of E-W meets with Yola arm of Benue Trough. Two depths were discovered from the spectral analyses which are deeper depth and shallow depth to magnetic sources. The deeper depth ranges from 1900 m to 2620 m which is at the basement, and that of shallow depth is ranging from 512 m to 670 m magnetic sources

A Case History of Magnetic data processing for hydrocarbon exploration in the Pannonian Basin, Yugoslavia

In order to add value to the description of magnetic data processing, we present a case history (Milenko, Milinko and Vako, 2001) of Magnetic data processing for hydrocarbon exploration in the Pannonian Basin,Yugoslavia. Research of hydrocarbon exploration in the area was conducted through the interpretation of magnetic data acquired in the Southern part of the Pannonia Tertiary basin; the data was obtained within 1993 and 1997 with the help of magnetometer geophysical surveying instruments. The area covered was about 3700 km^2 in the Northern Yugoslavia. Aeromagnetic data have long been used by the petroleum industry to map structure in and to estimate depth to magnetic basement (Steenland, 1965). In the 1960 computers began to be used for processing and interpreting geophysical data. One application that became popular was estimation of depth to basement from potential field data, particularly aeromagnetic data (Spector and Grant, 1970). Most aeromagnetic surveys flown for petroleum exploration prior to 1992 were intended to map magnetic crystalline rocks that were known to be buried several kilometers below "non-magnetic" sedimentary rocks. Therefore, the surveys were flown at a ground clearance designed to eliminate or minimize signal from surface features and at line spacing adequate to sample any deep source adequately, which may be line spacing equal to one-half the depth to the sources (Reid, 1980).

Milenko *et al.* (2001) acquired the magnetic data and it was subjected to qualitative and quantitative interpretation for the purpose of isolating the weak signal of magnetic anomalies with 1-D digital filtering processing. The magnetic sources was isolated, it was observed that local magnetic anomalies was with the amplitude of ±10nT towards the east west direction parallel to the predominant structural grain.

The magnetic anomalies obtained were combined with 3-D seismic data; it shows that the filtered magnetic field was in line with the one obtained from the oil field. Hydrocarbon potential zones were identified through magnetic data processing.

DISCUSSION AND CONCLUSION

Aeromagnetic data interpretation method for locating solid minerals and hydrocarbon deposit has been employed in different part of the world over the years. This review paper shed more light on significant of the method of aeromagnetic data interpretation in the field of geology and geophysics. Two case studies were considered in this paper, spectral analysis play a vital role in the two case studies, the data of the first case study area was divided into 16 x16 data points; the data was subjected to 2D Fourier transformation. After the spectral analysis the depth to magnetic sources were discovered ranging from 1900 m to 2620 m at the basement and hallow depth was ranging from 512 m to 670 m magnetic sources. The second case study area was on magnetic data processing for hydrocarbon exploration in the Pannonian Basin,Yogoslavia, from the magnetic data analysis , hydrocarbon potential zones were identified.

Reference

Abraham, E.M., & Nkitnam, E.E. (2017). Review of Geothermal energy research in Nigeria. The Geoscience front. *International Journal of Earth Science and Geophysics,* 3, (15),1-10.

Adewumi & Salako.(2018). Delineation of mineral potential zone using high resolution aeromagnetic data over part of Nasarawa State, North Central, Nigeria. *Egyptian Journal of Petroleum 27, 759-767*

Ajakaiye, D E., Hall, D H., Miller, T. W., Verherjen, P. J.T., Awad, M.B., & Ojo, S B. (1986). Aeromagnetic anomalies and tectonic trends in and around the Benue Trough Nigeria. *Nature,* 319, 582-584

Aldana, M., Costanzo-Alvarez, V., & Diaz, M. (2003). Magnetic and mineralogical studies to characterise oil reservoirs in Venezuela. *The Leading Edge,*22 (6), 526

Adelusi A. O., Kayode J. S. and Akinlalu A. A. (2013). Interpretation of aeromagnetic anomalies and electrical resistivity mapping around Iwaraja area Southwestern Nigeria, *Journal of Geology and Mining Research,*5(2), 38-57

Anudu , G .K , Onuba ,L .N , Onwuemes ,A. G., & Ikpokonte, A. E (2012). Analysis of aeromagnetic data over Wamba and its adjoining areas in north-central Nigeria. Earth Sciences Research Journal, 16(1) , 25 – 33

Anakwuba, E. K., & Chinwuko, A. I.(2015). One dimensional spectral analysis and curie depth isotherm of eastern Chad Basin, Nigeria. *Journal of Natural Sciences Research,*5(1),14-22.

Cornford, C. (1990). Source rocks and hydrocarbons of the North Sea In Glennie, K W (ed) *Petroleum Geology of the North Sea Basic Concepts and Recent Advances Blackwell Science, Oxford,* 376-462

Costanzo-Alvarez, V., Aldana, M., Aristeguieta, O., Marcano, M C., & Aconcha, E. (2000). Study of magnetic contrasts in the Guafita oil field (South-western Venezuela) Physics and Chemistry of the Earth, Part A: *Solid Earth and Geodesy,*25(5), 437- 445.

Cordell, L., & Grauch, V.J.S. (1985). Mapping basement magnetization zones from aero-magnetic data in the San Juan Basin, New Mexico, in: Hinze, W.J. (Ed.), *The Utility of Regional and Magnetic Maps: Society of Exploration Geophysicists,* 181–197.

Cooper, G.R.J. (2003). Feature detection using sun shading. *Computer Geoscience,* 29 (8), 941–948.

Cooper, G.R.J., & Cowan, D.R. (2008). Edge enhancement of potential-field data neither using normalized statistics. *Geophysics,* 73 (3), H1–H4.

Core,D., Buckingham, A., & Belfield, S. (2009). Detailed structural analysis of magnetic datadone quickly and objectively, SGEG Newsletter.

David, J.I., & Leigh, R,R. (2013). Geological interpretation of aeromagnetic data.*The Australian Society of Exploration Geophysicist.*

Debeglia N., & Corpel J. (1997). Automatic 3-D interpretation of potential field data using analytic signal derivatives, *Geophysics,* 62 (1), 87–96.

Dow, W.G.(1978). Petroleum source beds on continental slopes and rises (2) *American Association of Petroleum Geologists (AAPG) Bulletin 62*

Du, C., Chen.Y., Zhou.Y & Cheng. B. (2020). Application of a mathematical method in geophysics: Separating anomalies of horizontal gradients of the spontaneous potential field based on first-order difference. *Journal of Applied Geophysics*, 176, Article 104009.

GETECH.(2007). Advanced processing and interpretation of gravity and magnetic data GETECH Plc , Kitson House Elmete Hall Leeds, UK 27

Geosoft Inc., OASIS Montaj Version 4.0 User Guide. Geosoft Incorporated,Toronto, 1996.

Gleen,W.E., & Badgery ,R.A. (1998). High resolution aeromagnetic surveys for hydrocarbon exploration, *Canadian Journal of Exploration Geophysics* 34(1&2), 97-102

Gunn, P.J. (1997). Application of aeromagnetic surveys to sedimentary basin studies Australian Geological Society Organisation (AGSO).*Journal of Australian Geology and Geophysics,* 17(2), 133-144.

Gluyas, J., & Swarbrick, R. (2005). Petroleum Geoscience Blackwell Science, Oxford, 358

Holden, E.J., Dentith, M., & Kovesi, P. (2008). Towards the automatic analysis of regional aeromagnetic data to identify regions prospective for gold deposits. *Computer. Geosciece*.34, 1505–1513.

Hisarlis, Z.M.(1996). Determination of the curie point depths in Western Anatolia and related with the Geothermal Areas, PhD Thesis, Istanbul University, Turkey

Ikumbur, E.B., Chinwuko, A. I., Ogah,V. E., Akiishi ,M Usman A O., & Udoh,A. C. (2019). Curie-temperature depth and heat flow deduced from spectral analysis of aeromagnetic data over the southern Bida Basin, west-central Nigeria. *Scientific & Academic Publishing Geosciences*, 9 (2), 50-56.

Kasidi, S., & Nur, A. (2012). Curie depth Isotherm deduced from spectral analysis of magnetic data over Sarti and environs of North-eastern Nigeria, Scholarly *Journal of Biotechnology, 1, 49-56.*

Kasidi, S., & Ndatuwog , L.N. (2008). Spectral analysis of aeromagnetic over Longuda Plateau environs north eastern Nigeria. *Continental Journal earth science* 3, 28-32

Kearey, P., Brook, S. M., & Hill, I. (2002). Introduction to geophysical exploration 3rd Edition *Blackwell Scientific Publication, Oxford* 262

Macnae, J., (1995). Applications of geophysics for the detection and exploration of kim-berlites and lamproites. In: Griffin, W.L. (Ed.), Diamond Exploration into the 21st Century. *Journal of Geochemical Exploration*, 213–243.

Megwara, J.U., Udensi,E.E., Olasehinde, P.I., Daniyan, M.A., & Lawal, K.M. (2013). Geothermal and Radioactive heat studies of parts of Southern Bida basin, Nigeria and surrounding basement rocks, *International Journal of Basic and Applied Sciences,* 2(1), 125-139.

McGraw, H. (2003). Dictionary of geology and mineralogy (2nd ed.). United State of America: McGraw-Hill Companies

Moghaddam, M., Mohammad, S., Saeid, M., & Nasim, H. (2015). Interpretation of aeromagnetic data to locate buried faults in North of Zanjan Province, Iran. Journal of Remote Sensing & GIS, 4(2), 1 -5.

Miller, H.G., & Singh, V. (1994). Potential field tilt-a new concept for location of potential field sources. *Journal of Applied Geophysics*, 32, 213–217.

Milenko, B., Milinko .G., & Vako, Z. (2001). Magnetic data processing for hydrocarbon exploration in the Pannonian Basin , Yugoslavia. *Article in Geophysics,* 66 (6), 1669-1679

Milligan ,P.R., & Gunn , P.J. (1999). Enhancement and presentation of air borne geophysical data. AGSO *Journal Geology, Geophysics* 17 (2) 65-75.

Nabighian, M.N. (1984). Toward a three-dimensional automatic interpretation of potential field data via generalized Hilbert transforms – Fundamental relations, *Geophysics,* 49, 780–786.

Nwankwo, L.I., Olasehinde, P.I., Akoshie, C.O. (2011). Heat flow anomalies from the spectral analysis of airborne magnetic data of Nupe Basin, Nigeria, *Asian Journal of earth science* 1(1), 1-6.

Nur, M.A., Mosto O. K., & Charles, O. O. (1994).Spectral analysis of aeromagnetic data over the middle Benue trough, Nigeria. *Journal of Mining and Geology,* 30 (2), 211-217.

Oke, I.O., Adebayo, A., Adetona, T.A., & Sunday.O.A. (2018). Interpretation of high resolution aeromagnetic data to determine sedimentary thickness over part of Bida Basin, North Central Nigeria. *Journal of Geology and Mining Research,* 10(6),72-80.

Onyedim, G C ., Awoyemi, M.O., Ariyi, E. A., & Arubayi, J.B. (2006). Aeromagnetic imaging of the middle Benue Trough basement morphology in part of the Middle Benue Trough, *Nigeria Journal of Mining and Geology,* 42,(2),157-163.

Oladunjoye, M. A., Olayinka, A. I., Alaba, M., & Adabanija, M. A. (2016). Interpretation of highresolution aeromagnetic data for lineaments study and occurence of banded iron formation in Ogbomoso area, Southwestern Nigeria. *Journal of African Earth Sciences,* 43-53.

Olasehinde, P. I., Pal, P C & Annor, A. E. (1990). Aeromagnetic anomalies and structural lineament in the Nigerian Basement Complex Journal of African Earth Sciences, 11 (3-4),351-355

Olasunkanmi ,N.K , Sunmonu ,L. A., Adabanija M. A, & Oladejo, O. P. (2018). Interpretation of high resolution aeromagnetic data for mineral prospect in Igbeti-Moro area, southwestern Nigeria. *IOP Conference Series: Earth and Environmental Science* 173 012033

Paoletti, V., Gruber, S., Varley, N., D’Antonio, M., Supper, R., & Motschka, K. (2016). Insights into the structure and surface geology of Isla Socorro, Mexico from airborne magnetic and gamma-ray surveys. Surveys in Geophysics, 37, 601–623. doi:10.1007/s10712-015-9352-0

Paoletti, V., Supper, R., Chiappini, M., Fedi, M., Florio, G., & Rapolla, A. (2005). Aeromagnetic survey of the Somma-Vesuvius volcanic area. *Annals of Geophysics,* 48(2), 199–213

Paterson, N. R., & Reeves, C. V. (1985). Applications of gravity and magnetic surveys: *the state of the art in Geophysics.*

Richard, A. M. (2001). Dictionary of geophysics, astrophysics and astronomy. Boca Raton London New York Washington, D.C.: CRC Press.

Reid. A.B (1980). Short note. Aeromagnetic survey design, *Geophysics* 45(5) 973-976

Spector.A., & Grant.F,S.(1990). Statistical models for Interpreting aeromagnetic data, Geophysics 35(2) 293-302

Stephen,W.R.,James, D., Misener, P., G., Watson, L., Hernan. A. U., McMaster U., Jacob. S. G., & Olaniyan.O,(2010). Nigeria's nationwide high airborne geophysical survey. Nigerian Geological Survey Agency. *Conference Paper* DOI: 10.3997/2214-4609.20149924.

Steenland, N.C. (1965). Oil fields and acromagnetic anomalies. Geophysics. 30(5), 239.

Wijns, C., Perez,C., & Kowalczyk, P. (2005). Theta map: edge detection in magnetic data. Geophysics 70 (4), 39–43.