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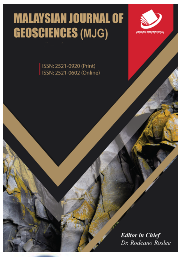

DERIVATIVES AND ANALYTIC SIGNALS: Improved Techniques for Lithostructural Classification.

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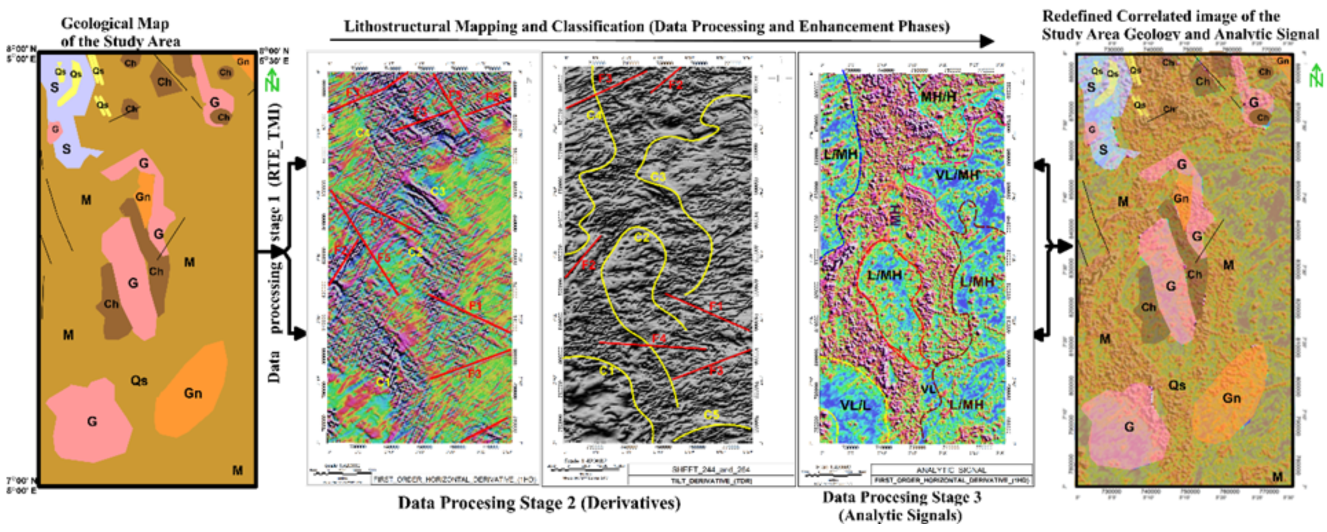
ABSTRACT

In this study, magnetic derivatives and Analytic Signal (AS) techniques were employed to reveal the nature of rocks and lithostructural relationships that exist within the basement complexes around Ekiti and Ondo States. The derivatives techniques were used to enhance the Reduction to Equator Total Magnetic Intensity (RTE_TMI) data. In order to make the results from derivatives techniques worthwhile and robust, Analytic Signal (AS) technique was then applied. The results of the derivatives and analytic signals revealed seven different lithological suites, namely: migmatite (M), migmatite/granite-gneiss (M/Gn), gneiss and granite (Gn/G), schist and quartzite schist (S/Qs), granite-gneiss and charnockite (Gn/Ch), charnockite and granite (Ch/G), and granite (G) with their respective edges and trends. Five different major lineaments/faults and lithological contacts were also identified. The lineaments/faults were classified as F1, F2, F3, F4 and F5 with NW-SE, NNE-SSW, NE-SW, E-W and NNW-SSE trends respectively. While lithological contacts were classified into C1, C2, C3, C4 and C5 as contact of migmatite and granite, migmatite and granite-gneiss/charnockite/granite, migmatite and gneiss/granite, migmatite and schist/quartzite schist, and migmatite and gneiss respectively. It is evident from the study that migmatites and gneisses which form the basement in the area have been highly deformed and evince many intrusives. A detailed correlation image of the study area geology and analytic signal is produced as deduced from the results analyses.



KEYWORDS

Derivatives, Analytic Signal (AS), Lithological Suites, Structures, Contacts.

1.0 INTRODUCTION

The essential aspect of magnetic data processing is to simplify the complexity of derived information by removing the effects of data artifacts and obscured signals emanating from background noises, shallower and deeper crustal bodies and structures. The derived information is usually enhanced by using relevant techniques that can identify and map lithologies, structures, trends, and contacts among others after necessary reduction processes had been applied.

Derivatives and analytic signal (AS) are improved enhancement techniques and have been adopted by quite number of authors for lithostructural purposes, such as mapping of fractures (lineaments, faults and joints), trends, geological contacts, etc.

The significance of fractional order derivatives (horizontal and vertical) in locating the position of Cordell and Grauch [1]; Cooper et al [2]; Okpoli and Akingboye [3]. These techniques enhance shallow wavelength features that are results of near surface structures obscured by stronger effects of broader regional features. Recently, much interest has been shown in the use of derivatives of fractional order, enabling an optimum balance between feature enhancement and noise. The first vertical derivative is used instead of the second vertical derivative because it suppresses noisy data [4, 5].

According to Salem et al [6] and Okpoli and Akingboye [7], tilt derivatives is an enhancement technique used to determine structures (lineaments, faults and joints), contacts and edges or boundaries of magnetic sources, and to enhance both weak and strong magnetic anomalies of the area by placing an anomaly directly over its source. Okpoli and Akingboye [7] used tilt derivative to map different structural features and contacts in three quarry sites in Ondo State [7].

On the other hand, Analytic Signal (AS) centers the peak of magnetising bodies symmetrically over their sources through transformation of the shapes of inclined magnetising bodies. Ansari and Alamdar [8] showed that analytic signal is formed through the combination of the horizontal and vertical gradients of the magnetic anomaly and it is applied either in space or frequency domain to generate a maximum directly over discrete bodies as well as their edges [8]. This improved technique have been applied to detect the edge, depth estimation of magnetic bodies and to detect the structures responsible for the observed magnetic anomalies over an area [9-13].

Analytic signal images are useful as a type of reduction to the pole in low magnetic latitude areas where inclination is less than 15^0, as they are not subjected to the instability that occurs in transformations of magnetic fields from low magnetic latitudes [14].

Therefore, this present study discusses the use of first order horizontal and vertical derivatives, tilt derivative and analytic signal for litho-structural classification of the basement complex rocks of parts of Ekiti and Ondo States, in order to reveal the litho-structural features, trends and anomalous zones, as well as to produce a detailed correlation map to evince the relationship between the earlier geological map and analytic signal of the study area.

2.0 LOCATION AND GEOLOGIC SETTING

The study area is located around Ekiti and Ondo States, Nigeria. The aeromagnetic knitted sheet (244 and 264) used for this study falls within Latitude 7^0 00' - 8^0 00' N (770000 - 885000 mN) and Longitude 5^0 00' - 5^0 30' E (720000 – 777500 mE) of Zone 31N Greenwich Mercator (Figures 1 and 2).

The study area is underlain by rocks of the Precambrian Basement Complex of Southwestern Nigeria. The rock types found in the area include: migmatite-gneiss, schist with minor phyllite, quartzite, charnockite, granite and other minor felsic and mafic intrusives such as dyke, sill and vein of dolerite, aplite and pegmatites (Figure 1) [15-18].

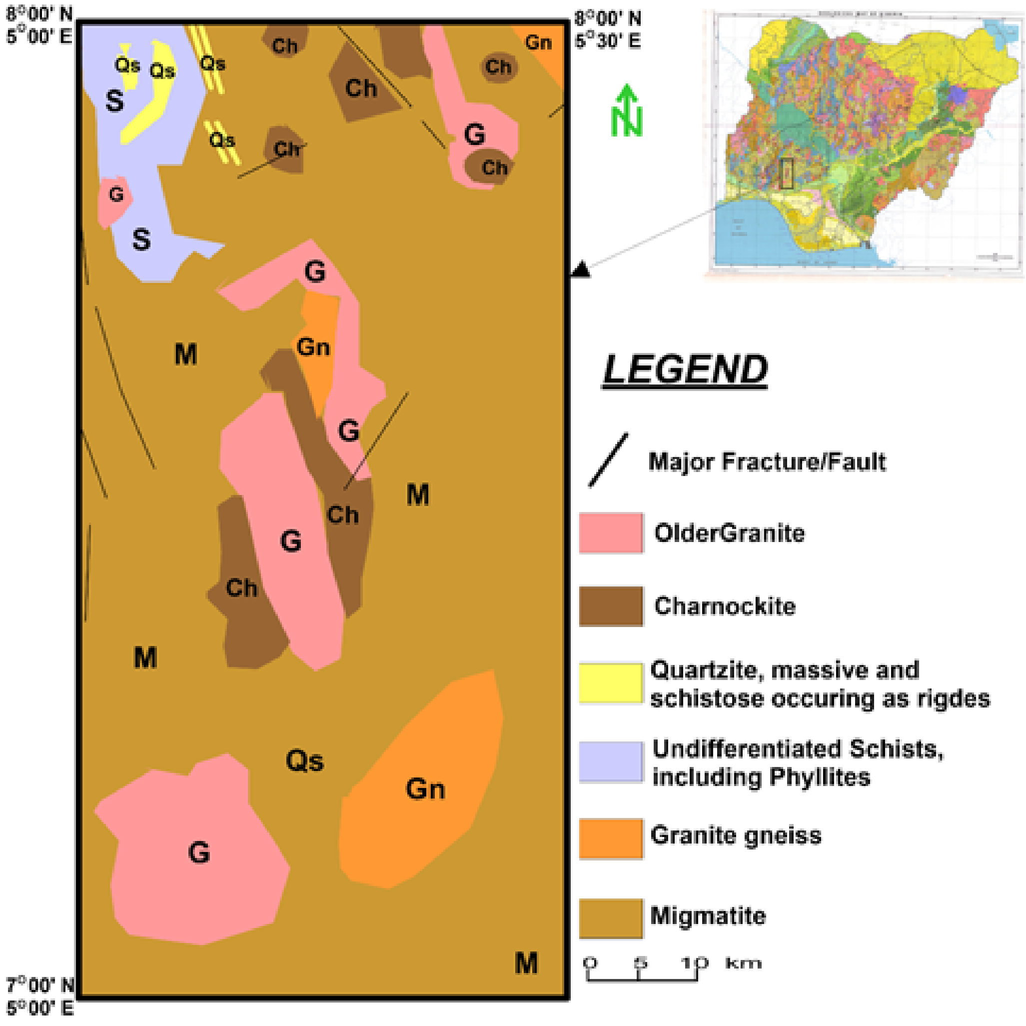


Figure 1: Geological Map of the Study Area (Created from Geological Map of Nigeria, [19])

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3.0 MATERIAL AND METHODS

Aeromagnetic data of Sheet 244 and 264 for Ado-Ekiti and Akure respectively were acquired from Nigerian Geological Survey Agency (NGSA). The aero-sheets were knitted and processed using Geosoft® Oasis Montaj™ software, but other software like Surfer was also used for this work.

The data processing phase involved reductions and enhancements done by using the MAGMAP Step-By-Step Filtering. The removal of near surface noise (NSN) and reduction to magnetic equator of the total magnetic intensity gridded data were performed to accentuate intensities signals and center the anomalous bodies and structures over their sources to give an output of RTE_TMI grid. Thereafter, RTE_TMI data enhancement in First Order Derivative in X (horizontal) and Z (vertical) directions were performed to produce the first order derivative in horizontal (1HD) and vertical (1VD) respectively. The tilt derivatives (TDR) of RTE_TMI and analytic signal (AS) of RTE_TMI, 1HD and 1VD were later produced sequentially.

4.0 RESULTS AND DISCUSSION

4.1 Reduction to Equator Total Magnetic Intensity (RTE_TMI)

The RTE-TMI image (Figure 2) is produced to center the peaks of magnetic anomalies over their sources depending on the inclination and declination of the local field of the magnetizing body, as this would enable proper mapping and delineating of inclined and other aligned form of structures.

On comparison, Figure 3 evinces the litho-structural similarities between RTE_TMI image and geological map. It is evident that the highly deformed rocks in the area correspond to the Migmatite-Gneiss Complex with evidences of both positive and negative intensity values that ranged from 13.50 – 162.04 nT and -63.04 to -12.13 nT respectively. These anomaly differences envisaged by the rocks are associated with ferromagnesian minerals that often give rise to very high magnetic intensity and intense degree of metamorphism and deformities that produce low and negative intensity values. The RTE_TMI image also show some of the major lineaments/faults and trend as seen in Figure 1.

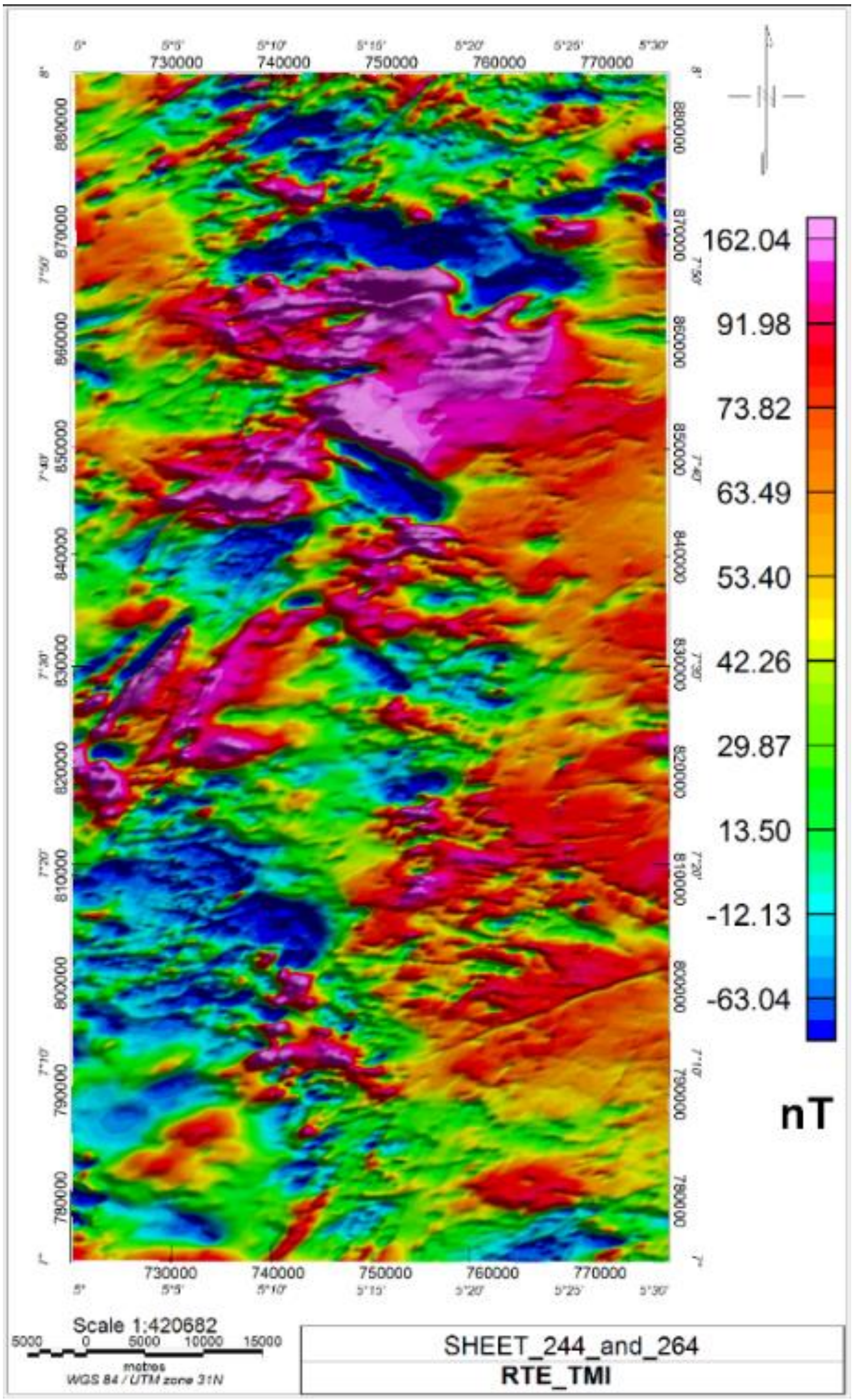


Figure 2: Colour Shaded Reduction to Equator Total Magnetic Intensity (RTE_TMI) Image

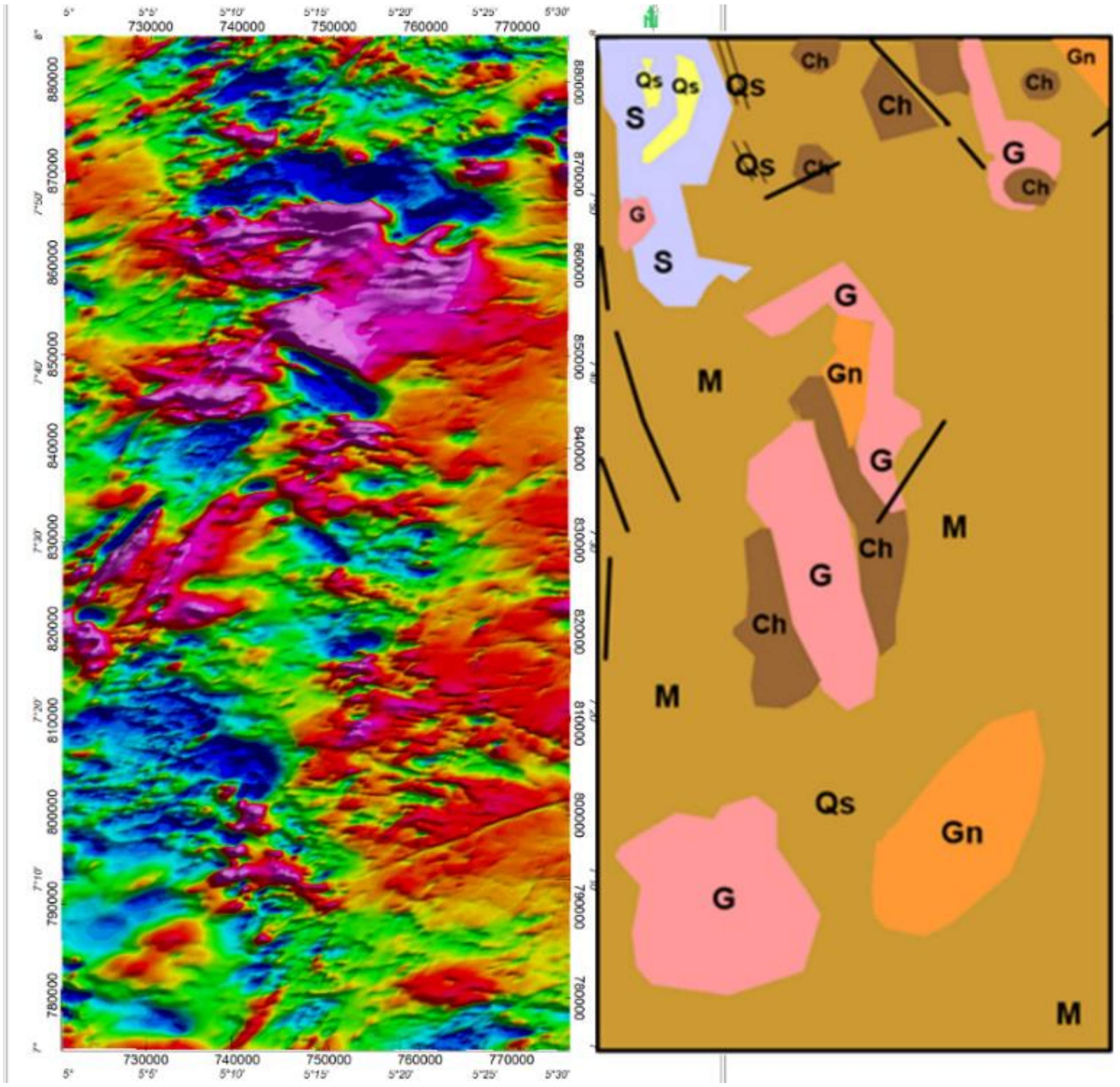


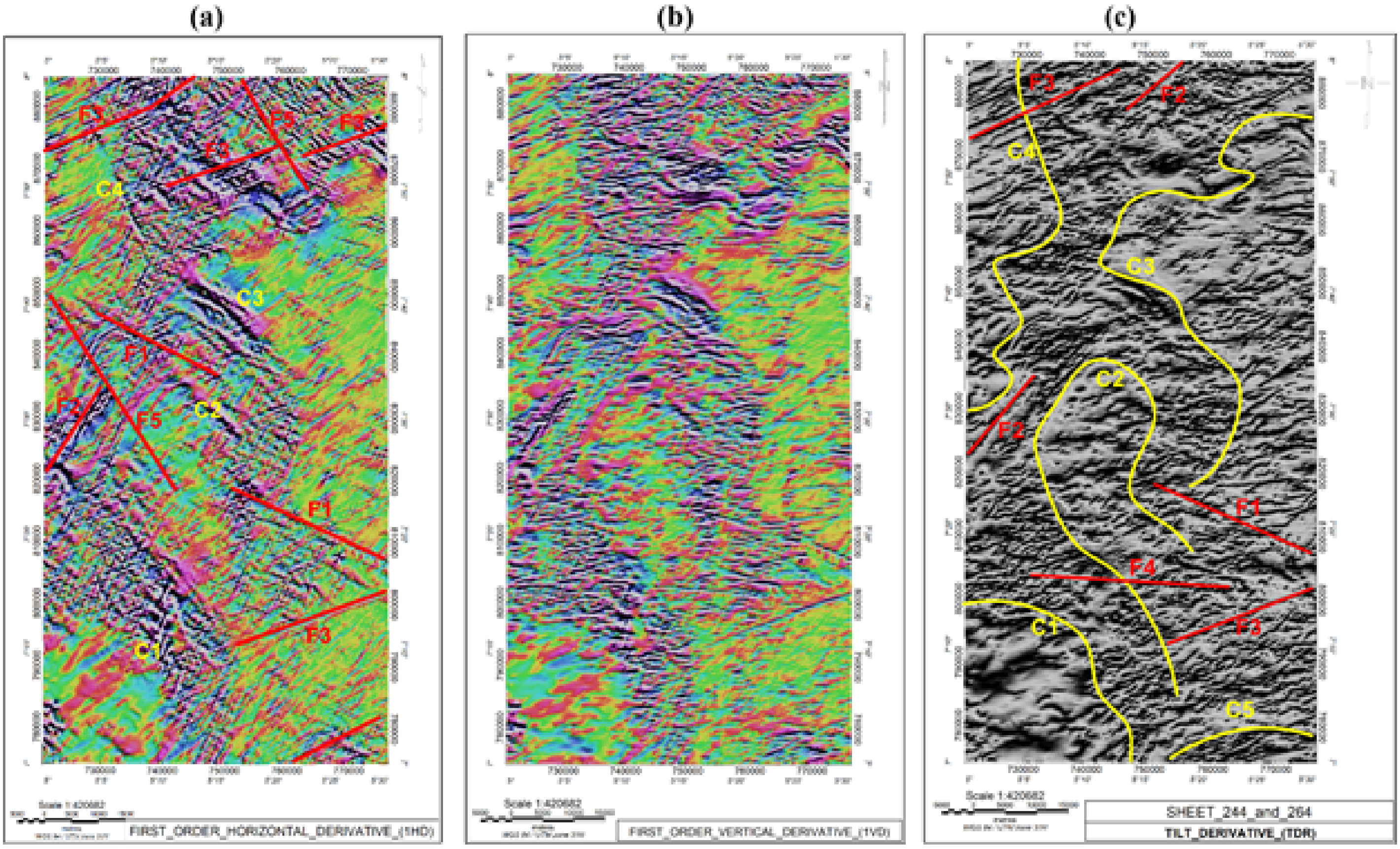
Figure 3: Comparing the RTE_TMI Image with Geological Map of the Study Are

4.2 Derivatives: First Horizontal (1HD), First Vertical (1VD) and Tilt (TDR)

The derivative in both x (horizontal) and z (vertical) directions sharpen the edges of magnetic anomalies, gives clearer contrast between the geologic units and causative structures such as lineaments/faults joints, etc. The first horizontal and vertical derivatives were applied on the RTE_TMI gridded data to enhance shallow wavelength features, that are results of near surface structures obscured by stronger effects of broader regional features and suppresses the long wavelengths (deeper sources/ regional features) thereby provide a better and clearer picture of the subsurface. The tilt derivative (TDR) other the hand performs similar functions by accentuating structural deformations such as faults, joints, and arched zones or even geological contacts. The techniques were used to map and delineate both minor and major structures (lineaments/ faults, joints, etc) in the area, and classify them base on their trends, occurrences and tectonic frameworks.

Figures 4 (a-c) show the derivative images for First Horizontal Derivative (1HD_RTE_TMI), First Vertical Derivative (1VD_RTE_TMI) and Tilt Derivative (TDR_RTE_TMI) respectively. 1HD_RTE_TMI (Figure 4a) shows the major lineaments/faults and even contacts between rocks with better clarity than 1VD_RTE_TMI (Figure 4b), but 1VD does it better for trends identification because it has suppressed the interfering horizontal wavelengths to a better range. While the TDR_RTE_TMI (Figure 4c) reveals its ability in lithological, structural, and contacts classifications.

The derivatives images (Figures 4 a – c) reveal five (5) different lineaments/faults (F), lithological contacts (C) and four (4) types. The lineaments/faults are delineated and classified as F1, F2, F3, F4 and F5 with NW-SE, NNE-SSW, NE-SW, E-W (less) and NNW-SSE trends respectively. Comparing Figure 4a with Figure 1, it is evident that F5 is a fault with two major displacements along F3 as seen at the northeastern section of both images. While geological contacts are classified into C1, C2, C3, C4 and C5 as contact of migmatite and granite, migmatite and gneiss/charnockite/granite, migmatite and gneiss/granite, migmatite and schist/quartzite schist, and migmatite and gneiss respectively. These are relatively sharp contacts and not interpretive/inferred boundaries, they give a distinctive boundary amongst the rocks in the area.



Figures 4:(a) First Horizontal Derivative (1HD_RTE_TMI), (b) First Vertical Derivative (1HD_RTE_TMI), and (c) Tilt Derivative (TDR_ RTE_TMI).

**C (1-5)-Contacts, F (1-5)-Lineaments/Faults.*

4.3 Analytic Signal (AS) of RTE_TMI, 1HD_RTE_TMI and 1VD_RTE_TMI

The analytic signal (AS) centers the peak of the magnetising bodies symmetrically over their sources through transformation of the shapes of inclined magnetising bodies by relying on the magnetisation strength and direction of geologic strike with respect to the magnetisation vector, thereby making the interpretation of analytic signal amplitude easier to deal with than in the original total field data or reduction to pole. Hence, this technique shows the amplitude strength of respective litho-structural features based on their magnetisation contrast [14, 20] as the major driving ability that enables easy mapping and for litho-structural classification.

Figures 5 a – c show the analytic signal (AS) results generated for RTE_TMI and respective derivatives data. Analytic signal of RTE_TMI (AS_RTE_TMI) (Figure 5a) was used for delineating the edges and trends of the migmatitic rocks based on its high amplitude signal probably due to its high magnetisation generated by sources rich in ferromagnesian-bearing minerals. It is evident from the image that the migmatite complex covers relatively large portion of the study area with a regional trend of NW-SE and NS to some extent

The analytic signal of the first order horizontal derivative of RTE_TMI (AS_1HD) (Figure 5b) was used to map and delineate other lithological trends and contacts in the area. While analytic signal of first order vertical derivative of RTE_TMI (AS_1VD) (Figure 5c) was used to map and classify the structures in the area. The AS_1VD reveals some lineaments/faults that were not mapped on the derivatives images. Note that Figures 5a and 5b can be used for such structural classification, but Figure 5c is chosen in order to reduce congestion of annotations on the other two images. The images also reveal that most of the complexes have intrusives and inclusions seen as trends of high and low amplitude variations.

Different range of amplitude signals were revealed on the analytic signal images (Figures 5 a – c), due to varying magnetisation strength evinced by various rock types. Based on the amplitude strength of these magnetizing bodies [20, 21], and study area geology [16, 19], the following classifications were made:

i. very high analytic signals; classified as edges and trends of the migmatite (M) complexes. However, some sections of the images reveal varying amplitude signals due probably to varying strength of the magnetising bodies

ii. moderately high to high analytic signals; classified as magnetisation responses from rock bodies like migmatite/ gneisses (M/Gn), charnockite (Ch) and granite (G) (around Ikole and within the schists) and granite-gneiss (extreme end of Ikole-Ekiti). However, low amplitude signals are seen along some axis of the images

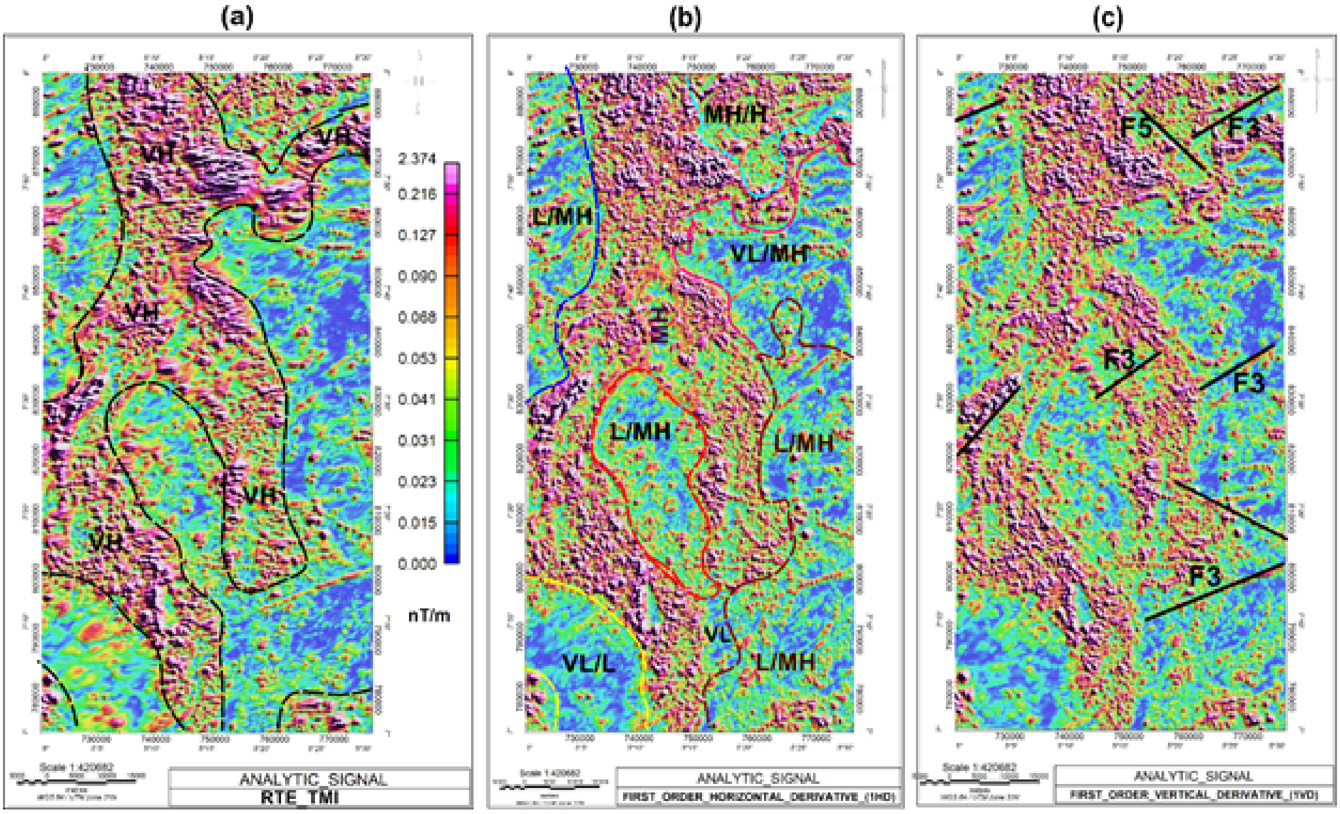
iii. very low to low analytic signals; classified as rocks with low magnetising strength such as some schist (S) and quartzite (Q).

Structural trends in NW-SE, NE-SW, and NNW-SSE as seen in the study area were also identified based on their signals and classified as:

i. high analytic signal trends as basic intrusives like doleritic dyke, sill, and vein.

ii. very low analytic signal trends as felsic intrusives and veins of quartz, pegmatite and aplite.

Some of the delineated structures - lineaments/faults trends in NW-SE, NE-SW, and NNW-SSE. These structures and trends are similar to those identified in Figures 4



Figures 5: Analytic Signal Images; (a) AS_RTE_TMI, (b) AS_1HD, and (c) AS_1VD.

**VH-Very high, MH/H-Moderately high to high, MH-Moderately high, L/MH-Low to moderately high, VL/L-Very low to low Analytic Signals*

The correlation of geological and analytic signal image for the study area is shown in Figure 6. This proposed correlation image reveals the litho-structural features such as lineaments/faults, contacts, and lithological trends that were not shown in Figure 1 (Study area geology). Some of these features in Figure 1 were not mapped due to some reasons like soil and vegetation cover, etc. The rocks in the study area reveal varying signal strength that differs from one area to another, which could likely be attributed to varying magnetisation strength of different sources and mineralogical compositions. This variation also led to complexity in grouping the granite-gneissic and granitic rocks to having relatively similar amplitude strengths

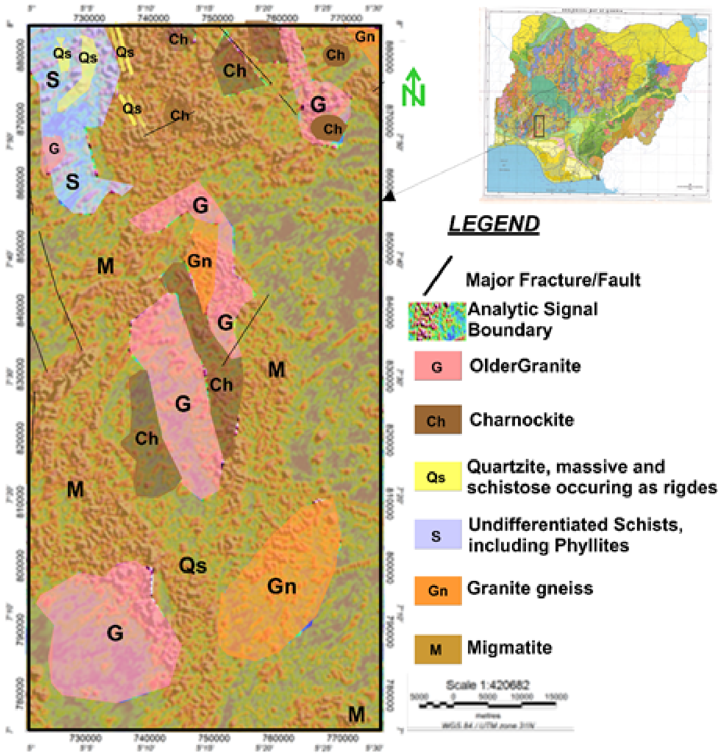


Figure 6: Correlation Image of the Study Area Geology and Analytic Signal.

The inferred summary of the lithostructural relationshipof major lineaments/faults, trends, and lithological contacts of the study area as deduced from derivatives and analytic signals results for quick and better understanding is shown in Table 1.

Table 1: Summary of Litho-structural Classification for the Study Area

S/N	Rock Type / Complex	Lineament/ Fault Type	Structural/ Lithological trend	Contact	Analytic Signal (Interpretation)
1	Granite (G)	---	NW-SE	C1	low to moderately high; depending on the variation of felsic/basic mineral compositions within the magnetising bodies
2	Charnockite / Granite (Ch/G)	F4; F5	E-W; NNW-SSE	C2	Charnockite (moderately high to high) while Granite is low to moderately low
3	Granite-gneiss / granite (Gn/G)	F2	NNE-SSW	C3	low to moderately high, depending on the variation in mineralogical compositions of the magnetising bodies
4	Granite-gneiss / Charnockite (Gn/Ch)	F2; F3; F	NNE-SSW; NE-SW; NNW-SSE	C3	moderately high to high
5	Schist (with minor phyllite) schist (S/Qs) and Quartzite	F1; F3; F5	NW-SE; NE-SW; NNW-SSE	C4	low to moderately high for schist and quartzite (probably due to sources with low magnetisation peaks due to felsic minerals)
6	Migmatite/Gneiss (M/Gn)	F1; F3; F4	NW-SE; NE-SW; E-W	C3 and C5	moderately high to high; variations in signals of migmatitic and gneissic rocks are evidence of different peaks of magnetising bodies.
7	Migmatite (M)	All present	Possess all the trends. It showsa regional trend of NW-SE and approximately NS directions	shared contact with all rock types	very high (due to high magnetisation from sources rich in ferromagnesian-bearing minerals). Although, some sections show varying amplitude signal probably due to varying strength of magnetising bodies

**F1, F2, F3, F4 and F5 indicate NW-SE, NNE-SSW, NE-SW, E-W (less) and NNW-SSE trends respectively. While C1, C2, C3, C4 and C5 as contact of migmatite and granite, migmatite and granite-gneiss/charnockite/granite, migmatite and gneiss/granite, migmatite and schist/quartzite schist, and migmatite and gneiss respectively*

5.0 CONLUSION

In this study, the lithostructural relationship that exist within the basement complexes around Ekiti and Ondo States revealed the following:

1. Seven litho-structural suites that include migmatite (M), migmatite/granite-gneiss (M/Gn), gneiss and granite (Gn/G), schist and quartzite schist (S/Qs), granite-gneiss and charnockite (Gn/Ch), charnockite and granite (Ch/G), and granite (G)
2. Five lineaments/faults, classified as F1, F2, F3, F4 and F5 with NW-SE, NNE-SSW, NE-SW, E-W (less) and NNW-SSE trends respectively
3. Five contacts (C 1 – 5); as contact for migmatite and granite, migmatite and granite-gneiss/charnockite/granite, migmatite and gneiss/granite, migmatite and schist/quartzite schist, and migmatite and gneiss respectively. The contacts further reveal the exact extension of the rocks in the subsurface (i.e. below the overburden) compared to limited range of the interpretive/inferred boundaries used for the surface mapping
4. The correlated geological and analytic signal image clearly reveals the litho-structural features such as lithological trends, lineaments/faults, trends, arched structures, contacts and amplitude strengths of respective rocks
5. Intrusives and inclusions seen as trends of high and low intensities

Furthermore, it is evident from this study that the Migmatite-gneiss complex of the area have been highly deformed and extensively intruded compared to other complexes as a result of pronounced faulting, shearing, jointing and other geological processes.

The images, lithostructural classifications and detailed discussion of the results for this study have shown the worthiness and abilities of these improved techniques as tools for regional litho-structural charaterisation.. Further ground truth is suggested, in order to map out and give details of the various rocks within the migmatite suite, as well as litho-structures and contacts that were revealed by various images produced for this work.

REFERENCES

[1] Cordell, L., Grauch, V.J.S. 1985. Mapping basement magnetization zones from aeromagnetic data in the San Juan basin, New Mexico. In: HINZE WJ, eds. The Utility of Regional Gravity and Magnetic Anomaly Maps. Society of Exploration Geophysicists, 181-197.

[2] Cooper, G.R.J., Cowan, D.R. 2004. Filtering using variable order vertical derivatives. Computers and Geosciences, 30 (5), 455–459.

[3] Okpoli, C., Akingboye, A. 2016a. Reconstruction and appraisal of Akunu–Akoko area iron ore deposits using geological and magnetic approaches. RMZ – Materials and Geoenvironment (Materiali in geookolje), 63 (1), 19-38.

[4] Gunn, P.J., FitzGerald, D., Yassi, N., Dart, P. 1997. New algorithms for visually enhancing airborne geophysical data. Exploration Geophysics, 28 (1-2), 220–224.

[5] Cooper, J.R.G., Cowan, D.R. 2003. The application of fractional calculus to potential field data. Exploration Geophysics, 34 (4), 51–56.

[6] Salem, A., Williams, S., Fairhead, J., Ravat, D., Smith, R. 2007. Tilt-depth method: a simple depth estimation method using first-order magnetic derivatives. The Leading Edge, 26 (12), 1502-1505.

[7] Okpoli, C.C., Akingboye, A.S. 2016b. Magnetic, radiometric and geochemical survey of quarry sites in Ondo State, Southwestern Nigeria. International Basic and Applied Research Journal, 2 (8), 16-30.

[8] Ansari, A.H., Alamdar, K. 2009. Reduction to the Pole of Magnetic Anomalies Using Analytic Signal. World Applied Sciences Journal, 7 (4), 405-409.

[9] Nabighian, M.N. 1972. The analytic signal of two-dimensional magnetic bodies with polygonal cross-section: its properties and use for automated anomaly interpretation. Geophysics, 37 (3), 501–517.

[10] Nabighian, M.N. 1984. Toward a three-dimensional automatic interpretation of potential field data via generalized Hilbert transforms: fundamental relations. Geophysics, 49 (6), 780-786.

[11] Roest, W.R., Verhoef, J., Pilkington, M. 1992. Magnetic interpretation using the 3D analytic signal. Geophysics, 57 (1), 116-125.

[12] Hsu, S., Sibuet, J.C., Shyu, C. 1996. High-resolution detection of geologic boundaries from potential field anomalies: An enhanced analytic signal technique. Geophysics, 61 (2), 373-386.

[13] Hsu, S., Sibuet, J.C., Shyu, C. 1998. Depth to magnetic source using the generalized analytic signal. Geophysics, 63 (6), 1947-1957.

[14] MacLeod, I.N., Jones, K., Dai, T.F. 1993. 3-D analytic signal in the interpretation of total magnetic field data at low magnetic latitudes. Exploration Geophysics, 24 (3-4), 679-688.

[15] Rahaman, M.A. 1988. Recent Advances in the Study of the Basement Complex of Nigeria. In: Oluyide, P.O., Mbonu, W.C., Ogezi, A.E.O., Egbuniwe, I.G., Ajibade, A.C., Umeji, A.C. eds. Precambrian Geology of Nigeria. Geological Survey of Nigeria, Kaduna, 11–43.

[16] Ademilua, O.L. 1997. A Geoelectric and Geologic Evaluation of Groundwater Potential of Ekiti and Ondo States, Southwestern Nigeria [M.Sc. Dissertation]. Department of Geology, Obafemi Awolowo University, Ile-Ife, Nigeria, 1-67.

[17] Oyinloye, A.O. 2011. Geology and Geotectonic Setting of the Basement Complex Rocks in Southwestern Nigeria: implications on Provenance and Evolution. Earth and Environment Science, 98 – 117.

[18] Ayodele, O.S. 2013. Geology and Structure of the Precambrian Rocks in Iworoko, Are, and Afao Area, Southwestern, Nigeria. International Research Journal of Natural Sciences, 1 (1), 14 – 29.

[19] Geological Map of Nigeria. 2004. Nigerian Geological Survey Agency (NGSA), Garki, Abuja.

[20] Macleod, I. A., Vieira, S., Chaves, A. C. 1993. Analytic Signal and Reduction-to the-Pole in the interpretation of Total Magnetic Field Data at Low Magnetic Latitudes.3rd Conference of the Brazillian Geophysical Society. pp. 831-835

[21] Telford, W.M., Geldart, L.P., Sheriff, R.E., Keys, D.A. 1990. Applied Geophysics. 2nd ed. Cambridge University Press.