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DERIVATIVES AND ANALYTIC SIGNALS: Improved Techniques for Lithostructural Classification.

Akingboye A. Sunny

Department of Earth Sciences, Adekunle Ajasin University, Akungba-Akoko, PMB 001, Ondo State, Nigeria.
****Corresponding Author's E-mail: adedibu.akingboye@aaua.edu.ng***

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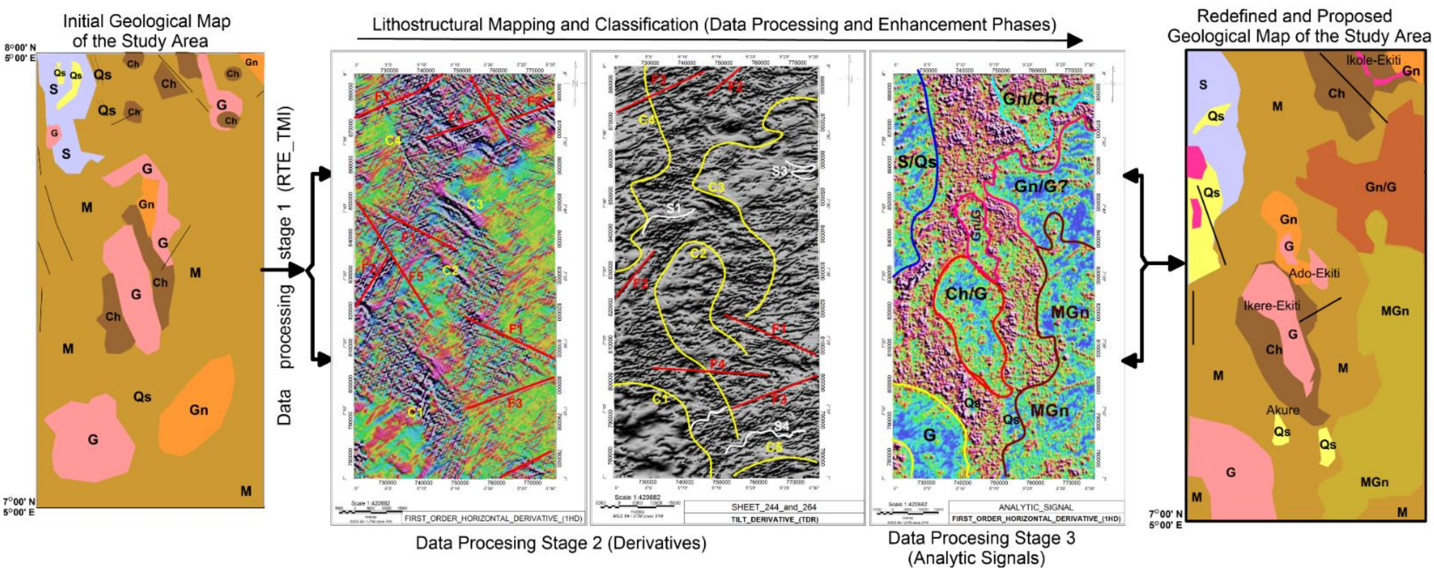
ABSTRACT

In this study, 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-gneiss (MGn), 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). Five different major lineaments/faults, folds 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. Folds were classified into S1, S2, S3, S4 and S5 as symmetrical, asymmetrical, recumbent, ptygmatic and drag folds respectively. While lithological contacts were classified into C1, C2, C3, C4 and C5 as sharp 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 geological map for the study area is proposed as deduced from 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), folds and geological contacts.

The significance of fractional order derivatives (horizontal and vertical) in locating the position of the magnetization boundaries were given in the work of a group researchers [1-3]. 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 some studies, tilt derivatives is an enhancement technique used to determine structures (faults and folds), 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 [6, 7]. Okpoli and Akingboye 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. Some researcher 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 lithostructural classification of the basement complex rocks of parts of Ekiti and Ondo States, in order to reveal the surface and subsurface rock types, structures, trends and anomalous zones, as well as to produce a detailed geological map as an update to the earlier geological map used for 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].

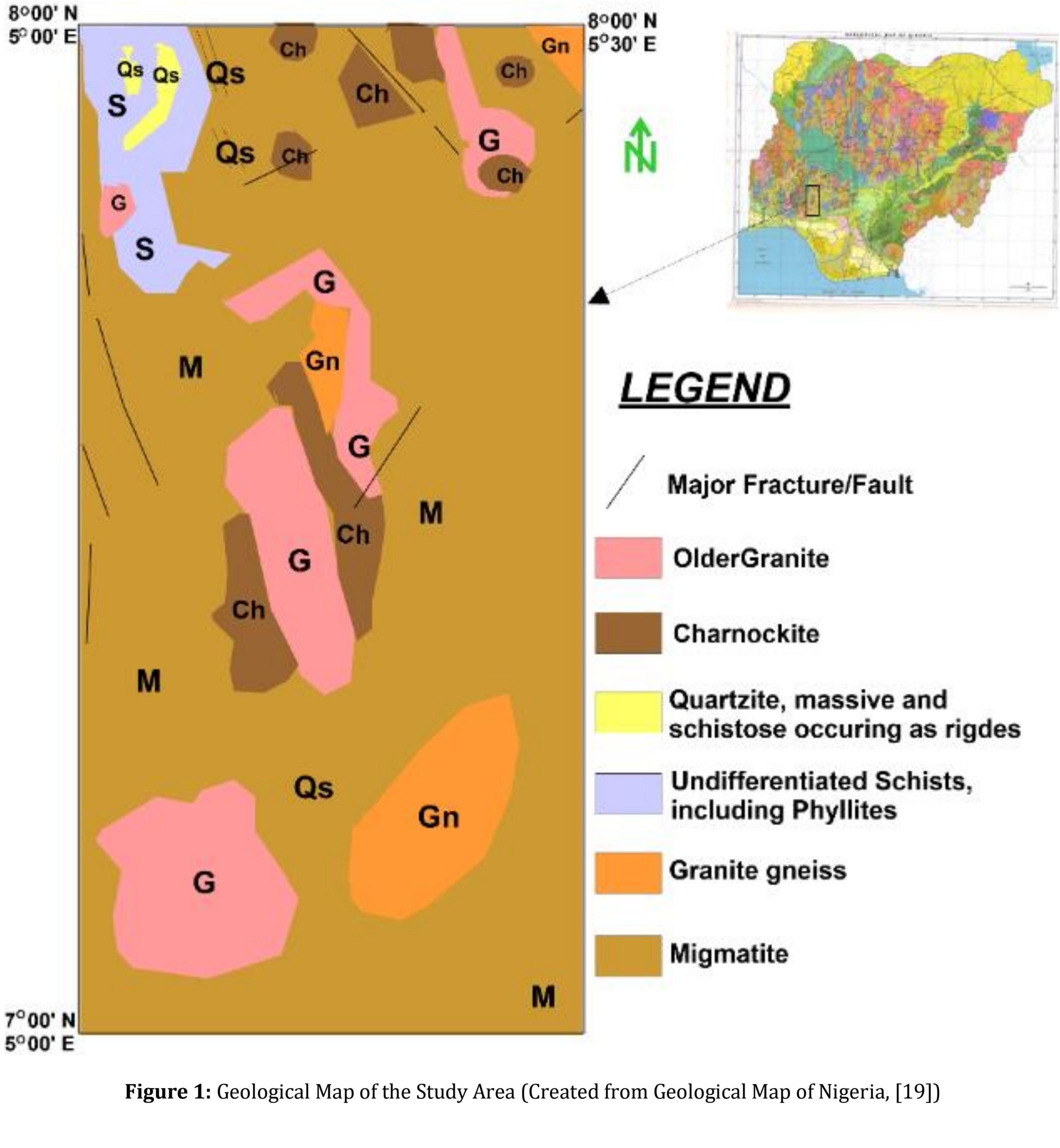


Figure 1: Geological Map of the Study Area (Created from Geological Map of Nigeria, [19])

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 noises (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 lithostructural 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.

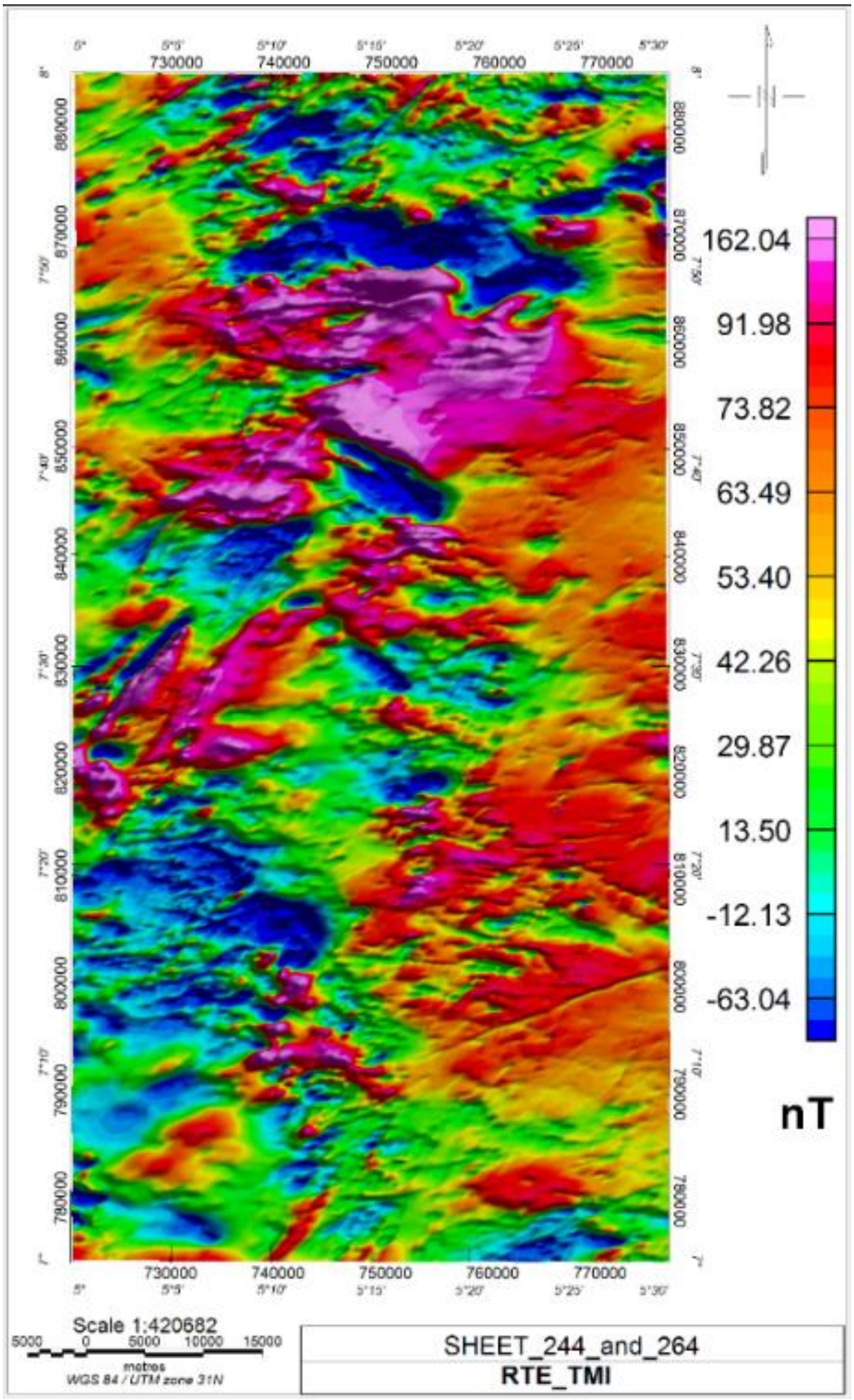


Figure 2: Colour Shaded Reduction to Equator Total Magnetic Intensity (RTE_TMI) Image

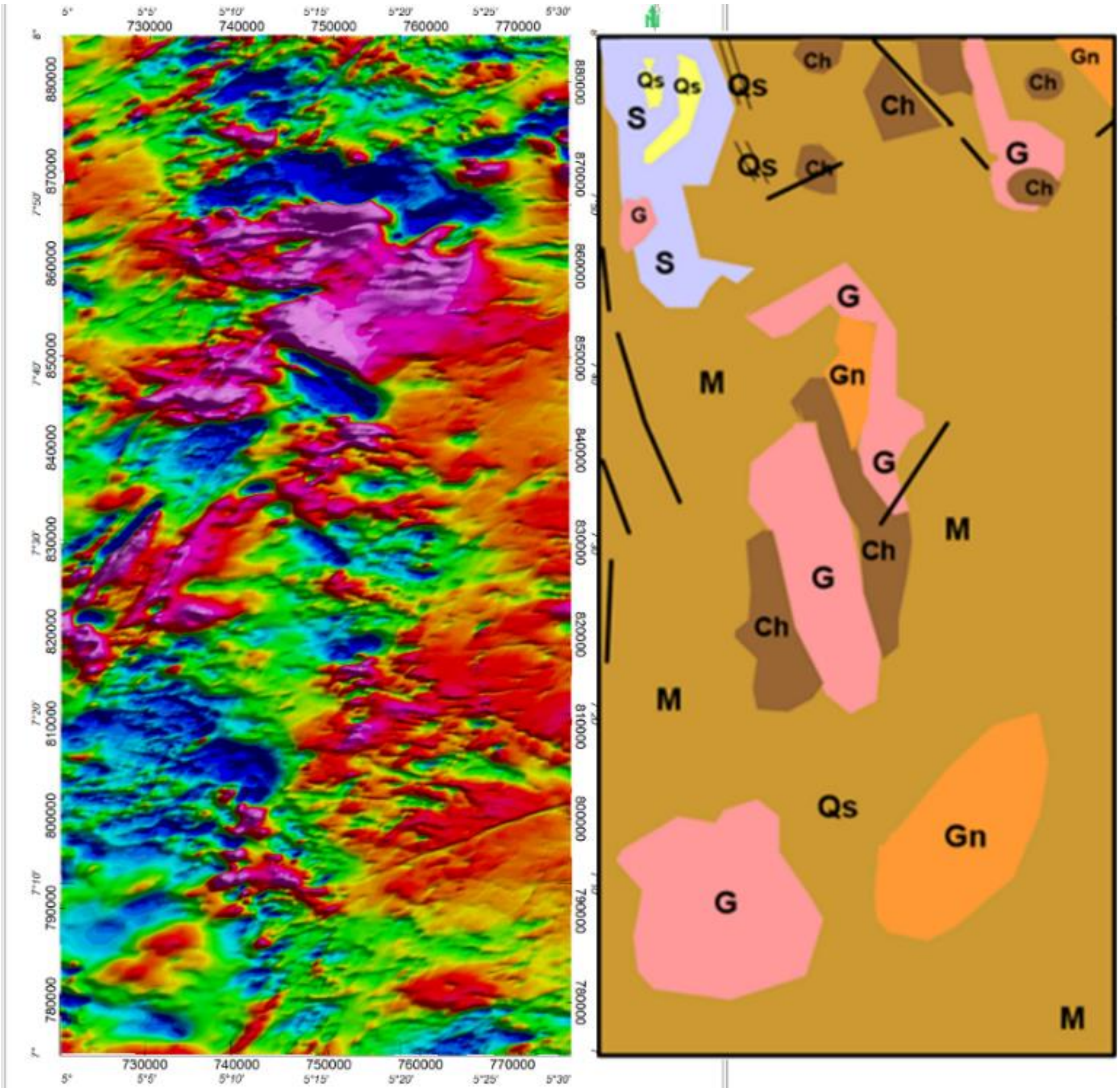


Figure 3: Comparing the RTE_TMI Image with Geological Map of the Study Are

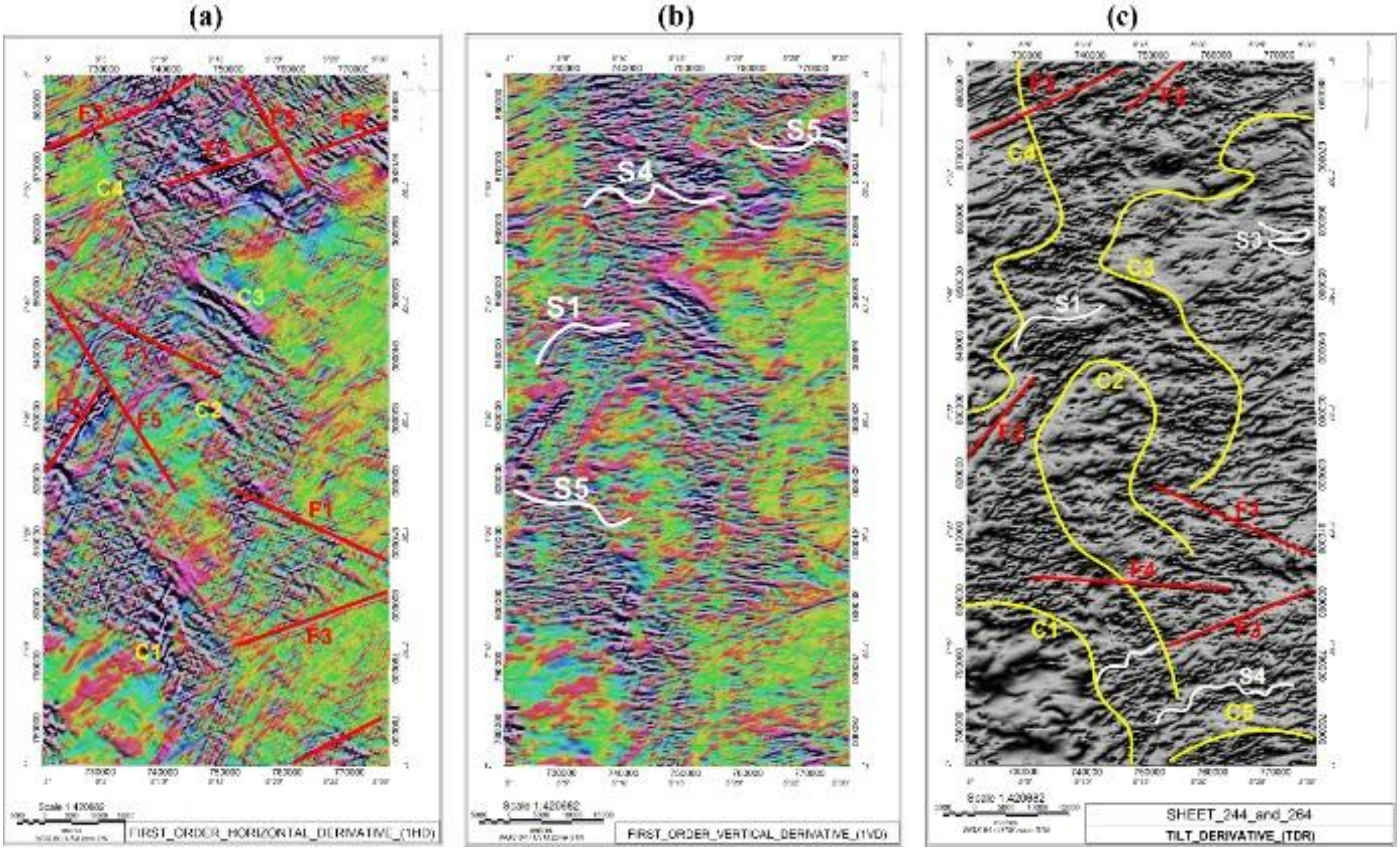
4.2 Derivatives: First Horizontal (1HD), First Vertical (1VD) and Tilt (TDR)

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 and folds. 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 and folds) 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 folds identification because it has suppressed the interfering horizontal wavelengths to a better range. While the TDR_RTE_TMI (Figure 4c) reveals its efficacy 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) fold (S) 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 deep-seated fault with two major displacements along F3 as seen at the northeastern section of both images. The fold types are classified into S1, S3, S4 and S5 as symmetrical, recumbent, ptygmatic and drag folds respectively with northwards plunging axes. 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 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, S (1, 3, 4 and 5)-Folds.*

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. The technique shows the amplitude strength of respective rocks based on mineralogical compositions as the major driving ability that enables easy mapping and lithostructural classification [20].

Figures 5 a – c shows the analytic signal (AS) results generated for RTE_TMI and respective derivatives data. Analytic signal of RTE_TMI (AS_RTE_TMI) (Figure 5a) is used to delineate the entire area occupied by the migmatitic rocks based on its high amplitude magnetic signal that is often attributed to highly rich ferromagnesian-bearing rocks [20, 21]. It is evident from the image that the migmatite complex covers over 45% on the study area with a regional trend of NW-SE and NS to some extent.

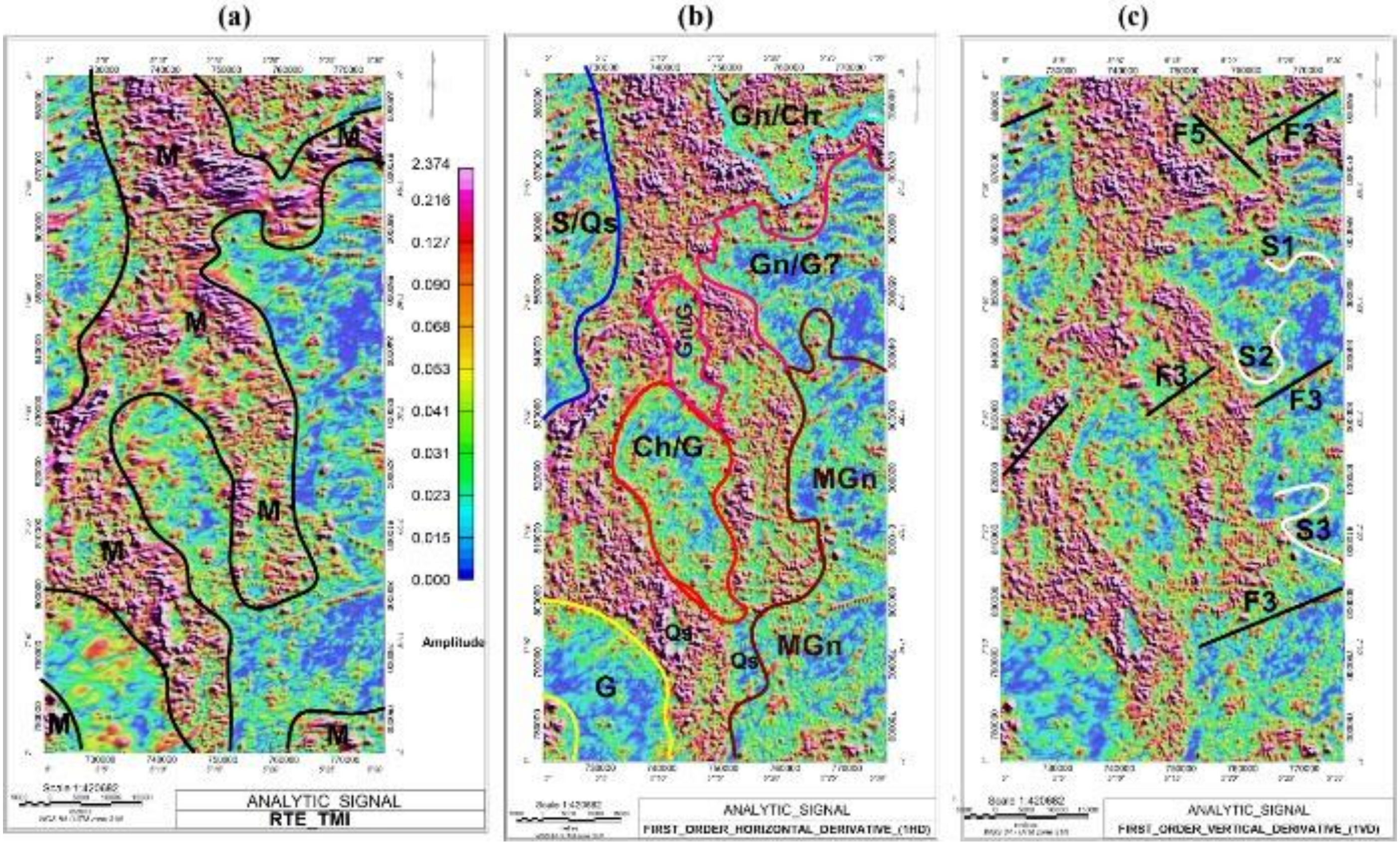
The analytic signal of the first order horizontal derivative of RTE_TMI (AS_1HD) (Figure 5b) was used to map and delineate other rock types in the area. The rocks are grouped together based on mode of occurrences and mineralogical similarities. While analytic signal of first order vertical derivative of RTE_TMI (AS_1VD) (Figure 5c) is used to map and classify the structures in the area. The AS_1VD reveals some lineaments/faults and S2 fold type (asymmetric fold) that were not mapped on the derivatives images. Note that Figure 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 intrusive and inclusions seen as pockets of high and low intensities variations.

The different amplitude signals revealed on the analytic signal images (Figures 5 a – c) are due to different mineralogical compositions in various rock types. Based on amplitude strength and mineralogical compositions, the following classifications are made:

i. very high amplitude signals (0.127 – 2.374) defined as migmatite (M) complexes because the rocks of this group are highly rich in ferromagnesian minerals;
ii. moderately high to high amplitude signals defined as rocks that are moderately rich in ferromagnesian minerals such as migmatite-gneiss (MGn), charnockite (Ch), biotite-rich granite (around Ikole and within the schists) and gneiss (extreme end of Ikole-Ekiti).
iii. very low to low amplitude signals as areas occupied by rocks that are rich in felsic minerals such as the undifferentiated gneisses and granites (Gn/G), porphyritic granite (Gn), schist (S) and quartzite schist (Qs).

Structural trends as seen in the study area were also identified based on their amplitude signals and classified as:

i. high amplitude signal trends as basic intrusives like doleritic dyke, sill, and vein.
ii. very low amplitude signal trends as felsic intrusives and veins of quartz, pegmatite and aplite.



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

**M-Migmatite Complexes, MGn-Migmatite Gneiss Complexes, Gn/G-Granite Gneiss and Granite Complexes, S/Qs-Schist and Quartzite Schist Complexes, Gn/Ch-Granite-Gneiss and Charnockite Complexes, Ch/G-Charnockite and Granite Complexes, G-Granite Complexes, F (3 and 5)-Lineaments/Faults, S (1, 2 and 3)-Folds.*

The proposed geological map for the study area is shown in Figure 6. This proposed geological map updates the lithostructural features that were not indicated in Figure 1. Some of these features in Figure 1 were not mapped due to some reasons like soil and vegetation cover, etc.

The undifferentiated gneissic and granitic rocks on the proposed map are areas with different types of gneisses and granites and cannot be grouped as granite-gneiss and granite because of the character of their amplitude signals, but evidence of grey gneiss, granite gneiss, biotite gneiss, granodiorite, granite, etc. in the eastern part (Ikare-Akoko) have confirmed that rocks in the marked area belong to the complex.

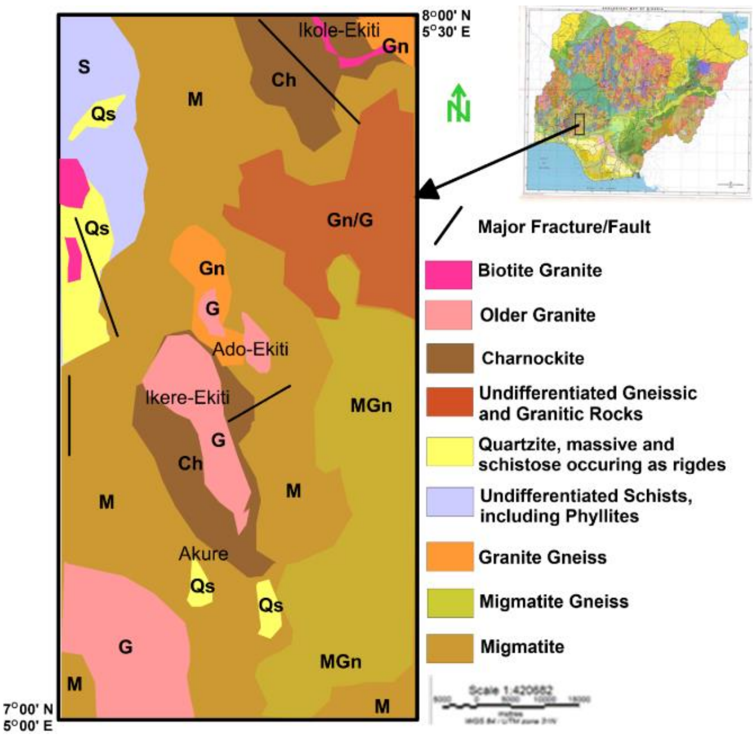


Figure 6: Proposed Geological Map for the study area.

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

Table 1: Summary of lithostructural Classification for the Study Area

S/N	Rock Type/Complex	Lineament / Fault Type	Structural/ Lithological trend	Fold Type	Contact	Analytic Signal (Amplitude)
1	Granite (G)	- -	NW-SE	- -	C1	low to moderately high; depending on the amount of felsic mineral composition
2	Charnockite/Granite (Ch/G)	F4; F5	E-W; NNW-SSE	S5	C2	Charnockite (moderately high to high) while Granite is low to moderately low
3	Granite-gneiss/granite (Gn/G)	F2	NNE-SSW	S1 and S2	C3	low to moderately high. The felsic gneissic and granitic rocks have low but the biotite rich ones are moderately high.
4	Granite-gneiss/Charnockite (Gn/Ch)	F2; F3; F5	NNE-SSW; NE-SW; NNW-SSE	S5	C3	moderately high to high
5	Schist (with minor phyllite) and Quartzite schist (S/Qs)	F1; F3; F5	NW-SE; NE-SW; NNW-SSE	S1	C4	fairly low for schist and very low for quartzite (made up of over 90% quartz)
6	Migmatite Gneiss (MGn)	F1; F3; F4	NW-SE; NE-SW; E-W	S4 and S3	C3 and C5	moderately high to high. Variations in signals are evidence of varieties of migmatised gneissic rocks ranging from felsic to basic types
7	Migmatite (M)	All present	Possess all the trends. It shows a regional trend of NW-SE and approximately NS directions	All present	shared contact with all rock types	very high (highly rich in ferromagnesian-bearing minerals of over >90 %)

**F1, F2, F3, F4 and F5 indicate NW-SE, NNE-SSW, NE-SW, E-W (less) and NNW-SSE trends respectively. S1, S3, S4 and S5 as symmetrical, recumbent, ptymagtic and drag folds 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 lithological suites that include migmatite (M), migmatite-gneiss (MGn), 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. Two major folds, classified as S1 and S2 denoting symmetrical and asymmetrical folds respectively with northward plunging. These major folds were later refolded to produceS3, S4 and S5as recumbent, ptygmatic and drag folds respectively due to change in degree of metamorphism.
4. Five contacts (C 1 – 5);as sharp 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.
5. Intrusives and inclusions seen as pockets of high and low intensities.

Based on these classifications, a detailed geological map for the study area was established and proposed. Furthermore, it is evident from this study that the migmatites and gneisses which form the basement in the area have been highly deformed and extensively intruded compared to other complexes as a result of pronounced faulting, shearing, jointing and folding 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 and detailed geological mapping.

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