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Quantitative Analysis of Aeromagnetic Data Showing Magnetic Source Depth of Dutsin-Wai within Kubau Local Government Area, Kaduna State, Nigeria

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ABSTRACT
Delineation of mineralization zone using Aeromagnetic data, sheet 125 (Dutsen - Wai) of NE part of Kaduna state. The result was delineated tom identify areas with high potential for cassiterite deposits by locating potential host structures, lithological contacts, and magnetic susceptibility contrast that give inside on the distribution of this mineral in prospect. It was obtained using quantitative techniques such as Euler Deconvolution and spectral analysis, the Euler deconvolution with a structural index of 1 and 0 for dyke mapping and contact respectively. The spectral analysis was used for the depth to the magnetic sources model for both regional and the residual anomaly sources, and all the results were incorporated with the geologic map of the area to map out the prominent structures and determine their depth and tend of those potential structures found within the host rock which is identified as the biotite granite. Three potential areas were identified from the interpretation and are mapped out on the geologic map around the host rock which is of Biotite granite component of the area.

Keywords:
Lithological,
Contacts,
Magnetic susceptibility,
Euler deconvolution,
Spectral analysis,
Biotite granite.

INTRODUCTION

The earth and its resources are of great benefit to humanity. Man tried to reveal its complexity and get to its origin using various geophysical methods. The subsurface is of particular interest to geoscientists who seek to explore them with various means, some of which are designed to acquire knowledge, while others do so for exploration of economic resources such as minerals.

The mineral Cassiterite, SnO_2, is the most important ore of tin. It is often found in hydrothermal veins that are usually related to igneous rocks, such as granites. Can also be formed as a result of secondary processes in oxidation zone of weathered tin deposit (Abubaka et al., 2009). Cassiterite can wear to nodules and large grains that are eventually concentrated in placer deposit during erosion. The nodules have a greasy luster and seem to be heavy in the hand. Some cassiterites are very black and hence tests are sometimes essential.

Tin mineralization in Nigeria occurs within the Younger Granite province of Nigeria. Tin mining has a very long history in Jos, Plateau State. It started in 1904 and by the mid-1920s more cassiterite (tin ore) discoveries had been made which resulted in more mechanized extraction techniques to meet the high demand for tin by 1960s (Akanbi, 2012). The demand increased, got to a peak and gradually declined in the late 1980s. Recently, the world demand for tin is quite steady, and is growing at about 5% a year (Cowie, 2010).

Two types of tin mineralization were identified in Nigeria, the primary deposits found as dissemination in biotite granite and pegmatities and placer deposit found among gravels pockets in both ancient and modern stream channels (Pastor, 1985). Most sources of cassiterite today are found in alluvial or placer deposits containing the resistant weathered grain. The Younger Granite Complex of the Dutsen-wai and surrounding areas are richly mineralized with alluvial cassiterite (Akanbi, 2012). Cassiterite is associated with other mineral such as columbite, monazite and accessories like zircon and topaz.

Consequently, a lot of mining activities (formal and informal) have been carried out over many years in the area. Many of these mining activities carried out presently are done by trial and error means.

The method employed for this research is aeromagnetic survey which involves the use of aircraft to conduct magnetic surveys in order to study subsurface. This method uses changes in the Earth's magnetic field as a detecting tool. Variations in the magnetic field are often used as diagnostics of regional structures. In magnetic research, the main purpose of the application is the main field that changes slowly and has an internal origin, a

small field that changes rapidly and occurs outside the Earth, and the spatial variations of the main areas that are smaller compared to the main field (Telford et al., 1990). It is usually constant with time and place and is caused by local magnetic anomalies in the near surface of the Earth's crust (Telford et al., 1990).
Aeromagnetic method can be used to outline mineralization zones, it can be used to cover an area of 500-5000 square km (Atkinson, 1989) and can be integrated with other geophysical methods for ground study. Traditionally, aeromagnetic methods have been used primarily in sedimentary terrain for the purpose of mapping faults associated with hydrocarbon accumulation in the crystalline basement complex (igneous and metamorphic rocks), as well as to study mineral resources such as cassiterite.
The aim of this work is to using quantitative analysis method in other to delineate zones of cassiterite mineralization in the study area.

Location of the Study Area
The study area Dutsen-wai is situated at 10.30°-11.00°N latitude to 8.00°-8.30°E longitude and 729 m elevation above the sea level. Dutsen Wai is a small town in Nigeria, having a population of 22,062(NPC, 2019). Dutsen-wai is a district in Kubau Local Government Area, a Local Government Area in Kaduna State, Nigeria. Its headquarters are in the town of Anchau.

MATERIALS AND METHODS

Material Used in the Study
The materials used for this study include, one(1) sheet of Aeromagnetic map (sheet 125), geologic map of Nigeria, both were obtained from the Geological Survey Agency (NGSA) Abuja, computer. Software applications used includes: Oasis Montaj, MS world used for processing and interpretation of aeromagnetic map.

Data Acquisition
A high-resolution aeromagnetic (HRAM) data sheet (sheet 125, Dutsen-Wai) was purchased at the National Geological Survey Agency (NGSA), in Abuja. The aeromagnetic data was obtained as part of a nationwide aeromagnetic survey sponsored by the geological survey of Nigeria. The data was acquired at a flight altitude of 80m along with a series of NW – SE flight lines with a spacing of 500m. The data was made available in a grid form on a scale of 1:100,000 and in half degree sheets. The sheets when put together extend from 10.30°-11.00°N latitude to 8.00°-8.30°E longitude covering the study area and beyond.

Methods
Total Magnetic Field
Total Magnetic Intensity Map is a combination of the regional and residual components over the area. Total intensity map contains long and short wavelength component arising from both regional and residual structure, and it show larger scale geologic features, such as basin shape or anomalous rock types deep within the basement. The terms residual and regional are used to separate anomalies from local, near-surface masses and those arising from larger deeper features

Residual Magnetic Field
The residual anomaly shows large variations over a short distance, residual anomaly has a short wavelength and is the anomaly of geological interest in this specific area under study. They bring out the subtle magnetic anomalies that result from the changes in rock type across basement block boundaries, and the residual field is usually subjected to more intense study.
A regional low-pass filter is supplemented by a high-pass filter or a residual filter. The residual grid may be obtained either by applying such a filter in the wavenumber domain, or by subtracting the regional field from the original data grid. In practical cases, the residual filter would usually be designed to roll-off again at wavenumbers corresponding to noise so that noise could be eliminated simultaneously. The filter then becomes a band-pass filter, retaining only information from arrange of wavenumbers considered important for the study of the residual anomalies at hand (Hinze, 1990).

Regional Magnetic Field
Regional anomaly is of long wavelength and it shows a gradual change in value and regional trend of the total intensity and can be calculated using Gussian regional, residual separation technique, it uses both low-pass and high-pass filters to produce regional and residual map. The regional field is taken as the component of the field with low curvature (or section occupying the low frequency end of the field spectrum). The regional field trends in the NW-SE directions. Its magnetic anomaly intensity is increasing northward (Nettloton, 1976).

Euler Depth Deconvolution
Euler deconvolution is a method use to estimate the depth of subsurface magnetic anomalies. It is particularly good at delineating the subsurface contacts and rapid depth estimate. Euler depth estimation increases with N and real bodies are simulated by superposition of bodies. Structural index which is a measure of the rate of change with distance of a field (John and Emmanuel 2014) directly relates to the shape of the source of the field (Raimi et al., 2014). An index that is too low gives depths that are too shallow, one that is too high gives estimates that are too deep. Thompson (1982) proposed a technique for analyzing magnetic profiles based on Euler's relation for homogeneous functions. The Euler deconvolution technique uses first-order x, y and z derivative to determine location and depth for various idealized targets

(sphere, cylinder, thin dyke, pipe and contact), each characterized by a specific structural index (Reid et al., 1990). Extended the technique to 3D data by applying the Euler operator to windows of gridded data sets.

Spectral Analysis Depth Estimation

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, in the practical version now, the FFT (fast Fourier transform) can be used to calculate it. 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.

Spectral analysis is a depth technique used to estimate depth to anomaly sources within an area, and it was a concept by Spector and Grant's (1970), understanding of the power spectrum has another widespread application. If the slope of the log power spectrum indicates the depth to source, then a section with constant slope defines a spectral band of potential field originating from sources of equal depth. Hence, it appears to be possible to separate the contribution of these particular sources from the rest of the field by band-pass filtering (Spector and Grant, 1970, Jacobsen 1987, Cowan and Cowan 1993, Pawlowski, 1994, 1995). Since the low-wavenumber (long-wavelength) portion of the power spectrum is usually rather steep, this implies that the long-wavelength anomalies necessarily originate from deep-seated sources. In the current study Fast Fourier Transform (FFT) filter are used to calculate the depth. The data is transformed from the space domain to the wavenumber domain using an FFT. The wavenumber increment of the resulting transform will be 1/ (line-length).

RESULTS AND DISCUSSION

To obtain the subsurface configuration of the magnetic interface in the study area, quantitative analysis was applied. The analysis consists of generating the Euler deconvolution technique, the Spectral analytical technique and Source Parameter Imaging (SPI) to estimate the depth of the causative magnetic sources in the study area.

Euler Depth Solution

Two maps were produced to determine the causative magnetic depth using the Euler depth estimation techniques.

The first was produced with a structural index (S I) of 1 and depth tolerance of 5% (figure 1) to target concordant and discordant intrusions (sills and dyke) within the study area. The S.I of 1 has a dimension of probe in the x, y and z, the S.I of 1 emphasizes this intrusive bodies which could be associated with the localized mineralization in the area, the S.I of 1 highlights and identifies these bodies and estimate their depth and also their trends/orientation and position within the area, and this will serve as a guide to further ground probing into the assessment of mineralization potential of the area. The depth ranges of various concordant and discordant potentially mineralized intrusions are categorized with color Variation in the study area. Intrusion of the basement rocks occurred at depth equals or greater than 700m (pinkish color) while reddish coloration represents depth between 500 m and 700 m, depths occurring at 300m to 500 m are shown in yellow. Blue coloration represents depths from 100m to 300 m (Fig 1). Most of the areas with depth ranges greater and equal to 700 m are area underlay by the Coarse Porphyritic Biotite and Hornblende granite, From Fig 1, those areas designated with depth less than 100m the ones that are nearer to the surface the most and this are the most latter intrusions which reasonable exploration depth (i.e) easily followed up with ground exploration because of depth nearer to the surface hence can be easily mined with less expenses. However, the Euler solution does not determine if a dyke is mineralized or not, it only gives a guide on the orientation, position and depth of such body and hence the structural index (S.I) of 1 is essential because the prominent mineral associated with this environment occurred within veins, which can be as dyke to the orientation of the host rock which it intrudes.

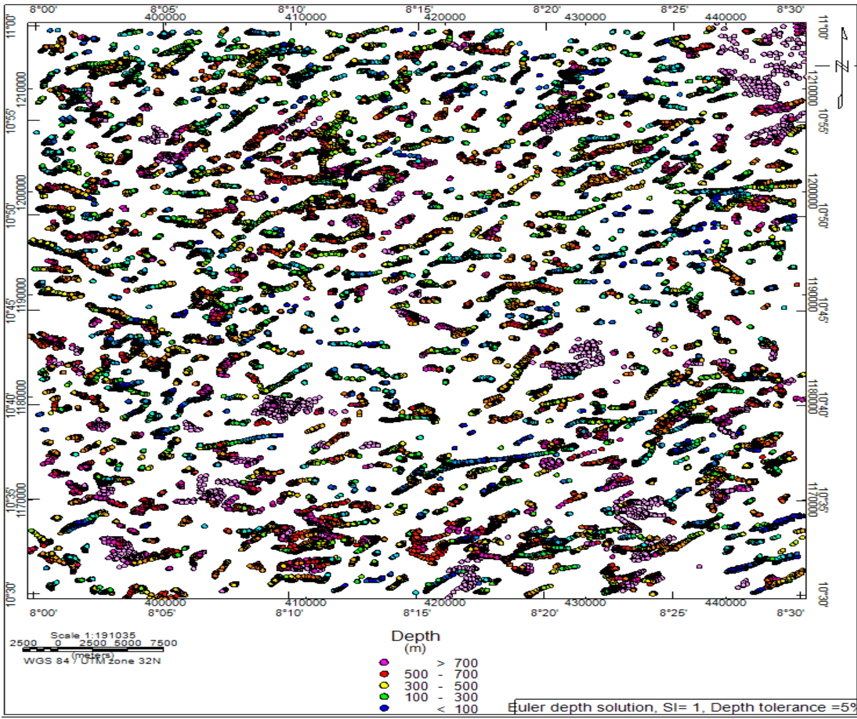

Figure 1: The Euler deconvolution map across the study area using the structural index of 1 for dyke mapping

The second map was produced using the structural index of 0 (figure 2), the structural index of 0 is that which is used for lithological contact. However, a 0 index implies that the field is a constant regardless of distance from the source model. These situations are physically impossible for real data and a zero index represents a physical limit, which can only be approached as the infinite dimensions of the real source increase. In practice, an index of 0 can often be used to obtain reasonable results when the index of 0 would otherwise be indicated, the structural index of 0 was used so as to map the lithological contacts which could serve as interfaces intruded by mineralized veins.

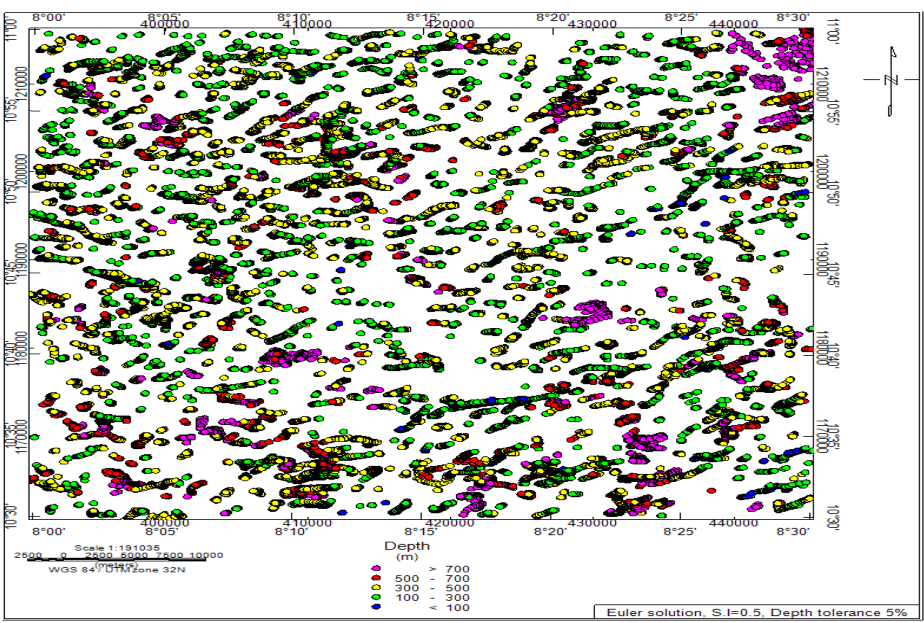

Figure 2: The Euler deconvolution map of the study area using the structural index of 0 for mapping lithological contacts which could serve as host zones for mineralized vein intrusions

Spectral Analysis

The spectral depth analysis was performed on the filtered map of the area, and this was done by dividing the area into 25 spectral blocks each of 18 square kilometers and labeled block 1 to 25 (figure 3), The average energy spectrum plot was applied for each of the block and a total of two depths were generated. The first is the shallow depth magnetic sources (D1), which are residual in nature and resulted from the near surface rocks or intrusions within the area which are found to be responsible for localized or remnant magnetic signals and also are the point of interest in the exploration for near surface mineral deposits occurring within veins. The shallow (D1) depth ranges from 333.3 m to 692.1 meters and an average of 524.7 m and the second is the deep magnetic source depth (D2) which are from those regional anomaly sources within the area and this are magnetic signals from great depth.

And it ranges from 1796.7 m to 2577.4 m with an average of 2577.37 m. The depths, both Shallow and Deep calculated are tabulated in table 1.

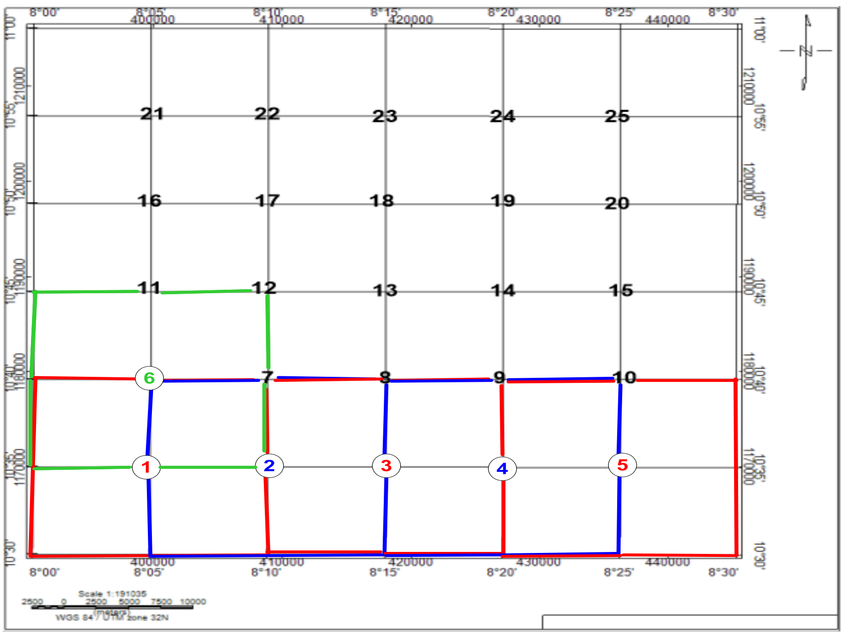

Figure 3: The spectral block schematics, the filtered TMI aeromagnetic data of the area was divided into 25 blocks each of 18 square kilometers

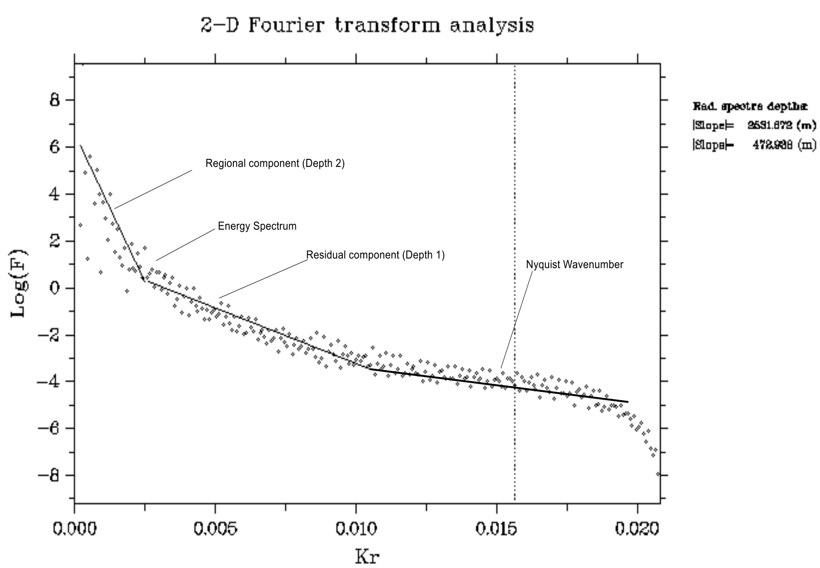

Figure 4: The energy spectrum in the wavenumber domain for block 1, spectral analysis and the design of filters for regional-residual separation

Table 1: The two depths estimation for the 25 aeromagnetic blocks D1 is shallow depth and D2 is deep source

Block ID	Midpoint Coordinate		Deep source D2 (m)	Shallow depth source D1 (m)
	Long (Degree)	Lat (Degree)		
1	8.083333	10.58333	2531.672	472.938
2	8.166667	10.58333	2537.716	392.305
3	8.25	10.58333	1796.698	333.343
4	8.333333	10.58333	1872.957	450.131
5	8.416667	10.58333	2198.478	438.04
6	8.083333	10.66667	2252.125	529.13
7	8.166667	10.66667	1984.87	424.299
8	8.25	10.66667	2134.3	539.656
9	8.333333	10.66667	2512.334	621.444
10	8.416667	10.66667	2307.166	646.428
11	8.083333	10.75	2156.602	609.904
12	8.166667	10.75	2190.341	558.902
13	8.25	10.75	2148.713	569.052
14	8.333333	10.75	2112.695	550.362
15	8.416667	10.75	2479.828	649.283
16	8.083333	10.83333	2139.268	480.735
17	8.166667	10.83333	2359.738	599.618
18	8.25	10.83333	2092.383	642.357
19	8.333333	10.83333	2075.262	692.115
20	8.416667	10.91667	2577.372	554.833
21	8.083333	10.91667	2250.167	475.331
22	8.166667	10.91667	2504.215	507.716
23	8.25	10.91667	1836.861	399.261
24	8.333333	10.91667	2356.657	516.105
25	8.416667	10.91667	2241.135	489.248

Depth to Shallow Magnetic Sources Map

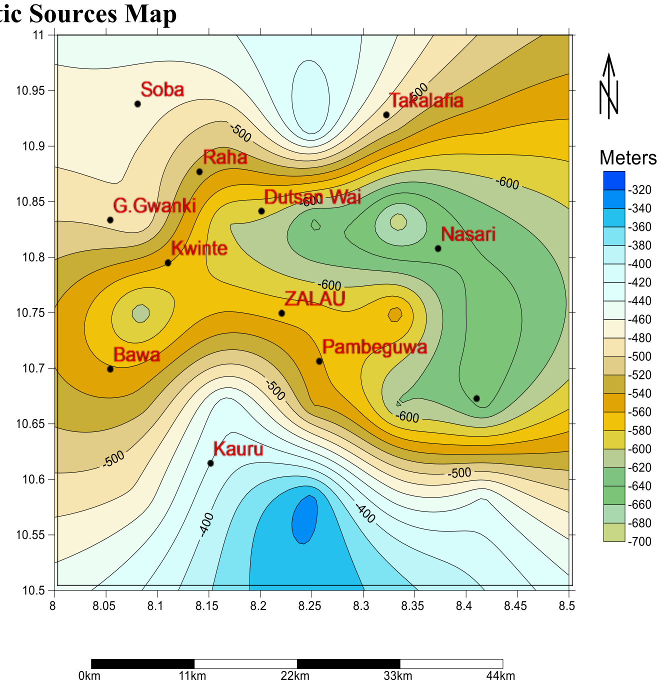

Figure 5a: The Depth estimation spectral analysis map of the shallow magnetic basement sources (residual depth) (D1) across the area calculated from the average energy spectrum of the area, showing the variation in basement depth sources across the area

In exploration the importance of depth cannot be over emphasized, the nearer to the surface the deposits, the easier and more economical the extraction processes hence, the areas with near surface basement are of high priority than those areas with deep basement occurrence, the depth variation across the area can be seen in the depth estimation map (fig 5), the area (Southeast) SE of Kauru has depth ranges around 320 m which is the shallowest across the whole area and this is an indication of the Basement being very close to the surface or can be an outcrop occurrence. This is an indication that the rocks are highly resistant to weathering and can also be an indication of the likely mineral structure within the rock structure is near to the surface. The area around Nasari have the deepest basement occurrence with values between 620 m to 700 m, the other area in the Northern part of Dutsen-wai also have depth ranges between 460 m and 380 m, this are also not so deep and also a likely occurrence of geological exposure and are also likely occupied by highly resistant rocks of granitic origin, this is an indication of a shallow possibly mineralized structures, as the mineral deposit is found within the host rock as later intrusions. Therefore, near surface basement will have near surface structures which might host mineralization while deeper surface basement will have structures too but the mineralization potential solely depends on the mode of emplacement of these structure in question, is usually as lode and occurs within near surface structures, and are usually host within the biotite granite rock according to the previous research done by (Verheijen et.al., 1980*)*.

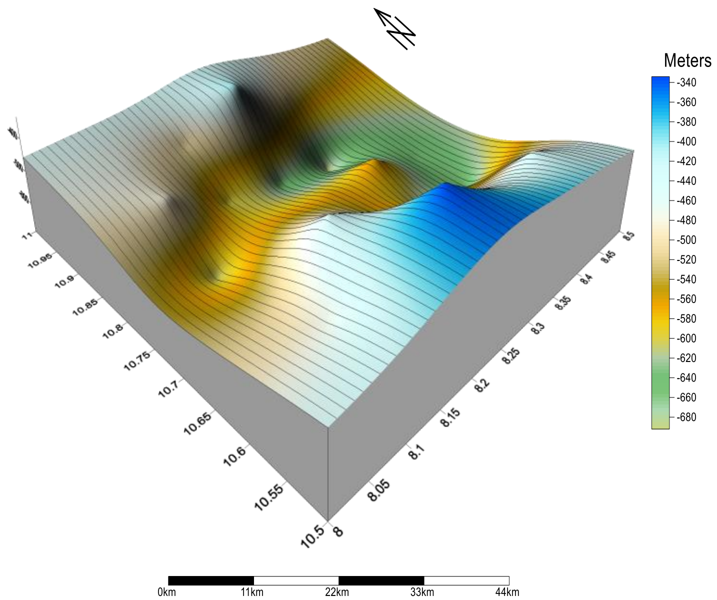

Figure 5b: The 3-dimensional Depth estimation map of the shallow magnetic basement sources (residual depth) (D1) across the area calculated from the average energy spectrum of the area, showing the variation in basement depth sources across the area

Other area across the shallow depth to magnetic source map can be seen in the displayed 2D and 3D maps, the 3D map however gives us a better and more graphical visualization of the undulation shape of the basement occurrence within the area, showing the trench like occurrence running from West to East at the middle part of the study area, the areas with shallow basement are clearly understood and the area with deep basement are also seen.

Source Parameter Imaging (SPI) Method

The source parameter imaging (SPI) map displays the estimated depth to magnetic source bodies in the study area, it depth ranges from 1231.25m to 101.69m, these depths are equally distributed within the study area and with a difference of 1129.56m. It suggests that the top of the basement is not even but undulating.

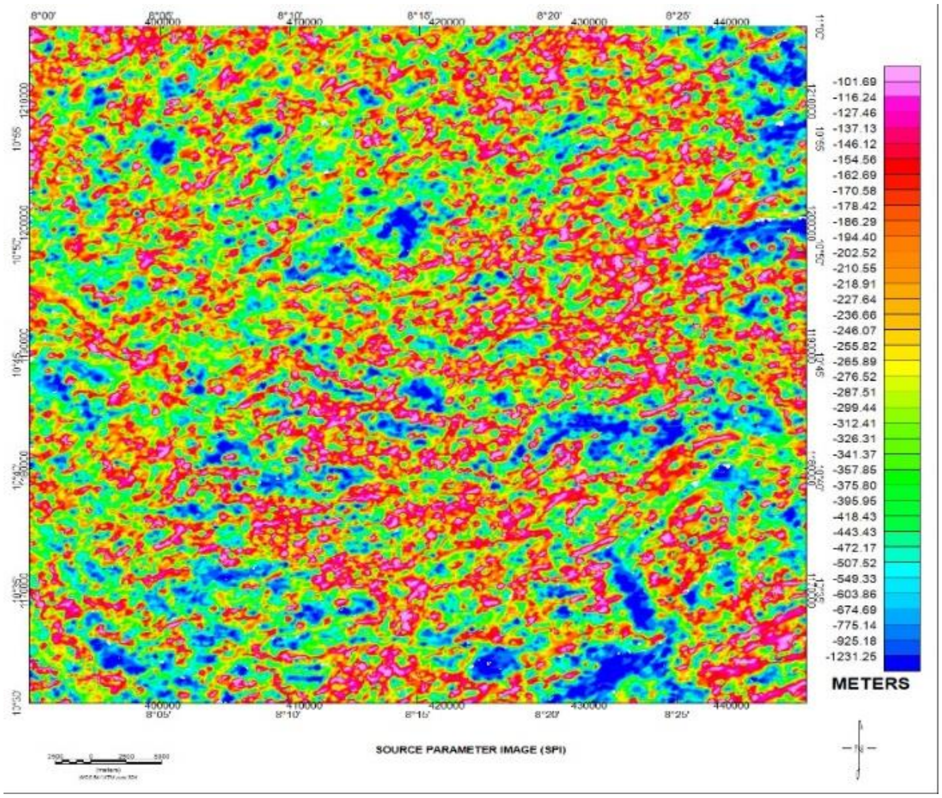

Figure 6: Source parameter image (SPI) of the study area

Litho-structural Interpretation

The litho-structural map of the area (fig 7), is showing the aeromagnetic structures being superimposed on the geologic map. Here the structural orientation of the area can be seen. And the rocks with most structures can be deduced and the areas with most geologic activity can also be seen. This is showing the interpretation of the lithology in correlation with the structures identify from the derivatives map and the average depth estimation of this structures from the Euler Deconvolution map and the spectral analysis. And these structures from the aeromagnetic dataset was superimposed on the geological map of the area and the potential mineralization are domicile within those structure situated within the biotite granite rock, serving as the host.

The structures of interest which are potential host to mineralization, the mineral potential of the area is that of cassiterite which is an oxide of tin and this usually occurs in lode, the shape of the Lode is approximately that of a vertical dyke. However, the potential lithological type hosting this Lode is of the Biotite Granite rocks and hence attention is on those structures found on the Biotite granite rock within the study area (figure 7). The biotite granite occupies the North-Eastern part of the study area and they trend in a NE-SW axis as seen in (figure 7), and they are of two types the first is that of the Coarse porphyritic Biotite and Hornblende granite found within the Dutsen-wai and the second is of the Medium -Coarse Biotite granite found within the kauru axis which occurs in association with each other. Most of the Structures which are found around this axis are in the ENE – WSW directions and hence this is the direction of emplacements of the Lode in the area, therefore attention is more on these structures found within the host rock than any other lithological type found within the area.

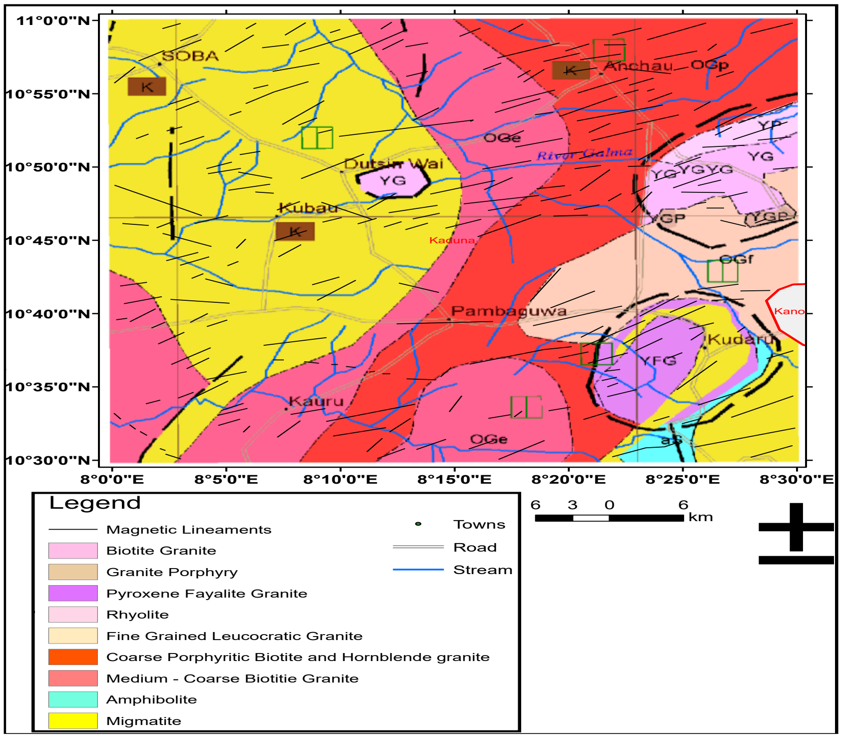

Figure 7: The litho-structural interpretation of the study area

Potential Area Map of the study Area

Three major potential areas were identified from the cross interpretation of the aeromagnetic map with correlation with the geologic map of the area namely 1, 2, and 3 (fig 8). The inferences derived from the residual, derivatives, structural, analytical signal, Euler deconvolution and the shallow depth sources spectral analysis depth map of the area, the residual map was produced from the regional-residual separation, then subjected to the mathematical derivations to produces the vertical derivatives maps the analytical signal and the tilt derivatives map was also produced all in the effort to extracts the structures within the area which are potential host mineralization, the quantitative methods which are the Euler deconvolution and the spectral analysis map were used to determine the depth variation around the already identified structures from the qualitative interpretation, the areas with near surface basement were given priority to as the mineral and the structures hosting our deposits are near surface, and are mined as alluvial deposits and the shape of the lode is approximately that of a vertical dyke (Verheijen et.al., 1980*)*.The veins themselves have an irregular but roughly banded structure with quartz dominantly at the centre and greisen containing most of the mineralization around the quartz. The major minerals are: zincblende, cassiterite, columbite, wolframite, galena and pyrite. Normally the host rock consists of medium to coarse grained or fine-grained biotite granite (Verheijen et.al 1980*)*,

The geologic map was used in the combination with the aeromagnetic quantitative and qualitative interpretation of the structures and depth to identify the areas with the rock hosting the mineralized vein within the area which are the Biotite granite rocks and hence these areas were highlighted and grouped into three potential zones, the structures within these host rock are those we consider as likely mineralized structures, however the limitation to this is the regional nature of the data, and also limitation or the magnetic data interpretation, magnetic method are not a direct tools in mineralization mapping, however, they are good tool in the mapping of primary structures which host mineralization and the scope of the areas identified are limited to the natural limitation of the aeromagnetic data interpretation. Hence the need for further ground study and incorporation of other geophysical methods.

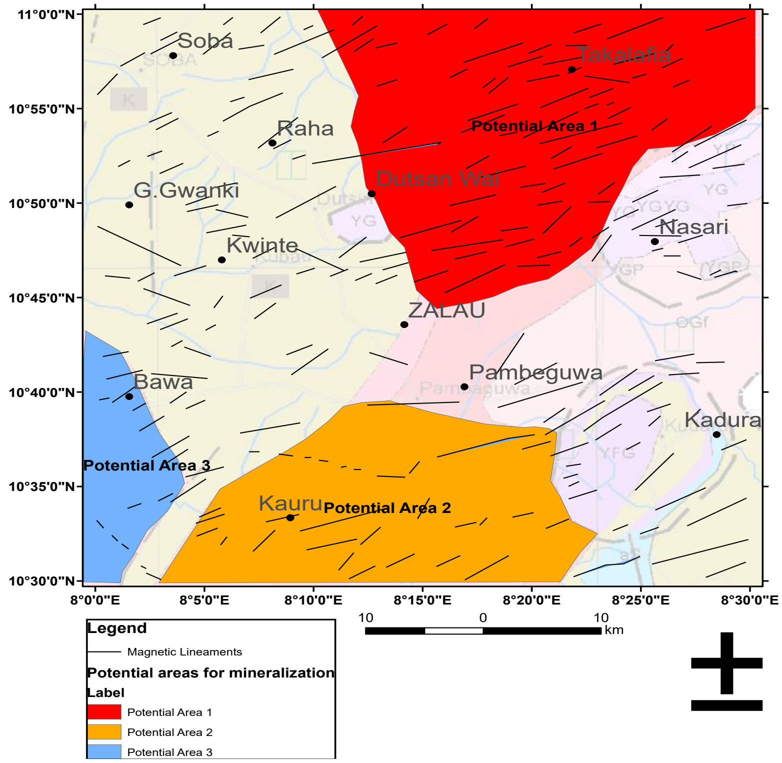

Figure 8: The three potential areas for cassiterite mineralization identified from the aeromagnetic data interpretation

CONCLUSION

The subsurface geological information obtained from the analysis of the aeromagnetic data (sheet 125) to estimate magnetic source depth has been achieved using the Euler deconvolution, source parameter imaging and spectral analysis map. The obtained Euler solution map show the depth solution that ranges from 700m to 100m. using structural index 0 and 1 to delineate the depth and location of the basement contact and dyke. And the various colors in the source parameter image (SPI) represent the depth estimates to magnetic source bodies in the area with values ranges from 1231.25m to 101.69m that is similar to the Euler solution depth obtained and it also portray undulations in the basement surface. The 2D and 3D spectral analysis depth estimation map of the shallow basement sources across the area calculated from the average energy spectrum of the area with values ranges from 700m to 320m, which still falls within the range of that of Euler solution and SPI but will be different due to mathematical approach in the techniques applied. The structural map superimposed on the geologic map of the study area reviewed the main potential areas in order of priority for prospect for cassiterite.

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