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Interpretation of Airborne Gravity Data over Kushaka Schist Belt, Northwestern Nigeria

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Abstract
The Kushaka Schist Belt has a peculiar importance due to its minerological potential. The area is located on the Latitudes 10°30'-110 and Longitude 6°30'-7° in the northwestern part of Nigeria. Kushaka airborne dataset (Sheet 222) obtained from Nigerian Geological Survey Aagency was interpreted to delineate litho- structural architectures that could favour the exploitation of potential economic minerals over the area. The analyzed results of the bouguer map of Kushaka show the distribution of the gravity anomalies and magnitudes of the concealed shear and weak zones being characterized by low to very high gravity anomalies. The upward continued bouger anomaly map at distance of 3000m reveal the regional trends so as to generate a subsequent residual field where several filtering operations were carried out. Several enhancement techniques were carried out on the airborne gravity data to reveal the locations, edges/boundaries, trends, and depths of gravity anomalies. The analytic signal gravity and its superimposed maps reveal areas with low to high amplitude signals. Low amplitude regions are suggested to be dominated by highly fractured schistose, quartzitic rocks and fractures. On the other hand, high amplitude regions are likely occupied by denser biotite granitic and gneissic rocks. Also, the First Vertical Derivative gravity anomaly map shows low gravity region which indicate the presence of fracture. The horizontal gravity gradient map shows high, positive gravity regions which may be attributed to the presence of a regional structure trend in the area. Low gradient anomalies can also denote presence of graben-like structures or other geological depressions. The depth analysis over Kushaka schist Belt suggests depth to top for shallow bodies ranging from 385m to 560 m with an average depth of 440.55 m while the deep sources have depths ranging from 1910m to 2480m with an average depth of 2111.1m. The obtained Euler anomalies depths ranged from <2607m to >5858m suggesting that mineralization around the study area is structurally controlled, an evidence of hydrothermal alteration zones. The structural solution (S.I=0) result displays two NW-SE trending short linear features, an indication of tectonic metamorphic phases of Pan-African orogeny that harbor mineralization. The results therefore, suggested intensed deformation of the basement rocks with tectonic framework suitable for mineralization.

Keywords : Gravity, Kushaka, Schist belt, Bouguer map, Reduction-to-equator, Gravity anomaly, Fualts, Lineaments, Hydrothermal alteration zone.

Introduction
Gravity method is a non-destructive geophysical method that measures the difference in the earth's gravitational field at definite locations. Gravity field is a potential field and thus obey Laplace's equation ($\nabla^2 \phi = 0$). It is based on the measurements on or near the surface of the total earth fields (main field). Gravity surveys can be carried out on the earth's surface as ground gravity survey, in the air, which is known as aero or airborne gravity survey or at sea as marine gravity survey. Gravity surveys are used for large-scale crustal study, where measurements of earth's gravitational field are used for mapping variations in subsurface rock densities, basement topography and sedimentary basin alongside its structural architecture. Gravity interpretations are aimed at delineating the subsurface litho-structures such as geologic contacts and border of geological information originating from sources with different geometries, situated at different depths and with different density properties [1,2].

Gravity method involves the measurements of the gravitational field at a series of different locations over an area of interest.

The goal of gravity survey is to locate and describe subsurface structures from the gravity effects caused by their anomalous densities [3,4]. Gravity methods alongside other methods such as magnetic, electromagnetic induction, electrical resistivity and self-potential methods are commonly used in mineral exploration studies [5]. For this reason, interpretation of these potential field methods assists in delineation of different ore bodies hosted in the shear zones, faults, folds, joints and dykes. Gravity anomalies can be used to help define and estimate the physical property of the source structures that cause the anomalies and indirectly can be mapped as a fault, fractures and contacts which do acts as a channel for mineralizing fluids [6]. Mineral deposits are associated with type of deformation in the lithosphere (crust) and most theories behind ore formation and mode of its occurrence centered on tectonic/deformational phenomenon [7]. Fractures play a dual role in mineralization; as channel ways for the mineralization solution and as loci of deposition of mineralization. Regional features are very important in the selection of targets for mineral exploration, while localize features such as contact zone and shear zones are responsible for the localization of the ore deposit. Primary mineralization in Nigeria is mostly lithologically and structurally controlled [8]. Structures include faults, shear zones (lineament), pegmatites, quartz and quartzite veins. These geologic features could either be directly observed or interpreted from data sets such as airborne gravity data set.

The main target of this study is to use airborne gravity data of Kushaka Schist Belt to identify the lithological and structural features which may control the occurrences of mineralization (metallic minerals), as this is expected to provide better understanding of the formation and location of mineralization in the Kushaka schist belt of northwestern Nigeria.

Location and Geological Settings of the study area

The study area is located in the north-western part of Nigeria and readily defined by Latitudes 10°30’-110 and Longitude 6°30’-7°. The study area forms part of the Kushaka and Birnin Gwari schist Belts in North-Western Nigeria. Generally, the geology of the study area (Fig 1) predominantly consists successive units of gneissic, schistose and migmatitic suites in the western part of the study area. The central part of the study area is cut across by quartz vein which could likely harbor mineralization. Other rock types in the area includes fine-grained and coarse-grained porphyritic granites, amphibolites, biotite granite and so on. The older granite suite in the study area may include embrechitic, anatexitic migmatites, metasomatic and intrusive granites.

The Kushaka Schist Belt known to develop in the Neoproterzoic age is composed of low grade meta-volcano sedimentary rocks and minor igneous rocks [9,10]. The Schist Belt is known to form a number of curving Schist Belts usually separated by domes and gneiss anticlines. Kushaka Schist Belt is known to be cut across by a deeply seated Kalangai fault which serves as a migratory route for mineralizing fluids as it is channeled to subsidiary fractures where they are trapped. The study area is also known to develop between 1100Ma (Kibaran age) and 600 (Pan-African age) from the isotopic dating of syn-late intrusive granitic rocks present in the Schist Belt. Gold mineralization is also known to occur as observed by that primary gold deposits are associated with Kushaka Schist Belt and are spatially related to amphibolites and regional NE-SW to N-S shear zones [11,12]. The gold mineralization occurs in Pan-African (500Ma) orogeny event mainly after granitoid intrusion, regional metamorphism and fracturing episodes in the Belt. They are mainly associated with greenstones, phylites and gneiss often occurring with pyrites, molybdenite, chalcopyrite, galena and chalcocite [9]. The passage of the hydrothermal auriferous fluids is controlled by conjugate fault system (i.e. NE-SW dextral transcurrent and subsidiary NW-SE faults) stemmed from the uplift and ductile to brittle deformation of Late Pan-African orogeny (530Ma) [8,9,13,14].

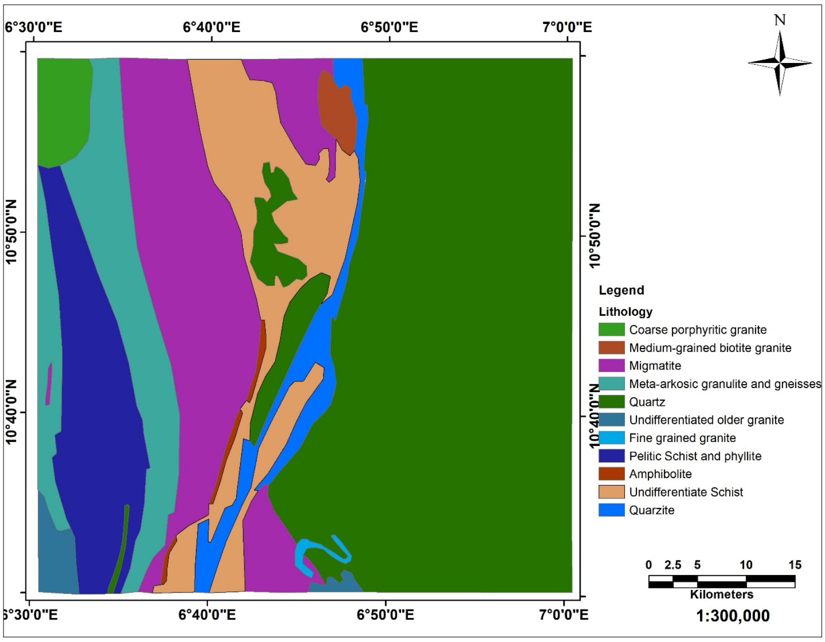

Figure 1: Geological map of the study area (modified after NGSA)

Material and Methods

Digitized airborne gravity data sheet 122 (Kushaka) was acquired from the Nigerian Geological Survey Agency (NGSA). The data were obtained from the survey carried out and readily processed by FUGRO Airborne Survey in 2006. The survey produced high resolution airborne geophysical information for geological mapping and mineral exploration purposes. Some basic corrections such as drift correction, latitude, elevation, terrain/topography, free air, bouguer and Eotvos were carried out on the data by the agency (NGSA). The data was acquired along a series of NW-SE flight lines with a spacing of about 500 m and flight line spacing of about 250m, while the tie lines were about 500m interval with an average of 80m terrain clearance. The first step in this study is the gridding of the potential field data, because the imaging, processing and interpretation require the data to be converted to an evenly spaced two dimension (2D) grid. The data was interpolated using a minimum curvature gridding algorithm (available in the Gesoft Oasis Montaj Software v6.4.2).

The airborne gravity data was used to produce the Bouger map of the study area. The bouguer map is presented as a 2D map (Fig. 2). The reduction-to-equator (RTE) of the airborne gravity data was carried out prior to further processing and analysis for accurate positioning of the anomalies (to remove asymmetry). The RTE data was then upward continued to 1000m to attenuate the high-frequency responses (cultural noises) from thesources on or near the ground surface. Thereafter, several filtered or enhancement maps (Analytical Signal AS, Horizonata Gradient HG, Tilt Derivative TD, Vertical Derivative VD and Euler Deconvolution ED) were generated with the aim of enhancing the signature of the subsurface structural and lithologic boundaries associated with faults, contacts and fractures that eventually assisted in mapping mineralized zones in the study area.

Results and Discussion

Bouguer Map

The analyzed Bouger anomaly map (Fig. 2) ranges from -47.7 to – 34.9mGal denoting variations in density properties of the rocks over the study area. The regions of negative gravity highs (pink/red) correspond to region with high density contrast beneath the surface (-35.4 to – 34.9mGal) while negative gravity lows (blue/light blue) correspond to regions of low density contrast (-47.7 to 40.7 mGal). The northestern part trending west of the study area comprises of very long, moderate to very low wavelength anomalies almost straighten up probably indicating anomalies originating from deeper sources while the closely spaced anomalous bodies in the eastern part of the area indicate anomalies originating from shallow sources. Very high negative anomaly, – 34.9mGal (pink) located at the north, northwestern and southwestern region seen as circular closures indicating the presence of subsurface denser rocks. The north-eastern trending south-eastern parts of the study area show very low negative gravity anomalies (yellow to blue/light blue). This may be attributed to the presence of less dense and deformed rooks in the study area. Structurally, the area is divided into zones, high density zones trending NE-NW-SW and the low density zones occupies the NE trending SE. The areas with high Bouger values which correspond to high-density contrasts may be generated by denser and shallower biotite granitic and gneissic rocks while areas of low density contrast correspond to zones of highly fractured schistose and quartzitic rocks. These observed features may suggest fracture zones, edges and contacts of different rocks in the area.

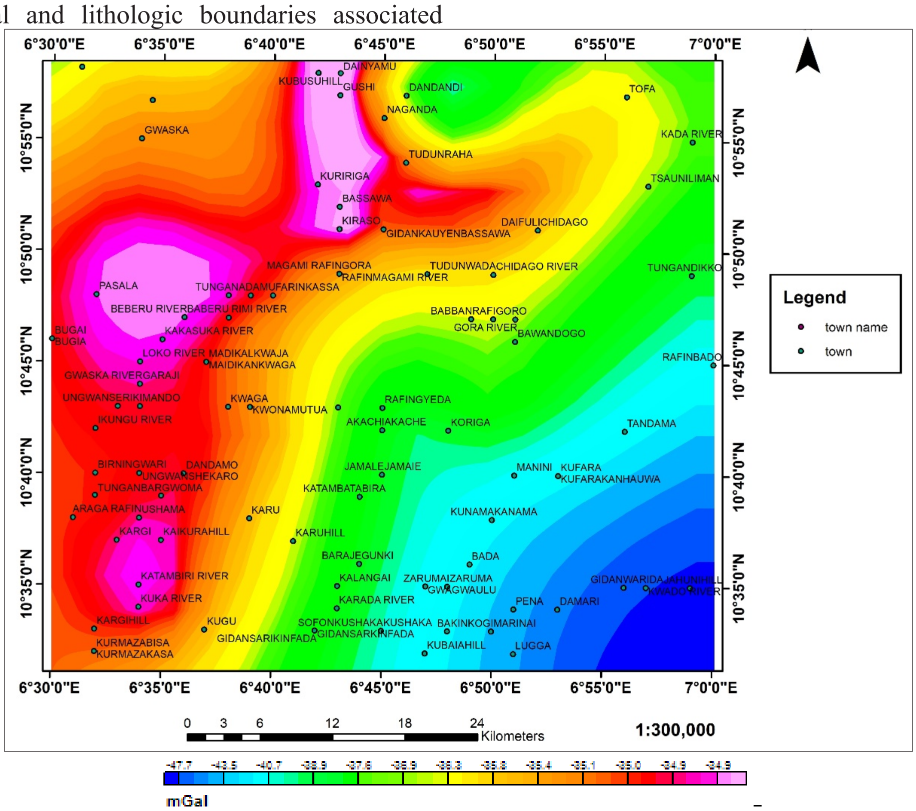

Figure 2: Bouger anomaly map of the study area

Reduction-to-Equator (RTE)

Reduction to equator (RTE) is a useful and effective operation designed to transform bouger anomaly caused by an arbitrary source into the anomaly that this same source would produce if it were located at the pole. It is normally used to centre the peaks of gravity anomalies over their sources by removing the asymmetry from the anomaly. The gravity anomalies in figure 3 (RTE) now have a definite and major structural trend or pattern majorly in the NW-SW-N-S-NE-SE direction.

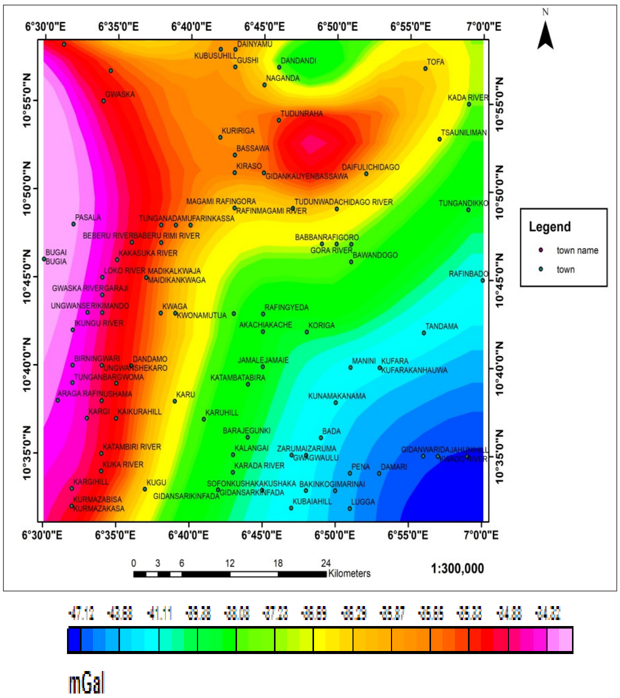

Figure 3: Reduction to Equator

Residual Map

Regional-residual separation was performed on the RTE transformed data by using upward continuation filter (to 1000m) that is available on Geosoft Oasis Montaj version 6.4.2 (HJ) software. The residual gravity field (fig. 4) reflects the distribution of lateral density variations within the crust and highlight concealed lithologies. It displays maximum anomaly value (pink) of 0.68 mGal to 0.8mGal at the north-eastern and western part trending N-S of the area while minimum anomaly value of -0.87 mGal to 0.62 mGal (blue/light blue) occur at the northern, central, southern and southeastern part of the study area. The moderate gravity anomalies (green) is observed trending north-southwards. This area may have been possibly affected by intense metamorphism that produced the observed lineaments/faults in the area meaning that they are possible alteration zones. The low Bouger anomalies (deep-blue) may be attributed to features such as shear zone and structures such as faults and fractures. The prominent positive Bouger anomaly (pink) occurring in the north-eastern and western part trending N-S suggests a major structural trend in the area probably due to increased rock density along the trend or may suggest the presence of subsurface shallower or near surface uplift and denser basement rocks.

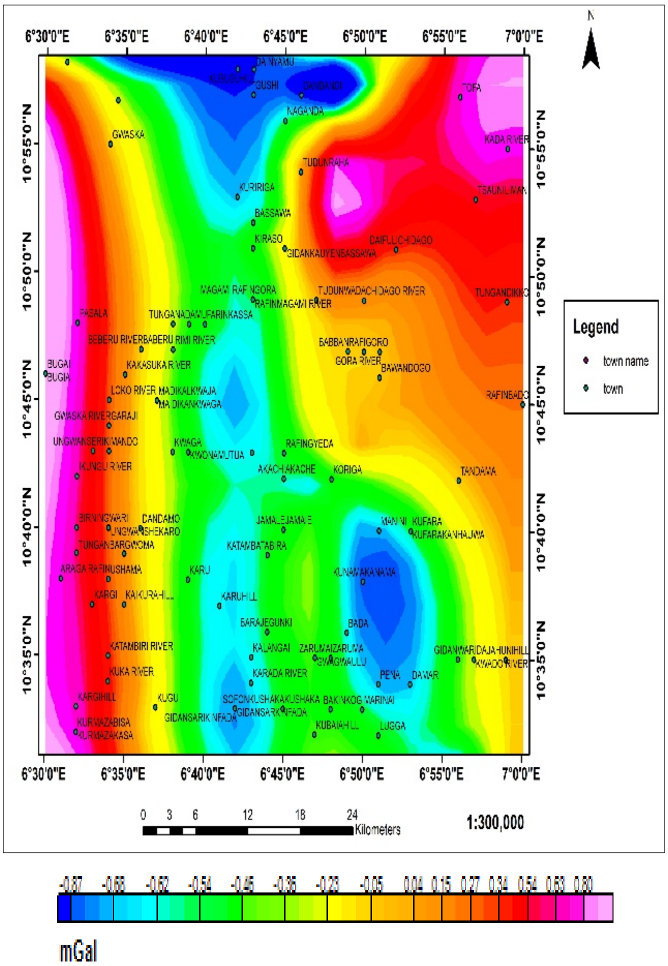

Figure 4: Residual map

Analytical Signal (AS) map

The AS map shows amplitude signal values that ranged between 0.00003 mGal/m and 0.00029mGal/m (Fig 5). The Bouger analytic signal map shows high amplitude signal values that ranged above 0.0013 mGal/m (red-pink) at the western, southern, northern and parts of the central region of the study area. The areas with high analytic signals probably correspond to high-density contrasts generated by denser and shallower biotite granitic and gneissic rock. The north-eastern and central-southern parts showed zones of very low amplitude signal (light-blue to deep-blue) which varies from 0.000003 mGal/m to 0.00006mGal/m. These zones are suggested to be highly fractured schistose, less dense felsic rocks (porphyritic granites) and quartzitic rocks. It marks the zones of weakness that are lineaments /faults, these fractures are most pronounced and deeply penetrating fractures in the area.

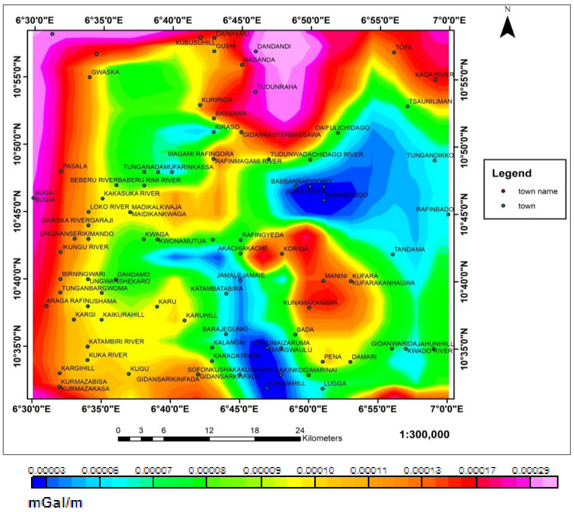

Figure 5: Analytical map of the study area

Tilt Derivative map

The TDR map (Fig 6) enhanced weak gravity anomalies, otherwise overshadowed by stronger structures in the study area. The map delineates several circular to linear shaped high and low frequency gravity anomalies. The central part of the study area with N-S trending low gravity anomaly (blue) correspond to the edges of weaknesses in the study area. Other notable very low gravity anomalies also occur at the south-eastern and northwestern part trending southwest wards of the study area while an isolated zones can also be seen in the northern part. The low gravity regions (low density zones) correspond to granitic/gneissic and quartzitic bodies in the area. Areas in the north-eastern and south-western parts are marked by prominently high gravity anomalies (i.e. high density zones) and may be as a result of the presence of high density structures in the area.

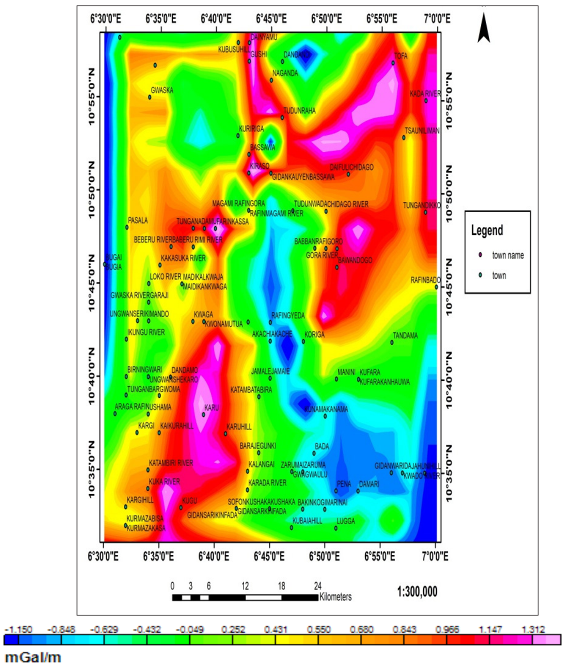

Figure 6: Tilt Derivative map of the study

First vertical derivative map

The first vertical derivative (FVD) map (Fig 7) helps to attenuate broad, more regional anomalies and to enhance local anomalies due to their sensitive response to shallow source bodies and contacts. The first vertical derivatives have some features that are relatively similar to that of the Bouger anomaly map as it consists of series of concentric oval, rounded to sub-rounded high amplitude signals(pink) occurring in the north-eastern part of the study area trending in the NE-SW and N-S directions. There is also lies a high amplitude signals in the western portion of the study area trending N-S. Low, negative amplitude signals (blue) also occur as short, linear and concentric bodies mostly occupying the central, southern and northern parts of the study area which could originate from local sources due to their short wavelengths. The low gravity region could indicate the presence of a fractured zones in the study area.

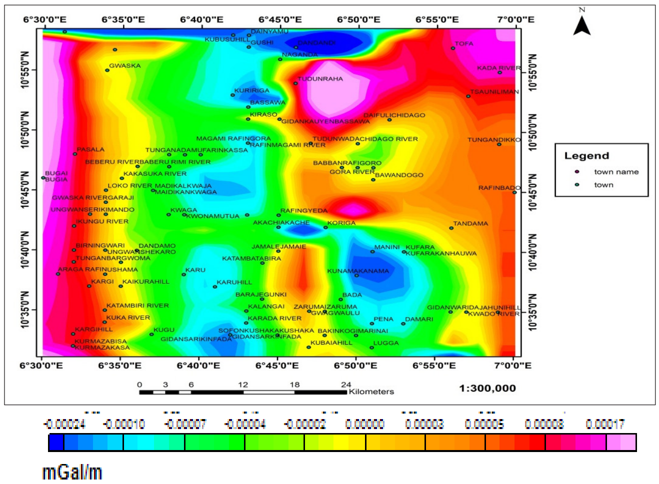

Figure 7: First vertical derivative map

Horizontal gradient map

The horizontal gravity gradient map (Fig 8) shows a notable high positive gravity anomalies (red/pink) in the northern part of the study area trending in the SE-NW. Broadness of the high gradient anomalies may be attributed to the offset in the horizontal gravity gradient from a position directly over a dipping deep anomalies of series of closed spaced boundaries. The continuity of these positive gradient anomalies suggests a regional structural trend in the area. Low gradient (lightblue/blue) anomalies can be seen conspicuous in the southern part of the study area trending northwards and may be attributed to graben-like structures or other depressions likely to be present.

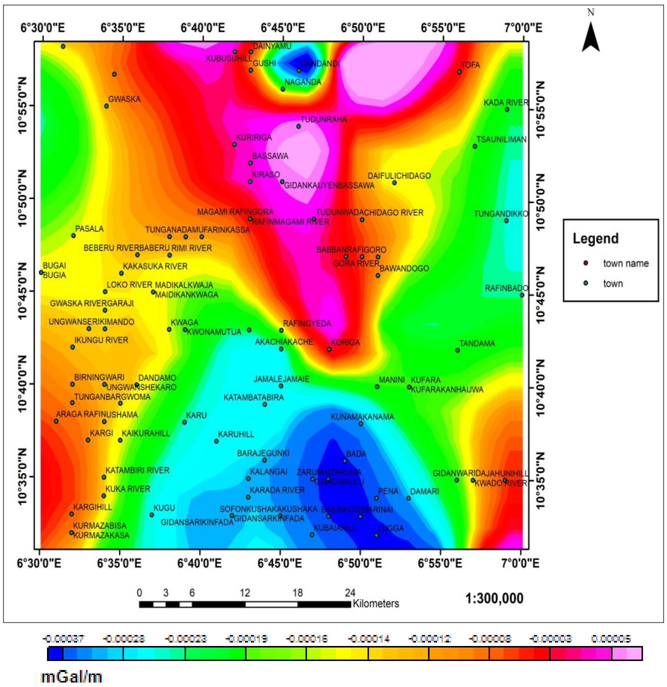

Figure 8: Horizontal gradient map

Gravity Anomaly Depth Determination

Depth estimation of the source bodies that caused potential field anomalies is one of primary concern in gravity prospecting. For the purpose of depth determination in this work, Euler deconvolution method was adopted. Euler deconvolution technique was not only used for delineating trends of subsurface structures, but also for determining the average depth of gravity sources. Euler deconvolution structural indices (S.I) of zero was applied to the Bouger anomaly data used for this study. S.I of zero was used for delineating line cylinder, thin sheet edge, thin sill and dyke. The structural solutions result (Fig. 9) is scanty, but displays two NW-SE trending short linear features. The approximate trend of NW-SE is an indication of tectonic metamorphic phases of Pan-African orogeny that harbor mineralization.

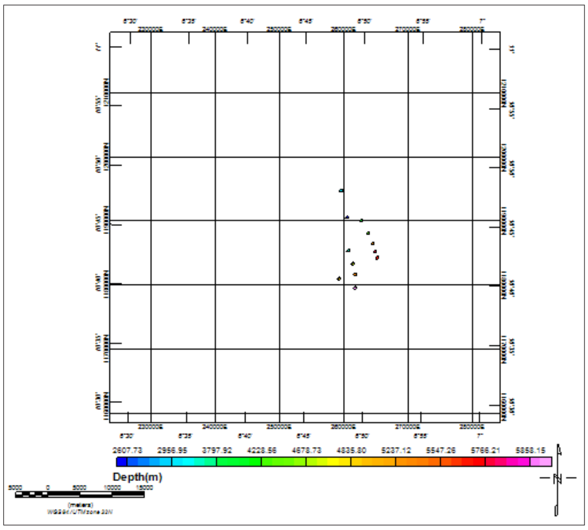

Figure 9: 4.50 Results of Standard Euler Solution (S.I=0) from Gravity Data

These results confirm that the right side of the central part of the study area are characterized by deformed/fractured rocks. The obtained Euler anomalies depths ranged from <2607m to >5858m suggesting that mineralization around the study area is structurally controlled, an evidence of hydrothermal alteration zone.

The Bouger anomaly map was divided into twenty spectral blocks (Fig. 10) to produce their radial spectrum (Figures 11 to 14) and **depth estimate maps.**

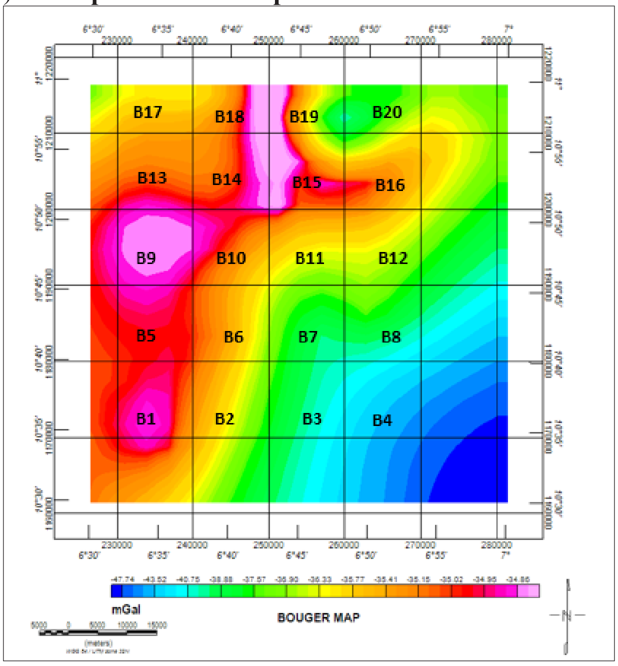

Figure 10: Bouger Anomaly Map of the study Area showing the Overlapping Grids B1 to 20

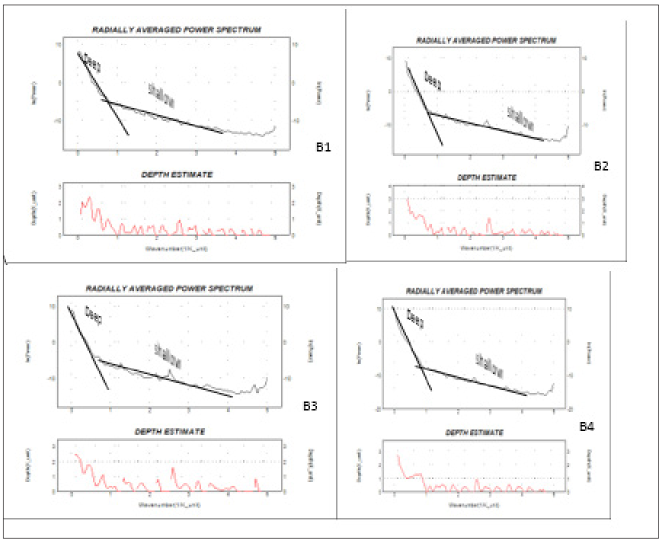

Figure 11: Radially Averaged Power Spectrum Estimates of Depth to Anomaly Sources from the Demarcated Blocks (B1 to B4)

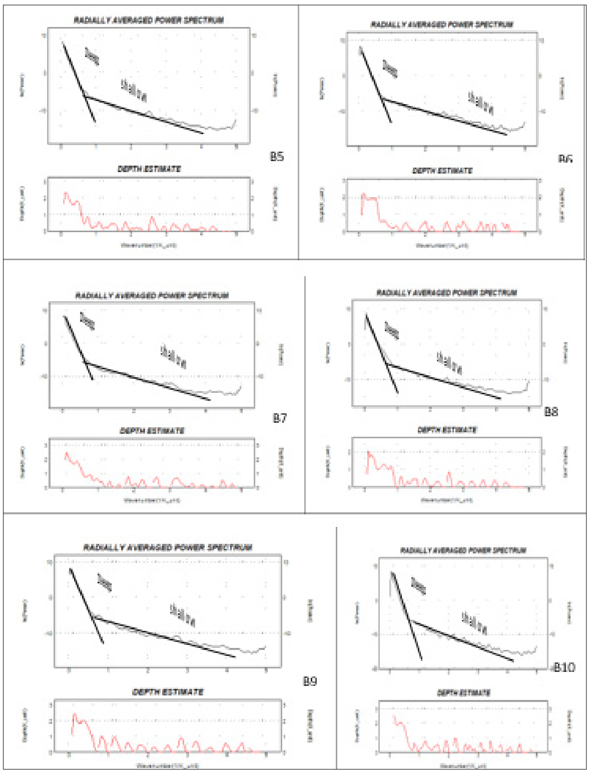

Figure 12: Radially Averaged Power Spectrum Estimates of Depth to Anomaly Sources from the Demarcated Blocks (B5 to B10)

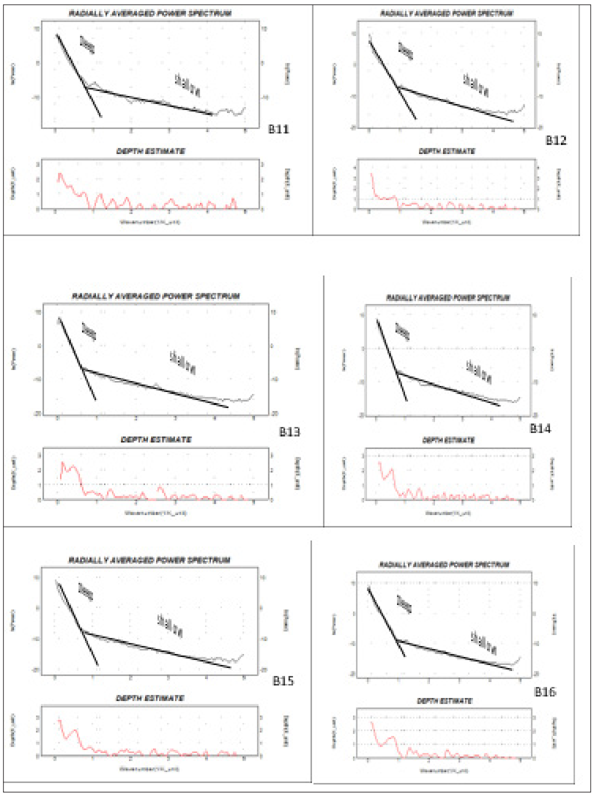

Figure 13: Radially Averaged Power Spectrum Estimates of Depth to Anomaly Sources from the Demarcated Blocks (B11 to B16)

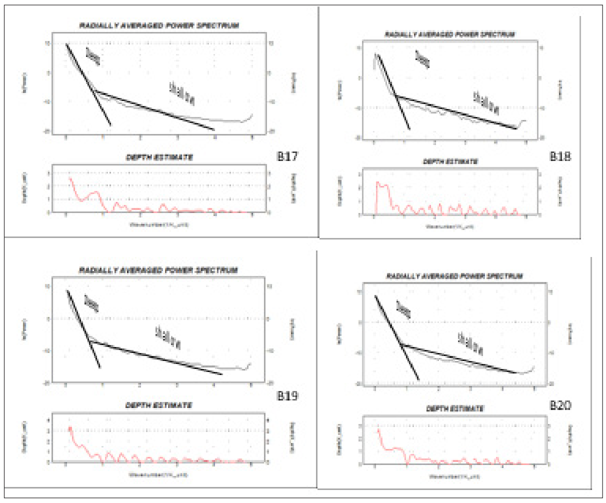

Figure 14: Radially Averaged Power Spectrum Estimates of Depth to Anomaly Sources from the Demarcated Blocks (B17 to B20).

Two depth sources which include shallow and deeper sources were delineated on the 2D spectrum of respective spectral blocks based on wavelengths of density anomalous sources. The coordinates and estimated depths to top of gravity sources for the respective blocks are shown in Table 1. The spectral analysis over Kushaka Schist Belt suggests depth to shallow bodies ranging from 385m to 560 m with an average depth of 440.55 m while the deep sources have depths ranging from 1910m to 2480m with an average depth of 2111.1m; Okpoli [15-17]. From the depth estimation of the gravity data, a deeper depth to basement was evident thereby showing that mineralization over Kushaka Schist Belt is structurally controlled through hydrothermal alteration zones.

Spectral Blocks	Eastings		Northings		Depth (m)	
	(Xmin)	(Xmax)	(Ymin)	(Ymax)	Deep	Shallow
B1	238200	250000	1160000	1180000	2160	470
B2	240000	260000	1160000	1180000	2400	462
B3	250000	270000	1160000	1180000	2135	450
B4	260000	281400	1160000	1180000	2047	477
B5	238200	250000	1170000	1190000	2110	480
B6	240000	260000	1170000	1190000	2100	460
B7	250000	270000	1170000	1190000	2159	390
B8	260000	281400	1170000	1190000	1910	425
B9	238200	250000	1180000	1200000	2250	428
B10	240000	260000	1180000	1200000	2300	560
B11	250000	270000	1180000	1200000	2010	500
B12	260000	281400	1180000	1200000	2300	547
B13	238200	250000	1190000	1210000	2390	487
B14	240000	260000	1190000	1210000	2380	385
B15	250000	270000	1190000	1210000	2420	410
B16	260000	281400	1190000	1210000	2120	400
B17	238200	250000	1200000	1220000	2310	435
B18	240000	260000	1200000	1220000	2250	480
B19	250000	270000	1200000	1220000	2480	565
B20	260000	281400	1200000	1220000	1990	70

Table 1: Depth Estimates of the Study Area Calculated from Gravity Spectral Analysis

Conclusion

In this study, several enhancement techniques were carried out on the airborne gravity data to reveal the locations, edges/boundaries, trends, and depths of gravity anomalies over Kushaka Schist Belt (using Kushaka sheet 122), Northwestern Nigeria. The analyzed results of the bouguer map of Kushaka show the distribution of the gravity anomalies and magnitudes of the concealed shear and weak zones being characterized by low to very high gravity anomalies. The upward continued bouger anomaly maps at distance of 3km (3000m) reveal the regional trends so as to generate a subsequent residual field where several filtering operations were carried out. Furthermore, the analytic signal gravity and its superimposed maps reveal areas with low to high amplitude signals. Low amplitude regions are suggested to be dominated by highly fractured schistose, quartzitic rocks and fractures. On the other hand, high amplitude regions are likely occupied by denser biotite granitic and gneissic rocks. Also, the FVD gravity anomaly map shows low gravity region which indicate the presence of a fracture. The horizontal gravity gradient map shows high, positive gravity regions which may be attributed to the presence of a regional structure trend in the area. Low gradient anomalies can also denote presence of graben-like structures or other geological depressions. The spectral analysis over Kushaka schist Belt suggests depth to top for shallow bodies ranging from 385m to 560 m with an average depth of 440.55 m while the deep sources have depths ranging from 1910m to 2480m with an average depth of 2111.1m. The obtained Euler anomalies depths ranged from <2607m to >5858m. The structural solution (S.I=0) result displays two NW-SE trending short linear features. The approximate trend of NW-SE from the Euler solutions shows an indication of tectonic metamorphic phases of Pan-African orogeny that harbor mineralization.

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