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Full Length Research Article

PSEUDO-GRAVITY INTERPRETATION OF HIGH-RESOLUTION AEROMAGNETIC DATA OVER NORTHERN BIDA BASIN AND ENVIRONS, NORTH-CENTRAL NIGERIA: IMPLICATION FOR MINERAL EXPLORATION

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ABSTRACT

In view of the ongoing interest of the Federal Government of Nigeria to diversify the country's economy by moving away from dependence on fossil fuel to solid mineral sector; this research work was carried out to map potential areas of mineralization within the northern sector of Bida basin and environs. High resolution aeromagnetic data over the study area was subjected to regional residual separation, pseudo-gravity transformation and CET structural analysis using Oasis Montaj software. Result of the pseudo-gravity transformation showed anomalies ranging from -0.14 to 0.15 milligals. High density anomalies ranging from 0.11 to 0.15 milligals, observed in areas around Tegina, Kagara, Bako, Pandogari, Gurmana, Kuta, Bida, Wuya and Jima have been interpreted as mineralized zones. The lineament map revealed a major structural feature trending in the NNE-SSW direction cutting across Tegina, Kagara, Bako and Pandogari. This structural feature has shaded more light on the relationship between geologic structures and deposit of interest in the study area. Therefore, the NNE-SSW structural trend of anomalies within these zones depicts structurally controlled mineralization and is conformable with the NNE-SSW general trend of the Nigerian Schist belts. A ground truthing exercise over an extension of one of the anomalies at Anguwan Dorawa, southwest of Tegina town lead to the discovery of a gold mining site where mineralization is hosted within the schist phyllite and quartzite veins.

Keywords: High resolution aeromagnetic, Pseudo-gravity, Tegina town, Anguwan Dorawa, Gold mineralization

INTRODUCTION

In the field of mining geophysics magnetic method is used in preliminary exploration of mining regions and for detailed studies of igneous intrusions, igneous dikes, and contact-metamorphic zones in relation to which various types of ores may occur. Iron ore deposits of magnetite and, in some cases, hematite, and also numerous forms of occurrences of sulphide ore bodies, where some minerals present are appreciably magnetic, can be successfully mapped using magnetic method. In an indirect way, magnetic method can be used to locate non-magnetic minerals if they are associated with magnetic minerals such as magnetite, ilmenite or pyrrhotite. This applies to gold or platinum bearing placer deposits where magnetite is present. In view of the ongoing interest of the Federal Government of Nigeria to diversify the country's economy by moving away from dependence on fossil fuel to solid mineral sector. Furthermore, Orazulike (2002) and Obaje (2009) avowed that every state of the Federation is blessed with at least one or more mineral resources. In these regards, this research work was carried out to map potential areas of mineralization from interpretation of high resolution aeromagnetic data within Bida basin and environs.

The study area lies between Longitudes 5^{0}00'00" – 7^{0}00'00"E and Latitudes 8^{0}30'00" – 10^{0}30'00"N and covers the northern sector of Bida basin and parts of the north-central and south-western Basement Complex of Nigeria (Fig. 1).

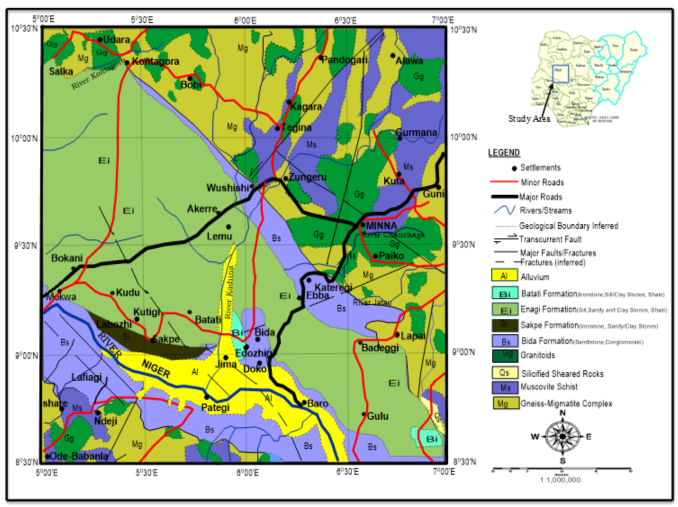

Fig. 1: Geological map of Northern Bida basin and environs. Modified from (GSN, 1994; Obaje et al. 2013)

The area comprises of Precambrian Basement rocks consisting of Migmatite-Gneissic Complex dated Archean to early Proterozoic [2,700 to 2,000 Ma], and the Schist being part of the Zungeru – Birnin Gwari Schist belt. Also noticeably in the area are the Older Granite suites, believed to be pre-, syn- and post-tectonic rocks which cut both the migmatite-gneiss complex and the Schist belts. They range widely in age (750–450 Ma) and composition. They represent a varied and long lasting (750–450 Ma) magmatic cycle associated with the Pan-African orogeny (Obaje et al. 2009).

The Basement complex rocks in the study area flanks a NW-SE trending sedimentary basin refers to as the Bida basin. The stratigraphic sequences within the basin, comprises from the oldest the Bida, Sakpe, Enagi and Batati Formations. The Bida Formation is dated Campanian – Maastrichtian (Nwajide, 2013); and consists of basal conglomerate and a successions of cross-bedded white to grey sandstones intercalated with koalinitic clays which were derived from deeply weathered Basement Complex rocks (Nwajide, 2013). The Sakpe Formation which is Maastrichtian in age (Whiteman, 1982); comprises mainly of oolitic and pisolitic ironstones with sandy claystones locally at the base, followed by dominantly oolitic ironstone exhibiting rapid facies changes across the basin (Obaje et al. 2013). The Enagi Formation consists of siltstone and subordinate sandstone, claystone and siltstone/sandstone intermix. The Enagi Formation is also associated with a shale sequence (Kudu Shale Member), a dark-grey to black shale unit (Obaje et al. 2013). Maastrichtian age has been suggested for Enagi Formation (Nwajide, 2013). The Batati Formation constitutes the uppermost units in the sedimentary sequence and consists of argillaceous, oolitic and goethitic ironstones with ferruginous claystone and siltstone intercalations and shaley beds occurring in minor proportions, some of which have yielded nearshore shallow marine to fresh water fauna (Obaje et al. 2013).

MATERIALS AND METHODS

Materials

Sixteen half degree high resolutions aeromagnetic data provided both in grid and data based format including IGRF removed as at January 2010, each on a scale of 1:100,000 were purchased from the Nigerian Geological Survey Agency in Abuja. The data sheets comprises of Kontagora (sheet 140), Bobi (sheet 141),Tegina (sheet 142), Alawa (sheet 143), Fashe (sheet 161), Akerre (sheet 162), Zungeru (sheet 163), Minna (sheet 164), Mokwa (sheet 182), Egbako (sheet 183), Bida (sheet 184), Paiko (sheet 185), Share (sheet 203), Pategi (sheet 204), Baro (sheet 205) and Gulu (sheet 206). The data was acquired by Fugro Airborne Survey Ltd. in the year 2004-2009 as part of a programme aimed at assisting and promoting mineral exploration in Nigeria using 3X Scintrex CS3 Cesium Vapour Magnetometer. The following flight parameters were utilised during the survey; flight line spacing was 500 meters, terrain clearance was 80 meters, flight direction was in the NW-SE, tie line spacing was 2 kilometres and tie line direction was in the NE-SW direction. Software used for data analysis is the Oasis Montaj version 7.0.1.

Methods

Pseudo-gravity transformation is useful in interpreting magnetic anomalies, not because a mass distribution actually corresponds to the magnetic distribution beneath the magnetic source, but because gravity anomalies are in some ways more instructive and easier to interpret and quantify than magnetic anomalies (Blakely, 1995). Baranov (1957) was the first to apply pseudo-gravity transform to magnetic data using pseudo gravity transformation. In this method, the apex of the magnetic anomalies was shifted over the source body and the distortion due to the earth's magnetic field was easily removed. In order to locate and outline crustal magnetic sources, transformation techniques were applied to the data as magnetic anomalies are rarely centred above their source. The pseudo-gravity transform was applied to the residual of total magnetic intensity data using the Fast Fourier Transform (FFT) filter extension available in Oasis Montaj version 7.0.1 environment. The pseudo-gravity transformation follows from Poisson's relation between the magnetic potential and the gravitational field considered as a body with uniform magnetization and density occupying a volume *v* Baranov (1957). Then magnetic scalar potential is:

$$V(p) = -M\nabla_p \iiint_v \frac{1}{d}\, dv \tag{1}$$

Where p is the observed point, d is the distance from p. The gravitational potential is:

$$U(p) = G\rho \iiint_v \frac{1}{d} dv \tag{2}$$

Where G is the gravitational constant and ρ the density, combining equation (1) and (2) then:

$$V(p) = -\frac{1}{G\rho} M\nabla_p U = -\frac{1}{G\rho} M g_M \tag{3}$$

g_M is the component of gravity in the direction of magnetization and equation (3) is the equation for the Poisson's relationship.
The outcome of the transform was a pseudo-gravity map which was subjected to 1 km upward continuation to filter out shallow source anomalies. The upward continued map was utilized for mapping of potential areas for mineralization.
CET grid analysis is an extension in the Oasis montaj environment that analyses the texture of an image to detect lineaments along ridges and edges, as well as areas of structural complexity in any geophysical data, sensitive to geologic structures. The residual data was subjected to this process to delineate geologic structures and the outcome was a lineament map. The structural analysis has shaded more light about the practical relationship between geologic structures and deposit of interest in the study area.

RESULTS

The total magnetic intensity map (Fig. 2) has magnetic anomaly ranges from 32,932.11 nT to 33,110.48 nT. The residual magnetic map over the study area (Fig.3) obtained by subjecting the total magnetic intensity data to regional residual separation is characterised by positive and negative anomalies scattered in different parts of the map. The positive anomalies with amplitude ranges between 11.83 nT to 124.08 nT (light blue to magenta colours),were observed in places around Kontagora, Zungeru, Wushishi, Tshipo, Dabba, Batati, Sakpe, Bokaji, Katcha, Rogun Kpada, Gulu, Baro, Isanlu Esa and Koro. The negative anomalies with amplitude range of -37.75 nT to -4.55 nT (deep blue colours) were observed in areas around Ibeto, Pandogari, Tegina, Kuta, Lemu, Marara, Doko, Agie, Pategi and Agena..

The pseudo-gravity map (Fig. 4) have anomalies ranging from -0.14 to 0.15 milligals. On this map, three prominent zones labelled **A**, **B** and **C** recorded high anomaly ranging from 0.11 to 0.15 milligals. The high density anomalies depicted by anomaly **A**, **B** and **C** was observed in area around Tegina, Kagara, Bako, Pandogari, Gurmana, Kuta, Bida, Wuya and Jima. This high anomaly perhaps resulted from mineralization and considering the N-S to NNE-SSW structural trend of anomalies within these zones, the mineralizations are indeed structurally controlled.

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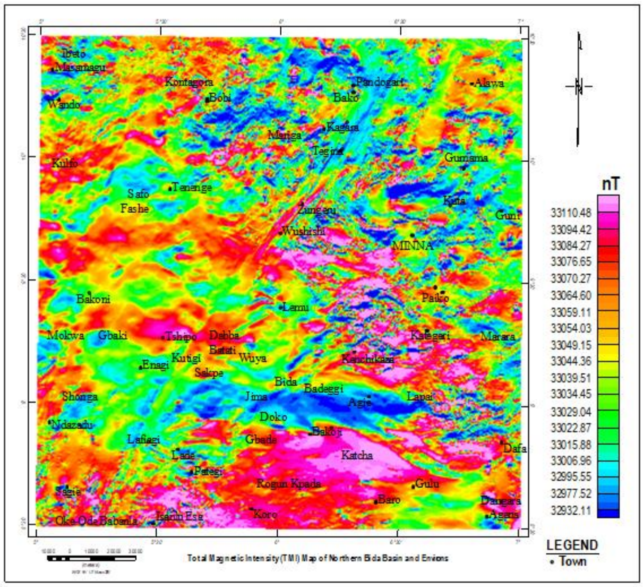

Fig. 2: Total Magnetic Intensity Map of Northern Bida Basin and Environs

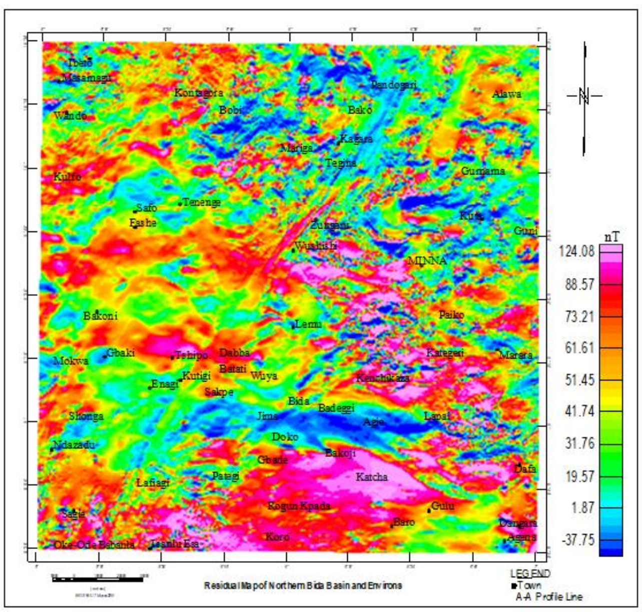

Fig. 3: Residual Magnetic Map of Northern Bida Basin and Environs

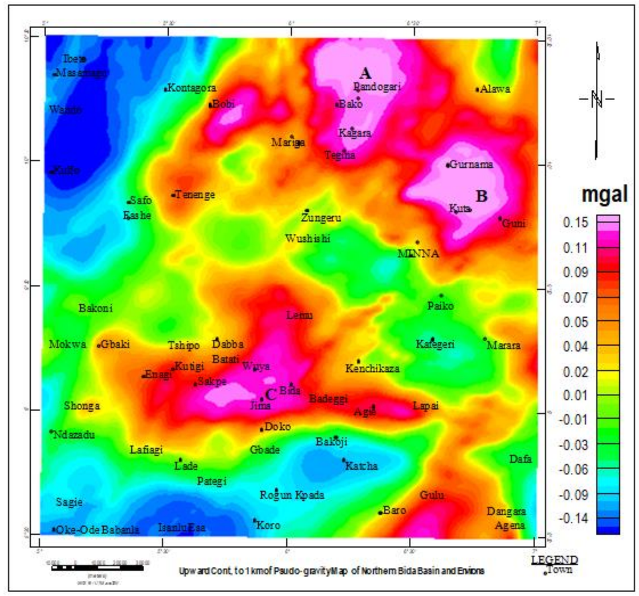

Fig. 4: Pseudo-gravity Map of Northern Bida Basin and Environs (upward continued to 1 km)

The lineament map (Fig.5) revealed linear and curve linear features over the north-central and south-western Basement Complex exposures. Sandwich between this is the sedimentary basin showcasing minor linear features. The most conspicuous among them is a linear feature traversing Oke-OdeBabanla, Lafiagi, Wushishi, Zungeru, Tegina, Kagara and east of Bako and Pandogari towns. This linear feature trending in the NNE-SSW direction coincides with the structural trend of anomalies as interpreted from the pseudo-gravity map. The lineaments have been interpreted to depict geologic structures such as faults veins, joints and foliations.

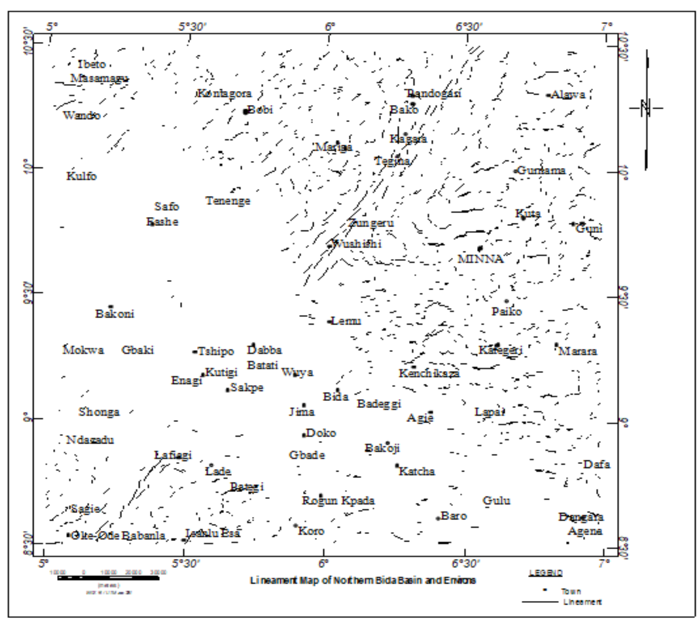

Fig. 5: Lineament Map of Northern Bida Basin and Environs

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To pinpoint one of the interpreted anomalies on ground (anomaly **A**), sometimes in June, 2017 a ground truthing mapping exercise was carried at Anguwan Dorawa located about eight kilometres (8km) south-west of Tegina. Artisanal gold mining site was observed in the area (Fig. 6) which is an indication of mineralization around this area as suggested by the pseudo-gravity data.

Fig, 6: Artisanal Miners at Anguwan Dorawa Gold Mine SW of Tegina

Field observations in the study area revealed that the gold mining site is located within the Schist belt, precisely the Zungeru-Birnin Gwari Schist belt. On the surface the geology comprises of fine to medium grained quartzo-feldspathic rocks interbedded with Amphibolites and quartzite; while rock fragments excavated from the subsurface by the artisanal miners, revealed a highly banded phyllites and high grade biotite-muscovite schist rock units.

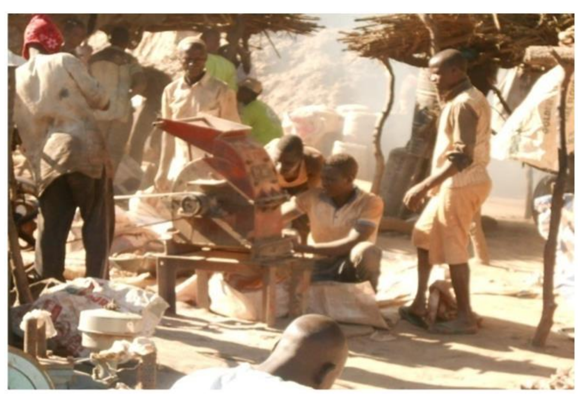
Mining operations in this site are carried out by artisanal miners with mining pits located at intervals and generally trending in the NNE-SSW direction (Fig. 6). At this mining site, the artisanal miners' uses locally fabricated tools such as diggers and shovels for their mining operations. Mining of gold is done by means of digging vertical pits down the subsurface with horizontal tunnels within the host rock of gold mineralization. On the surface, the mining pit has a dimension of about 1.5 by 2 m and this size increases with depth. The miners have to excavate to a depth of about thirty meter in to the sub-surface before encountering the mineralized zone. This process continued until the artisanal miners get to a depth where the zone of mineralization pinched out.

The stages involved in extracting the mineral from its host rock to its final sell out point include:

i. Mining of mineral from its host rock (Fig. 6)
ii. Crushing of the host rock material in to smaller size to a diameter of about 30 mm or less using locally fabricated crusher machines. (Fig. 7a)
iii. Sieving of the crushed rock to get finer materials using perforated head pan. (Fig. 7b)
iv. Grinding of the sieved materials in to powdery form to reduce the surface area using locally fabricated grinding machines. (Fig. 7c)
v. Separating the finer sand/clay materials from the gold metal using decantation filtration method. (Fig. 7d)
vi. Further Separation of the finer sand/clay materials from the gold metal with the aid of a head pan using decantation filtration method. (Fig. 7e)
vii. Mixing in a head pan the residue from the decantation process with mercury metal . At this stage further process of separation using decantation process continued until all the dust particles are washed out living only the gold metal attracted within the mercury. (Fig. 7f)
viii. The final stage is to put the mercury in a cone like foil paper with little opening at the apex of the cone and subjecting the foil paper to heat. At a temperature above 100^0C the mercury metal melts out of the foil paper living only the gold metal

a. Artisanal miners crushing the host rock

b. Sieving the crushed rock materials



c. Grinding into powder the crushed rock materials

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d. Separating Gold from sandy-dayey materials using decantation method

e. Further decantation process using head pan

f. Mixing the residue with mercury metal

Fig. 7(a-f): Stages in processing of Gold to finish product at Anguwan Dorawa Gold mine SW of Tegina, Nigeria.

DISCUSSION

The magnetic field of northern Bida basin and environs as revealed from the residual map ranging from 124.8 nT to – 37.75 nT is a contribution of high (positive), medium and low (negative) magnetic anomalies. The high magnetic anomalies are indicative of basement rocks exposure on the surface or near the surface (Keary *et al.,* 2002). The central part of the study area exhibiting medium to low magnetic anomalies are attributed to basement rocks at depth overlain by thick sequence of sedimentary rocks (Keary *et al.,* 2002).

In this study high density anomalies depicted by anomaly **A**, **B** and **C** was observed in area around Tegina, Kagara, Bako. Pandogari, Gurmana, Kuta, Bida, Wuya and Jima. The NNE-SSW trend of these anomalies is conformable with the NNE-SSW trend of structures as interpreted from the lineament map and the general trend of the Nigerian Schist belt. Anomaly **A** extending from Tegina, Kagara, Bako and Pandogari extends for about 25 km, anomaly **B** interpreted over Gurmana, and Kuta has an approximate dimension of 30 by 30 km and it extends in the NNE-SSW direction, while anomaly **C** observed over Bida, Wuya and Jima has an approximate dimension of 11 by 21 km and extends in the NE-SW direction. These high density anomalies ranges were interpreted to depict mineralized zones. Kankara and Darma (2016) and the Ministry of Mines and Steel Development in Nigerian's Mining and Metal Sector Investment Promotion Brochure (2016) reported the occurrence of mineralization of gold in localities like; Maru. Anka, Malele, Tsohon Birnin Gwari and Kwaga; Bin Yauri, Gurmana, Okolom-Dogondaji, Iperindo, Minna, Kuta etc. But the occurrence of gold mineralization in Anguwan Dorawa about eight kilometres south-west of Tegina is not well documented in literature. Kankara and Darma (2016) also reported that occurrence of gold mineralization in Nigeria occurs both as placer and primary vein deposit with associated minerals like lead zinc (Galena), copper sulphite (sphalerite), chalcopyrite, magnetite etc. These authors went further to report that the primary gold mineralization occurred within the Schist belts in veins, stringers, lenses, reef and similar bodies of quartz and quartzo-feldspathic rocks.

The geological map of the study area showed that Tegina, Kagara, Gurmana and Kuta areas were underlain by Schist belts trending in the NNE-SSW direction. Field work in Anguwan Dorawa gold mine further confirmed that, Schist is the host rock for mineralization. In this mining site, gold mineralization is hosted by schist phyllites and quartzite veins of the Zungeru-Birnin Gwari Schist belt. Field study also revealed that gold mineralization occurs in association with lead-zinc (galena) and biotite as observed from hand specimen sample of rock hosting the minerals. With the reported occurrence of gold mineralization in Kuta and Gurmana which was picked by the pseudo-gravity anomaly map as anomaly **B**, and personal field observation in Anguwan Dorawa gold mine south-west of Tegina falling within anomaly **A**, by extension anomaly **C,** infers occurrence of gold and associated minerals around Bida, Wuya and Jima. The gold mineralization in Anguwan Dorawa south-west of Tegina is believed to have extended to Kagara, Bako and Pandogari. The lineament map showcasing a major structural feature trending in the NNE-SSW, extending from Oke-Ode Babanla. Lafiagi and traversing Wushishi, Zungeru, Tegina, Kagara, east of Bako and

Pandogari towns is an indication that mineralization in these areas settled within this major structure._The NNE-SSW trending direction of gold mines as observed in Anguwan Dorawa gold mine which concur with this structural trend portrait that mineralization in these areas were structurally controlled. Gold and its associated mineralization in Tegina, Kagara, Bako, Pandogari, Gurmana and Kuta were believed to be primary mineralization considering their occurrence in the Basement Complex terrain. Whereas that in Bida, Wuya and Jima occurring in the sedimentary basin as interpreted from the pseudo-gravity map occurred as placer deposits. Other mineral occurrence in the study area as reported by Nigerian Ministry of Mine and Steel Development (2016) include: quartz, feldspar, granite, talc, gemstones, manganese, iron ore, marble, tantalite etc.

Conclusion

The interpreted anomalies from pseudo-gravity map showed high density anomalies around Tegina, Kagara, Bako, Pandogari, Gurmana, Kuta, Bida, Wuya and Jima. The occurrence of gold and its associated mineralization in Anguwan Dorawa south-west of Tegina hosted within schist phyllites and quartzite veins is considered to be structurally controlled. The mineralization is believed to have extended to Kagara, Bako and Pandogari considering the relationship between geologic structures and mineralization. Areas around Gurmana, Kuta Bida, Wuya and Jima are believed to host gold and its associated mineralization as interpreted from the pseudo-gravity map. In respect of the aforementioned the author recommends that, anomalies identified on the pseudo-gravity map should further be investigated using detailed geophysical investigation (gravity, electrical and core drilling) to further confirm the occurrence of gold and associated mineralization.

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