Qualitative Interpretation Of Aerogravity And Aeromagnetic Survey Data Over The South Western Part Of The Volta River Basin Of Ghana

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Abstract: The study area (South western part of Volta River Basin of Ghana), covering an area of 8570 km^2, which is one-eleventh the area of the Volta River basin of Ghana, has been subjected to numerous academic research works but geophysical survey works because of virtual perceptive reasons. It is now believed to overly mineral-rich geological structures, hence, the use of magnetic and gravity survey methods to bring out these mineral-rich geological structures.Geographically, it (study area) is located at the south western part of the Voltaian basin at latitudes 07^o 00' N and 08^o 00' N and longitudes 02^o 00' W and 01^o 00' W respectively. Airborne gravity and magnetic survey methods were employed in the data collection. The field data correction and error reduction were applied to the two raw data on the field after which, Geosoft Oasis Montaj 7.01, Encom Profile Analysis (P.A) 11 and 13, Model Vision 12 and ArcGIS 10.0 were used to process, enhance (e.g. reduce to pole at low latitude, first vertical derivative etc.), model the reduced and corrected airborne magnetic data, and also, to produce maps from them (data). Low-to-moderate-to-high gravity and magnetic anomalies were obtained in the complete Bouguer anomaly (CBA) and total magnetic intensity (TMI) reduced to pole at low latitude with many of these anomalies trending NE-SW by which the Birimian Metasediments and Metavolcanics can be said to be part of the causative structures of these anomalies with cross-cut NW-SE faults. From the quantitative point of view, the intrusive granitic bodies of the study area have a mean depth location of 1.7 km, while the isolated anomaly is located at a depth of 1.4 km (computed from Euler deconvolution). The NE-SW trending anomalies show the trend direction of their causative structures which are the basement rocks and the basinal intrusive bodies.

Keywords: Aeromagnetic, Aerogravity data, Qualitative,interpretation, Volta River basin, Anomalies, Birimian, Tarkwaian**,** Voltaian Supergroup, Eburnean plutonic suite.

INTRODUCTION

Each geophysical method investigates a unique physical property of the crustal Earth which tends to solve a peculiar problem within the Earth's subsurface, while in some cases, a combination of two or more of these methods gives better results (Keary et al., 2002). Magnetic and gravity methods are mainly used in metalliferrous minerals exploration, but in some situations, electromagnetic induction, electrical resistivity, induced polarisation and self-potential methods are employed together with the gravity and magnetic methods for better results (Keary et al., 2002). Therefore, interpretation of airborne gravity and magnetic data is a very vital tool in the mineral exploration industry. The geology of the Voltaian Basin and its bordering Dahomeyide orogenic belt, since 1977, have been mainly of academic interest because of the perception that, they do not contain any significant economic resources Kalsbeek (2008).

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This negative perception about the Voltaian basin changed not too long ago after the Geological Survey Department of Ghana, under the European Union- funded Mining Sector Support Programme (MSSP) in 2005, contracted Fugro Airborne Surveys Ptys Ltd., to conduct a series of airborne geophysical surveys (magnetic, electromagnetic, radiometric and gravimetric) over the Voltaian and the Keta basins Kalvig (2008).The new findings by Fugro Airborne Surveys called for further works on the Voltain basin to have results that may align with their (Fugro Airborne Surveys Ptys Ltd.) findings. Ore bodies, which may host most of the economic minerals in the study area (Voltaian basin), are expected to be denser and also, have higher magnetic susceptibilities than their surrounding bodies (Voltaian Basin sediments), making them coincidentally reveal significant anomalies (both gravity and magnetic) when ran over by both gravity and magnetic survey methods (Keary et al., 2002). Airborne gravity and magnetic (aeromagnetic) data may be able to qualitatively and quantitatively reveal, compare and interpret the potential fields (gravitational and magnetic) anomalies that may come from the ore bodies hosted in the shear zones, faults, folds, joints, dykes and intrusive igneous rocks within the sediments of the study area (Voltaian Basin). The study area was flown with separate flight specifications for both magnetic and gravity surveys. For flight line spacing, 500 m was used for magnetic while 5000 m was used for gravity; for flight line direction, 135° was used for magnetic survey while 312° was used for gravity survey; for survey height, 75 m and 859 m were separately used for magnetic and gravity surveys respectively. The collected data (magnetic and gravity) were corrected for field operational errors on the field before further corrections and enhancements, like, heading, lagging, reduction to pole (RTP), analytic signal (AS), first vertical derivative (1VD), tilt horizontal derivative (HD), etc. These corrected and enhanced data were left in gridded images, and further analysis and interpretations were drawn from them (images). Birimian and Dahomeyan basements rocks might have sourced most of the gravity anomalies while the intrusive granatoids contributed largely towards the existence of the magnetic anomalies of the study area. The airborne gravity anomalies depicted deeper and broader structures while the magnetic anomalies brought out the shallower and small intrabasin structures. The dykes, found to be few within the study area, trend N-S of the study area, and tend to divide the area into almost equal halves. All these structures are potential mineral-hosting zones which are targets in mineral exploration. Since Ghana's economy is hugely influenced positively by the mining sector, exploring these structures may further boost the country's socioeconomic status and that of the world as a whole.

GEOLOGICAL SETTINGS

The study area lies unconformably above the Eburnean basement of the West African Craton. It thickens eastwards, towards the centre of the Volatain basin. It is interpreted in past literature as a foreland basin, formed by sediment infill as the region underwent extension, resulting from the subduction of the West African Craton's eastern margin during the Neoproterozoic era (Jordan et al., 2009a). The basement is overlain by the Voltaian Supergroup; Khawu-Morago, Oti-Pandjari and the Obosum groups (Bertrand-Sarfati et al., 1991). The Khawu-Morago group outcrops at the northwestern and southern parts of the study area, while its topography reflects the basement, it unconformably drapes over and overlies part of the Oti Group (Couëffé and Vecoli, 2011). The Obosum or Tamale group (upper layer of the Voltaian Supergroup) largely occupies the study area's central part (Couëfféand Vecoli, 2011).

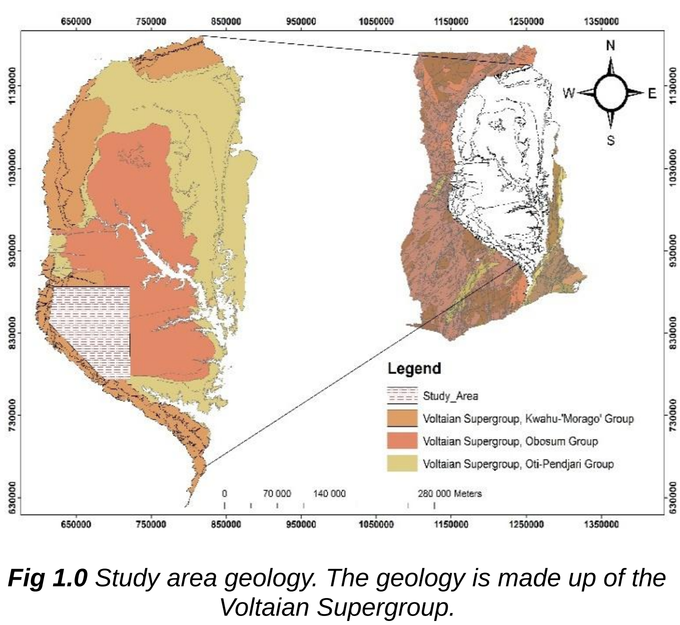

Fig 1.0 *Study area geology. The geology is made up of the Voltaian Supergroup.*

LOCATION AND ACCESSIBILITY

The study area is located at the south western corner of the Volta River Basin and covers an area of approximately 8570 km2. Its south western part is almost 200 km from Accra while its southern part is 50 km from Kumasi. It is situated at the centre of the political regional boundary that separates the Brong Ahafo and Ashanti regions. Although there are no major cities and towns within the study area, Kintampo (in Brong Ahafo region) is almost 5 km beyond it in north eastern part, while Ejura (in Ashanti region) is located within it. It is bound by latitudes 07^o 00' N and 08^o 00' N and longitudes 02^o 00' W and 01^o 00' W.

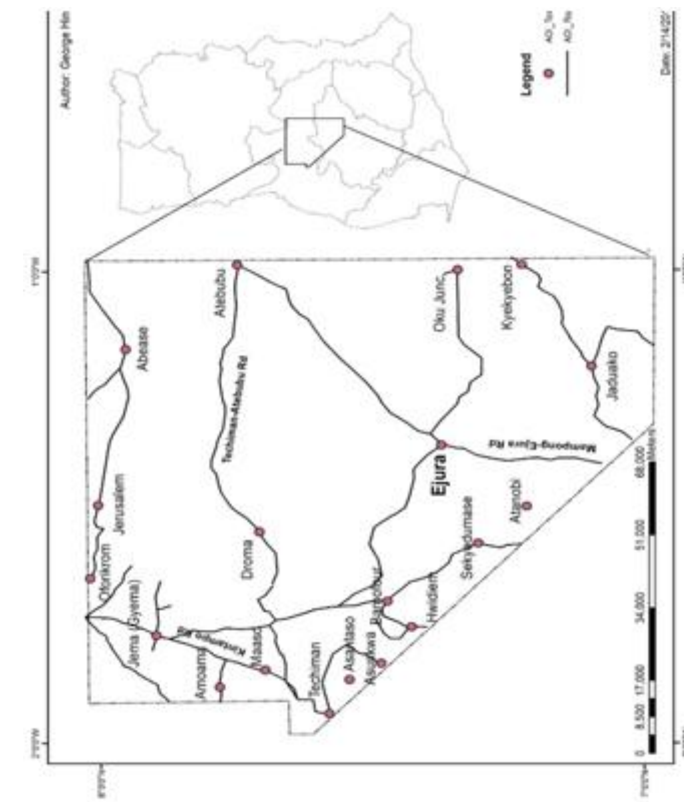

Fig 2.0 *Location and accessibility Map. It shows the road networks and some towns within study area.*

MATERIALS AND METHODS

Data Acquisition

Under the supervision of the Geological Survey Department of Ghana, Fugro Airborne Surveys Ltd., conducted airborne geophysical survey over the Volta and Keta Basins to collect airborne geophysical data from December 2005 to April 2008. This project was in connection with the European Union sponsored Mining Sector Support Programme (MSSP) for Ghana Two separate projects constituted the whole airborne geophysical survey. The first project was executed through five separate phases, and it was within the phases 2 and 3 that a high resolution magnetic gradiometry survey was conducted together with 256-channel gamma-ray spectral and regional GEOTEM electromagnetic survey. Fugro Airborne Surveys (Johannesburg) conducted the phase 2 survey (high resolution airborne magnetic gradiometry and 256-channel gamma-ray spectral data survey) while phase 3 survey (airborne regional GEOTEM electromagnetic and magnetic data) was conducted by Fugro Airborne Surveys (Ottawa). The airborne gravity data was collected (by Fugro Airborne Surveys- Johannesburg) over the same area(s) as that of the airborne magnetic in a separate second project, though, in each survey, survey specifications differed. The airborne data acquisition parameters are summarized and in Table 4.2.

TABLE 4. 1 2 SUMMARISED ACQUISITION PARAMETERS FOR SURVEY DATA COLLECTION. (MODIFIED FROM FUGRO AIRBORNE SURVEYS/GEOLOGICAL SURVEY DEPARTMENT INTERPRETATION TEAM INTERNAL REPORT, 2009).

Acquisition Type	Fixed-Wing Magnetic	Fixed-Wing Gravity
Flight line spacing	500 m	5000 m
Tie lie spacing	5000 m	50000 m
Flight line direction	135°	312°
Tie line direction	225°	042°
Sensor height	75 m AGL	450 m AGL (gentle drape flying
Magnetometer along line sampling	0.05 sec (20 Hz) (4-5 m)	0.1 sec (10 Hz) <7.5 m at 160 knots
Spectrometer along line sampling	1 sec (1 Hz) (80 - 100 m)	Not collected
Gravity system along line sampling	Not collected	2 Hz (<45 m at 160 knots)
Survey height	75 m	859 m
Survey Area	8570 km2	8570 km2
Total line kilometres	18,801 km	1908 km

Processing of Potential Fields

The airborne magnetic and gravity survey data were made available by Geological Survey Department of Ghana to be used for academic purposes. The two data had been corrected of diurnal (magnetic data), lag, levelling and heading errors in situ, at the base station. Using Geosoft Oasis Montaj, Encom P.A, and Model Vision Pro as the geophysical software, the survey data were uploaded (into the software's database system), gridded, enhanced for better resolution, and finally, processed to produce anomaly maps. These steps were employed sequentially. ArGIS and MapInfo were the GIS software used to digitise the geologic structures, anomalous features, and create all the other geospatial maps from the maps produced by the geophysical software. The modelled structures, believed to be the sources of the anomalies, were created trial and error using Geosoft GM-SYS, Encom P.A, Model Vision Pro and Quickmag software

Airborne Magnetic Data

The airborne magnetic data, left in db (database) file extension, was imported into Geosoft database system using the Database Tool menu button in Geosoft, and also, micro levelled using the MAGMAP extension of Geosoft. The total magnetic intensity (TMI) of the imported data was calculated, and the resulted TMI channel was gridded with cell size of 125 m (¼ of the profile line spacing), using Bidirectional Line gridding method from the Grid and Image menu button, and afterwards, the gridded file was loaded into the all-in-one MAGMAP filtering extension platform of Geosoft Oasis Montaj. The loaded TMI gridded file in the MAGMAP extension produced a control file that was used in the filtering and enhancement processes. The remaining data processing were managed using Encom P.A software. The filtering and enhancement techniques used are detailed in the next section.

Airborne Gravity Data

The airborne gravity data, left in geosoft database extension (gdb), was loaded into Geosoft Oasis Montaj database using the Database Tools Menu button in Geosoft, and gridded using a cell size of 1250 m (1/4 of profile line spacing). The data have a flight height and line spacing of 859 m and 5000 m respectively, making it difficult to detect most of the shorter wavelength signals emanating from the intrusive and the other intrabasin geological bodies. With the exception of reduction to pole at low latitude (RTPLL), most of the potential field data transformation and enhancement techniques were applied to the data. It is very worthy to note that almost all the signals were from the basement rock underlying the basin sediments. The following specific filtering and enhancement techniques as they have been thoroughly outlined in the following section were applied.

RESULTS

In both the magnetic and gravity maps, great emphasis was laid on a high to low range of values, and they (high to low range of values) corresponded correlatively to the high to low values of the magnetic susceptibility and density distributions of the airborne magnetic and gravity data respectively. In the quantitative interpretation, the discussion was focused on an isolated anomaly, where the depth of burial, magnetic susceptibility, density and location of the source of the anomaly were exclusively examined.

Interpretation of Gravity Data

Complete Bouguer anomaly (CBA) is obtained when the theoretical gravity calculation takes into account, the terrain correction. This type of Bouguer anomaly is preferred to the simple Bouguer anomaly in geophysical exploration (Hinze et al., 2013). The complete Bouguer anomaly map (Fig), gridded from the cba_density_267 and projected on WGS84/UTM 30 N, has five (5) red and three (3) blue outstanding patterns labelled GA (GA1, GA2, GA3, GA4 and GA5) and B (B1, B2 and B3) respectively. These two outstanding colours, red and blue represent the low to high gravity anomalies of the study area. The moderate-to-high gravity values that range from -50.5 mGal to -41.2 mGal come from the NE-SW anomaly trends (GA2-GA3, GA5-g and GA4) (Fig.5.1). These high gravity values give the indication that the source structures that trend NE-SW may be dense rocks.

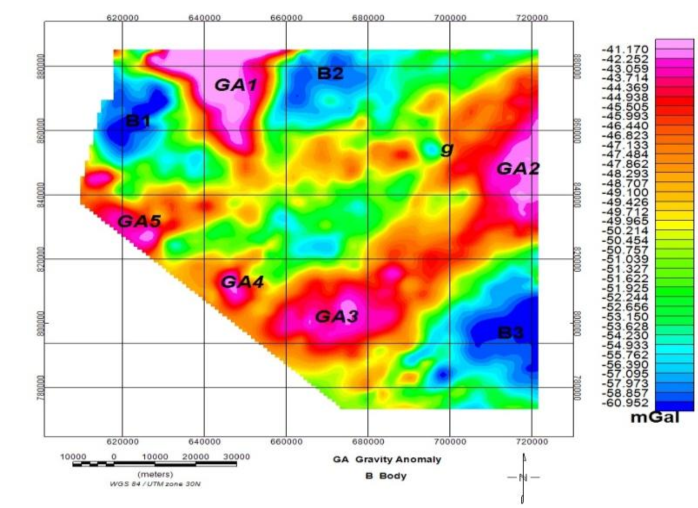

***Fig. 3.1** Complete Bouguer Anomaly Map.*

GA1, GA2, GA3 and GA4 individually and specifically have the highest gravity anomaly values (-41.2 mGal) in their separated locations other than their NE-SW trending moderate-to-high gravity anomaly values (-50.5 to -41.2 mGal). These individual highest gravity values may be interpreted to have come from denser rock sources than the entire NE-SW trend rock sources they (GA1, GA2, GA3 and GA4) are situated in. The moderate-to-low gravity anomaly values, ranging from -50.8 mGal to -70.0 mGal are seen to come from almost the entire study area. B1, B2 and B3 uniquely have the lowest gravity anomaly values that are almost around -70.0 mGal. This low gravity anomaly value (-70.0 mGal) may indicate that the locations (of B1, B2 and B3) may have source rocks that are less dense than the entire rock formation within the study area, and these less dense rocks may have facilitated the intrusion of the granatoids within the study area. The basement map (Fig. 5.1) from the gravity data helps in the identification of the faults that might have triggered the offsets of the sediments of the study area. The gravity field values of the study area are all negative (from -70.0 mGal to -41.2 mGal) as indicated by the legend in Fig. 5.1, and this is an indication that the observed gravity field values are lower than the theoretical gravity values. The lower gravity field values are believed to have come from the Kwahu mountainous range, indicated later in Fig. 5.5 as red-high in the digital elevation map. Isostatic conditions made the rock density of the mountain root to be lower, compared to the density of the surrounding Earth’s mantle, and this may have resulted in the lower observed gravity values of the study area. It is also observed that, the highest values of the gravity fields dominate along the NW-SE part of the study area (Fig. 5.1), a location along which the highest elevation values are also found. Because majority of the anomalies from the gravity data were from structures beneath the study area, the CBA map (Fig. 5.1) was low pass filtered to enhance the anomalies from the deep structures that might have been shielded by the anomalies from shallower structures. Fig. 5.2 shows the enhancement of CBA map (Fig. 5.1).

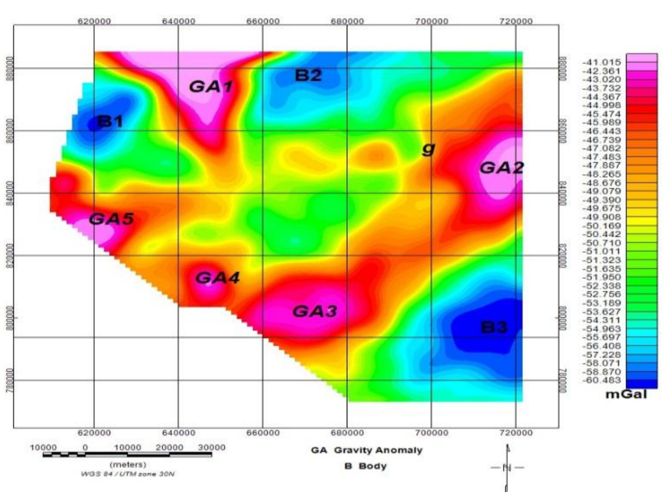

Fig 5.2 *Enhanced Complete Anomaly map*

A careful look at Figs. 5.1 and 5.2 shows that, Fig 5.2 has been reduced of noises, and also, has its gravity anomaly values increased (from -70.0 mGal to -60.5 mGal, and -41.2 mGal to -41.0 mGal, if the extreme ends values are to be considered). The reduction in noises, and the gravity anomaly values increment, may have been resulted from the removal of the short wavelength anomalies that may have shielded the long wavelength anomalies, and compromised their (long wavelength anomalies) recorded anomaly values. The application of first vertical derivative (1VD) filter on the Bouguer anomaly and low-passed maps distinctively displayed the localised anomalies from the causative structures. This is shown in Fig. 5.3.

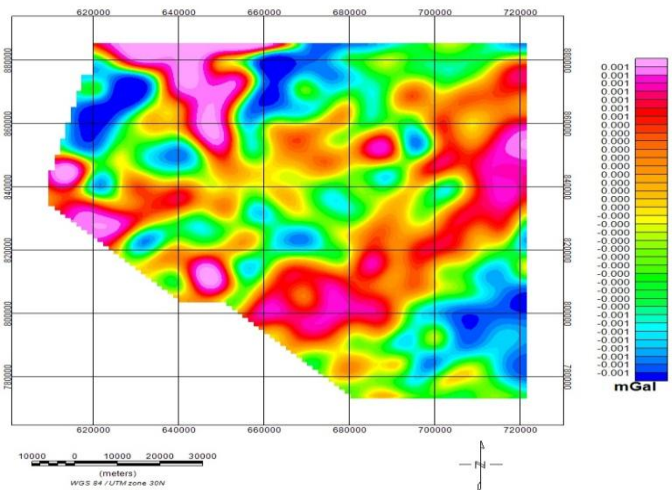

Fig. 5. 1 *1st vertical derivative (1VD) of low pass filtered CBA.*

Interpretation of Magnetic Data

The total magnetic map (TMI), with the low magnetic anomalies, labelled SS1, Ss and AA, and moderate-to-high anomalies, A1, A2, A3 and A4 respectively, has magnetic field intensities that range from 221 nT to 324 nT. The TMI map, shown as Fig. 5.4, exhibited numerous ambiguities in its (TMI map) interpretation as a result of the collection of the data at low magnetic latitude.

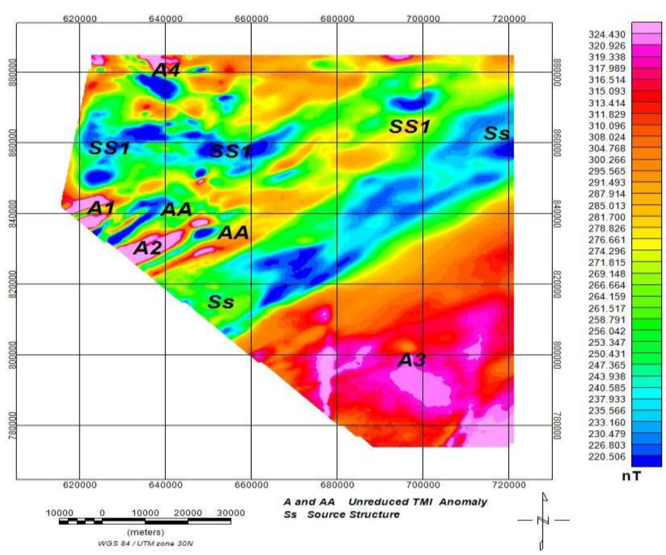

Fig. 5.4 Total magnetic intensity map (TMI) of study area. This map has not been reduced to pole. A1, A2, A3 and A4 are moderate to high magnetic anomalies, and SS1, Ss and AA are low magnetic anomalies.

Reduction to Pole at Low Latitude (RTPLL)

In this study, as the data were collected at low latitudes, reduction to pole at low latitudes (RTPLL), characterised with -10.51° inclination and -4.25° declination angles, was applied to the upward continued TMI gridded file to make all the magnetic anomalies at low latitudes appear to be found at the magnetic poles, and also, to be located exactly on and at the centres of their causative bodies. According to Zhou and Yao (2009), reduction to the pole at low latitude is effectively used at low magnetic latitudes. They (Zhou and Yao, 2009) used it (RTPLL) to effectively process magnetic data collected from the low latitudes of the South China Sea. The TMI anomaly map (Fig. 5.4) was reduced to pole at low latitude (not the traditional reduction to pole) to obtain Fig. 5.5 as shown below. In the TMI reduced to pole at low latitude map (Fig. 5.8), the anomalies were placed directly over their causative bodies making it easier to identify the NE-SW trending of majority of the anomalies from which it can be inferred that their causative bodies may also be trending NE-SW.

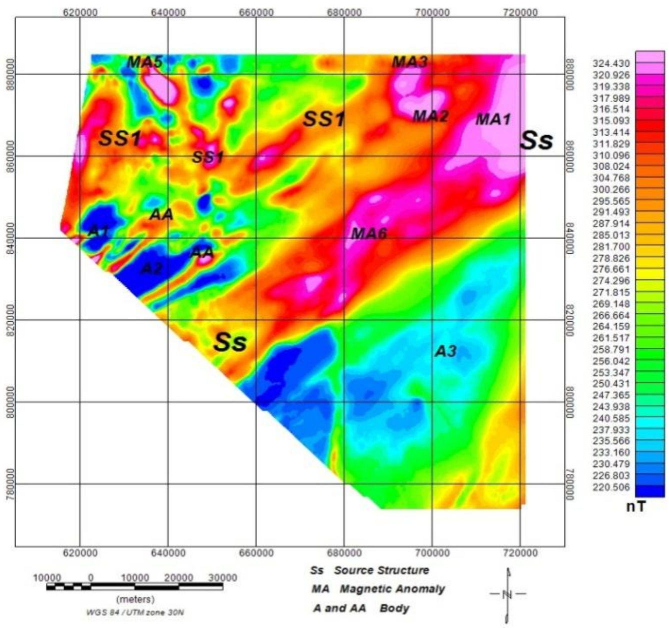

Fig. 5. 5 Reduction to pole at low latitude of TMI (in nT). (Majority of the anomalies trend NE-SW). A3 is a truncated NE-SW structure.

For a clearer view of the intrabasin geologic structures, a shaded relief map (Fig. 5.6) of the total magnetic intensity reduced to pole map (Fig. 5.5), and with the structural map of the study area superimposed on is provided. It is generally observed that from the middle to the western part of the study area, is heavily faulted. These faults, believed to be major, normal, thrust and local faults, cross-cut most of the NE-SW trending anomalies (Fig.5.6).

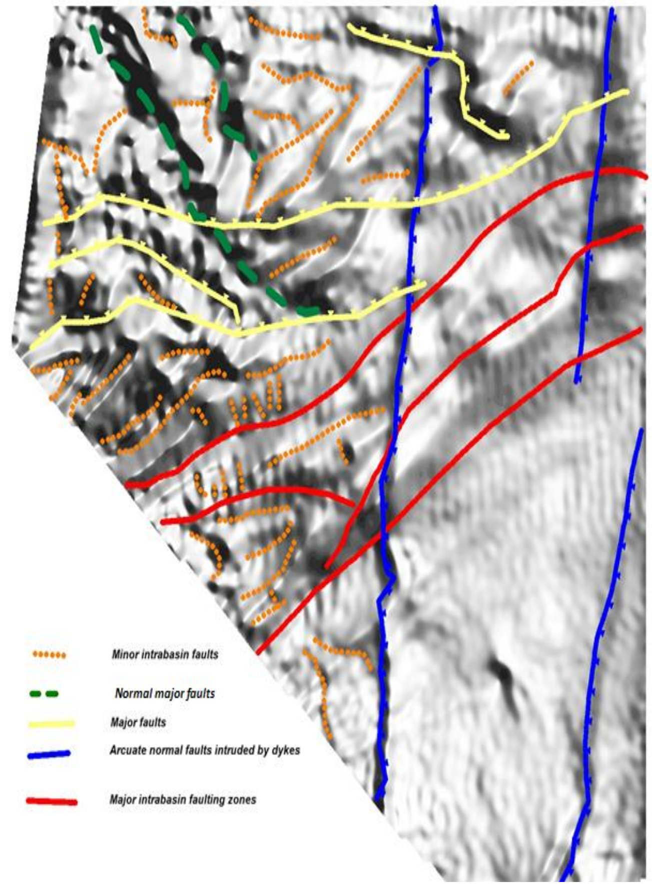

***Fig. 5.6.** Structural map of study area superimposed on a shaded relief map.*

From Fig. 5.6, the NE-SW trending features, represented by the red lines, are the major intrabasin faulting zones that may have been resulted from the Eburnean orogeny. They extend beyond the south western part of the study. However, these faults are not visible in the gravity dataset. Visibly shown again in Fig. 5.6 are three continuous N-S linear geologic features (arcuate dykes in blue) that pass through the eastern part of the study area. They are interpreted to be late reactivated faults, as would be seen in Fig. 5.7, as moderate to high amplitude magnetic signature. Major faults (in yellow) divide the study area into southern and northern parts. They may have caused most of the minor intrabasin faults (in orange) that surround the major faults and also cover almost half of the study area. Almost cutting the major faults at a normal angle, are the normal major faults (faults in green), that trend NW-SE direction, but terminate at half way through their direction.

First Vertical Derivative

Importantly, Fig. 5.7 seems to reveal that, some of the anomalies may not have come from the uniformly continuous causative structures, but from separated individual causative structures beneath the study area. Closer to the southern part of the study area is a uniquely isolated low-high amplitude magnetic anomaly labelled IA.

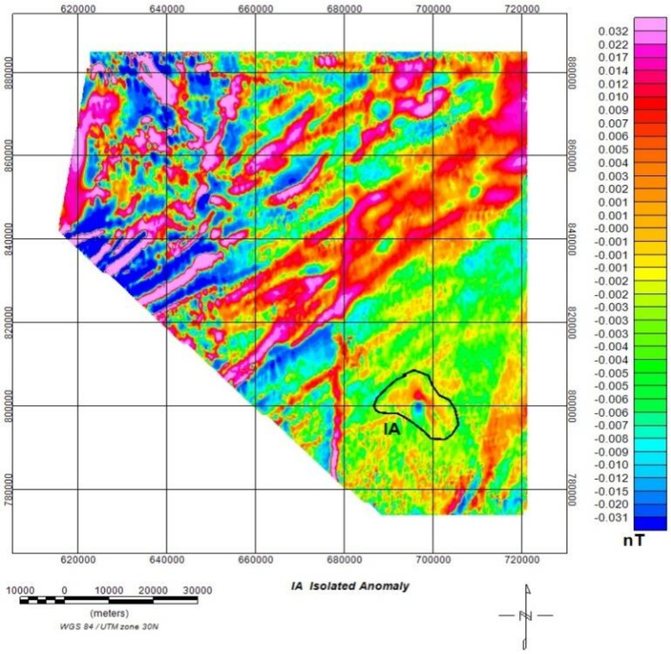

Fig. 5. 7 *First vertical derivative (1VD) of TMI reduced to pole at low latitude showing an isolated anomaly (IA).*

The high amplitude magnetic anomaly appears to be arcuate around the low amplitude magnetic anomaly (Fig. 5.7). This anomaly appears to be coming from two separate causative structures, but it may be otherwise.

Structural Interpretation of the Gravity and Magnetic Data

In mineral exploration, fractured zones, shear zones and intrusive bodies are the areas of interest that are believed to host most of the mineralised ore deposits. According to the Fugro Airborne Surveys Ltd. Report (Jordan et al.,2009a), the airborne geophysics data of the study area displays important basement structures associated with known deposit underlying the cover sediments of the study area. It can be then inferred that the underlying basement structures, mentioned in Fugro Airborne Surveys Airborne Geophysical Survey Report (Jordan et al., 2009a), could have intruded and fractured the study area. Junner (1940) reported the existence of small amount of gold deposits in the basal conglomerates of the Voltaian sediments while Jordan et al. (2009) also believed there could exist in the study area, both orogenic gold deposits and placer gold deposits. These fractured zones (faults) and some of the intrusive bodies are what Fig. 5.8 is showing. It is clearly visible from the structural map (Fig. 5.8) that, the western half of the study area is dominantly faulted. The minor intrabasin faults, outnumbering the remaining faults at the highly fractured zone, may have been caused by the reactivation of the major faults which are also believed to have resulted from the Eburnean orogeny of the Birimian volcanics and sediments, on which the lower layer sediments of theVoltaian supergroup overly. The major and normal major faults which occupy the greater portion of the northern part of the study area may have resulted from the intrusion of the Birimian and the Dahomeyan basement rocks in the basinal sediments of the Volta river basin. The fractured zones are widely and evenly distributed in the study area. An intrusive linear structure, trending N-S, and believed to be a dyke, divides the study area into almost equal halves, and it extends beyond the southern boundary of the study area to the southern part of Ghana. In finding orogenic gold deposits, structures play important role. Real evidence, seen from a range of areas in Ghana like the Obuasi Mine, Bogoso Mine and Bibiani Belt mean that the N to NE structural corridors play an unparalleled part in locating mineralisation within the study area (Jordan et al., 2009b). Most of the mineralised hydrothermal solutions, through their journey within the Earth's subsurface may find such faults and contacts accommodating, and leave behind them, mineral deposits (IOCG ore deposits) within these cracks. Jordan et al. (2009b) reported that the essential geological components of a mineral system are the source of the driving energy of the system, sources of fluids (and metals and ligand), pathways for fluids to migrate to their trap zones and ultimately, the trap zones within which the fluids composition becomes modified. Lindsay et al. (2014) used structural interpretation of gravity and magnetic data to find mineral potentials in west Kimberley, Australia. In their work, intrusion related base metals, including tin-tungsten, iron-oxide-copper-gold (IOCG) and porphyry deposits were among the five main targets of the findings. The Volta River Basin contains volcanics, and the interpretations from the extensive mapping, aerial magnetic, gravity and EM studies by Fugro, show several intrusive bodies; indicating periods of magmatism and volcanism, and these make IOCG mineralisation during the phases possible (Jordan et al., 2009a). In situations where the country rocks or the surrounding rocks cool the moving fluid faster than usual, the fluid may solidify, forming a hydrothermal vein, as shown in Fig. 5.8 as dyke. Mineral explorers do not ignore such structures during mineral exploration.

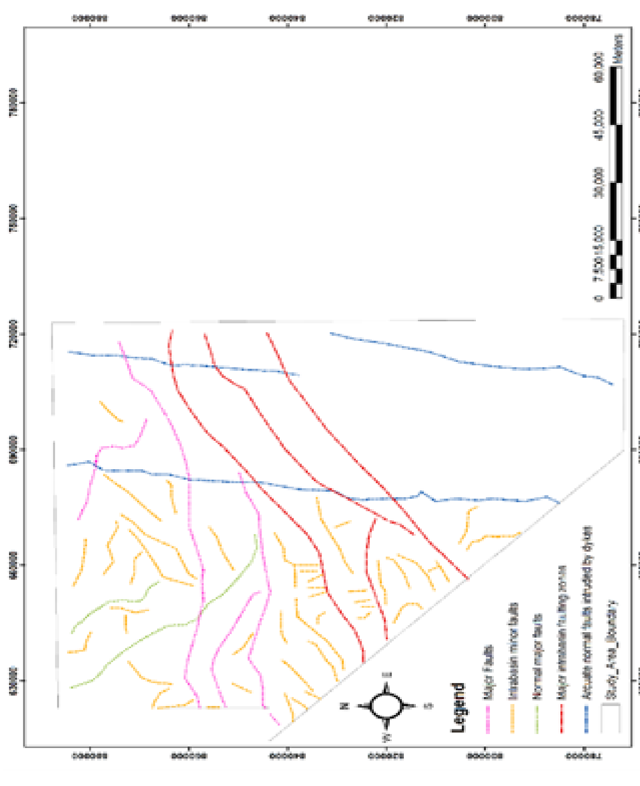

Fig. 5.8 *Structural map of study area*

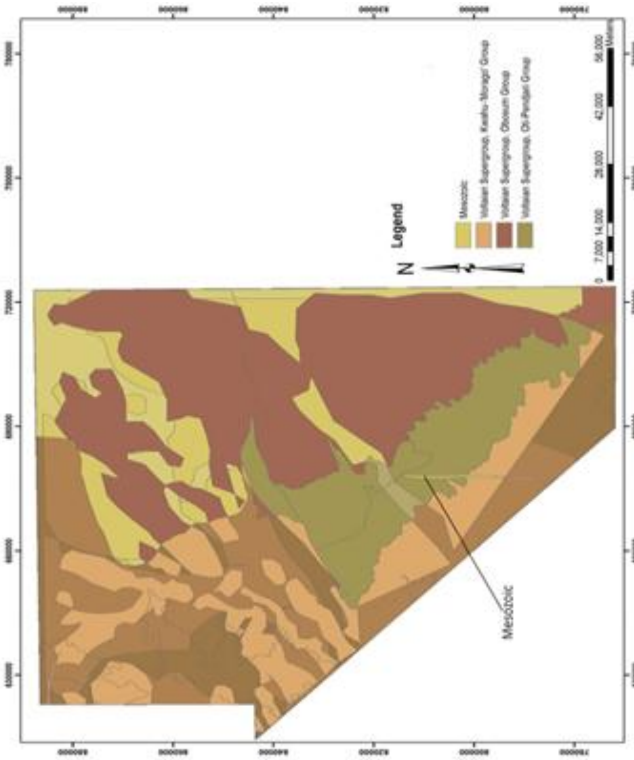

Fig. 5.9 *Interpreted basement geology of study area. From both magnetic and gravity data.*

CONCLUSION

The Birimian (meta-volcanics and meta-sediments) and the Dahomeyan basement rocks sourced most of the anomalies conveyed in the airborne gravity data while the intruded granatoids may also source most of the anomalies conveyed in the magnetic data within the study area. The anomalies from the airborne gravity data are believed to have contributed to the magnetic anomalies. In other words, the causative structures of the gravity anomalies may be the sources of most of the causative structures of the magnetic anomalies within the study area. The airborne gravity anomalies depicted deeper and broader structures while the magnetic anomalies brought out the shallower and small intrabasin structures. The unequal anomaly patterns between the airborne gravity and magnetic data confirm that the gravity data show deeper and broader structures while magnetic data, important than gravity data in mineral exploration, show shallower and small structures. The anomalies from both data have revealed several structures within the study area. Faults, dykes, contacts and intrusive granitic bodies are some of the structures within the study area. Faults and the intrusive bodies dominate the other structures with majority of the faults trending NW-SE while the intruded structures, characterised with cross-cut NW-SE faults, trend NE-SW. The prominent among these intruded granitic bodies are the Birimian meta-volcanics and meta-sediments believed to have originated from the Birimian basement rocks of the study area. The dykes, found to be few within the study area, trend N-S of the study area, and tend to divide the area into almost equal halves. The Kwahu-Morago and the Oti-Pandjari groups overly the smaller intruded causative structures (granatoids) while the Obosum and Mesozoic formations overly the larger causative structures (Birimian rocks) of the study area. All these structures are potential mineral-hosting zones which are targets in mineral exploration. Since Ghana's economy is hugely influenced positively by the mining sector, exploring these structures may further boost the country's socioeconomic status and that of the world as a whole.

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