Use Of Euler Deconvolution of Gravity Data for Structural Evaluation: A Case of Tarkwa-Nsuaem Area

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Abstract

Euler deconvolution is a useful tool for providing initial estimates of the locations and depths of magnetic and gravity sources. In this study, Euler deconvolution was applied to gravity geophysical data from the Tarkwa-Nsuaem Municipality, Ghana to interpret the structures present in the area. The Euler deconvolution method was applied to the residual bouguer map produced using the Kriging method. In addition, other filters including the derivative of the gravity data along the x, y and z directions were employed for the proper delineation of the locations of the various anomalies observed. The surface elevation of the study area varies from -12 .7 m at the sea in the southern part, to 270.6 m at the highest point in the northern part. It is observed that the basin (Volta Basin) to the south also accommodates some ridges, which appear elongated with a high elevation rise of about 134 m, while the upper terrain is associated with several north-south trending ridges with the highest elevation rise of 270.6 m. Euler solutions with different structural indices depicting specific geologic models were obtained from the Euler analysis carried out on the gridded residual data in order to identify the type of structures present in the study area. The best geologic model was derived using the structural indices of 0.5 and 1.0, which are diagnostic of the dyke structures and are significant to mineralisation of the area. The Euler solution revealed a series of dyke-like structures at a depth of 55 to 75 km across the study area. It was discovered in many parts of the study area that lack of appreciable density variation has led to the production of few solutions from the data.

Keywords: Euler deconvolution, kriging, gravity data, structures, bouguer anomaly, Tarkwa-Nsuaem Municipality

1 Introduction

As part of the economic hub of Ghana, Tarkwa Nsuaem Municipality (TNM) situated in the western region of Ghana is very significant to the economic growth of the country due to a lot of mining activities in the area. Tarkwa has been an ancient city hosting diverse mining companies with the gold mines being in the majority. Gold mineralisation is usually associated with primary geologic hosts such as dykes, veins, and alterations zones of varying geometries. Due to the formation of the gold deposits, folds, faults and some structures are present. These structures can develop either before or after the deposition of the mineral or the formation of the parent rocks.

This paper presents a review of the Tarkwa Nsuaem Municipality area in terms of structural disposition using gravimetric data with a view to investigating the occurrence and subsurface features in the area and the possible implication of structural disposition of the area on its mineralization potential. Structures are very important in geological analyses because of the information they give about the lithology and geology of an area. This work details the use of Euler deconvolution of gravimetric data in evaluating the subsurface geology of the study area based on anomalies from the gravimetric field or density contrasts in the underlying rocks (Mueller et al., 2021). The Euler deconvolution technique is commonly used in mapping geological boundaries between magnetically (or density) differing lithologies and structures like faults, etc (Ramotoroko et al., 2016).

1.1 Description and Geological Setting of The Study Area

The Tarkwa Nsuaem Municipality forms part of the 260 Metropolitan, Municipal and District Assemblies (MMDAs) in Ghana and forms part of the 14 MMDAs in the Western Region. It is located in the eastern part of the Western Region with coordinates within Latitude 400'N - 500 40'N and Longitudes 10 45' W - 20 10'W. Tarkwa is the administrative capital of the Tarkwa-Nsuaem municipality was created from Wassa West District under Legislative Instrument (LI) 1886 in 2007 (Mantey., 2019).

The Municipality is located within the physiographic area of forest-disserted plateaus. The forest-disserted plateau is underlain by Pre-Cambrian rocks of the Birimian and Tarkwaian formations. The area is generally undulating with few scarps and the land elevation ranges from about 240 to 300 m above sea level. The Municipality falls within the rainfall belt, thus giving it the "green" physical outlook. The Municipality can boast of about 440.15 km^2 of Forest Reserves comprising the Bonsa Reserve (209.79 km^2), Ekumfi Reserve (72.52 km^2) and Neung Reserve (157.84 km^2) as well as other off-reserves. The length of trees ranges between 15 m and 40 m with wide crowns (Atuburoah,2019). Climbers and lianas that can reach into the top tree layer abound in the forest. Economic trees in the Municipality's Forest include Mahogany, Wawa, Odum and Sapele (Atuburoah, 2019). Due to its proximity to the South-Western Equatorial Zone, the municipality, therefore, has fairly uniform temperatures, ranging between 26° C in August and 30° C in March (Atuburoah, 2019). For most of the year, the average amount of sunshine per day is seven hours. The relative humidity is generally high throughout the year ranging from 70 to 80 percent in the dry season and 75 to 80 percent in the wet season.

The regional geology constitutes part of the western unit, which lies at the eastern margin of the Precambrian West African shield or Craton. This part consists of the Birimian Supergroup, which was deformed, metamorphosed, intruded by syn- and post-granitoid during the Eburnean orogeny that occurred about 1800 million years ago, which has been uplifted and (Ackon-Wood, 2016). The erosion products were deposited as sediments of the Tarkwaian Group in long along and narrow tramontane grabens, which formed due to rifting preferentially in the central portions of the north-easterly trending Birimian belts. The Birimian and Tarkwaian rocks occur mainly in the eastern, central and western Regions. The Tarkwaian group of meta-sedimentary rocks lies unconformably above the Birimian in each of the Birimian volcanic belts. The Tarkwaian consists entirely of conglomerates, sandstones, phyllites and slates derived from the Birimian country rocks (Ackon-Wood, 2016) separating the Paleoproterozoic Eburnean orogeny into two distinct phases known as Eburnean I and II. The Eburnean orogeny predates the deposition of Tarkwaian sediments and is associated with a major period of magmatism and metamorphism in the Sefwi Group basement Montsion *et al.* (2021).

The local geology of the area is dominated by the Banket series, which can be subdivided into a footwall and hanging wall predominantly of barren quartzites, separated by a sequential mineralized conglomerate and pebbly quartzites (Milési *et al*., 1991). The stratigraphy of the individual quartzite units is well established, with auriferous reefs interbedded with barren immature quartzites (Figure 1). The units thicken to the west and current sediment ologist parameters indicate a flow from the east and north-east (Milési *et al*., 1991).

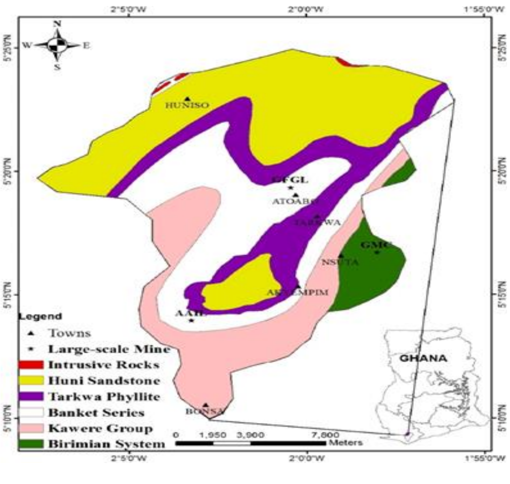


Figure 1: The Geological Map of the Study Area (Ewusi *et al*., 2017)

2 Materials, Methods

2.1 Data Acquisition and Processing

The gravity data utilized in this research is secondary data procured from the archives of the Geological Engineering Department of the University of Mines and Technology, Tarkwa, Ghana. The gravimetric data was acquired over the entire Volta Basin and subjected to preliminary data processing, which included Butterworth filtering, data reduction to the equator (RTE) and residual anomaly separation. As a result, the secondary data type acquired is the residual Bouguer gravity data saved as dbf (database format). Both the residual Bouguer gravity values and the height of gravity data points are included in the dbf data.

During data analysis and processing using both the Surfer and Geosoft software later used for the interpretation of the Bouguer gravity data, all the datasets including geophysical and topographic data originally acquired using the World Geodetic System of 1984 (WGS-84) were georeferenced to the projected Universal Transverse Mercator (UTM), Zone 30N datum for the Northern hemisphere. The geological map of the research region was taken from the BGS's Geological Map of Ghana, published in 2009, and converted to a dbf format for ease of portability and use in the Surfer software, where the geological map of the study area was digitized and georeferenced to the same datum with other sets of data.

2.2 Gravity Data Processing

The initial quality check involving processing and enhancement of the geophysical datasets was carried out with the aid of the Surfer program. The acquired data initially in dbf format was quality checked and gridded into the residual Bouguer gravity of the Tarkwa-Nsuaem area using the Surfer program. The same set of the dbf data was later exported into the Geosoft (Oasis Montaj) software that was used to regenerate the residual Bouguer gravity grids and in the Euler deconvolution of the gridded that used for structural evaluation of the study area.

The processing of data involved the sequential processes of editing, application of derivative filters on the grids and Euler deconvolution of the derived gridded data on the assumption of a specific geologic model/body. The Geosoft software was used to produce the topography map and contour maps from processed gravity data. The sets of maps include the residual bouguer map, the Euler derivative maps (dx, dy and dz components) and the Euler deconvolution solution maps (of structural indices of 0.5 and 1.0) that indicates source locations and depth-to-sources of the structures present in the study area.

2.3 Euler Deconvolution of the Gravity Data

The residual bouguer map was generated using the Oasis Montaj (Geosoft) software and the Euler deconvolution algorithm was applied to evaluate the geologic structures that could be of significance in mineralisation potential of the study area based on density variations of rocks underlying the study area.

The optimum gridding spacing of 5.0 km was achieved in generating gridded gravity data. The raw data show Bouguer anomaly lows and highs with respect to their background values (-2.94 to 27.04) within the study area. The “minimum curvature” gridding was applied in producing the residual Bouguer grid that was used in generating the residual Bouguer anomaly map. Furthermore, the 3D Euler deconvolution (ED) solutions obtained from interpreted gravity anomaly grids were used to evaluate the locations and depths of the inferred structures.

The ED technique estimates the source location of the causative anomalies by assuming the type of body which is defined by a specified Structural Index (SI) before computation. A window size of 3 - 15 grid size with an acceptable maximum depth tolerance for the different structural indices was specified for the Euler deconvolution of the residual anomaly grid. The SI value is set to 0, 0.5, 1 or 2 for the Euler deconvolution operation, with the solutions obtained displayed in terms of coordinates of the location and the depth to the targets. The structural indices for the various geologic structures and the uncertainty parameters used in the Euler deconvolution operations are presented in Tables 1 and 2. However, optimum solutions were achieved with structural indices of 0.5 and 1.0 respectively, which are indicative of dykes and contacts in the study area.

Table 1: Structural Indices for various Geologic Bodies

STRUCTURAL INDEX	STRUCTURAL INTREPRETATION IN GRAVITY
0.0	Sill/ dyke/step
0.5	Ribbon/dyke
1.0	Pipe/dyke
2.0	Sphere

Table2: Structural Indices and Depth Tolerance

STRUCTURAL INDEX	DZ MAXIMUM DEPTH TOLERANCE
0.0	20 %
0.5	15 %
1.0	10 %
2.0	10 %

3 Results and Discussions

3.1 Terrain and Residual Bouguer Anomaly Maps

Figure 2 shows the topographic map of the Volta Basin area generated using the Geosoft software. The surface elevation varies from -12 .7 m at the sea in the southern part to 270.6 m at the highest point in the northern part. It is observed that the Volta basin also accommodates some ridges, which appear elongated with a high elevation rise of about 134 m across the central area, while the upper land is associated with several north-south trending ridges with the highest elevation rise of 270.6 m.

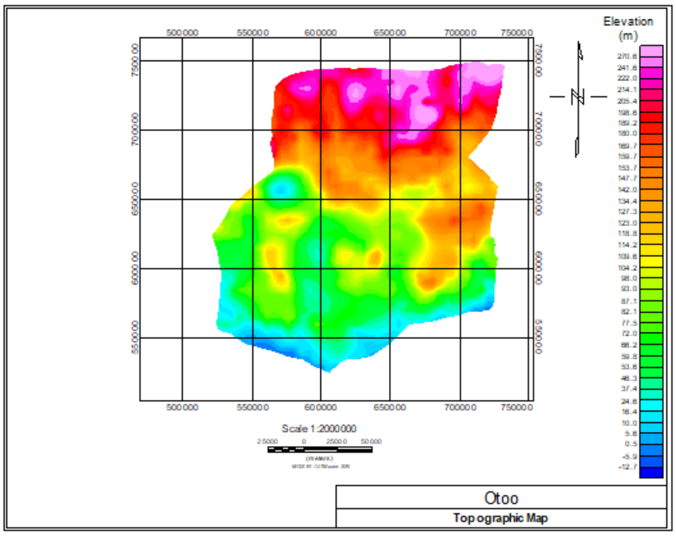


Figure 2: Topographic Map of the Study Area

The Bouguer gravity anomalies in the earth's gravity field are caused by variations in density in the rocks and maps of these anomalies can be interpreted in terms of geology (Silva *et al.*, 2003). The first phase of this work was devoted to the recognition of trends and patterns in the Bouguer gravity map of the study area. The residual Bouguer anomaly map was generated using both Surfer and Geosoft programs. Figure 3 shows the original Bouguer residual map before reconciliation with the geology of the area, while Figure 4 shows the superimposition of the Bouguer anomaly map over the geology using the Surfer program. Figure 3 shows different gravity anomalies corresponding to different lithological units and geological structures in the study area. The amplitude of a gravity anomaly is directly dependent on the level of difference in density (mass) of the rocks at specific geographical locations. This also highlights variations in the strength of the gravitational force over the surface of the study area.

3.2 Reconciliation of Bouguer Gravity Anomaly Map with Geological Map

Figure 4 below shows the Bouguer gravity anomalies over the geologic map of the study area, produced in the Long-Lat formats. The anomaly variation that corresponds to variation in density in the area ranges from -20 to 55 mgal. The subtle variations in the anomaly pattern reflects low rate of gravity changes within the area generally, which means a low-density variation across the area.

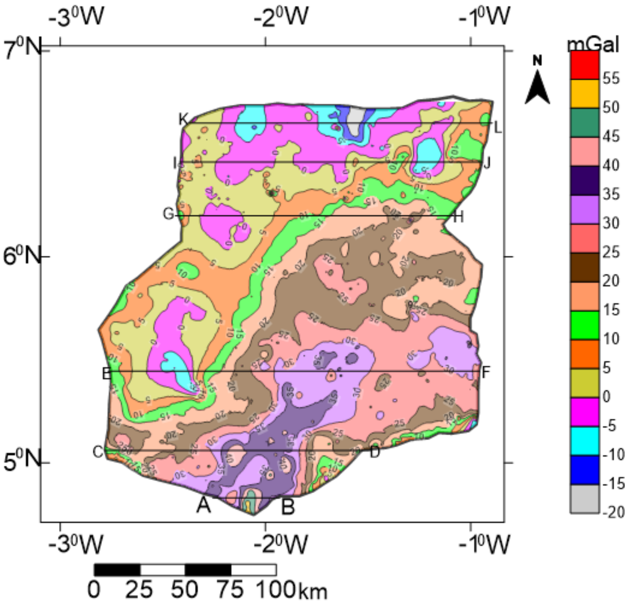


Figure 3: Residual Bouguer Map of the Study Area

It can be observed that the anomaly variation present in the area is not really appreciable, except in areas where volcanic intrusions have been identified close to the central part of the area with low-gravity anomalies (or negative), while most high Bouguer residual anomalies (positive values) correlate with rocks represented with the Birimian Argillaceous Sediments 'bsa' group (argillitic rocks, pelitic sediments dominant, ± Kerogene ('graphite').

Most of the elongated bodies that are present in the residual Bouguer map and the derivative maps are characteristic of dykes. It can be observed from Figure 3 that the area around the intrusion has a high-density value that is 20 to 40 mgal. Some of the negative anomaly trends in the Bouguer anomaly maps are found to correspond to the high terrains of ridges in the northern part of the area from the topographic map in Figure 1. These anomalies are often responses from some low-density structures that are often associated with some plutonic suites.

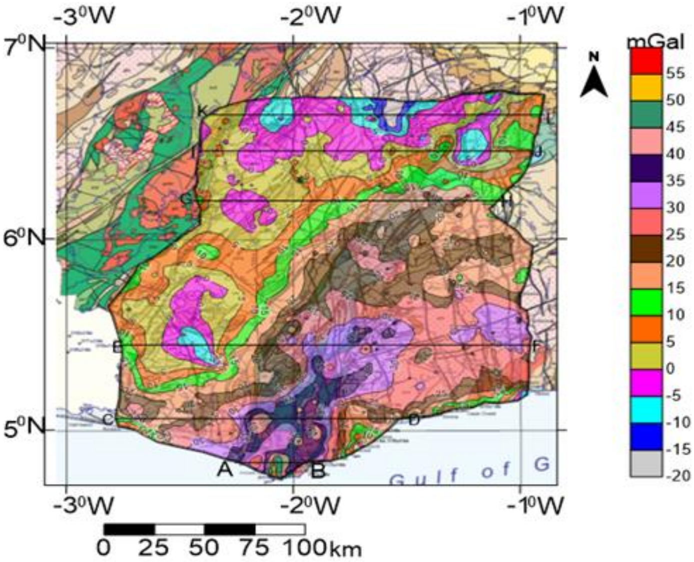


Figure 4: Superimposition of Residual Bouguer Map over the geological map of the Study Area

3.3 Euler **Deconvolution Results**

Delete The results of Euler deconvolution of the residual gravity data are presented in the following sequence:

- Residual gravity Anomaly Map
- Derivative Maps
- Euler Structural Maps

Residual gravity Anomaly Map

The residual anomaly map is reproduced using the minimum curvature gridding algorithm of the Geosoft software in order to perform the 3D Euler Deconvolution necessary for the structural evaluation of the gravimetric data. The residual gravity anomaly map was subjected to enhancement using Butterworth filters taking advantage of the high display capacity of the software to eliminate the values with high uncertainties.

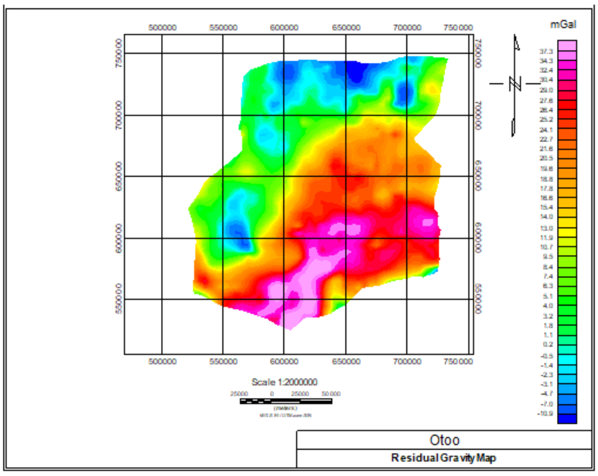


Figure 5: Residual Gravity Map

3.3.1 Derivative Gravity Anomaly Maps

The derivative maps along the three (x, y, z) orthogonal coordinates were generated as part of operations for the execution of 3D Euler deconvolution of the residual anomaly grids generated. The gridded Bouguer residual data and its derivatives along the horizontal direction of the grided cell (dx and dy) and the vertical component dz serve as input into the standard Euler Deconvolution program employed in the structural evaluation of the residual gravity data in the Geosoft software.

Figures 6(A, B and C) present the derivative maps, which reveal the rate of change of the gravitational field along the three Cartesian coordinates (x, y, z). These derivative maps can be used to identify the location of linear features such as faults contacts and edge effects of various targets arising from anomalies showing different density contrast over these targets. Figure 6A shows the rate of changes in the gravity field along the x-direction in radians, which revealed several sources of anomalies that could be recognized as basins, ridges and intrusive structures within the study area. The map defines better the north-south and northeast-southwestern trends of anomalies that conform with the general geologic trends in the geological map of the study area (Figures 2 and 3). Similarly, Figure 6B shows anomaly patterns and trends from the derivative residual anomaly map in the y-direction that can be attributed to a series of geologic structures and contacts mostly revealing the east-west orientation of some geologic targets, which could arise due to secondary geologic events as revealed in the geologic map of the study area, which is observed in Figures 2 and 3. The vertical derivative of the residual gravity field also shown in Figure 6C revealed several elongated and concentric anomalies that are characteristic of various geologic targets that can be attributed to the geologic structures in the study area. The map is observed to have resolved better the location of geologic bodies that are associated with recent geologic events in the study area.

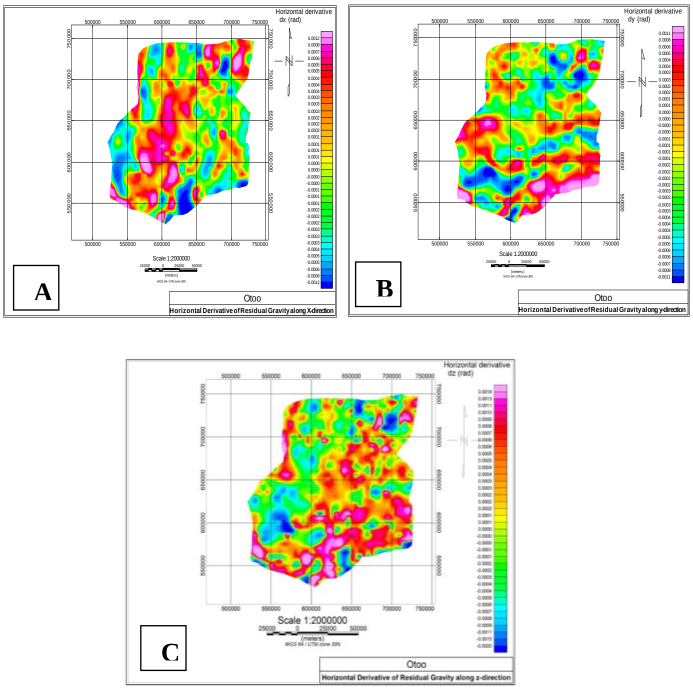


Figure 6A, B and C Horizontal and vertical Derivative in the x, y and z direction of Residual Gravity

3.3.2 Euler Solution Maps for the Various Structural Index

The Standard Euler deconvolution method was adopted in the determination of location and depth to geologic bodies from the Euler deconvolution of the residual gravity data based on Euler structural index values for the assumed geologic model in order to evaluate the structural type present at the area of study. The maps were produced for a structural index of 0, 0.5, 1 and 2 with optimum grid size translating to a maximum distance of grid coverage of 45, 000 km as shown in Figures 7(A and B) and 8(A and B). It was discovered that the best geologic model was derived using the structural indices of 0.5 and 1.0 are diagnostic of the dyke structures that are significant to mineralisation of the area. A structural index of 0.0 that is diagnostic of contact can be seen to lack good resolution for the contact or dyke structures due to the large data sampling rate, which is an order of four times the optimum gridding cells used (5,000 km) at a maximum sampling rate of 20,000 km. Likewise, the index of 2.0 for the pipe/ribbon gravity model also lacks a good solution as the solution obtained could only be recognised to be characteristic of dyke or sill or intrusive bodies at a deep section of the subsurface.

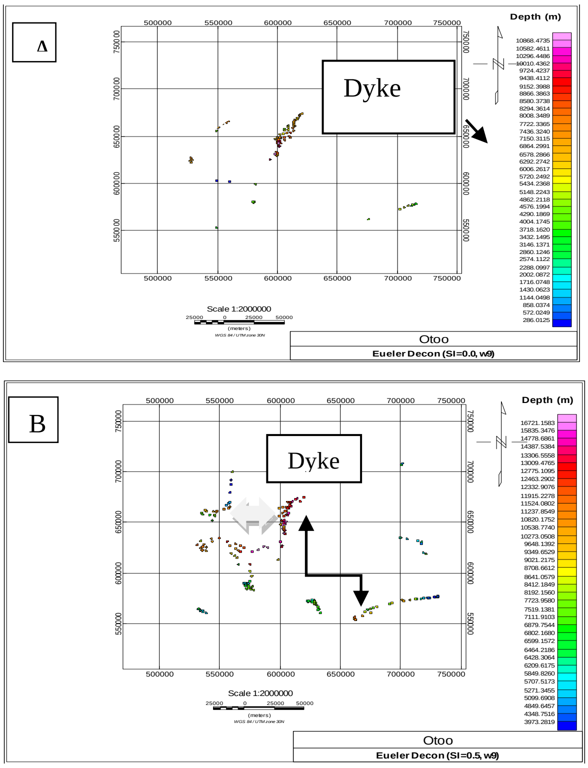
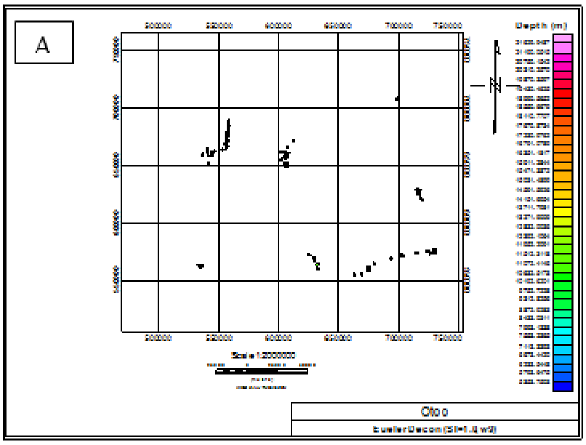


Figure 7: Euler Deconvolution Maps for Structural Index (SI) of; A (SI = 0.0) and B (SI = 0.5) respectively



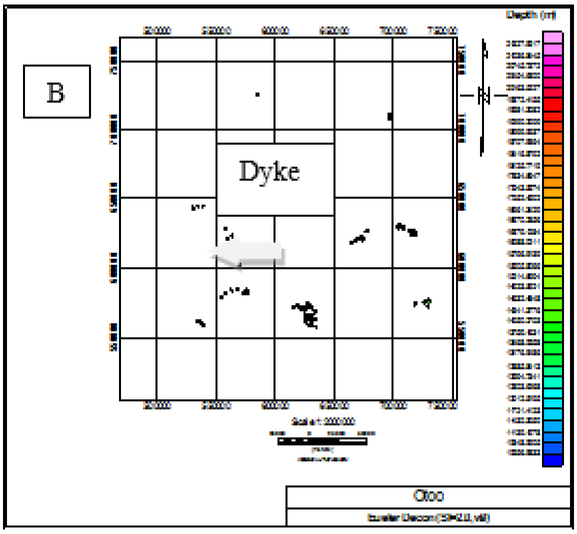


Figure 8: Euler Deconvolution Maps for Structural (SI) Index of; A (SI = 1) and B (SI = 2) respectively

4 Conclusions

The geophysical approach of using Euler deconvolution of gravity data was successfully used in identifying the various geological structures over the Tarkwa Nsuaem Municipality (TNM) area of the Volta Basin. Geological structures of the study area were effectively interpreted using gravity data, which were processed and enhanced through the application of Butterworth and derivative filters before the Euler deconvolution of residual gravity data over the study.

The residual gravity map shows that the density variation in the area is not generally large in values due to the closeness of the density of rock materials in the area, although the gravimetric data suggest density increases across granitoids and ridges of argillitic rocks and pelitic sediments. The igneous intrusions showed high-density variations compare to other areas, which can be attributed to the presence of dykes and sills at inferred locations and intermediate depths across the area. From the 3D Euler results, the dominant or the most present structure is the dyke which can be associated with the intrusion of the igneous or metamorphic bodies. Most mineralisation in the area is presumed to be associated with veins and dykes in the host environments.

The subtle variations in the anomaly pattern reflect a low rate of gravity changes within the area, which can be attributed to gravity lows that reflect generally low-density variation across the area. Thus, substantial gravity effects that were observed in some local areas are diagnostic of volcanic intrusions that have been identified close to the central part of the area with low-gravity anomalies (or negative), while most high Bouguer residual anomalies (positive values) correlate with rocks represented with the 'bsa' group (argillitic rocks, pelitic sediments dominant, ± Kerogene ('graphite')).

A Series of structural trends and patterns observed over the area can be attributed to complexity in the geology and level of transformation of parental rocks in the area. Despite the subtle variations in the rock density, the gravity derivative maps have been effectively used in mapping regional geologic trends mainly in the NE-SW and N-S orientations, while the first vertical derivative map shows better resolution of the NE/SW dykes largely concentrated in the Ashanti belt and the sedimentary area of the volta basin.

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