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Edge Detection And Depth Estimation Using A Tilt Angle And Euler Deconvolution From Combined Terrestrial And Grace Gravity Data Of The Adamawa Plateau Region (North-Cameroon)

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Abstract
This study aims to analyse in detail the gravity data covering the Adamaoua Plateau region in order to improve our understanding of its geological setting. To achieve this, terrestrial gravity data were combined with data computed from the GGM02C gravity model, and the tilt angle method and Euler deconvolution were applied to the densified Bouguer anomalies of the study area to highlight the different geological contacts and estimate their depth. A strong correlation was observed between the results of the two techniques, indicating that their integration can help to delineate the structural framework of the area. The results obtained made it possible to draw up a structural map of the Adamaoua Plateau region, confirming the existence of structures already recognized or suspected by previous studies and highlighting new faults. The map shows that the fault system responsible for structuring the study area is organized along WNW-ESE, ENE-WSW, E-W, NE-SW and NW-SE directions. These trends were associated with the main structural directions observed in this region of Cameroon. According to the Euler deconvolution, the depth of the source roofs exceeds 10 km. The structural map obtained is an important document that could serve as a guide for the study and exploitation of thermomineral springs and groundwater in the area studied, facilitating the identification of favourable points (faults) for their existence or emergence.

***Keywords** : Structural map, GGM02C*

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I. Introduction

Potential field methods have been widely used for many years to map anomalies due to specific contrasts in the Earth's crust. Gravimetry can be used to highlight areas of the subsurface with density contrasts. The boundaries between these zones are identified by gravimetric gradient analysis [1-4]. The Adamaoua Plateau, located in the central domain of the Cameroonian part of the North Equatorial Pan-African Range, has been the subject of several geophysical studies using the gravimetric method [5-9]. The main results of this work suggest the presence of a thin crust [5, 6] intruded by basic, non-outcropping igneous bodies that would have been emplaced by reactivation of the Central Cameroon Shear [7]. The lithosphere would also have been thinned by upwelling of asthenospheric fluid in an incipient rift context [5, 10]. Although this work has succeeded in highlighting certain structures in the subsurface of the Adamaoua Plateau, it is clear from this analysis of existing information that further investigations are required to characterise the observed variations in rock density and to specify the structural geometry to which they relate. The aim of this study, which complements previous work, is therefore to analyse in detail the gravity data covering the study area in order to improve our understanding of its geological setting, particularly from a structural point of view.

Like other geophysical methods, gravity inversion is limited by the poor quality of gravity data and sparse spatial coverage, mainly due to inaccessible topography and remoteness. Ground gravity data from the ORSTOM database [10] have been used in the Adamaoua Plateau [7, 10][7], but their low spatial resolution in the study area (as they only follow roads, [10]) means that only approximate results can be obtained. This limitation has recently been partially overcome by advances in satellite gravity modelling. Global knowledge of the gravity field has increased significantly over the last decade with the launch of three space gravity missions: CHAMP in 2000, GRACE in 2002 and GOCE in 2009. In this study, gravity data from the GGM02C model have been combined with terrestrial data to improve the accuracy of previous work. Tilt Angle Derivation (TDR) and

Euler Deconvolution (ED) were applied to the Adamaoua Plateau to locate the boundaries and depths of gravity sources.

II. Geologic And Tectonic Setting Of Study Area

Following the exploratory surveys carried out on the Adamaoua Plateau in the 1950s (Guiraudie, 1955; Lasserre, 1961), more recent geological data have been obtained from work carried out on the central part of the Pan-African chain in Cameroon [11-17]. These works, which are generally more detailed, use different approaches such as geochronology, microtectonics, metamorphic studies, petrology, geochemistry and volcanology. The results of this work indicate that this zone is mainly composed of Precambrian rocks such as migmatites, gneisses and granites granitised during the Pan-African tectonic event. It is overlain by a sequence of Tertiary basaltic lavas [18] (Fig. 2). These lavas are alkaline, indicating an affinity with continental rifts [19]. The sedimentary formations consist mainly of conglomerates, arkosic sandstones and limestones from the Cretaceous Djerem Basin and Mbere Graben [18]. These formations have undergone intense volcanic activity leading to the formation of the basin structure, which is covered by volcanic materials that reach the surface through deep fractures. These fractures lie at the base of the main crustal lineaments [20]. Three major tectonic structures are associated with the Adamawa Plateau: the Cameroon Volcanic Line (CVL), the Foumban Shear Zone (FSZ) and the Southern Adamawa Trough (SAT). The CVL is a Y-shaped chain of intraplate volcanoes extending from the island of Pagalu in the Atlantic Ocean in West Africa for about 2,000 km [21]. The first (northern) branch corresponds to the crossing of the Benoué River, and the second (eastern) branch corresponds to the Adamawa Plateau. The volcanic rocks on this line are composed of alkaline basalt, trachyte and limestone.

Structural studies carried out in the region [22, 23] show that it has been affected by three phases of deformation:

- D1 phase of tangential tectonics oriented NNE-SSW;
- D2 phase of clamping, essentially dominated by flattening and partial melting;
- D3 phase of essentially E-W trancurrent dextral shearing.

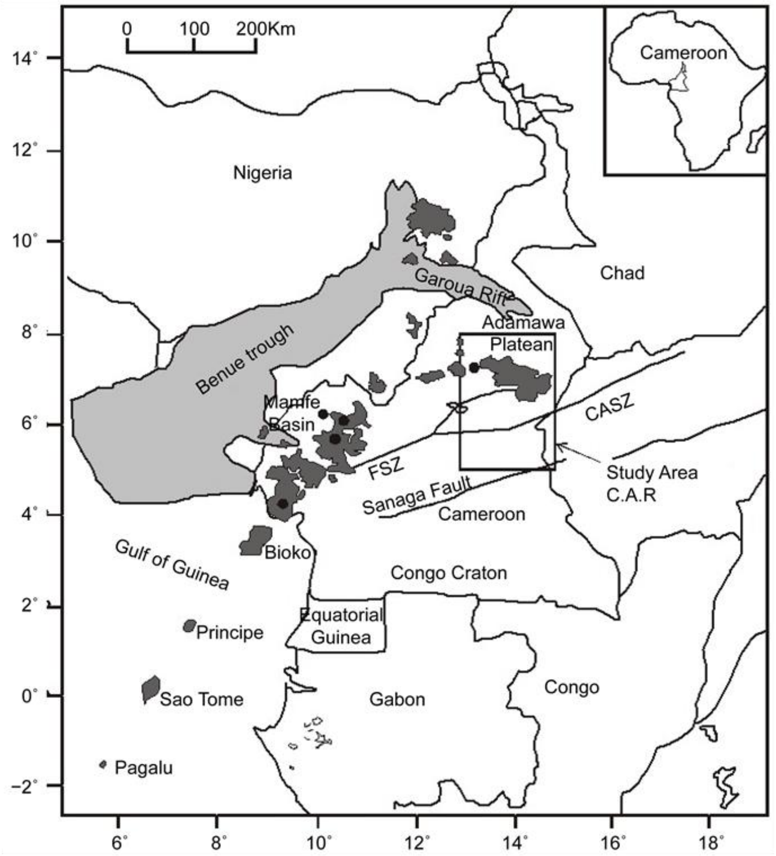

Fig. 1 Location Map Of The Adamawa Plateau Modified After [24].

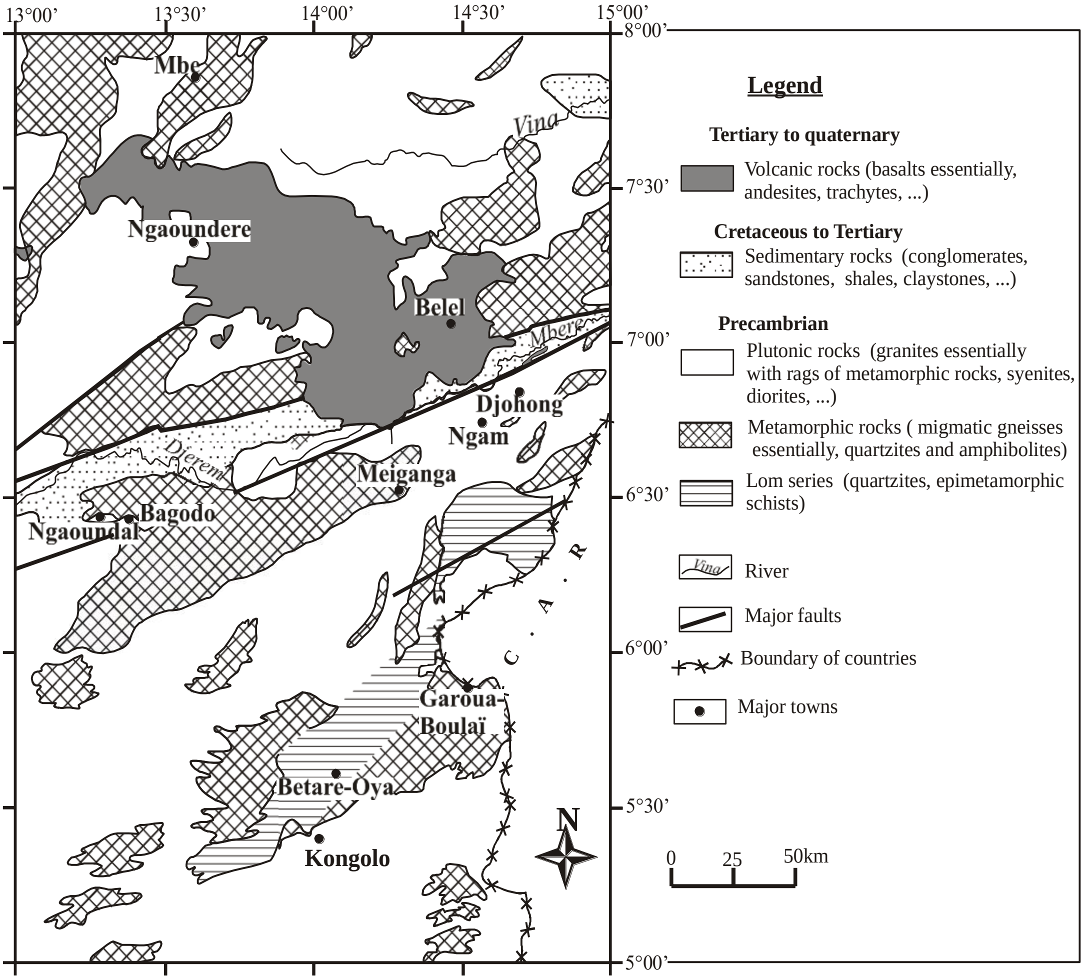

Fig. 2 Geological Map Of The Adamawa Region-Cameroon Modified From [18].

III. Materials And Methods

Gravity data

The gravity data used in this study come from two different sources. The first dataset was derived from terrestrial gravity data. However, due to their limited coverage of the entire study area, a second source was required. This second source was derived from the field model (GGM02C).

The terrestrial gravity data used in this study were obtained from the BGI (International Gravimetric Bureau) database specifically for Central Africa. These data cover the study area, which is limited to the region between longitudes 13° and 15°E and latitudes 5° and 8°N. Most of these measurements were carried out by ORSTOM (Office de Recherche Scientifique des Territoires d'Outre-Mer), now known as IRD (Institut de Recherche pour le Développement). The survey campaigns were carried out by car, using roads or tracks suitable for motor vehicles. Station coordinates were determined using topographic maps and compass bearings. Elevations were determined using Wallace and Tiernan altimeters. Measurements were taken every 3 km, with others between 4 and 10 km, and sometimes more. A total of 672 irregularly spaced points were collected across the study area.

The second data set was obtained using the Grace gravimetric model (GGM02C) [8]. This potential field model compensates for the lack and scarcity of ground or airborne gravity data [9]. It provides gravity data with a degree and order of 200 and better represents gravity anomalies on the Adamawa Plateau [25][9]. According to [8], airborne and terrestrial gravity data have the same accuracy and can therefore be superimposed. A ground correction was applied to the combined gravity network using an average rock density of 2.67 gcm-3. No terrain correction was applied due to the relatively smooth topography of the Adamawa Plateau. These dense gravity data allowed us to produce a simple Bouguer anomaly map of the region (Fig. 3) using generic mapping tools [26].

The tilt angle derivative (TDR)

The tilt angle method [27-29] is the calculation of the inverse tangent of the ratio of the modulus of the horizontal partial derivatives to the vertical derivative of the magnetic field, given by equation:

$$\theta = tan^{-1} \frac{\frac{\partial M}{\partial z}}{\sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2}} \qquad (1)$$

Where M is the magnetic field anomaly. The advantage of the transformation is that by calculating an angle, all shapes are represented similarly, whether the anomalies are of low or high amplitude. [30] have also shown the value of the operator in a specific but fairly general case. If we consider that the operator is applied to the pole-reduced magnetic anomaly map (double pole reduction), it is shown that for a vertical contact (a tabular structure infinite in y, negative in x and below a given value in z), the zero value of the angle corresponds to the structure boundary (h = 0) and the distance between the ± 45° value and the zero value is equal to the structure depth (h = ± Zc). In this way, the boundary of tabular structures and their depth can be observed directly on the transformed map.

Euler deconvolution

Euler deconvolution is a filtering method that allows precise localization of anomaly sources in the horizontal plane, as well as estimation of their depths [31, 32]. Consider a source S located at point M with coordinates (xo, yo, zo). The magnetic field intensity at observation point P is (Reid et al., 1990):
Thompson (1982) showed that Euler's homogeneity equation can be written as:

$$\frac{(x - x_o)\partial T}{\partial x} + \frac{(y - y_o)\partial T}{\partial y} + \frac{(z - z_o)\partial T}{\partial z} = N(B - T) \qquad (2)$$

Where (xo, yo, zo): position of magnetic source; (x, y, z): position of observer; T: total magnetic field detected at (x, y, z); B: regional value of total field; N: degree of homogeneity, often called structural index.

According to [33], then [34]: the choice of the structural index seems to be very important, and they have established a structural index N for a number of structures. It turns out that the structural index N can take values between 0 and 3, corresponding to integers for certain simple structures. Thus, they consider that an index of N=1 is best for thin veins, dykes and faults with low vertical rejection, an index of N=0 for faults with high rejection and an index of N=0.5 for intermediate cases.

IV. Result And Discussion

Interpretation of the Bouguer Anomaly Map

The Bouguer map of the region traces the evolution of the most prominent gravity anomalies in the area under study. Its description allows us to delineate the heterogeneities created by geological formations due to density variations in the Earth's crust [35]. Fig 3 shows the densified Bouguer anomaly map for the study area, highlighting two gravity zones. Analyses performed on this map according to color amplitude allow us to recognize the shape, size and boundaries of the different anomaly shapes. The color distribution represents a combination of shallow and deep anomalies. This color distribution shows two types of anomalies: high density red anomalies associated with a high density level and low density green, blue and yellow anomalies associated with a low density level. The color scale shows that the amplitudes of these anomalies range from -117.4 to -48.6 mGal.

The first zone covers southern Kongolo and western Mbe. This zone is characterized by strong anomalies (-40 mGal) indicating the effect of very dense formations at depth. Examination of the map shows that light anomalies occur in the centre of the massif. Heavy anomalies appear on the eastern and western flanks of the Adamaoua massif and may correspond to the intrusion of very dense basaltic or migmato-gneissic rocks. The second zone, located in the central part of the survey area, is characterized by a zone of long-wave negative anomalies. The negative anomalies at Ngaoundéré and those to the north of Belel are due to local thickening of the sedimentary series caused by subsidence of the basement roof. The shape of these anomalies is the signature of the folding that the crust has undergone as a result of the various tectonic phases that have affected the region [22]. South of Belel, we observe an alignment of negative anomalies (-80 mGal), which is visibly more developed than on the Bouguer map of simple measured anomalies. The Mbéré tectonic trough is located at the localities of Meiganga, Ngam and Djohong. This trench is clearly asymmetric, with the southern flank being much more pronounced than the northern flank (-110 and -48 mGal respectively). The first and second domains are separated by a strong gradient, the result of discontinuities between adjacent formations in the crust, such as faults, flexures or contacts of intrusive rocks.

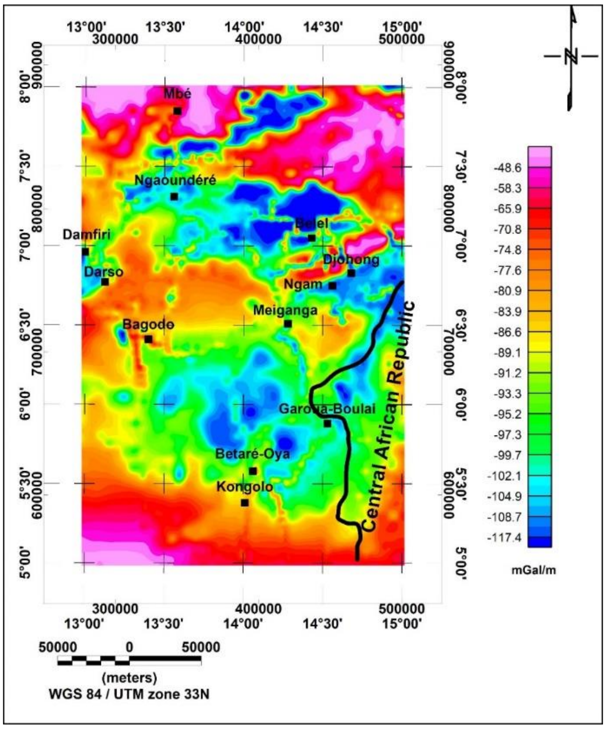

Fig. 3 Densified Bouguer anomaly map of the Adamawa plateau.

Tilt angle map

The TDR method was used to locate the boundaries of these regional and residual sources. The TDR map of the study area (Fig. 4) shows values ranging from -1.37 to 1.29 radians. Zero dip values are interpreted as geological contacts (black lines in Fig. 4). A summary of the contacts is shown in Fig. 5, which summarises the main boundaries between areas of high density contrast. It highlights most of the vertically dipping faults and gives a clearer picture of faults at different depths. Most of these faults correspond to unmapped faults.

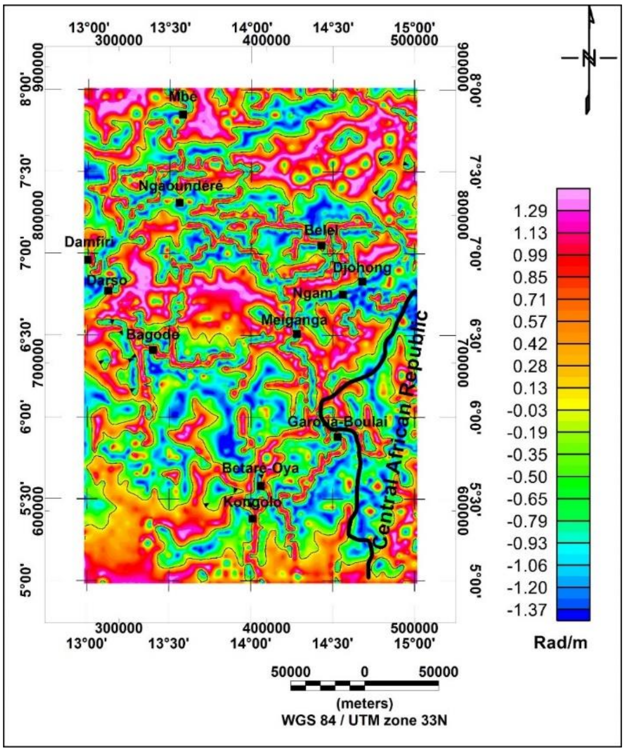

Fig. 4 TDR map, The black lines show the 0 radian contour of the tilt angle.

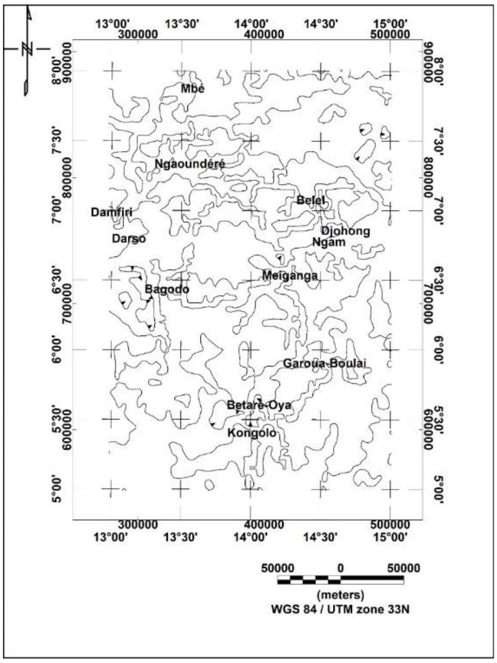

Fig. 5 lineament TDR map.

Euler deconvolution

Euler deconvolution was performed using a computational program integrated into Oasis Montaj. Euler deconvolution is particularly effective for delineating contacts and assessing their depth. The quality of this assessment depends largely on the appropriate choice of structural index, which is a function of the geometry of the causal bodies. The ED technique is applied to data from the densified Bouguer anomaly grid of the study area. The window size used is 10 × 10, with a maximum depth tolerance of 10%. The structural index used is 0 to locate and determine contact depths. The resulting map is shown in Figure 6. Good clustering of solutions indicates that the source location is well defined, and scatter indicates that solutions should probably be ignored [34]. On this map, Euler's solutions are generally well grouped. These solutions are represented by coloured circles. The colour of these circles is a function of depth. Solutions (faults and fractures) are grouped into six depth ranges, from shallow to deep subsurface at [0; 2 km [, [2; 4 km [, [4; 6 km [, [6; 8 km [, [8; 10 km [and over 10 km intervals, respectively. Euler solutions are well clustered along the WNW-ESE, ENE-WSW, E-W, NE-SW and NW-SE directions.

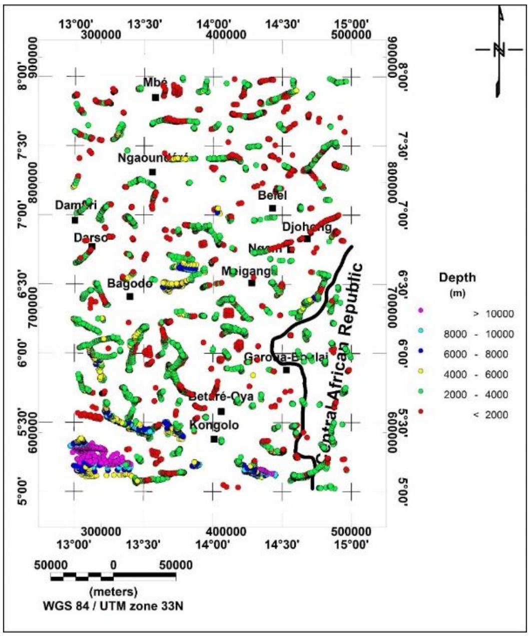

Fig. 6 3D Euler depth solution map shows the cluster of source depth locations positioned at the boundaries.

The Euler solutions were superimposed on the lineaments generated by the tilt angle method (Fig. 5). In the absence of field data, this procedure can be very useful for cross-validating the results obtained by these two different methods. Visual inspection of Fig. 7 shows a strong correlation between these different results, confirming their accuracy. There is some complementarity between the two methods.

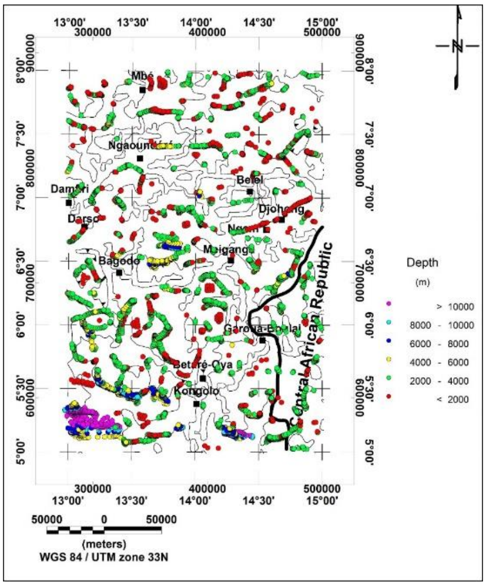

Fig. 7 3D-Euler Solutions Plotted On Lineament TDR Map, N.B. Euler Solutions Are Located On Zero Radian Contour Line Of TDR Map.

The Euler deconvolution map has allowed us to construct a synthetic structural map, highlighting faults and the contours of intrusive formations in the bedrock. This map is an important document that could serve as a guide for the study and exploitation of thermomineral springs and groundwater in the study area, facilitating the identification of favourable points (faults) for their existence or emergence. The rose diagram (Fig. 7B) shows two main directions: WNW-ESE and ENE-WSW; and three secondary directions: E-W, NE-SW and NW-SE. The WNW-ESE direction is the most important and is thought to be due to the emplacement of the Pan-African nappe. The ENE-WSW orientation is indeed the one that characterises Pan-African tectonics on a regional scale and has been highlighted on the Adamaoua structures by [36] and [37]. It is also the orientation of the main Pan-African structures in Cameroon, namely the Central Cameroon Shear and the Sanaga Fault. Several works have been carried out in the study area and in regions close to it, in particular [8, 9, 36, 38-40]. The lineaments directions identified in the study area are similar to those found in neighbouring regions, suggesting that these areas have been affected by similar, if not identical, tectonic activity.

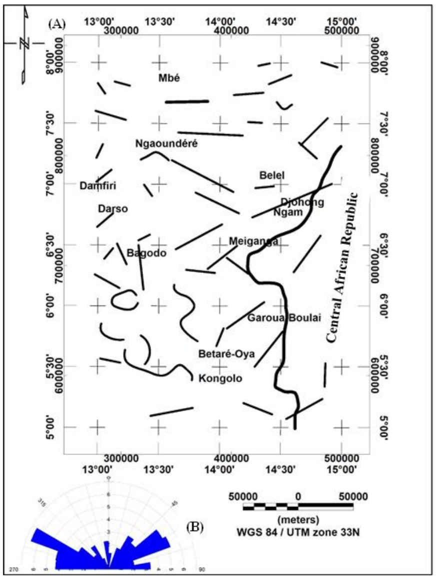

Fig. 7 Structural map from euler's solutions.

V. Conclusion

Terrestrial gravity data, combined with data calculated from the GGM02C gravity model, were analyzed and interpreted using the tilt angle method and Euler deconvolution. The results suggest the presence of several structural lines in the region. The main results of the study provide new insights into the geological structure of the study area, in particular the main lineaments responsible for this structuring. These lineaments are part of the general tectonic context of the North Equatorial Pan-African chain. Statistical analysis of the lineaments obtained in this study revealed five families of magnetic lineaments of regional significance. These lineaments are oriented in the WNW-ESE, ENE-WSW, E-W, NE-SW and NW-SE directions. 3D Euler deconvolution was used to determine the depths of the structures responsible for the gravity anomalies observed in the study area. The depths of these structures exceed 10 km. Given the geological structures highlighted in this study, it is clear that tectonic activity continues in the region. Knowledge of the petrophysical characteristics and geological constraints, particularly those brought to light by drilling, is necessary in order to propose the most pertinent results.

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