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Geophysical features of Douala Sedimentary Basin inferred from the analysis of Aeromagnetic data

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ABSTRACT
The Douala Sedimentary Basin (DSB) isacoastalsedimentary basin withbasement made up of granite and gneiss. Itscomplextectonicswasbornedfrom the separation of African and American plates. The first geological sketch wascarried out in 1955 by Hourq and supplemented by variousstratigraphsworking in the petroleumfield and the synthesis of theirresultscan help today to determine a seriousstratigraphy of the geological stages and formations of the basin. To supplementthis information, we are going to use the aeromagnetic data collected by CGG society in 1980 to bring out the geologicalfeatures of the study area. To achievethis, we first proceedwith the Blakely and Simpson method to determine the maxima of the maps of the horizontal gradient and of the analytic signal, then, next, analyse them in orderto bring out the differentlineaments, and finally, interprettheselineaments in order to bring out their nature. To verify the validity of ourresults, we have drawn up Euler'sdeconvolutionmapwhichreveals the existence of manyfaultsthatpreviousstudies have not been able to point out.

Keywords: Aeromagnetic, Horizontal gradient, Analytic signal, Lineament, Fault

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I. INTRODUCTION

The history of the DSB begins in the lower Cretaceous with a break marking the separation of South American and African plates. The filling of the basin began during this initial rift phase with the stacking of the first deposits of the lower Mundeck formation [1, 2]. The geological studies like stratigraphical studies, paleogeographical studies and palynological studies of the said basin has been the subject of research of several researchers like Nguené et al. [2], Tamfu et al. [3], Ntamak-Nida et al. [4], Giresse[5], Lawrence et al. [6], Batupe[7], Regnoult[1], SNH [8], Dumort[9], Hourcq[10], Reyre [11, 12], Belmonte[13], NjikeNgaha[14], Robertson [15], NjikeNgaha[16], Reyment[17], Kenfack et al. [18], Salard-Cheboldaeff[19-23], Meyers et al. [24], Brownfield and Charpentier [25], ECL [26], Logar and al. [27], Furon and Lombard [28],Pauken et al. [29]. Apartfromgeologicalstudies, the Douala Sedimentary Basin has also been the subject of geophysicalworks in gravity of Ndikum et al. [30]and magnetotelluricworks of Manguelle-Dicoum et al. [31].

The use of aeromagnetic data to determine the internalfeatures of the Douala basin canguarantee more detailled and precisedresultssincethismethod has the advantagethatitdoes not takeintoaccount the density of vegetation and accessdifficultyduring data collection. This advantagemakes the aeromagnetic method a large spectrumgeophysicalmethod. The aim of thisworkwillbe to use it to determine the map of maxima of the horizontal gradient of the total magneticintensityreduced to pole, and that of the amplitude of the analytic signal of the total magneticintensity, leading us to sketch the structural map of the DSB. Next, using Euler's deconvolution map, this mapwillbeanalyzed in order to reveal the dips of the variousfaults, whichcould serve as an orientation for future geophysical investigations, and can of course gives up plementary geological information to the DSB.

II. GEOLOGICAL AND GEOPHYSICAL SETTINGS OF THE STUDY AREA

The Douala basin is one of the coastal sedimentary basins in Cameroon. It covers an area of 19000 km^2 of which 7000 km^2 onshore has three marginal fields in production [8]. It extends under the waters of the Gulf of Guinea by a 25 km wide continental platform and is made up of two sub-basins: the Douala sub-basin limited on the north by the volcanic line of Cameroon and on the south by the Nyong river, and the Kribi-Campo sub-basin locatedbetween Nyong river in the north and the

Ntem river in the south[2]. The relief of this region is relatively flat and its altitude does not exceed 200 m. The geological sketch of the Douala basin was first made in 1955 by Hourcq [10] (Fig.1) and the stratigraphy of the deposits was essentially established by the study of deep drilling which highlighted an accumulation of sediments ranging fromCretaceous to Neogene.

Our study area islocated in the Douala sub-basin between the altitudes 4°00' and 4°70'N and longitudes 9°40' and 10°00'E, represented on the geological map of the region (Fig.2). The sedimentary deposits of the Douala basin were formed in three successive intervalsfrom the Albian to the Actual. During this period, a passive margin was formed by accumulation of unconformity sediment deposits, separated by cuts due to phases of orogenesis[6,4,29]. Previous geological works allowed them to estimate the depth of the sedimentary section to a value ranging between 8 and 10 km. Manguelle-Dicoum et al. [31]brought out the existence of two blocks of different morphologies and estimated the total sedimentary thickness at 1100 m using the audio magnetotelluricsurvey. Also, in 2014, Ndikum et al. [30] proceeded with gravity studies to detect an intrusive body in the north-west part of the onshore portion of the basin at a depth of about 6 km and the thickness was estimated at 27 km. The works of Hourcq[10] have been completed and refined by variousstratigraphs, and the synthesis of their results now makes it possible to determine a stratigraphy composed of two series and several stages. In addition, on the basis of the works of Regnoult[1], Tamfu et al. [3], Nguene et al. [2], Meyers et al. [24], Lawrence et al. [6], Brownfield et Charpentier [25], sevengeological formations have been described in the Douala basin and are represented from the oldest to the most recent as follows:

Mundeck formation,
Logbadjeck formation,
Logbaba formation,
Nkapa formation,
Souellaba formation,
Matanda formation,
Wouri formation.

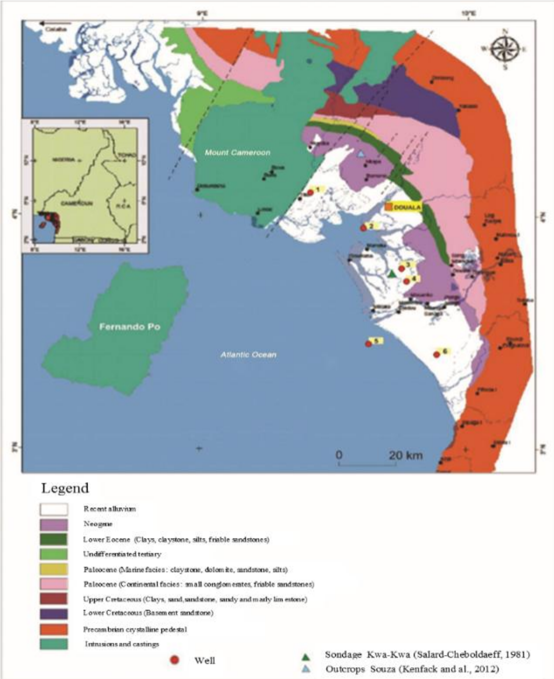

Figure 1: Geological sketch of the Douala sedimentary basin and surveys location (fromHourcq [10] / Salard-Cheboldaeff [23]).

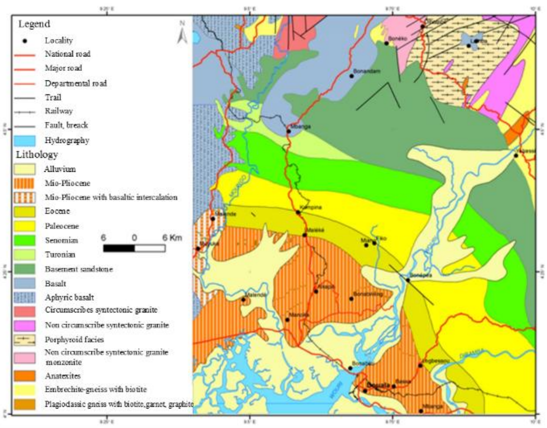

Figure 2: Simplifiedgeologicalmap of the Douala sedimentary basin [9].

III. DATA INTERPRETATION

1.1 The origin of data

The aeromagnetic data used for thiswork are from GETECH Group plc. (Leeds, UK). This data wascollectedin 1980 by the CGG Company for the account of the Elf Companywith the following parameters: a line spacing of 2500 m, aflyingheightof 400 m in a line direction of 0. Before the processing of the data, we have applied the IGRF (International Geomagnetic Reference Field) filterfrom the Oasis Montaj software in order to determine the nature of these data. So, wenoticedthat the data contained values of the total magnetic field anomaly collected ateach of the given measurement point, ready to beinterpreted.

1.2 Data processing

In order to bring out all the contact/fault lineaments of the DSB, we successively applied several filters on the anomaly map of the total magnetic field. Among these filters, we have the reduction to pole, the vertical gradient, the horizontal gradient, the analytic signal and the Euler's deconvolution.

1.2.1 The total magnetic intensity map

The total magnetic field anomaly map of the study area was gridded using the Oasis Montaj software with a constant move of 0.01 degree, whether about 1.1 km. The total magnetic intensity map shows that the amplitude of magnetic anomaly is directly proportional to magnetization which depended on magnetic susceptibility of the rocks [32]. This map highlights the sum of the effects of all the magnetized bodies, regardless of their orientation, their nature and their intensity of magnetization (Fig.3).

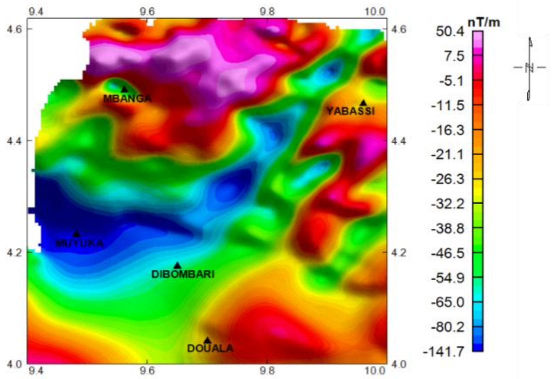

Figure 3: Total magnetic intensity map of the study area.

A superficial analysis of this map shows that the magnetic relief of the Douala basin is disturbed by numerous anomalies of different wavelengths, whose maxima reach peaks of amplitude of 50 nT and the minima reaching values of -120 nT. We can also notice that these anomalies are in most cases oriented along directions N70°E and N45°E, and positive anomalies represent outcrops of basalt in the basin while negative anomalies represent outcrops of Precambrian gneiss formed at the origin of the drift of American and African plates, surrounded by sediments like sandstone, conglomerates and clay in intercalation.

1.2.2 The total magnetic intensity map reduced to pole

Because of the bipolar nature of the magnetic bodies, their signatures at low latitude always have two extrema and this has the disadvantage of making interpretation difficult especially when the effects of several sources interfere. Then, making a link between the observed anomalies and the positions of the sources, their structures are not at all evident, and to solve this problem, we will use the reduction to the pole operator. The reduction to pole transforms the observed magnetic anomaly into an anomaly that would be measured if the magnetization and the ambient field were all vertical. This places the limit of the anomaly directly above its source as in gravity facilitating the interpretation. The total magnetic intensity map was transformed into reduction to the pole grid (Fig.4) using the 2D-FFT (Fast Fourier Transform) filter in Geosoft Oasis Montaj software, with an inclination of -16,720° and a declination of-5,357°. These parameters represented the mean value for the area taken on the 01/01/1980 according to IGRF.

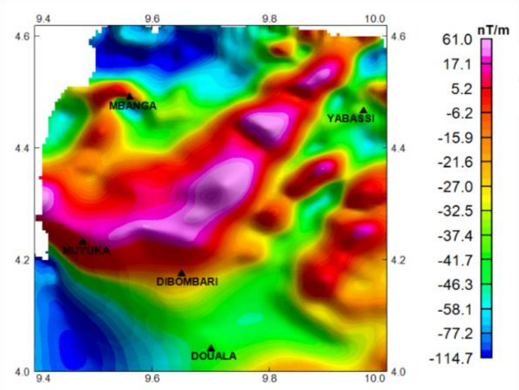

Figure 4: Total magnetic intensity map reduced to the pole.

This map shows that the zones of positive anomalies are parallel to the direction NNE-SSW whichwouldbe the major direction of faulting due to the separation of the African and American plates. From the form and distribution of these anomalies, thismap shows a greatcorrelationbetween the anomalies and the geologicalfeatures, markedhere by the predominance of the magnetism of the igneous formations compared to the metamorphic formations. In conclusion, the positive magnetic anomalies observed in the zone have their sources mainlylocatedinside the Earth'scrust.

1.2.3 The vertical gradient map

The vertical derivationoperatorisapplied in order to individualize the differentobserved anomalies. It alsohelps to betterdistinguish the various anomalies becausewhenseveral structures are close enough and locatedat comparable depths, the measured signal shows the existence of a single anomaly. Figure 5 shows the first order vertical derivativemap of the DSB. This mapwith no regionalfeaturesreveals areas of positive gradients that are clearlydistinguishedfrom zones of negative gradient. Also, thismapindividualizes the anomalies whichwererepresented in the block above, and reveals anomalies thatwere not visible on the maps of anomalies of the total magneticintensity and of total magneticintensityreduced to the pole.

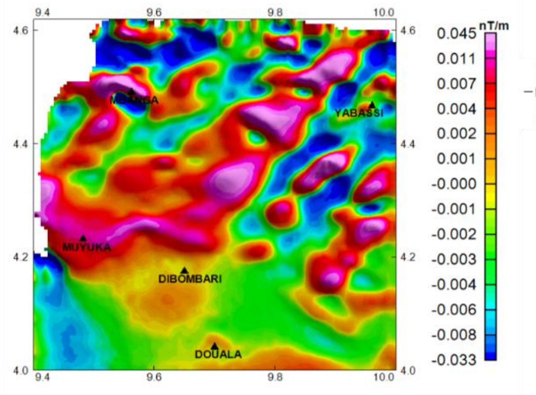

Figure 5: The first order vertical gradient map of the total magneticintensityreduced to the pole.

1.2.4 The horizontal gradient map

In the spatial domain, the horizontal gradient (HD) of the total magnetic field T is given by:

$$HD\,(x, y) = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2} \qquad (1)$$

According to Phillips [33], this function gives a peak anomaly above magnetic contacts under the following assumptions: (1) the regional magnetic field is vertical, (2) the magnetizations are vertical, (3) the contacts are vertical, (4) the contacts are isolated,(5) the sources are thick.

In low latitudes, for the existence of a horizontal gradient to corresponds to the presence of a magneticsusceptibility, we must apply the horizontal gradient directly to the map of total magneticintensityreduced to the pole ratherthan to the map of total magneticintensity. The maprepresented on figure 6 shows high gradient areas thatappear in variousformswithpeaks of amplitude up to 0.04 nT. On thismap, we observe areas of strongly positive anomalies in the North, East and West parts of the study area. These anomalies are associatedwithdeep and superficial structures whoseboundaries correspond to tectonic accidents in the study area.

Finally, these resultsconfirmthose of the geologica lstudieswhichstipulatethat the sedimentary deposits of the Douala basin are unconformably repose on aPrecambrianbasement made up of granite and gneiss.

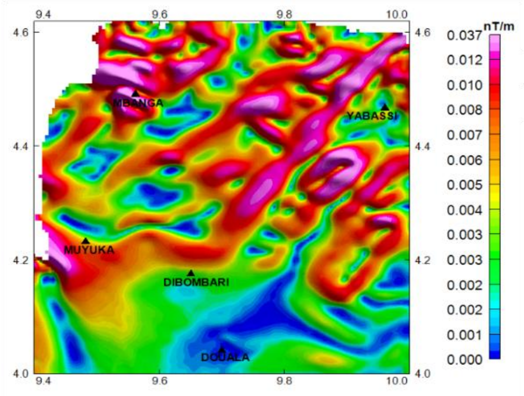

Figure 6: Horizontal gradient map of the total magneticintensityreduced to the pole.

1.2.5 The analytic signal map

The significant characteristic of the analytic signal is that, it is independent of the direction of magnetization of the source [34,35]. This is why it is applied directly to the map of the total magnetic intensity. Moreover, the amplitude of the analytic signal can be related to the amplitude of magnetization [36, 37]. The amplitude of the analytic signal of the anomaly T of the intensity of magnetic field is given by [34]:

$$AS = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2} \qquad (2)$$

The purpose of the analytical signal is to stronglyidentifymagnetizedgeological structures. The map of the analytical signal represented in figure 7 has an analogywiththat of the horizontal gradient.

The positive anomalies are oriented NNE-SSW and NNW-SSE and the major maxima underlined on the map of the horizontal gradient are wellrepresented on the map of the analytic signal, and reach amplitude peaks of 0.07 nT.

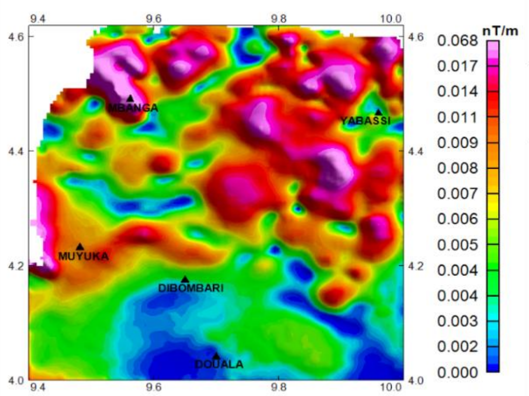

Figure 7 : Analytical signal map of the total magneticintensity.

IV. RESULTS OF DATA INTERPRETATION

After a qualitative analysis of the filteredmapsoutlinedabove, nextwillbe quantitative analysis in order to highlight all the lineamentsissuedfrom the creation of the Douala basin. For this to bedone, wewill use the method of Blakely and Simpson [38] to determine the maxima of the horizontal gradient and the one of the analytic signal. Once the maxima are determined, wewillsuperimposethem in order to plot the structural sketch of the study area, and finally use Euler'sdeconvolutionmap to justify the fracturing directions obtainedafterthisstudy.

1.3 Quantitative analysis of the horizontal gradient map

On the map of the horizontal gradient of the total magneticintensityreduced to the pole, we observe zones of strongly positive anomalies in the North, East and West. These anomalies are associatedwithdeep and superficial structures the boundaries of which correspond to tectonic accidents in the study area. These anomalies are parallel to the NNE-SSW direction, whichwouldbe one of the major structural directions of the Douala sedimentary basin. To assertthis information, wesketched the maxima of the horizontal gradient represented in the figure 8.

On this map, we can confirm the structural complexity of the study area. The lineaments located here can be assimilated to linear contacts that can correspond to faults, circular contacts that can correspond to the horizontal contours of intrusive body boundaries and magnetic strips that can be assimilated to domes or folds.

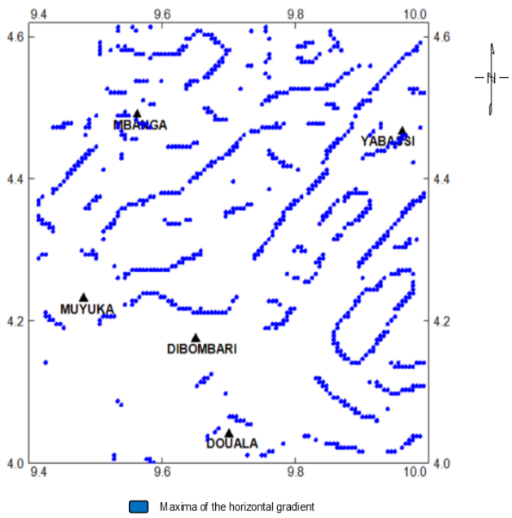

Figure 8: Maxima'smap of the horizontal gradient.

1.4 Quantitative analysis of the analytic signal map

The map of analytic signal of the total magnetic intensityalso shows the anomalies parallel to the NNE-SSW and NNW-SSE directions, and the maxima'smap of analytic signal (Fig.9) weredrawn to assertthese information.

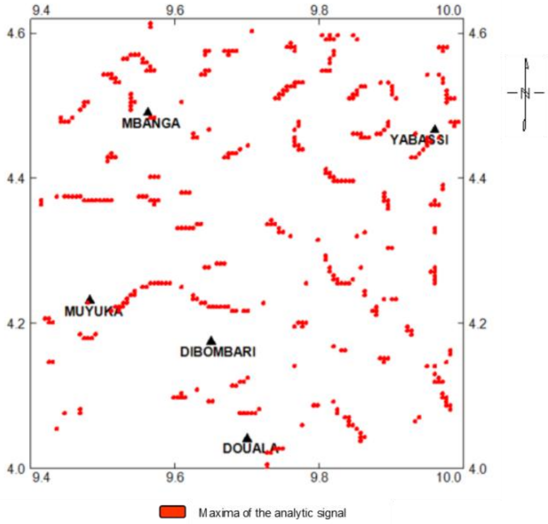

Figure 9: *Maxima'smap of the analytic signal.*

This map highlights linear geological contacts that can be assimilated to faults and magnetic strips that can be assimilated to domes or folds.

1.5 Analysis of contacts locations

The maxima'smaps of horizontal gradient and analytic signal wassuperimposed in order to determine the geological contacts of the study area (Fig.10). This mapwillbeanalyzedlater in order to highlight the nature of the contacts mentionedabove.

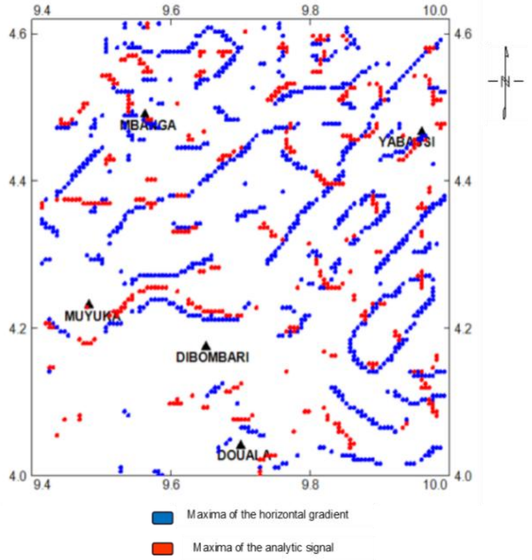

Figure 10: Maxima'smap of the horizontal gradient and the analytic signal.

1.6 Contribution of Euler's deconvolution

Euler's deconvolution is a quantitative interpretation method whose objective is to trace directly from the map of total magnetic intensity the lineaments of the study area while showing their orientation and their depths. It was applied to the grid of magnetic anomalies with the following parameters: N = 1, Z = 15%, W = 10x10, H = 400 m. On this map shown in figure 11, we can see that the deep and superficial tectonic accidents are in NE-SW and NW-SE directions, and this justifies also the results obtained from the graphs of horizontal gradient and analytic signal.

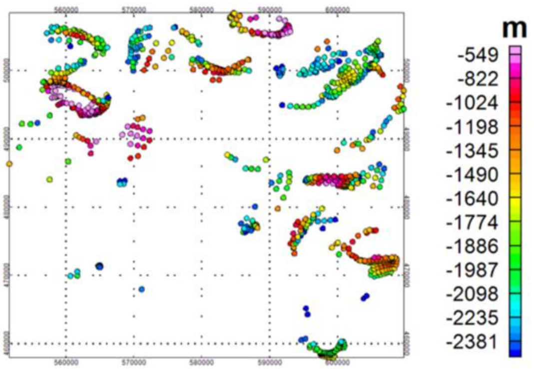

Figure 11: Euler's solution map of the study area.

1.7 Structural map of the study area and interpretation of features

The map of figure 10 will be interpreted with the aim of drawing the structural sketch of the study area. The method used stipulates that when the maxima of the horizontal gradient and that of analytical signal are superimposed it gives fault location and where contacts of horizontal gradient are parallel to analytic signal and slightly offset from them, in this case the analytical contact represents the true feature location and the down dip direction is illustrated by the horizontal gradient contacts. The structural sketch of the study area shown in figure 12 were drawn based on the results of the graphs of the maxima of horizontal gradient and maxima of analytic signal. The underlined contacts on this structural sketch are presented under three distinct natures:

- Main faults (*in strong lines*), which would represent zones of main tension existing at the opening of the South Atlantic;
- Secondary faults (*in thin line*), which would represent zones of secondary tension;
- A geological intrusion (*red*), which could be assimilated to an intrusion of igneous bodies into the sediments;
- A magnetic trip (*in green*), which is a direct observation of magnetic peaks and troughs, which can be assimilated to a fold.

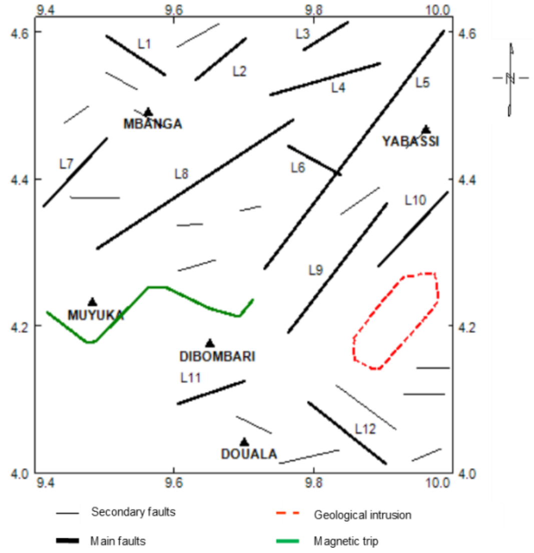

Figure 12: Structural map of the study area.

In the aim to justify the results obtained from the Euler's deconvolution map of the study area, we plotted the rosace of the structural directions represented in figure 13 and calculated the structural directions with respect to the North azimuth as shown in Table 1:

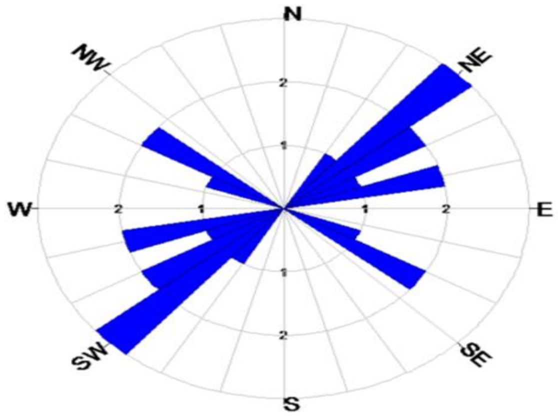

Figure 13: Rosace of faulting cartography.

Table 1: Directions of main contacts interpreted as faults.

Fault	Direction
L1	N121°E
L2	N54°E
L3	N61°E
L4	N75°E
L5	N40°E
L6	N117°E
L7	N46°E
L8	N59°E
L9	N40°E
L10	N45°E
L11	N73°E
L12	N126°E

According to our results, we can say that during the opening of the South Atlantic, the tectonics of the study area were subjected to faulting along two major directions, namely NW-SE and NE-SW. A comparison of the structural map obtained with the one drawn by Dumort[9] shows the existence of several other faults that were not visible from the old geological study results.

V. CONCLUSION

The acknowledging work of the Douala basin had not yet integrated the study by aeromagnetic approach in order to the realization of its structural map. It has enabled us to highlight several structures which were not visible up till now, and opened a broad field of research for future geophysical studies. The faulting system responsible for fracturing of the basin basement has been highlighted by analysis of the maxima's maps of the horizontal gradient and of the analytic signal. An analysis of these faults based on Euler's deconvolution map showed that the major fracturing directions are oriented NW-SE and NE-SW, and the main faults are located at depths up to 2 km.

The complexity of the tectonics of the region has been highlighted by the rosace of directions and the calculation of dips and these results could serve as an orientation for future research in the basin. We also observed a clear increase in geological information on the old results and this can be explained either by the limit of the previous methods or by the evolution of the tectonics of the region with time.

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