IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 10, Issue 1 Ser. I (Jan. – Feb. 2022), PP 01-11
www.iosrjournals.org

Contribution of aeromagnetism to the lithostructural identification of the aquifer system of Bouaké department (Central Ivory Coast)

Kouamé Gbèlè Hermann Loukou, Loukou Nicolas Kouamé,
Boko Célestin Sombo
(Equipe de recherche Géophysique, Unité de Formation et de Recherche des Sciences de la Terre et des Ressources Minières (UFR STRM) / Université Félix Houphouët-Boigny d'Abidjan, Côte d'Ivoire)

Abstract: *This study, carried out in Bouaké (Central department of Cote d'Ivoire), is based on the review processing of the aeromagnetic data collected during 1974 to 1976 by Kenting Earth Sciences company. Reduction to the equator and vertical integration filters were applied to the data to emphasizing the role of the geological structures on the productive aquifer network located in Bouaké area. As a result, the aquifer network of Bouaké is composed of felsic rocks (granitoids), schists and numerous faults with different directions such as N-S, NE-SW (main direction) and NE-SW, ESE-WNW, NNE-SSW and ENE-WSW. The schists and the fractures especially in N-S direction are the most interesting zone for underground water exploitation.*

***Key Word**: Bouaké, aeromagnetic data, filters, aquifer.*

Date of Submission: 03-01-2022 Date of Acceptance: 14-01-2022

I. Introduction

In hydrogeology, the lithological composition of aquifers has a particular interest especially in groundwater exploration. Moreover, understanding of the fracture networks before any drilling operations becomes a good parameter to characterize the discontinuous aquifers. Therefore, the design of an accurate lithostructural map should be an additional guide to lead a successful hydrogeophysical exploration, especially in a basement area to solve one aspect of the water scarcity problem faced by the population in Bouaké department.

Commonly, the aeromagnetic data represents the most popular data used by the geophysical community to map the hydrogeological most interesting structures [1-6]. Therefore, the use of the aeromagnetic data to highlighting the lithological, structural features as well as the fracture network in Bouake department should be a good approach to better understand the whole hydrogeological interest of this locality.

II. Material And Methods

II.1 Geological setting

The department of Bouaké is located in center region of Cote d'Ivoire (about 340 km from Abidjan) with area estimated around 3,541 km^2. The department lies between longitudes 4°30 and 5°14 W and latitudes 7°18 and 8°02 N (Fig. 1).

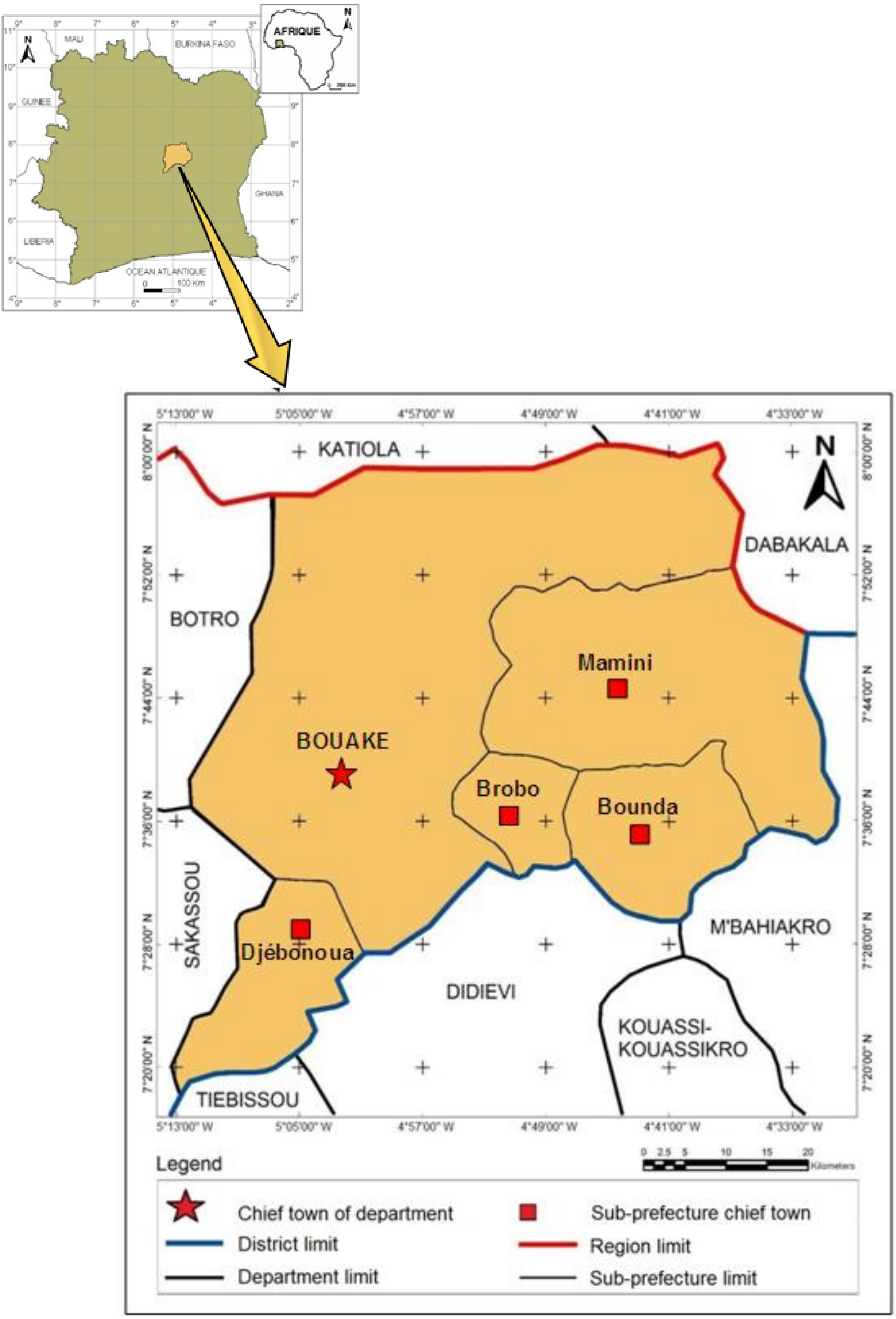

Figure 1. Location map of Bouaké department

The geological structures of Bouake were established during the Eburnian orogeny (2,500 Ma to 1,600 Ma). In addition, the geology of Bouaké is demarcated by two (02) series: the Eburnian and the Birimian series (Fig. 2).

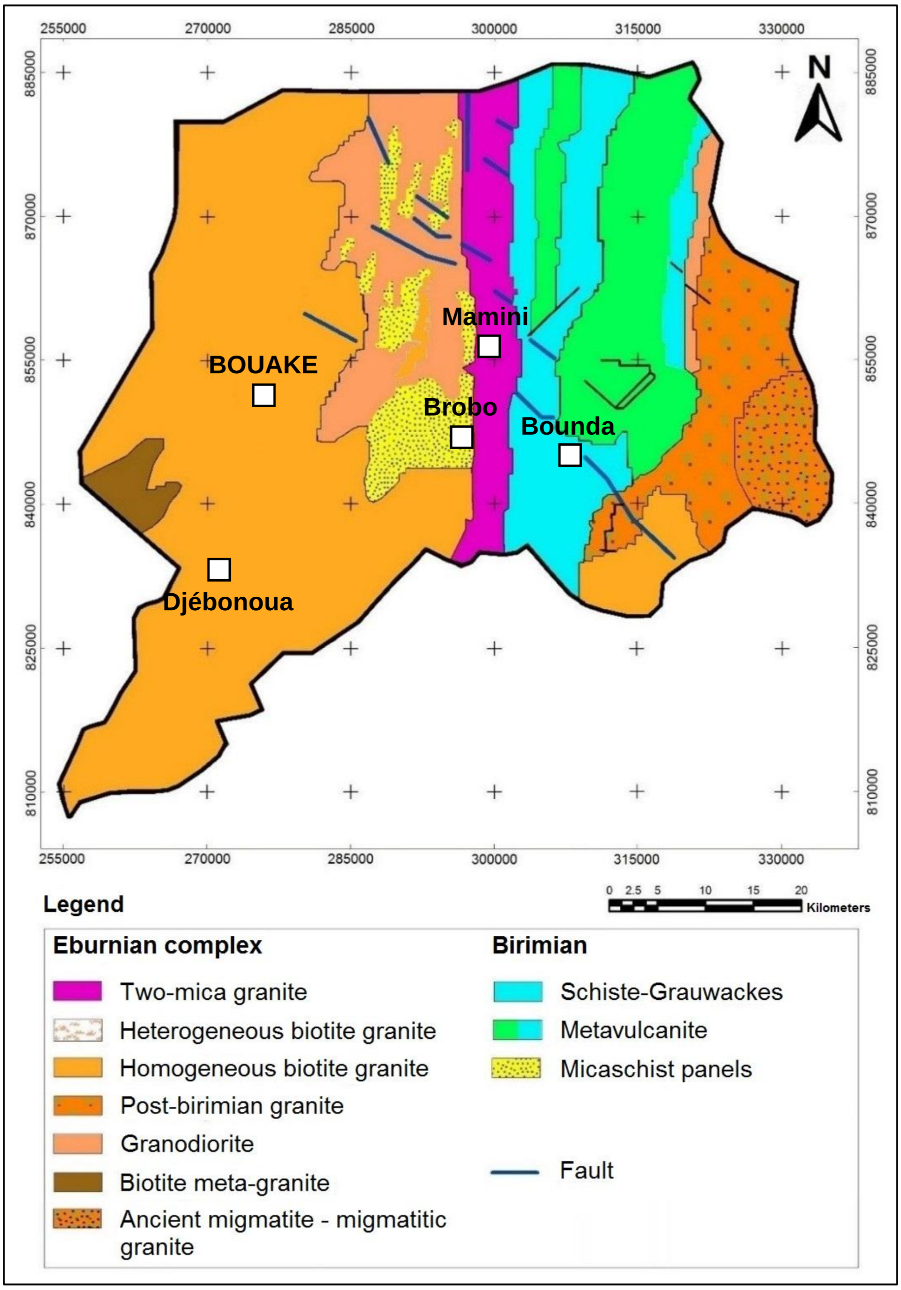

Figure 2. Geological map of Bouaké department [7]

The Eburnian is composed exclusively of granitoids with various types: the granitoids with intrusive features and the hybrid features composed of the granites, granodiorites and migmatites [8-9].

The Birimian is a set of volcano-sedimentary series composed of the metamorphic rocks ranged from the greenschist to the amphibolite rocks oriented to N-S. In addition, the Birimian series also include the intermediate eruptive rocks such as the volcano-deposits and the meta-deposits (schists, quartzites).

Moreover, three main deformations have affected the geological structures in Bouake area [10-15]:

- Deformation of type I (also called early stage) is characterized by the vertical tectonics of diapirism type;
- Deformation of type II, characterized by the SW-NE rift that affects the sedimentary rocks of the Bandama basin;
- Deformation of type III, which is demarcated by a N-S break-plan.

Deformations II and III are related to the transpressure closure of Bandama basin to which belongs the study area. During this local tectonic motion, the isoclinal folds were set in place with the horizontal axis tilted to the NE-SW.

II.2 Data and methods

The aeromagnetic data was acquired by Kenting Earth Sciences company during the years 1974 to 1976. The survey covers the Bouaké 2d, 4b, 4d and M'Bahiakro 3a, 3b, 3c and 3d sections.

The aeromagnetic data was firstly preprocessed which consists to digitalizing the raw data format to the numerical format and to store the digitalized data into a database. Secondly the transformed data was processed using the Oasis Montaj software from Geosoft Corporation to build the residual magnetic field map from which two filters were applied (Fig. 3).

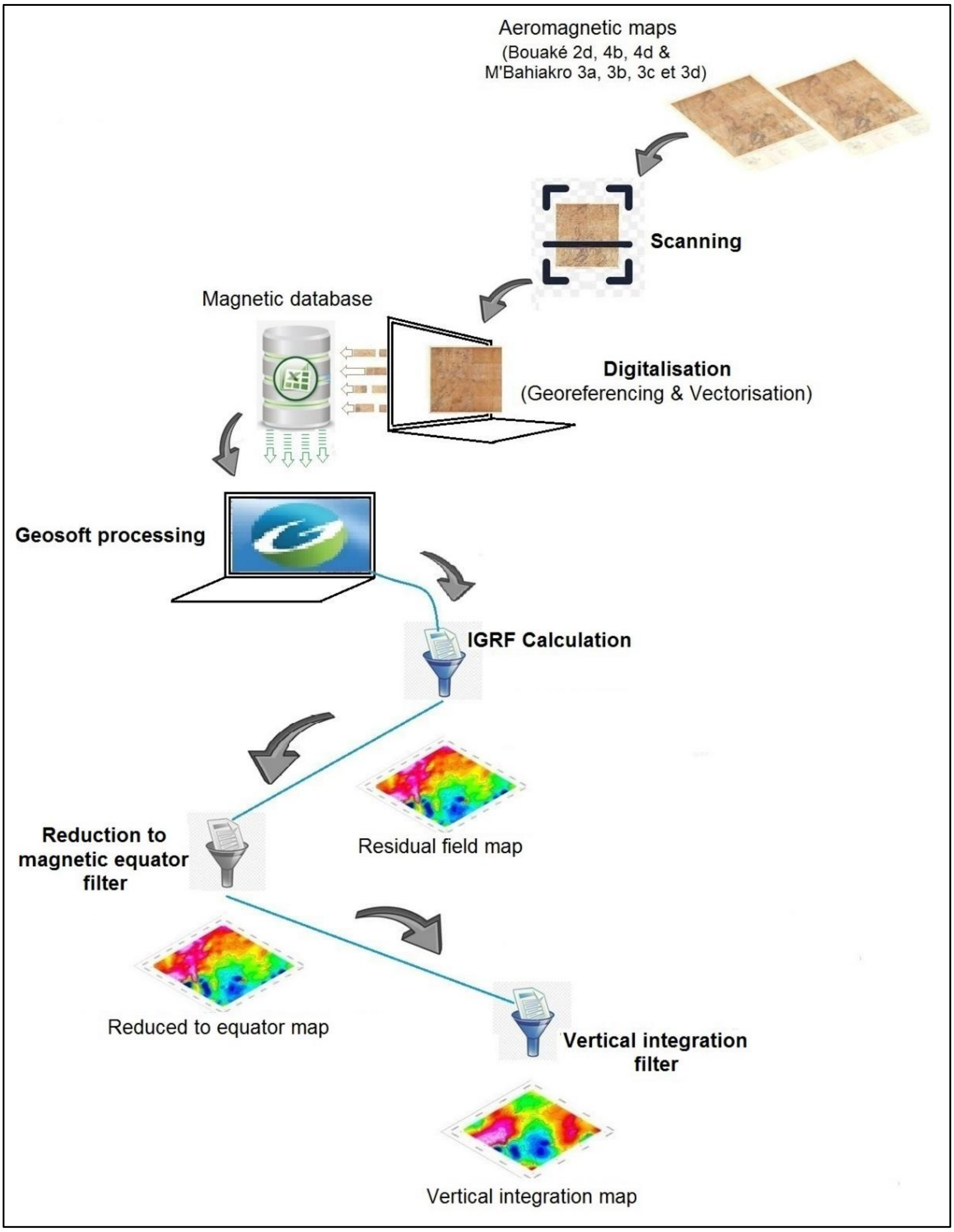

Figure 3. Aeromagnetic processing flow

The International Geomagnetic Reference Field (IGRF) is used to compute the intensity, the inclination as well as the declination of the earth's magnetic reference field from the geographical coordinates of the measurement stations. These processing flows were done considering the date of the aeromagnetic survey. Indeed, taking into account of the reference magnetic field value, the intensity of the residual field emanating from the rocks in place can easily be deduced using the following formula:

$$H_0 = H_1 - H_2$$

where:
H_0: Residual or induced magnetic field, H1: Magnetic field read or total; and H2: Earth's reference magnetic field.

The equatorial reduction filter was used in low-latitude magnetic areas, (In the case of Cote d'Ivoire), to center the threshold of the magnetic anomalies from their sources. That could solve the magnetic anomaly asymmetry problem by making the data easier to interpret. This filter can be expressed as:

$$L(\theta) = \frac{[sin(I) - i.cos(I).cos(D-\theta)]^2 \, x \left(-cos^2(D-\theta)\right)}{[sin^2(Ia) + cos^2(Ia).cos^2(D-\theta)] \, x \, [sin^2(I) + cos^2(I).cos^2(D-\theta)]}$$

If (|Ia|<(|I|), Ia = I
where: L: Latitude of the station, I: Magnetic inclination; Ia: Tilt for amplitude correction, D: Declination, sin(I): Amplitude component; and $i \cdot \cos(I) \cdot \cos(D - \theta)$ are In-phase component.

The addition filter such as the vertical integration is useful to determine the long-wavelength anomalies especially those generated by the basement rock [16]. This filter operates as the upward analytical extension. Indeed, the signal is smoothed and the responses of the deep structures gave priority to shallow objects. The vertical integration filter is given as:

$$H_{iv} = \left(\vec{\nabla} H_{/z}\right)^{-1} = \left[\left(\frac{\partial H}{\partial z}, \frac{\partial H}{\partial x, y}\right)\right]^{-1}$$

where: Hiv: Vertical integration of the field, H: Magnetic field, x, y: Horizontal directions in the spectral domain, z: Vertical direction in the spectral domain.

III. Results

III.1 Reduced to equator map

Figure 4 shows that the magnetic susceptibility is very weak in the Bouaké department with the difference between maximum and minimum of the magnetic anomaly value approximated to 100 nT. These aeromagnetic signatures seem to belong to the same geological structures and its segmentations. However, the qualitative analysis of the reduced field map demarcates three (03) main zones (magnetic domains):

- the magnetic anomalies with higher amplitude (from red to pink);
- the intermediate aeromagnetic zone (green to yellow-orange);
- the magnetic anomalies with low amplitude (light to dark blue).

For the following study, we will use the term of "high" and "low" magnetic domain to specify the magnetic anomalies with higher and with lower amplitude respectively.

Thus, the high magnetic domain (with higher amplitude) is distributed throughout the study area and mostly lied along with the NE-SW direction. They are in Figure 4, represented by the anomalies A1 (in the North-Eastern), A2 (in the Eastern), A3 (in the Center) and A4 (in the South-Western), and show some distorted and irregular contours caused by intense tectonic activity in this region. Whilst, the low magnetic domain mainly lied from the northwestern to the southwestern with little presence in to the western, center and eastern part. Like the high magnetic domain, low magnetic domain structures are mostly oriented in NE-SW direction. This structures direction demarcated in study area fit property to the Eburnian direction. However, the geological structures resulting from an intermediate domain (the transition zone: between the high and the lower magnetic domain) are mostly dominated with various magnetic structures directions.

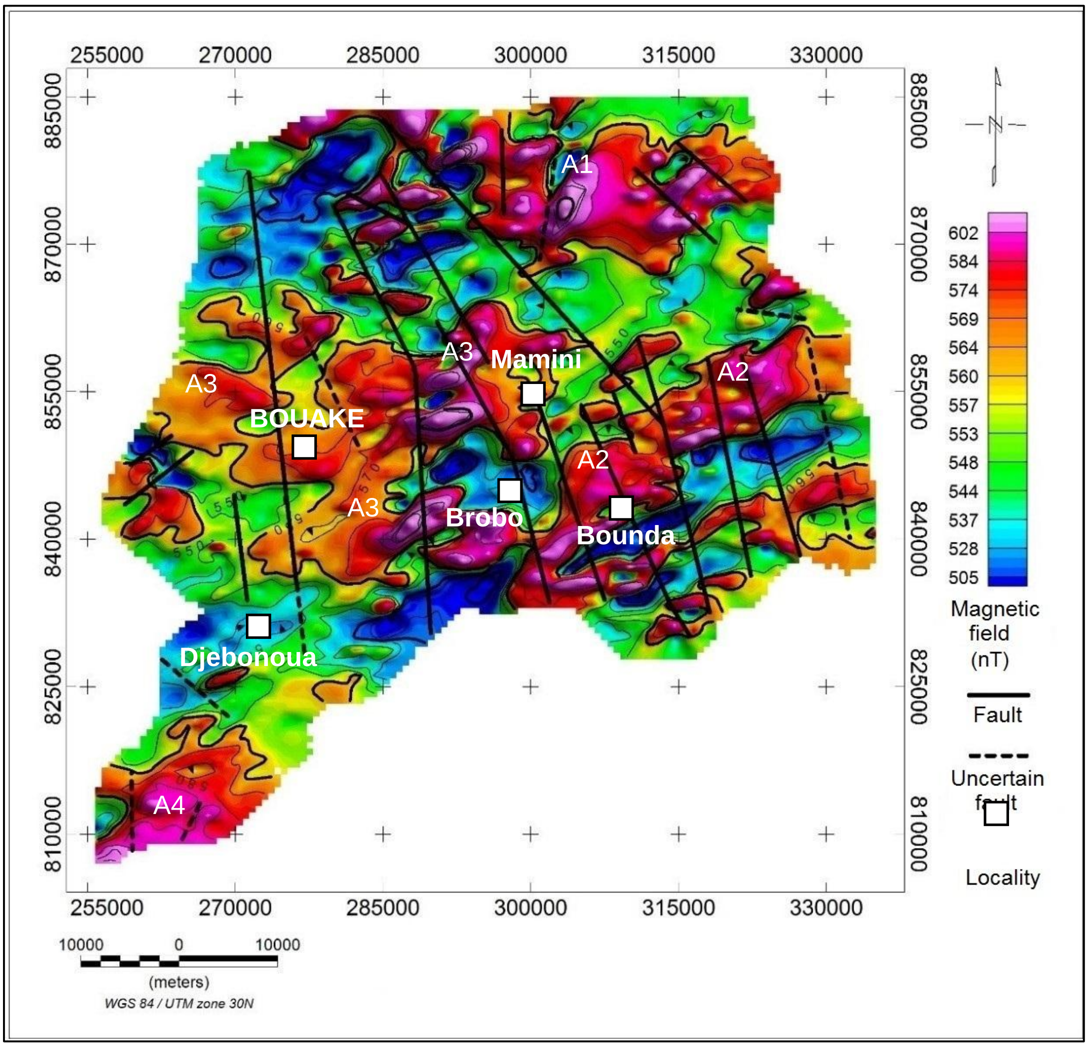

Figure 4. Reduced to equator map of Bouaké department

III.2 Vertical integration map

Similar to the reduced Equator map, the high (red to pink) and low (light to dark blue) magnetic domain structures were demarcated. Figure 5 shows that the magnetic structures located in the center part of the study area are surrounded by the structures with low magnetic intensity. This can be explained by the fact that the higher magnetic structures would be the more recent geological structures. In addition, we can speculate that the structures with higher magnetic value are deeper with regular shape based on the previous analysis performed in figure 4 (from A1 to A4).

Furthermore, the most faults located on the reduced equator map (Fig.4) does no longer appear on the vertical integration map. Indeed, except the faults relating to the A2 anomaly, the faults emphasized by the use of the vertical integration filter are oriented in the NE-SW direction with the strike angle tilted to N-S (NW-SE) from the shallow to deep.

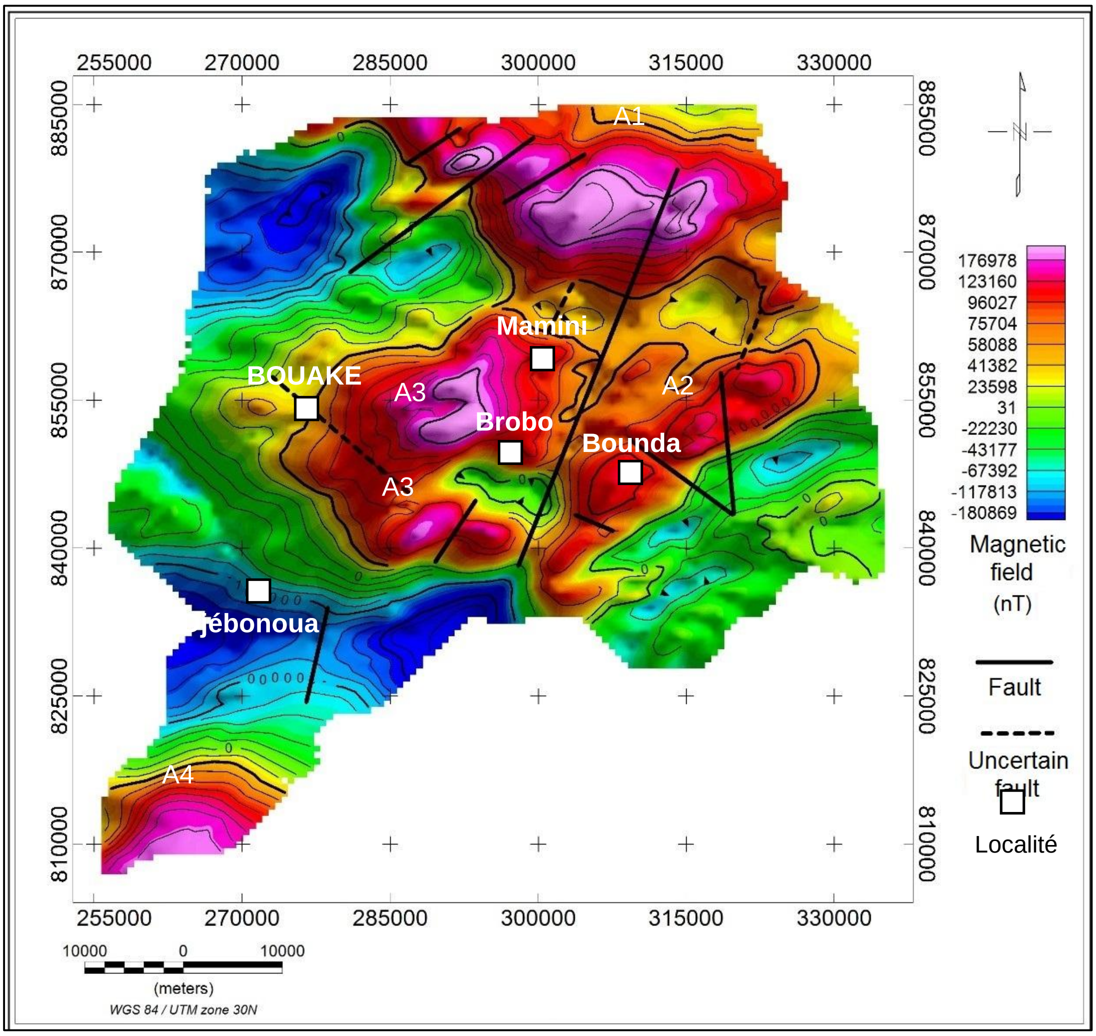

Figure 5. Vertical integration map of Bouaké department

III.3 Lithostructural synthesis and borehole productivity

III.3.1 Lithological analysis

The lithostructural map in Figure 6 results from the combination of the reduced equator and the vertical integration maps.

The high magnetic domain (in pink color) is demarcated by the rocks dominated by dark minerals with the existing of more boreholes. However, the borehole data collected in this domain reveals that the aquifer is more granitic (i.e. composed of granite rocks) although the aeromagnetic responses are higher. Indeed, the granitic structures are presumed to not have a higher magnetic signature. The non-consistency of the high magnetic response can be explained by the mineral composition of the targeted rock. For instance, the granitic structures composed of the minerals such as biotite and amphibole can indicate some high magnetic responses due to existing ferromagnesian silicates (biotite and amphiboles) and some magnetic oxides which are able to increase the magnetic susceptibility value.

Otherwise, the low magnetic domain (silvery-blue color) corresponds to the felsic rocks (with low magnetic susceptibility) and schists confirmed by the previous borehole data collected in this domain.

The both magnetic domain (high and lower) are separated by the magnetic aureoles shown in yellow in Figure 6. These aureoles are the result of intermediate magnetic signatures. In addition, the boreholes drilled in this domain has shown the existing granites with less amount of the ferromagnesian and/or oxides than the high magnetic domain granites.

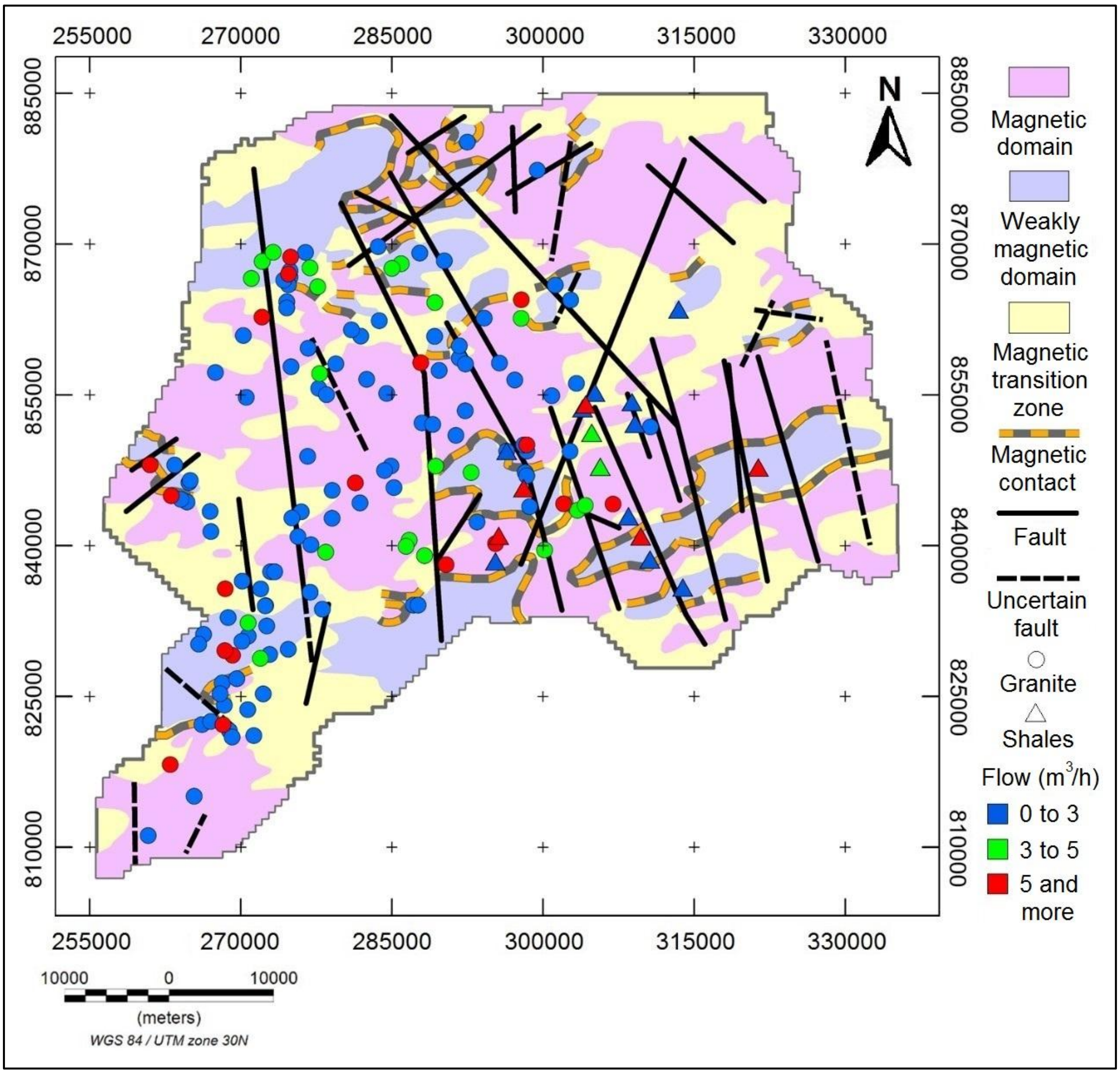

Figure 6. Lithostructural map of Bouaké department

III.3.2 Productivity of geological formations

Table 1 shows the correlative study between the flow rates and the types of geological structures collected at the same place where the boreholes were drilled.

Table 1: Distribution of flow rates according to lithologies

Lithology		**Number of boreholes**	**Flows Q (m^3/h)**			**Total**
			[0 ; 3[	[3 ; 5[	[5 ; →[	
Undifferentiated rocks	Granites	Number Percentage (%)	105 72,92	21 14,58	18 12,50	144 100
	Schists	Number Percentage (%)	10 55,55	3 16,67	5 27,78	18 100
Differentiated granites	Granite I	Number Percentage (%)	42 70	9 15	9 15	60 100
	Granite II	Number Percentage (%)	42 85,72	3 6,12	4 8,16	49 100
	Granite III	Number Percentage (%)	21 60	9 25,72	5 14,28	35 100
Differentiated schists	Schists I	Number Percentage (%)	2 50	1 25	1 25	4 100
	Schists II	Number Percentage (%)	6 75	1 12,5	1 12,5	8 100
	Schists III	Number Percentage (%)	2 33,33	1 16,67	3 50	6 100

With:

I: Magnetic domain (relatively rich in oxides and ferromagnets);
II: Intermediate magnetic domain (relatively poor in oxides and ferromagnets);
III: Weakly magnetic domain (free of oxides and ferromagnets).

The analysis of Table I shows that with a total of 144 boreholes (with various granitic rocks types), only 27 % show the average to high flow rate values ($Q \geq 3$ m^3/h). In addition, around 44 % of the boreholes drilled on schists provides an average to high flow rates values. The schists are considered as the interesting rocks than the granites according to their magnetic signature. However, it remains difficult to ascertain this assumption because of the few numbers of boreholes drilled on the schists in the survey area.

Furthermore, based on the magnetic signature of the magnetic domains aforementioned, a correlation between the boreholes productivity (related to the flow rates) and the type of geological structures can be demarcated. Thus, the most interesting rocks in Bouake area should be the granites III with 40 % representation (flow greater ≥ 3 m^3/h) following by the granites I and granites II with 30 % and 14 % of flow rate ≥ 3 m^3/h respectively. Similarly, the schists located in the high magnetic domain can be considered as the less productive than the ones located in the low magnetic domain which represent of flow rates ≥ 3 m^3/h. From this analysis, we can deduce that the magnetic rocks with low signatures are the most productive than the rocks with higher magnetic signatures. However, locating a drilling on the intermediate magnetic rocks can be considered more risky based on Table 1 stats which show that 85 % of the boreholes drilled in granites and 75 % in schists indicated the flow rates < 3 m^3/h.

III.3.3 Structural analysis and fracture productivity

The rose diagram in Figure 7 show the overall number direction of fractures (N = 38) in Bouake area. The analysis of this diagram indicates that the NNW-SSE direction category composed the main direction of the fracture pattern following by the NE-SW, NNE-SSW, NW-SE, N-S and ENE-WSW and WNW-ESE categories.

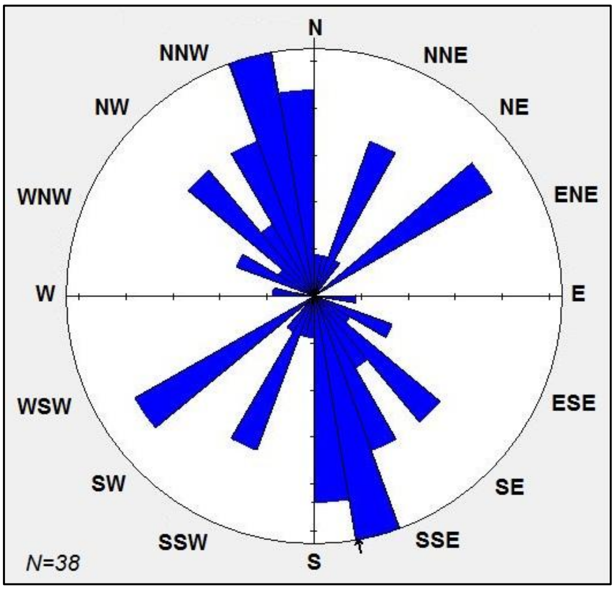

Figure 7. Rose diagram of the existing fractures

The hydraulic productivity differs from one magnetic domain to another along with the same fracture. Overall to 162 boreholes drilled, 28 have the high flow ($Q \geq 5$ m^3/h), 24 have average flow ($3 \leq Q < 5$ m^3/h) and 110 have low flow ($Q < 3$ m^3/h).

The study of the drillings location according to the existing fractures from aeromagnetic results demarcated two (02) categories of boreholes:

- the boreholes located near a fracture zone (less than 1 km away) (52 boreholes)
- the boreholes located out of a fracture zone with number estimated at 110.

Table II summarizes the two categories of boreholes.

Table 2: Borehole productivity according to the fracture direction

Direction of fractures	**Number of boreholes**	**Percentage of boreholes (%)**	**Number of boreholes**			**Borehole rate at $Q \geq 3$ m^3/h (%)**
			$Q \in [0 ; 3[$ (m^3/h)	**$Q \in [3 ; 5[$ (m^3/h)**	**$Q \in [5 ; \rightarrow[$ (m^3/h)**	
ENE-WSW	1	1,92	1	0	0	0
NE-SW	4	7,69	2	0	2	50
NNE-SSW	6	11,54	5	0	1	16,67
NNW-SSE	23	44,23	17	4	2	26,09
N-S	13	25	8	3	2	38,46
NW-SE	4	7,69	3	0	1	25
WNW-ESE	1	1,92	0	1	0	100
Total	52	100	29	7	4	21,15

From the table II, the flow rate ($Q \geq 3$ m^3/h) considered as the success flow rate are mainly located on or close to a fracture and the rate is estimated at 21.5 % (around 1/5). This low rate clearly indicates that the location of the drilling rate on or close to a fracture zone cannot be considered as a confident criterion to obtain a good flow rate after the drilling operations. The type of fracture as well as its direction can also be considered.

Moreover, the NNW-SSE and N-S directions are the most considering direction in the Bouake area. These directions have the higher rate of success drillings ($Q \geq 3$ m^3/h with 26.09 % for the NNW-SSE and 38.46 % for the N-S directions. The NNW-SSE and N-S directions are the most productive than the NE-SW and WNW-ESE directions although the latter direction seems to give a good flow rate. Furthermore, the fractures in N-S direction are parallel to the Precambrian series tectonic constraints which are considered as the crack tensors and the most interesting zone for the groundwater exploration.

IV. Discussion

This aeromagnetic study contributed to emphasizing of the geological structures of Bouaké department. About the lithology, despite the weak contrast in magnetic susceptibility, the rocks with higher magnetic signatures were clearly differentiated from the low magnetic signatures. The correlative study of the magnetic signatures with the petrographic of the boreholes rocks demonstrates the existence of some granites with high magnetic domain (felsic rocks) composed of the strong ferromagnesian minerals (with high magnetic susceptibility). Moreover, the study shows that the granites with high magnetic signature especially composed of biotite and/or amphibole are less productive than schists. These results were confirmed by the work of [17], who argues that the boreholes located on a granite are the most the less productive.

According to the structural analysis, the various fractures with different directions were demarcated (NNW-SSE, NE-SW, NNE-SSW, NW-SE, N-S, ENE-WSW and WNW-ESE) using the aeromagnetic data. The main NNW-SSE fractures, were generated by a regional post-eburnian NNE-SSW tectonic phase [9]. The work of [18], indicated that the main fractures of the Bouake area result from late deformation and were characterized by a crenulation schistosity (S4) of N120 direction. Moreover, the fracture with the NNW-SSE and N-S directions have been identified in the Man-Danané region [19]. The additional works of [19] concluded that the NNW-SSE and N-S directions are to the most interesting fracturing in the Bouake area. About the origin of these fractures, [20] argued that the fractures NNW-SSE result from the ductile shearing while the N-S fractures are setting up during the shearing zone.

V. Conclusion

Despite the few variations of the aeromagnetic signatures in the Bouaké department, three (03) domains were identified:

- the high magnetic domain composed of the felsic rocks (with ferromagnesian oxides or silicates minerals), the green schists and the granites (with biotite and/or amphibole minerals);
- the medium magnetic domain corresponding to felsic rocks relatively poor in ferro-magnesian oxides or silicates;
- the low magnetic domain corresponding to felsic rocks very poor in oxides or ferromagnesians.

The main demarcated fractures in Bouaké are oriented along the NNW-SSE, NW-SE, N-S directions while the secondary fractures steered to the NE-SW, ESE-WNW, NNE-SSW and ENE-WSW directions.

Furthermore, the analysis of the boreholes productivity demonstrated the influence of the petrographic aspect of aquifers as well as the fractures direction according to the success rate of the flow collected on the Bouake area after the drilling operations. Finally, the schists, the granites with low magnetic signatures as well as the fractures in N-S direction remained the most interesting the most productive and constituted the most interesting targeted for groundwater exploration. Therefore, combining the type of rocks by considering its direction and its magnetic signatures can be a great approach to find the better place to locate drillings point after geophysical survey. Thus, the isostructural study before the operating study can minimize the risk of failures associated to the drillings which indirectly could solve one aspect of the water scarcity problem.

References

[1]. S. Naba, "Propriétés magnétiques et caractères structuraux des granites du Burkina Faso oriental (Craton Ouest Africain, 2,2 – 2,0 GA) : implications géodynamiques", Thèse de Doctorat, Université Toulouse. 163 p, 2007.

[2]. T. Chennouf, D. Khattach, A. Milhi, P. Andrieux, P. Keating, "Principales lignes structurales du Maroc nord-oriental : Apport de la gravimétrie", Compte Rendu de Géoscience, (399), pp. 383-395, 2007.

[3]. B. Randrianasolo, "Nouvelles méthodes de cartographie du socle protérozoïque sud de Madagascar. Nature et géométrie de la croûte continentale moyenne d'un domaine orogénique en convergence, implications économiques", Thèse de Doctorat en Science et Technologie, Université Joseph-Fourier-Grenoble, 315 p, 2009.

[4]. D. Groune, M. Djeddi et M. A. Aïtouche, "Application de la déconvolution d'Euler aux données aéromagnétiques enregistrées dans la zone de Tesnou (Hoggar occidental) pour la localisation des contacts", Bull. Serv. Géol. Nat., Algérie 20, n° 2, pp. 205 - 219, 2009.

[5]. M. Aryamanesh, "Aeromagnetic data interpretation to locate buried faults in Yazd Provinec-Iran", World Journal Applied Sciences 6 (10), pp. 1429-1432, 2009.

[6]. R. El Gout, D. Khattach, M. R. Houari, O. Kaufmann, and H. Aqil, "Main structural lineaments of north-eastern Morocco derived from gravity and aeromagnetic data", Journal African Earth Sciences 58, pp. 255-271, 2010.

[7]. Géomines, "Inventaire hydrogéologique appliqué à l'hydraulique villageoise. Carte de Bouaké", cahier n°18, République de Côte d'Ivoire, Ministère des Travaux Publics et des Transports, Direction Centrale de l'Hydraulique, 40 p, 1982 d.

[8]. D. B. Yao, "Notice explicative de la carte de géologie feuille de M'Bahiakro", Mémoire, n°2, 27 p, 1990.

[9]. Y. Siméon, C. Delor, Z. Zeade, Y. Koné, B. Yao, M. Vidal, I. Diaby, G. Konan, B. I. Djé, D. N'Da, A. Dommanget, J. P. Cautru, C. Guerrot et J-C. Chiron, "Notice explicative de la carte géologique de la Côte d'Ivoire à 1/200 000, feuille M'Bahiakro", Mémoire de la Direction des Mines et de la Géologie de la Côte d'Ivoire, n°8 Abidjan, Côte d'Ivoire, 1995.

[10]. B. Tagini, "Esquisse structurale de la Côte d'Ivoire. Essai de géotechnique régionale", Thèse Univ. Lausanne (Suisse), 302 p, 1971.

[11]. S. Lemoine, "Évolution géologique de la région de Dabakala (Nord-Est de la Côte d'Ivoire) au Protérozoïque inférieur. Possibilité d'extension au reste de la Côte d'Ivoire et du Burkina Faso : Similitudes et différences ; les linéaments de Greenville-Ferkessédougou et Grand Cess-Niakaramandougou", Thèse de doctorat d'état, Université Blaise Pascal, Clermont-Ferrand, 334 p, 1988.

[12]. A. Pouclet, M. Vidal, C. Delor, Y. Siméon et G. Alric, "Le volcanisme birinien du nord-est de la Côte d'Ivoire, mise en évidence de deux phases volcano-tectoniques distinctes dans l'évolution géodynamique du Paléoprotérozoïque", Bull. Soc. Géol. France, 167 p, 1996.

[13]. S. Doumbia, A. Pouclet, A. N. Kouamelan, J. J. Peucat, M. Vidal et C. Delor, "Petrgenesis of juvenile-type Birimian (Paleoproterozoic) granitoids in Central Côte-d'Ivoire (West Africa): geochemistry and geochronology", Precambrian Res. 87, pp. 33-37, 1998.

[14]. S. Nomande, "Evolution géodynamique des cratons des Guyanes et d'Afrique de l'Ouest : apport des données paléomagnétiques, géochronologiques (40Ar/39Ar) et géochimiques en Guyane et Côte-d'Ivoire", Thèse de Doctorat, Univ. d'Orléans, 301 p, 2001.

[15]. D. Gasquet, P. Barbey, M. Adoua et J. L. Paquet, "Structure, Sr–Nd isotope geochemistry and zircon U–Pb geochronology of the granitoids of the Dabakala area (Côte d'Ivoire): evidence for a 2.3 Ga crustal growth event in the Palaeoproterozoic of West Africa", Precambrian Res. 127, pp. 329-354, 2003.

[16]. F. Simon, "Méthode magnétique appliquée à l'exploration Multi-échelle du Bassin de Franceville", Thèse de Doctorat, Université Louis Pasteur, Strasbourg, 272p, 2011.

[17]. K. E. G. Kouakou, "Contribution de la géophysique à l'étude structurale et à la connaissance des ressources en eau souterraine du district de la vallée du Bandama (Côte d'Ivoire)", Thèse de doctorat, Université Félix Houphouët Boigny d'Abidjan, 193 p, 2012.

[18]. G. Ouattara, G. B. Koffi et A. K. Yao, "Contribution des images satellitales Landsat 7 ETM+ à la cartographie lithostructurale du Centre-Est de la Côte d'Ivoire (Afrique de l'Ouest)", International Journal of Innovation and Applied Studies ISSN 2028-9324 Vol. 1 N° 1, pp. 61-75, 2012.

[19]. T. Lasm, F. Kouamé, M. S. Oga, J. R. P. Jourda, N. Soro et H. B. Kouadio, "Étude de la productivité des réservoirs fracturés des zones de socle. Cas du noyau archéen de Man-Danané (Ouest de la Côte d'Ivoire)", Rev. Ivoir. Sci. Technol., 05 pp. 97-115, 2004.

[20]. S. C. Djro, "Evolution tectono-métamorphiques des gneiss granulitiques archéens du secteur de Biankouma", Thèse d'Etat, Univ. Abidjan, (1998) 171 p, 1998.

Kouamé G. H. LOUKOU, et. al. "Contribution of aeromagnetism to the lithostructural identification of the aquifer system of Bouaké department (Central Ivory Coast)."*IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)*, 10(1), (2022): pp 01-11.