International Journal of Science, Environment and Technology, Vol. 6, No 5, 2017, 3548 – 3564

ISSN 2278-3687 (O)
2277-663X (P)

AEROMAGNETISM CONTRIBUTION TO THE STRUCTURAL IDENTIFICATION OF THE AQUIFER SYSTEM OF AGNIBILÉKROU DEPARTMENT (EAST OF COTE D'IVOIRE)

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Abstract: The present study focuses on the improvement of the knowledge of aquifer in the department of Agnibilékrou (East Côte d'Ivoire). Its main objective is to map the fracture network in igneous and metamorphic rocks using the aeromagnetic method.

The interpretation of the total field and tilt angle maps made by the Magmap module of the Geosoft software helped to identify fractures oriented NW-SE whose the most remarkable is the IFOU watercourse fault. The analysis of the vertical integration map revealed that these fractures are not very deep. They would therefore be located in the alterites and / or in the fissured horizon. The positioning of certain drill holes already executed in the study area on the identified fractures testifies to the presence of groundwater. They are generally fed by the Comoé River and these tributaries, the main river of the region. This study highlights the importance of aeromagnetic mapping in the structural identification of the aquifer system of Agnibilékrou department.

Keywords: Aeromagnetism, fracture, aquifer, Agnibilékrou.

Introduction

In Côte d'Ivoire and particularly in Agnibilékrou, the supply of drinking water, in quantity and quality, is a vital necessity for the economic and social well-being of the population. Access to drinking water stood at 72% in 2015, contrary to millennium development goal drinking water targets, which estimated it at 82.5% in 2015 [1]. This deficit results from the poor management of existing infrastructure and low flow of boreholes. Groundwater is the main source of drinking water for the population. In the Precambrian basement, they are mainly found in aquifers of alterites and fissures. However, more than 20% of the drilling done in crystalline and crystallophyllian environment is negative because of their too low productivity as indicated by several works [2] [3] [4] [5] [6] [7] [8] [9]. This high failure rate often observed is due to the absence of serious studies during the installation of structures in

*Received Nov 10, 2017 * Published Dec 2, 2017 * www.ijset.net*

the hydraulic campaigns [10]. In some areas, drilling has been implemented only from geomorphological studies [11]. Thus, to optimize the production of drilling, a better knowledge of aquifers in the basement environment is essential. To do this, the present study aims to improve the knowledge on the geological structure deep of the aquifer system of Agnibilékrou department. It focuses on the reinterpretation of aeromagnetic data from the former geophysical survey carried out by Kenting Earth Sciences Ltd during the years 1974 to 1976. Various methods using several mathematical transformation operators to identify the fracture network serving as drains for groundwater has been applied.

1-Presentation of the study area

1.1- Geographical location

Located at 270 km from Abidjan, in the east of Côte d'Ivoire, between latitudes 6°46 and 7°22N and longitudes 3°04 and 3°40 W, the department of Agnibilékrou belongs to the region of Indénié-Djuablin (Figure 1).

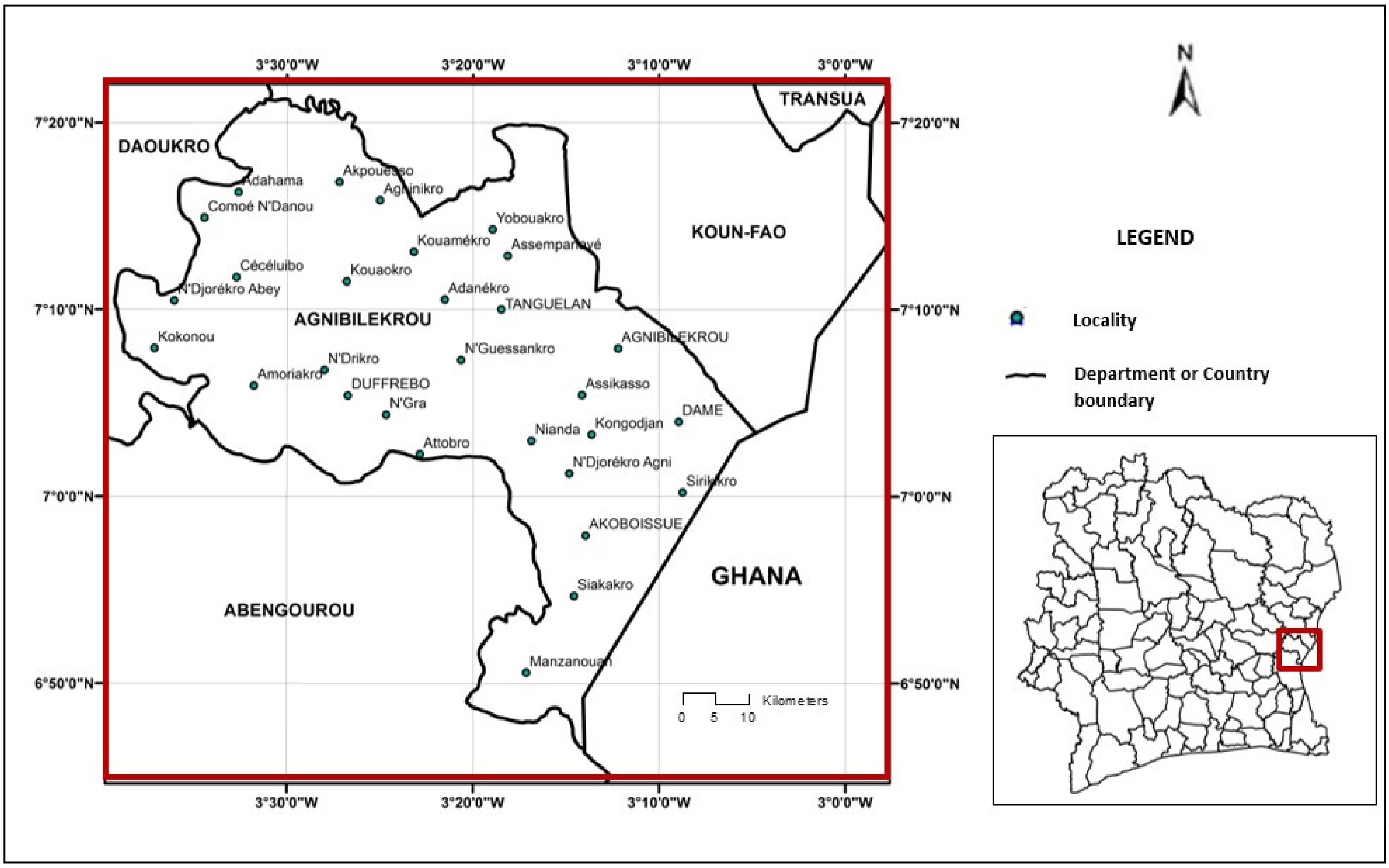

Figure 1: location of the study area

1.2- Hydrographic framework

The Comoé river flows in a north-south direction and forms a natural boundary in the north-west of the region of Agnibilékrou (Figure 2); Its tributaries are: the Niambo, the Kouna, the

Ehouman and the Ba. Apart from the Comoé river tributaries, other streams irrigate the region, such as the Ifou, Manzan, Tingoulan, Kassi, N'Zuépli and Anandou.

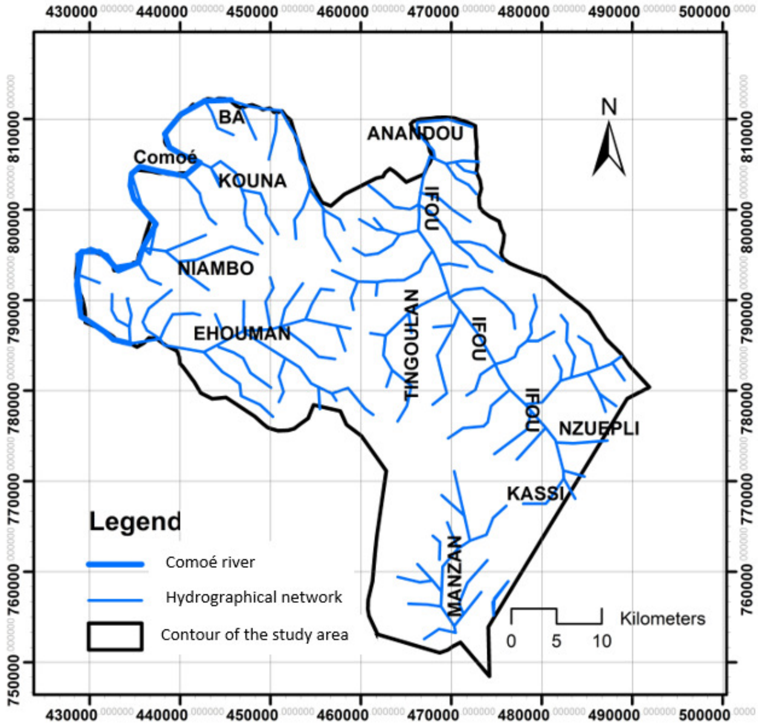

Figure 2: hydrographical network of Agnibilékrou department

1.3- Geological and hydrogeological framework

The geological history of the region of Agnibilékrou is closely linked to that of the West African craton. Thus, all the geological formations of the region have been structured during the Eburnean orogeny and are of Proterozoic age (Figure 3).

Several works [12] [13] have focused on the geology (petrography and tectonics) of this region. The results show that tectonics is polyphase and has resulted in the establishment of numerous fractures of variable sizes ranging from a few meters to several kilometers. The formations of this zone were affected by a regional metamorphism. From a petrographic point of view, the granitoids estimated at 9% and the volcano-sedimentary formations composed of 80% schists and NE-SW oriented are the main geological formations encountered in the study area.

The hydrogeology of this region is dominated by the presence of groundwater in the alterites and fissured rocks. The different borehole logs coupled with the works of [12] showed that the schists formations very easily get altered and produce large thicknesses of alterites. Thus, in the study area, the thickness of alterites can reach 75 m in places (Manoukro: 75.14 m, Koffikro: 74.60 m). In the granitic zone, alteration levels can reach 31 m in places (Kouakro:

31 m, Kabran N'Djoré: 29 m), but sometimes do not exceed 2 m (Bakarykro). The BADEA2 (Arab Bank for the Economic Development of Africa) and DBG (Belgian Donation) programs show on average that the alteration thickness is 41 m and 21 m respectively in schist and granitic zones.

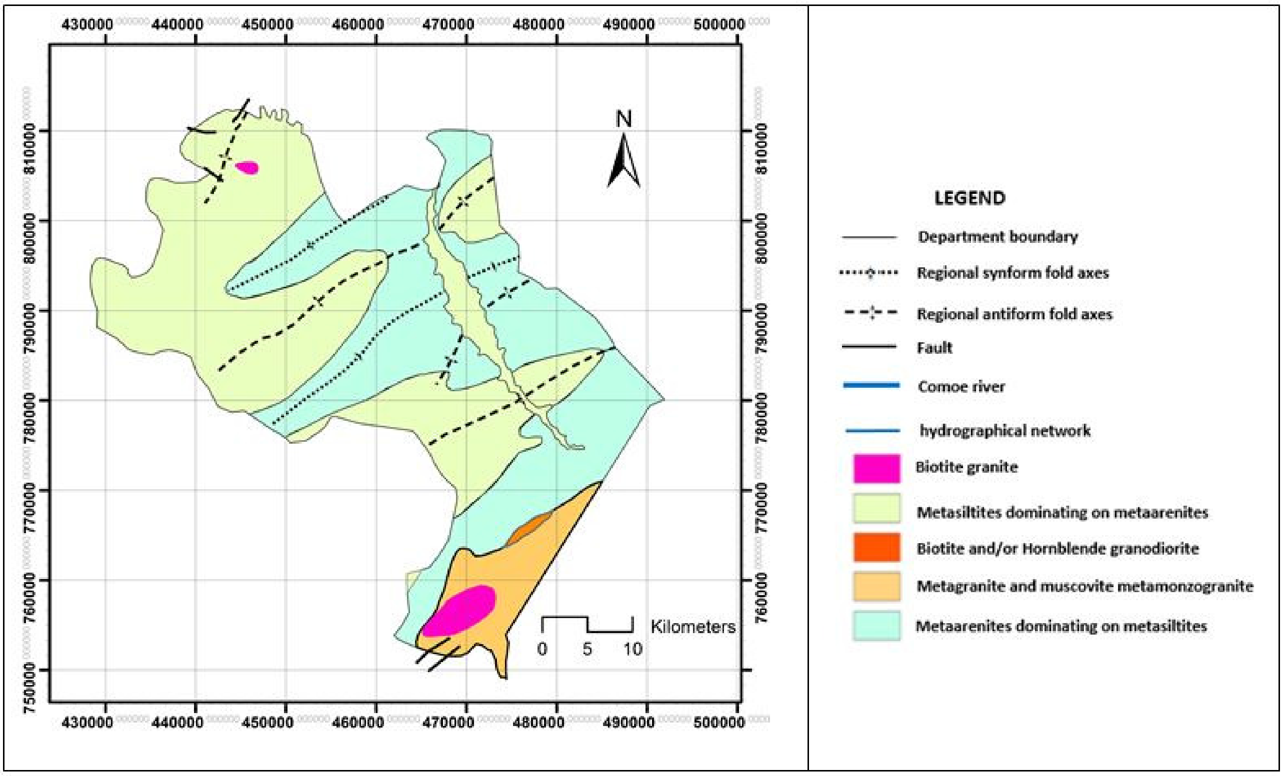

Figure 3: geological map of Agnibilékrou department (Delor *et al*., 1995)

2- Methodological Approach

2-1 Methodology for building up the database

The aeromagnetic maps used were made available to us by the Direction of Geology of Côte d'Ivoire. They were obtained from the airborne surveys carried out by Kenting Earth Sciences Ltd during the years 1974 to 1976. They were taken from recordings along flight lines whose theoretical spacing and height were respectively set at 500m and 150m±15m after altitude, latitude and diurnal corrections. The flight lines were reported on the photomosaic and the coordinates of the turning points were determined and compiled numerically on magnetic tape. The intensities of the field were derived either from the analog magnetometric profiles after digital translation on tape, or from the digital profiles recorded as such during the flight. The values of the magnetic field were interpolated to the nodes of a 2.5 mm square grid, as a function of a simulated polynomial variation of the field in the direction perpendicular to the flight lines. The grid was used as a basis for the mechanical mapping of isogams. Thus, several maps, cut in square degrees, were drawn up. For the study area (department of Agnibilékrou), five (5) maps were used. These included the Abengourou 4c and 4d and the Agnibilékrou 1b, 2a and 2b aeromagnetic maps.

2-2 Methodology for processing magnetic data

The purpose of this study is to apply filters to aeromagnetic data in order to highlight the fracture network. Thus, the aeromagnetic maps of the direction of geology were vectorized. The coordinates of the set of points constituting the magnetic field isovalues were recorded and inserted into an Excel file so as to build up a new database (latitude, longitude, magnetic field) on which filters were applied using the module Magmap of Geosoft software in order to draw up the different aeromagnetic maps (figure 4).

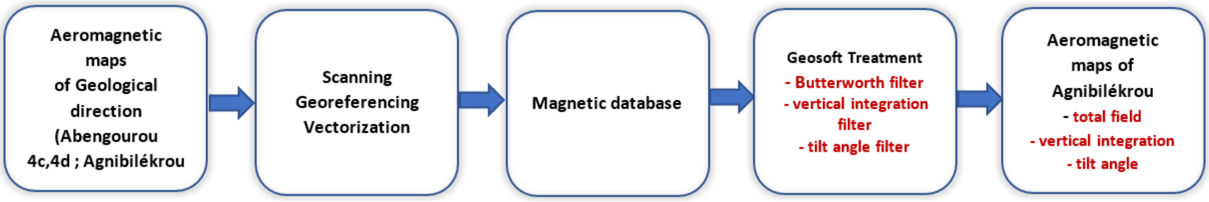

Figure 4: general flowchart for the processing of aeromagnetic data

2.2.1 Butterworth filter

This filter enables the retention of short magnetic wavelengths which correspond to superficial anomalies and the passage of the longest magnetic waves which reflect deep source anomalies. It is generally used to smooth magnetic waves by an easy control of the degree of the filter. Its mathematical expression is:

$$L(k)=\frac{1}{\left[1+(1+\left(\frac{k}{k_0}\right)^n\right]}$$

Avec ; n : The degree of the Butterworth filter function. By default, a degree of 8 is used;

k_0 : The central wavenumber (cycles/ground_unit) of the filter;

k : wavenumber (cycles/ground_unit) of the filter. It is worth 4.

The Butterworth filter was used in the realization of the total magnetic field map.

2.2.2 Tilt angle filter

The tilt angle operator [14] [15] [16] is defined as the arctangent of the vertical derivative ratio of the total field anomaly F with the module of its horizontal gradient. The tilt angle or inclination derivative and its total horizontal derivative are useful for mapping shallow underground structures. This filter finds its interest in the similar representation of low or high-amplitude anomalies [17].

Moreover, [16] showed that the tilt angle filter, applied to pole-reduced data, might help estimate the depths of the sources. The tilt map thus allows a combined analysis of the limits of 2D structures and their depth [18].

The operator of the tilt angle H_θ applied to the anomaly F is thus written:

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

2.2.3 Integration vertical filter

The vertical integration, inverse of the vertical derivative, serves as a low-pass filter like the upward continuation. The signal is smoothed and the effects of large deep structures are favored over small objects on the surface. It can be useful for the study of large anomalies, especially those generated by the basement [18]. The mathematical expression of this operator is:

$$Hiv = \left(iLu + iLv - N\sqrt{u^2 + v^2}\right)^\gamma$$

Avec ; Hiv : vertical integration

(L, M, N) : cosines directors of the magnetic field

u, v : angular pulses associated with the x, y directions in the spectral domain

γ: negative real number for γ order integration

The interpretation of these maps have allowed to identify fractures whose orientation was determined by using a directional rosette made with Georient software.

3- Results and interpretation

3.1 Total magnetic field map

The total magnetic field map highlights the magnetic signatures of the deep and superficial structures. With an intensity variation of 31503 nT to 31572 nT, it is subdivided into magnetic, soft magnetic and moderately magnetic domains (Figure 5).

The magnetic domain, of blue color, was characterized by the presence of two (2) quasi-parallel magnetic anomalies named A1 and A2 respectively located in the north-west and south-east of the study area. These elongated magnetic structures were NE-SW oriented. This domain could reflect the existence of basic and ultrabasic rocks. However, according to [19], the whole sediment of the Comoé basin consists mainly of decimetric rhythmic alternations of siltites and arenites. The chemical and mineralogical composition is typically that of dismantling granite rocks [20]. The presence of accessory minerals such as magnetite in metaarenites and metasiltites, already highlighted by the works of [19], could explain the magnetization of the rocks present in this domain. Moreover, the degradation of the colors indicating the magnetic and non-magnetic zones shows a gradual decrease in magnetization intensity from the south-west to the north-east. This could be explained by the progressive leaching of the magnetite from high altitudes towards low altitudes of the study area.

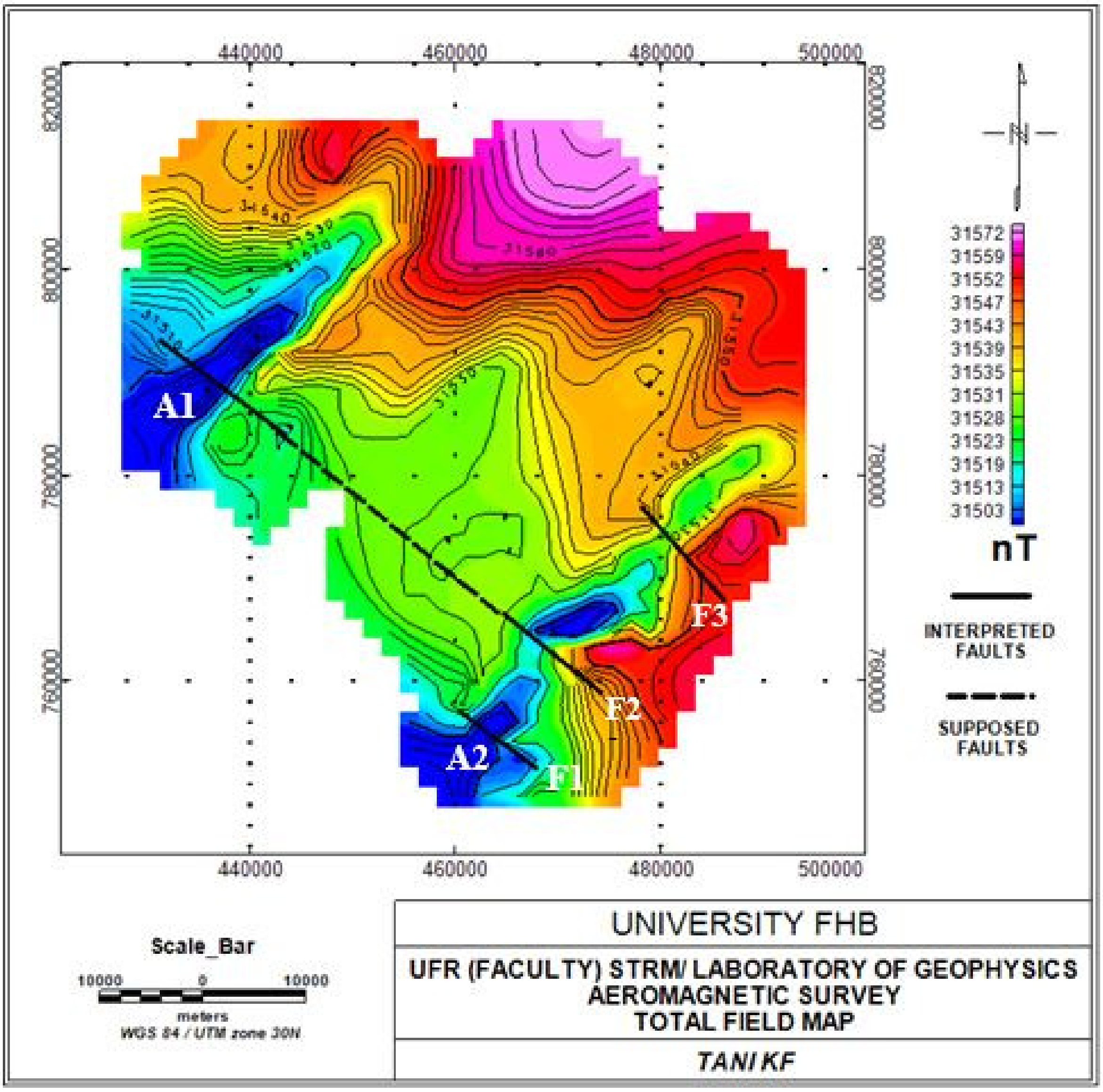

Figure 5: total magnetic field map

The soft magnetic domain, of orange-to-magenta color, is found in the northern and eastern parts of the study area. It highlights the presence of granitoids and its alteration products that are siltites and arenites as indicated on the geological map.

The two (2) domains are separated by a moderately magnetic domain (Green). This magnetic aureole may correspond, in some places, to metamorphic aureole due to granodiorite intrusions near which green biotites have been identified. It could also result from gradual leaching of ferromagnesians or magnetite from high altitudes.

Numerous distortions, due to the effect of fractures, were observed on the total field map (Figure 5). These faults, roughly oriented NW-SE, are denoted F1, F2 and F3.

Fault F1, located in the south of the study area, was less expressive than the others and affected only magnetic anomaly A2.

F2 crossed the entire study area from the south-east to the north-west by affecting the magnetic and moderately magnetic domains.

F3, located in the east of the study area, affected the soft and moderately magnetic domains.

These sinistral strike-slip faults F1, F2, and F3 might be synchronous with the regional schistosity S2, which sinistral shear was confirmed by the works of [21].

3.2 Tilt angle map

The tilt angle revealed an alternation of magnetic (blue to green) and soft magnetic (orange-to-magenta) formations, oriented NE-SW (Figure 6). Magnetic anomalies A1 and A2, observed on the map of the total field, were more expressive on the tilt angle map. They extended to the north-east and presented regular contours with numerous distortions indicating the presence of fractures. Another anomaly A3, located in the center of the study area, was wider and above all superficial since it did not appear on the total field map. Like anomalies A1 and A2, A3 had an elongated shape and oriented NE-SW. It was affected by a dextral strike-slip fault, denoted F and oriented NW-SE, which was well superimposed with the course of the IFOU stream. It differed from fault F3 by the displacement direction of their movement. Fault F could be the result of a late regional deformation, characterized by an N120° crenulation cleavage [22] [23]. It might be a recovery of fault F3 which affected the recent and superficial geological formations dating from 1700 M [22].

All the geological formations in the study area were affected by numerous substantially fractures oriented NW-SE that were likely to constitute good water reservoirs, which is of great interest for groundwater research. Indeed, the works of [24], carried out in the region of Tanda, indicated that the majority of boreholes implanted on NW-SE fractures provided good flows ($Q \geq 2.5 m^3 / h$).

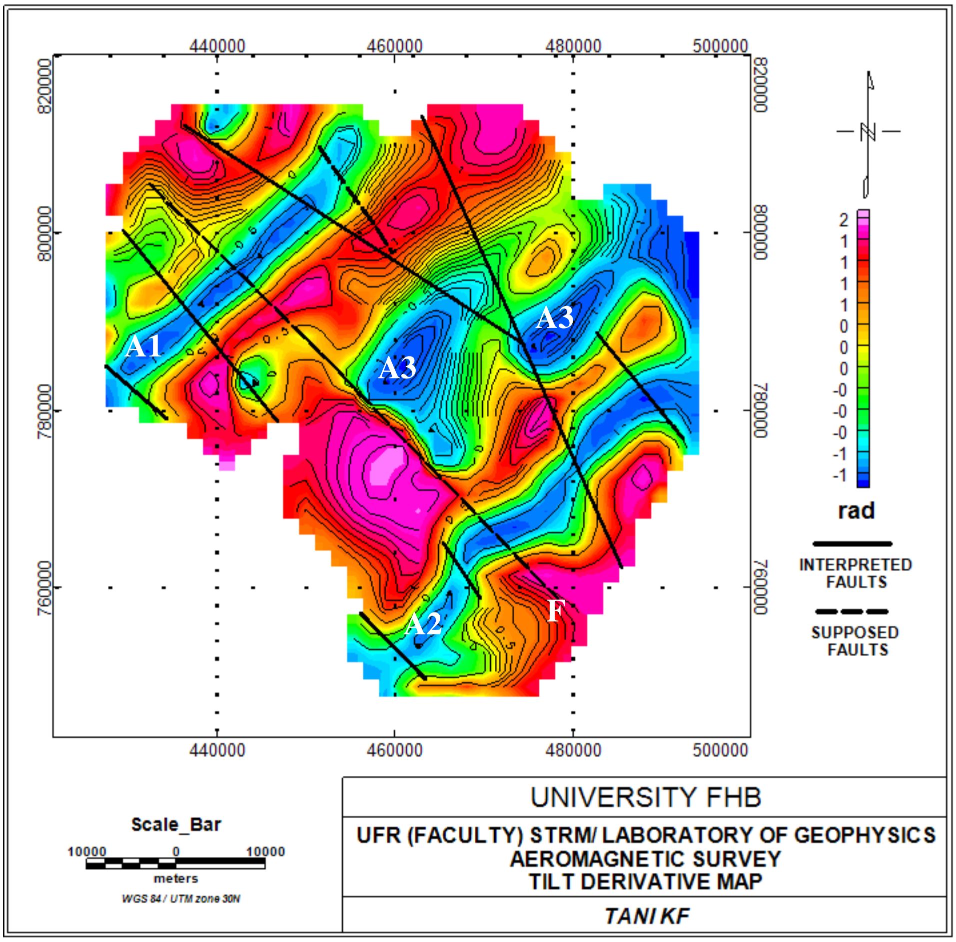

Figure 6: derivative tilt angle map

3.3 Vertical integration map

Like the tilt angle, an alternation of magnetic (blue to green) and soft magnetic (orange to magenta) formations is observed on the vertical integration map (Figure 7). They are also oriented NE-SW. They are more spread out in depth and correspond to the rooting of anomalies A1 and A2 described in Figure 6. The anomaly A3 evidenced by the tilt angle has completely disappeared with the depth favoring the spreading of the anomaly A2 . Almost all the fractures revealed by the tilt angle don't appear on the vertical integration map (Figure 7). Only the fault F1 identified on the map of the total field is included. These fractures are therefore not deep enough. They would therefore be located in the alterites and / or in the fissured horizon as described by the stratiform conceptual model of the hydrogeological structure of basement aquifers [25]. From a hydrogeological point of view, they would therefore be potentially interesting to the groundwater catchment.

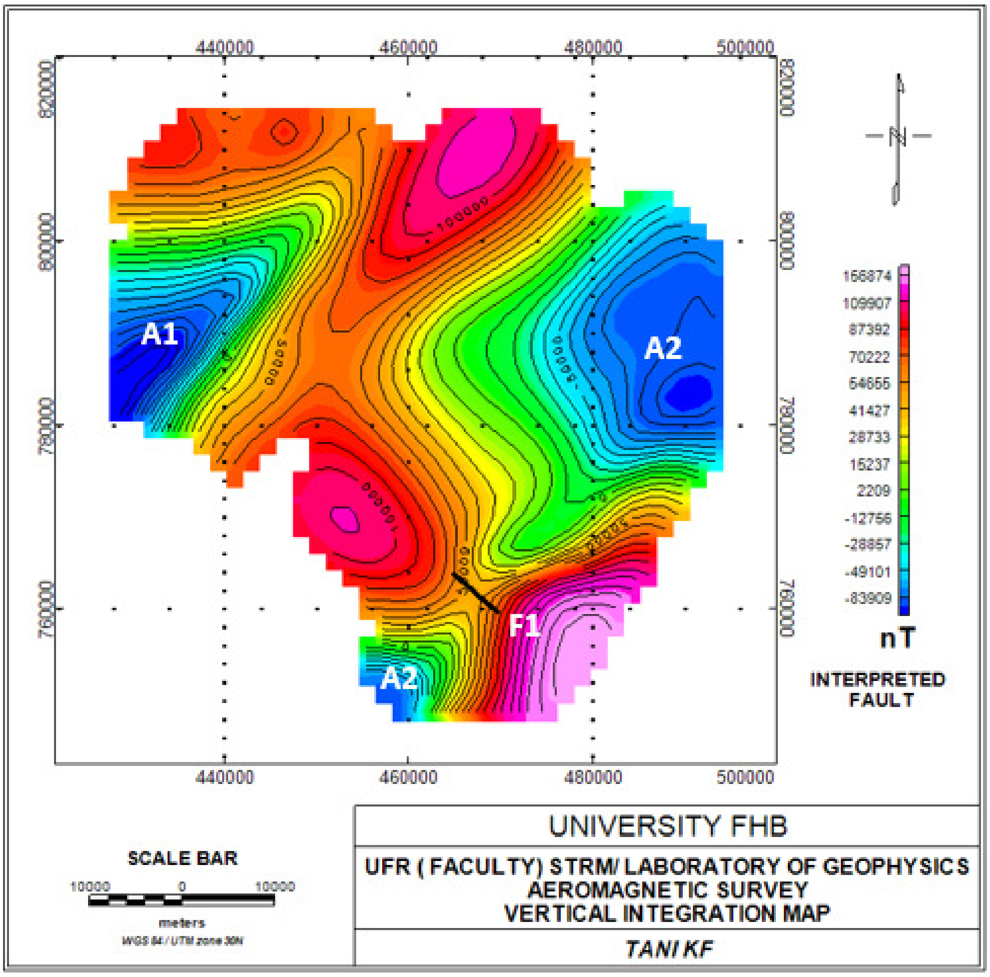

Figure 7: vertical integration map

3.4 Structural Interpretation

The interpretation of the different magnetic maps revealed several fractures in the department of Agnibilékrou. These fractures affected granitoids in the southeast and schists over the rest of the study area. The superposition of these fractures with the hydrographical network of the Agnibilékrou department shows that they are mainly supplied by surface waters (Figure 8). This is notably the case of dextral strike-slip fault (F) which affected magnetic anomaly A3 and which was well superposed on the bed of the IFOU stream. This is therefore the IFOU fault.

The majority of identified fractures intercepted the Comoé river, main stream of the region, in their extension to the north-west. The water supply of this fracture network in the Agnibilékrou department might strongly depend on the water regime of the Comoé river.

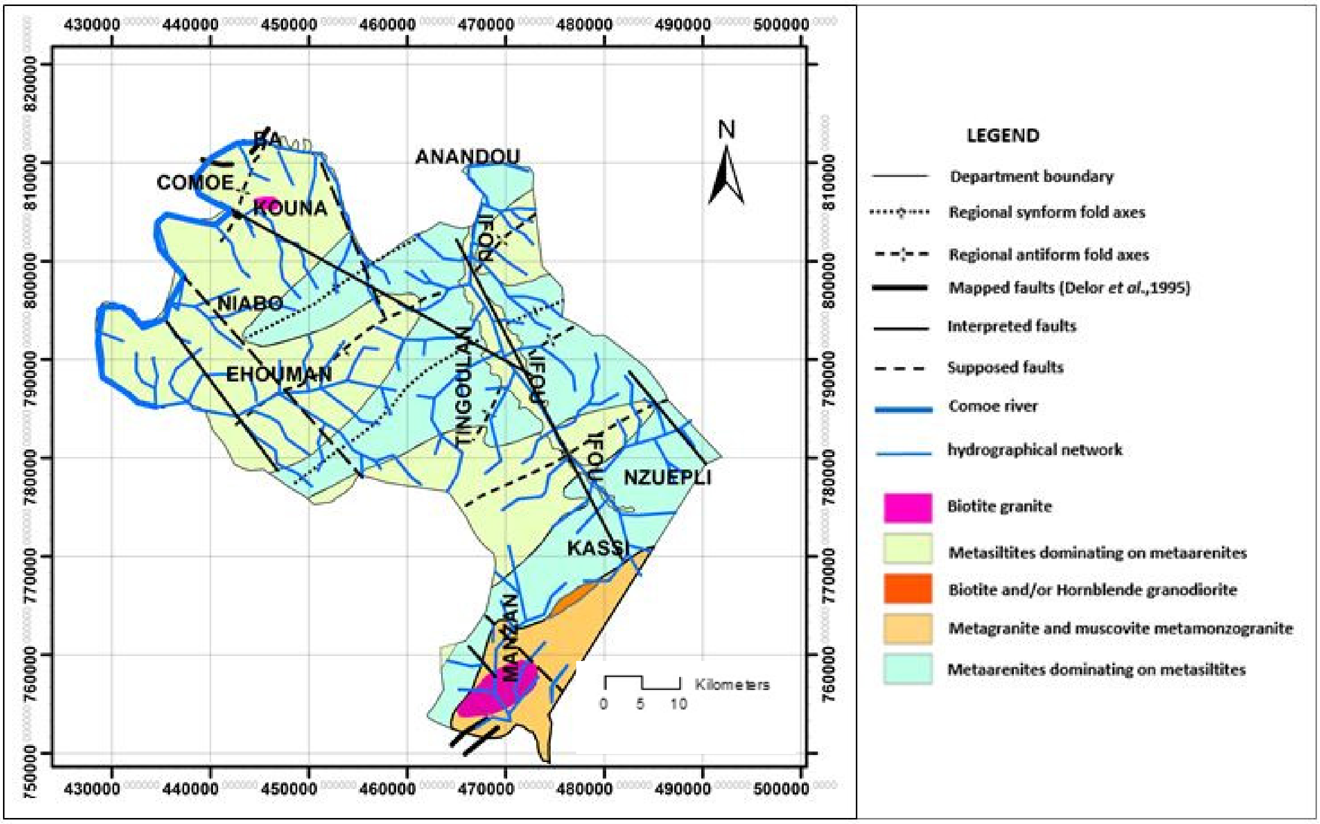

Figure 8: fracture and hydrographical network superposition map and geological map of the study area

The rose diagram shows two (2) preferential directions of fractures (Figure 8). The main orientation is NW-SE, followed by the NNW-SSE direction.

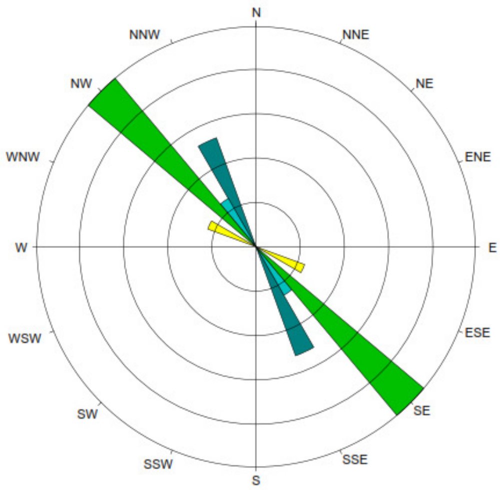

Figure 9: Rose diagram of fractures identified by aeromagnetic methods

These directions are perpendicular to the Birrimian direction. The fractures, substantially NW-SE oriented, might therefore have been established during the Eburnean orogeny. They might also result from the progressive opening of the Atlantic Ocean between 200 Ma and 180 Ma.

3.5 Superposition of drilling coordinates on the aeromagnetic fracturing map

This superposition shows that drilling already carried out in the department of Agnibilékrou are positioned on the fractures identified by aeromagnetism (Figure 10). This demonstrates that the identified fracturing corresponds effectively to fissured aquifer. Aeromagnetism is therefore a good geophysical method for researching groundwater in the basement environment.

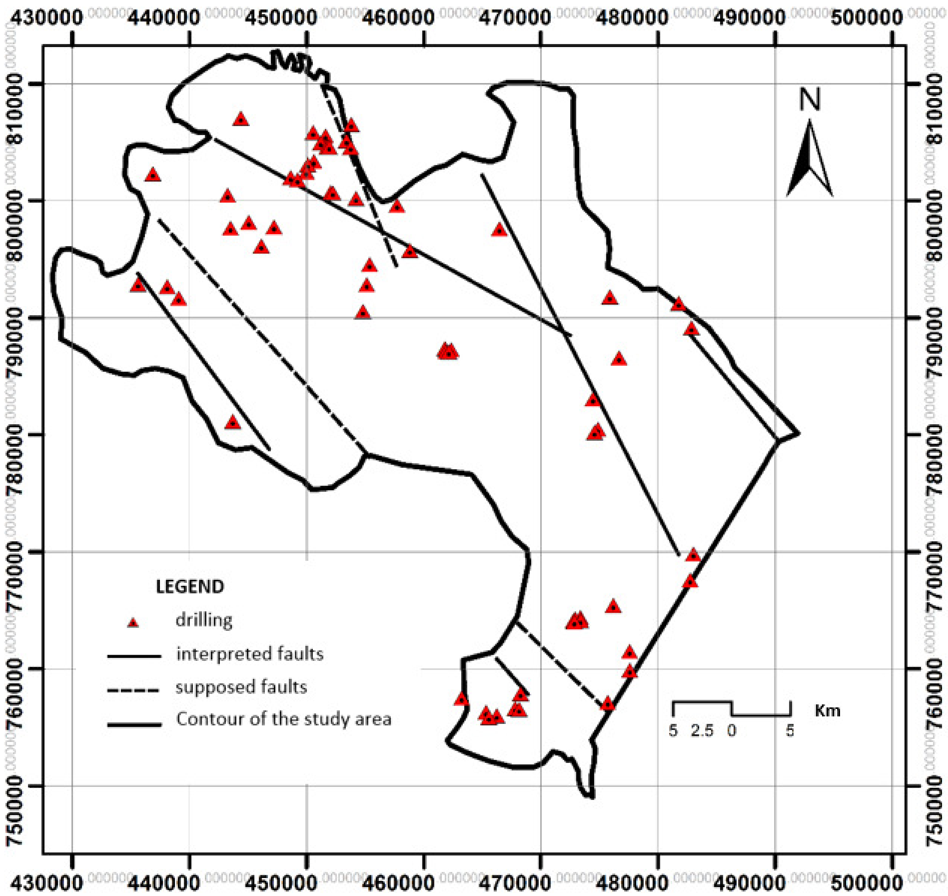

Figure 10: map of superposition of drill coordinates on aeromagnetic fracturing map

4- Discussion

The magnetic method is one of the most extensively and transversely used geophysical methods [26] [27]. It has long been used to support the mapping of geological structures and accidents that affect them or to detect concentrations of magnetic minerals [28].

The reinterpretation of the aeromagnetic maps of the Agnibilékrou department has made it possible to identify several regional accidents, the most notable being the IFOU watercourse fault. These accidents have so far been poorly known to the scientific community because no previous work has allowed to highlight them. For some authors such as [2], previous studies on fracturing were only very fragmentary. The fractures thus highlighted are oriented generally NW-SE. This direction is confirmed by several authors. In Bondoukou, [10], using remote sensing and geographic information systems to map fracturing, showed that NE-SW and NW-SE fractures would be the preferred directions. Also, electric trainers made by [29] at Yakassé Attobrou have identified many fractures including that oriented around the directions N178 °, N140 ° and N160 °. In addition, [5] has shown using Landsat data to Odienné that the major directions of tension fractures that can sometimes have productive openings have directions NE, NW, NS. The work of [30] [31] [32] in central-eastern Ivory Coast revealed similar directions ranging from N120 ° to N140 ° sinister and N150 ° to N160° sinister. Finally, the NW-SE direction coincides with that of Eburnean magmatism, represented by the doleritic dykes in the south-western Ivory Coast and determined by [33].

[22] attribute the NW-SE direction to a regional tensioning phase post-eburnean NNE-SSW that also contributed to folds oriented WNW-ESE and flat foliations affecting the Tanda / Koun Fao conglomerate series. According to [34] and [35], these deformations could also result from a late deformation, characterized by a crenulation schistosity (S4) of direction N120 °.

Conclusion

The application of the filters on the aeromagnetic data of the Agnibilékrou department made it possible to highlight several NW-SE oriented fractures which constitute the main potential aquifers of the zone studied. This direction is characteristic of Eburnean magmatism. These fractures are not deep enough. They are generally fed by the Comoé River and these tributaries. Their superposition with the realized drillings proves that they drain underground water. They constitute interesting aquifers for the drinking water supply of the populations. The results of the present study show the interest of the aeromagnetic mapping in the detection of the fracture network in basement environment. They constitute a compass in the hydrogeological prospection of this region.

Although this method is useful for regional studies, it does not allow detailed mapping of fracturing. It is therefore necessary to integrate it with other prospecting methods such as remote sensing, which offers extensive regional information. At the local level, more precise studies with other geophysical methods (electrical method, Proton Magnetic Resonance method) could be considered.

Bibliography

[1] Ins, 2015. Enquête sur le niveau de vie des ménages en côte d'ivoire. Rapport, 91p.

[2] Faillat j. P. 1986 a. Hétérogénéité et effet d'échelle dans les aquifères fissurés. Approche par pompage d'essai sur station expérimentale, Afrique de l'ouest. Hydrogéologie, n. ° 1, pp. 65-76.

[2] Faillat J.P. 1986b. Aquifères fissurés en zone tropicale humide : structure, hydrodynamique et hydrochimie, Afrique de l'ouest. Thèse Univ. Languedoc Montpellier, France, 534 p.

[3] Soro N., (1987). Contribution à l'étude géologique et hydrogéologique du sud-est de la côte d'ivoire. Thèse de 3è cycle univ. Scient. Technol. et médicale de Grenoble, France, 243 p.

[4] Biemi J. 1992. Contribution à l'étude géologique, hydrogéologique et par télédétection des bassins versants subsahéliens du socle précambrien d'Afrique de l'ouest : hydrostructurale hydrodynamique, hydrochimique et isotopie des aquifères discontinus de sillons et aire granitique de la haute Marahoué (côte d'ivoire). Thèse de doctorat ès sc. Nat., université de

Cocody, côte d'ivoire 479 p.

[5] Savané I., 1997. Contribution à l'étude géologique et hydrogéologique des aquifères discontinus du socle cristallin d'Odienné (nord-ouest de la côte d'ivoire). Apport de la télédétection et d'un système d'information hydrogéologique à référence spatiale. Thèse d'état, université de Cocody, côte d'ivoire, 396 p.

[6] Soro G., 2010. Evaluation quantitative et qualitative des ressources en eau souterraines dans la région des lacs (centre de la côte d'ivoire) : hydrogéologie et hydrochimie des aquifères discontinus du district de Yamoussoukro et du département de Tiébissou. Thèse unique. Université de Cocody. Abidjan (côte d'ivoire). 250 p.

[7] Assemian A.E, Kouamé F.K., Djagoua E.V., Saley B.M., Affian K., Youan Ta M., Jourda J.P.R., et Biemi J., 2014. Étude de la productivité d'un aquifère de socle et approche statistique pour la détermination des tranches de profondeurs potentiellement productives : cas de la région de Bongouanou, est de la côte d'ivoire. Rev. Sci. Eau, 27, pp 81-97.

[8] Ahoussi k. E., Koffi Y. B., Kouassi A. M., Soro g., Soro n. et Biemi J. 2013. Fonctionnement hydrodynamique des aquifères discontinus de la région d'Abidjan-Agboville, sud de la côte d'ivoire. International journal of geography and geology, 5, pp 52-69.

[9] Koudou A., N'dri b. E., Niamké K. H., Adjiri O. A., Sombo A. P., Niangoran K. C. 2016. Analyse de la productivité et estimation de la vulnérabilité à la pollution pour l'optimisation

de l'implantation des forages dans les aquifères de socle du bassin versant du n'zi , côte d'ivoire. Bulletin de l'institut scientifique, rabat, section sciences de la terre, n° 38, pp.149-164.

[10] Youan Ta. M., 2008. Contribution de la télédétection et des systèmes d'informations géographiques à la prospection hydrogéologique du socle précambrien d'Afrique de l'ouest : cas de la région de Bondoukou (nord-est de la côte d'ivoire). Thèse de doctorat, univ. Cocody, 236 p.

[11] Kouassi A. M., Coulibaly D. Koffi Y. B. Kouassi A. M. et Biemi J. 2013. Application des méthodes géophysiques à l'étude de la productivité des forages d'eau en milieu cristallin: cas de la région de Toumodi. International journal of innovation and applied studies. Vol. 2, no. 3, pp. 324-334.

[12]Géomines, 1982. Inventaire hydrogéologique appliqué à l'hydraulique villageoise. Ministère des travaux publics et des transports, direction centrale de l'hydraulique, république de côte d'ivoire, carte de Gagnoa, 31p.

[13] Delor C., Diabi I., Dommanget A., Tastet J. P., Yao B., Simeon Y. et Vidal M., 1995. Notice explicative de la carte à 1 / 200000, feuille d'Abengourou, première édition, 21p.

[14] Miller, H.G and Singh, v., 1994. Potential field tilt- a new concept for location of potential field sources. Journal of applied geophysics, 32, pp. 213-217.

[15] Verduzco B. Fairhead J.D. Green C.M. and Mackenzie C., 2004. New insights into magnetic derivatives for structural mapping. Seg the leading edge, 23, 2, pp. 116-119.

[16] Salem A., William S., Sairhead D., Smith R. and Ravat D., 2008. Interpretation of magnetic data using tilt-angle derivatives. Geophysics, 73, pp. 1-10.

[17] Bouiflane M., 2008. Cartographie aéromagnetique et magnétique multi-échelles : étude structurale d'une région du fossé rhénan. Thèse de doctorat, université louis pasteur, Strasbourg 1, 206p.

[18] Simon F., 2011. Méthode magnétique appliquée à l'exploration multi-échelle du bassin de Franceville. Thèse de doctorat, université louis pasteur, strasbourg, 272p.

[19] Simeon Y., Delor C., Zeade Z., Koné Y., Yao B., Vidal M., Diaby I., Konan G., Djè B.I., N'da D., Dommanget A., Cautru J-P., Guerrot C. et Chiron J-P., 1995. Not. Explicative de la carte géol. De la côte d'ivoire à 1/200 000, feuille Agnibilékrou, *mémoire de la direction des mines et de la géologie de côte d'ivoire, n°8, Abidjan, côte d'ivoire*, 21p.

[20] Alric G., Guibert p. et Vidal M., 1987. Le problème des grauwackes birimiennes de côte d'ivoire : une revue et des données nouvelles. Le cas de l'unité de la Comoé. *C.r.acad.sc. Paris*, t. 303, série ii, n°7, pp. 289-294.

[21] Guibert P.H. et Vidal M., 1984. Un modèle d'évolution structurale du birrimien du sud-est de la côte d'ivoire. *Ann. Univ. Abidjan,* série c (sciences), t. Xx, pp. 277-293.

[22] Simeon Y., Delor C., Vidal M., Chiron J-C. et Zeade Z., 1992. Mise en évidence d'un épisode tectonique tardi-éburnéen en côte d'ivoire. *Comptes rendus de la r.s.t., Toulouse, ed.* Soc. Geol. Fr., paris., 142p.

[23] Vidal M., Delor C., Pouclet A., Simeon Y., et Alric G., 1995. Evolution géodynamique de l'Afrique de l'ouest entre 2,2 Ga et 2 Ga: le style "archéen" des ceintures vertes et des ensembles sédimentaires birimiens du nord-est de la côte d'ivoire. *Bulletin de la société géologique de france,* sous presse.

[24] Coulibaly A., 2014. Contribution de la méthode de résistivité électrique (traîné et sondage électriques) à la localisation d'aquifères en zone de socle cristallin et cristallophyllien: cas de la région de Tanda, (nord-est de la côte d'ivoire). Thèse de doctorat unique, université FHB- Abidjan (côte d'ivoire), 151p.

[25] Wyns R., Gourry J.C., Baltassat, J.M. et Lebert F., 1999. Caractérisation multiparamétrés des horizons de subsurfaces (0-100 m) en contexte de socle altéré. 2ème colloque geofcan brgm ird upmc, Orléans, France, pp 105-110.

[26] Thompson D. T., 1982. Euldph: a new technique for making computer-assisted depth estimates from magnetic data. Geophysics, 47 (1), pp 31-37.

[27] Hinze, W. J. 1985. The utility of regional gravity and magnetic anomaly maps.

[28] Brgm, 2006. Recherche d'aquifères profonds dans le socle du département de l'ille-et vilaine. Rapport provisoire, 36 p.

[29] Kouakou K.E.G., Dosso l. Kouamé l.N., Sombo A.P., Sombo B.C. 2015. Contribution des méthodes de résistivité électrique à la recherche d'eau en milieu cristallin : cas de Yakassé Attobrou et d'Abié, région de la Mé, côte d'ivoire. Rev. Ivoir. Sci. Technol., 26, pp. 194-211.

[30] Ouattara G., Koffi G. B. et Yao A.K., 2012. 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 no. 1 nov. 2012, pp. 61-75.

[31] Delany F., 1965. Mission hydrogéologique des régions à substratum schisteux (côte d'ivoire). Rapport de mission Sodemi, côte d'ivoire.

[32] Koita M., Jourde H., Ruelland D., Koffi K., Pistre S. et Savané I., 2010. Cartographie des accidents régionaux et identification de leur rôle dans l'hydrodynamique souterraine en zone de socle. Cas de la région de Dimbokro-Bongouanou (côte d'ivoire), hydrological, sciences journal, 55 :5, pp. 805-820.

[33] Djro S.C. 1998. Evolution tectono-métamorphiques des gneiss granulitiques archéens du secteur de Biankouma. Thèse de doctorat d'état ès sciences naturelles. Univ. Abidjan (côte d'ivoire), 171p.

[34] Bard J-P. et Lemoine S., 1976. Classifications et origines des granitoïdes éburnéens du craton ouest-africain. *Precambrian research*, 3, pp. 209-229.

[35] Vidal M., 1987. Les déformations éburnéennes de l'unité birrimienne de la Comoé (côte d'ivoire). *Journal of African earth sciences*, vol.6, n°2, pp 141-152.