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CHARACTERIZATION OF THE ALTERATION PROFILE OF FRACTURED AQUIFERS IN THE AGNIBILEKROU DEPARTMENT (EAST OF COTE D'IVOIRE)

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ABSTRACT

This study focuses on improving knowledge of the geometry and structure of the alteration profile of the various composite parts of aquifers in the Agnibilékrou department (East Côte d'Ivoire). The interpretation of the vertical electrical soundings and the drilling logs showed a strong variation in the thicknesses of alteration ranging from 2 to 70 m. The alterites are approximately 33 m, 45 m and 50 m respectively at Siakakro, N'guessankro and Mossikro. They generally consist of topsoil, alteration clays and schistose clays. Due to the mineralogical composition and the structure of the geological formations, the alteration is less pronounced in the granites (0 to 20 m) than in the schists (20 to 70 m). Water inflows are more observed for alterites thicknesses between 10 m and 30 m in granites and between 30 m and 40 m in schists. Between 60 m and 80 m thick, the frequency of water inflows is more significant in the granites than in the schists. The largest flows are provided by boreholes with alterites thicknesses less than 30 m in granitic rock while in schistous rock, they could come from alterites thicknesses between 30 m and 60 m. This study therefore highlights the importance of alteration in understanding the hydrodynamics of fractured aquifers in the basement.

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INTRODUCTION

Groundwater is very essential in supplying people with potable water. They also constitute a main reserve of fresh water exploitable for agriculture and industry. In the basement, they are generally found in discontinuous aquifers. These aquifers exhibit significant vertical heterogeneities (composite aquifers with several compartments with distinct geometries and hydraulic properties) as well as significant horizontal heterogeneities attributed to lithological variations (Koïta, 2010). They are closely linked to the physical characteristics of the surface part of rocks (Detay *et al*., 1989). These characteristics are mainly linked to the alteration processes they have undergone in the past, on the geological time scale, and to the possible effects of subsequent erosion (Wyns, 1991; Taylor etHoward, 2000; Lachassagne *et al*., 2001; Wyns*et al*., 2004). Understanding the hydrodynamics of fractured aquifers requires an exact knowledge of the geometry and structure of the alteration profile of the various composite parts of these aquifers (Maréchal *et al*., 2006). This present study therefore aims to characterize the alteration profile of fractured aquifers in the Agnibilékrou department through an integrated use of vertical electrical soundings and drilling data. Located 270 km from Abidjan, in the east of Côte d'Ivoire, between latitudes 6 ° 46 and 7 ° 22 N and longitudes 3 ° 04 and 3 ° 40 W, the department of Agnibilékrou belongs to the Indénié-Djuablin region (Figure 1). Belonging to the West African craton, the Agnibilekrou region consists of geological formations of Proterozoic age structured during the Eburnian orogeny. The work of Géomines (1982) and Delor *et al*. (1995) have shown that tectonics is polyphase and has resulted in the placement of numerous fractures of varying sizes ranging from a few meters to several kilometers. The formations in this area have been 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 oriented NE-SW are the main geological formations encountered in the study area (Figure 2). The hydrogeology of this region is dominated by the presence of groundwater in the alterites and fractured rocks. The various drilling logs coupled with the work of Géomines (1982) have shown that the schists formations deteriorate very easily and produce large alterites thicknesses.

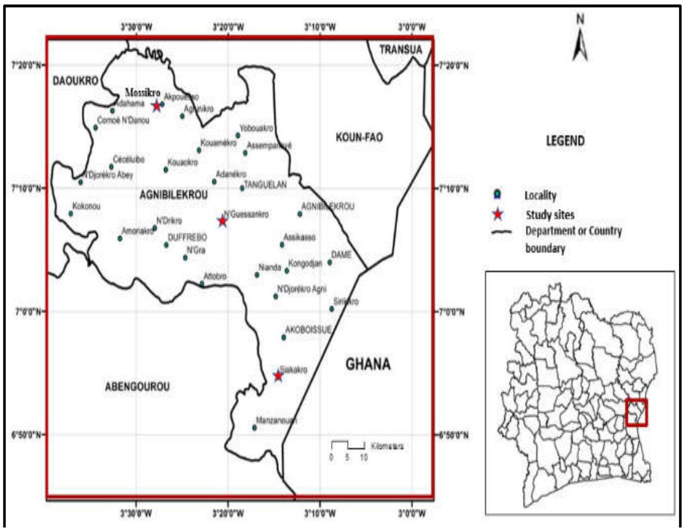

Figure 1. Location of the study area

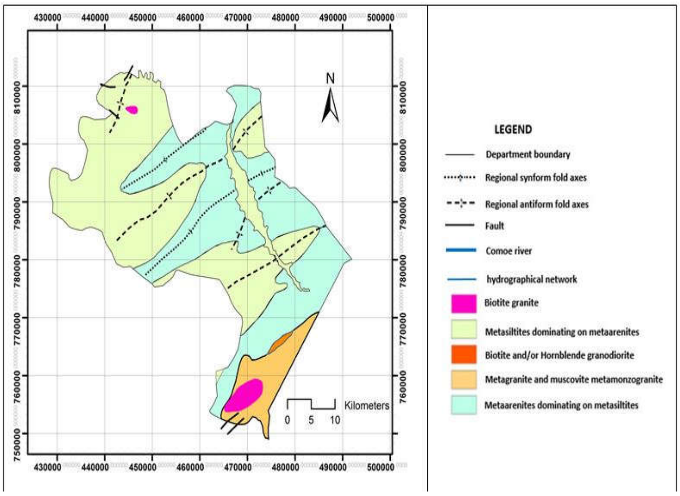

Figure 2. Geological map of Agnibilékrou department (Delor *et al.*, 1995)

Methodological approach: Vertical electrical sounding (VES) is an investigative technique used to quantitatively determine variations in the electrical resistivity of the basement as a function of depth. It is carried out directly above conductive anomalies previously detected or confirmed by the profiles (electrical drag) of apparent resistivities. As the depth of the investigation is proportional to the length of the line AB, the survey is carried out in the field, gradually moving the electrodes A and B away (Figure 3). Electric current is sent to electrodes A and B placed at the outer limits of the device. The potential difference is measured between the electrodes M and N placed on either side of the center of the device (O). The distance AB is 8 times that of MN. An AB / MN ratio of between 4 and 20 is generally tolerated. The electrodes A and B are gradually and symmetrically distant from the center O, without displacement of the electrodes M and N. When the ratio AB / MN becomes too large (that is to say greater than 20), it is then necessary to increase the MN spacing by symmetrically moving the potential electrodes. Two readings are taken for the same spacing AB, one for each of the spacings MN. The device readings (placed in the center O of the ABMN quadrupole) represent the dV / I ratio. These readings are then multiplied by the appropriate geometric factor K. The apparent resistivity values are plotted on a bilogarithmic scale as a function of the distances AB / 2. For the Schlumberger device used on the three (3) sites studied, AB / 2 varies from 1 to 100 m while MN / 2 is between 0.4 to 10 m.

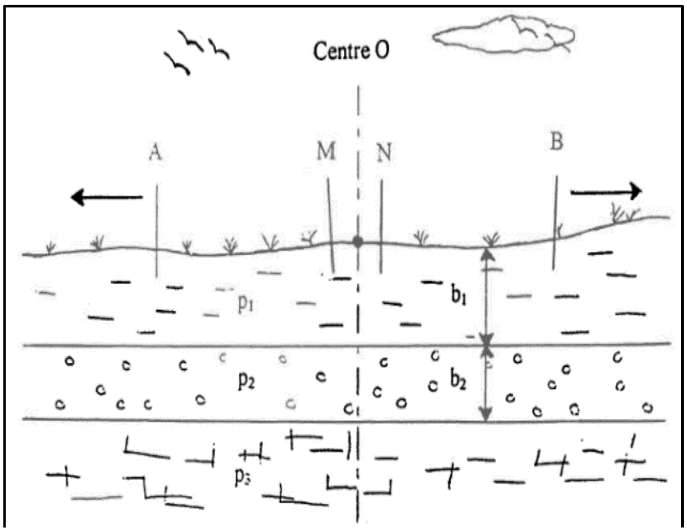

Figure 3. Illustration of the electrical survey by the Schlumberger configuration (Lavoie, 1998)

RESULTS AND INTERPRETATION

Results of vertical electrical surveys: Vertical electrical soundings (VES) were carried out on the three (3) study sites in order to assess the vertical distribution of the geological formations (Figure 1).

Siakakro site: Three (3) VES were carried out at Siakakro according to the Schlumberger configuration with a maximum spacing of the AB electrodes of 250 m. Overall, a succession of Five (5) geoelectric fields is highlighted by VES SE1 and SE3 (Figures 6 and 8). The VES SE2 shows a succession of Six (6) fields which are the following (Figures 7):

- a low resistance field with a resistivity of 203 Ω.m and a thickness of 1.34 m. It corresponds to topsoil ;
- a second conductive field with a resistivity of 29.5 Ω.m and a thickness of 0.76 mcorresponding to the alteration clay of reddish or ocher color as indicated by the drilling logs of the region (Annex 4);
- a third slightly resistant field of 231 Ω.m and 11.10 m thick. It wouldconsist of schistoseclay of yellow to greenishcolor;
- a fourth conductive field with a resistivity of 164 Ω.m and a thickness of 23 m. It would be affected by a partially altered open schistosity with numerous cracks and joints generally filled with alteration products;
- Finally, a resistant schist bedrock of 9641 Ω.m located 36.2 m deep. It would be affected by a fracture located at 102 m which would constitute the sixth (6) layer on the VES SE2.

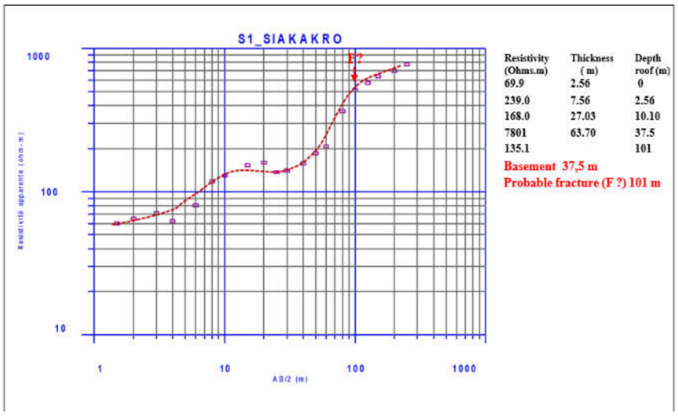

Figure 6. Siakakro SE1 vertical electricalsounding curve

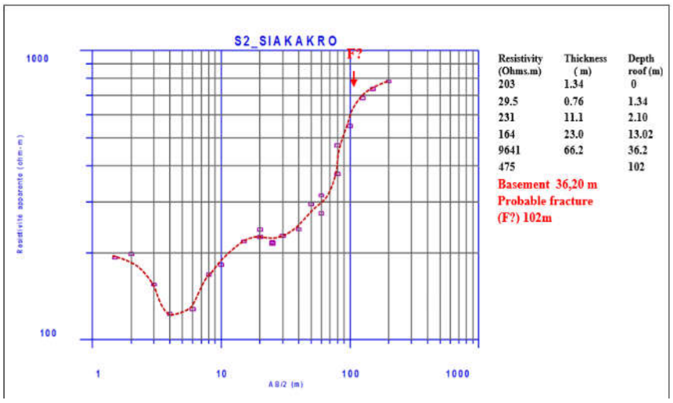

Figure 7. Siakakro SE2 vertical electrical soundingcurve

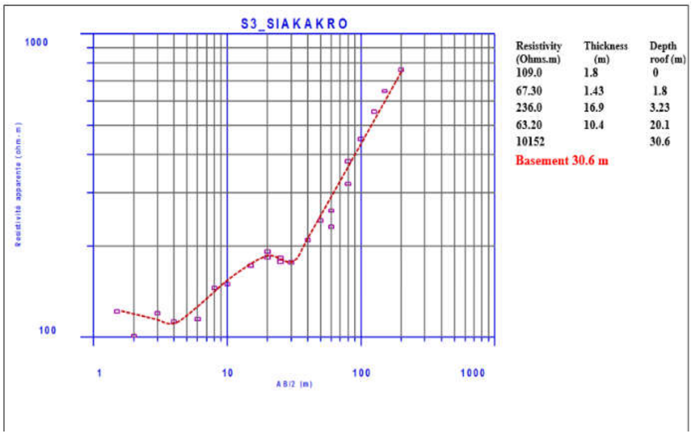

Figure 8. Siakakro SE3 vertical electrical soundingcurve

A slightly different structure of the layers is observed on the VES SE1 and SE3. Five (5) geoelectric fields are highlighted by these holes. Indeed, the layer 6 described previously does not appear on the VES SE3. The schist basement is therefore not affected by a major fracture at this location. The VES SE1 shows that the second conductive field observable on the VES SE2 is almost non-existent. It testifies to the small thickness of the alteration clays at the level of VES SE1. The interpretation of the three (3) VES led to the establishment of a lithostratigraphic section over the first hundred (100) meters of the Siakakro site (Figure 9). The Siakakro F2 borehole shows that the thickness of the alteration is 32 m. Composed of topsoil, alteration clay, schistose clay and open schistosity, the alterites vary in thickness from 30.6 m to 37.5 m on the Siakakro SE1, SE2 and SE3 VES curves.

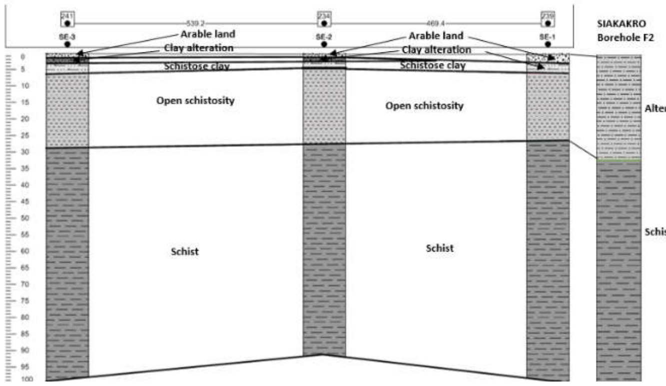

Figure 9. Lithostratigraphic correlation of the Siakakro site

Site de N'guessankro: Three (3) VES were also carried out at the N'guessankro site. The VES SE1 and SE2 are of the "single rising staircase branch" type (Figures 10 and 11). The presence of a single branch in shale is explained by the existence of topsoil, a dry horizon, active alteration front and schist bedrock. Four (4) fields are therefore highlighted by the VES SE1 and SE2.

- the first layer, the thickness of which varies between 1.80 m and 2.41 m, has a resistivity of between 57.6 Ω.m and 105 Ω.m. It corresponds to topsoil.
- the second high resistivity layer (625Ω.m and 647Ω.m) has a thickness of between 8.43 m and 9.86 m. This dry horizon is made up of dry ocher-colored clay, as indicated by the drilling log ;
- the third layer has a variable resistivity between 193Ω.m and 242Ω.m. It has a thickness between 29.20 m and 39.40 m. This active alteration front is formed of greenish clay ;
- the fourth resistant layer (976 Ω.m to 1481 Ω.m) constitutes the shale substratum. It is located around 41 m deep.

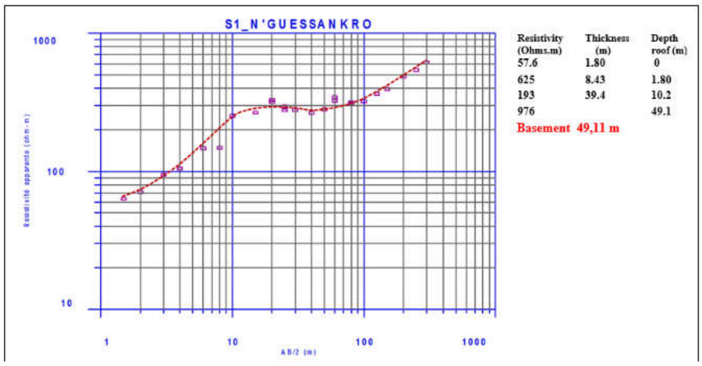

Figure 10. N'guessankro SE1 vertical electrical soundingcurve

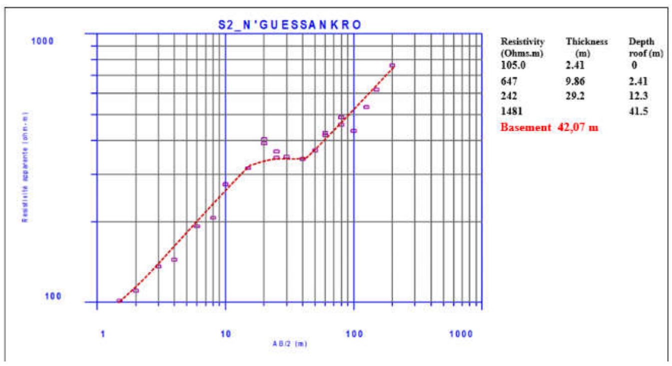

Figure 11. N'guessankro SE2 vertical electrical sounding curve

Made up of 5 layers, the VES SE3 has a slightly different appearance from the VES SE1 and SE2 surveys. It is of the "staircase on the rising branch" type (Figures 12). The additional conductive layer with a resistivity of 32.70 Ω.m and a thickness of 1.74 m observed on VES SE3 could result in the presence of imbibition water in the upper part of the second layer previously described. The lithostratigraphic section resulting from the interpretation of the electrical soundings of the site of N'Guessankro is represented in Figure 13. The N'Dakro F2 hole, drilled some 4 km from the N'guessankro site, shows a succession of topsoil, ocher clay, greenish clay and shale base. These strata were also highlighted by the N'guessankro SE1, SE2, SE3 electrical surveys. However, differences are observed in the thickness of the layers. Ocher clay has an average thickness of around 8 m on the boreholes while it is 23 m on the N'Dakro F2 borehole. The holes indicate an average thickness of 33 m of greenish clay while in drilling it is 15 m. Generally speaking, clays have more or less the same thickness, both on boreholes and in drilling. The schist base is 44 m on average on the boreholes and 40 m in drilling. The differences are due to the distance of the borehole from the N'guessankro site. They reflect the heterogeneity of the environment studied.

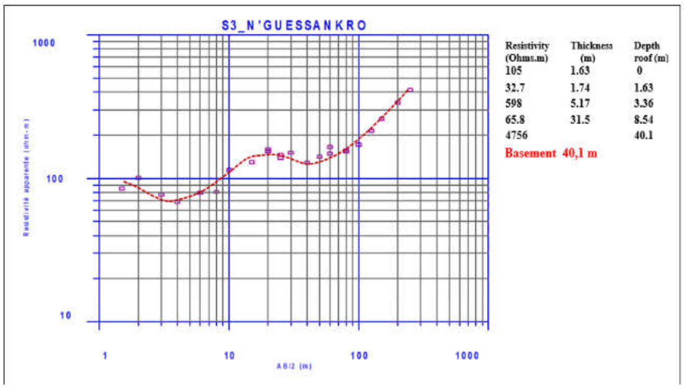

Figure 12. N'guessankro SE3 vertical electrical soundingcurve

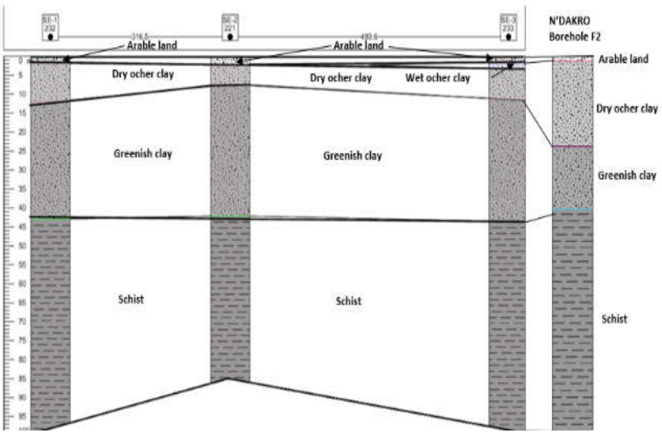

Figure 13. Lithostratigraphic correlation of the N'guessankro site

Site de Mossikro: Located to the northwest of the study area, the Mossikro site rests on a schist bedrock. During the geophysical campaign in this locality, four (4) VES were done according to the Schlumberger configuration with a maximum spacing of the AB electrodes of 250m. The shape of the VES SE1, SE2, SE3 and SE4 shows that they belong to the family of sounding curves at the "bottom of the boat" generally characterized by a surface covering, a conductive complex and a resistant base (Figures 14, 15, 16 and 17). A fourth resistant layer between the conductive complex and the resistant base is however observed on these sounding curves.

a surface covering: With a resistivity varying between 247.5 Ω.m and 603.3 Ω.m, this first layer has a small thickness of between 0.86 m and 3.05 m. It corresponds to the descending branch of the curve until the slope breaks and is made up of topsoil and / or clays (Annex 5).

a conductive complex: Materialized on the sounding curve by the ‘‘ bottom of the boat ’, this second layer has a thickness of between 8.78 m and 15.66 m. It has a low resistivity which varies between 26.02 Ω.m and 55.79 Ω.m thus translating the presence of water in the yellowish to greenish clay formations.

Resistant formation: This resistivity layer between 403.5 Ω.m and 765.3 Ω.m, has a thickness which varies between 31.79 m and 40.53 m. It corresponds to greenish-colored clay formations strongly marked by drying.

Resistant bedrock: Located between 47.63 m and 50.08 m deep, the schist base has an average resistivity of 1652 Ω.m. Low resistivity is observed at the roof of the base between 50 m and 60 m. It could correspond to a sudden setting characterized by the presence of a small conductive mass in the ground. It could also be explained by the presence of a contact zone between the clays and the schist base. Its strong expression on holes SE3 and SE4 could also reflect the passage of a fracture that could constitute a usable water collector.

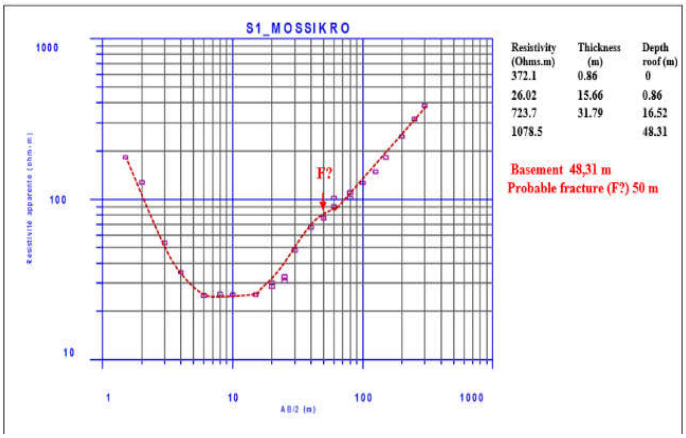

Figure 14. Mossikro SE1vertical electrical soundingcurve

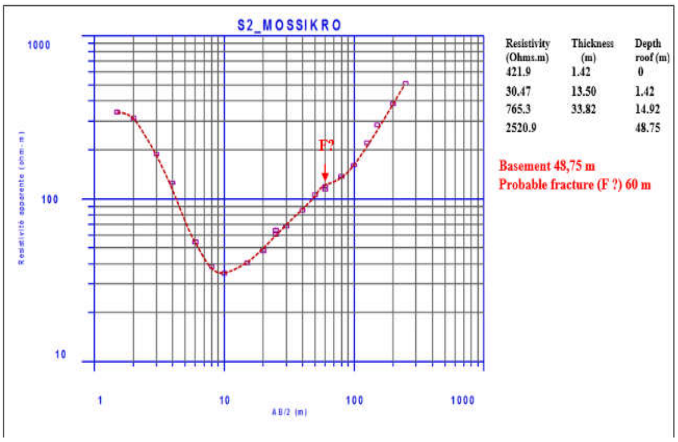

Figure 15. Mossikro SE2 vertical electrical soundingcurve

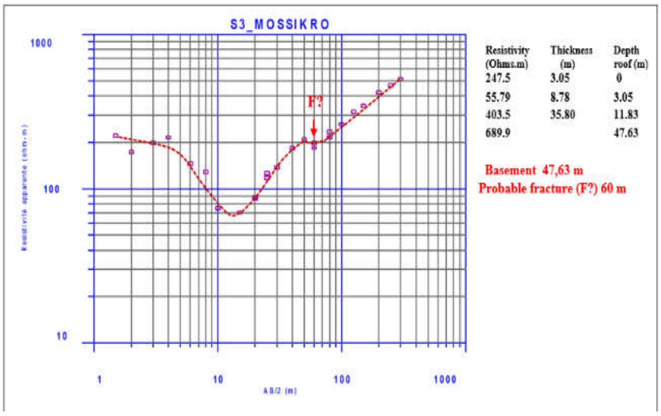

Figure 16. Mossikro SE3 vertical electrical soundingcurve

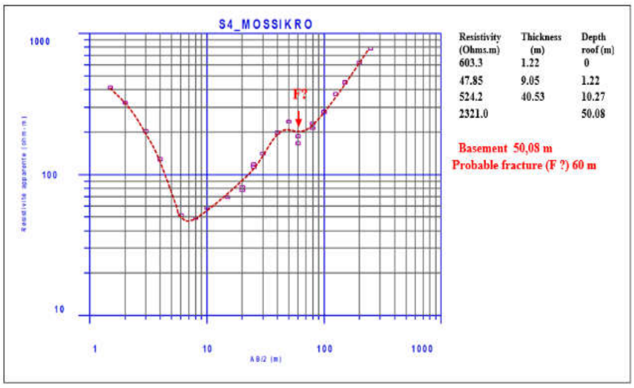

Figure 17. Mossikro SE4 vertical electrical soundingcurve

The interpretation of the Mossikro VES SE1, SE2, SE3 and SE4 led to the establishment of the following lithostratigraphic section (Figure 18).

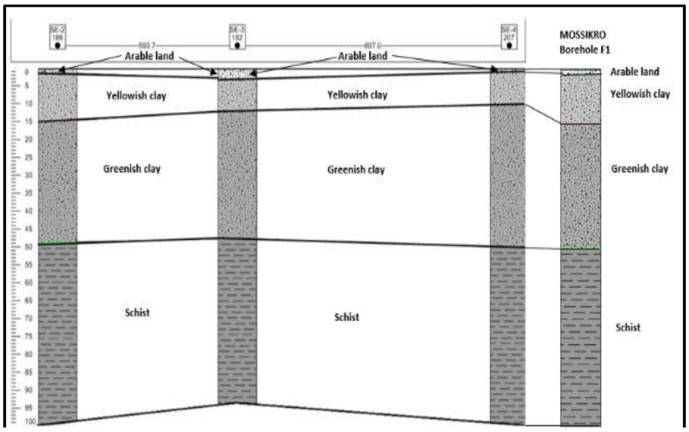

Figure 18. Lithostratigraphic correlation of the Mossikro site

Thickness of the alterites revealed by drilling: Drilling has shown that the thicknesses of alterites vary between 2 m (Bakarykro / Akoboissué) and 70 m (Kouamékro / Duffrebo) with an average of 33.47 m. Alterites with thin thicknesses (0 to 20 m) are mainly observed in granite formations while alterites with moderately thick thicknesses (20 to 40 m) are generally encountered in schist formations with thickness classes corresponding to 50% of the drilling results (Figure 19). In schist, 7.69% of the boreholes show a thickness of the alterites between 0 and 20 m while 50% indicate a thickness between 20 and 40 m. A thickness greater than 40 m is observed for 42.31% of the boreholes. Thus, more than 90% of the holes drilled on a schist substratum have a thickness of alterites greater than or equal to 20 m.

In a granite, 50% of the boreholes indicate a thickness of alterites between 0 and 20 m. 30% of the boreholes have a thickness of alterites varying between 20 and 40 m. Finally, 20% of the boreholes show a thickness greater than 40 m.

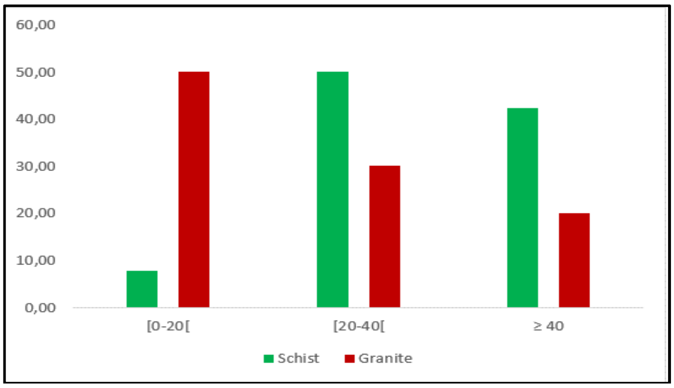

Figure 19. Alterites thicknesses depending on the nature of the bedrock

Thus, at least 80% of the drilling carried out in a granite medium has a thickness of alterites between 0 and 40 m. The frequency of drilling with thicknesses of alterites between 0 and 20 m is considerably high (50%) in granite than in schist (7.69%). However, the opposite is observed for alterite thicknesses of 20 to 40 m with a drilling frequency of 50% for schists and 30% for granites. Beyond 40 m, the same observation is observed in schist (42.31%) and granite (20%) formations. In sum, the granite formations have small thicknesses of alteration than the schist formations. This is explained by the mineralogical composition and the structure of each formation. Indeed, granite is a magmatic rock composed of 80% of quartz, alkaline feldspars (orthosis or microcline) and plagioclases (albite, oligoclase). Quartz and feldspar (orthosis) are minerals with high hardness (7 and 6) according to the Mohs scale. As for the schist, it is of sedimentary or metamorphic origin. On the granites, it is much lower, around 9 m on the vertical electrical sounding and 13 m on the boreholes.

Water inlets and flows according to the alterites thicknesses: Figure 20 shows the frequency of water inlets as a function of the thickness of the alterites. The frequency of these inflows increases with the increasing thickness of the alterites and reaches a maximum of 40 m. From this depth, it generally decreases to 100 m where water arrivals become rare. 85% of the inflows are between 10 m and 50 m of alterites thickness while 55% of these inflows are between 20 m and 40 m.

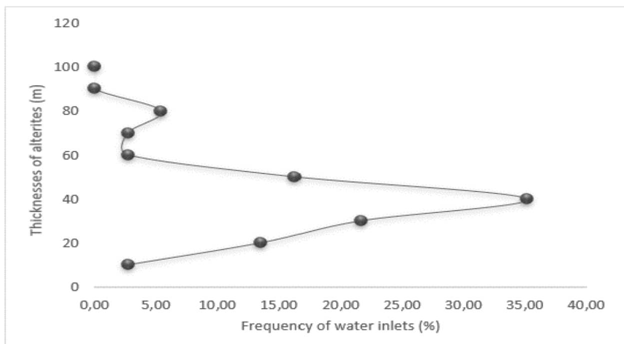

Figure 20. Water inlets distribution according to the alterites thickness

The high frequencies of water inflows are encountered in granites for alterites thicknesses between 10 m and 30 m and in schists for thicknesses between 30 m and 40 m (Figure 21). For alterites thicknesses between 60 and 80 m, the frequency of water inflows is more significant in the granites than in the schists.

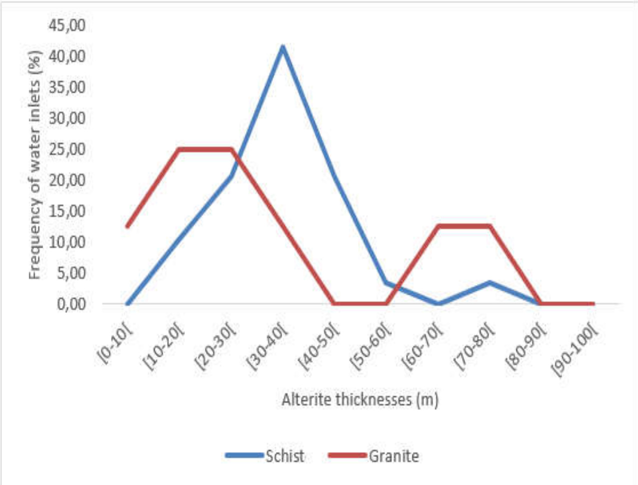

Figure 21. Water inlets frequencies distribution in the schists and granite depending on the alterites thicknesses

FIG. 22 reveals that the very low and low flow rates and the average flow rates are provided by alterites thicknesses varying from 10m to 70m in general. The alterites thicknesses between 10m and 50m provide high flow rates. This variation in flow rates depending on the alterites thicknesses shows that the importance of the flow rates does not seem to establish a particular relationship with the alterites thicknesses. In granite formations, the alterites thicknesses between 30 m and 70 m provide very low and low flows while between 0 m and 30 m medium and high flows are observed (Figure 23). The largest flows are therefore provided by boreholes with alterites thicknesses less than 30 m while the least important flows come from alterites thicknesses greater than 30 m. In schist formations, the alterites thicknesses between 15 m and 70 m provide very low and low flow rates. However, medium and high flows are still observed between 25 m and 55 m (Figure 24). Thus, in schist, the largest flows could come from the alterites thicknesses located 30 m and 60 m.

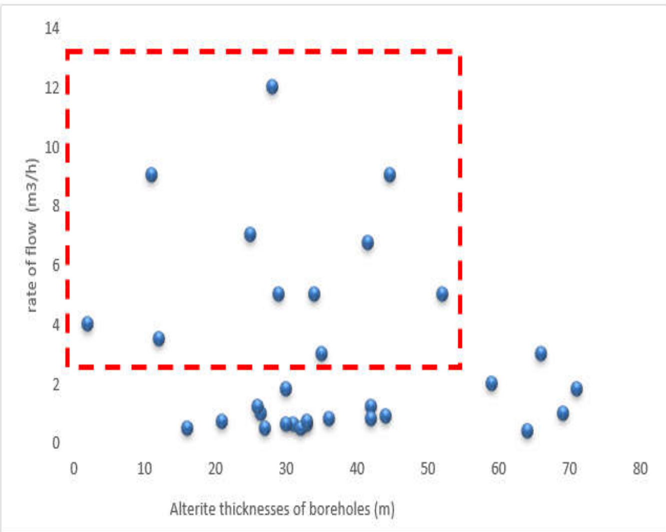

Figure 22. Relationship between flow rates and alterite sthicknesses recorded from boreholes

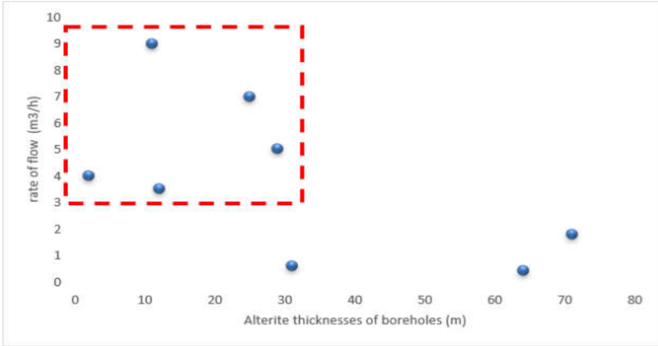

Figure 23. Relationship between flow rates and alterites thicknesses drilling on granite

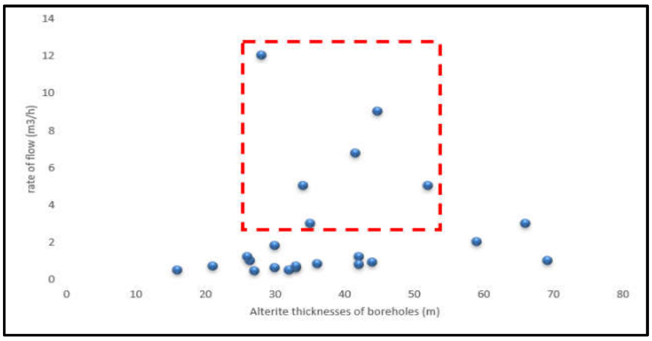

Figure 24. Relationship between flow rates and alterites thicknesses drilling on schist

DISCUSSION

The lithology of the healthy rock and the intensity of the fracturing have a considerable impact on the nature and thickness of the alteration products. More than 90% of the holes drilled on a schist bedrock have an alterite thickness greater than or equal to 20m, while in granite bedrock, 50% of the holes indicate an alterite thickness between 0 and 20m. Thus, the granitic formations have smaller thicknesses of alteration than the shale formations at Agnibilékrou. This result is similar to that of Sombo (2012) in the areas of Sikensi and Tiassalé (South of Côte d'Ivoire). According to the author, on the schist formations, the average thickness of the alterites is 24.64 m on the vertical electrical soundings against 22 m on the boreholes. On the granites, it is much lower, around 9 m on the vertical electrical soundings and 13 m on the boreholes. The work of Assemian *et al.* (2014) have shown that in the Bongouanou department, the alterites thicknesses (loose alterites, also called saprolite ; fissured horizon not included) observed vary between 4 and 105.5 m. In the Agboville region, the thicknesses of alterites vary from 2.2 m to 66 m, with an average of 24.47 m (Ahoussi *et al.*, 2013). According to the authors, the frequent alterites thicknesses occur in the 10 m to 30 m range, with a probability of 67.58%. The alterites thicknesses on granite varies between 2.2 and 47 m, with an average of 21.51 m. On schist, the average alteration thickness is 27.03 m, which is 5 m more than on granite. In granitic formations, the most important flows are provided by boreholes with alterites thicknesses less than 30 m while in schistous formations, they could come from thicknesses of alterites located between 30 m and 60 m. Similar results were obtained by Dibi *et al.*, (2004) in the Agboville region. Without however specifying the nature of the substratum, Koudou *et al.* (2016) have shown in the N'zi catchment area that the average (between 2.5 m3 / h and 5m3 / h) and high (between 5 m3 / h and 10 m3 / h) are generally found in areas where the thicknesses of the alterites are between 6 and 70 m approximately. Also, works carried out in the Bongouanou department by Assemian *et al*., (2014) have shown that the influence of the thickness of alterite is apparently significant as regards the productivity of the cracked horizon in groundwater. in this basement aquifer. According to these authors, for thicknesses of otherites less than 15m and greater than 75m, the flow rates of the boreholes (capturing the cracked horizon) are less than 3 $m^3.h^{-1}$; it is only the interval between 20m and 70m which provides many flow values greater than 3 $m^3.h^{-1}$. However, according to Mangoua *et al*. (2010), the variation in operating flows as a function of the thicknesses of alterites shows that the importance of the flow rates of the structures does not seem to establish a particular relationship with the thickness of the alterites of in general. The diagram shows very clearly that in the Baya watershed, the strong and very strong flows are provided by thicknesses of otherites ranging from 2 to 92.31 m in general.

Conclusion

The interpretation of the vertical electrical soundings and the drilling data made it possible to study the alterite profile of the Agnibilékrou department. A large variation in alteration thicknesses ranging from 2 to 70 m was observed in the localities. The alterites are approximately 33 m, 45 m and 50 m thick at Siakakro, N'guessankro and Mossikro, respectively. They generally consist of topsoil, alteration clays and schistoses clays. Depending on the nature of the substratum, alterites with small thicknesses (0 to 20 m) are mainly observed in granite formations while alterites with moderately high and high thicknesses (20 to 70 m) are generally encountered in schist formations. Water inlets are commonly encountered for alterite thicknesses between 10 m and 30 m in granites and between 30 m and 40 m in schists. Between 60 m and 80 m thick, the frequency of water inflows is more significant in the granites than in the schists. The greatest flows are provided by boreholes with alterite thicknesses less than 30 m in granite while in schist, they could come from alterite thicknesses located between 30 m and 60 m.

REFERENCES

AHOUSSI K. E., KOFFI Y. B., KOUASSI A. M., SORO G., SORO N. ET BIÉMI J. 2013. Fonctionnement hydrodynamique des aquifères discontinus de la région d'AbidjanAgboville, Sud de la Côte d'Ivoire. *International Journal of Geography and Geology,* 5, pp 52-69.

ASSEMIAN A.E, KOUAME K.F., DJAGOUA E.V., SALEY B.M., AFFIAN K., YOUAN TA M., JOURDA J.P.R., ET BIÉMI 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.

DELOR C., DIABI I., DOMMANGET A., TASTET J. P., YAO B., SIMEON Y. ETVIDAL M. (1995). Notice explicative de la carte à 1 / 200000, feuille d'Abengourou, première édition, 21 p.

DETAY M., POYET P., *ET AL* (1989). Development of the saprolite reservoir and its state of saturation : influence on the hydrodynamic characteristics of drillings in cristalline basement. C.R. Acad. Sci. Paris Série II (t. 309) pp 429-436.

DIBI B., INZA D., GOULA B. T. A., SAVANE I., BIÉMI J. (2004). Analyse statistique des paramètres influençant la productivité des forages d'eau en milieu cristallin et cristallophyllien dans la région d'Aboisso (Sud-Est de la Côte d'Ivoire). *Sud Sciences & Technologies* n°13 pp22-31.

GEOMINES (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. 31 p.

KOITA M (2010). Caractérisation et modélisation du fonctionnement hydrodynamique d'un aquifère fracturé en zone de socle. Région de Dimbokro-Bongouanou (Centre Est de la Côte d'Ivoire). Thèse unique de Doctorat de l'Université de Montpellier II. 220 p.

KOUDOU A., N'DRI B. E., NIAMKE 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.

LACHASSAGNE P., WYNS R., BERARD P., BRUEL T., CHERY L., COUTAND T., DESPRATS J.F., LE STRAT P. (2001). Exploitation of high-yields in hard-rock aquifers :downscaling methodology combining GIS and multicriteria Analysis to delineate field prospecting zones. Ground Water, 39 (4), pp 568- 581.

MANGOUA M. J., TOURE S., GOULA B. T. A., YAO K B., SAVANE I. ET BIÉMI J.(2010). Evaluation des caractéristiques des aquifères fissurés du bassin versant de la Baya ouBâ (Est de la Côte d'Ivoire). *Rev. Ivoir. Sci. Technol.,* 16, pp. 243-259.

MARECHAL J.C., DEWANDEL B., AHMED S., GALEAZZI L. AND ZAIDI F. K. (2006). Combined estimation of specific yield and natural recharge in semi-arid groundwater basin irrigated agriculture. *Journal of Hydrology,* vol329, pp. 281-293.

SOMBO A. P. (2012). Application des méthodes de résistivités électriques dans la détermination et la caractérisation des aquifères de socle en Côte d'Ivoire. Cas des départements de Sikensi et de Tiassalé (Sud de la Côte d'Ivoire). Thèse de Doctorat. Université Félix Houphouët Boigny de Cocody (Abidjan, Côte d'Ivoire), 203 p.

TAYLOR R., HOWARD K. (2000). A tectono geomorphic model of the hydrogeology of deeply weathered crystalline rock : evidence from Uganda. *Hydrogeology journal* 8(3), PP 279-294

WYNS R. (1991). Evolution tectonique du bâti armoricain oriental et cénozoïque d'après l'analyse paléo-surfaces continentales et des formations géologiques associées. Géologie de la France, 3, pp 11-42.

WYNS R. (1991). L'utilisation des paléo-surfaces continentales en cartographie thématique probabiliste. Géologie de la France, 3, pp 3-9.

WYNS R., BALTASSAT J. M, LACHASSAGNE P., LEGCHENKO A., VAIRON J. et MATHIEU F. (2004). Application of proton magnetic resonance soundings to groundwater reserve mapping in weathered basement rocks (Brittany, France). *Bull. Soc. Géol. France,* Vol. 175,N°1, pp. 21-34.

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