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Siting High-yielding Boreholes: In the Crystalline Basement in Burkina Faso: Contribution of Electrical Anisotropy Measurements

Samuel Nakolendousse[1*], Pibgnina Bazie[2] and Yousouf Koussoube[1]

[1]Department of Earth Sciences, Georessources Laboratory, Ouaga 1 University, Burkina Faso.
[2]Centre Agrhymet, Department of Hydrology, Niamey, Niger.

Authors' contributions

This work was carried out in collaboration between all authors. Author SN designed the study, performed the methodology, wrote the protocol and wrote the first draft of the manuscript. Authors SN, PB and YK managed the analyses of the study. Author SN managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Geological studies, remote sensing and geophysical investigation around twenty two boreholes (highly and moderately productive, or dry ones) have clarified aquifers productivity factors of the crystalline basement of Burkina Faso as well as their geophysical signature. To boost the rate of successful siting of highly productive boreholes (rate greater than 5 m3 / h) from 15 to 56%, the square device enabling to perform anisotropy profile was tested. This system provided some very interesting results for research of high yielding drilling sites.

Thanks to electrical and electromagnetic geophysical methods after a geological and remote sensing study, ten sites with twenty-two yielding, mildly yielding or dry boreholes have been studied in details. Some number of productivity factors of crystalline rocks aquifers in Burkina Faso has been detected as the contribution of electromagnetic hydro geophysical prospecting. Migmatic granites characterize the geology of the sites. These rocks are very fractured with important pegmatic veins intrusions.

**Corresponding author: E-mail: altesseroi1@yahoo.fr, altesseroi@yahoo.fr;*

The yielding wets drilling are located on fractures longer than five kilometres.
Lateral extension of the discontinuity is less than fifty meters.
An important thickness of fractured rock is necessary, it characterize the "trailing rise" of electrical sounding curve.
There is a correlation between the yield of a borehole and the anisotropy ratio. A perpendicular anisotropic profile allows choosing a site for yielding boreholes.

Keywords: Crystalline basement; siting; electrical anisotropy; productivity; aquifer; hydrogeology.

1. INTRODUCTION

Burkina Faso, like the other countries of the Sahel, faces serious water problem because of climatic and geological conditions; its relief consists of a vast plateau of 200 to 300 meters, slightly tilted from north to south. The climate is of Sudanese type in the South with rainfall ranging from 650 to 1400 mm but has the features of a desert climate as one travels to the North where rainfall decreases to less than 250 mm.

The lack of water resources, consequence of the shortness of the rainy season and its irregularity requires to use groundwater for feeding men and livestock. To find the key for siting high yielding boreholes in the crystalline formations of Burkina Faso and other Sahel countries becomes an absolute necessity for the supply of medium-sized cities and for off-season irrigation purposes. The works on the exploration and exploitation of underground water: [1,2,3,4,5,6,7, 8,9,10,11,12] have clarified the mode of groundwater occurrence.

A geological, remote sensing and geophysics survey campaign helped clarify the context of the study. This conventional methodology allows a success rate of about 15% for high yielding boreholes. In order to improve this success rate, we experimented for the first time in Burkina Faso, square device profiling, enabling to perform anisotropy measurements as a profile. Siting of high yielding boreholes in medium-sized cities confirmed the methodology.

2. CONTEXT OF THE STUDY

The different sites selected for the a posteriori study are primarily located in the central part of Burkina Faso. The choice of the sites was done randomly taking into account only yield of the borehole and geological context from over ten thousand existing boreholes in the area.

The Table 1 provides the yield of boreholes on six different sites. All rates were obtained outdoors during drilling operations, thereby leaving some imprecision in the absolute values while allowing the comparison between the performances of each item. All the boreholes except those of Nioko site have a diameter of 6 inches: high yielding boreholes obtained can only come from the cracked bedrock fringe because, works of this diameter could not obtain such yield at the level of alterites.

Table 1. Yields of boreholes

Sites	Borehole 1	Borehole 2	Borehole 3
Nioko	90 m^3/h		
Laye	50 m^3/h	07 m^3/h	00 m^3/h
Rakaye	36 m^3/h		
Boudri	32 m^3/h	00 m^3/h	
Sambin	32 m^3/h	1.8 m^3/h	
Pissi	32 m^3/h	1.2 m^3/h	

3. GEOLOGICAL RESULTS

Out of all the sites studied, except that of Toessin, the geological survey or analysis of drill sections shows that we are in the presence of migmatitic granites. At Boudri, they are of a gabbroic trend. These granites are generally very tectonized, very cracked and intruded by numerous pegmatite lodes. The sites of Rakaye and Sambin showed a very disturbed environment. Measurements of cracks 'directions, veins and foliations, show that the veins preferentially inject in a dominant direction corresponding to that of the conductor axes found in geophysical prospection. Fracturing induces a more or less thick layer alteration, which typically generates in the crystalline basement zone, the superposition of two aquifers: the alterites and cracked basement [13,14].

4. REMOTE SENSING RESULTS

The remote sensing survey consisted in the analysis of aerial photographs and digital satellite images. Analysis of aerial photographs at 1/50 000 on which were traced lineaments and the hydrogeographic network showed that the Pobé Mengao borehole is located on a pluri-kilometric lineament with N150 direction corresponding to a prevailing direction of cracking and in a preferred direction of veins injection. In the vicinity of borehole, the hydrographic network is quickly dry when the rain stops, because of an intense infiltration favored by a sandy cover. The Rakaye borehole is located at the intersection of two lineaments including the one of N150 direction coupled to the direction of the veins. The hydrographic network is sparse and the boreholes are located at the head of the watershed.

5. GEOPHYSICAL RESULTS

The geophysical study by the traditional electric method (dragged resistivity and survey) and by the electromagnetic method MaxMin (Figs. 1, 2 and 3) shows that boreholes with high yields are located on long mega fractures of 5 km long at least; the larger yields are found in the case where drilling would be at the intersection of two mega fractures (case of Nioko borehole, Fig. 1). Generally a lateral extension is at least 50 meters long. Electrical polls do not predict the productivity of a work but can indicate which of several surveys present the greatest probability of providing the best results, especially when looking at the rise of the sampling curve. Thus, when the curve has at the beginning of the rise, a slope of less than 45 °, which is called “trailing rise” [14]. This trailing rise reflects an important cracked fringe of the bedrock. Indeed in the case of a non-fractured basement, topped by alterites, the rise of the sampling curve is direct with a 45 ° slope, characteristic of healthy bedrock.

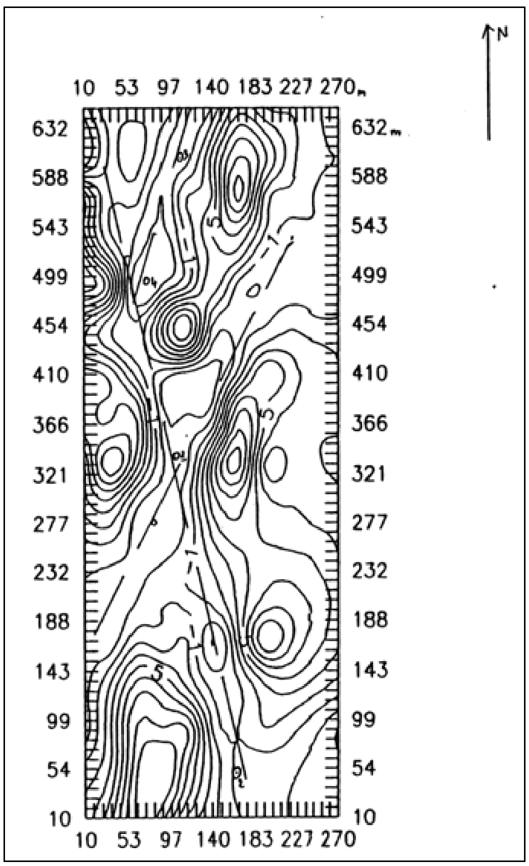


Fig. 1. Electromagnetic map (site of Nioko)
The wet drilling 1 is at the intersection of two Conducting axis. The map reproduce the variation of the four boreholes production out phase compoment (%) (From [15])

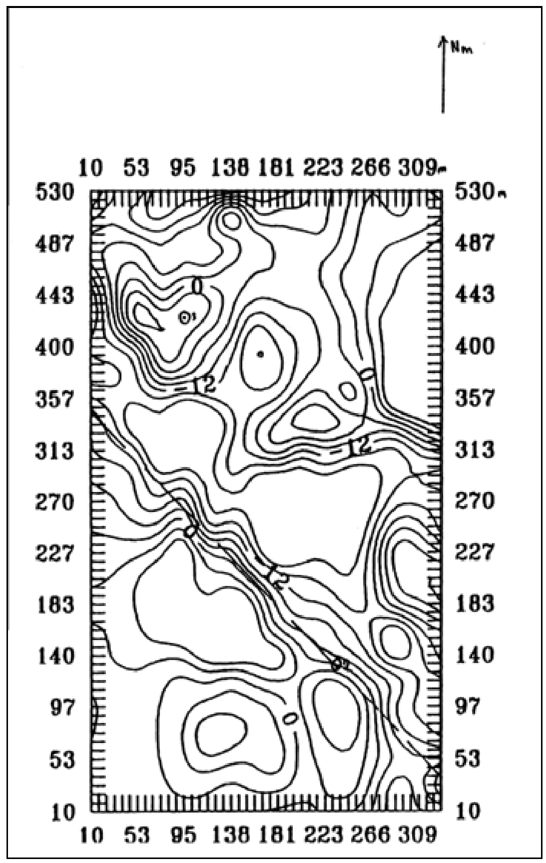
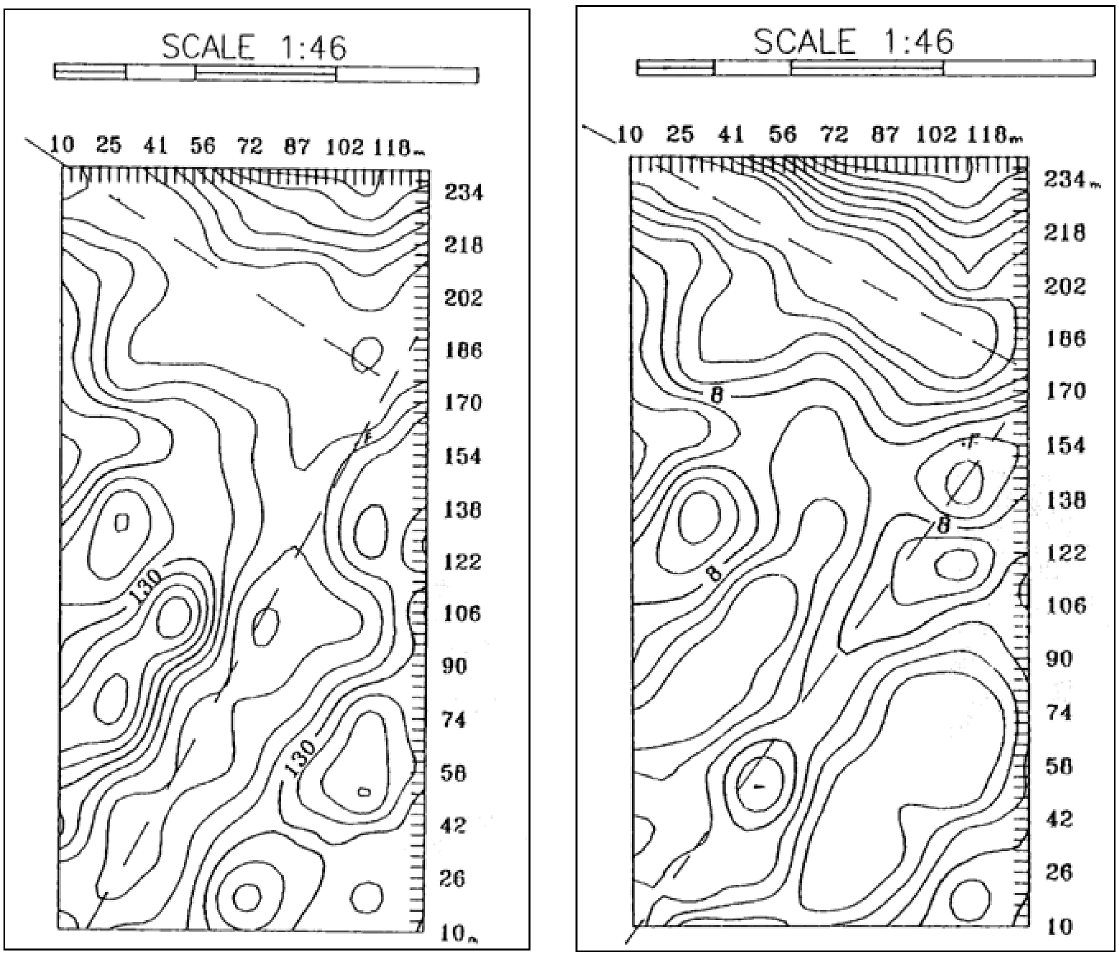


Fig. 2. Electromagnetic map (site of Laye)
Two conducting axis in this representation explan the production of well 1 out phase compoment (%)



(A) (B)

Fig. 3. Electric and electromagnetic prospecting (site of Laye)
A- apparent resistivity map Oh.m With AB / 2 = 100m
B- electromagnetic map, Out phase compoment (%)
The two maps are comparable and show a conducting axis NW-SE and a other NE-SW (from [15])

The various geological, remote sensing and traditional geophysical certainly helped us improve the success rate in siting high yielding boreholes (5% to 16%). But performance remains low, which has led us to experiment anisotropy measurements.

6. ELECTRICAL ANISOTROPY MEASUREMENTS RESULTS

6.1 Reminders on the Square Profiling Technics

The principle of the electrical method is based on measuring the apparent resistivity using a Thus, we have:

ABMN quadripole. The electrical conductivity of aquifers rocks inverse of the resistivity, is proportional to the electrical conductivity of the fluid and to a certain power of the porosity [16,17]. For square device, the ABMN electrodes are located on top of the square with side l, the measurement corresponds to the square of the center O of that square. The three positions of the electrodes are defined (Darboux Afouda and Louis-P, 1989), but for the trailing with square device we use two positions (PFig. 4).

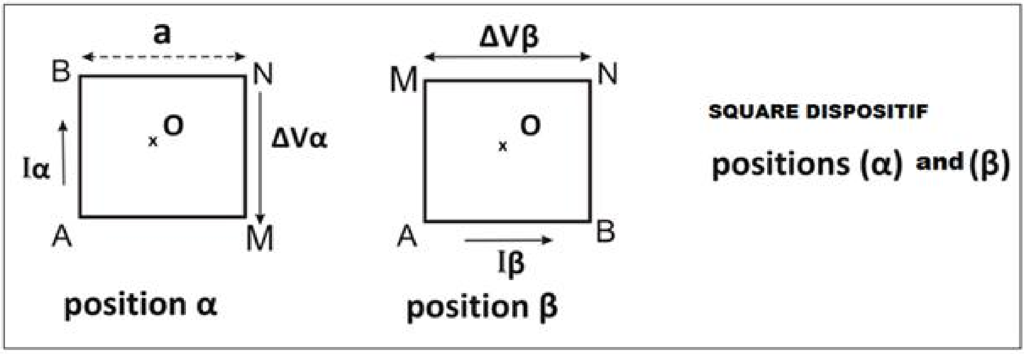


Fig. 4. Square dispositif

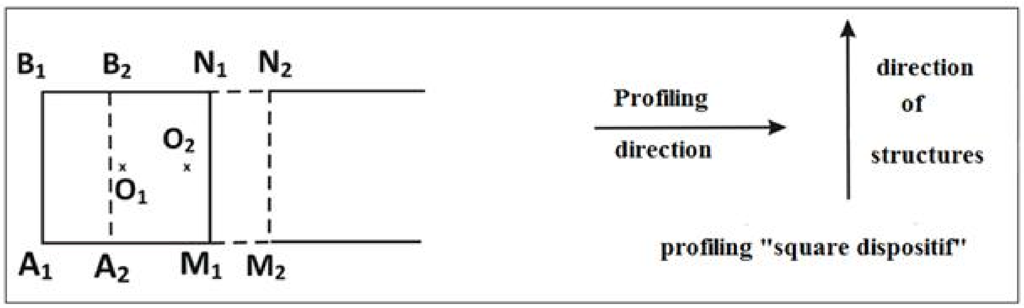


Fig. 5. Square dispositif traversing

$\rho_a(\alpha) = K^*\Delta V_\alpha / I_\alpha$ and $\rho_a(\beta) = K^*\Delta V_\beta / I_\beta$

If $\rho_a(\alpha) \neq \rho_a(\beta)$, then we have an anisotropy and we define a coefficient for the anisotropy.

$\lambda_a = (\rho_a(\alpha)^{1/2} / (\rho_a(\beta)$

This coefficient anisotropy often reflects the state of the fracturing of the basement. A much fractured basement, usually in the form of cracking corridor translates Indeed a strong anisotropy coefficient [18].

During a survey, after setting the direction of cracking, moving the square ABMN device by sliding in a direction perpendicular to this direction (Fig. 5). We go from one direction to another by switching the connections at the level of resistivity which makes implementation on the ground inexpensive.

Note that the work of the [19]) have shown that the square device is more sensitive to the anisotropy than other devices.

The works of Darboux-Afouda and Louis [18] were used to calculate the theoretical models of anisotropic behavior of fractured zones in granites, in schists, as well as influence of clay core in the recovery. But the last two cases are not presented in this study.

6.2 The Results of the Square Profiling

Fig. 6 shows the results of 9 sites over which we have performed anisotropy profiles when terrain conditions allow.

These results have the following characteristics:

At the site of Pissi, there is a positive peak just in line with the high performance drill ($Q = 32m^3 / h$) while we observe a hollow at the level of near zero speed drilling;

- At Rakaye, the anisotropy profile has a bell curve, with a positive peak in the drilling plumb with high yield ($Q = 32m^3 / h$);
- At Doulougou, there is a sawtooth curve. We do not record an absolute maximum

drilling plumb. The borehole is powered by a vein acting as a drain. The vein behaves differently from a fracture. Indeed, an open vein non-injected with lode product is a fairly homogeneous conductor, while the lode is very heterogeneous with respect to conductivity with conductive fissures containing water contrasting sharply with the rest of the very strong lode.

- At Sambin we have a bell curve for the very productive borehole (Q = 32m³ / hr) and one bearing at the second borehole level which present a yield of 1.2 m³ / h;
- At Laye, there are two bell curve for the boreholes with respective yields of 7 and 50 m³/h and a nearly horizontal curve with no change for dry well;
- At Nioko and Toéssin, the anisotropy profiles are bell-shaped curves with a maximum offset from the well;
- At Boudri, there is a sawtooth curve for the positive drilling and for the dry borehole. We notice that the positive drilling curve remains above that of the dry borehole except for one point located 20 meters away from the borehole.

The plumb conductor axes in which are generally sited the drillings are characterized by a high coefficient of anisotropy, contrasting with the surrounding values and reflecting a significant fracturation of the basement. All the boreholes with high yield are characterized by bell-shaped curves with a maximum value of the anisotropy in the drilling plumb. Dry wells are characterized by either a flat curve or by boat bottom curve.

If we consider the Laye site, the borehole curve with a yield of 7 m³ / h sees its diagram intercalate between that of the high yielding borehole (Q = 50 m³ / h) and the dry borehole.

We can notice that in some cases (Nioko, Nabmayaoghin) that the maximum is offset from the drilling. These boreholes having high yield, we can make two assumptions:

- The siting of the drilling is not optimal in that case, there could be a greater yield by siting the drillings on top of the maximum anisotropy value;
- We have an oblique fracture, which allowed the drilling which is vertical to cross the plane of the fracturation.

Given these anisotropy diagrams, one might think that there is a relationship between the curve of the square profiling and yield of drilling. The point showing the maximum fracturing is awakened by the maximum anisotropy but if it is small (cases of Pissi sites and Sambin). At this study a posteriori, we have applied the methodology for high yielding boreholes siting in medium-sized towns in Burkina Faso, especially Gourcy Yako, Leo, Manga, and in some areas in the city of Ouagadougou.

Remote sensing has enabled the choice of platforms particularly after a confrontation of satellite image data and those from aerial photographs.

The lateral investigations have brought to light the faults and electrical soundings have allowed choosing the best sites for boreholes siting particularly by analyzing the fringe cracked bedrock and the thickness of the alteration. Profiles with square devices have helped to locate the points with the highest anisotropy. We notice that the maximum anisotropy does not necessarily coincide with the lowest resistivity value and the best borehole yield always have the maximum anisotropy.

Thus, as shown in Fig. 7, at the site of Gourcy, the maximum anisotropy that allowed moving the point of drilling 40 meters away from the one which is recommended by other methods.

Indeed, SE1 is located in the area with the smallest resistivity value. The results of electromagnetics survey totally confirmed the one of the electric trailing. The maximum anisotropy value has been achieved in the SE3 survey. The borehole sited of top of SE3 gave a yield of 9 m³/ h which is very rare in the area.

Drilling point SE1 gave 3 m³ / h. On the Ouagadougou site (Fig. 8), in order to get three positive boreholes one had to drill in the following order 1-2-3. The anisotropy studies allowed drawing the following order: 3-2-1. The yields obtained are proportional to the anisotropy values. As a matter of fact, the site 3 has given 10 m³ / h, site 2, 2 m³ / h and the site 1 was a negative borehole. At site 1, the drilling encountered significant mud thickness which explains the weak resistivity values observed.

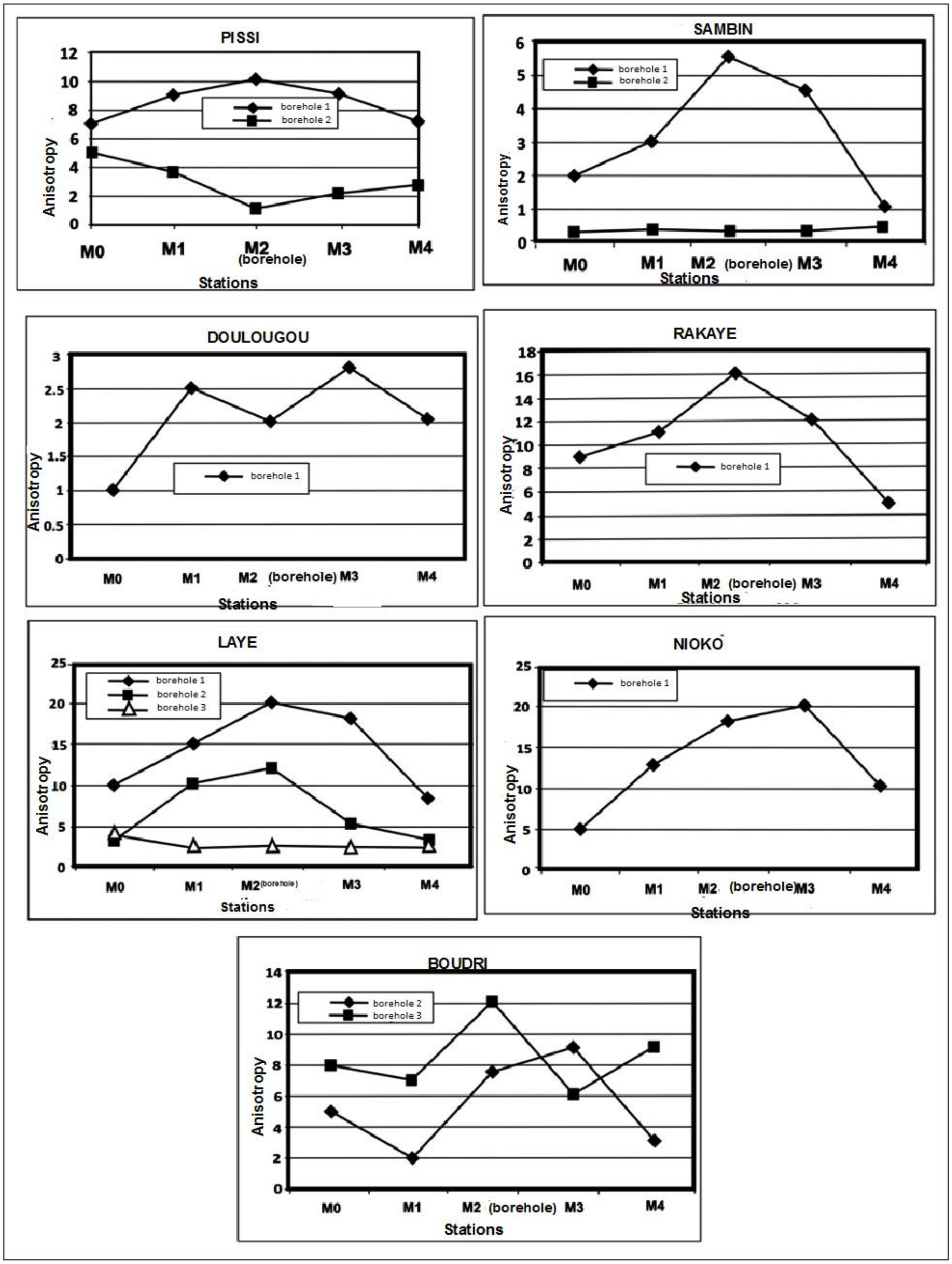


Fig. 6. Electrical anisotropy travelling results (step measuring = 20m, M0,...= measuring station)

At Yako and Manga sites, thanks to the use of anisotropy measurements we were able to get high yielding boreholes respectively 10 and 13 30 m^3 / h.

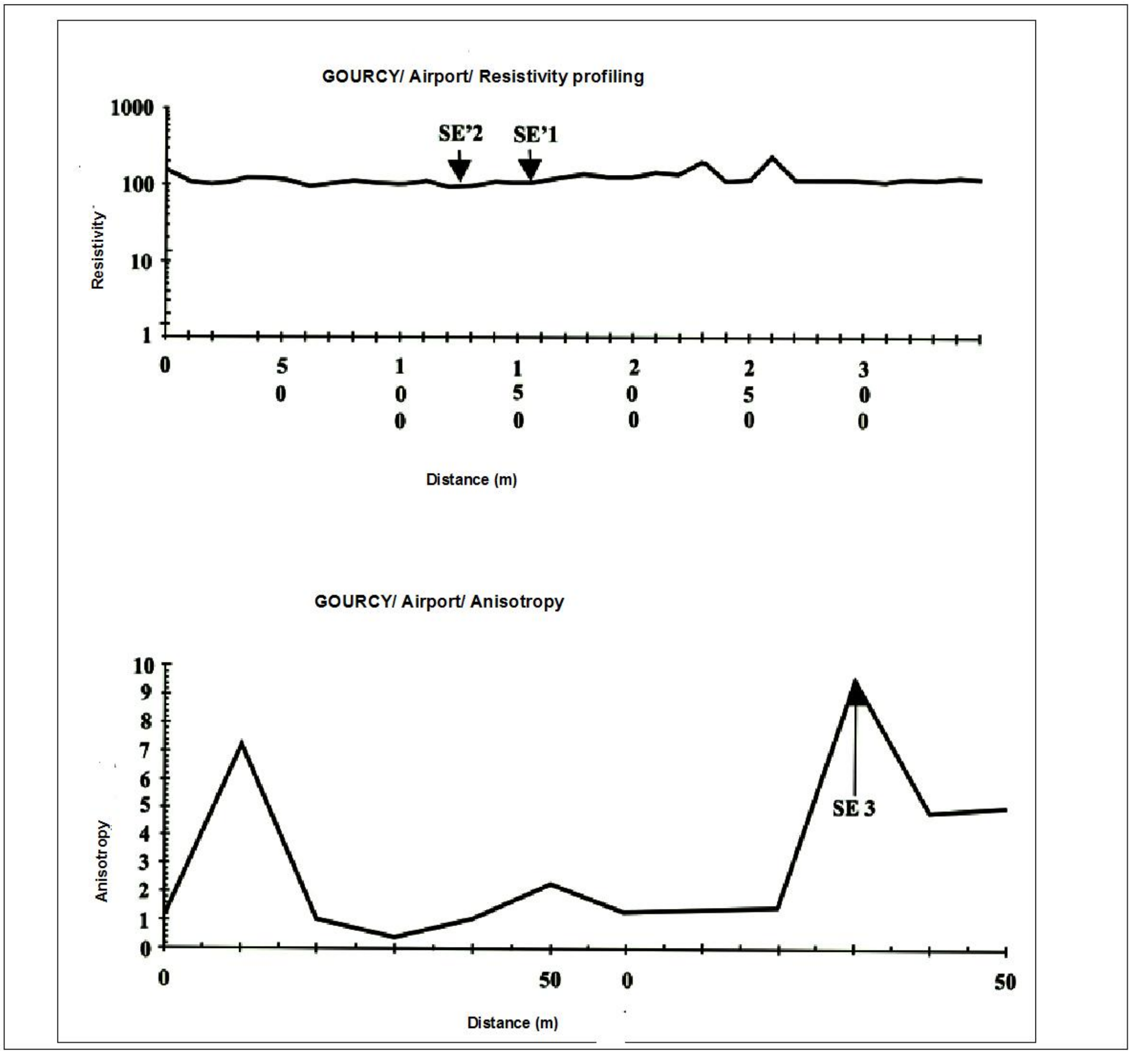
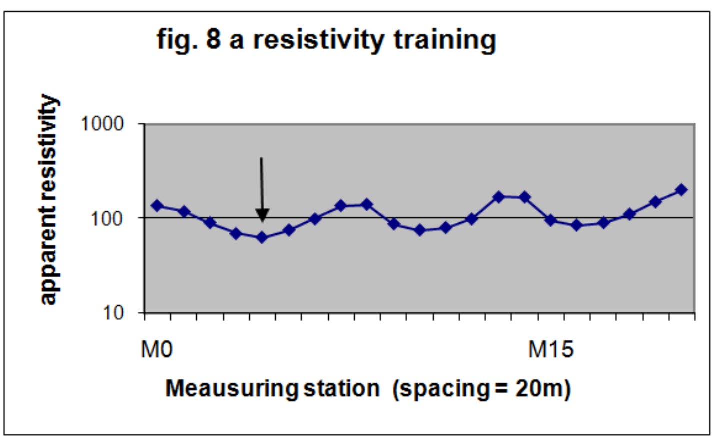


Fig. 7. Anisotropy at Gourcy airport



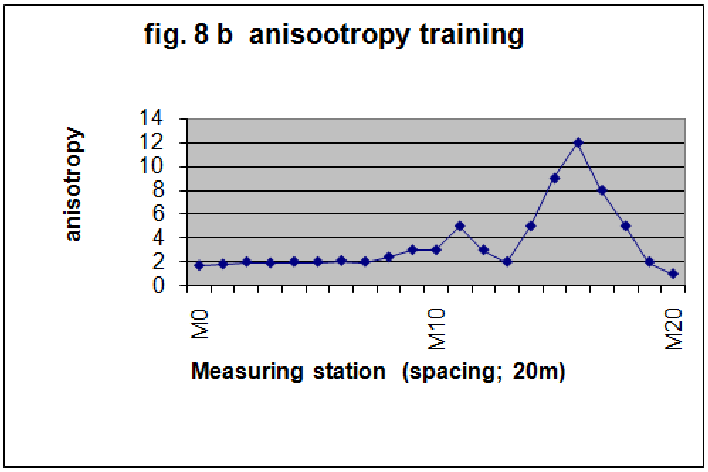


Fig. 8. Electrical and electrical anisotropy traversing (site of Ouagadougou)

7. CONCLUSION

The anisotropy coefficient is a very interesting factor in the search for high yielding boreholes because there is a relationship between the latter and the yielding of boreholes. The realization of anisotropy profiles perpendicular to the axis of the fracture allows, firstly to remove the majority of failures, and then to select the sites for high yielding boreholes especially in the case the medium-sized towns water supply and for irrigation off- season.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Astier JL. Géophysique appliquée à l'hydrogéologe, Masson et Cie., Paris. 1977;277. French
2. Bernard A, et al. Intérêt de la prospetion géophysique: Exemple du programme d'urgence d'hydraulique villageoise Nord-Cameroun Bull. CIEH; N° 74-75, Octobe 1988-Janvier 1989:47-68. Frenh
3. Bernard A, Mouton J. Les recherches d'eau dans le socle africain; apports de la géophysique Bull. BRGM. 1980;2:293-309. French
4. Burgeap-CGG. Utilisation des méthodes géophysiques pour la recherche d'eau dans les aquifères dscontinuss. Bull. CIEH, Série Hydrogéologiee. 1984;236. French
5. Bro M, Hubert C, Moulard P. Research of fracture aquifers in schist and sandstone series in Mali. Hydrogeology. 1980;4:311-324.
6. Darboux-Afouda. Recherches hydrogéolo-giquespar les methods géophysiques dans les regions de socle en Afrique Occidentale. Thèse Université des Sciences et Techniques de Languedoc. 1985;228. French
7. Darboux-Afouda R, Louis P. Contribution of electrical anisotropy measures to research in aquifer fractures in crystalline environment in Benin. Geophysical Prospecting. 1989;37:91-105.
8. Collin JJ. Groundwater and irrigation water in Sahelian Africa. Hydrogeology. 1989;4: 247-248.
9. Pointet Th. Overview of the hydrogeology of the basement of fissured environments. Technical Note of BRGM 85/31; 1985.
10. Dutartre P, King C, Motti E, Pointet T. Using SPOT imagery in hydrogeological exploration in Burkina Faso: Small-scale irrigation from groundwater fissured environment. Hydrogeology. 1990;2:145-154.
11. Pointet Th., Steenhoudt M, et al. Small-scale irrigation under semi-arid climate: A three-year experiment in Burkina Faso. 29th Intern. Geol. Congress. Kyoto; 1992.
12. Castaing C, Duartre P, Gouet JF, Loiseau P, Martin P, Pointet T. Multidisciplinary study of discontinuities spot-image network, covered granite medium. Hydrogeology implications of fissured

environments. Hydrogeology. 1989;1:19-25.
13. Pointet Th. Aperçu ur l'hydrogéologie du socle des milieux fissurés. Note technique du BRGM 85/31; 1985. French
14. Savadogo NA. Géologie et Hydrogologie du socle de le Haute Volta, étude régionale du bassin versant de la Sissili. Thèse de doctorat en Sciences Naturelles présentée à l'Université Scientifique de Grenoble, France; 1984. FRENCH
15. Nakolendoussé S. Méthoe d'évaluation de la productivité des aquières du socle cristallin au Burkina Faso. Géologie-Géophysique-Télédétection. Thèse, University Joseph Fourier, Grenoble I France. 1991;328. French
16. Archie GE. The electrical resistivity log as an aid to determining some reservoir characteristics. AIME Technical Paper 1422, Petroleum Geology. 1942;54-62.
17. Astier JL, et al. Evaluation et revisions des études géophysiques au sahel de Haute Volta en vue de l'implantation de forages d'eau. Division de la Mise en Valeur des Terres et Des Eaux. 1981;129. FAO Rome
18. Darboux-Afouda R, Louis P. Contribution of electrical anisotropy measures to research in aquifer fractures in crystalline environment in Benin. Geophysical Prospecting. 1989;37:91-105.
19. Le Masne D. Application des méthodes électriques et électromagné-tiques à l'étude géophysique des milieux fissurés. Thèse de 3ème cycle. Universisité des Sciences de Montpellier France. 1979;171. French

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