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Contribution of the Vertical Electric Sounding to the Geotechnical Study of Some Soils of the West Region, Cameroon

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ABSTRACT: Different combinations of soil affect how well it's going to be suited for construction. So the knowledge of the soil underneath foundation is a geotechnically engineered solution for maximum stability of buildings. In the present study, vertical electric soundings have been carried out in some villages of the West Cameroon region to evaluate the parameters of the soil for geotechnical purposes. Using the Schlumberger method, twenty-two (22) Vertical Electric Sounding (VES) were conducted. The data collected were successively analysed qualitatively and later inverted to determine the nature and thickness of the underground layers. The inverted models for the subsurface were found to be constituted of four or five layers. Each obtained layer was described in terms of its resistivity and corresponding thickness. The layers are made up of clay, granite and basalt. The iso-resistivity map shows the presence of a zone of low resistivity, thus indicates a weak soil spreading from the North-East to the South-West with the concentrated recharge in the southern part of the study zone. The study revealed that some areas would be of risk for the completion of major civil engineering projects. The findings are in agreement with previous geological investigations.
KEYWORDS: Vertical Electric Sounding; Apparent resistivity; Geotechnical; Geoelectric Section; West Cameroon.

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I. INTRODUCTION

Construction works depend on a large extend to geological and geotechnical studies. Therefore, the aims of the present investigation are to produce a database useful for civil engineering and also characterize the soil in order to propose a practical solution for the implementation of geotechnical works. To design and to build structures, engineers and architects need information about the nature and properties of the soil sub-surface layers as well as their depths. This work, which is an application of the electrical resistivity method, is an attempt that could provide a solution to this problem. From several past investigations [1] - [7], the method applied has been qualified as a powerful tool for environmental and geotechnical investigations. To determine the nature and characteristics of the underground layers, we used some data from the existing boreholes in the region. Moreover, we carried out a survey in twenty two localities of West Cameroon. This region is undergoing several building constructions, stadiums, hotels and roads. Analysing the collected data will help evaluate the physical parameters of the underground structures, and their interpretation will be of great importance for designing solutions for unstable soils.

II. GEOLOGICAL AND TECTONIC CONTEXT

The region of West Cameroon is located between 5° 00'N and 5° 24'N latitude and 10 °00'E to 10 °30'E longitude. It covers an area of about 13700 km^2 [8]. The geological cover of the region mainly comprises the basement formations and the volcanic formations, which occupy most of the Bamileke plateau [9]. The basement formations are mainly composed of calc-alkaline fribite gneisses, anatexites and syntectonic granites that are always found in the anticlinal position (Fig. 1). The volcanic formations belong to three main series: The lower black series, the middle white series and the upper black series. Past geological works [10], [11], have been carried out to figure out the main geological features of the study area as illustrated on fig. 1. We observed in the area ante-Cambrian tectonics of the basement where intense wrinkling of the isoclinal ginger and hypersthene gneisses. Tertiary tectonics, which may be due to the replay of the Cameroonian fracture following subsidence sedimentation in the Gulf of Guinea, may also be due to the constraints that followed the separation of the South American continent from Africa.

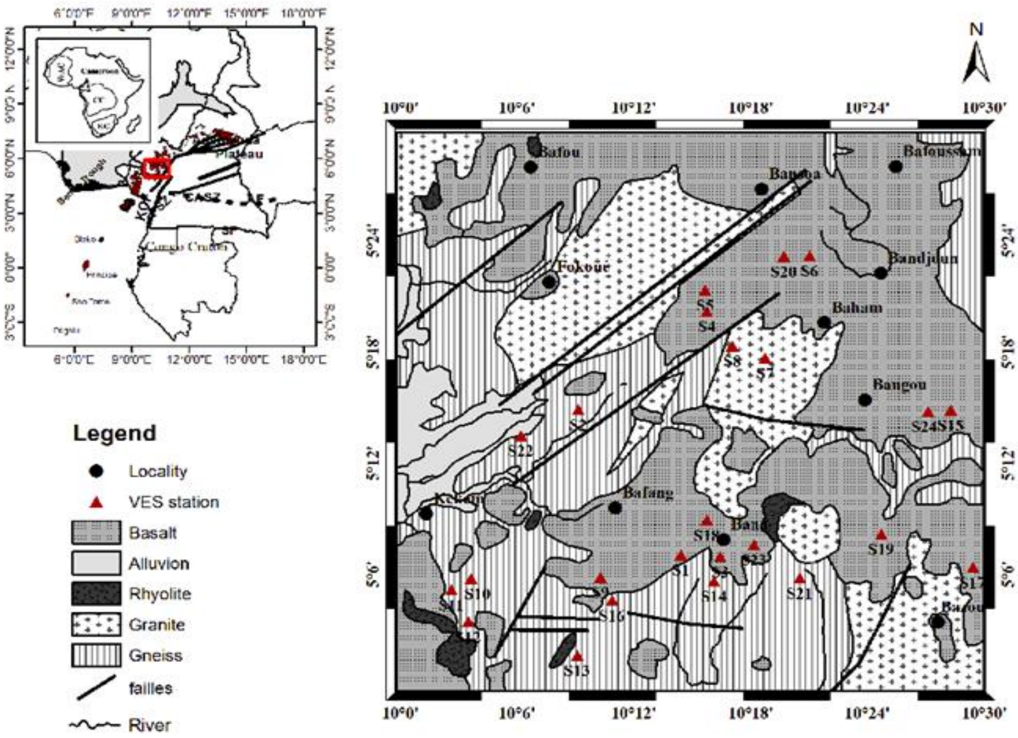


Fig. 1: Geological sketch of the Region of West Cameroon showing VES stations labeled Sxx; 1) gneiss; 2) granite; 3) rhyolite; 4) allusion; 5) basalt; 6) fault; 7) river; 8) VES station; 9) localities. Modified from [11]

III. DATA AND METHOD

A. Data

For this investigation, we used an ABEM SAS 4000 device with 64 stainless steel electrodes and 16 multi-electrode cable coils as disposed on Fig. 2. The electrodes were connected to the cable via clamp connectors. The different cable portions are also interconnected. An ABEM Terrameter ES 10-64C electrode selector is connected to the cable from either side of the profile and is placed in the center of the device. It is associated with an ABEM resistivity meter, and both are powered by a battery. To obtain the best possible contact at the electrodes, salt water and clay (bentonite) are added to the electrodes. The data were collected in 2016 on 22 sounding sites using the schlumberger geometry of the DC electrical method.

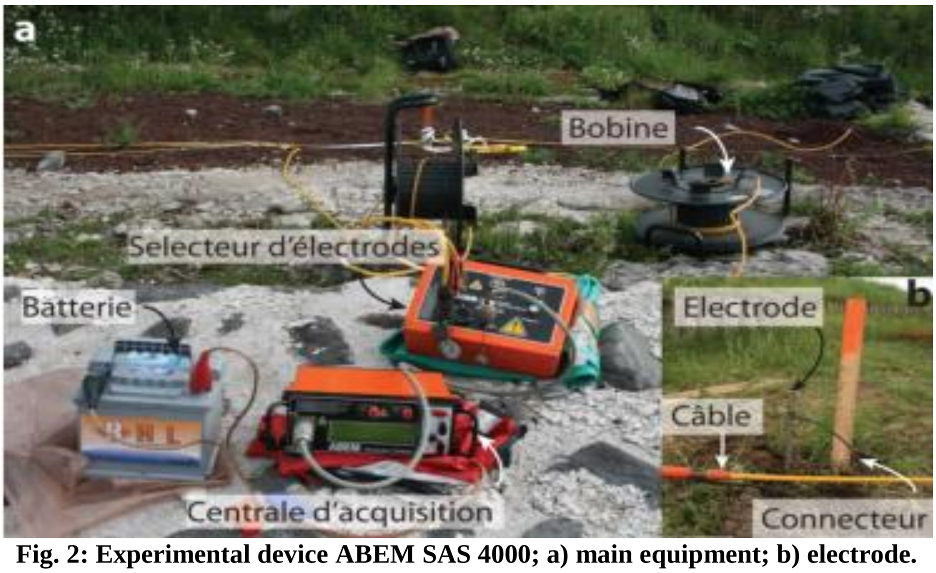


Fig. 2: Experimental device ABEM SAS 4000; a) main equipment; b) electrode.

B. Method

The subsurface is in reality a heterogeneous and anisotropic medium [12]. Therefore, it is essential to introduce the notion of apparent resistivity. The apparent resistivity corresponds to the contribution of all materials crossed by the injected current for a given electrode geometry. It represents the resistivity of a homogeneous block that would generate a response equal to that measured. This is an excellent way of normalizing measurements according to the geometry of the measuring system. The apparent resistivity measured in the field is represented as $\boldsymbol{\rho_a}$. In the case of a measuring device with two injection electrodes (A and B) and two receiving electrodes (M and N), the apparent resistivity is a function of the potential difference measured between the two measurement electrodes M and N, and a geometric factor, denoted k, which depends on the relative position of the four electrodes A, B, M and N, [13]. In the case where the electrodes are placed on the surface of the ground, this geometric factor is defined by equation (1)

$$k = \frac{2\pi}{\left(\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}\right)} \tag{1}$$

Thus, the apparent resistivity is defined by the equation(2):

$$\boldsymbol{\rho_a = k\frac{V_{MN}}{I}} \tag{2}$$

Where: $\rho_a =$ Apparent resistivity (Ω.m)

$k =$ Geometric Factor (m)

$V_{MN} =$ Potential difference measured between M and N electrodes (V)

In the present study, we have: 4 <AB / MN <20; the length of the line MN is changed when the measurement of the potential difference ΔV, which is proportional to MN, becomes too small. The value ΔV gives the apparent resistivity $\boldsymbol{\rho_a}$ as equation (3):

$$\boldsymbol{\rho_a = \pi\left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}\right]\frac{\Delta V}{I}} \tag{3}$$

Where: AB = spacing between current electrodes in meter,

ΔV = potential difference in meter,

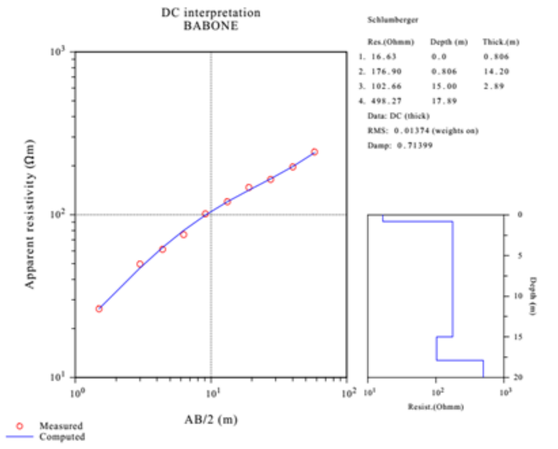
MN = spacing between potential electrodes in meter and

I = electric current in ampere.

IV. RESULTS AND DISCUSSION

A. Sounding curves

Twenty-two electrical sounding curves were plotted using Jointem Software and interpreted quantitatively. This interpretation is intended primarily to provide the geo-electrical parameters and geo-electrical sections of the study area. The geo-electrical parameters are the true resistivities and the thicknesses of the underground layers. The determination of the geo-electrical parameters was made in correlation with the geological sections obtained by the drilling carried out at the right of each polling station.



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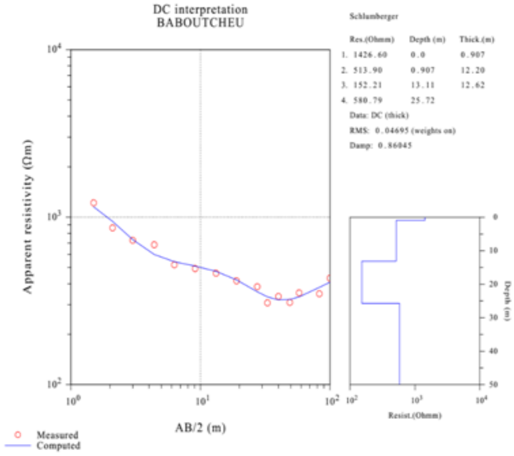

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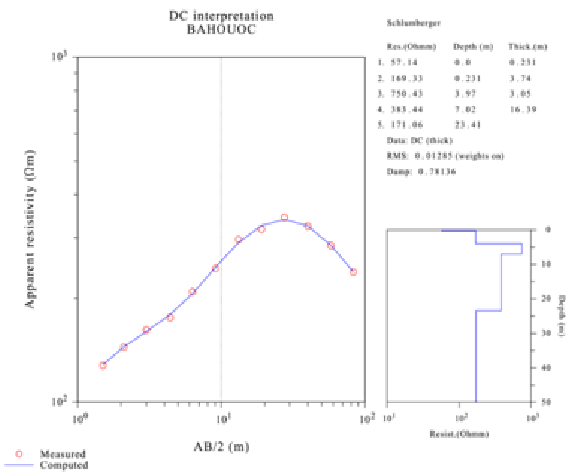

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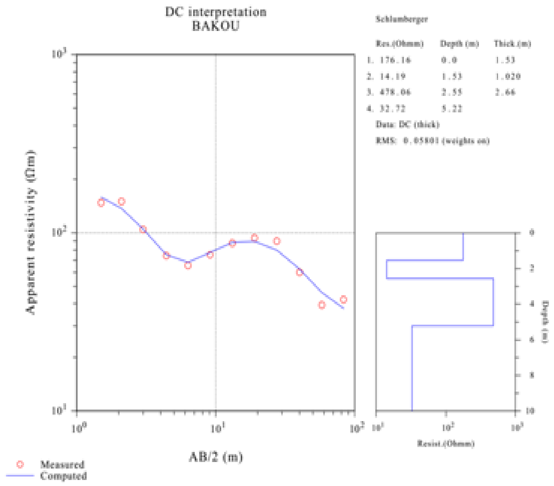

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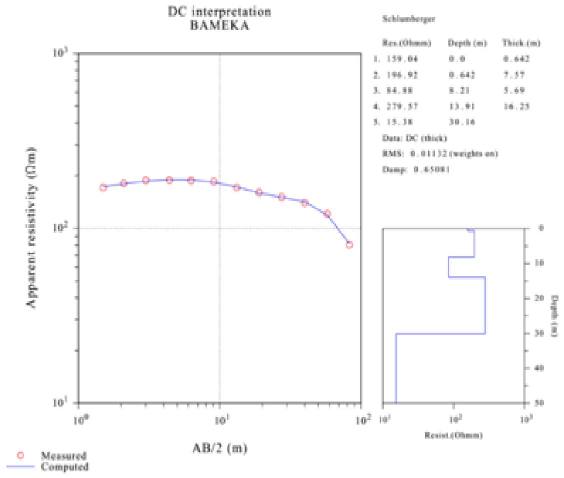

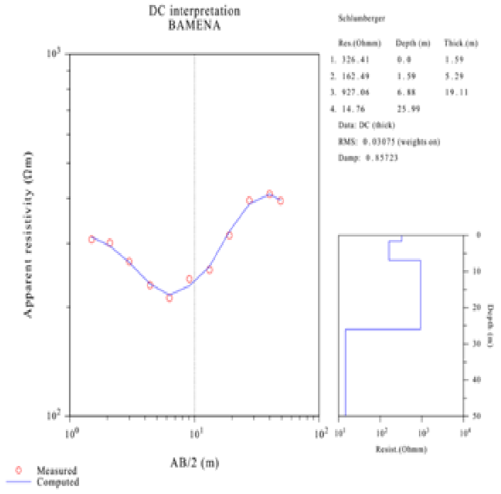

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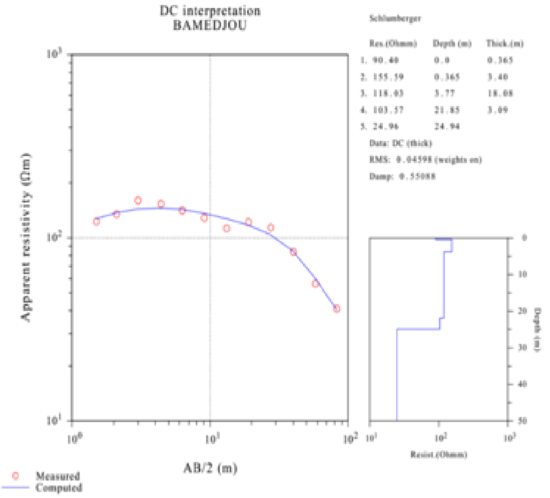

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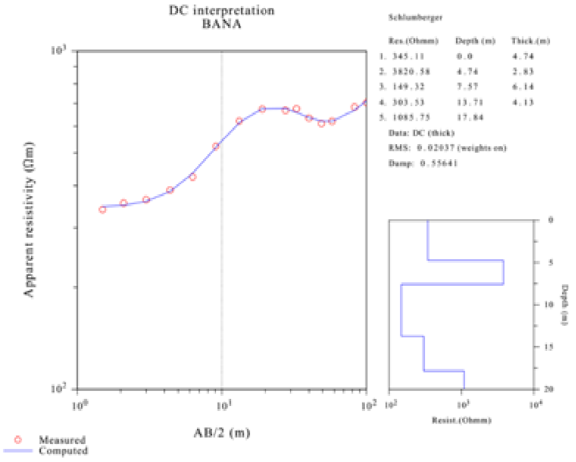

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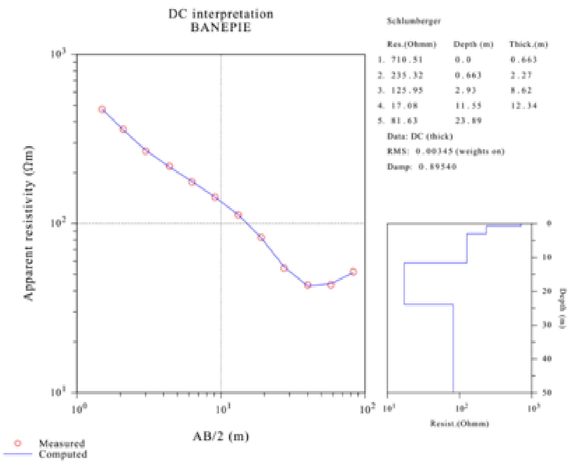

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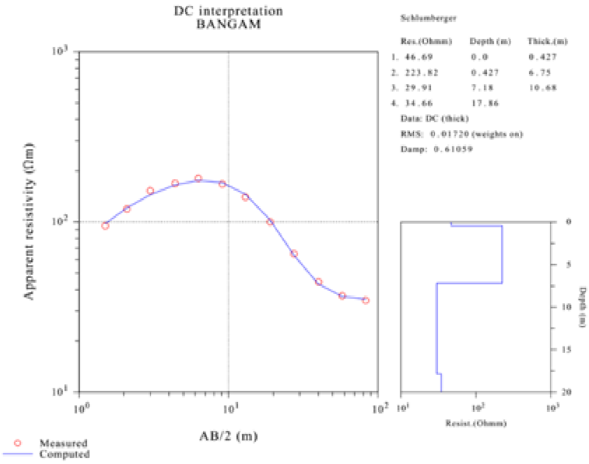

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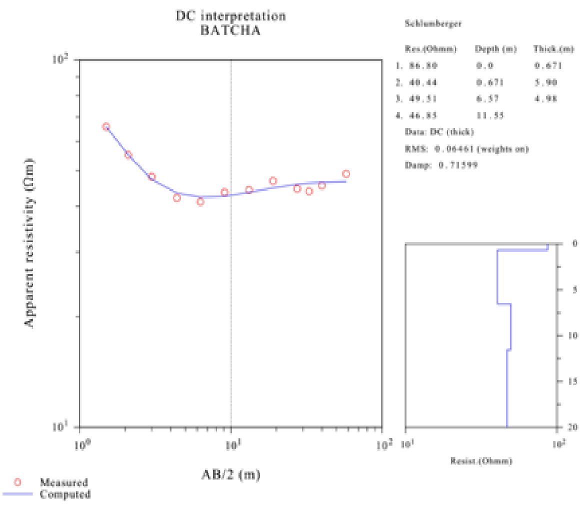

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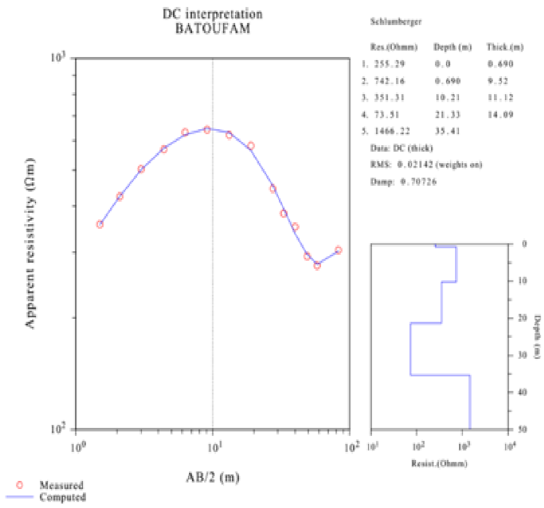

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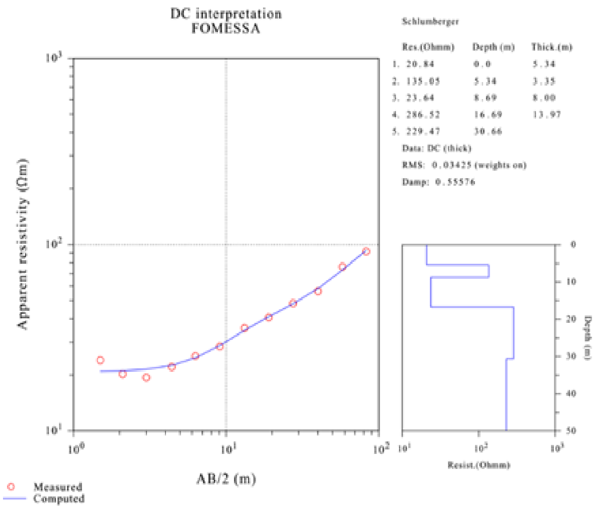

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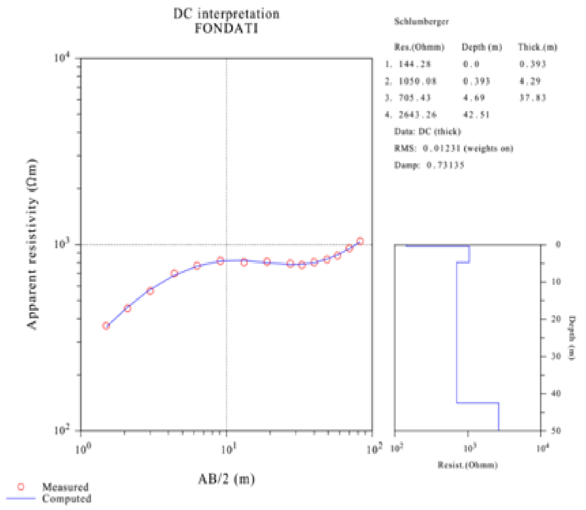

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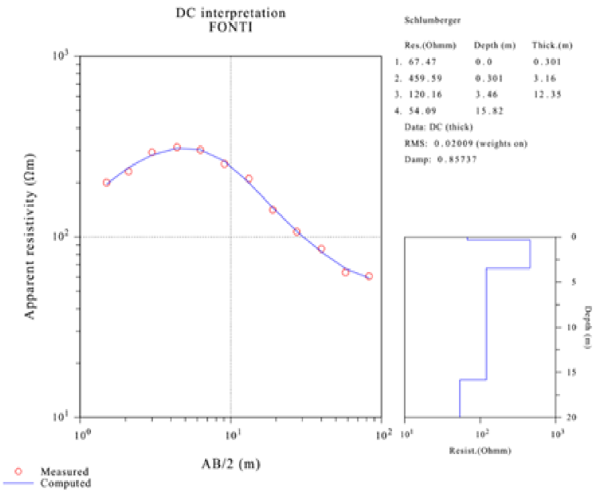

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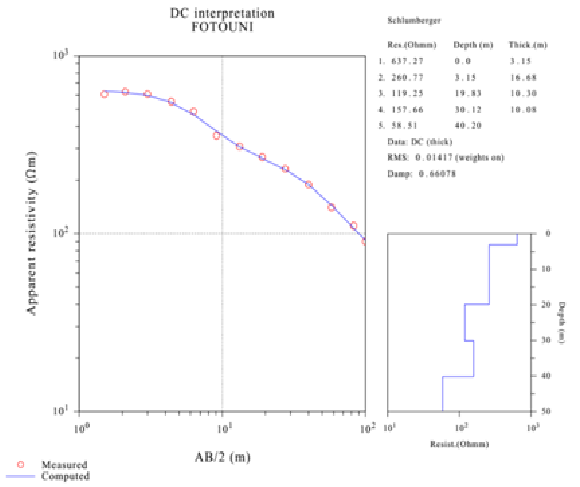

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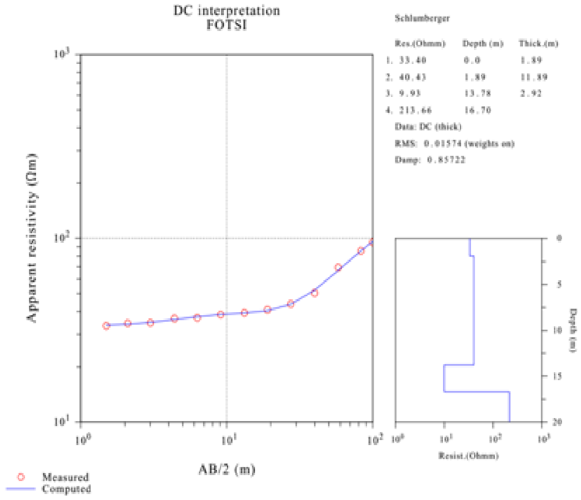

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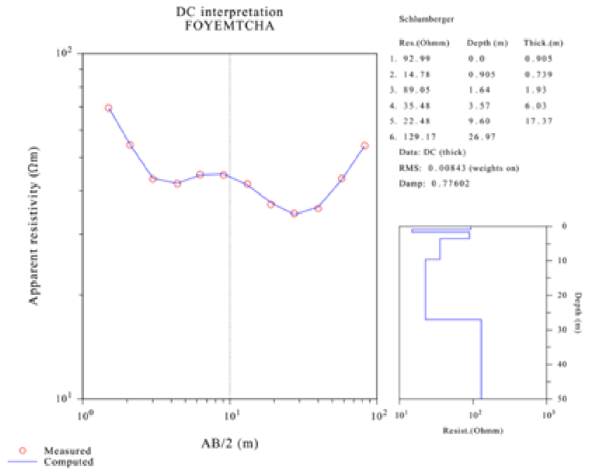

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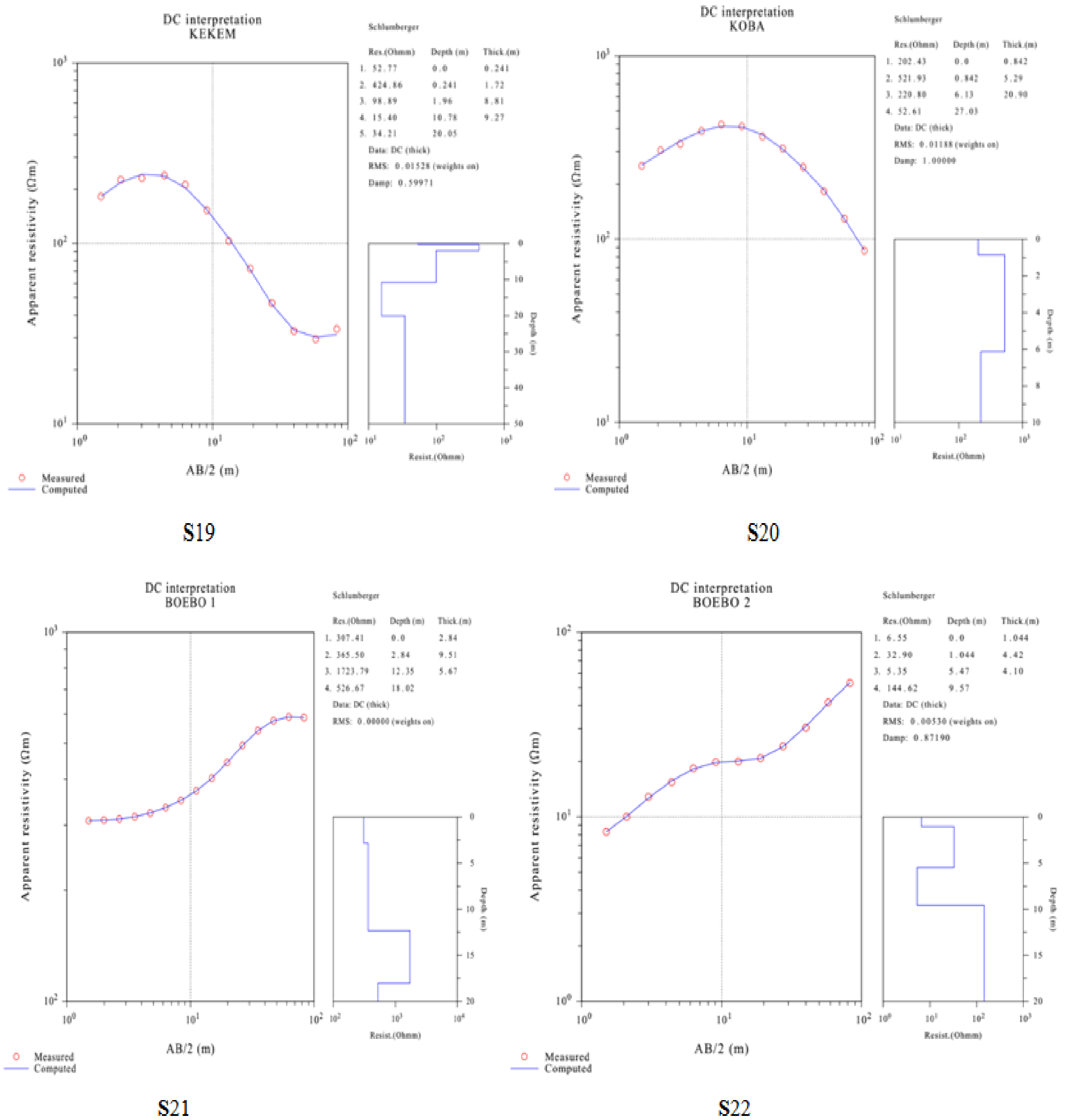

Fig. 3: Vertical Electrical Curves of the Study Area, Si are stations.

The VES curves (Fig. 3) show the vertical evolution of the resistivity of the different layers as a function of depth. They also give an estimation of the number of layers beneath the investigated zone. It could come out from these representation that the top bedrock is on average found from the third layer. For civil engineering work, preliminary studies will be done based on the characteristics of these superficial layers. The main features are the thickness and resistivity of the layer. The contribution of the bedrock must also be taken into consideration because it is the base of any foundation. Thus, if one refers to the locality of Bana, (S8), it could be noticed that superficial layers have relatively high resistivity with considerable thicknesses; the values decrease with depth. This could be due to the fact that the region has not been affected by the previous tectonic activity. This zone could therefore be advisable for large-scale building constructions. On the contrary, the locality of Bamendjou presents superficial layers with weak thicknesses at depth, this could be explained by a fracture due to the previous tectonic effects. This category is probably a geotechnical risk zone. A close look to all the stations could help to advise the government which zone is more amenable for the construction of the big infrastructures which is on line as project. **Table 1** is a summary of the VES results obtained from the twenty two investigated stations. It gives overall information on the true resistivity, the thickness, and the lithology of the different geological features at each measuring station.

Table 1: Results of vertical electrical soundings

VES Station	Resistivities $(\rho_1/\rho_2 \ldots/\rho_n)\ \Omega.m$	Thickness $(h_1/h_2 \ldots/h_n)\ m$	Lithology	Types of curves
1	17/176/103/498	0,8/14,2/2,9	TS/sandy clay/basalt*/basalt	AH
2	1426/514/152/26	0,9/12,2/12,6	TS/clay/basalt*/basalt	QH
3	54/169/750/383/171	0,23/3,74/3,05/16,4	TS/clay/clay/alterite/basalt*	AKQ
4	176/14/478/32	1,53/1/2,66	TS/alterite/clay/granite*	HK
5	159/197/85/280/15	0,64/7,57/6,69/16,3	TS/clay/clay/clay/basalt*	KHK
6	226/163/927/15	1,29/5,29/19,11	TS/clay/alterite/granite*	HK
7	91/156/118/103/25	0,3/3,4/18/3	TS/clay/clay/alterite/basalt*	KQQ
8	345/3820/150/304/1086	4,7/2,83/6,14/4,13	TS/clay/alterite/basalt*/basalt	KHA
9	711/235/126/18/82	0,6/2,27/8,62/12,34	TS/clay/clay/alterite/basalte*	QQH
10	47/224/30/35	0,427/6,75/10,68	TS/clay/aletrite/alterite	KH
11	87/40/50/47	0,671/5,9/4,98	TS/clay/clay/granite*	HK
12	255/742/358/74/1466	0,69/9,52/11,12/14	TS/clay/clay/basalt*/basalt	KQ
13	21/135/23/287/229	5,34/3,35/8/13,97	TS/clay/alterite/basalt/granite	KHK
14	144/1050/705/2643	0,39/4,29/37,83	TS/clay/granite/granite	KH
15	68/460/120/54	0,3/3,16/12,35	TS/clay/basalt*/granite*	KQ
16	637/261/119/158/59	3,15/16,69/10,3/10	TS/clay/alterite/alterite/granite*	QHK
17	33/40/10/214	1,89/11,89/2,92	TS/clay/granite*/granite	KH
18	93/15/89/22/129	0,9/0,74/2/23,37	TS/clay/alterite/alterite/granite*	HKH
19	53/425/99/15/34	0,24/1,7/8,8/9,27	TS/clay/clay/basalt*/basalt*	KAH
20	203/525/221/53	0,8/5,29/20,9	TS/clay/alterite/granite*	KQ
21	307/365/1724/527	2,84/9,51/5,67	TS/alterite/alterite/granite	AK
22	7/33/5/145	1/4,42/4,1	TS/clay/alterite/cracked granite	KH

TS = Top Soil
Basalt* = Fractured basalt
Granite* = Fractured granite
Alterite = laterite, sandy clay, sandstone clay, altered basalt or altered granite

The geoelectric sections of the study area (Fig. 4) give clear view of the five different layers. Together with previous geological findings and the knowledge from the abacus, the fifth level has been identified to topsoil, clay, alterite, basalt and granite.

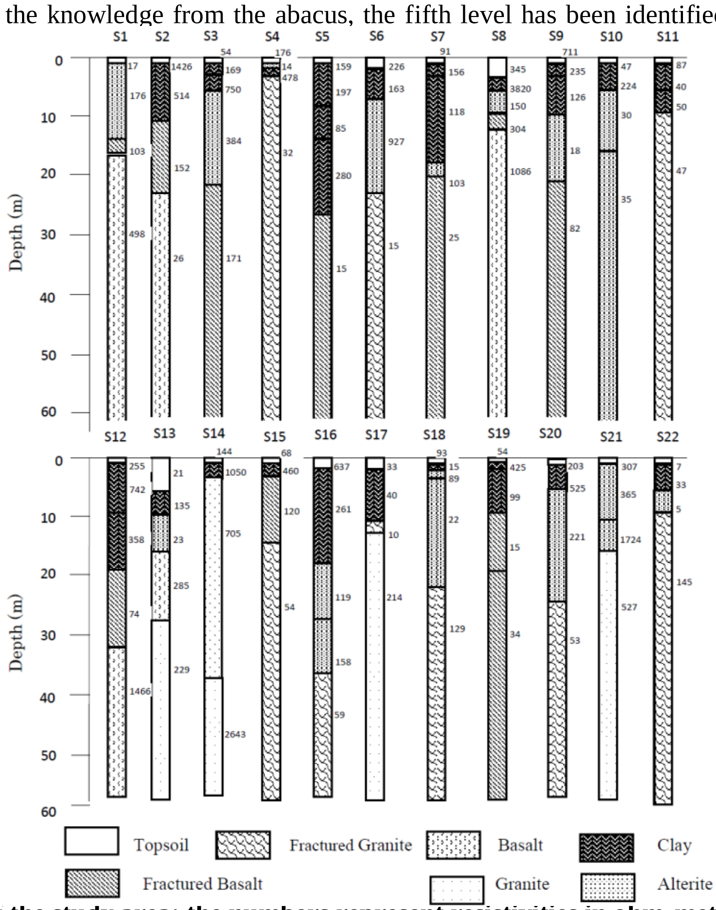

Fig. 4: Geoelectric sections of the study area; the numbers represent resistivities in ohm-meter; The Si represent the different stations of the study area (i ranging from 1 to 22)

B. Iso-resistivity map of the study area

Fig. 5 illustrates the lateral variation of the apparent resistivity on a horizontal plane at a given depth. Based on the penetration depth of the current, the apparent iso-resistivity map for AB/2 = 83 m corresponds to a depth of about 32 m. At this depth the subsurface is composed essentially by basement rocks that are sometime fractured. The map shows relatively low resistivities around the central domain due to the presence of saturation zones. These areas of low resistivity reflect the presence of aquifers and can indicate the flow direction of groundwater.

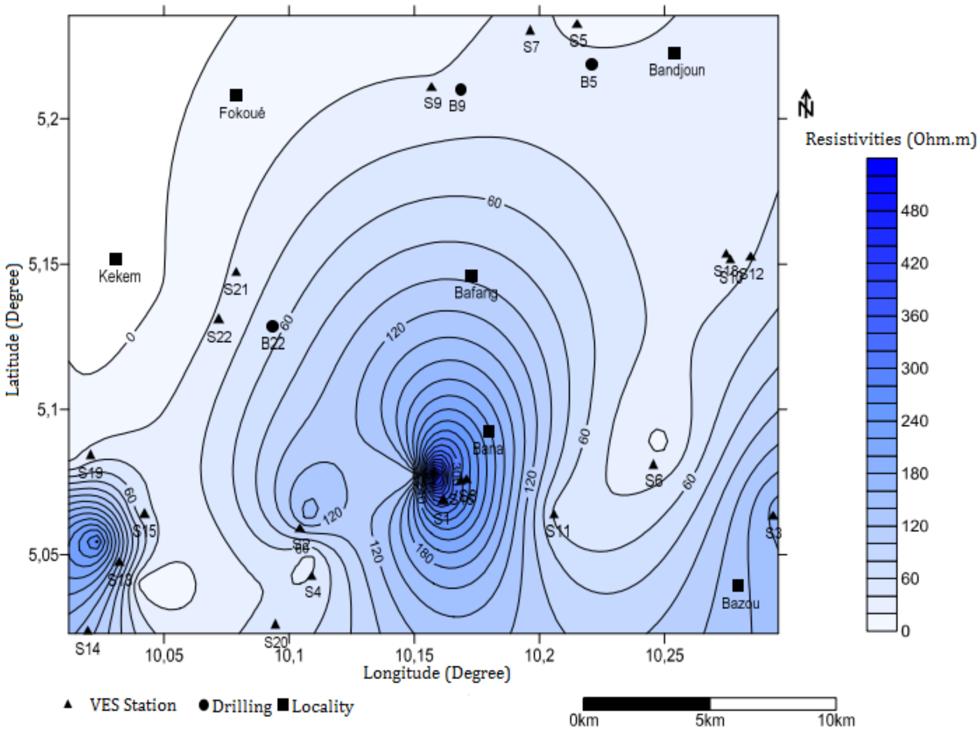

Fig. 5: Iso-resistivity map for the study area for AB/2 = 83 m

C. Discussion

This work is a general study of geoelectricity applied to civil engineering. The main results obtained provide elements to characterize the basement of the study area (West Cameroon). The analysis and interpretation of the various results made it possible to map an important and reliable geotechnical baseline. The quantitative interpretation of the sounding curves obtained (Fig. 3) reveals a dominance of the KH curves over the entire study area. The dominance of this type of curve shows a succession of almost homogeneous underground layers including topsoil, clay layers, alterite, basalt and granite. The results above confirm the geological work carried out by [14] on the influence of the lithological nature and geological structures on the quality and dynamics of groundwater in the western Cameroon highlands

For all the curves, the first layer corresponds to the topsoil whose resistivity varies from 7 to 1426 Ωm with the thickness extending from 0.23 to 5.34 m. The second layer which is made of clay and alterite has resistivity values ranging from 14 to 3820 Ωm and a thickness that ranges from 1 to 16.4 m. The third and fourth geoelectric layers are made of clay and granite / basalt with thickness ranging from 2.92 to 37.83 m. The resistivity values of the aquifer layers is ranging from 5 to 2643 Ωm.

The iso-resistivity map reflects the lateral distribution of the materials in depth and thus provides reliable information on the study areas for the location and the layout of the structure to be built, information on how to design its foundations and to make decisions based on aquifer construction processes. From these analyses, stations S4, S5, S7, S9, S10, S12, S13, S16, S19 and S20 are areas of risk for large-scale civil works because they contain altered and fairly fractured formations. On the other hand, the stations S2, S3, S8, S15, S21 and S22 show good or slightly fractured basement formations. These findings can therefore bring idea that are of great importance for major drilling projects or supplying local communities with drinking water; the interpretation of the sounding curves correlates with the lithology of the drillings already present in the localities.

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V. CONCLUSION

Using the geoelectrical method, we have been able to characterize the subsurface of many localities in the region of West Cameroon in order to propose practical solutions and areas amenable for the realization works. The aim is to provide various stakeholders of a project such as engineers, architects, and contractors, etc., with information on the nature and the physical properties of soils. This work gives reliable information regarding the depth and resistivity of the underground layers and thus provides vital information for preliminary geotechnical works, moreover, it provides geotechnical recommendations that enable authorities to conceive and to realize the projected work. The iso-resistivity map shows the presence of a low resistivity which indicates the circulation of an underground water from the North-East to the South-West and thus constitutes a zone of risk for large-scale civil engineering construction. This includes the localities of Baku, Bameka, Bamendjou, Banepie, Bangam, Batufam, Fonti, Fotouni, Kekem and Koba.

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