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Geoelectrical Inversion Study of Limestone Attributes at Mayo Boki Area (Northern Cameroon)

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Abstract

A geoelectrical survey using the electrical resistivity method was carried out in the Mayo Boki (Northern Cameroon), to investigate the subsurface layering and evaluation of the limestone characteristics. In addition to geological data collection, three vertical electrical soundings and one electrical resistivity profile were measured. Joint interpretation of the DC data allows us to obtain reliable 1D models of the resistivity distribution. The interpretation of the field data was carried out using the RES2DINV software, which converts the apparent resistivity as a function of electrode spacing to the true resistivity as a function of depth in two dimensions. The results obtained from the electrical resistivity survey showed that: 1) A limestone layer was put in evidence at a depth of 4 m and the thickness varies from 13 m to 44 m; 2) The limestone layer resistivity is ranged from 125 to 2410 ohm.m; 3) An area of probable limestone deposit with interesting thicknesses have been identified. These facts are useful for future mining exploration as drilling map definition and operations. The geologic section of a nearby location termed resistivity profile was delineated and its total depth was found to be 57 m, which corroborates the lithologs of the boreholes from the area. The correlation of geological data and the geoelectric section has led to envisage pursuing exploration activities. Based on the limestone layer characteristics extracted from this DC investigation, the exploration drilling operations have to be initiated in order to define the limestone resource over the area of study, which will certainly enables to built the exploitation project prefeasibility document.

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Keywords

Geoelectrical Method, 1D Model, Resistivity, Limestone, Mayo Boki, Cameroon

1. Introduction

Mine sector is an essential part of the economy and has significant role in supplying materials for industries [1]. The progress of any society would be at stake with lack of access to mineral resources. Geophysical exploration is usually conducted to locate significant accumulations of limestone deposits, gold deposits, oil, natural gas and other minerals, including ground water, which are of economic importance to Cameroon.

What makes the value of a geological deposit be the amount of useful fraction which can be recovered; whatever it is an ore mineral or earth building material, accessibility to valuable resources is often hindered. The geological study suggested a tectonic and stratigraphic evolution of the area while geoelectrical soundings using the Schlumberger method was focused on the superficial (soil) structures. The electrical resistivity method involving vertical electrical sounding (VES) technique was adopted for this survey. It involves the measurement of apparent resistivity of subsurface as a function of depth or position by changing the electrode spacing interval [2]. It also involves the detection of induced effect when a continuous electric current crosses the ground. This technique was used in the present investigation. The target area, Mayo Boki, is located between latitudes 8˚30'N and 8˚44'N, and longitudes 13˚1'E and 13˚45'E. The aim of this study is delineating the geophysical/geologic features such as limestone thickness, concealed basement morphology, fractures (where they exist) in the subsurface thus, enabling the evaluation of the feasibility of the area for future exploitation.

2. Geography and Geological Setting

The studied region is located between latitudes 8˚30'N and 8˚44'N, and longitudes 13˚1'E and 13˚45'E; is surrounded South by the Adamoua plateau, the Cretaceous trough of Garoua in the North, and the Mayos (river) Faro and Benoué on the West and the East, respectively.

The study area is located in the Poli Group (**Figure 1**) dominated by metavolcanic and metasedimentary rocks [3] [4]. The lithostratigraphy is poorly defined because these rocks are interleaved and have been strongly deformed [4] [5] although the metavolcanic unit is widely believed to alternate with metasedimentary units. The lower metasedimentary unit (Sakje unit) has been affected by medium- to high-grade metamorphism [5], while the upper unit underwent low grade metamorphism. However in some localities, transition from the low grade upper sedimentary unit to the Sakjé unit is gradational as at "Buffle Noir" and in western Poli (**Figure 1**) [6]. In both regions, the upper and lower metasediments show comparable greywacke composition [3]. The metasedimentary unit on a wider scale is composed of either purely volcanogenic clastic rocks (mainly tuffs) or variably reworked clastic rocks (metagreywackes). Conglomerate layers are frequently observed in most of the sedimentary sequences. The metavolcanic unit includes rhyolite and tholeiitic basalts.

The limestone of the area which is mainly represented by volcanites and volcanic sediments crosscut by many generations' plutonic acid and basic rock. These 830 - 650 Ma old units have been deformed by the panafrican orogeny (570 - 650 Ma) and discordantly overhanged by the Balché-Wami group. Granitic orthogneisses, limestones and metabasites are the three petrographic types in the area. Metabasites (essentially amphibolites) are fine, middle size or coarse grained and localy tend to brecciated facies; limestone's crop out in part as recurrent bands or 0, 5 to 200 m length lenses networks deeply associated to metabasites; limestones lenses are localy observed into granitic orthogneisses. Impurities present themselves as ultrabsic and basic cochades or folded bands. These metabasite features correspond to old subaquatic basalte flows interbedded by marbles. Granitic orthogneisses outcrop by bands (1 - 200 m) parallel to the regional foliation; they present pre to syntectonic characteristics of granite intrusions in metabasites.

Structurally, the Mayo Boki area is characterized by a regional foliation with a variable trend, and south low dip (0˚ - 5˚). However, strong dips (70˚) are locally observed in granitic orthogneisses and limestones; some low north-dipping features are observed in the western part of the study area in amphibolites. In addition, the area is characterized by N-S to N25˚E trend folds lowly diping to the South and N30˚E senestrial transverse faults. Millimetric cracks (not greater than 2 m) crosscut limestones. Some cracks are dry while others are clog up by calcites.

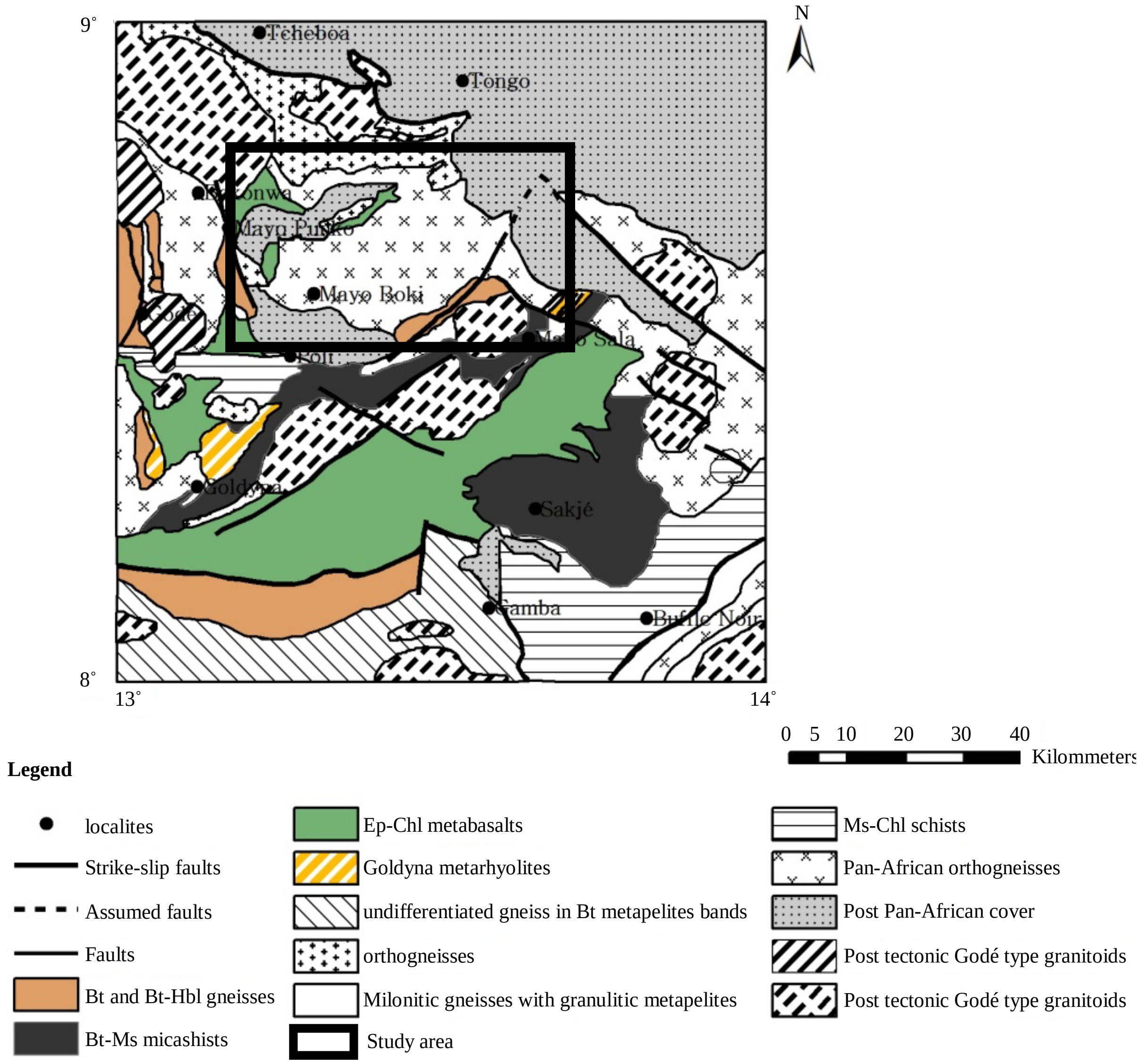


Figure 1. Geological map of the study area modified [6].

They form two main families; the first is subparallel to the foliation (N115˚E to N130˚E); the second, N30˚E to N60˚E oriented is secant to the foliation trend.

3. Methods

The electrical resistivity method is most used in engineering geology. It identified and locates, from the earth surface, the structures which have resistivity contrasts [7] (Telford *et al.*, 1990). There are different types of electrical resistivity theoretical approach based on electrodes array for interpreting resistivity data. The techniques of data interpretation used involved seeking a solution to the inverse problem namely the determination of subsurface apparent resistivity distribution from surface measurement [8]. There is a function called Kernel function which represents a very good solution to the inverse problem. It describes the apparent resistivity measurements in terms of subsurface lithological variation with depths. The function assumes the earth to be locally horizontally stratified, inhomogeneous and isotropic layers, and unlike apparent resistivity function, it does not depend on electrode configuration. It cannot be measured in the field but has to be obtained from the transformation of measured apparent resistivities. The kernel function utilized in this work is derived after [8], if the observed apparent resistivity is such that:

$$\rho_a(\lambda) = r^2 \int T(\lambda) J_1(\lambda r) \lambda \mathrm{d}\lambda \quad 0 \le \lambda \le \infty \tag{1}$$

where r is half current electrode separation, J_1 is the first order Bessel function and $T(\lambda)$ is the resistivity transform given by the Pekeris recurrence relationship [9].

$$T(\lambda) = r^{-1} \int \rho_a(\lambda) J_1(\lambda r) \lambda \mathrm{d}\lambda \quad 0 \le \lambda \le +\infty \tag{2}$$

with the following changes of variable, $x = \ln r$ and $y = \ln(1/\lambda)$, Equation (1) becomes

$$\rho_a(x) = \int T(y) \left[e^{2(x-y)} J_1 e^{(x-y)} \right] \mathrm{d}y \quad -\infty \le y \le +\infty \tag{3}$$

The resistivity transform is the input of the filter and the second term in (3) is the filter function. The forward resistivity problem uses the linear-filter method [10]. Mathematically, the linear-filter operation is defined as [11]:

$$\rho_a(x_0) = \sum_j f_j T(y_0 - j\Delta y) \tag{4}$$

where x_0 is the abscissa of the point of the output function (apparent resistivity), y_0 is the abscissa of the first point of the input function (resistivity transform), Δy is the sampling interval and f_i are the filter coefficients by which the sample values of the resistivity transform are multiplied to obtain the apparent resistivity.

However, when the earth is approximately composed of horizontally stratified isotropic and homogenous media such that the change of resistivity is a function of depth, the Schlumberger configuration is the most widely used array and may provide useful information in solving subsurface geophysical problems.

In electrical resistivity sounding, four electrodes are earthed along a straight line in the other AMNB. The calculated apparent resistivity ρ_a according to Schlumberger array condition of AB ≥ 5 MN is

$$\rho_a = K \Delta V / I \,(\text{ohm.m}) \tag{5}$$

ΔV is the potential difference, I is the electrical current are measured for electrode spacing and K is the geometrical factor that depends on the electrode arrangement. For the schlumberger array given by:

$$\mathrm{K} = \pi \left[(\mathrm{AB}/2)^2 - (\mathrm{MN}/2)^2 \right] / \mathrm{MN} \tag{6}$$

A total of three VES station and one electrical resistivity profile were established across the study area. The data were collected using a terrameter SAS 300B resistivity instrument. The locations of the VES sites were considered restricted by logistical difficulties. The presence of topography prevented a wider coverage. The maximum AB/2 spacing of the schlumberger array ranged is 150 m. The separation of the current electrodes was 10, 14, 20, 30, 40, 60, 80, 100, 150, 200 and 300. The potential electrode separation was 2, 6 and 20. The increasing of the potential electrode separation MN allowed that readings from the same current electrode spread AB with the previous and expanded MN were taken.

4. Results

The results of the geoelectrical investigation are presented as 2-D inversion section of the resistivity profile and 1-D inversion of the sounding curves. The electrical resistivity profile was interpreted qualitatively while the sounding curves and geoelectric section were interpreted quantitative. The inversion of data from electrical resistivity profile was made with the RES2DINV software [12]. The 2-D resistivity model is determined for the subsurface using data obtained from electrical imaging surveys. A forward modeling subroutine is used to calculate the apparent resistivity values, and a non-linear least-squares optimization technique is used for the inversion routine. The robust model constrain inversion method was used on the model resistivity values in this study to obtain electrical resistivity profile. This constrain tends to produce models with sharp interfaces between different regions with different resistivity values and it is apparently more suitable for basement complex terrain where a fresh basement interface geological situation exists. The method of quantitative interpretation involved curve matching where the data were plotted on double logarithmic diagrams and matched against 2 layer master curves.

The use of auxiliary point diagrams, pointed out the interpretation of sequences of several layers. **Figure 2** shows the results of the inversion. We notice at first sight that the image of the resistivity according to the depth does not show the cut outlines contours; indeed, the process of inversion privileges the weak gradients and the interpolator creates, around a body of much contrasted resistivity with its environment, a kind of intermediate halo of resistivity. The electrical resistivity profile which put to evidence a strong contrast of resistivity shows the succession of four layers. The limestone and marble formations present a range resistivity of 50 and 10^7 Ω·m, and of 100 and 2.5×10^8 Ω·m respectively. However, geological studies highlight some shallow limestone and marble structures. It permits us to suggest that the second layer is made up of limestone formations covered by marble structures. Generally, one finds a superficial thin and conductive part with 180 Ω·m of resistivity, which nearly spreads out in all the electrical resistivity profile and that may correspond to marble; then comes a mean conductive material with resistivity 620 Ω·m which correspond to schist within which a very resistive material (resistivity 1680 Ω·m), assumed to be limestone, is booby-trapped. At the distance x = 480 m, this resistant material is very close to the surface. The presence of a basin, Eastward from pseudo section, very convenient to the groundwater accumulation for a resistivity of 14 Ω·m, is put in evidence by presence of two weak intrusive bodies at distances x = 200 m and x = 380 m in a environment which correspond to fractures.

To verify the thickness of the resistivity anomaly, three VES were implemented at positions x = 120, x = 260 m and x = 480 m of the electrical resistivity profile where we find a high contrast of resistivity anomaly. One-dimensional inversion of the VES data was carried out using an interactive inversion code Jointem for quantitative analysis. The use of Jointem program [13] provides the opportunity to choose a set of equivalent solution and among that have chosen the one best fitting the geophysical model with least fitting error between the observed and inverted data. Sounding curves of **Figure 3** shows the interpretation results which are summarized in **Table 1**.

We observe for the VES 1:

- A conductive superficial thin layer with 11 Ω·m resistivity, and 4 m thick;
- A second resistive layer of 2410 Ω·m resistivity has also been identified and seems to correspond to an exploitable limestone with a thickness of 25 m;
- A third conductive layer presenting a mean resistivity of 15 Ω·m and a mean thickness of 28 m;
- Finally, a high resistive layer (5567 Ω·m resistivity), identified as the substratum of the study area.

The sounding curve VES 2 enables us to propose a four layered model:

- A first mean conductive layer (132 Ω·m of resistivity) with a thickness of 13 m which seems to correspond to the limestone;
- The second layer, with a mean resistivity of 987 Ω·m and thickness of 15 m could be identified as some marble which corresponds to the top of a slightly altered third conductive layer;
- The third conductive layer with 9 m thickness and 56 Ω·m resistivity is associated to a more altered fringe of the underlying basement;
- Finally, the fresh basement of 852 Ω·m resistivity has been localized at more than 38 m depth.

The sounding curve VES 3 to shows four layers:

A first and second layers comprising of lateritic having resistivity values ranging from 12 - 185 Ω·m and the thickness of 1.5 - 2.6 m;

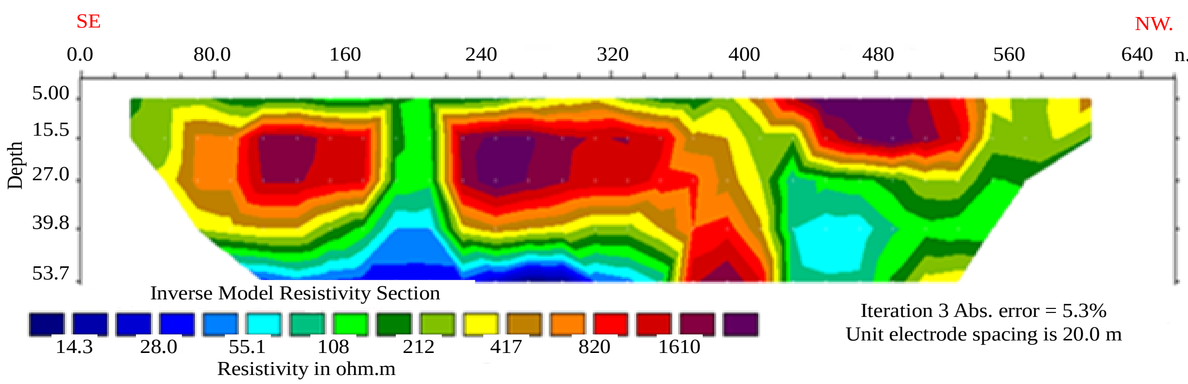
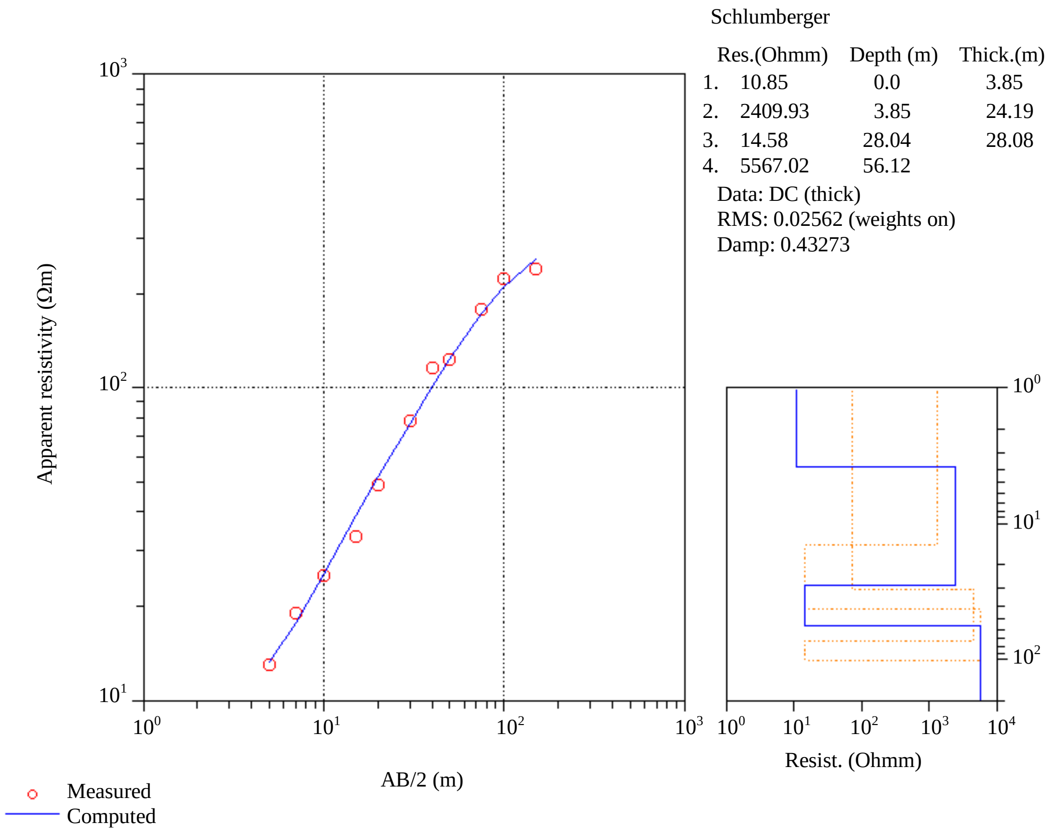
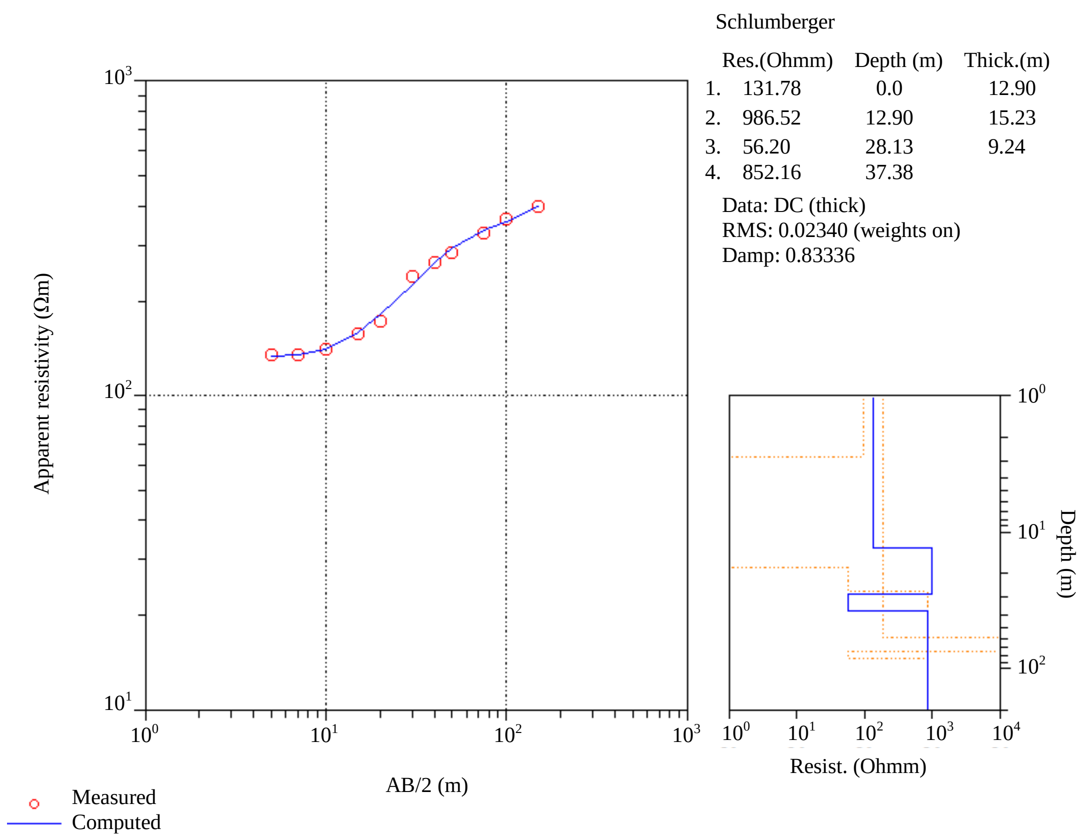


Figure 2. Electrical resistivity profile of Mayo Boki.


Schlumberger
Res.(Ohmm) Depth (m) Thick.(m)
1. 10.85 0.0 3.85
2. 2409.93 3.85 24.19
3. 14.58 28.04 28.08
4. 5567.02 56.12
Data: DC (thick)
RMS: 0.02562 (weights on)
Damp: 0.43273
Apparent resistivity (Ωm)
AB/2 (m)
Depth (m)
Resist. (Ohmm)
Measured
Computed


Schlumberger
Res.(Ohmm) Depth (m) Thick.(m)
1. 131.78 0.0 12.90
2. 986.52 12.90 15.23
3. 56.20 28.13 9.24
4. 852.16 37.38
Data: DC (thick)
RMS: 0.02340 (weights on)
Damp: 0.83336
Apparent resistivity (Ωm)
AB/2 (m)
Depth (m)
Resist. (Ohmm)
Measured
Computed

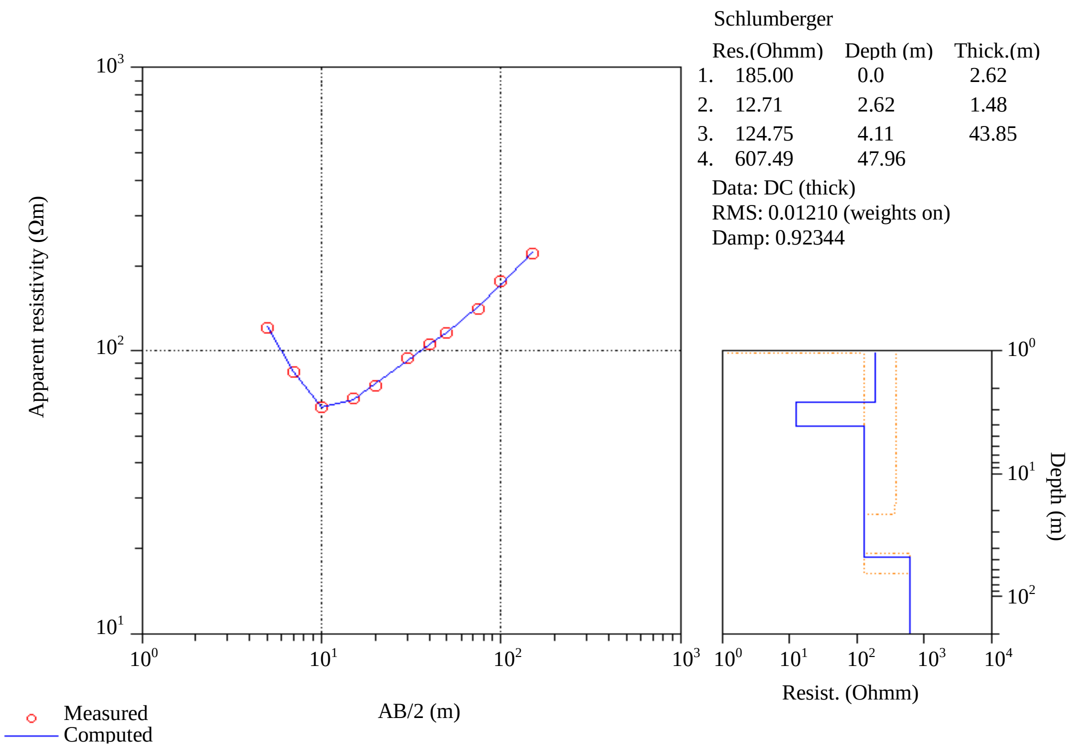


Figure 3. Resistivity curves sounding of Mayo Boki.

Table 1. Interpreted results of VES data.

VES	Layers	Resistivity (Ω.m)	Thickness (m)	Depth (m)	Lithology
1	1	10.85	3.85	0	Laterite
	2	2409.93	24.19	3.85	Limestone
	3	14.58	28.08	28.04	Schist
	4	5567.02	Infinity	56.12	Gneiss
2	1	131.78	12.90	0	Limestone
	2	986.52	15.23	12.90	Schist
	3	56.20	9.24	28.13	marble
	4	852.16	Infinity	37.38	Gneiss
3	1	185	2.62	0	Laterite
	2	12.71	1.48	2.62	Laterite
	3	124.75	43.85	4.11	Limestone
	4	607.49	infinity	47.96	Gneiss

- Limestone was intercepted at the third layers while the resistivity and thickness ranging between 125 Ω.m and 44 m respectively;
- Finally, the fresh basement of 607 Ω·m resistivity has been localized at 44 m.

5. Discussion

According to our observations, we can say that, globally, the resistive material of the study zone can be identified as limestone. The observed conductive anomalies are associated with the fine materials which have a strong water retention capacity. Results accurately show that electrical resistivity profile is very reliable in the detection on the one hand, of zones having strong resistivity. These zones correspond in our case study to limestone important for civil engineering. In the other hand, the results permitted us to identify broken zones along the fresh basement which generally contain aquifers which can help to alleviate the lack of drinking water in this region.

The further electric soundings, have served to check for the distribution of resistivity values and to estimate the thickness of the limestone which can be exploitable. The observed layer distribution seems to be in accordance with the geological evidence from the lithology described by many authors [3] [5].

In summary, the obtained results show sharply that the electrical resistivity profile is very interesting in the detection and the characterization of mining resources associated to civil engineering in the region. The results of analysis of sounding curves (**Figure 3**) reveal that the structure of our study area is of a four layered model. However, evaluation of sounding curves errors shows that the RMS error is below 3%. This vertical electrical soundings has served to control the distribution of resistivity and to improve the results of the electrical resistivity profile and the geological interpretation which ensued there. The RMS error that have been got in the modeling of the sounding curves is equal to the one observed in many similar studies [8]-[10] [12].

Close examination of all the VES stations lithologies revealed that limestone occurred in all the stations of the study area. The thickness limestone formation was observed in VES station one (1) with a thickness of about 24 m intercepted at a depth of about 3.85 m below sea level while the thickness limestone formation was seen in VES station two (2) with a thickness of about 13 m, intercepted of the surface. In VES three (3) the thickness of about 44 m intercepted at a depth of about 4 m below sea level.

However the studies based on the electric properties of limestone and marble revealed that, the limestone structures are more resistant than the marble. For some regions, the limestone structures are covered with schist and are directly in contact with the basement. For others, the limestone is in contact with the basement through schist due to the tectonic movement of Mayo Boki. The geoelectric section is presented in **Figure 4**. These results correlate with the geological studies of the region which show that for some areas on the northern border of the study area, one finds the four types of land: limestone, marble, schist and fresh basement (gneiss) [14]. At Mayo Boki, the total depth obtained is 56 m. There is a high correlation with the borehole section at Mayo Boki. Gathering all these remarks we can propose a geologic model of the zone under study (**Figure 5**) which shows the on-surface marble, the limestone inserted into the schist and the in-depth gneisses (aquifer layer) which can be exploited as well within the framework of a water supply.

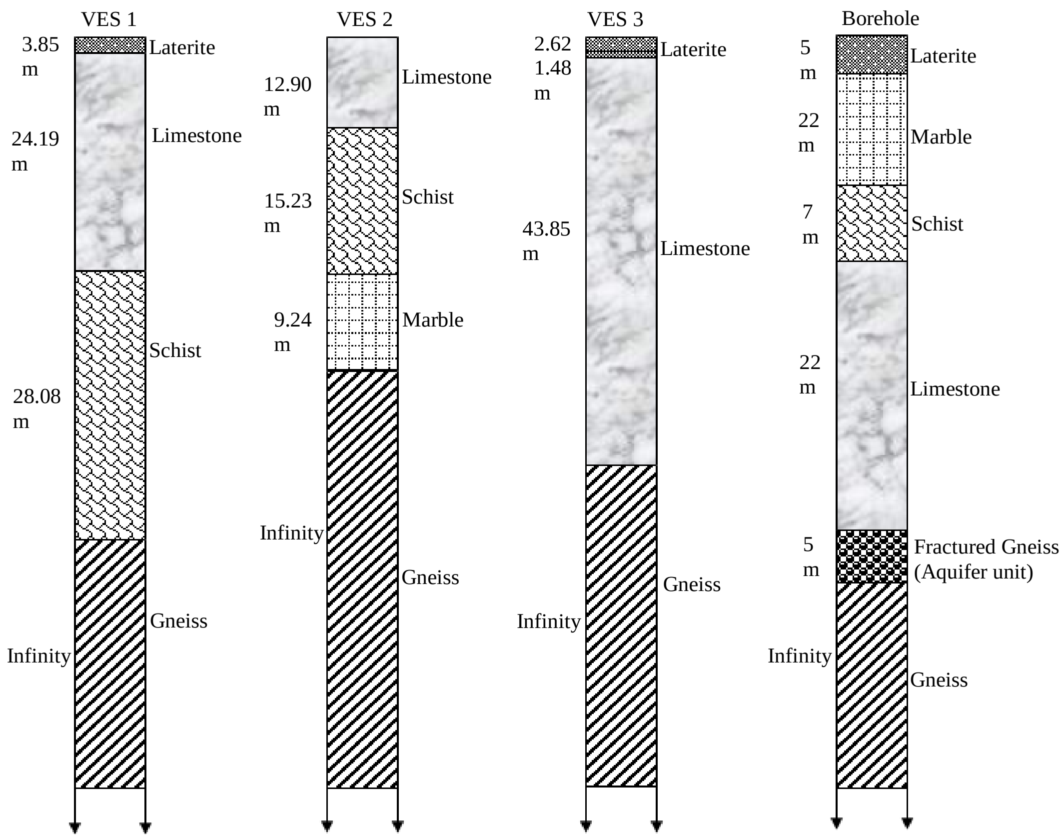


Figure 4. Geoelectric section of Mayo Boki.

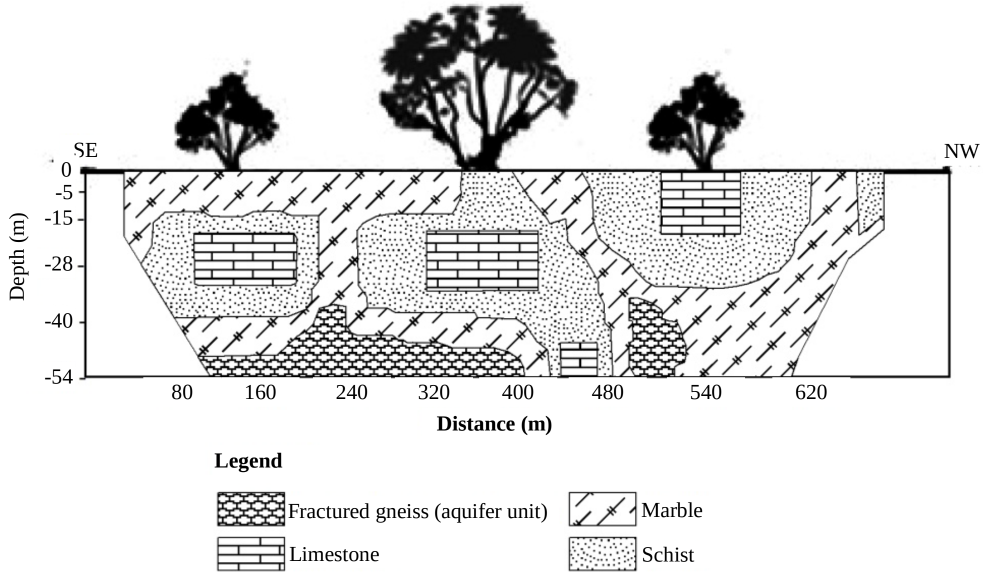


Figure 5. Geological model of the Mayo Boki subsurface area derived from pseudo section interpretation.

6. Conclusion

The 1D and 2D modelling of exploitable resistivity data of the study area based on the geoelectrical method principle and their interpretation have permitted us to put in evidence the resistant anomalies. These anomalies show that the tectonic activity of the Mayo Boki cannot be neglected, hence confirming the results of geological studies led in the region [3] [5] [14]. In accordance with geologists, the ongoing geological information collected during this study reveals downwards the presence of marble and limestone from near-surface, which rest on the basement directly or through schist result of the tectonic movements. The thicknesses of the limestone layer vary from 13 to 44 m according to prior geophysical results. The resistivity variation due to gneissic formations overlain by thin marble and limestone formation overlain by schist is observed in the study area. The spatial contact between schist and limestone was identified on the variation of resistivity values. Limestone and the marble layers' thicknesses evaluation permit us to supply mining information on the study area. The correlation between geological data and the geoelectric section has led to envisage pursuing exploration activities. Based on the limestone layer characteristics derived from this DC investigation, the exploration drilling operations have to be initiated in order to define the limestone resource over the area of study, which will certainly enables to build the exploitation project prefeasibility document.

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