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Hydrogeophysical and Structural Investigations Using VES: A Case Study of Dosso Region in the Southwestern Part of the Meso-Cenozoic Iullemmeden Basin (Southwestern Niger)

Abdou Ali Ibrahim[1*], Huguette C. Emvoutou[2,3], Alain Zanga[2], Konaté Moussa[4], Serigne Faye[3]

[1]Department of Life and Earth Sciences, Ecole Normale Supérieure, Université Abdou Moumouni, Niamey, Niger
[2]Department of Earth Sciences, Faculty of Sciences, University of Douala, Douala, Cameroon
[3]Department of Geology, Faculty of Sciences and Techniques, University Cheikh Anta Diop of Dakar, Dakar, Senegal
[4]Department of Geology, Faculty of Sciences and Techniques, Université Abdou Moumouni, Niamey, Niger
Email: *ibtazard@yahoo.com, *ibtazard@gmail.com

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Abstract

A regional study connecting geolelectrical surveys with geology and hydrogeology was carried out in the western part of the Iullemmeden basin, precisely in the Dosso region in Niger. One hundred and four (104) vertical electrical sounds have been realized, among them nineteen representative were thus be used as parametric surveys. The local resistivity values of the geological formations of Quaternary range from 100 Ω·m to 1000 Ω·m (sands and lateritic sandstones). The Oligo-Miocene formation of the Continental terminal (Ct) shows resistivity values ranging from 1 to 5 Ω·m (brackish groundwaters) to 1500 Ω·m (clay sandstones) while the Upper Cretaceous formation of the Continental "hamadien" (Ch) indicates values ranging from 20 Ω·m (sandy clay) to 5000 Ω·m (clayey sandstones). The geological formations of Paleocene have values from 2 Ω·m (marls) to 60 Ω·m (calcareous marl), while the Precambrian basement exhibits values of granite around 300 Ω·m to 60,000 Ω·m. The update of the structural settings reveals many faults in the study area which explain both the shape of the basin and the geometry of the aquifers. Tectonics is also consistent with the hydraulic characteristics of aquifers. In addition, brackish groundwaters were identified as perched aquifer groundwaters in different depths in Dosso region. They probably come from the marine brines during the regression of the Paleocene Sea.

Keywords

Vertical Electrical Soundings, Continental Terminal, Continental "Hamadien", Brackish Groundwaters, Iullemmeden Basin, Dosso Region

1. Introduction

Water supply demands increase in sub-Saharan African countries since these decades. In Niger republic and particularly in the study area namely Dosso region (**Figure 1**), the population's drinking water supply is in more than 80% dependent on groundwater from the Iullemmeden basin [1]. The Iullemmeden sedimentary basin contains one of the most important groundwater resources of Niger Republic.

In the past two decades, many hydraulic programs were thus set up to meet these needs and to cover the ever-increasing water demands of the population. Unfortunately, their implementation faced a strong demand which impacts the efficient management of these resources.

It therefore appears important to improve knowledge and understanding of the geological but also hydrogeological characteristics of the aquifers of the Iullemmeden basin. Thus, several studies carried out have made it possible to improve knowledge of this basin [1]-[9]. However, none has addressed the question of the influence of tectonics in this basin, neither its impact in the architecture of the basin leading to its geometry model. The aim of this study is to improve the knowledge of the multilayer aquifer system of the Iullemmeden basin in the Dosso region.

Specifically, this involves to:

- establish a resistivity scale of the different geological formations of the study area;
- determine the role played by tectonics in the geometry of multilayer aquifers;
- propose a geometric model of the spatial arrangement of the multilayer aquifers in the study region.

To achieve these objectives, as part of this study, geophysical prospecting methods, mainly electrical methods, will be used. These geophysical methods constitute a powerful tool to explore the geology of the subsurface and gather more information about the layers and structures of the subsurface [10].

The study area namely Dosso region is one of the eight (8) regions in the republic of Niger. It is located in the southwestern part of Niger (**Figure 1(B)**) in the Iullemmeden basin. It covers an area of 33,844 km^2 so around 2.7% of the national territory. The study area is bounded to the north-east by the Tahoua region, to the north-west by the Tillabéry region and to the south-east by the Republic of Nigeria and to the South by the Republic of Benin (**Figure 1(B)**).

Reference [1] reveals that the Dosso region is an agricultural area with around 70% of farmland and the canopy represents about 20%. Housing areas are mostly located in the main towns like Dogondoutchi and Gaya in the north-east and south-east, respectively; in Loga, Birnin N'Gouaré and Dosso in the western part of the study area. The population is around 2,037,713 inhabitants [11]. The Digital

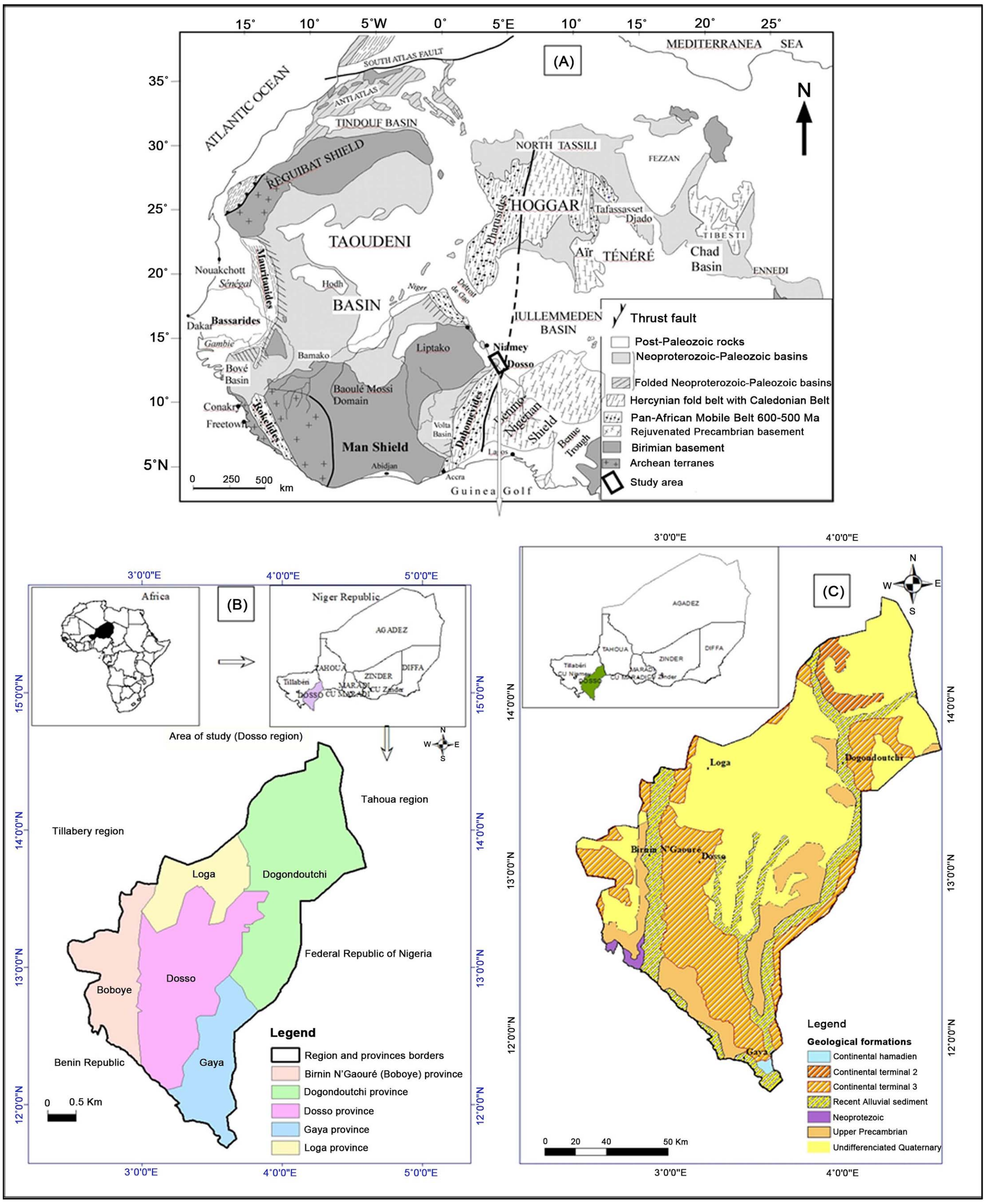


Figure 1. Location of the study region.

Elevation Model (DEM) ranges from 150 to 350 m. Rainfalls can reach 280 mm/year and the Niger River flows towards the South of the Region. Soil survey of the study area showed that the erodible sandy soils namely aeronosols are much represented (96%) while the hydromorphic and ferrallisol soils occupy substantially 3.43% and 0.57%, respectively [1].

2. Geological Context

The Iullemmeden basin is a vast intracratonic basin (Figure 1(A), Figure 1(C), Figure 2), which belongs to several countries (Algeria, Benin, Mali, Niger and

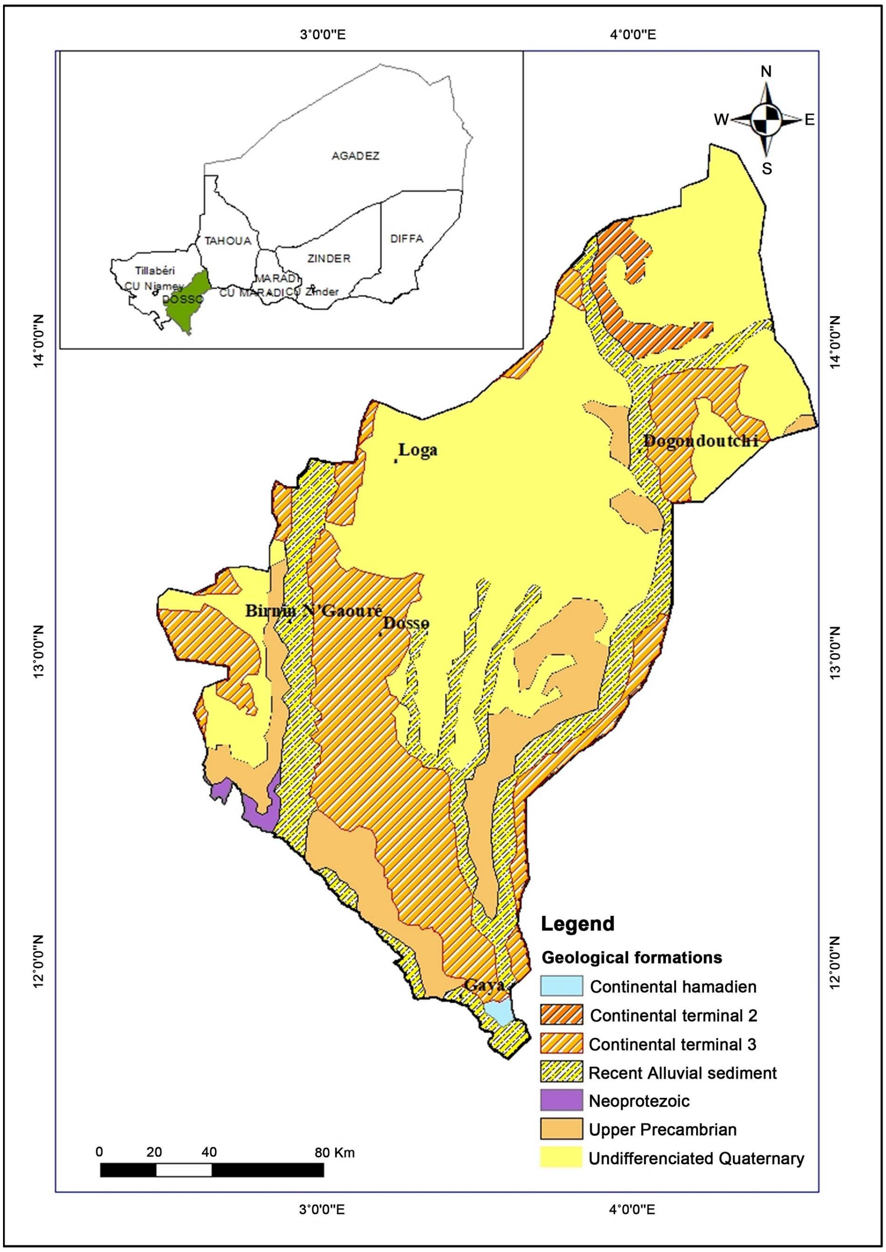


Figure 2. Geological map of the studied area. [18] modified.

Nigeria). It takes its name from the important Targui federation called Kel Iullemmeden, populating its central part [12].

It extends from North to South for a length of approximately 1000 km and from East to West over a width of 800 km [3]. The Iullemmeden basin communicates to the West with that of Taoudenni via the Gao strait. To the East, it is continuous with the eastern Niger basin (or Chad basin) via the Damergou threshold [13].

The Iullemmeden basin in its overall structure presents a syncline-shaped geometry whose southern axis is located approximately between the 3˚ and 4˚ East meridians [3] [13] [14].

The sedimentary infilling is essentially made up of Paleozoic (to the north) and Meso-Cenozoic (to the south) deposits. The Iullemmeden basin was the site of sedimentation characterized by a migration of depositional areas from the north-east to the south-east. Paleozoic formations crop out in the northern part of the Iullemmeden basin (Tin Séririne sub-basin and Tim Mersoï sub-basin), as mentioned by [13] as well as at its southwestern end (Kandi Benin-Niger basin). Mesozoic sediments occupy most of the basin. The most recent Cenozoic serie-soverlay sometimes directly the Liptako and the North Benin basements.

Numerous fault systems have affected the basement and the sedimentary cover of the basin in its North to north-eastern and south-western parts, the orientations of which are NW-SE for the latter (**Figure 1**). The significant changes in thickness, facies and discontinuities, as well as in the nature of the beds, are the striking sign of the synsedimentary tectonics that affected the Iullemmeden basin [3] [13] [15] [16].

The Iullemmeden basin, like many other basins, has undergone several deformations episodically. They have led to the tectonic readjustments of the basin according to the major lineaments of the African plate [13] [14].

The study area is located in the southwestern part of the Iullemmeden Basin in Niger (**Figure 2**). A synthesis of geological and hydrogeological knowledge of the study area (South-West of the Iullemmeden basin) based on data from previous studies determined the reference lithological levels [3]. These latter retained as a basis for stratigraphic correlations presented from bottom to top as follows:

- ❖ The Precambrian basement made up of granites and gneiss, is subcrops only along the Niger River in the Dosso Region [3] [9]. In the southern border of the study area, the Continental "hamadien" formation rests unconformably on the Precambrian basement.
- ❖ The Continental "hamadien" (Ch) formation is composed of fine to coarse sandstones with kaolin cement and medium to coarse sands more or less consolidated in the Dallol Maouri, with a coarser and more homogeneous facies towards the South. Overall, the Continental "hamadien" is represented in the study area by Upper Cretaceous continental deposits.
- ❖ The Paleocene/Ypresian marine deposits are essentially made of limestones, marls, marl-limestones and attapulgites to the top. In the study area, this marl-limestone series separates the continental sediments of the Upper Cretaceous (Continental "hamadian") and the Tertiary (Continental terminal).
- ❖ The Continental terminal 1 (Ct^1) formation is also characterized by thickness and facies variations in the study area. It overlays the limestones and the marl-limestones, or the gray-blue clays (attapulgites). In the northern part of the Dallol Maouri and in the Dosso area, the medium to coarse sandy facies changes to alternations of fine clayey sands and sandy clays with concretions of ferruginous oolites and pyrite crystals. In the West of Dallol Foga, the Ct^1 formation is made of soft oolitic sandstones. In the Dallol Bosso on the other hand, it is represented by gravels and oolites in a clayey matrix and slightly

silty clays with detrital elements and carbonaceous pastes.

- The Continental terminal 2 (Ct^2) formation is composed of two layers of gray clays with lignites and peats with a layer of sand and/or ferruginous oolites in between. The gray clays transition in places to more or less sandy or silty facies and show significant variations in thickness.
- The Continental terminal 3 (Ct^3) formation is essentially composed of sands, heterogranular sandstones and more or less clayey silts. Globally, the Ct^3 formation is made up of more or less clayey sands and silts in most of the study area.

3. Hydrogeological Context

Previous studies investigated on the hydrogeology in the South-West of Iullemmeden basin [1] [7] [9] [17] where the study area is located. They revealed that the hydrogeology of the basin is mainly controlled by geological parameters more specifically by lithology, topography and tectonics. In this part of the Dosso region, groundwater resources are mainly located in the sedimentary formations of the Cretaceous (Continental "intercalaire"/"hamadien"), the Tertiary (Continental terminal) and the Quaternary (alluvial valleys) (**Figure 2**).

4. Data Collection and Methodology

4.1. Data Collection

The geophysical data of the Dosso region were obtained following a geophysical survey campaign. The Electrical Survey (ES) sites were selected prioritising localities with a borehole with available lithostratigraphic descriptions allowing to make good correlations. The profiles were defined after a reconnaissance mission in order to obtain a good spatial distribution of the boreholes, enabling the morphology and the geometry of the aquifers to be reconstructed. 104 vertical electrical soundings with AB lengths between 200 and 2000 m were carried out throughout the Dosso region (**Figure 3**).

4.2. Material and Investigation Method Used

Electrical prospecting measuring electrical resistivity is the method implemented in the study area. Itis a preferable geophysical technique for groundwater exploration. As, the water content and its distribution change the electrical properties of the rocks. The resistivity is inversely proportional to the rock porosity and its water saturation. Water salinity also plays an important role as resistivity decreases when the salinity increases. If clays are present in the rock, the value of the resistivity decreases [19] [20] [21].

The most important characteristics of this electrical survey method consist to determine: 1) the geometric characteristics of groundwater reservoirs in terms of thickness, depths of the water-bearing layers, from the earth's surface and, 2) the lithological contrast in the horizontal and vertical direction and, 3) the expected water salinity.

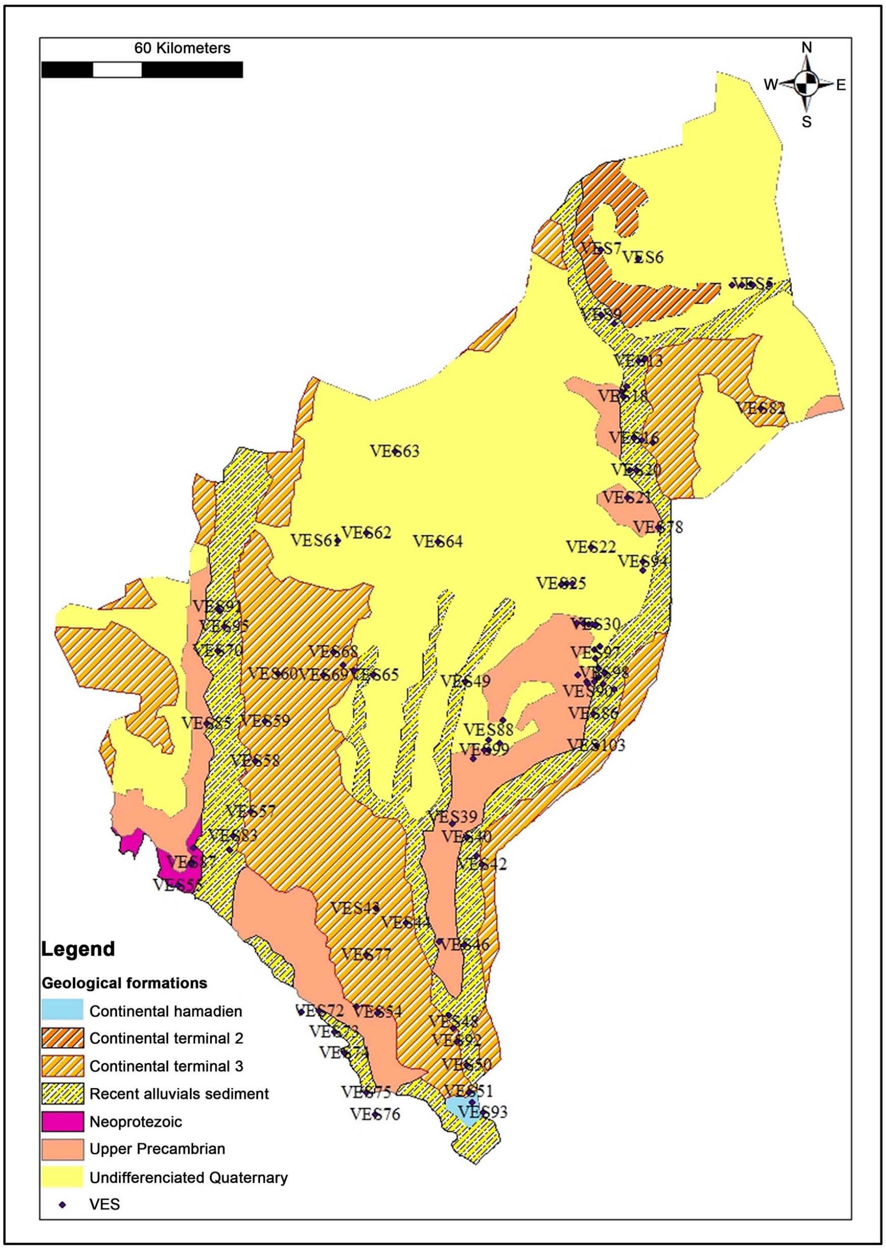


Figure 3. Vertical Electrical Surveys (VES) Spatial distribution.

The principle of electrical resistivity technique measuring electrical resistivity is based on the injection into the ground of an electric current of intensity I between two electrodes A and B, and the measurement of the potential difference ΔV induced between another pair of electrodes M and N. The positioning of these surface electrodes are variable and influence basically the current distribution. The value of the apparent electrical resistivity (ρ_{app}) in the subsoil is deduced from the values of the current intensity I, the potential difference ΔV and the geometric factor K specific to the geometry of the device used (spacing between the different electrodes) based on Ohm's law according to the following formula.

$$\rho_{app} = K * \frac{\Delta V}{I} \tag{1}$$

$$K = \frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}} \tag{2}$$

There are several configurations (Schlumberger, Wenner, Dipole-dipole, Gradient) to measure the electrical resistivity of the ground depending on the objective and the problem encountered.

For this study, the Schlumberger configuration (in which the four electrodes are aligned) was used. As part of this study, only vertical electrical sounding was used to measure the electrical resistivities of rocks. It should be remembered here that vertical electrical sounding is made up of a series of apparent resistivity measurements carried out with progressively increasing lines whose center and direction of movement of the device remain fixed. The variation in the apparent resistivities obtained is essentially due to the increasing penetration of the electrical current.

The equipment used for the geophysical campaign is the Syscal R1 Plus resistivimeter which is fully automatic resistivity meters. It was designed for intensive exploration of the subsurface using direct current electrical methods.

The SYSCAL R1 PLUS save the measurements in a built-in internal memory (more than 800 recordings). Each record contains the current intensity, voltage, resistivity, the confiuration (Schlumberger, Wenner, Dipole-dipole, Gradient), line lengths, station's number (VES's number). It automatically calculates the apparent resistivity when the values of AB/2 and MN/2 are entered.

4.3. Method for Interpreting Electrical Survey Data

The IPI2W in software (2002 version) was used as the treatment data tool. It is powerful software for the 2D interpretation of electrical surveys. It was developed by the Geophysics Laboratory of Moscow University [22]. Its particularity is to consider the profile of electrical surveys to be treated as a unit. This approach allows for better consideration of information. Using this principle, an average curve of a vertical survey can be plotted. This principle allows to consider the curve as being atypical for a specific sector. On the other hand it allows to consider its solution as a model for the inversion of the rest of the curves of the vertical surveys. It should also be noted that this software allows for each geoelectric section, a statistical analysis in the form of a representation which gives the frequencies of the apparent resistivity values of the electrical soundings forming the profile.

5. Results

Only the representative profiles are exposed and discussed. The profiles depending on the investigation depths reached with geophysics (AB lengths varying from 200 to 2000 m) and lithological logs of the boreholes are used as parametric surveys.

According to the appearance of the survey curves types obtained, the subsoil of the Dosso region is composed of several layers of resistivity $\rho 1$, $\rho 2$, $\rho 3$ and thickness h1, h2, which gives four terrain configurations:

- a conductor between two resistors, type H sounding or "boat bottom" (**Figure 4(A)**);
- a resistor between two conductors, type K or "bell" sounding (**Figure 4(B)**);
- a resistivity which increases in stages, type A sounding (**Figure 4(C)**);
- a resistivity which decreases step by step, type Qsounding (**Figure 4(D)**).

5.1. Interpretation and Discussion of Results

5.1.1. Resistivity Scale of Geological Formations

Parametric surveys are essential and are permit to establish true local resistivities of different geological formations considering, a certain constancy of facies in the study area. In order to facilitate the interpretation of the electrical soundings, Nineteen (19) parametric soundings spatially distributed throughout the study area, were carried out in the vicinity of the boreholes whose lithology was well described. The boundaries of the Continental terminal and Continental hamadian aquifers were thus defined based on the geochronology and their depths, giving a certain constancy of the geological facies described. In addition, the limits of the Ct aquifers namely Ct^3, Ct^2 and Ct^1 was not really established except in Bagagi.

For calibration, the lithology of some boreholes will be described with their survey curves. The figures presented below summarize the lithology of these parametric boreholes as well as their survey curves.

1) Bagagi parametric survey

The Bagagi borehole drilling carried out in 1969, describes a Ct^3 formation consisting of fine sandstones, clayey sandstone, sandy sandstones and clayey sandstones to a depth of 86 m. The resistivities obtained from the standard survey (**Figure 5**) vary from 45 to 1599 Ω·m and characterize these Ct^3 sandstones. Ct^3 formation is a low conductor resistant at certain levels. The resistant level (1599 Ω·m) corresponds to indurated sandstone and/or dry sand. The relatively conductive level (435 Ω·m) corresponds to a level of sandy sandstones which is probably the level where the Ct^3 aquifer would be located.

The Ct^2 formation, made of sandy clays, variegated clays and soft sandstones with sandy passage, is located between 86 m and 186.6 m. The resistivities of the standard survey corresponding to Ct^2 vary from 19.4 to 435 Ω·m. These reflect a conductive level due to the presence of clay (**Figure 5**).

The Ct^1 formation, constituted of oolite clay, marl, soft sandstone extends from 186.6 m to 291 m. The lower limit of Ct^1 probably corresponds to the Upper Paleocene limit. The survey was unable to reach the lower limit of CT^1. The presence of clay in this aquifer makes it conductive, the resistivity corresponding to this horizon is 19.4 Ω·m. That of marls is 0.12 Ω·m (**Figure 5**).

2) "Dogondoutchi km 300" parametric survey

This borehole realized in 1955 for the reconnaissance of the Iullemmeden basin in Niger, has a depth of 750 m. However, it should be noted that the depth of

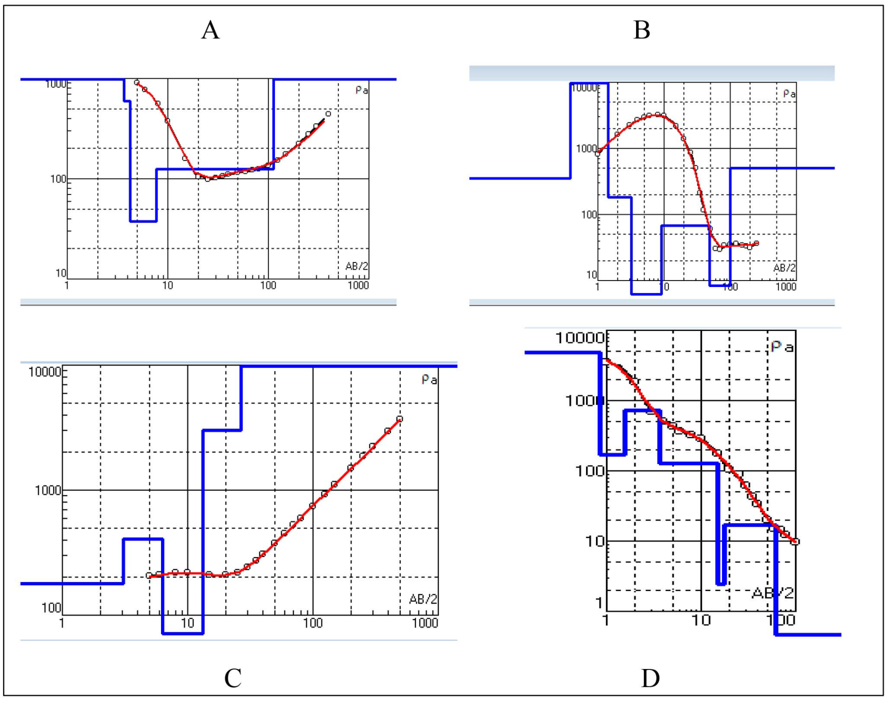
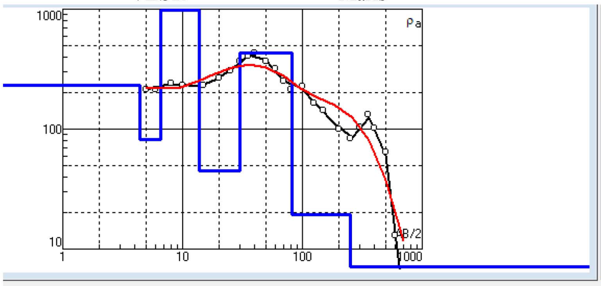


Figure 4. Configuration of electrical sounding curves of the Dosso region.

Resistivity (Ω.m)	VES 13 depth (m)	Lithology of Bagagi borehole	Depth (m)
233	0 to 4.39	fine sandstone	0 to 5
81.9	4.39 to 7	Clayey sandstone	5 to 27
1599	7 to 14	sandy sandstone	27 to 45
45	14 to 30	Clayey sandstone	45 to 57
435	30 to 82	Sandy sandstones and sands	57 to 118
19.4	82 to 251	Clays	118 to 141
0.12	from 251	Soft sandstones with sands	141 to 185
		Marls and lignites	185 to 190
		Clayey gray sands	190 to 193
		Blue and green marls	193 to 241
		Soft gray and green sandstones	241 to 259
		Dark green marls	259 to 272
		Sandstone-sand-clay alternation	272 to 291
		Marls	291 to 294

VES13



N	ρ	h	d	Alt
1	233	4.39	4.39	-4.39
2	81.9	2.2	6.59	-6.59
3	1599	7.17	13.8	-13.76
4	44.9	16.3	30.1	-30.06
5	435	51.4	81.5	-81.46
6	19.4	170	251	-251.5
7	0.119			

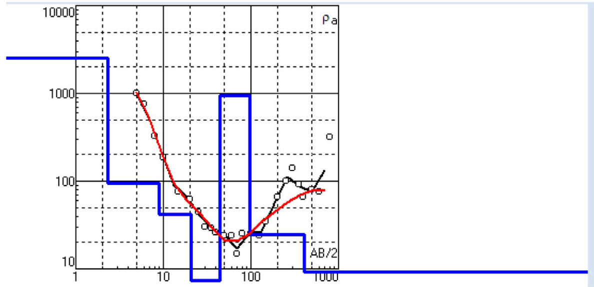
Figure 5. Bagagi borehole parametric survey.

investigation of vertical electrical surveys carried out in the Dogondoutchi area does not exceed 400 m. However, it is useful for describing lithofacies to a depth of 400 m corresponding to the upper limit of the Paleocene (Figure 6).

The Quaternary consists of sands with a thickness of 10 m with a resistivity of dry sand corresponding to 2524 Ω·m.

Resistivity (Ω.m)	VES 10 depth (m)	Lithology forage Doutchi km 300	Depth (m)
2524	0 to 2.31	Quaternary sands	0 to 10
93.9	2.31 to 9	Clayey sandstone	10 to 30
42.4	9 to 21		
7.29	21 to 44	Sandstone clays	30 to 45
945	44 to 92	Gray and yellow clayey sands and sandstones	45 to 92
24.5	92 to 400	Clays, sandy clays	92 to 400
9.14	From 400	Marl-limestone and limestone	400 to 450

VES10



N	ρ	h	d	Alt
1	2524	2.31	2.31	-2.31
2	93.9	6.63	8.94	-8.94
3	42.4	11.8	20.7	-20.74
4	7.29	23.7	44.4	-44.44
5	945	52.8	97.2	-97.23
6	24.5	310	407	-407.2
7	9.14			

Figure 6. "Dogondoutchi km 300" borehole parametric survey.

The upper limit of the Ct is approximately at 10 m deep and the lower limit is reached round 400 m. The Continental terminal formation (Ct) is composed of an alternation of sandy clays, sands, clayey sandstones, sandy clays and clays at its base. The resistivities corresponding to the Ct obtained from the parametric sound vary from 7.26 to 645 Ω·m reflecting a conductive to relatively resistant terrain. The lower limit of the Ct at this borehole is reached at 400 m and is made of marl-limestone, limestone, marl. They mark the upper limit of the Paleocene with a resistivity of 9.14 Ω·m.

3) Kiéché Boreholeparametric survey

This borehole drilled in 1956 shows the Quaternary consisting mainly of sand with a level of laterite crust over a depth of 20 m. The resistivity of the parametric sound corresponding to the Quaternary varies from 1424 Ω·m for the dry sand to 17,099 Ω·m for the laterite crust (**Figure 7**).

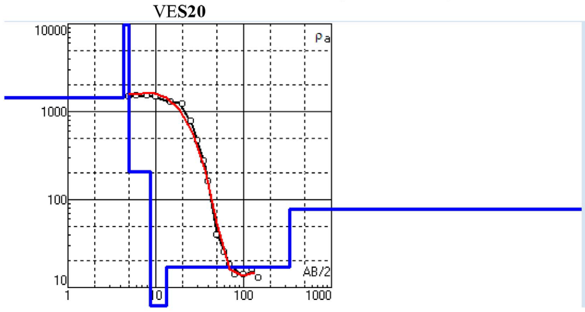
The Ct formation is constitued of clayey sandstone, alternation of sand and clayey sandstone, blue or black clay at the base. The resistivities of the Ct vary from 2 Ω·m (clay or possibly a brackish water level) to 206 Ω·m.

4) Dioundiou parametric survey

The Dioundiou borehole drilled in 1969 indicates the extension of the Ct formation from 0 m to a depth of 116 m (**Figure 8**). It is essentially constituted of medium sand with a level of lateritic gravel (1 m thick) at the top. From 7 m to 116 m depth, it is constituted of coarse sandstones, clayey and sandy sandstones, and clays. The resistivities corresponding to the Ct formation are 2037 Ω·m and 4910 Ω·m (sand), 21797 Ω·m (eolian sands and lateritic shells), 81 Ω·m to 528 Ω·m (for clays, siliceous clayey-sandstone, clayey and sandy sandstones). The Paleocene is reached between 116 m and 135 m depth. It is made up of marl-limestone and grayish clays with an average resistivity of 337 Ω·m.

Resistivity (Ω.m)	VES 20 depth (m)	Lithology Kiéché borehole	Depth (m)
1424	0 to 4.27	Sands, clays towards the base (Lateritic crust)	0 to 20
17,099	4.27 to 5.01	Clayey sandstone and fine sand	20 to 116
206	5.01 to 8.6	Clays	116 to 124
2	8.6 to 13.4	Alternation of sand-sandy clays-clayey sandstone	124 to 161
17	13.4 to 335	Green clays	161 to 163
77.7	from 335	Alternating clay sandstone-sand-clay	163 to183
		Black sandy clays	183 to 186
		Series of blue, green or black clays	186 to 237
		Black sands	237 to 239
		Blue clays	239 to 245
		Alternating sand-oolites-green clays	245 to 250
		Sands and oolites	250 to 270
		Green clays	270 to 272
		Fine sands, green clays with ferruginous pisoliths	272 to 287
		Sand-clay alternation	287 to 302
		Black, green, blue clays	302 to 345

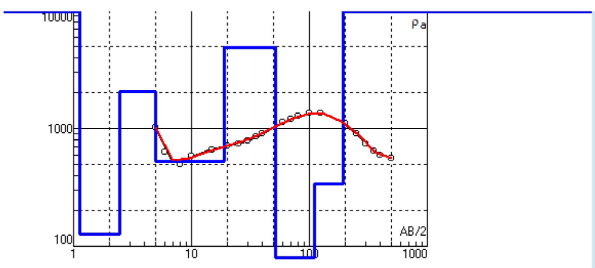
VES20



N	ρ	h	d	Alt
1	1424	4.27	4.27	-4.27
2	17099	0.735	5.01	-5.005
3	206	3.6	8.6	-8.605
4	2	4.75	13.4	-13.35
5	17	322	335	-335.4
6	77.7			

Figure 7. Kiéché borehole parametric survey.

Resistivity (Ω.m)	VES 39 depth (m)	Lithology of Dioundiou borehole	Depth (m)
21,797	0 to 1.1	Yellow medium sands	0 to 6
126.9	1.1 to 2.5	Lateritic shells	6 to 7
2,037	2.5 to 5	Coarse sandstones, clayey and sandy sandstones	7 to 43
528	5 to 19	Colorful clays	43 to 58
4910	19 to 52	Sandstone and sandy clays	58 to 90
80.47	52 to 110	Clays and peats	90 to 94
337	110 to 192	Quartz sandstone passing to sand	94 to 112
		Gray clays	112 to 116
12,598	from 192	Marl-limestone	116 to 121
		Grayish clays	121 to 135
		Clay sands	135 to 140
		Medium sands with clay passage	140 to 148
		Medium white and gray quartz sands	148 to 187
	VES39	Indurated sandstones	from 187



N	ρ	h	d	Alt
1	21797	1.129	1.129	-1.129
2	126.9	1.343	2.472	-2.472
3	2037	2.525	4.997	-4.997
4	527.8	13.97	18.97	-18.967
5	4910	32.58	51.55	-51.547
6	80.47	58.89	110.4	-110.44
7	337	81.66	192.1	-192.1
8	12598			

Figure 8. Dioundiou borehole parametric survey.

The Continental "hamadien" begins at a depth of 135 m (**Figure 8**), it is made up of clayey sands, white and gray sand, quartz, hard sandstone from a depth of

187 m. The average resistivities obtained for the Ch formation from the parametric sound are 337 Ω·m for clayey sands, medium gray and white quartz sands) and 12,598 Ω·m for indurated sandstones.

5) "Bengou I" borehole parametric survey

With a depth of 346.5 m, the "Bengou I" reconnaissance borehole was drilled in 1969. The quaternary has a thickness of 15 m (from 0 m to 15 m depth). It is essentially made of fine silto-clay sands, medium sands and ferruginized quartz sandstones (**Figure 9**). The parametric sound resistivity corresponding to the Quaternary vary from 85 Ω·m to 2741 Ω·m. The Paleocene is made of peats and silty clays with a thickness of 4 m (15 to 19 m) with an average resistivity of 43 Ω·m (**Figure 9**). The Continental "hamadien" (Ch) formation starts from a depth of 19 m and ended at 342 m. It is made of fine to coarse sands, more or less soft fine sandstones, ferruginous and clayey sandstones, compact gray-blue marls at its bottom (from 330 m to 342 m deep). The resistivities corresponding to Ch vary from 43 Ω·m to 298 Ω·m for sandstones and sands and 5.4 Ω·m for marls.

6) Talambou borehole parametric survey

This borehole, realized in 1987, has a depth of 104 m. The description of its lithology highlights fine clayey sands (0 to 2 m depth), sandy clays from 2 m to 8 m depth, clayey alterites from depth 8 m to 32 m, granite arenas from 32 m to 44 m. The unaltered pink granite is reached at a depth of 44 m (**Figure 10**). The parametric sound resistivity obtained reflect this lithology. Thus, fine clayey sands have a resistivity of 1200 Ω·m, clayey sands 598 Ω·m, clayey alterites and granite arenas 125 Ω·m and finally the unaltered pink granites 17,459 Ω·m.

7) Goutoumbou borehole parametric survey

The lithological description of the Goutoumbou borehole successively reveals fine red sands from 0 to 2 m depth, silty-clayey and clayey-silt from 2 m to 48 m, sandy-clayey from 48 m to 55 m, clayey-silts and silty clays from 55 m to 93 m. From 93 m to 146 m depth, there is an alternation of fine silty-clayey sands clayey-sands with silty-clayey oolites (**Figure 11**).

The parametric sound at this borehole gives resistivities reflecting this lithology. Thus for fine red sands, the resistivity varies from 102 Ω·m to 1833 Ω·m, clayey-silts and silty-clayey have a resistivity varying from 43 Ω·m to 323 Ω·m, clayey-sands indicates an average resistivity of 85 Ω·m, clayey-silts 85 Ω·m to 1131 Ω·m. Fine clayey-sands and fine sands with oolites have an average resistivity of 1131 Ω·m.

8) Wadata (Falwel) borehole parametric survey

To parameterize the resistivities of the layers in this part of the study region, the Wadata borehole (Falwel) was used. The observed layers define from top to bottom are: fine sands of 0 to 3 m, lateritic sands of 3 to 10 m, lateritic clays of 10 to 15 m, clayey-sands from 15 to 20 m, and an alternation of sandy-clayey and fine sands from 20 to 152 m (**Figure 12**). It is important to mention that water level in boreholes was measured during the survey where it is possible.

Resistivity (Ω.m)	VES 49 depth (m)	Lithology of "Bengou I" borehole	Depth (m)
85	0 to 3.44	Fine silty sand with little clay	0 to 12.75
165	3.44 to 5.4	Medium yellow sand	12.75 to 14
2,741	5.4 to13.7	Ferruginized quartz Sandstone	14 to 15
43	13.7 to 49.6	Peat and silty Clay	15 to19
60	49.6 to 64	Fine to coarse gray sand	19 to 45
298	64 to 332	Very fine soft Sandstone	45 to 60
5.4	from 332	More or less soft sandstone	60 to 73
		More or less hard sandstone with soft passage	73 to 95
		Red hard ferruginous sandstone	95 to 103
		hard red sandstone	103 to 107
		Red clay sandstone	107 to 116
		Soft red and gray sandstone	116 to 121
		More or less hard red sandstone	121 to 220
		Medium clayey gray sandstone	220 to 241
		Reddish gray sandstone	241 to 247
		Grayish sandstone becoming increasingly clayey at the base	247 to 300
		Very fine soft sandstone with passage of fine sand	300 to 330
		Plastic compact blue gray marl	330 to 342
		Weathered granite	342 to 346
		Granite	346 to 346.35

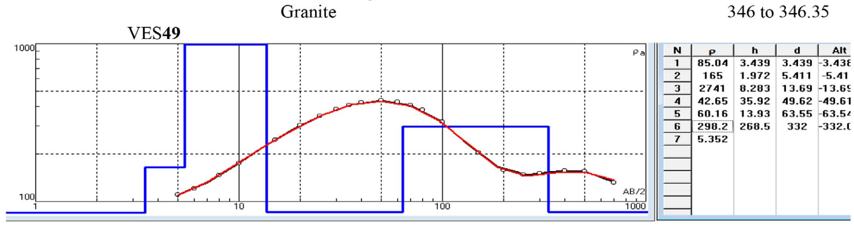


Figure 9. "Bengou I" borehole parametric survey.

Resistivity (Ω.m)	VES 54 depth (m)	Lithology of Talambou borehole	Depth (m)
1,200	0 to 3.7	Fine clay sands	0 to 2
598	3.7 to 4.3	Clay sands	2 to 8
38	4.3 to 7.8	Greenish yellow clay alterites	8 to 32
125	7.8 to 113	Granite arenas	32 to 44
17,459	from 113	Unaltered pink granites	44 to 105

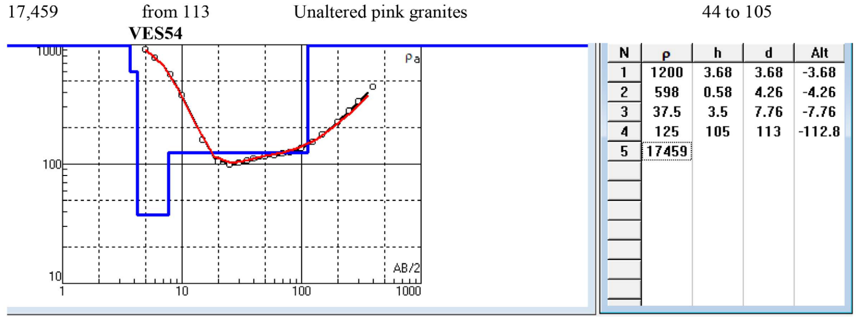


Figure 10. Talambou borehole parametric survey.

The layers surveyed present an average of resistivities that are summarized as follows: fine sands 5909 Ω·m, lateritic sands 306 Ω·m, lateritic clays 9016 Ω·m, layer made up of alternating clayey-sands, sandy clays, and sand 927 Ω·m and for a layer of sandy clay from 201 m with an average resistivity of 214 Ω·m.

9) "Birnin N'Gaouré II" borehole parametric survey

The Birnin N'Gaouré borehole drilled in 1954 was also used to parameterize the resistivities of the lithological layers. From top to bottom of this borehole,

Resistivity (Ω.m)	VES 61 depth (m)	Lithology of Goutoumbou	Depth (m)
102	0 to 3	Fine red sand	0 to 2
1833	3 to 6.6	Beige, yellow and red clayey silts	2 to 20
323	6.6 toto14.3	Ochre-yellow and white clayey silts	20 to 48
43	14.3 to 31.4	Sandy clays	48 to 55
85	31.4 to 69	Yellow-beige clayey silts	55 to 64
1131	69 to 150	Yellow-beige and red silty clays	64 to 93
7187	from 150	Fine clay sands	93 to 98
		Yellow silty clays	98 to 103
		Fine clay sands	103 to 111
		Fine brown clayey sands	111 to 116
		Silto-sandy clays	116 to 120
		Fine oolite sands	120 to 130
		Slightly silty clays	130 to 146

VES61

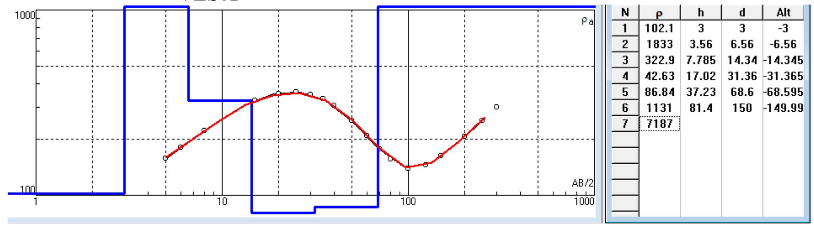


Figure 11. Goutoumou borehole parametric survey.

Resistivity (Ω.m)	VES 64 (m)	Lithology of Wadata (Falwel)	Depth (m)
5,909	0 to 3.7	Fine sands	0 to 3
306	3.7 to 9.6	Reddish lateritic sands	3 to 10
9,013	9.6 to 13.2	Lateritic sandy clays	10 to 15
927	13.2 to 201	Clay sands	15 to 20
214	from 201	Sandy clays	20 to 41
		Colorful clays	41 to 51
		Fine sands and clays	51 to 53
		Medium whitish sands with clays	53 to 70
		Yellow clays more or less variegated with coarse sands	70 to 85
		More or less variegated yellow clays	85 to 90
		Light gray clays with traces of sand	90 to 115
		More or less fine sands	115 to 135
		Sandy gray clays	135 to 152

VES64

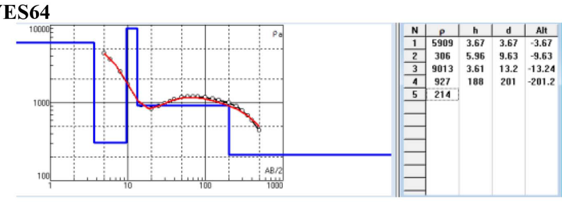


Figure 12. Wadata borehole (Fawel) parametric survey.

there are very coarse white sands from 0 to 12 m, lateritic gravels from 12 to 13 m, soft less or more clayey sandstones from 13 to 50 m, compact clay from 50 to 80 m, clayey sandstone from 80 to 90 m, black marls from 90 to 95 m, and an alternation of clayey sands, compact clays, clayey sands and clays from 95 to 170 m (Figure 13). The resistivities corresponding to the different layers according to the parametric sound are presented as follows: coarse white sands, a layer of lateritic gravels with a resistivity of 4488 Ω·m, soft sandstones from 15 to 50 m with a resistivity of 53 Ω·m to 453 Ω·m, a layer made up of alternating compact clays, clayey sandstones, clayey sands, sandy clays from 50 to 170 m, having an

Resistivity (Ω.m)	VES 70 depth (m)	Lithology of "Birnin N'Gaouré II"	Depth (m)
4,488	0 to 1.7	Very coarse white sands	0 to 12
68	1.7 to 4.8	clayey lateritic gravels	12 to 13
1,007	4.8 to 12	Soft, variegated sandstones less or more clayey	13 to 50
53	12 to 32	Beige and gray variegated compact clays	50 to 80
453	32 to 196	Less or more gray clayey sandstone	80 to 90
4137	from 196	Black marls	90 to 95
		Clay sands	95 to 100
		Compact clays	100 to 110
		Less or more clayey sands	110 to 155
		Clays	155 to 170

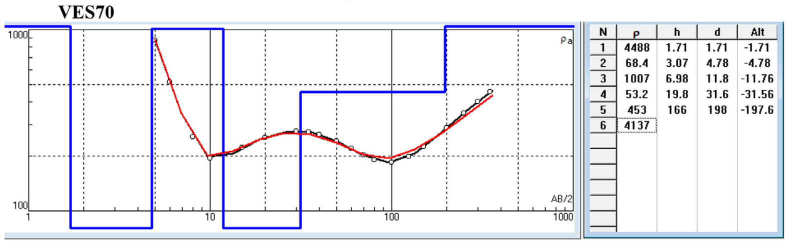


Figure 13. "Birnin N'Gaouré II" borehole parametric survey.

average resistivity of 453 Ω·m. From a depth of 196 m, the survey is characterized by the presence of a very resistant level probably corresponding to very hardened compact sandstones. The latter have an average resistivity of 4137 Ω·m.

In summary, we can conclude that from the correlations of the standard surveys with the lithological logs of the boreholes, typical resistivity markers were highlighted (**Table 1**). Thus, an average resistivity scale was established for the main formations of the studied region. The average resistivity values calibrated in the table below (**Table 1**) make it possible to interpret the resistivity values obtained with the other surveys, for the Quaternary, Continental Terminal (CT), Paleocene and Continental Hamadian formations (CH).

The surveys of the study area through the correlations of the parametric surveys coupled the lithological logs of the boreholes highlight typical resistivity markers (**Table 1**). An average resistivity scale was established for the main formations of Dosso region. These calibrated average resistivity values permit to interpret the resistivity values obtained.

5.1.2. Geoelectric Cross-Sections

The Iullemmeden basin undergone extensive tectonics which affected the Meso-Cenozoic formations (Ch and Ct) of the studied area.

Observation of the fracturing map of Dosso region [23] shows that the large sub-meridian fractures correspond to the replay in the sedimentary cover of the mega-shears which cut up the pan-African mobile zone. The geoelectric sections resulting from correlations of electrical soundings with lithological data from boreholes in the region make it possible to investigate the role of tectonics in sedimentation. A total of 21 profiles were produced (**Figure 14(A)**, **Figure 14(B)**), among which the four (4) most representative will be interpreted and discussed.

Table 1. Scale of resistivities in the Quaternary, Continental terminal (Ct), Paleocene and Continental "hamadien" (Ch) geological formations in Dosso region.

Geological Formations	Resistivities (Ω·m)
Quaternary covering	
Dry sands	1000 to 20,000
Lateritic sands and sandstones	1000 to 100,000
Sands and clayey sandstones	100 to 1000
Continental terminal (Ct)	
Clayey sands and sandstones	100 to 1500
Sandy clays and sandstone clays	20 to 500
Clays	5 to 100
Brackish waters	1 to 5
Paleocene	
Marls, marly clays, marl-limestones	2 to 60
Continental "hamadien" (Ch)	
Clayey sands and sandstones	100 to 5000
Sandy clays and sandstone clays	20 to 500
Precambrian Base	
Granite	3000 to 60,000

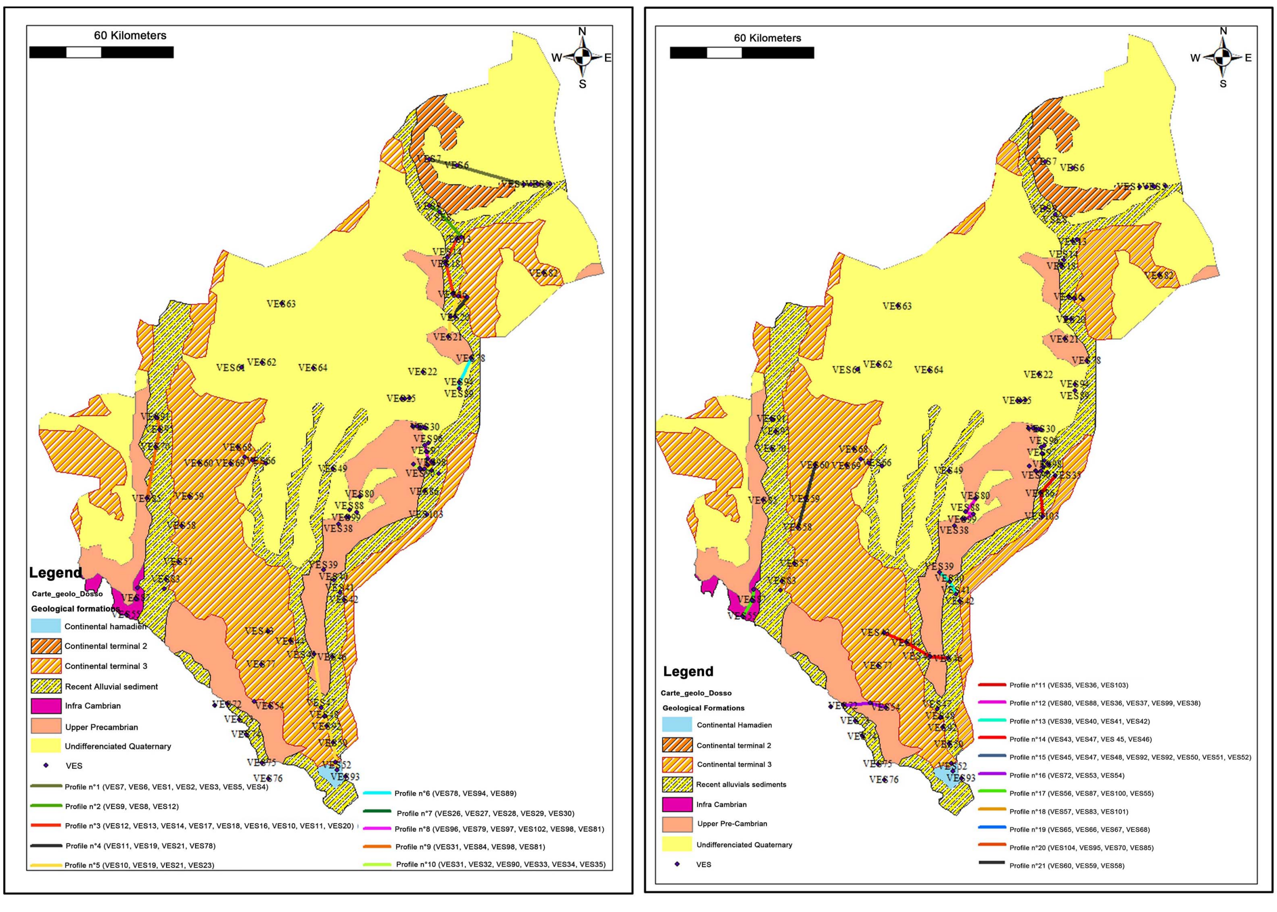


Figure 14. (A) Location of profiles (No. 1 to 10); (B) Location of profiles (No. 11 to 21).

They exhibit the following formations of: Quaternary, Continental terminal (Ct), Continental "hamadien" (Ch) and the Precambrian basement.

1) Geoelectric cross-section No. 1 (North of Dosso region)

The geoelectric cross-section (**Figure 15(B)**) of Dogon Kirya area is composed of seven (7) electrical soundings (VES1 to VES7). From top to bottom for the VES1, there is a succession of four alternating types of terrain: resistant-conductive-resistant-conductive. These terrains correspond respectively to dry sands, sandy clays, clayey sandstones, clayey sands, and marls. The VES5 shows three types of terrain: resistant-conductive-resistant. The surface terrain corresponding to Quaternary sands is widespread throughout the sector (VES7 to VES3) as seen in the pseudo section (**Figure 15(A)**). The underlying layers of sandy clays (approximately 90 Ω·m) and clayey sandstones/clayey sands rest on a very conductive layer of loamy clays (17 - 36 Ω·m) and marl (2 Ω·m) respectively. Between the surveys (VES1, VES2, VES3, VES5, VES4) of the geoelectric section (**Figure 15(B)**), the offsets of the different layers occur. These shifts were attributed to sets of normal faults (F) leading a structuring intouplifted zones and collapsed zones. This is clearly highlighted in the pseudo-section (**Figure 15(A)**) which indicates sudden variations attributed to probable accident replays between VES6, VES1, VES2, VES3, VES5 and VES4.

The accentuation of the slopes between the VES is caused by the effects of tectonics. Then they can retained:

- the steep slope between VES7 and VES6 would be caused by the morphology of the terrain. This morphology probably comes from fault movements which would have lowered the VES7 zone and raised that of VES6;
- the steeper slope between VES1, VES2 on the one hand and VES3 in the other hand would have been caused by the conductive layer below. In fact, this layer was lowered to the level of VES3 due to a probable accident. These effects are observed from a 100 m depth;
- the slope between VES3-VES5 and VES5-VES4 clearly shows a subsidence of the second compartment VES4 compared to the compartments of VES5 and VES3. The resistant layer between the two boreholes (VES3 and VES4) rises under the effect of a replay of faults would have created these two compartments.

2) Geoelectric cross-section of profile No. 3 (Bagagi to Kiéché)

The North-South geoelectric cross-section (Bagagi to Kiéché) (**Figure 16(A)** and **Figure 16(B)**), exhibits the effects of the fault played in this sector. The structuring of the studied area is organized into uplifted (horst) and collapsed (graben) compartments.

VES12 and VES13 at Bagagi are not more than a kilometer apart, but the disappearance of the conductive horizon at VES12 in the underlying layer can be attributable to the effect of tectonics.

Between VES13 on the one hand and VES14 on the other hand, the presence of a probable normal fault (F4) which would have favored the collapse of a compartment between Bagagi (VES13) and Matankari (VES 14). Also in the

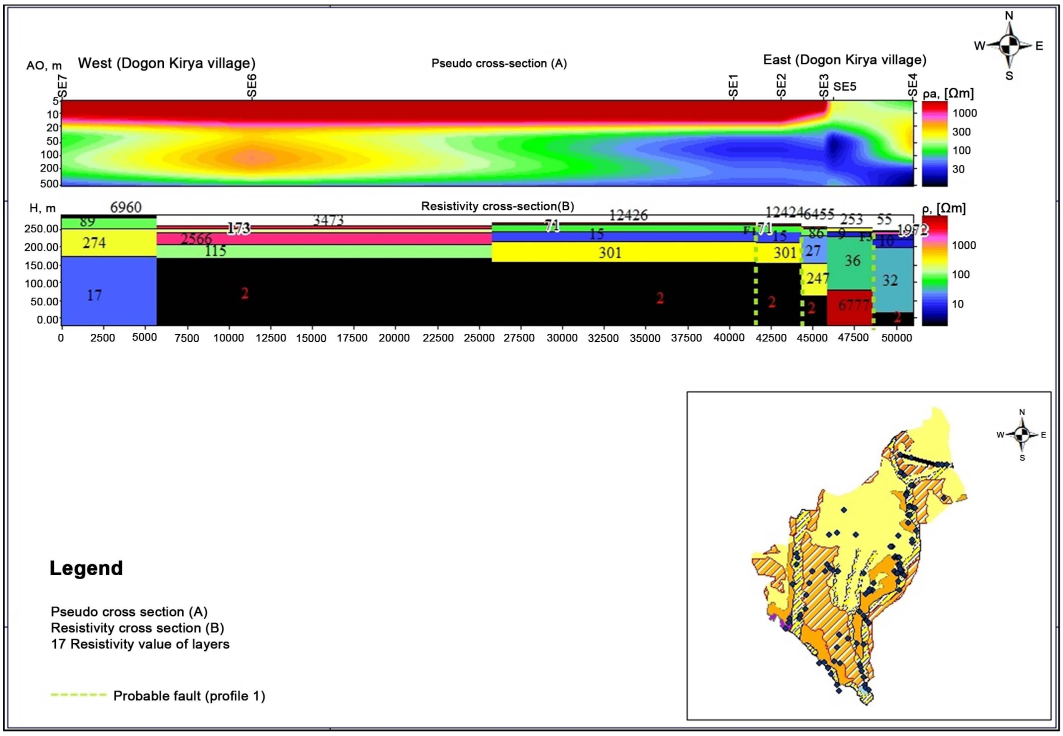


Figure 15. Geoelectric cross-section and pseudo cross-section of transec No. 1.

Matankari area (between VES14, VES17 and VES18), the presence of several faults (F) favours the creation of at least two compartments, one of which is uplifted and the other collapsed. Around Dogondoutchi (VES16, VES10, VES11), the disappearance of the very resistant horizon occurs. The presence of faults on this profile would have led to the creation of collapsed and uplifted compartments.

Up to a depth of 50 meters, the effect of the topography of the area influences the organization of the surface layers. Between 100 and 250 meters depth, the variation is minimal, this is consistent with the continuity of the formations on the geoelectric section (Figure 16). Beyond 250 m, there is a clear variation (at the level of the different surveys) that linked to the effects of tectonics.

3) Cross-section No. 15 (Daniakou to Sabon Birni towards the Niger River)

This geoelectric section (Figure 17(B)) shows the uplifting of the Precambrian basement from 123 m depth at Sabon Birni (VES1) and 110 m after Sabon Birni towards the Niger River. It thus shows the limit of the sedimentary infilling of the Iullemmeden basin in Dosso region. On the pseudo-section (Figure 17(A)), the limits of the resistant horizons correspond to the basement.

The analysis of the values (Figure 17) shows a certain consistency between VES45 and VES47, exhibiting the continuity of the formations in this area (Dallol Maouri). The values of the following surveys VES47, VES48, VES92 and VES50 correspond to a significant deepening of the layers, while the decrease in the values at the level of VES51 and VES52 towards the Niger River reflects the uplifting of the bedrock.

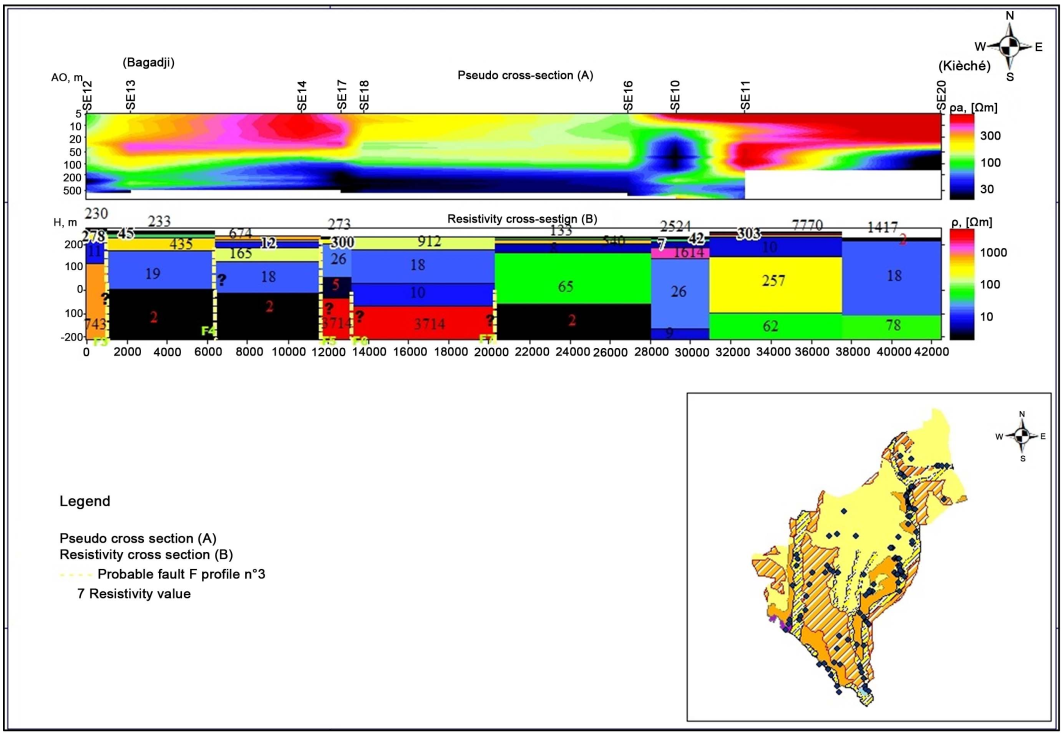


Figure 16. Geoelectric cross-section and pseudo section of profile No. 3.

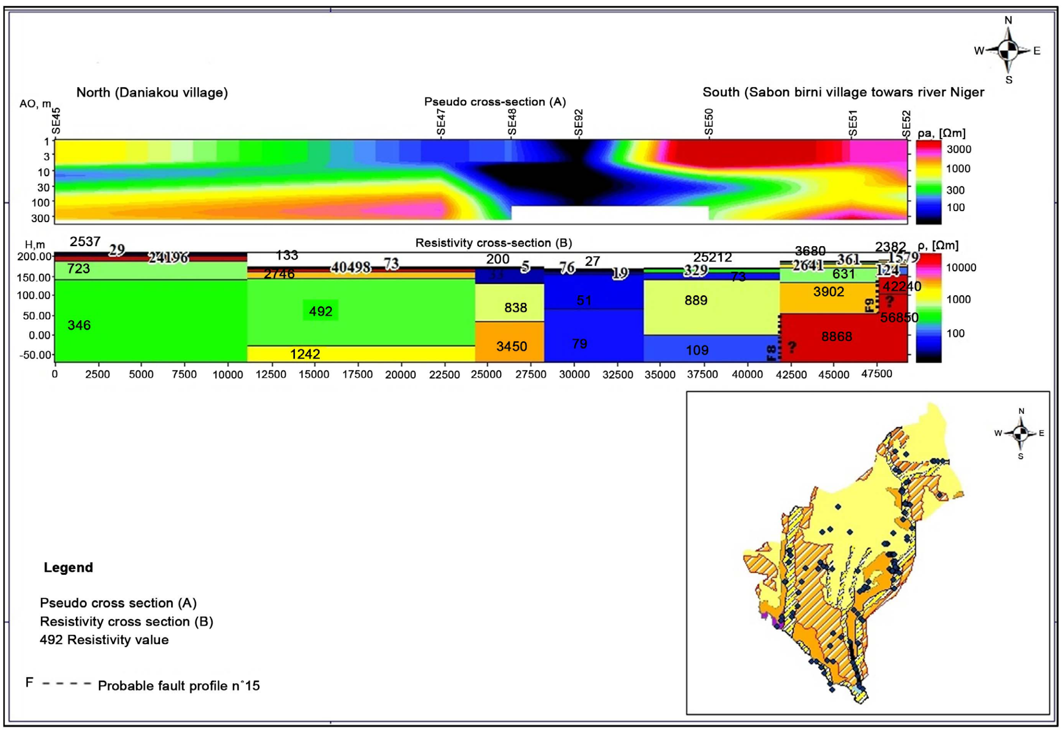


Figure 17. Geoelectric cross-section and pseudo cross-section of profile No. 15 (North-South from Daniakou to Sabon Birni).

4) Cross-section No. 16 (South-West between Tounga. M. Maichanou and Talambou)

This geoelectric cross-section (**Figure 18(A)** and **Figure 18(B)**) shows the same configuration as the previous one. At Talambou (VES54), the basement consisting of unaltered granite is encountered in the borehole which is used as a reference from a depth of 44 m. While at Sia village (VES53) which is located less than 10 km away, the resistant layer is more than 200 m away. The effects of tectonicsoccurred in this sector by uplifting or lowering the layers.

The evolution of the resistivity values on this profile shows the influence of the very resistant layer of 2666 Ω·m located between 16 and 37 m depth at VES53. Indeed, the decrease in conductance at VES53 up to a depth of 50 m is due to the presence of this very resistant layer at this depth. Beyond the depth of 50 m, the configuration of the layers as shown on the geoelectric section (**Figure 18**) with the granitic basement close to the surface observed at Talambou. The slope of the conductance on this profile demonstrates that beyond a depth of 50 m the bedrock rises as a result of normal faulting. This type of configuration was recorded in Algeria in the Mekam Sidi Khalifa sector by [24].

5.1.3. Synthetic Geological Sections

Synthetic geological sections were carried out based on altitude values taken from the DEM, the lithostratigraphical logs and the electrical survey data. The sections show the variability of the geometry of Ct and Ch formations in the studied areas where the lower and upper limits of the formations have been reached. There is an irregular geometry of these formations. On profile n˚ 2 (**Figure 19**) which represents the section between Kolifo and Bagagi, the limits of the different horizons forming the Ct^3 formation are well marked. The thickness of Ct^3 formation, composed of more of less clayey sandstones, between Kolifo (VES9) and Bagagi (VES12) is 110 m in Kolifo and approximately 85 m in Bagagi. The thickness of the clay level constituting Ct^2 in this sector varies from 160 m at Kolifo (VES9) to around 100 m towards Bagagi (VES12). Finally, the medium sands of Ct1 recognized in this sector (Kolifo-Bagagi) have a thickness of 110 m. At the bottom, the presence of resistivities of around 3 Ω·m indicates probably the presence of a marl or marl-limestone layer which represents the Paleocene upper limit.

On the profile No. 3 (**Figure 20**) between Bagagi and Kiéché, the limits of the Ct are well marked. At Bagagi and Matankari, the Quaternary is absent. At Dogondoutchi, the Quaternary consists of dry sand about 9 m thick, while at Kièché its thickness is approximately 5 m.

In the vicinity of Bagagi, the Ct has a thickness of 295 m, and 300 m around Matankari. At Dogondoutchi, the lower limit of Ct is reached at approximately 400 m, corresponding to the upper limit of the Paleocene, consisting of marl-limestone, limestone and marl.

Profile No. 15 (**Figure 21**) gives the upper and lower limits of the Ct, the Ch and the basement in the area between Daniakou and Sabon Birni towards the Niger River and the Nigeriaboundary. Around Daniakou (VES45), the thickness of the medium sands and soft sandstones of the Ct is reached at approximately the

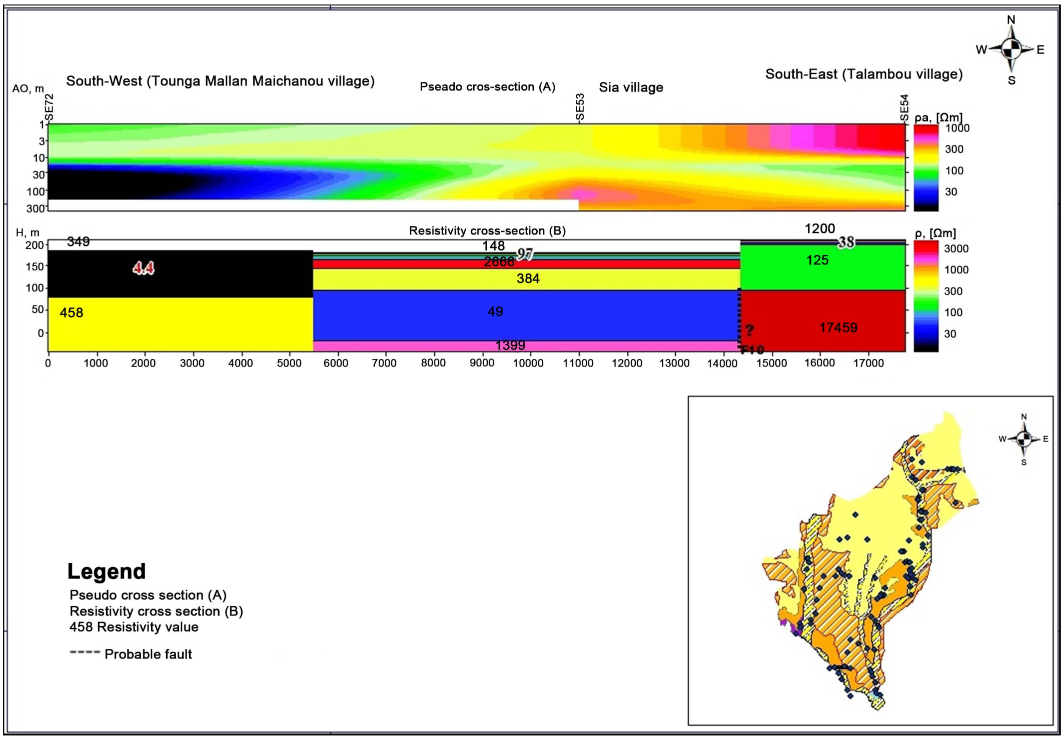


Figure 18. Geoelectric cross-section and pseudo cross-section of profile no. 16 South-West of Dosso (Tounga M. Maichanou in Talambou).

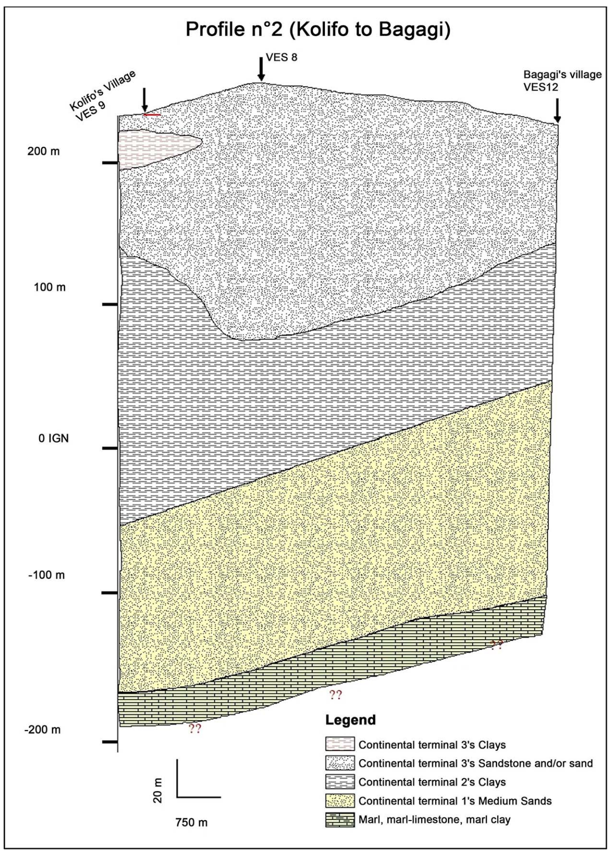


Figure 19. Synthetic geological section from Kolifo to Bagagi.

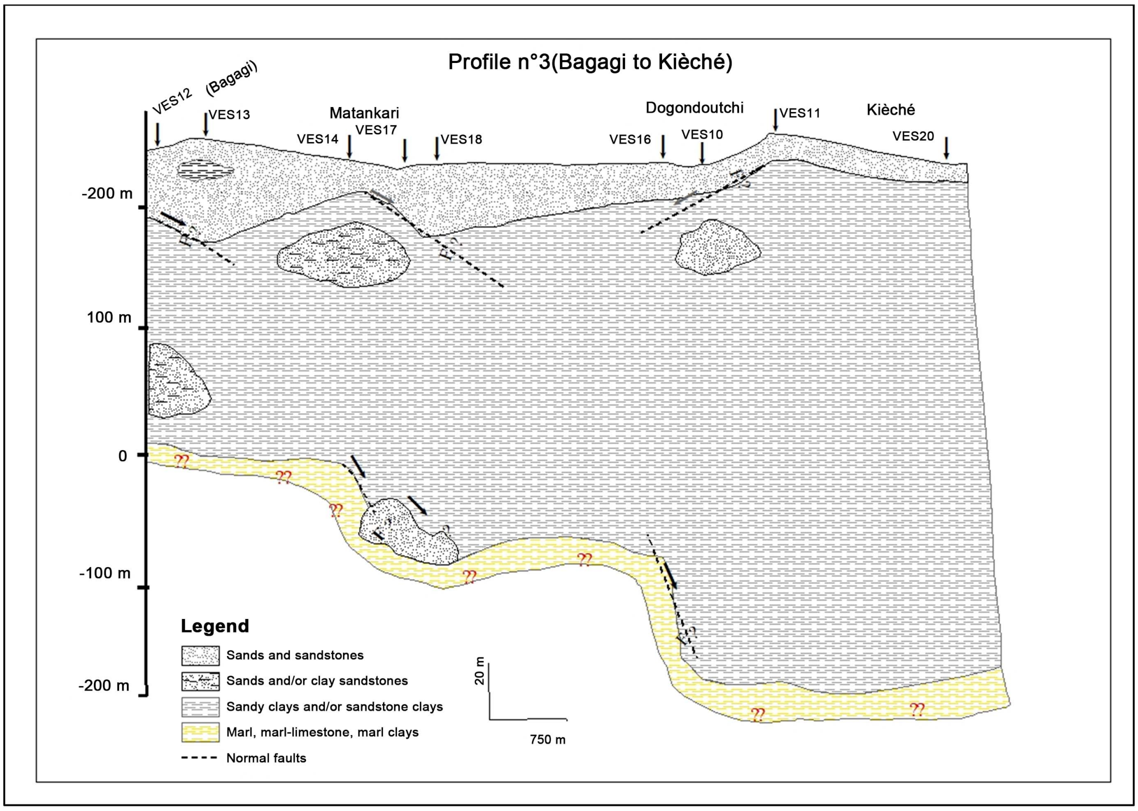


Figure 20. Synthetic geological section from Bagagi to Kiéché.

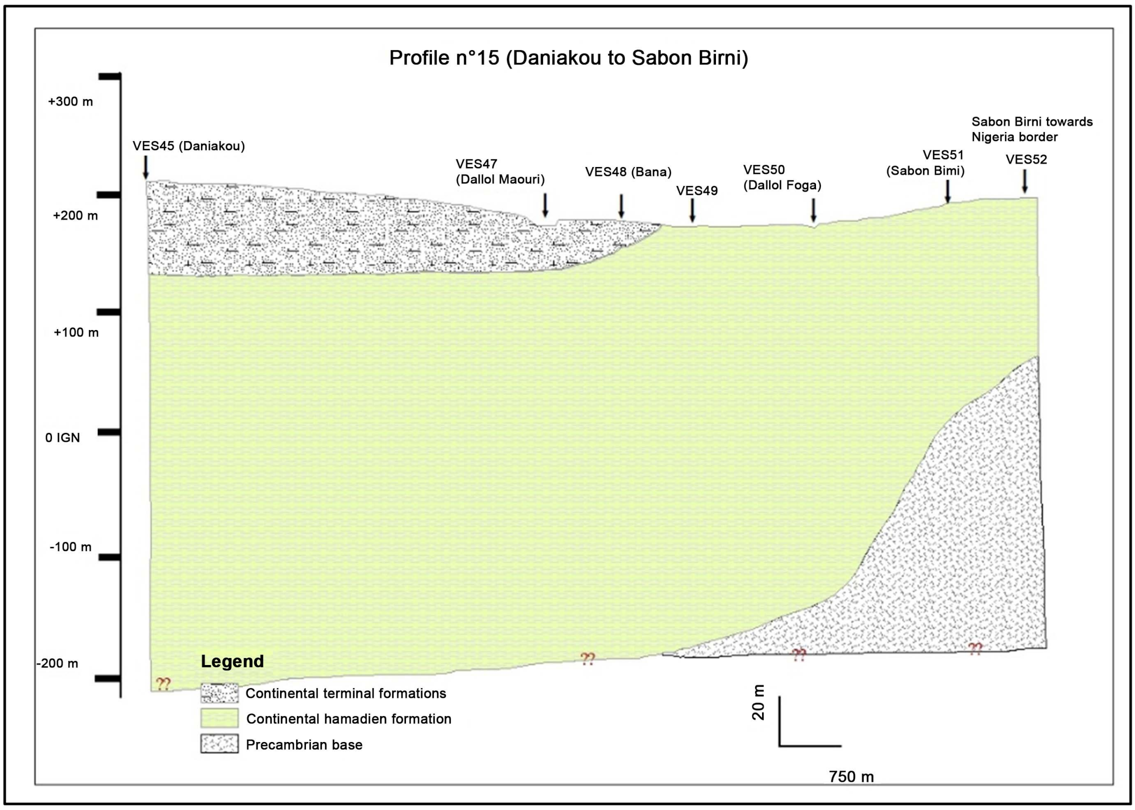


Figure 21. Synthetic geological section from Daniakou to Sabon Birni.

depth of 80 m. At Bana (VES48), the Ct is absent (0 m). At Daniakou (VES45), the upper limit of medium to coarse sands and fine to coarse sandstones of the Ch is reached at around 80 m of depth. At Bana, the Continental "hamadien" is sub-outcropping and its lower limit is reached at Sabon Birni (VES51) at a depth of 180 m.

The contact with the base is located near Sabon Birni (VES51) at a depth of 180 m and reached 110 m towards the river Niger.

The profiles No. 16 (**Figure 22**), and No. 17 (**Figure 23**), show the contact with the base (granites and gneiss) at Talambou village (VES 54) and Boumba village (VES55). Low resistivities observed at VES72 (Tounga Mallan Maichanou's village), VES87 and VES100 (village of Fono Birgui) of approximately 4 - 17 Ω·m correspond either to highly mineralized clays or marl-limestones, or to trapped marine brines.

5.1.4. Synthetic Hydrogeological Sections

The synthetics hydrogeological sections were established based on some piezometric datas and the Ct aquifers boundaries according to the lithology.

The morphology of the land and the positioning of certain layers constituting the different aquifers result from movements of the base under the effect of tectonics. The level of the water table was drawn from Bagagi to Kiéché on profile No. 3 (**Figure 24**), the boundaries of the Ct aquifers were marked. In addition the upper and lower limit of the sandy levels of Ct^3 are clearly visible. At Bagagi, the Ct^3 has a thickness of 85 m while that of the Ct^2 is 110 m, and that of the Ct^1 is around 100 m.

At Matankari, the lower limit of the Ct^3 is reached at 70 m, that of the Ct^2 is reached at 230 m and the Ct^1 at approximately 300 m. This latter corresponds to the upper limit of Paleocene made up of marl-limestone, limestone and marl.

At Dogondoutchi, the Ct^3 has a thickness of approximately 170 m, those of the Ct^2 and the Ct^1 are respectively 130 m and 100 m. The Paleocene marl and marl-limestone begins from400 m in this sector.

At Kiéché, the Ct^3 lower limit is reached at a depth of 190 m, that of the Ct^2 at a depth of 340 m and for the Ct^1 at approximately 390 m.

Brackish ground waters were also identified at different levels in the study area through local resistivity values.

Profile No. 14 shows a synthetic hydrogeological profile going from "Bella 2" to Yelou, where the local resistivities values obtained highlight brackish groundwater at a depth of 71 m at Kawara N'Debé (VES44). At Yelou (VES46) between 88 m and 116 m of depth, a highly mineralized clay level was located. This level could originate from contamination by trapped brines (**Figure 25**).

On profile No. 7 between the villages of Salkam and Kadidi a brackish groundwater was identified considering VES27 survey at a depth of 143 m (**Figure 26**). In the same order at the level of profile n˚ 8 (**Figure 27**), which goes from the village of Kalla Walailawa (VES96) to Tounga Tchiadi (VES81), a brackish water table was located at a depth of 102 m precisely in the locality of Tounga Zamnaou

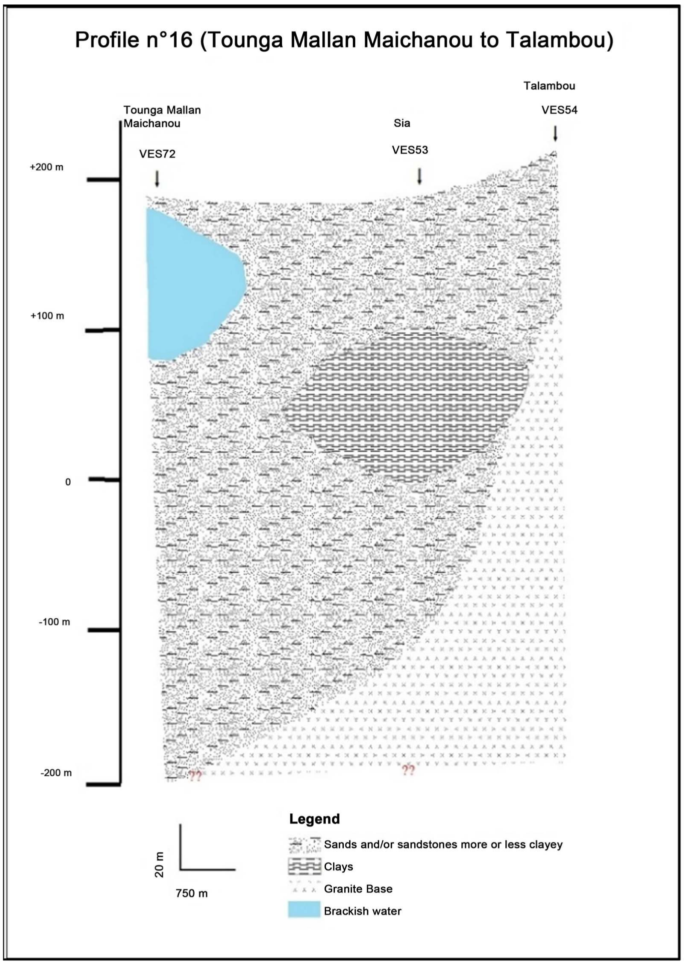


Figure 22. Synthetic geological section of Tounga Mallan Maichanou to Talambou.

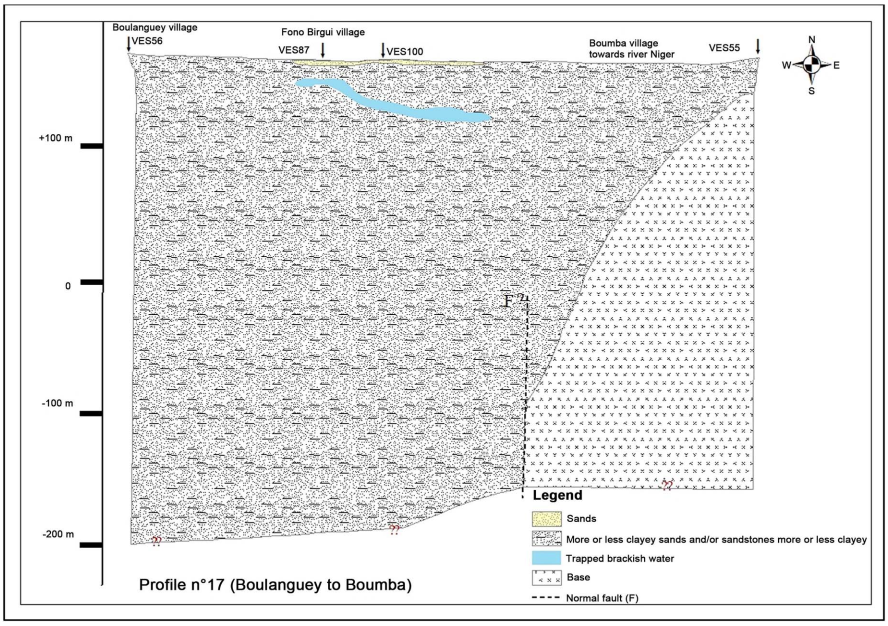


Figure 23. Synthetic geological section from Boulangueye to Boumba.

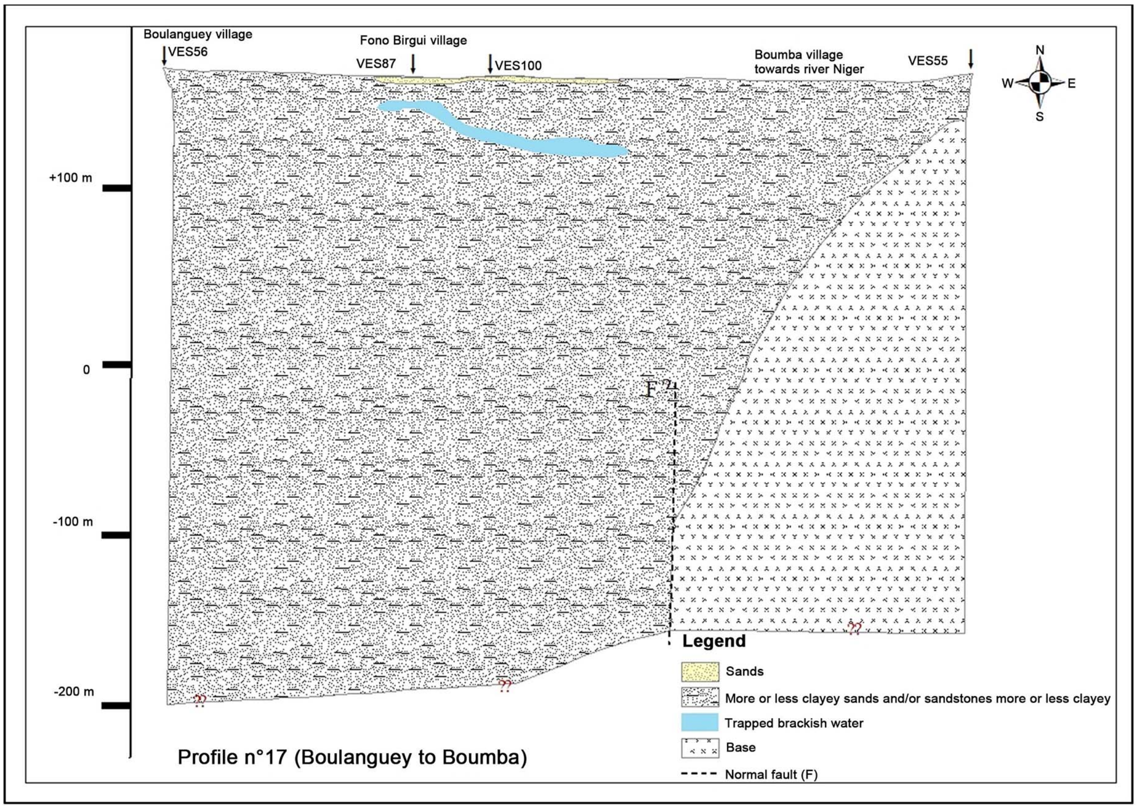


Figure 24. Synthetic hydrogeological section from Bagagi to Kièché.

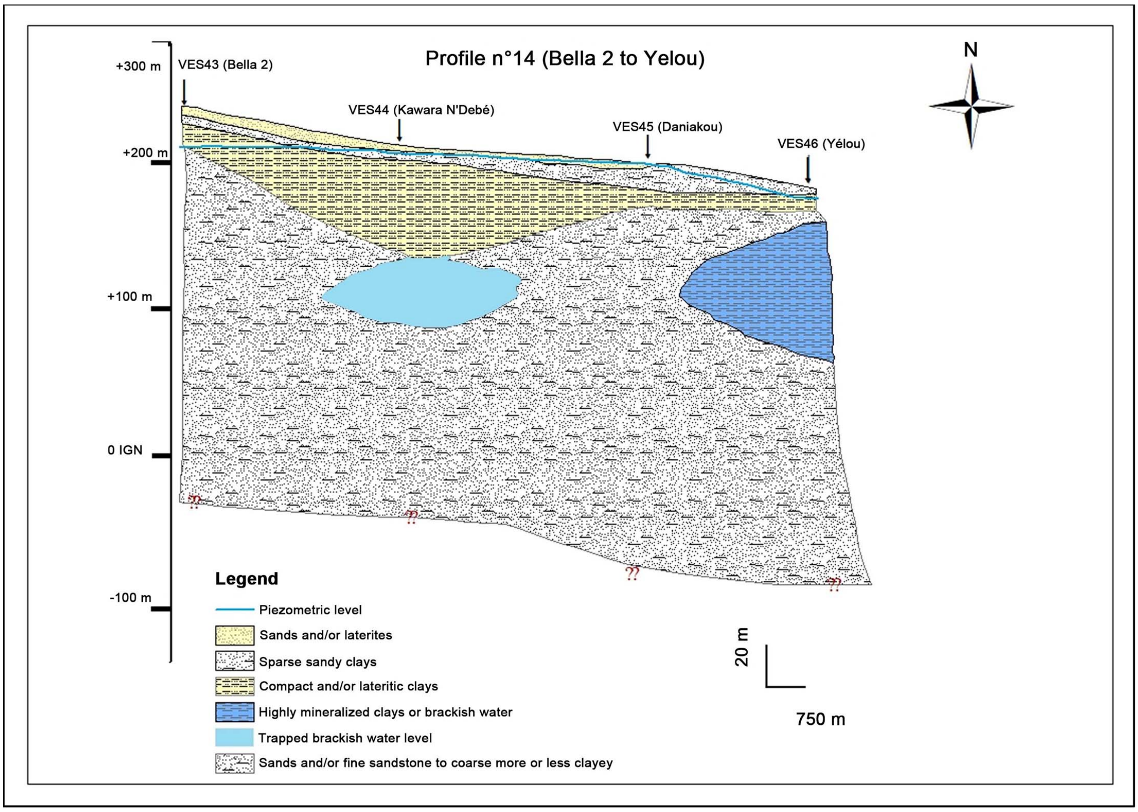


Figure 25. Synthetic hydrogeological section of Bella 2 to Yelou.

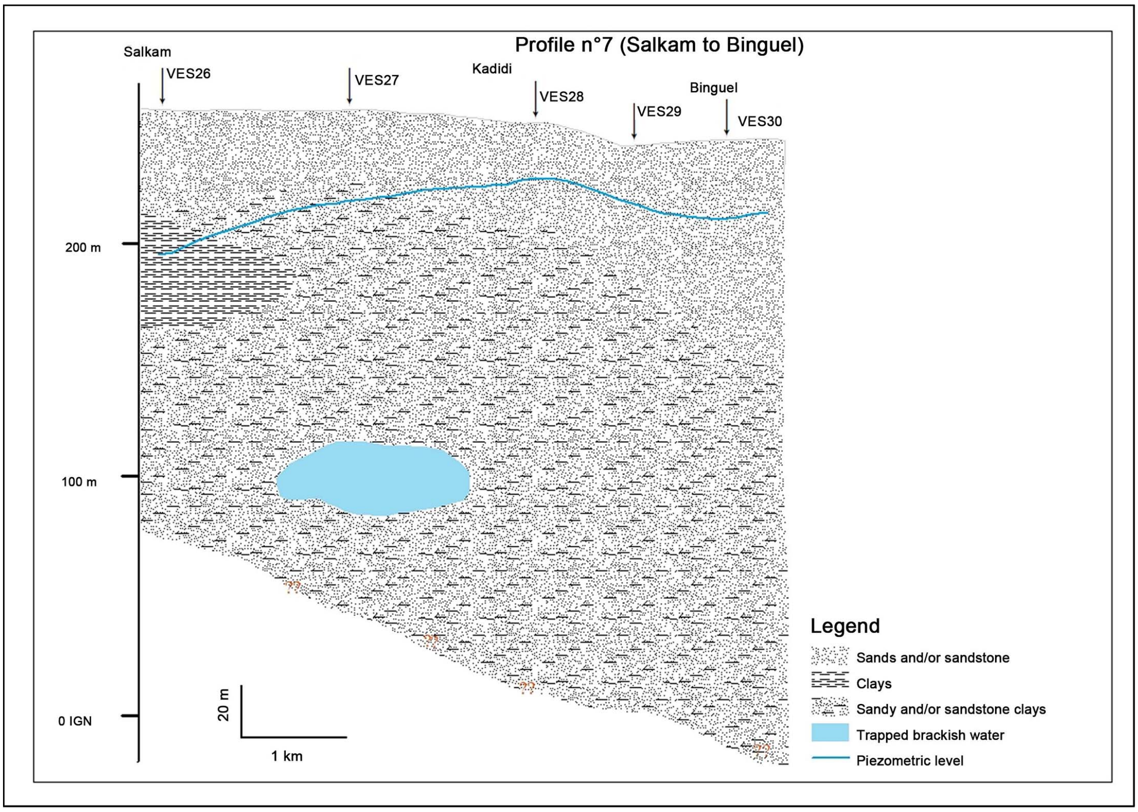


Figure 26. Synthetic hydrogeological section from Salkam to Binguel (Tibiri Doutchi).

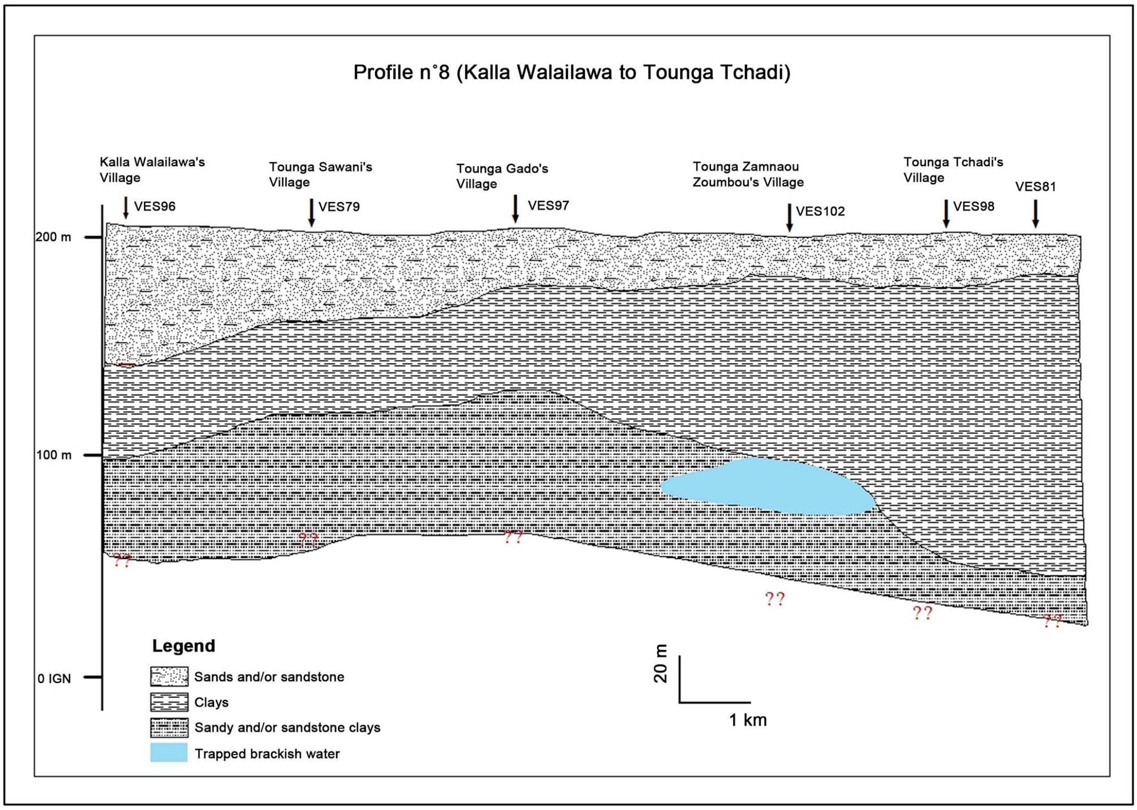


Figure 27. Synthetic hydrogeological section of Kalla Wailalawa to Tounga Tchadi (Dallol).

Zouma (VES 102). The profile No. 20 going from Kohinza Rizi (VES 91) to Bonbayin Gonda(VES 85), indicates the presence of two brackish ground waters (**Figure 28**). The brackish water or highly mineralized clay levels were located by electrical soundings in the village of Kiarangui (VES95) at a depth of 90 m. In the village of Kohinza Maraiché (VES104), the brackish water was also identified at a depth of 89 m.

Based on these different maps established from geophysics and drilling logs, we can say that the nature of the lithological facies, their variations and their distribution in the study area can have a certain influence on the hydraulic characteristics of the aquifers.

6. Conclusions

The hydrogeophysical study of the Dosso region, in the southwestern part of the Iullemmeden basin enabled an atypical characterization of the study area. About 104 wells, spatialed vertical electrical soundings, with AB lengths ranging between 200 and 2000 m, were carried out throughout the Dosso region. These investigations carried out as part of this study yielded the following results:

1) The resistivity scale obtained made it possible not only to delineate the various aquifers in the study area, but also to highlight the presence of brackish water aquifers;

2) The normal play of faults has strongly influenced the geometry of multilayer aquifers in the Dosso region;

3) A model for the spatial organisation of multi-layer aquifers in the Dosso region has been proposed.

Thus the study has shown the different hydrogeological characteristics of the Quaternary, Continental terminal (Ct) and Continental "hamadien" (Ch) formations in the study area. The electrical soundings exhibited the lateral and vertical thicknesses variations of the geological formations across the basin in the study area. It has also shown that the basin has undergone intense tectonics activities. As part of the thickness variations within the basin we can mention that of the Continental terminal, ranging from 0 m in Bana to 400 m around Dogondoutchi (VES10 and VES11). A similar observation can be made for the Continental "hamadien", whose thickness varies from 0 m (north of Sabon Birni) to 180 m (south of Sabon Birni).

Geophysical investigations have also shown the existence of salt water (or perched brackish groundwater) in the study area, hence the low resistivities recorded in certain areas, notably in the Dallols (Maouri and Bosso) and in the Ct^3 formation. These perched layers of marine brine have been identified in the vicinity of the following villages: Kawara N'Debé, Bonbayi Gonda, Fono Birgui, Tounga Zamnaou Zombo, Kohinza Maraiché, Kiarangui.

These marine brines may have been trapped after the retreat of the Paleocene sea, which would have left salts dissolved by the water of the different aquifers, hence the presence of the local brackish water aquifers in the southwestern part of the Iullemmeden basin.

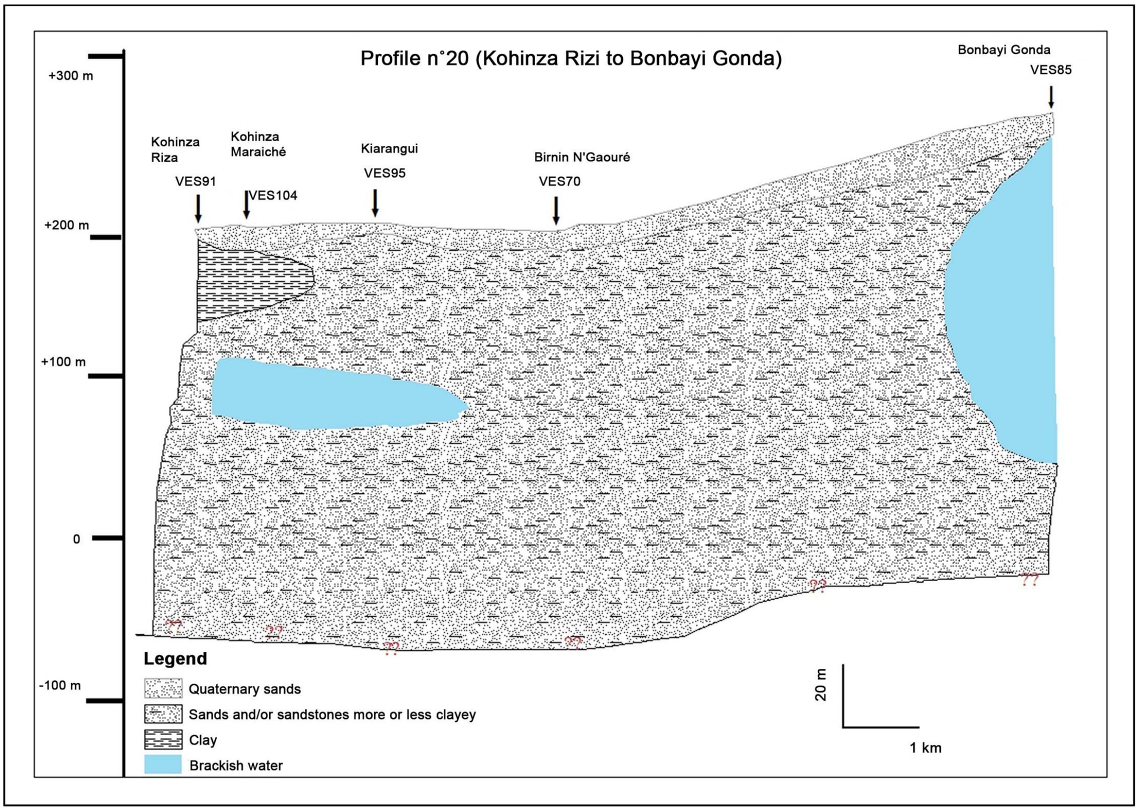


Figure 28. Synthetic hydrogeological section from Kohimza Rizi to Bonbayi Gonda (Dallol Bosso).

As a perspective, it is envisaged to correlate the geophysical information's of the study area with the physico-chemical datas of the water to determine the impact that the electrical resistivities of the rocks could have on the quality of water intended for human consumption but also for agriculture.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Abdou, A.I. (2018) Caractérisation des réservoirs aquifères multicouches du bassin des Iullemmeden dans la région de Dosso (sud-ouest Niger): Apports de la télédétection, du SIG, de la géophysique et de l'hydrogéochimie. Master's Thesis, Université Abdou Moumouni de Niamey, Niamey.

[2] Greigert, J. (1957) Introduction à la connaissance hydrogéologique du Niger: Deuxième partie, Structure des dépôts crétacés et tertiaires du bassin occidental du Niger. Dakar, Sénégal.

[3] Greigert, J. (1966) Description des formations crétacées et tertiaires du bassin des Iullemmeden (Afrique occidentale). BRGM, Paris.

[4] Tirat, M. (1964) Contribution à l'étude hydrogéologique du continental terminal. Rapport BRGM, 77 p.

[5] Boeckh, E. (1965) Contribution à l'étude hydrogéologique de la zone sédentaire de la république du Niger. Rapport technique BRGM/BFBH, DAK 65-A 20. Dakar.

[6] INC (1986) Programme d'hydraulique villageoise dans les départements de Tahoua et Dosso. Secteur géologique et hydrogéologique, rapport général. Ministère de l'Hydraulique et de l'Environnement de la République du Niger. Rapport technique INC, Niamey.

[7] Daddy Gaoh, A. (1993) Etude des nappes aquifères du continental terminal entre les Dallols Bosso et Maouri (République du Niger). Université de Liége, Liége.

[8] Favreau, G., Leduc, C. and Marlin, C. (2000) Représentativité de l'échantillonnage géochimique et hydrodynamique en nappe libre de milieu semi-aride. *Journal of African Earth Sciences*, **31**, 669-678. https://doi.org/10.1016/S0899-5362(00)80014-7

[9] Guéro, A. (2003) Étude des relations hydrauliques entre les différentes nappes du complexe sédimentaire de la bordure Sud-Ouest du bassin des Iullummeden (Niger): Approches géochimiques et hydrodynamiques. Master's Thesis, Université de Paris XI, Orsay.

[10] El-Sayed, H.M. (2010) Environmental Investigation on Lake Maryut, West of Alexandria, Egypt: Geochemical, Geophysical and Remote Sensing Studies. Master's Thesis, Alexandria University, Alexandria Governorate.

[11] Institut National de la Statistique (INS) (2012) Annuaire Statistique du Niger 2010-2014. Recensement Général de la Population et de l'Habitat de 2012.

[12] Radier, H. (1957) Contribution à l'étude géologique du Soudan oriental (A.O.F.). Bulletin du service géologique et de prospection minière, Dakar.

[13] Bellion, Y.J.C. (1987) Histoire géodynamique post-paléozoïque de l'Afrique de l'Ouest d'après l'étude de quelques bassins sédimentaires (Sénégal, Taoudéni, Iullemmeden, Tchad). Avignon Université, Avignon.

[14] Guiraud, R., Issawl, B. and Bellion, Y. (1985) Les linéaments guinéo-nubiens: Un trait structural majeur è l'schelle de la plaque africaine. C. R. Acad. Sc. Paris, t. 300, Sér. Il, No. 1, 17.

[15] Greigert, J. and Pougnet, R. (1967) Essai de description des formations géologiques de la république du Niger. Publication Direction des Mines et de la Géologie, Niger.

[16] Valsardieu, C. (1971) Etude géologique et Paléógéographique du Bassin de Tim Mersoï: Région d'Agadès (République du Niger). Université de Nice, Nice.

[17] Monfort, M. (1997) Étude des relations entre les aquifères du Continental terminal au nord de Niamey (Niger): Approche géologique, géochimique et hydrodynamique. Université de Paris-sud, Orsay.

[18] Greigert, J. and Pougnet, R. (1965) Carte géologique de la République du Niger au 1/ 2000 000. BRGM, Paris.

[19] Zohdy, A.A.R. (1974) Electrical Methods. In: Zohdy, A.A.R., Eaton, G.P. and Mabey, D.R., Eds., *Chapter D*1, *Application of Surface Geophysics to Ground-Water Investigation*, 5-66.

[20] Telford, W.M., Geldart, L.P. and Sheriff, R.E. (1990) Applied Geophysics. 2nd Edition, Cambridge University Press, Cambridge, 535-538. https://doi.org/10.1017/CBO9781139167932

[21] Reynolds, J.M. (2011) An Introduction to Applied and Environmental Geophysics.

2nd Edition, John Wiley and Sons Ltd., New York, 289-345.

[22] IPI2WIN-1D Program (2000) Programs Set for 1-D VES Data Interpretation. Dept of Geophysics, Geological Faculty, Moscow University.

[23] Abdou Ali, I., Konaté, M. and Ousmane, B. (2018) Lineamentary and Structural Cartography of Iullemmeden Basin in the Region of Dosso (South-West of Niger). *International Journal of Science and Research*, **7**, 1168-1176.

[24] Mahammed, D.M. (2012) Utilisation des dispositifs de géophysique électrique non classiques pour l'étude des couches géologiques profondes: Cas des Chotts El Gharbi et Chergui (Algérie). Master's Thesis, Université d'Oran, Es Senia.