Application of Electrical Methods for the Recognition of the Geometry of the Senonian Aquifer in the West Boudnib (Errachidia-Morocco)

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ABSTRACT

The province of Errachidia-Boudnib, located in southeast Morocco, is an arid area known for its rarity of precipitation. Desertification and overexploitation of groundwater have accentuated the downward trend in groundwater levels in aquifers. This study is made for implementation in parallel with the exploitation programs, of comprehensive studies for the recognition of the aquifer of Sénonien. Geophysical methods (drilling and electrical tomography), allow the geometric configuration of the aquifer system of the region of Boudenib, to help those responsible to make good decisions on the positions of the drilling of reconnaissance or exploitation. For these, two geophysical methods were used in this study, electrical boreholes (large extent) and electrical tomography (small extent). The first method allowed us to specify the appearance of the roof of the resistant substratum R2 corresponding to the limestone-clay sandstone formations of the base of the Sénonien whose depth is between 440 and 580 m admitted aquifer; The second method based on the study of the profile by electrical tomography (BD1) profile revealed the presence of conductive lenses corresponding to an aquifer. Therefore, the Senonian aquifer formation corresponds to sands, sandstone, and sandy clays.

Keywords: electrical survey, resistivity, electrical tomography, boudnib, water resources.

INTRODUCTION

Located in southeastern Morocco, the province of Errachidia-Boudnib is an arid area known for its scarcity of rainfall (Alali & Benmohammadi, 2013). Desertification is increasingly threatening, and overexploitation of groundwater (Coude-Gaussen & Rognon, 1993) in the area has exacerbated the reduction in groundwater aquifer levels. It is, therefore, necessary to implement, alongside the exploitation programs, studies for the recognition of these waters. The region of Errachidia Boudnib is recognized by several aquifer systems whose water potential is distinct from the Turonian, Conacian-Santonian, and Senonian ages. The geometric configuration of these aquifer systems remains poorly known despite the geological and hydrogeological exploration undertaken by several authors (Chamayou & Ruhard, 1977; El Ouali, 1992; ABH GZR, 2007; Kettani et al. 2011; Hilal, 2009). In recent decades, there has been a marked improvement in hydro-geoelectric application techniques to locate potential aquifer formations in many parts of Morocco, particularly in the Boudnib region. The objective of this work through geophysics (electrical boreholes

and tomography) (Arimieari, L. et al., 2018) is the knowledge of the aquifer of the Sénonien to master the hydrogeological potentialities in the study area.

To carry out this work 22 vertical electrical soundings (VES) and a small-area electrical tomography profile was carried out with line lengths (AB) of 2000 m and 1190 m for the tomography on the Western part of the Guir-Boudnib basin. This was done in collaboration with the geophysical society Africa Géo-Services.

General presentation of the study area

The Boudnib basin is located South of the Moroccan High Atlas. It is limited to the East by the Bechar basin, to the South by Hamada de Guir, and to the West by the Paleozoic outcrops of the Anti-Atlas. The Boudenib basin covers an area of approximately 43,819 km². (Fig. 1). The geological map of the study area (Fig. 2) was developed from the Rich and Boudnib geological map 1/200000 (Lyazidi M. et al.,1956) and the geological map of the High Atlas of Anoual-Bouanane 1/200000

(Ghissassi A. et al., 1976).The Cretaceous formations outcrop in the Boudnib Basin from the West and beyond Bouanane in the East. In the North, they are generally in abnormal contact with the limestones of the Central and Eastern High Atlas. In the South, they are located on the primary terrain of the Anti-Atlas (Margat, 1977). Sedimentation is carried out in the epicontinental regime and significant variations in thickness and facies. The Infra-Cenomanian corresponds to continental glyptogenic formations, the result of the destruction of pre-Cretaceous reliefs (Choubert G., 1920–1945).The Infra-Cenomanian outcropping to the South of the study area consists of alternating sandstone and marly clays. It has a variable thickness that exceeds 500 m in most regions.

The Cenomanian consists of limestone and dolomitic limestone, interspersed with marl. These marls become more frequent towards the base of the formation. Towards the center of the study area, the marl content seems to be increasing. The upper part of the limestone formation, found in the plateaus, is massive and
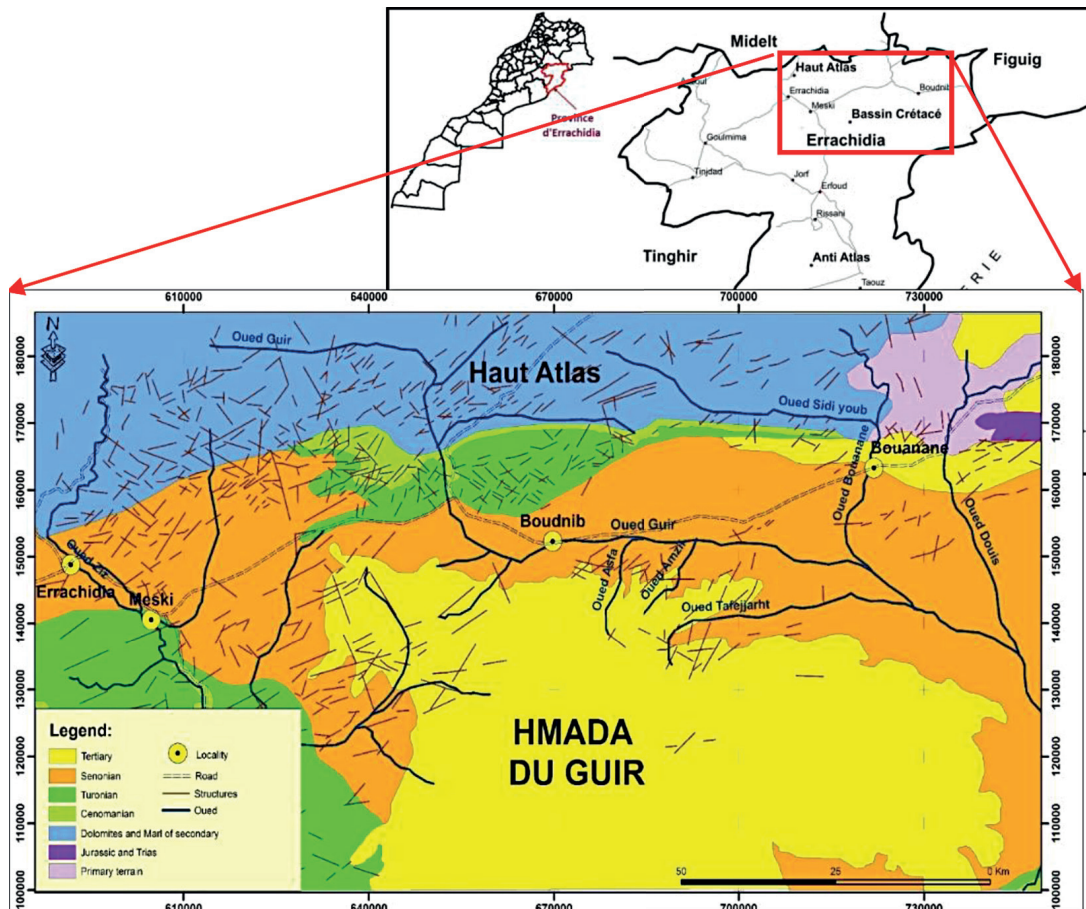

Fig. 1. Geographical and geological location map of the Cretaceous Boudnib Basin (extract from the geological map of the High Atlas of Anoual-Bouanane 1/200000,1976)

forms spectacular escarpments. The Cenomano-Turonian forms thick dolomitic limestone cliffs resting on a series of clays and sandstones. It was deposited during a period of a very important transgression of the sea, which then played a significant role in the colonization of the water tables by the marine crustaceans during the terminal regression (Boutin & Coineau, 1990; Boutin, et al. 1992; Boutin, 1993; Yacoubi-khebiza, 1996). The Senonian consists of very heterogeneous clay-sandstone continental formations, but also gypsum and anhydrite, which thickness varies from 70 m in the East to 500 m in the North (Benyoucef, 2012).

The quaternary

Quaternary lands are highly developed and occupy synclinal basins as well as plains, especially in the East. Depending on the place, more or less cemented puddings, gravelly alluvium, lacustrine limestone, silt, and alluvium represent these terrains. The Cretaceous basin of Boudenib forms, between the High Atlas and the Anti-Atlas, a vast asymmetrical syncline whose axis, oriented substantially WSW-ENE, is parallel to the structural orientation of the High Atlas (Boummane Kh., 2009) (Fig. 2). The climate of the Boudnib basin is arid and characterized by variations in temperature and low rainfall (Benamara et al 2009).

The Oued Guir starting in the Anti Atlas represents the hydrographic network, the Guir is almost permanent because of the contributions of many sources that compensate for the levies for irrigation and infiltration. The main Oued Aït Aïssa tributary and feeding the Bouanane is very similar to the Hight Guir and receives strong contributions from sources ensuring a permanent course (Fig. 1). Groundwater in the Cretaceous Basin plays a role in meeting the water needs of the province of Errachidia. These resources consist of, on the one hand, aquifers located along the valleys and characterized by their small extent and their direct dependence on climatic hazards and, on the other hand, deep layers that are subdivided from bottom to top into three aquifers: the Infracenomanian, the Turonian and the Senonian.

Phreatic table (quaternary)

Located along valleys and characterized by their direct dependence on climatic hazards. With the exception of the Tafilalet plain (Margat ,1977), which is relatively large in area, other quaternary aquifers are characterized by small areas. The persistence of cumulative rainfall deficits over the last five years, combined with the intensive use of the most accessible water resources, has resulted in a widespread decline in the piezometric level of most of the region's water tables. This drop varies between 4 and 5m and can reach 8 to 10m in the water tables of Errachidia and Tinjdad (ABH GZR, 2011).

Deep phreatic tables

The basin of Errachidia, which extends between the High and the Anti-Atlas, includes aquifers that are from top to bottom:
- senonian water, exploited by wells and sinkings;
- water tables of the Turonian limestones, which create the sources of Tifounassine, Meski, and Tarda;
- the aqueduct of the locally artesian Infracenomanian is drained by a Khettara complex South of the Goulmima Tinjdad area. This water table is little exploited due to its salinity in the downstream area and its depth.
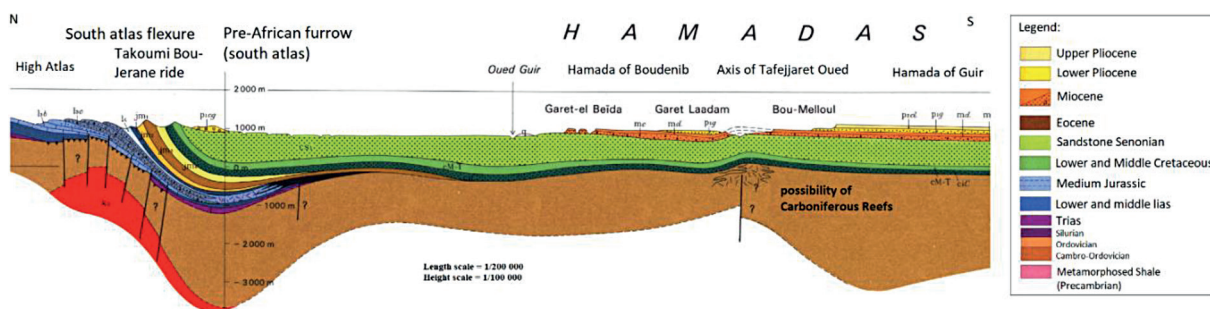

Fig. 2. Extract from the geological section of the High Atlas and the Cretaceous Basin (geological map of the High Atlas of Anoual-Bouanane 1/200000, Ghissassi A. et al., 1976)

MATERIALS AND METHODS

To meet the objectives of this study we used the method of electric sanding to know the geometry and structure of the aquifer of Sénonien, to help those responsible to make the right decision regarding the positioning of future drilling. We also used the 1190 m long method of electrical tomography to accurately detect the location of the drillings.

Vertical electrical sounding

Geophysical prospection through electrical soundings is a four-electrode geophysical prospection method with respect to the center (measuring point), commonly known; as the Schlumberger configuration (Fig. 3) that allows characterizing the subsoil through an interpretation of the apparent resistivity of the soil. The principle of the method consists in injecting the direct electric current of intensity (I) created by a transmitter through two injection electrodes (A, B) and measuring the potential difference (ΔV) between two electrodes (M, N). This depends on the electrical resistance of the subsoil. The vertical sounding allows knowing how the apparent resistivity varies vertically at a given point on the surface (Astier J.L, 1971, Benslimane A, 2005, Chouteau T, 2001). 29 vertical electrical soundings were made with line lengths AB = 2000 m (Fig. 4) on the Western part of Boudnib and cover an area of 150 km² (Fig. 3). The device used is that of Schlumberger (A-MN-B). Data acquisition is performed with the ARESII resistivity meter.

Geo-electric field data was processed and interpreted after inversion by GeoStudi's Jean Louis Astier processing software (JLA plus), which objective is to determine the geo-electric parameters (thickness and resistivity) characterizing each layer, on the basis of the correlation with the lithological and hydrogeological data of the drilling available in t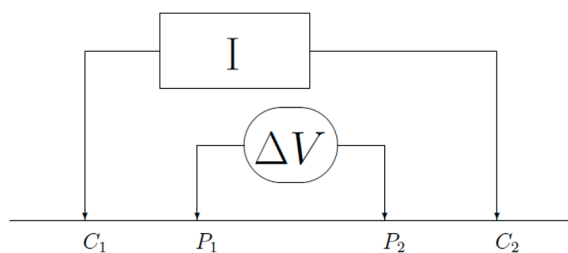he study area (Fig. 5). The results of this interpretation contributed to the construction of vertical electrical sounding models and geo-electric sections.

Electrical tomography

The electrical tomography method (called electrical resistivity tomography or ERT) has been developed with the aim of obtaining after inversion of the 2D or 3D model of the subsoil (Dahlin T., 1996) where the distribution of the resistivity true of the basement varies vertically and horizontally along the measurement profile. This was made possible by advances in computer science and mathematical processing of geo-electric data (Dahlin T. et al, 2011). The principle of the method is the measurement of electrical potential differences ΔV associated with the injection of an electrical current I. Ohm's law is used to calculate the apparent electrical resistivity. This value results from the contribution of all the portions of the medium that are crossed by the current emitted at the surface. We remind that electrical tomography (resistivity) is used for a detailed mapping of deep geological formations (Alabjaha et al., 2018).

We chose to do a small-scale electrical tomography profile that goes through drilling to show detailed imaging of the subsoil, the profile BD1 (Fig. 4) was produced over a total length of 1190 m, with 120 electrodes spaced 10 m apart according to the Wenner-Schlumberger device, in order to reach a depth of investigation of 176 m. For this profile, a cover ¾ Max (Roll Along) was put in place in order to have a terrain imaging of 132 m of thickness. This profile intersects drilling 2104/48 at station 59.

RESULTS AND DISCUSSION

The calibration survey 21BB10 was chosen to extract the true resistivities of the different formations constituting the aquifer of the Boudnib basin by their calibrations with the hydraulic sinkings and to establish electrical correlations throughout the electrical profiles (Fig. 6). The lithostratigraphic log returned from the sinking (2101/48), compared to the electrical sounding diagram 21BB10, enables the assignment of resistivity to each facies (Table 1). It shows that the aquifer, formed by heterogeneous deposits, corresponds to a succession of resistant and conductive
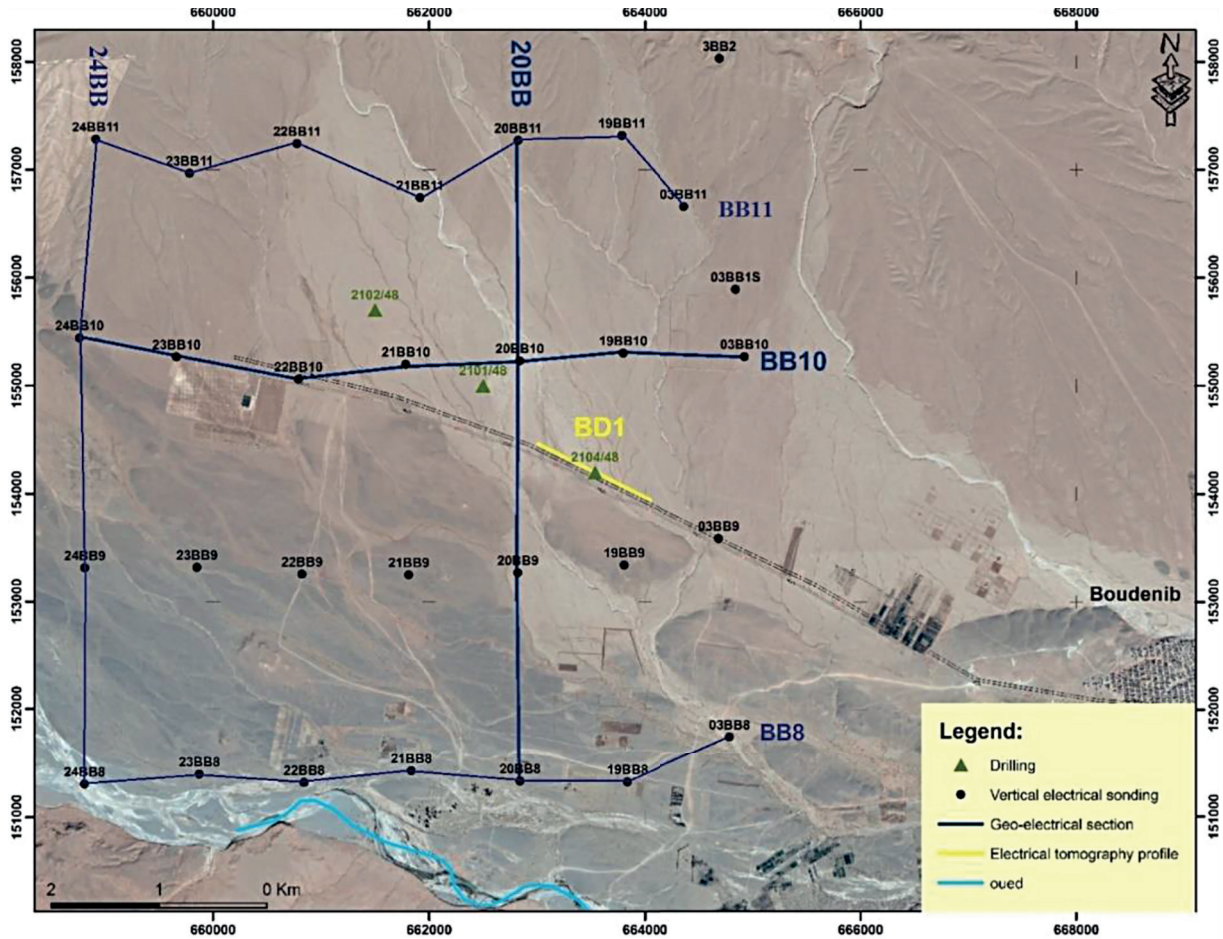

Fig. 3. Diagram of the Schlumberger device

Fig. 4. Distribution of soundings, electrical tomography profile, and geoelectric sections

Table 1. Resistivity values deduced from the calibration of the electrical soundings on the lithological logs

Layer (n)		Resistivity (Ω.m)	Thickness (m)	Depth (m)
R0	1	445	34	0
	2	73	44.6	-34
C	3	25	46.4	-78.6
R1	4	106	37	-125
C1	5	13	215	-162
R2	6	365	Inf.	-377.4

layers denoted R0, C, A1 (C1, R1), and R2 attributed from the surface to the Quaternary formations and surmounted the resistance level R2 of the Senonian (Fig. 6). The correlation made between the 21BB10 sounding and the lithological section shows the presence of a level R0 resistance of a thickness exceeding 200m and resistivity of around 200 Ω (Fig. 7). Examination of data from drilling 2101/48 shows that this level is attributed to Quaternary limestones. The C, R1, and C1 set represents the alternation of sands and clays of the Senonian roof. On this conductor

lays the R2 resistant substrate not reached by the drilling (2101/48), this level is attributed to the sandstone and calcareo-argillaceous series of the Senonian according to the deep sinkings located at the East of Boudnib. The results obtained from the electric sounding 21BB10 data lead to the following observations:

a) for the same training, the resistivity can vary widely from one sounding to another;

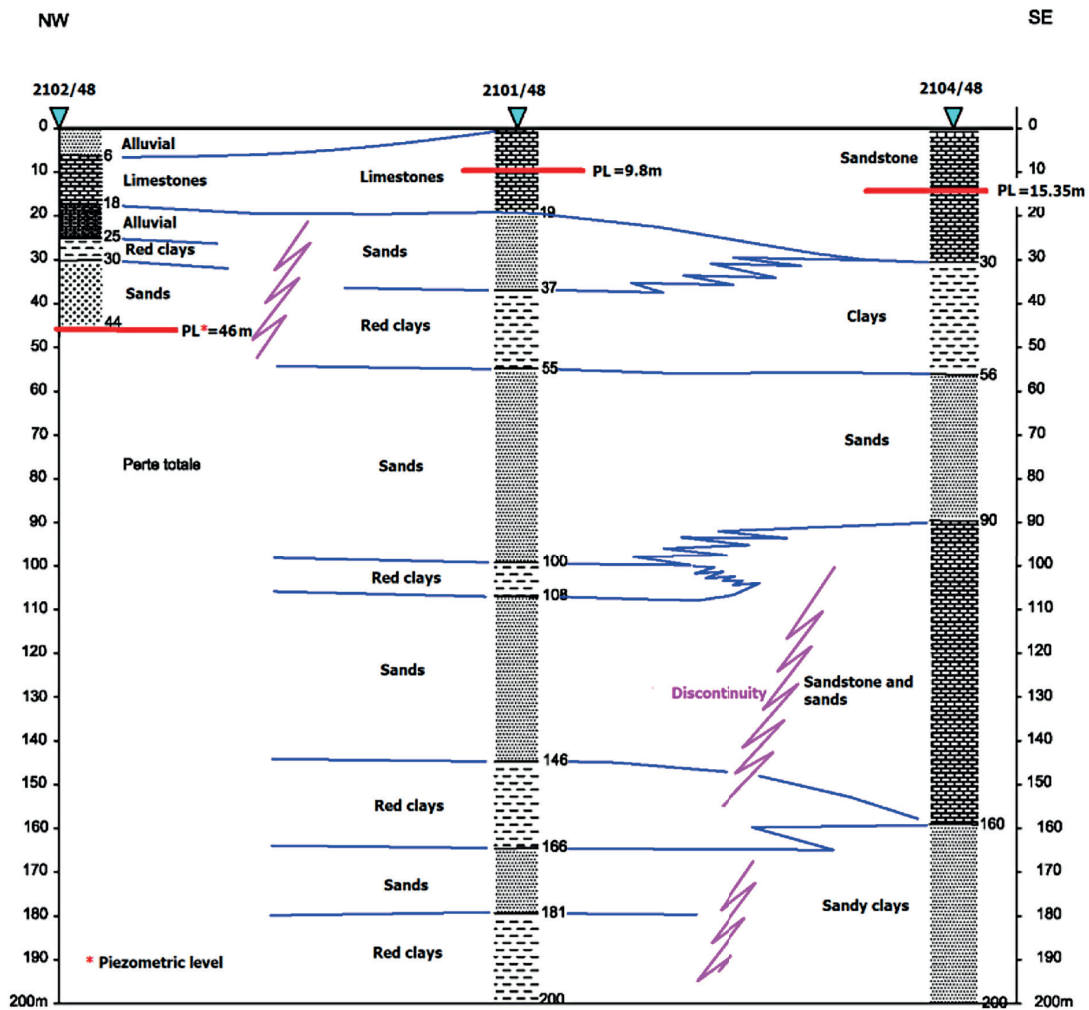b) the 198 m thick conductive level (C) is a good aquifer because it consists essentially of old sands and clays;

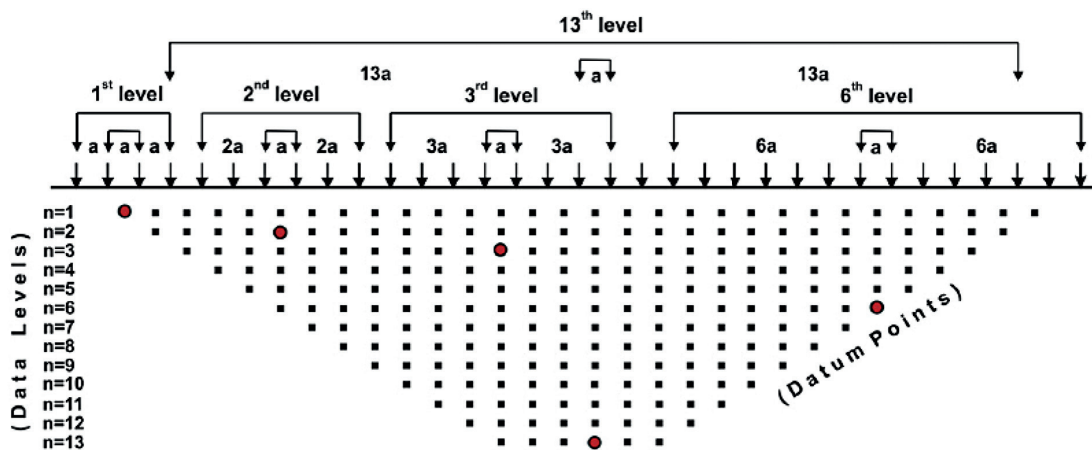**Fig. 5.** Simplified lithological section of correlation between drillings 2102/48, 2101/48, and 2104/48

Fig. 6. Setting up the equipment

c) the C1 conducting level represents the deep Senonian aquifer;

d) the sandstone and calcareous-clay formations of the Senonian correspond to the deepest resistant level or the resistant substratum R2.

Despite variations in resistivity, the results obtained from all the electrical soundings made it possible to determine the electrical characteristics of the various geological units, their thicknesses, as well as the geometry of the entire aquifer.
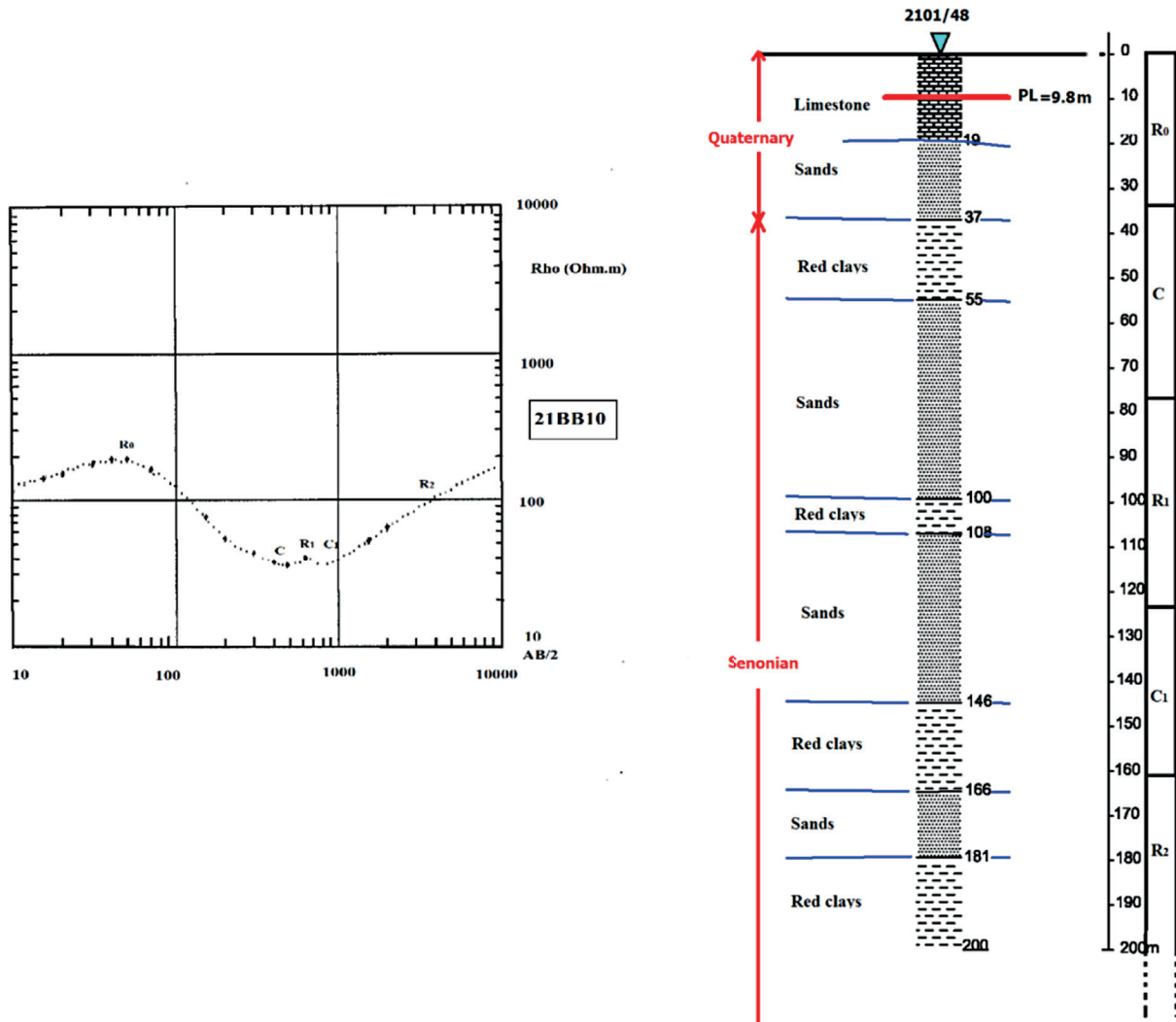
Fig. 7. Electrical sounding 21BB10 and the correlation between the lithological section and the resistant and conducting levels of the sounding

Analysis of the geo-electric sections

The realization and the analysis of the geo-electric sections are essential in this study because they make it possible to understand the geological structure of the area, the different electrical levels, and the set of tectonic accidents that affected the prospected lands. Therefore, three east-west geo-electric sections (BB8, BB10, and BB11) and two north-south sections (20BB and 24BB) are selected (Fig. 4). The correlations made between the electrical soundings have a physical meaning based on the resistivity values obtained in each sounding.

20BB and 24BB sections show the presence of a geoelectric discontinuity D2, centered in the electrical soundings (20BB9 and 20BB10) in the first section and centered between the soundings (24BB9, 24BB10) and (24BB10 and 24BB11) in the second (Fig. 8), this discontinuity is noticed by a change in the geoelectric behavior from a C1 conductive level to an A1 intermediate level, this change is perhaps due to the presence of a fault. This discontinuity separates two families of electrical soundings A and B. The areas with a well-developed conductive level C are centered between borings 20BB9 and 20BB11 (section 1) and 24BB9 (section 2). The transverse geoelectrical sections (Fig. 9) show the presence of the same D2 discontinuity as in the previous sections because there is a change in level from C1 to A1. The conductive level C is well developed in all the soundings of section BB10, except for the sounding 21BB10, where a rise in the resistant level R2 is noted. The correlation between the soundings and the geo-electrical sections revealed the presence of an electrical discontinuity D2 (Fig. 9), which separates two families of
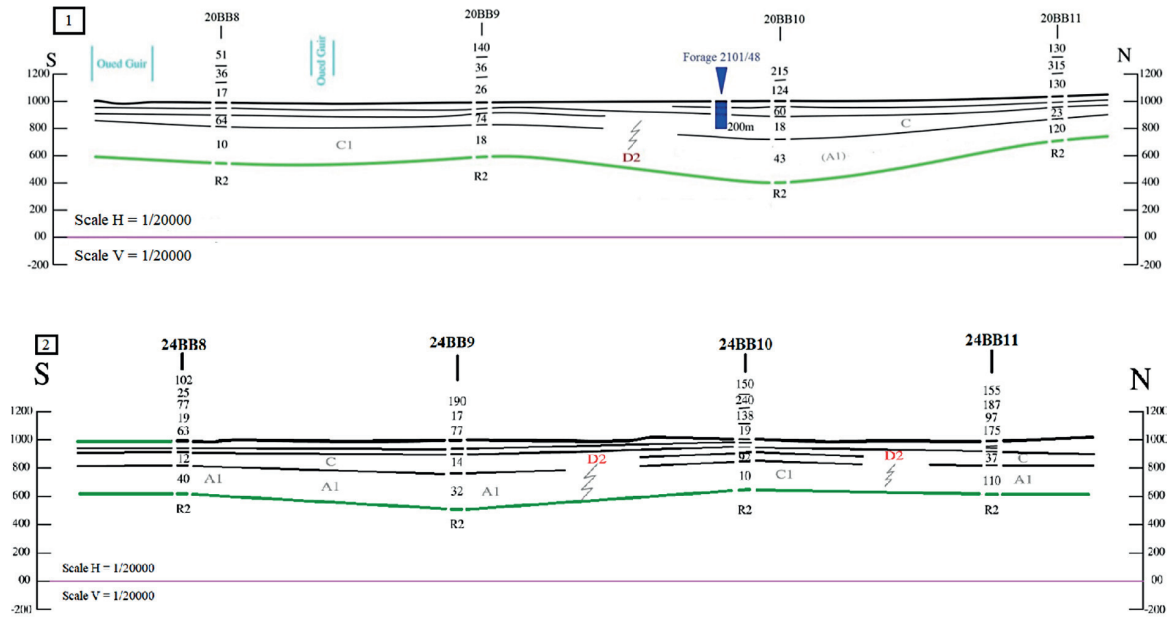
Fig. 8. Geoelectrical sections (1) 20BB-(2)24BB
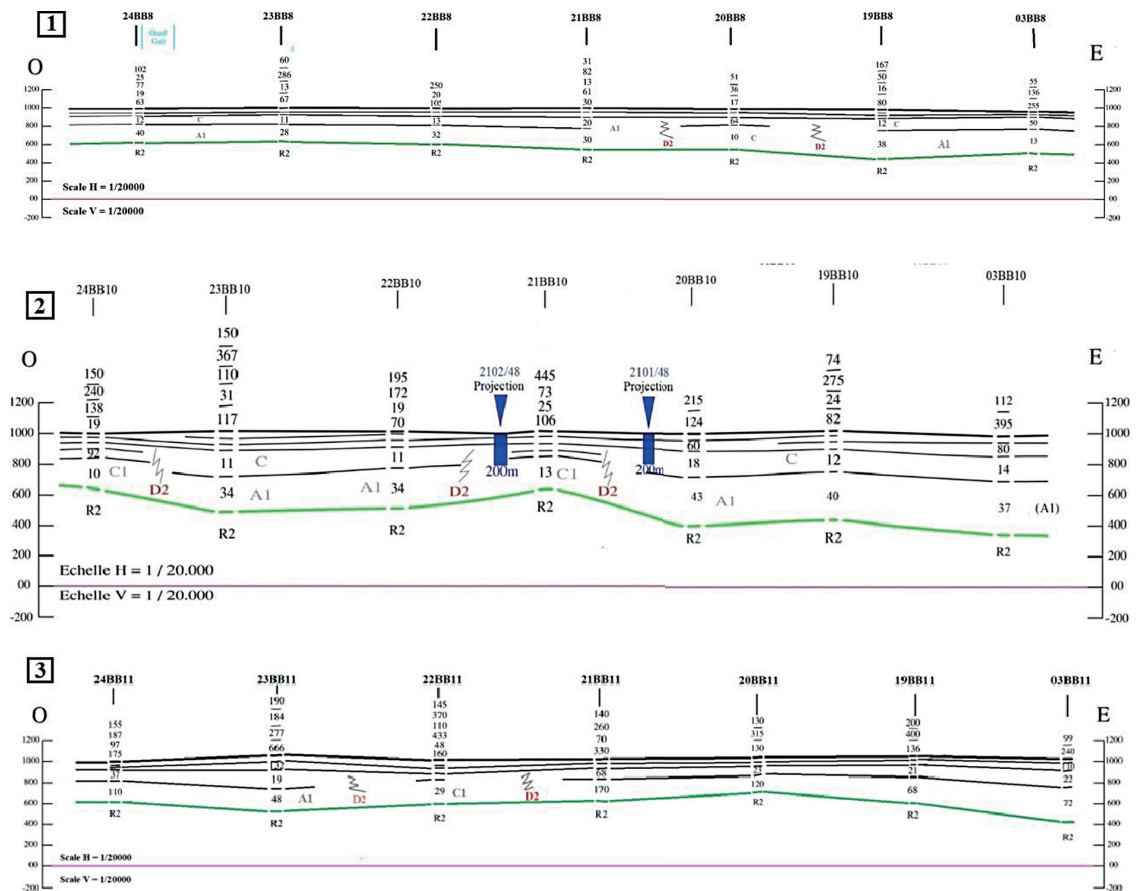

Fig. 9. Geo-electrical sections (1) BB8-(2)BB10-(3)BB11

electrical soundings A, and B. and the presence of the following levels:

- a set R0, C (185 m), which constitutes a good potential aquifer. It corresponds to sands and clays. Its resistivity is variable between 200 and 20 Ω·m ;
- an intermediate level A1 in the A family;
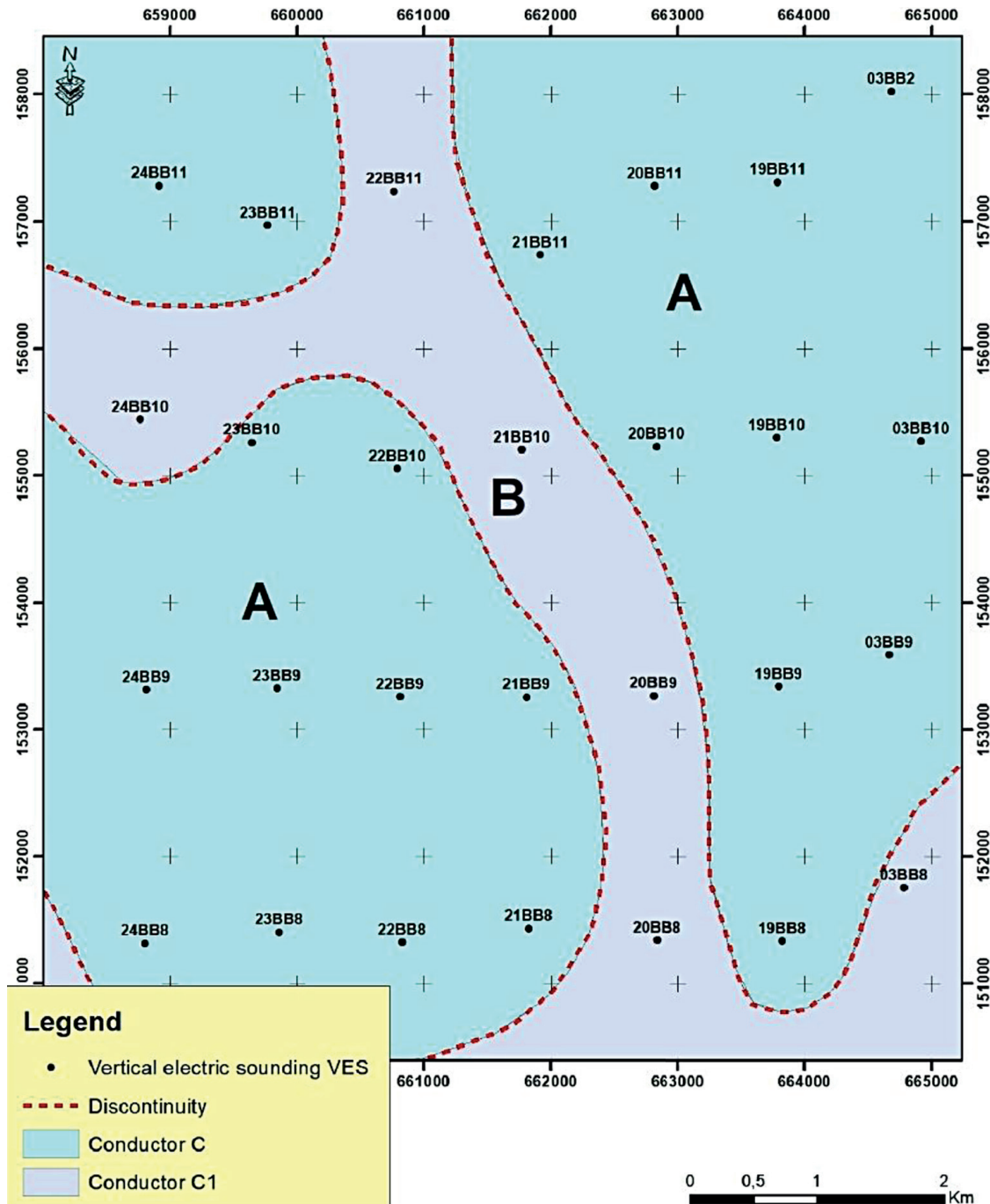- a C1 driver level in family B;

Fig. 10. Map of the main accumulation area for driver C

- a set R2, according to the seismic, the level R2 corresponds to the formations of Senonian (sandstone series and calcareous clay).

Electrical tomography (ERT)

The tomographic images calculated with the Res2DInv software reveal the presence of three ranges that can be seen as three zones: resistive, intermediate, and conductive. The examination of the BD1 profile belonging to family A (Fig.

10) highlights the presence of three levels of resistivities:

- resistivity levels: $\rho \geq 200$ Ω·m;
- intermediate levels: 40 Ω.m $<\rho <100$ Ω·m;
- conductive levels: 5 Ω.m $<\rho <30$ Ω·m.

The resistant levels correspond to the top part characterized by well-cemented sandstones with a very low porosity, whose wall coincides with the piezometric level (drilling 2104/48). The lenticular, conductive levels are attributed
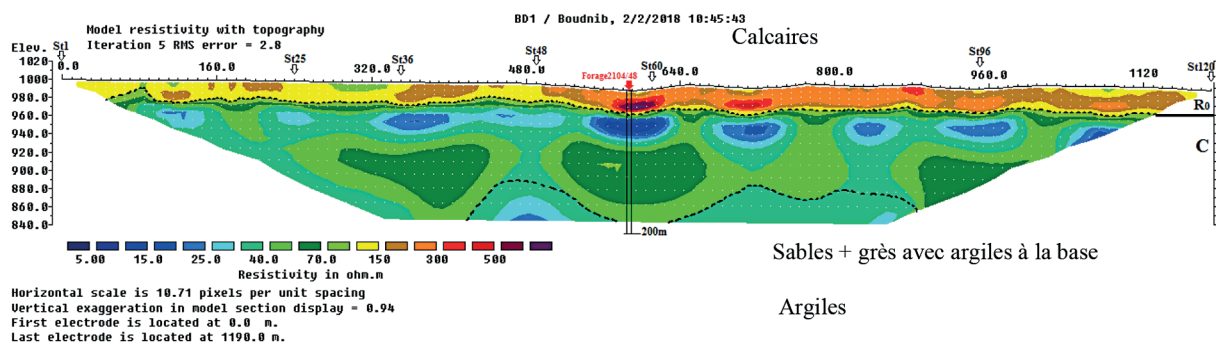
Fig. 11. Electric tomography profile BD1

to Senonian sands, sandstones, and sandy clays, generally located between the resistant and intermediate levels. The lithological section 2104/48 was used for the geological identification of the geo-electric levels highlighted by the profile of electrical tomography (Fig. 11).

CONCLUSIONS

Several aquifer systems are present in the Boudnib region and represent a distinct water potential: the carbonate and dolomitic formations of the Turonian age but also those of the Conacien-Santonian base. This work focused on the Senonian aquifers. This study demonstrates the potential of geophysical data, particularly the electrical methods associated with drilling data, for geometric and structural aquifer recognition in the Boudnib Basin. In addition, it has provided important information on the overall lithological structure of the subsoil, the definition of the different electric horizons and their geological correspondences, the geo-electric sections, and the main electrical discontinuities present in the region. The correlation of the 29 electrical soundings allowed us to trace this discontinuity and differentiate two electric sounding families whose family B represents a good place for future drilling to help the decision-makers make good decisions regarding the positioning of the drilling of reconnaissance or operating. The results obtained made it possible to distinguish the accumulation zone relative to the C conductor, attributed to the Senonian formations, whose aquifer potentialities were demonstrated by the results obtained by numerous drillings located east of Boudenib. and the distribution of the two families of electrical soundings A and B on the study area which are separated by the electrical discontinuity D2.

The detailed profile of electrical tomography showed the existence of sand, sandstone, and sand-clay lenses of the Seninian age according to drilling data. These results are of considerable interest on the socio-economic level. They allowed the evaluation of aquifer potentialities, in a region subjected to a recurrent water deficit.

Acknowledgments

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