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# Hydrogeophysical Study of the Mahafaly Plateau (Case of Masiaboay and Beantake Rural Municipalities)

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**ABSTRACT:** The Mahafaly Plateau, located in the semi-arid zone of southwestern Madagascar, has suffered successive droughts in the past few years. Access to water in this area was then difficult because of the climate disturbances and the hydrological nature of the land.

The purpose of this study is to identify the geological structure of the aquifer system using Vertical Electrical Sounding (VES) and Electrical Resistivity tomography (ERT). It is necessary to understand the hydrogeological and hydrodynamic implication of the region of interest.

The results highlighted the heterogeneity of the formations and the conductive layers thicknesses beneath the plateau. Also, the substratum is much deeper in this area. Following this configuration, the superficial aquifer system is dislocated in uplifted blocks and fractured by faults. The study area is then characterized by the discontinuity of groundwater flow and variety of hydrodynamic distribution.

**KEYWORDS:** Mahafaly Plateau, Hydrogeophysics, Groundwater.

### I. INTRODUCTION

For a very long time, the southwestern of Madagascar, with a semi-arid type of climate, has significant problems of water resources. This situation is reflected by many inhabitants of the area by the consumption of water with very poor quality both physico-chemically and bacteriologically [1]. The Mahafaly Plateau, which stretches along 200km, is particularly affected by this problem because of all the salinity problems experienced by most areas including the Rural Municipality of Masiaboay and Beantake are located in the least watered area of the island with a rainfall of about 300 to 400mm per year [2]. In short, this situation leads to a major obstacle to regional development.

This hydrogeophysical study aims to define the geometric characteristics of the Eocene aquifer of the Mahafaly plateau, in order to better understand the geological and hydrogeological structure as well as the origin of the mineralization of the aquifer in this zone.

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## II. PRESENTATION OF THE STUDY AREA

### Geographical location

The study area lies in the Rural Municipalities of Masiaboay and Beantaka, parts of the BetiokyAtsimo District (9829km<sup>2</sup>), in the southwest Region of Madagascar. It is located in the southern-part of BetiokyAtsimo District. It is surrounded by the Sakamasay Municipality in the East, the Municipality of Tameantsoa and ankazomanga in the North, the Municipality of Maroarivo in the West part, and the Municipality of Beahitse in the South. Approximately 4690 inhabitants live in an area of 485km<sup>2</sup> that gives an average population density of 28 inhabitants per square Kilometer.

The Rural municipality of Beantaka is located 15km away in the southwest of the BetiokyAtsimo village with a surface area of 400km<sup>2</sup> (Fig. 1).

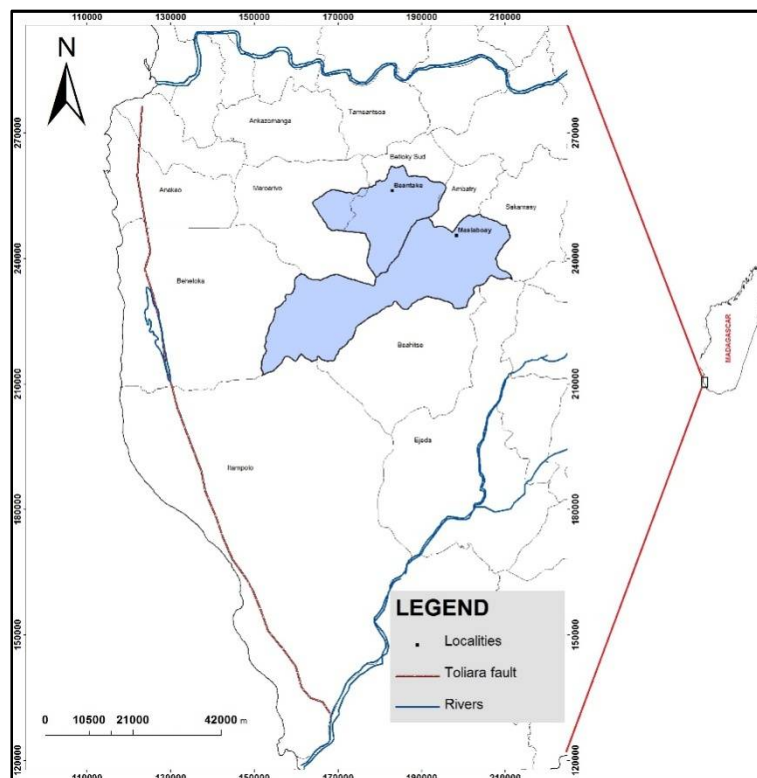


Figure 1: Location study area

### Climate context

The southwestern-part of Madagascar is marked by a dry season almost all year long and receives very little rain. It does not exceed 600mm per year in the whole region. Over 80% of the rainfall, on average, is during the rainy season (from November to March), and January is the rainiest month [3]. On the other hand, the period stretching from April to October is remarkably dry, the minimum rainfall received by the area is between 2mm and 2.5mm in the month of July. The annual average value of evapotranspiration is between 800mm and 1000mm while the annual average value of evaporation, is less than 1400mm in the South-West [4]. The calculated value using the Thornthwaite method for 10years was 1030mm in Betioky[5].

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## Geological setting

The large group of the Mahafaly Plateau (approximately 8000 km<sup>2</sup>) is respectively above the crystalline basement lands in the South and the ancient sedimentary rocks in the North [6]. This plateau is usually covered by a thick sandy shell or limestone crust that hides the rock in site. Slightly inclined towards the sea, it is cut by several actual or fossil valleys [7]. Beneath this cover, the Glossopteris sandstones and shales have been stratified and inclined to the west following a monoclinial structure.

Glossop sandstones and shales are deposited beneath the nodule clay and it is the hardest layer of the Sakamena. This formation extends approximately along 9km in NNE-SSW direction. Towards the Masiaboay west town, alternation sandstone-schist manifests itself, but in the Municipality of Beantaka, the area is dominantly covered by sandstones. Because of their hardness and resistance to erosion, sandstones formed the hard rocks in riverbeds and formed the escarpments on the surface. Slightly inclined towards the sea, it is cut by several actual or fossil valleys

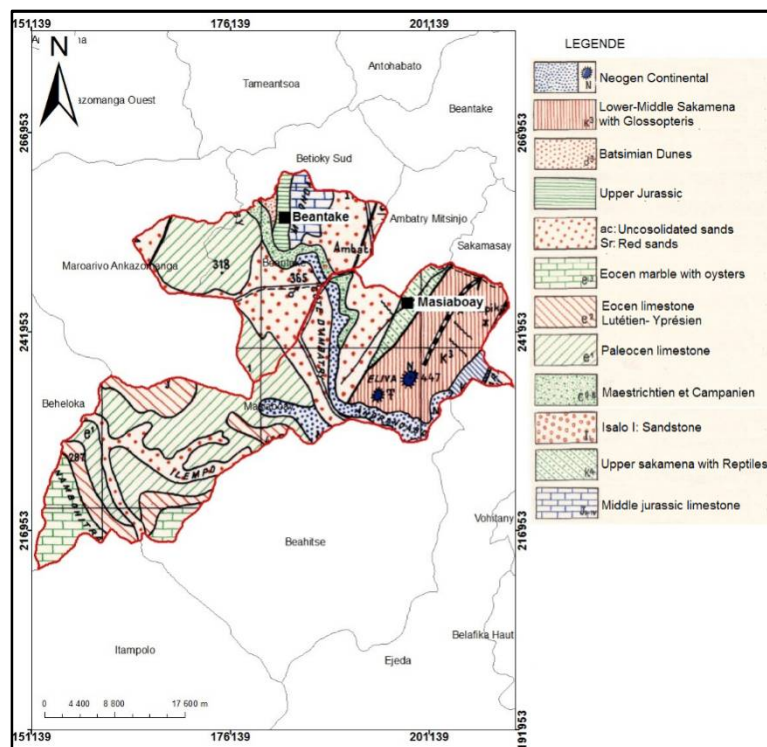


Figure 2: Geological map of the study of area

## Hydrogeological context

The study area is drained by Sakamena, an affluent of Onilahy which has a mixed regime. Its maximum hydrological level is related to the maximum rainfall. As a result, most of the watersheds in the area are drying up but often have an underflow. The superficial circulation waters that meet underflow are of good chemical [2].

Often, sudden the heavy rains arose and were immediately followed by the floods. Areas in low altitude and terraces are flooded during heavy rain according to local residents. The high waters last only for a few months (December-March), with a significant rise in January and a period of erosion (mid-July to mid-September), due to high temperatures and very low atmospheric humidity. The flow of Sakamena on the NorthernAmbatokapika-Masiaboay road is around 4.5l/s (May 2013)

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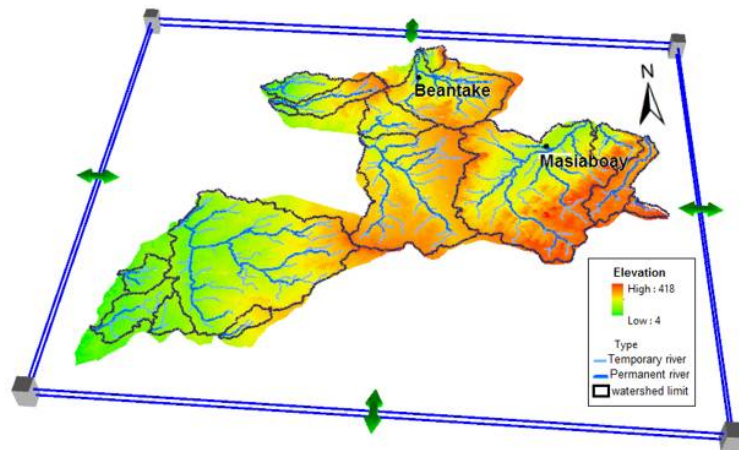


Figure 3: 3D watersheds characteristic in the study area

In the rainy season, where there is a lot of flooding, the flood waters feed the groundwater despite the very violent flow. The water table ensures the low flow of water and the flow of streams after the rainy season. This phenomenon is proven by the physico-chemical measured in the surface water with similarities in some wells. The recharge is ensured by the infiltration of rainwater in the watershed.

In the fractured areas with a compact layer (basement or sedimentary), the hydrographic catchment often coincides with the watershed. Drains (on surface and underground) are controlled by fracture networks to the outlet. The flowrate depends on the slope of the piezometric line between the feed zone and the outlet.

Apart from the outflow lines observed along the rivers, no outlet of the groundwater was identified in the area during our field work. Drainage is by evaporation and direct capture by drilling or by wells in the aquifer.

### III. GEOPHYSICAL METHODS

The geophysical study began with calibration of the vertical electrical soundings of the existing works (well or drilling) to wedge the results obtained. Subsequently, 41 VES with AB/2 separation 800m and 4 ERT were established within two Municipalities. Figure 4 shows the distribution of the measurements. These profiles have been oriented in such a way that (i) orthogonally cross-cut the faults and folded structures, assumed to play a role in the flows; (ii) capture the maximum of the stratigraphic series in order to test the hydraulic behavior of the main formations (aquifers, aquitards, raincoats, roof, wall, etc.), and to have as much information as possible on their geometry, hoping to intercept the main pipes groundwater if the hypothesis of the dominance of the preferential flows is confirmed. Otherwise, invalidate, or qualify such an assumption, if necessary. The instrument used in this study was SYSCAL R2 resistivimeter [8].

The acquired data are presented in the form of apparent resistivity sections. Respectively, the horizontal and vertical axes match to the distance along the profile and the separation between the two mobile electrodes. On the panels, the measurements are plotted in the middle of the acquisition device at a scale corresponding to the value of the current separation of the moving electrodes [9]. Basement models showing the sectional distribution of resistivity were calculated from the sections using the data inversion method by [10].

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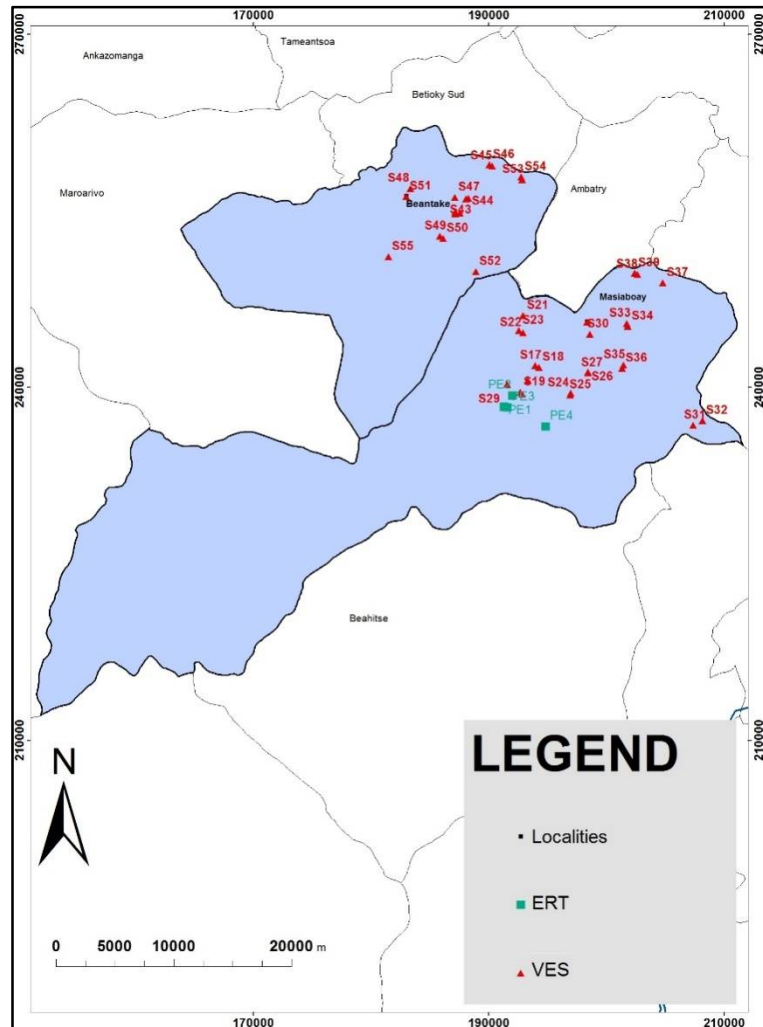


Figure 4: Spatial distribution of geophysical measuring station

## IV. RESULTS

Results are interpreted in two steps. The first step consists of the VES curve analysis produced by the QWSEL software in order to highlight the physical contrasts between the different layers. Attempts were made with lateral correlations establishment in the whole area covered by the geophysical measurements in order to establish correspondences between the lithological layers and the value of the electrical resistivities. The interpretation of the ERT was performed with the Res2Dinv (resistivities 2D inversion) software based on an inverse technique developed by [10].

It is an interactive program that calculates the theoretical response of a terrain consisting of several horizontal layers, each with its own resistivity. The number of layers, their thicknesses and their resistivities should be modified to obtain a result compatible with the data collected in the field. Since several solutions are possible, the model is subject to certain limits based on the geological structure of the study area. In the area of interest, the geological data collected in the immediate area allowed us to better calibrate the modelling.

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## Vertical electrical soundings (VES)

Depending on their shape, the curves were grouped into four groups: I, II, III and IV (Fig. 4 and 5). The VES depth of investigation was varied between 1/4 to 1/3 of AB/2 [11].

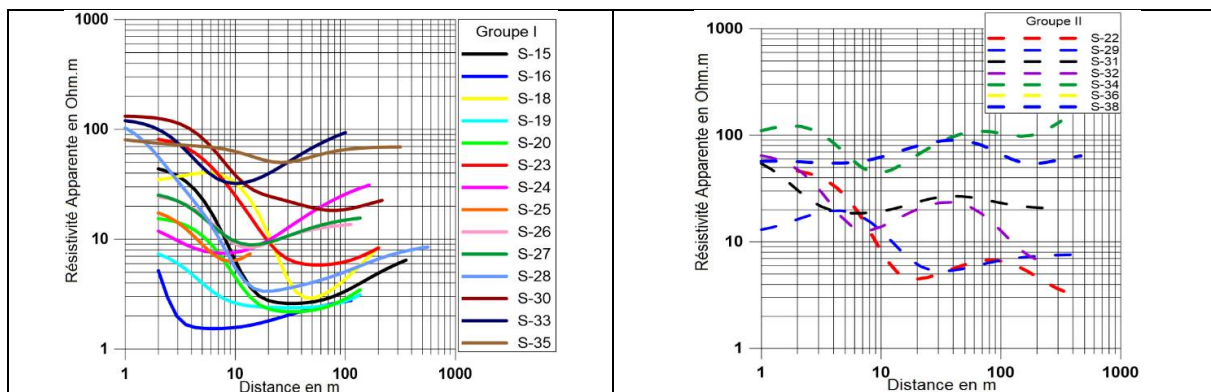
*Group I:* It shows a model with three layers of type H ( $\rho_1 > \rho_2$  and  $\rho_3 > \rho_2$ ) highlighting the first layer at surface, a resistivity approximately between 20Ωm to 50Ωm which would correspond to a sandy shell or red sand; the second layer, thick, had a resistivity between 4Ωm to 15Ωm and could be assimilated to an aquifer and the last layer, moderately conductive would correspond to shale or clay that constitutes the substratum.

*Group II:* It represents a model in "bell and bottom of boat" highlighting the first resistant layer at the surface, with a resistivity of 86Ωm and 3m thickness which can correspond geologically to a sandy layer. The second layer, less resistant, with a resistivity around 25Ωm matches to sandstones. The third, conductive layer, which is based on a layer of sandstone, corresponds to a very thick ferruginous aquifer.

*Group III:* It is characterized by "two consecutive curves at the bottom of the boat". The first three pitches define a perched aquifer with its complex conductive in the bottom of the boat. The second aquifer is represented by the more conductive ground of the second bottom of the boat. This shape of curves also reflects the presence of a superficial aquifer which is separated from the fracture aquifer by a thick layer of dry clays, the lower aquifer is therefore often charging. It is therefore, in all cases, superimposed aquifers. This group shows: a resistant surface layer of 40Ωm resistivity corresponding to alluvial formations, a second resistivity conductive formation of 10Ωm, with a thickness of 8m. It is a waterproof layer supposed to be a layer of nodular clay. The third moderately resistant (resistivity 20Ωm) formation with a thickness of 13m corresponds to the alteration of Glossopteris sandstones and shales. It is a waterproof layer enclosing the aquifer. It is laying directly on a layer of thick clay, impermeable, conducting resistivity of 8Ωm. Finally, a very resistant layer of resistivity higher than 171Ωm which agrees with Glossopteris sandstones and schists

*Group IV:* It represents a particular model of incomplete survey curves, which doesn't show the rise of the basement. This group illustrates an electrical survey of highly altered shales that is much altered schists and the thickness exceeds 100m. To be able to reach the resistant shales lengths of the line should be very long ( $AB / 2 \geq 500m$ ). This peculiar shape of VES curves can be encountered in schistose, greenstone, or granitic rocks with very strong alteration (shear corridor).

### Case of Masiaboay Rural Municipality



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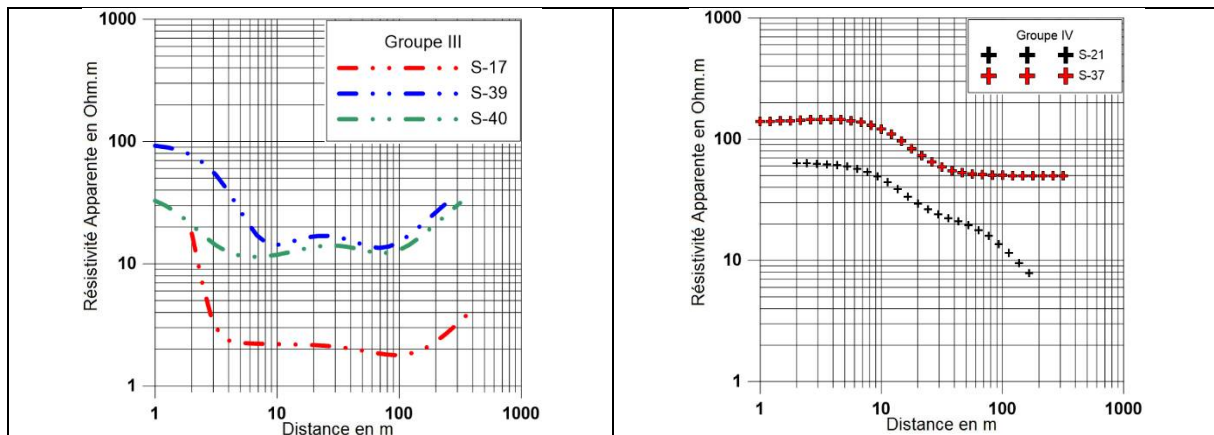


Figure 5: Types of Schlumberger sounding curves in the rural municipality of Masiaboay

## Case of Beantake Rural Municipality

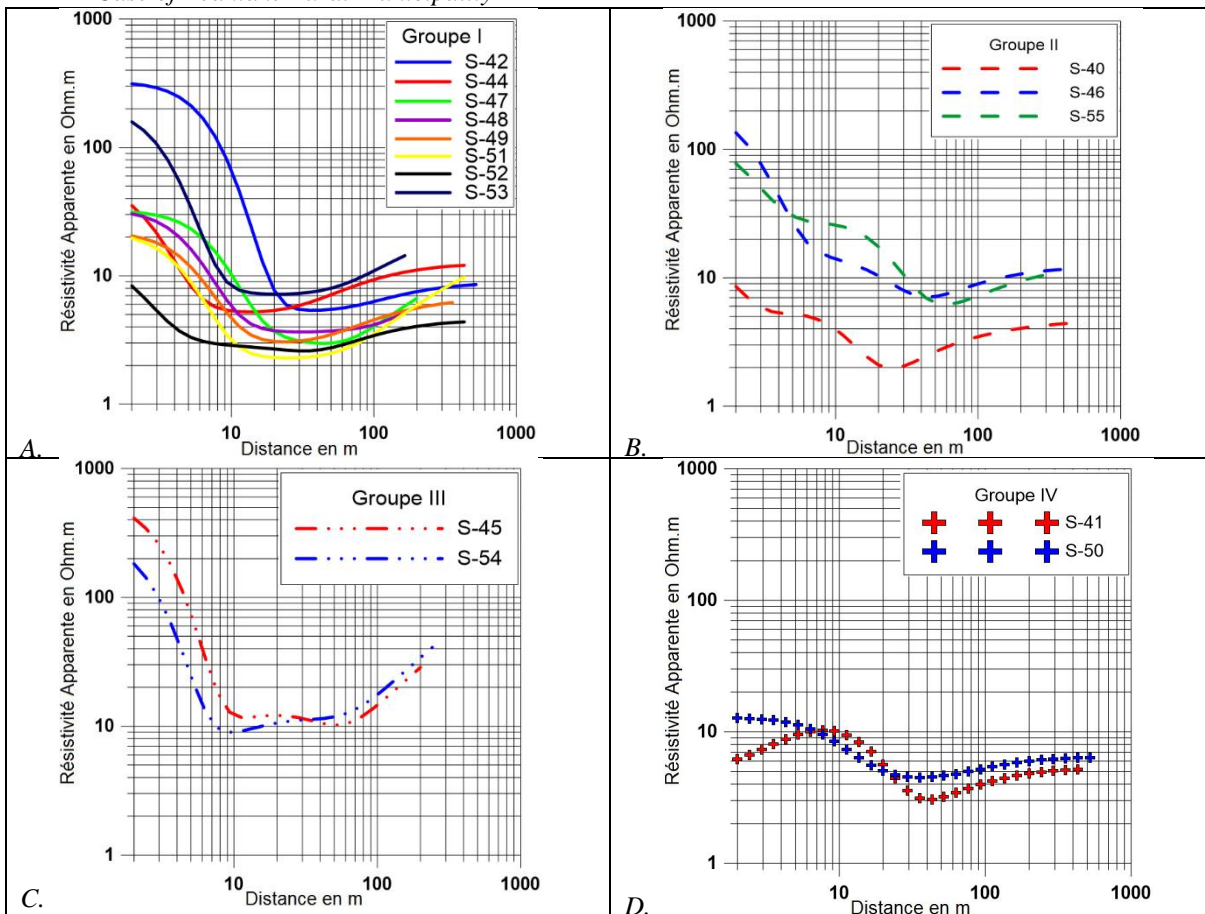


Figure 6: Types of Schlumberger sounding curves in the rural municipality of Beantake

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A similarity of layers has been seen in the two zones of intervention. They consist of an alternation of sandstone and shale below a sandy shell or red sands. The alternation is done in a random way, it changes from one place to another. Sometimes the sandstone layer that is dominant, whereas some another zones are dominated by shales.

Shales are sometimes clay so friable dry and plastic in the wet state. The other variant is shale, which is more sandy and rich in micaceous elements with debris of fossil plants. The preferred target is the sandy-clay shale formation, since its porosity and laminated texture promote high storage capacity.

## Electrical resistivity tomography (ERT)

The results of the geophysical survey show measured data in the form of real resistivity models of the underground obtained by inversion of these data. An initial examination of all the obtained results tells the existence of significant variations of the resistivity of the subsoil, proved by its heterogeneity. Schematically, the area covered by the geophysical survey is formed by 3 geoelectrics levels corresponding to 3 large lithological units:

- 1- a layer which has a resistivity higher than 70Ωm corresponding to the sandy shell or red sand
- 2- a moderately conductive level of resistivity lower than 40Ωm corresponding to the formation of clayey sandstone;
- 3- a conductive level considered as an aquifer is well represented on the profiles with resistivity between 8 to 15Ωm.

ERT profile was conducted using 64 electrodes with 7m and 10m spacing. In this case, we had 217m and 310m profiles length and between 35m to 50m depth of investigation

**ERT1:** It highlights the presence of three distinct layers. The first (red colour) at the surface is a sandy with a resistivity higher than 14Ωm, this formation begins to reappear just below 13m deep. The second (green colour) with resistivity lower than 2Ωm located on the north-western part of the profile could be a clay and the third which is interesting during the prospection of underground water with a resistivity of 8Ωm would match to the aquifer.

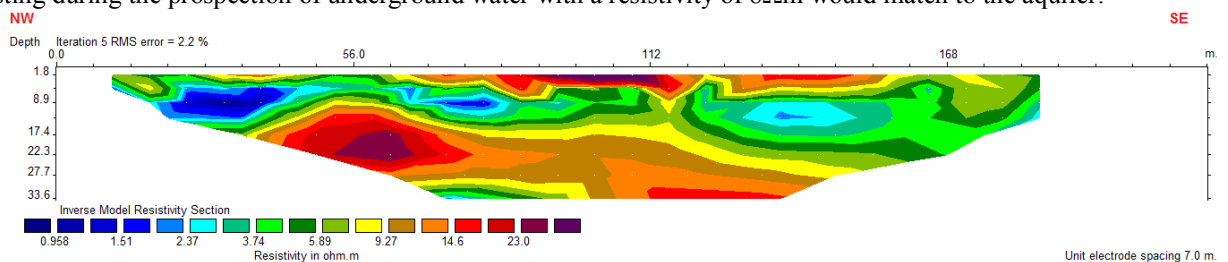


Figure 7: Resistivity section ERT1

**ERT2:** On this profile, the stratigraphic sequence was found on the local geology such as a superficial coverage with an average resistivity of 10Ωm. This layer corresponds to the wet sandy and, its average thickness is of 3m. A conductive layer with a resistivity of 4Ωm was observed. That layer would probably correspond to the aquifer with 20m thickness. The third formation, an extensive high resistivity higher than 22Ωm is located at the base of the section is located at about 35m depth and consists a clay sandstone

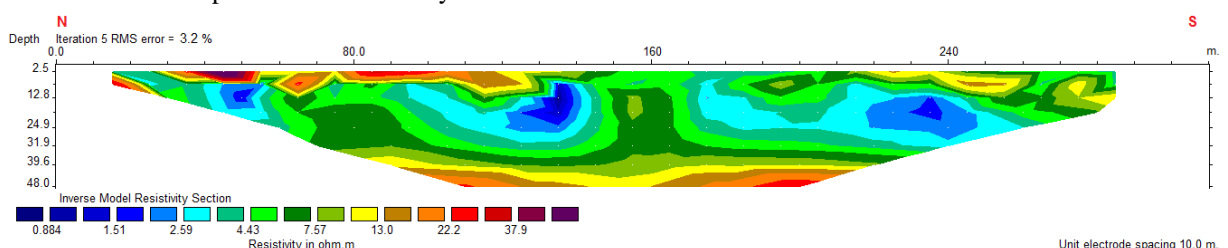


Figure 8: Resistivity section ERT2



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**ERT 3:** the superficial formation is dominated by a layer of sandy shell and red sand, its resistivity is higher than  $12\Omega\text{m}$ . The second formation, conductive, has a resistivity around of  $4\Omega\text{m}$  and could be a wet clay layer. Then comes a moderately resistant formation with resistivity between 4 to  $8\Omega\text{m}$ . Located between 160m and 240m of the profile, it is a formation of average resistivity equal to  $20\Omega\text{m}$  corresponds to a sandstone.

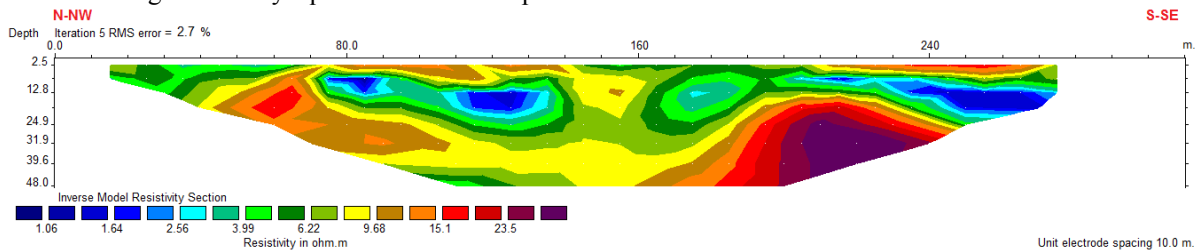


Figure 9: Resistivity section ERT3

**ERT 4:** This geophysical profile generally shows three distinct formations: a highly conductive surface layer with a resistivity less than  $7\Omega\text{m}$  located in the north-eastern part of the section could correspond to a clay layer. A moderately resistant formation of resistivity between 10 to  $20\Omega\text{m}$  which is located mainly at the centre of the profile represents an aquifer. Finally, a layer with resistivity higher than  $20\Omega\text{m}$  can correspond to the sandstone limestone, which plays a role of substratum

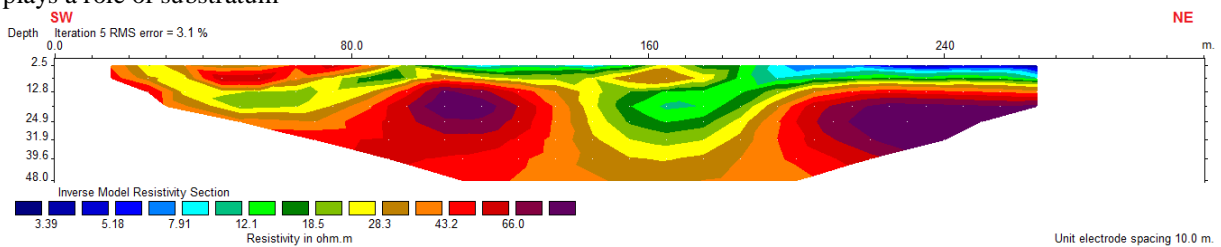


Figure 10: Resistivity section ERT4

## V. CONCLUSION

The electrical method has several kinds of technics whose two of them have been used: the VES and the ERT. The great advantage of using the electrical section is its ability to design subsurface imagery to geometrically determine an aquifer in its thickness average, and lateral extent. To do this, the Wenner configuration has been of great importance since it is sensitive to the vertical variation of the resistivity. Regarding the electric sounding method, it can be said that it is a 1D-V investigation technic, depending on the depth. This is why the Schlumberger device is more appropriate to detect an aquifer in the limestone zone.

As for our results, it was possible to detect aquifer with a thickness ranging from 4m to 21m in each studied point. In some points greasy layers have been identified and in other clay layers. But the point where the underground water table is at a depth about 15m to 35m, with an average thickness of 10m, probably corresponds to the hydrogeological target.

It can be said that the objective of the work has been largely achieved. However, as a perspective, it is proposed to expand the knowledge through physico-chemical and environmental studies to determine the water potability in the localized aquifer for safe exploitation for the local population

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