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3D Modeling and Estimation of the Tonnage of the Granite Quarry of Linguésso (North-West of Côte d'Ivoire) by Electrical Methods

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Abstract

A survey and evaluation was carried out on a potential granitoid quarry site in the locality of Linguésso (North West of Ivory Coast) with the aim of identifying and estimating the quantity of exploitable granite based on the electrical resistivity methods. The combination of electrical trailing, sounding and tomography techniques allowed the determination of the characteristics of the rock deposit, namely the electrical signature (between 19,259 Ωm and 86,316 Ωm), the extension (N90˚), the rooting (between 0 and 45 m) and the fracturing (between N14˚ and N160˚) of the granitic formation sought. The modeling resulted in an estimated mineable rock volume of 2,936,250 m^3 providing a production quantity of 7,927,875 tonnes.

Keywords

Eelectric Resistivity, 3D geoelectric Model, Granitic Quarry, Linguésso, Ivory Coast

1. Introduction

The use of crushed granite in carrying out economic infrastructure works such as roads, bridges and buildings has been known for several decades. The construction of road infrastructures therefore requires the use of a large proportion of aggregates, which make it possible to ensure the solidity of the work in preparation. In Western Europe and particularly in France, for example, there is an increase in the production of crushed aggregates from massive rocks to the detriment of alluvial materials (Aghui, 1980). This is directly linked to the depletion of exploitable alluvial resources (Aghui, 1980). In West Africa, granites are the most important basement formations in terms of surface area (Aghui, 1980). In Côte d'Ivoire, the territory is 97.5% occupied by the Precambrian basement (Yacé, 2002). The study of these materials is certainly not devoid of interest from the perspective of a rational use of available resources (Aghui, 1980) but also for sustainable development. It is therefore a significant rock potential that needs to be assessed for use in the construction of pavement structures and the making of hydraulic concrete. This abundance of massive rocks therefore calls for a generalized use of crushed aggregates (Touré, 1985). It is for this reason that knowing the quantity and quality of recoverable aggregates in a granite rock deposit located near a road construction project becomes a real challenge for the economic and technical planning of the works. The combination of trailing, drilling and electrical tomography methods in this work has been very useful to know the geoelectric characteristics, fracture systems related to this rock deposit of Linguésso in particular, and the North-West of Ivory Coast in general. This part of the Ivorian basement has been the subject of several geological and hydrogeological studies (Roche and Chaperon, 1966; Couture, 1968; Mathez, 1972; Tagini, 1972; Camil, 1984; Kouamélan, 1996) but rarely of geophysical studies aiming at highlighting the structuring of the rock deposit at depth. It is therefore the beginning of a vast campaign of prospecting by electrical methods of massive rock sites in the Ivorian Birimian. The objective of this work is thus to carry out the modeling of the granite quarry of Linguésso in order to determine its geoelectric characteristics and the quantity of exploitable crushed stone.

2. Geographical and Geological Context

The study site is located 2 km from the village of Linguésso (**Figure 1**) in the department of Odienné, in the North-West of Côte d'Ivoire, about 867 km from Abidjan. The coordinates (Lat/long)) of the center of the site are N 9.21; W-7.63. The Odienné region has been the subject of pedological (Eschenbrenner & Badarello, 1978) and geological (Tagini, 1972) studies. According to the latter, the formations of the Odienne region belong to both the Archean (age greater than 2300 million years) and the middle and/or lower Proterozoic (1500 - 2300 million years). These trainings consist of:

- Archaean: gneisses, migmatites and quartzites with magnetite, attributed to the Liberian cycle;
- Proterozoic: Heterogeneous granitoids, two-mica granites, structured volcano-sediments during the Eburnean megacycle.

The geological context of the Odienne region is shown in **Figure 2**.

3. Materials and Methods

Geological prospecting aimed at identifying the rock deposit was carried out with conventional line-opening equipment. The resistivity measurements were carried out using the syscal pro and its accessories consisting of cables and electrodes.

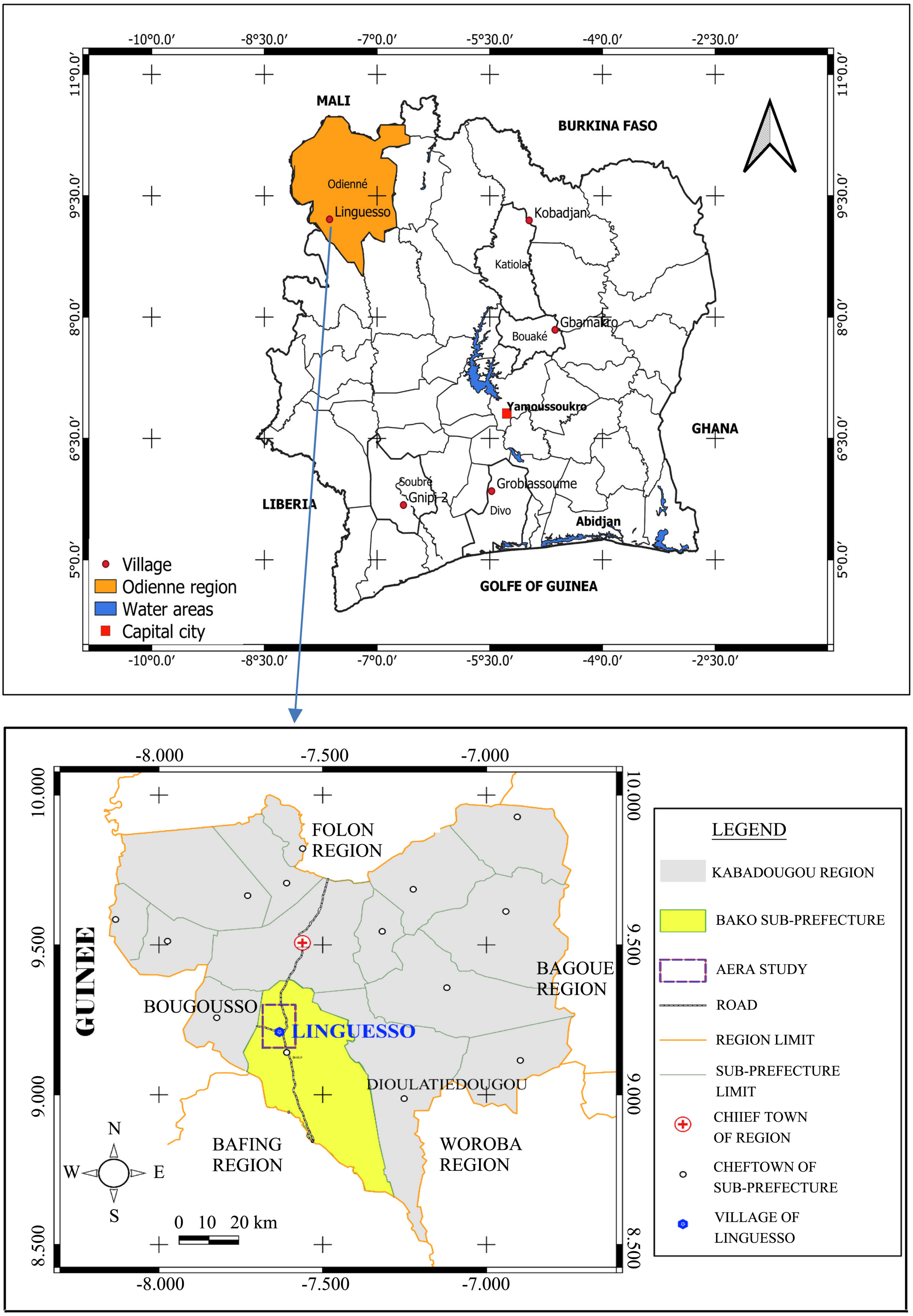

Figure 1. Situation of the Linguésso site.

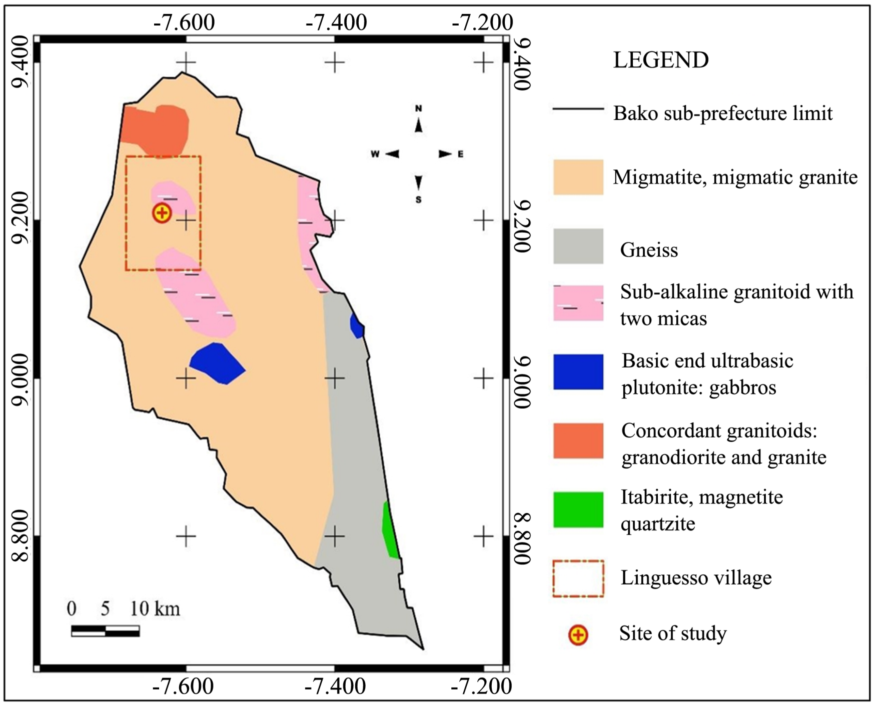

Figure 2. Geological map of the study area.

For the execution of the surveys on the Linguésso site, nine (09) lines of 300 to 320 m were opened (Figure 3) for dragging and electric tomography. Ten (10) electrical soundings in Schlumberger mode were also carried out. A total of 2735 m of line covered the Linguésso site. The lines are oriented N113˚ (7 transverse lines) and N23˚ (base lines), with measurement steps (station) spaced 10 m apart.

The acquisition methods used are based on the injection of a direct electric current of intensity I by electrodes A and B and the measurement of the potential difference ΔV from the reception electrodes M and N (Figure 4, Equation (1)). The electric drag method was carried out with a gradient device whose injection electrodes A and B are 900 m apart and remain in a fixed position. The potential measuring electrodes M and N are 10 m apart. The MN dipole is moved 10 m along the profiles (Figure 5). Electrical resistivity tomography was performed on five (05) profiles with the pole-dipole device (Figure 6). A pole is a single transmitting electrode, and a dipole is a pair of oppositely charged electrodes that are so close together that the electric field seems to be a single electrode field instead of fields from two different electric poles. The profiles frame the resistive zone highlighted by the electrical resistivity map. The inter-electrode spacing is 10 m and infinity is located at 1088 m, perpendicular to the measurement line. The electrical soundings were carried out using the Schlumberger device (Figure 7). The basic principle of the Schlumberger sounding method is to inject a current into the ground through current electrodes AB at the surface. This current creates a potential field in the ground. The subsurface resistivity can be inferred by measuring the resulting potential difference ΔV_{MN}

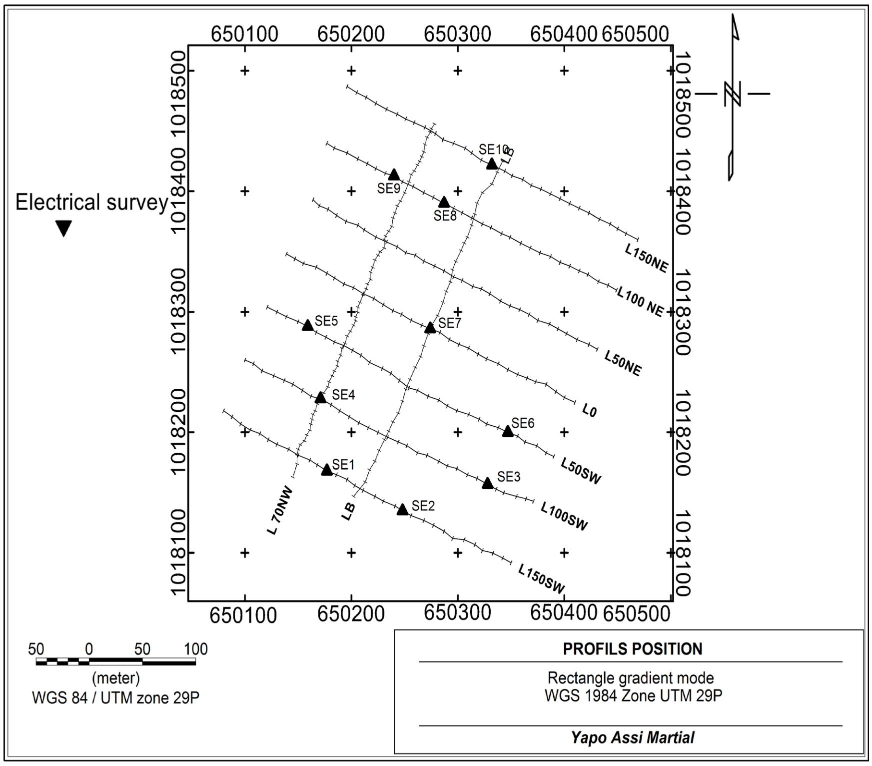

Figure 3. Position map of the profiles.

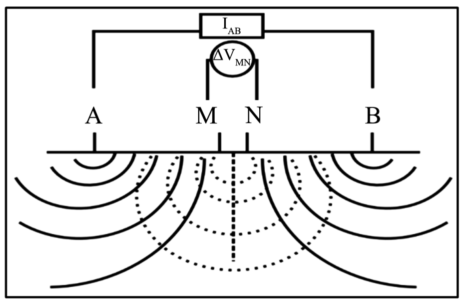

Figure 4. Principle of prospecting by direct current (case of a Schlumberger configuration).

(Equation (1)) and resistivity (Equation (2)). In the Schlumberger array, two potential electrodes and two current electrodes are positioned symmetrically along a straight line (Figure 7). The potential electrodes are placed at M and N. The distance between the potential electrodes MN, is kept much smaller than the distance between the current electrodes AB (at least five times smaller).

$$\Delta V = V_M - V_N = \frac{2\rho I b}{\pi\left(a^2 - b^2\right)} \tag{1}$$

$$\rho = \pi \frac{\Delta V}{I}\left(\frac{a^2 - b^2}{2b}\right) \tag{2}$$

where

ΔV: Difference potential (V);

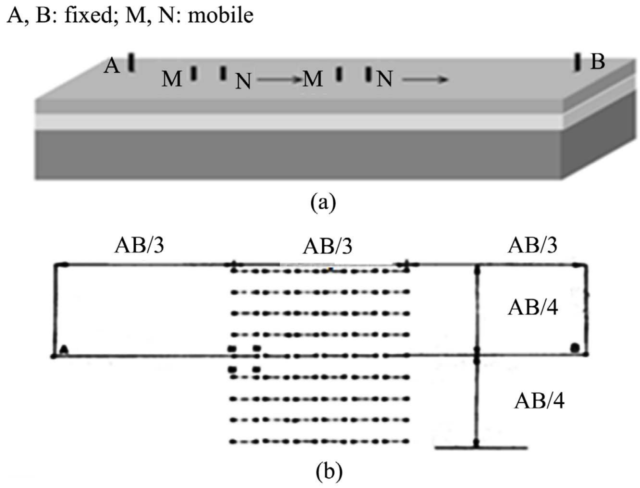

Figure 5. Rectangle gradient configuration. (a) Configuration in space; (b) Configuration in plan.

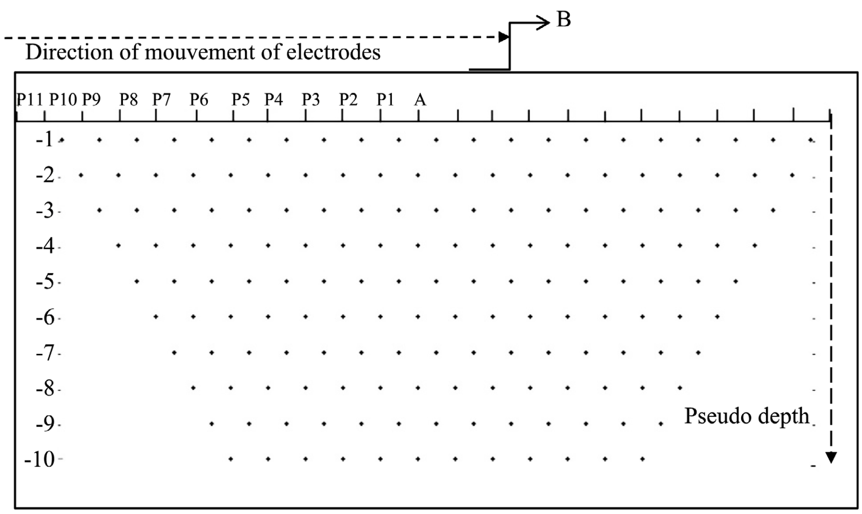

Figure 6. Acquisition configuration with the pole-dipole device.

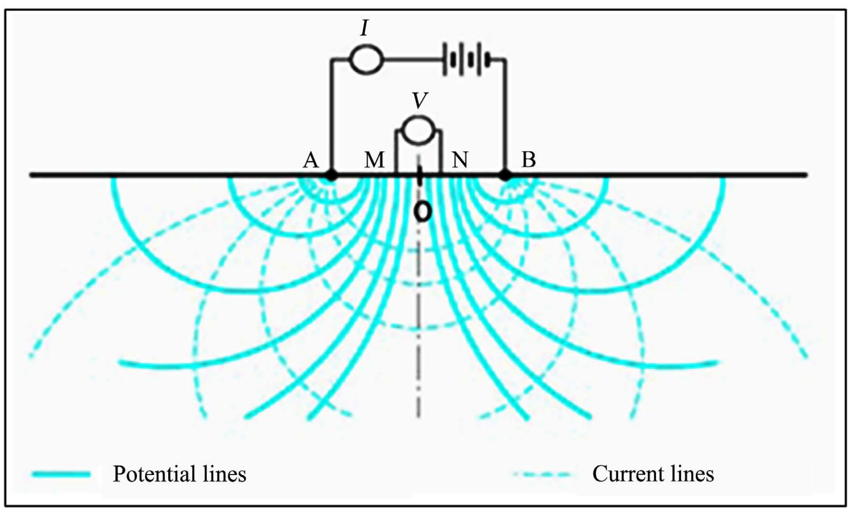

Figure 7. Principe du sondage électrique.

ρ: Resistivity (Ohm·m);

I: Current strength (A)

π: Constante 3.14

a: Half the current electrode spacing (AB/2) (m)

b: Half the potential electrode spacing (MN/2) (m).

4. Data Processing

The processing of the electrical drag data was done with the Oasis Montaj software for the establishment of the map of the apparent resistivity of the site. The TomoLab and ERTLAB software were used to produce the inverted electrical tomography profiles and the 3D model. As for the electrical soundings, the use of the Winsev 6 software was useful for their 1D inversions.

For a better clarity of the analysis and the interpretation of the different tomographic profiles, we used a common chromatic and resistivity scale for all the profiles.

These profiles will make it possible to create a primary 3D model of the resistivity distribution on the site. From the interpretations of the tomographic profiles and the electrical soundings, we considered as granite basement a resistivity value of 4500 Ωm. By eliminating the resistivity values below this threshold, we obtained the 3D model of the granite deposit.

The volume of the deposit is determined from the 3D model and the tonnage (T) is obtained using the Equation (3):

$$T = \text{Granite density}\left(2700\ \text{kg/m}^3\right) \times \text{Granite volume} \quad (3)$$

5. Results

5.1. Analysis and Interpretation of Resistivity Profiles

The seven (07) curves (**Figure 8**) show the lateral variations of the electrical resistivity values on each profile. These values are between 800 and 14786.70 Ωm. High values reflect electrical signatures of resistant rocks attributed to granite.

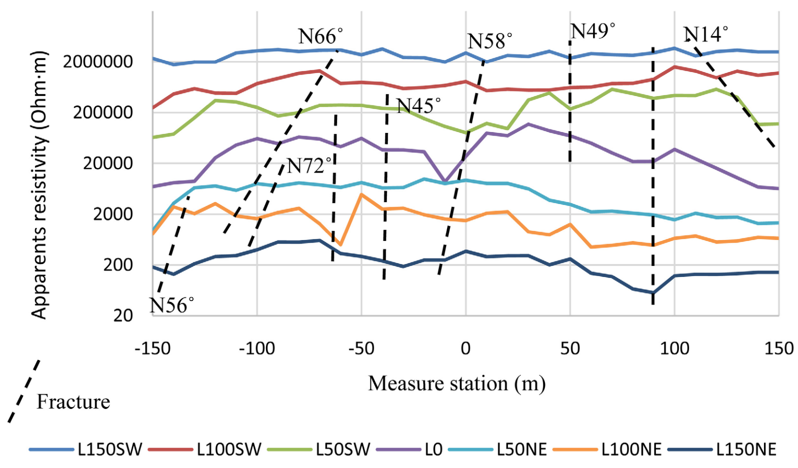

Figure 8. Electrical resistivity profiles.

However, the low resistivities on each profile indicate fracture zones oriented between N14 and N72˚ (Figure 8). These fractures could constitute groundwater circulation corridors.

Analysis of the electrical resistivity map (Figure 9) makes it possible to distinguish three geoelectric formations:

- A conductive domain (blue) with a low electrical resistivity value which is between 800 and 1602 Ωm;
- A moderately resistant assembly with intermediate resistivity values (green, yellow) between 1602 and 4316 Ωm;
- A resistant formation indicated by resistivities ranging from 4316 to 14,786 Ωm (red, pink).

The resistant zone (Figure 10) could be interpreted as an interesting granite unit for the exploitation of a quarry. The formations with intermediate and low resistivities (Figure 10) correspond respectively to a transition formation and a set of volcano-sediments. Several fractures could be identified with directions varying between N45˚ and N160˚ (Figure 10).

5.2. Analysis and Interpretation of Electrical Soundings

5.2.1. Electrical Sounding Curve in "a Single Rising Branch"

The electric sounding curve SE7 (Figure 11) represents this family of curves which shows two types of geoelectric formations. A first conductive ground whose resistivity is around 7402 Ωm. Its thickness is around 1.3 m. The second terrain corresponds to the sound basement with resistivity values exceeding 48,685 Ωm. Here, the angle of last ascent is 30˚.

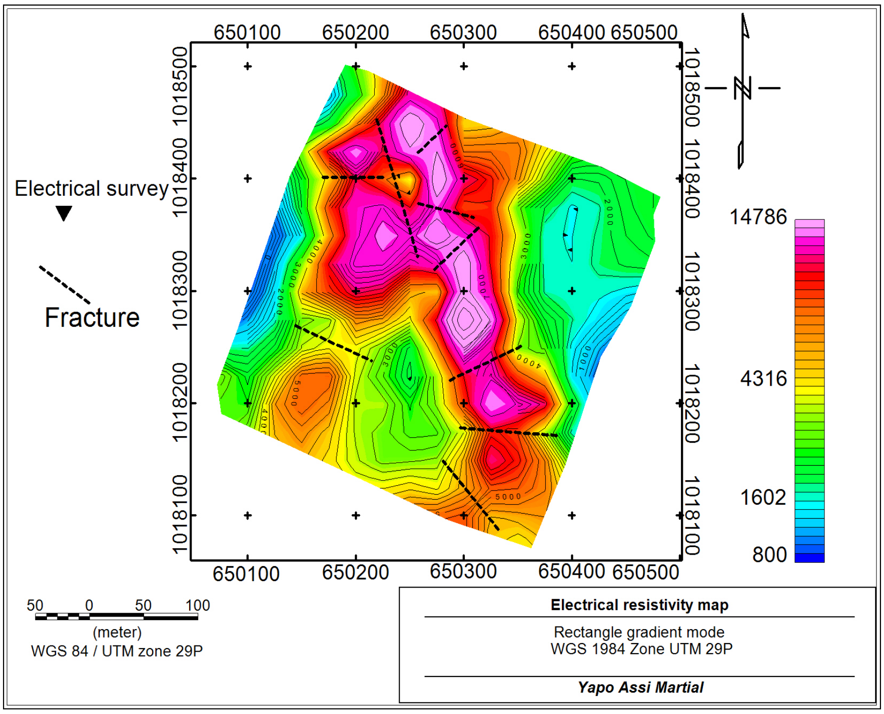

Figure 9. Electrical resistivity map.

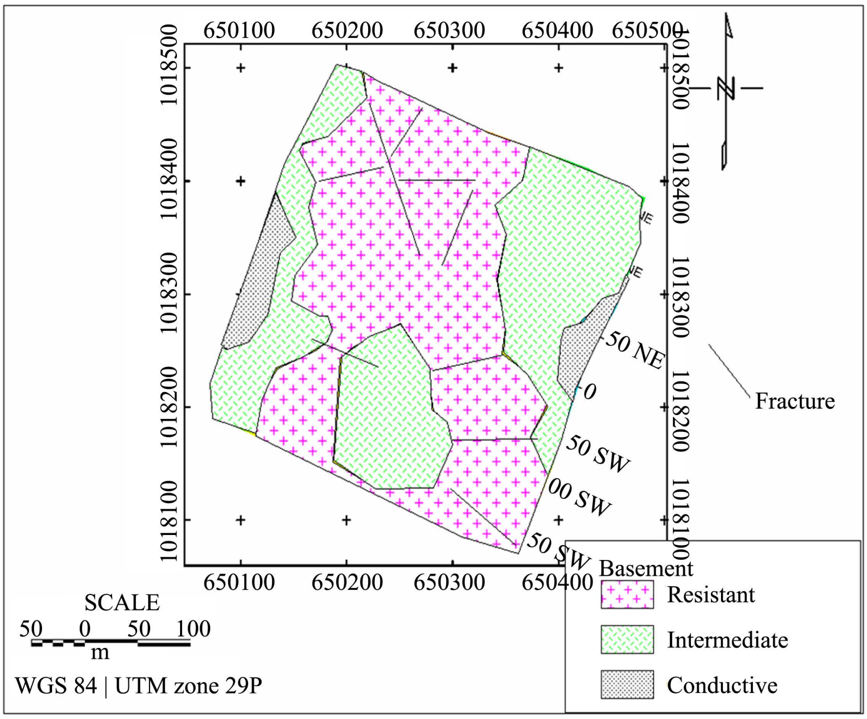

Figure 10. Summary map.

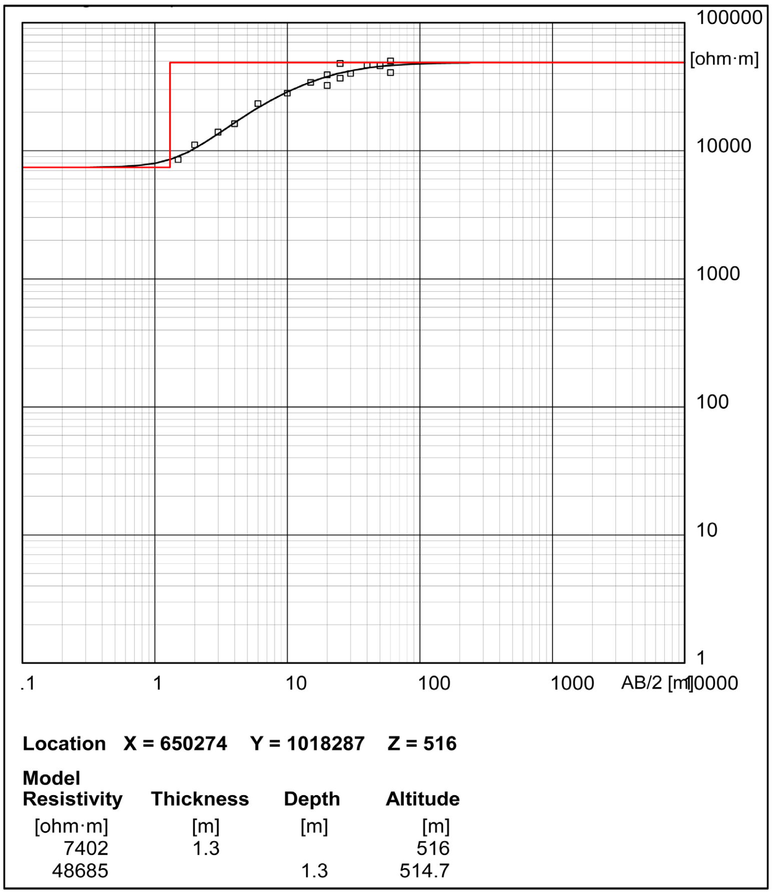

Figure 11. Electrical sounding curves in "single rising branch".

5.2.2. Electrical Sounding Curve at the "Bottom of the Boat"

Three distinct geoelectric terrains have been identified on the SE4 electrical sounding curve (Figure 12):

- The surface covering with a resistivity of 1356 Ωm and 0.5 m thick. It is similar to a lateritic cuirass;
- The conductive level on the curve corresponds to the "bottom of the boat". These would be clayey or sandy alterites with a thickness of 8.4 m with a resistivity of 295 Ωm;
- Finally, the resistant level attributed to the sound basement with resistivity equal to 29,226 Ωm, corresponding to the last rise in the sounding curve with an angle of 42˚.

5.2.3. "Trailing Lift" Electrical Sounding Curve

The electric sounding curve SE6 (Figure 13) shows a significant inflection of the rising branch from a depth of 11 m. This survey was carried out practically on the outcrop.

The electric curve of this type highlights four geoelectric layers:

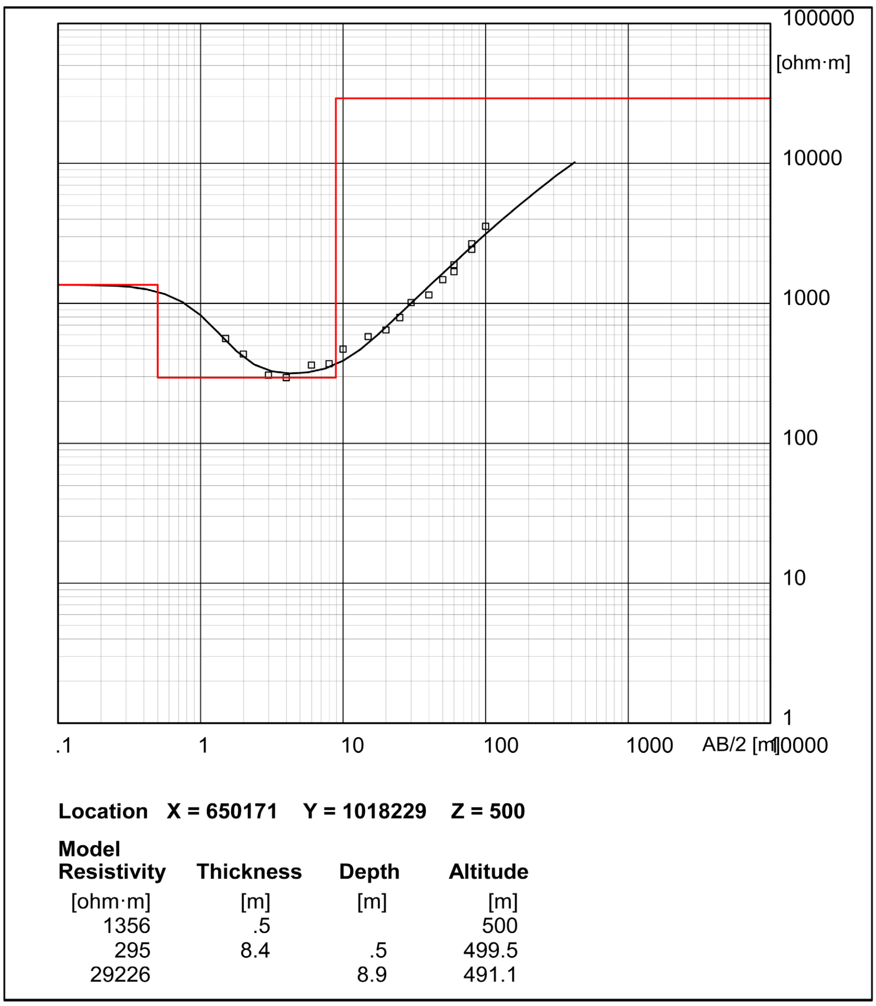

Figure 12. SE4 electric sounding curve "at the bottom of the boat".

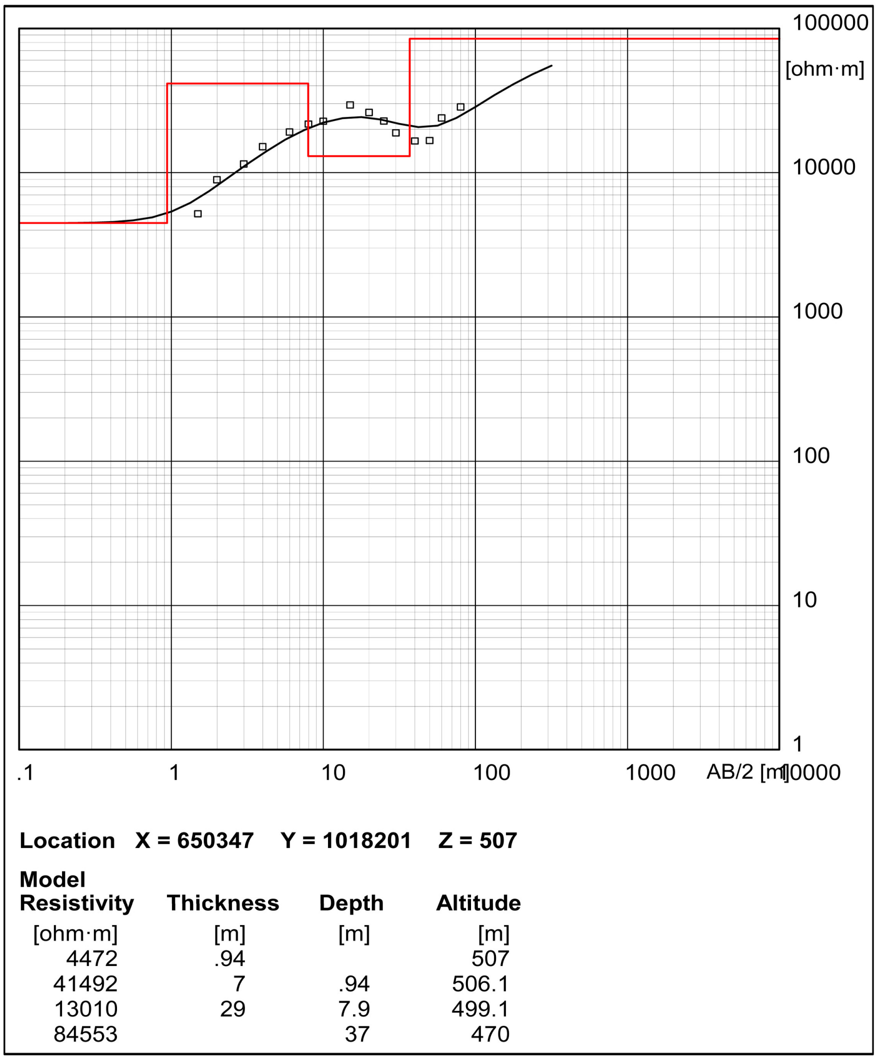

Figure 13. SE6 electrical sounding curve with "trailing lift".

- A first conductive surface level 0.94 m thick and 4472 Ωm as resistivity;
- A second resistant layer whose resistivity is 41,492 Ωm and 7 m thick;
- A conductive stratum with 13,010 Ωm;
- Finally, a fourth very resistant level at about 37 m depth whose resistivity is equal to 84,553 Ωm. Here, the angle of last ascent gives a value of 30˚.

5.3. Analysis and Interpretation of Electrical Tomography Profiles

The five (05) tomography profiles carried out on the site (Figure 14) made it possible to know the alteration profile and the rooting of the rock deposit. Three main tomographic profiles will be interpreted here.

On all the profiles produced (Figures 15-17), three geoelectric signatures can be identified:

- Conductive formations (blue) with resistivities between 61 and 684.83 Ωm;
- A set with intermediate resistivities (light blue, green) whose resistivities range between 684.83 and 19,250 Ωm;

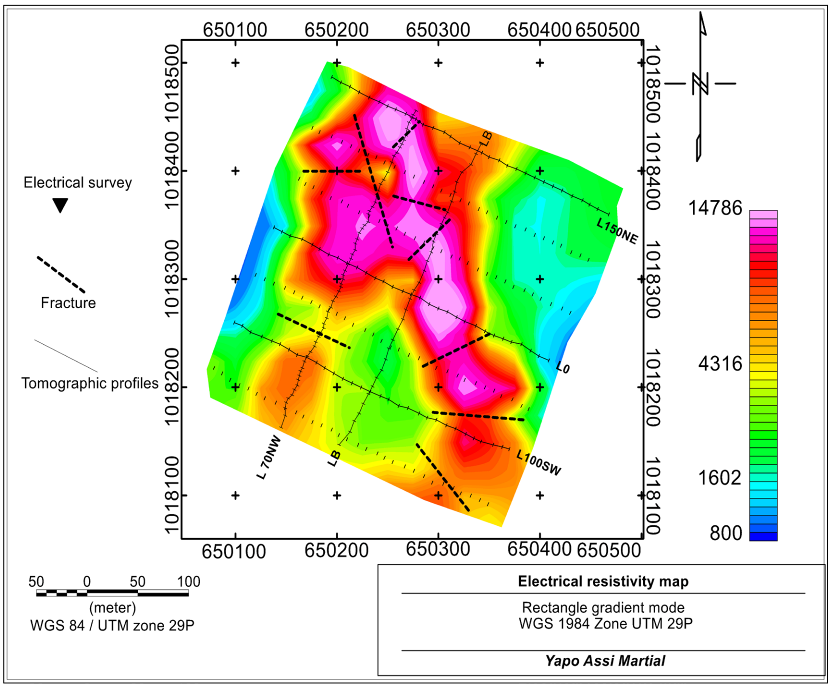

Figure 14. Position map Tomographic profiles and electrical sounding points.

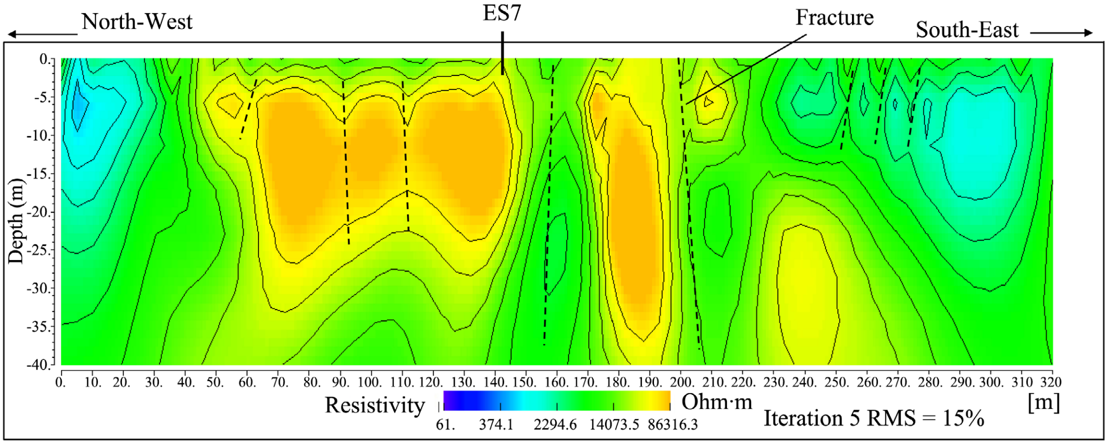

Figure 15. Electrical tomography section L0.

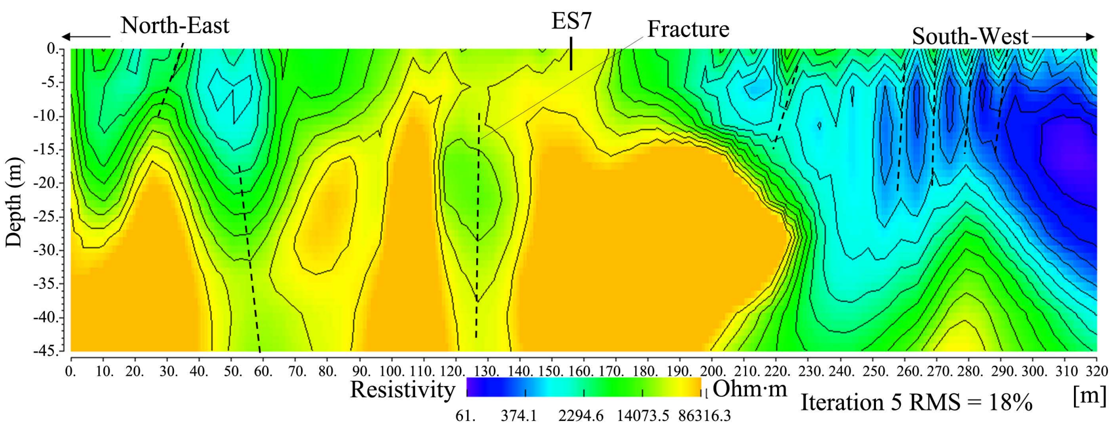

Figure 16. LB electrical tomography section.

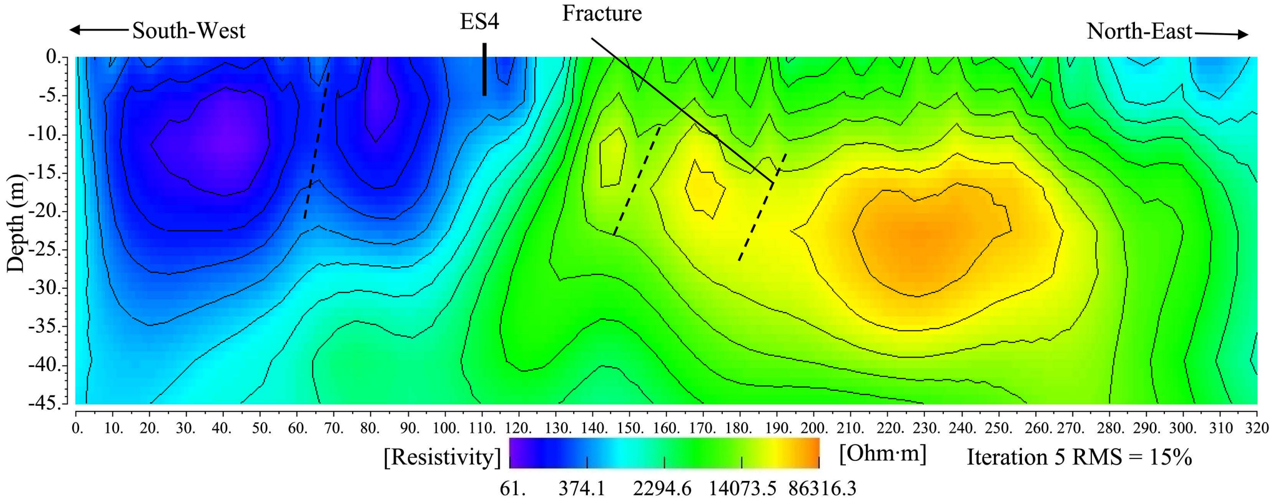

Figure 17. L70NW electrical tomography section.

- The resistant formations (yellow, orange) with resistivities oscillating between 19,250 and 86316.23 Ωm.

Profile L0

The L0 profile (**Figure 15**) crosses an outcrop observed on the site and approximately 180 m long. This outcrop is well marked on the section between stations 50 and 225 m. In the interval between the 225 m and 320 m stations, the healthy bedrock is located at a depth of around 20 m. At the 160 m and 210 m stations, potential deep faults with dips between 80˚ and 90˚ were interpreted. The dips of these faults are between 80˚ and 90˚ towards the NW have been identified.

LB Profile

The North-East part of the LB profile (**Figure 16**) is dominated by resistant formations which extend between the 0 and 230 m stations. In the extreme North-East, the resistant layer is very buried, about 20 m deep. In the South-West, between stations 230 and 260 m, the roof of the resistant formation attributed to granite is covered by a thick alterite and is located at a depth of more than 45 m approximately. It should be noted the presence of superficial faults in the South-West and deep faults at points 60 m, 130 m and 235 m with dips of 45˚ and 90˚ towards the NE.

Profile L70NW

This L70NW profile (**Figure 17**) is located 70 m northwest of the LB line and crosses a large part of the granite outcrop observed in the field. The section highlights, in the northeast part, the granite basement from the station (x = 120 m) to the station (x = 330 m), where it outcrops over 100 m. The basement is altered and covered by a conductive level to the southwest. The resistant formations would be about 45 m deep at this location.

On all the pseudo-sections, the high resistivity values can be attributed to granitic formations, but fractured in places. These granitic formations are often very altered (conductive formations) thus leading to weak electrical signatures.

5.4. 3D-Geoelectrical Modeling of the Linguésso Site

The 3D model of the Linguésso site (**Figure 18**) shows that the area consists mainly of resistant geoelectric formations attributed to granite. It is a fractured rock deposit and preferentially oriented in the N90˚ direction.

The model made it possible to estimate the exploitable rock volume at 2,936,250 m^3, which gives a relative quantity of 7,927,875 t.

6. Discussion

Electrical tracing of the Linguésso site in the northwestern part of the Ivorian basement has revealed a north-trending resistant geoelectric domain with an electrical signature ranging from 4316 to 14,786 Ωm. This resistant zone attributed to the basement has fractures oriented between N14˚ and N135˚. However, some sites in the Ivorian basement have shown other preferential fracture orientations. This is the case of the departments of Sikensi and Tiassalé, in the south of Côte d'Ivoire, where the work of Sombo (2013) showed that the preferential direction of structural alignments is N0˚ - 10˚ (North-South). These differ from those we obtained in northwest Côte d'Ivoire. Geological discontinuities related to the N10˚ - 20˚, N30˚ - 40˚, N150˚ - 160˚ and N160˚ - 170˚ directions are secondary in this southern part of Côte d'Ivoire. Similarly, in the Niéllé area in northern Côte d'Ivoire, the work of Kouakou et al. (2017) revealed discontinuities oriented between N6˚ and N175˚ in this part of the basement. In this area, the preferential direction is E-W and NW-SE. These different directions are substantially close to those interpreted at Linguésso by our study. Furthermore, the study by Loukou et al. (2008) in the Bondoukou area of eastern Côte d'Ivoire highlighted fractures oriented generally around directions N43˚, N55˚, N162˚ and N171˚. All these fractures interpreted in different parts of the country are not strictly identical. Fracture systems interpreted at Linguésso in northwestern Côte d'Ivoire thus provide new data on the diversity of discontinuities in the Ivorian basement.

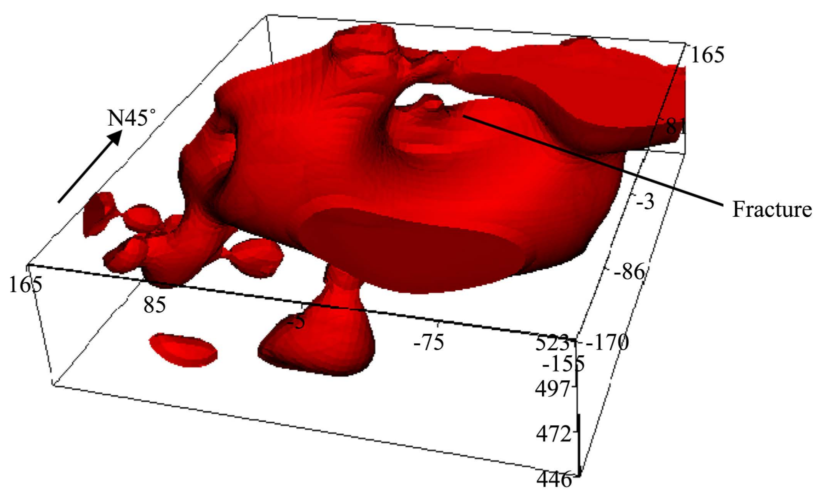

Figure 18. 3D model of the granitic rock of the Linguésso site.

The electrical soundings of this work also revealed three (03) families of curves at the Linguésso site (North-West of Ivory Coast):

- Electrical sounding curve in “a single ascending branch”;
- Electrical sounding curve in “boat bottom;
- Electrical sounding curve with a “dragging rise”.

Contrary to the zone of the South, Center of Côte d’Ivoire and several localities of the Burkinabe base, which are characterized by seven (07) categories of drilling curves according to the work of Biémi (1992), Sombo (2013), and Koussoubé et al. (2003); They have respectively counted in the Ivorian and Burkinabe bases seven (07) families of drilling curves:

- Electrical sounding curves in “boat bottom”;
- Curves of electric soundings in “bell in the bottom of the boat”;
- Curves of electric soundings in “bell and bottom of the boat”;
- Electrical sounding curves with “one ascending branch”;
- Electrical sounding curves with “stairs on the ascending branch”;
- Electric sounding curves with “trailing rise”;
- Electrical sounding curves with “clutch jumps”.

The slope of the last ascent of the three types of drilling curve determined on the Linguésso site in northwestern Côte d’Ivoire is between 30˚ and 42˚. The massive rock at the Linguésso site is therefore highly fractured. Indeed, a final rise of less than 45˚ reflects the presence of an intensely fissured or altered zone above the sound rock (Sombo, 2013; Doumbia, 2020).

The 3D modeling and volume estimation was possible thanks to the combination of electrical panels. It highlighted the rock roof between 0 and 45 m depth, an orientation N90˚ and a volume of 2,936,250 m^3. This modelling technique using the combination of tomography cross-sections provides precision on the orientation and estimation of the rock deposit. This is in contrast to the study and estimation using the resistivity map technique at different depths used by Ada et al. (2008) on the Andalamby site (Madagascar). This study has certainly allowed to estimate at about 37,500 m^3 the rock volume without however highlighting the morphology and the orientation of the rock volume.

7. Conclusion

The use of electrical resistivity tomography for the three-dimensional evaluation of the Linguésso granite quarry was possible thanks to the combination of several 2D profiles produced on the site. Electrical soundings were positioned on these profiles to determine the rooting depth of the sound rock. These two techniques were preceded by an electric drag which showed a sound basement with deep fractures oriented between N45˚ and N160˚. These fractures can constitute obstacles for the exploitation of the quarry, because they generally correspond to water inlets.

The 3D model of the deposit made it possible to estimate the quantity of exploitable rock at 7,927,875 tonnes for the Linguésso deposit. The Linguésso granitoid is a rock that is deep in places and fractured with a preferential orientation in the N90˚ direction. These multiple fractures should limit the exploitation of this quarry.

Acknowledgements

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Conflicts of Interest

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

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