IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 10, Issue 6 Ser. I (Nov. – Dec. 2022), PP 58-65
www.iosrjournals.org

The Underground Granitic Massif of Ery-Makouguié 1 (South-East Côte d'Ivoire): Geophysical Quantification and Exploitation Potential

Djroh Simon Pierre [1,2*], Kouamelan Serge Kouamelan[1], Soro Donissongou Dimitri[1], Ahadhé Yaba Mariana Aimée[1,2], Gnoléba Serge P. Dégine[3] and Kouamé Loukou Nicolas[1]

[1]Applied Geophysics Research Team Laboratory, Mineral and Energy Resources, Faculty of Earth Science and Mineral Resources, Félix Houphouët Boigny University, 22 BP :582 Abidjan 22, Côte d'Ivoire
[2] Geophysical Research Office Côte d'Ivoire, 01 BP : 4765 Abidjan 01, Côte d'Ivoire
[3] Ministry of Mines and Geology, Yamoussoukro, Côte d'Ivoire
[*]Corresponding author: djrohsp@gmail.com ; ORCID ID: 0000-0002-1964-782X

Abstract
Geophysical campaigns based on the measure of electrical resistivity were carried out in the locality of Ery Makouguié 1 (South-East of Côte Ivoire) to map and evaluate the quantity of exploitable granite. The electrical resistivities were measured with the pole-dipole configuration for 2D tomography and with the Schlumberger device for control electrical surveys. The equipment used was a Syscal Pro Switch 42, which consists of a pulsed transmission and reception module. The results of this work have helped to map the high resistivity formations associated with the healthy granite. The analysis of the 2D sections shows that the depth of the granite roof would be between 0.15 and 52 m. They also reveal the presence of two fractures with hydrogeological potential which are located at ~20m depth and which could limit its exploitation. The 3D model defines an irregularly shaped, sub-cropping granite on the western edge of the prospect and projects its mineable potential at approximately 14 million tonnes of granulate.

***Key words**: 2D Tomography, Electrical Survey, Granite Quarry, Ery Makouguié 1, Côte d'Ivoire.*

Date of Submission: 15-12-2022 Date of Acceptance: 30-12-2022

I. INTRODUCTION

Granite is a material of the earth's crust that is widely used as aggregate in the construction of civil engineering works. In nature, it still does not appear as a homogeneous mass because it can be composed of several petrographic, geochemical and geotechnical criteria [1]. In addition, it is the important primary material in the development of habitat and major works [2]. Locally, granite can be altered and show lateral and transverse discontinuities. Knowledge of the overburden thickness, identification of fractures as well as quantification of sound granitic material is paramount for quarry siting. In order to achieve these objectives, 2D tomography and electrical sounding are used to evaluate the thickness of the overburden and the granitic potential for exploitation in the Ery Makouguié 1 prospect. The measure of electrical resistivity contrast from these two techniques will allow the imaging of the subsurface and the collection of data necessary for the dimensioning of the quarry.

II. GEOGRAPHICAL AND GEOLOGICAL CONTEXT

The department of Agboville (**Figure 1**) is located 80 km North-East of Abidjan, between longitudes 3°55'W and 4°40'W and latitudes 5°35'N and 6°15'N [3]. It covers an area of 3850 Km^2 and enjoys a humid tropical climate of the Atean type, with four seasons including two rainy seasons and two dry seasons with rainfall varying between 1200 and 2000 mm [4]. The hydrographic network is covered by the Agnéby River and its tributaries such as the Gossi, Assobié and Mafou rivers.

The geology of the study area belongs to the Proterozoic domain. It is composed of supergroups of fillings made up of conglomerates, sandstones and shales; non-quartz vulcanite such as basalt and andesite [5]. Granite, granodiorite in intrusion with associated metamorphic haloes are added to this ensemble (**Figure 2**).

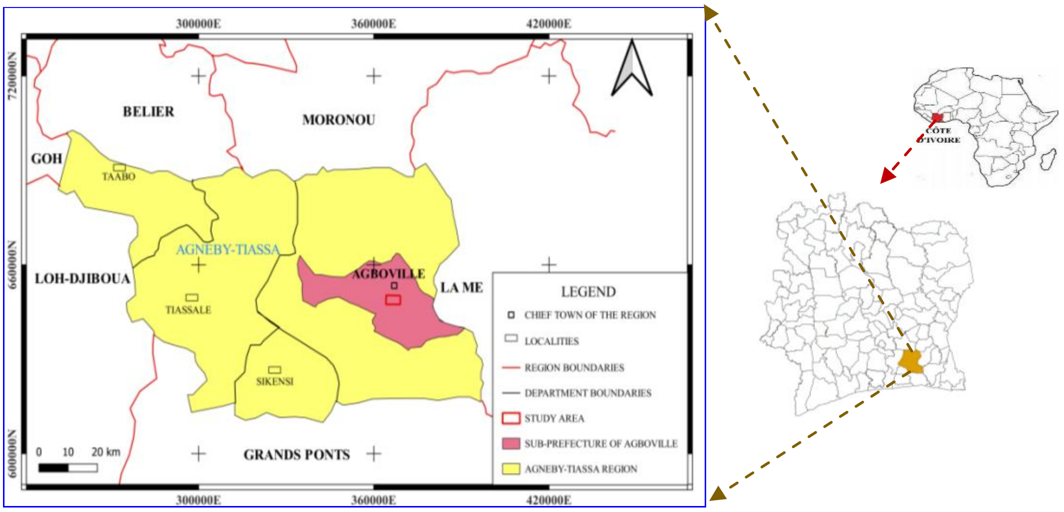

Figure 1: Map of the study area

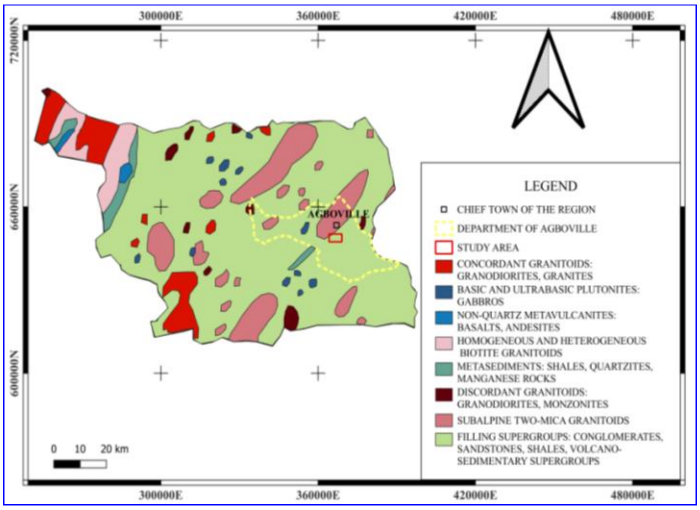

Figure 2: Geology map of Agboville, [6].

III. MATERIALS AND METHODS

Pole-dipole and Schlumberger configurations were used to sample the apparent resistivities of the subsurface during this study with a Syscal Pro Switch 48 resistivitimeter. The principle is to inject a current into the subsurface and measure the resulting potential difference for each measuring station. The values of the apparent resistivity (ρ_a) are calculated, for different measurement steps, from the relation:

$$\boldsymbol{\rho_a = \frac{\Delta V}{I} K} \quad \textbf{(1)}$$

With I: current intensity (A), ΔV: potential difference (V) and K: geometric factor (m).

The pole-dipole device is used on sixteen parallel profiles oriented E-W and equidistant from each other by 50 m for the measurement of apparent resistivities in the Profiling-Probing mode (**Figure 3a**). It consists of injecting electric current through two active electrodes (AB), one of which is mobile at each station, and the other is fixed at infinity (i.e. at a great distance from the measurement area). The potential is measured by ten receiving electrodes (MN) placed at 25 m intervals on the surveyed profile. The measured resistivities are reported at different depth levels which are determined by the separation distance between the injection pole and the receiver dipoles (Figure 3b).

According to [7], this investigated depth is given by the following empirical expression:

$$\boldsymbol{P = 0.36\, a\, (n + 1)} \quad \textbf{(2)}$$

With P: depth; n: acquisition level; a: distance between two consecutive electrodes.

The distribution of resistivities at depth represents a pseudo-section which, imported into the Res2DinV® software, allows the 2D quantitative interpretation of the different profiles. This software subdivides the pseudo-section into several cells which are centred on each value of the resistivity at depth. Using the least squares method, and after several iterations, it proposes a calculated model that is the true image of the subsurface with the minimum possible RMS error [8, 9]. This image model provides information for each profile on the thickness of cuttings and the depth of the granite roof as well as the presence of any fractures. The amount of exploitable granite is estimated with the Voxel module of Geosoft. This software first sums up all 2D sections. It then subtracts the values of resistivity lower than 3000 Ω.m which are associated with excavations and/or conductive zones. Finally, it proposes a 3D model by integrating the geometric parameters that are associated with the retained resistivities ($\rho_a \geq$ 3000 Ω.m) and proceeds to its volume calculation. Thus, for a mining depth fixed at 100 m, the exploitable granitic potential is estimated with the following equation:

$$\boldsymbol{Qg = V.d} \qquad (3)$$

Where: ***Qg*** quantity of granite in tonnes (t); V: volume (m3) and d: density of granite.

Four electrical boreholes were drilled with the Schlumberger device at station 00 (Reference Line 00) of each measurement profile to corroborate the results of the 2D image sections. The injection dipole (AB) varies from 3 to 700 m while the reception dipole (MN) varies from 1 to 4 m, depending on the increase of AB. The borehole data are processed with the Ix1d software. It allows the plotting and interpretation of electrical sounding curves. It is an inversion algorithm that is based on the superposition of the theoretical curves with the pre-calculated models from the real data included in the software (**Figure 3c**). This operation is an iterative calculation technique that uses the gradient method to minimise the sum of the squared deviations between the two curves [10]. The interpretation is of good quality when the measured resistivity values coincide as well as possible with the pre-calculated curves.

Four electrical boreholes were drilled with the Schlumberger device at station 00 (Reference Line 00) of each measurement profile to corroborate the results of the 2D image sections. The injection dipole (AB) varies from 3 to 700 m while the reception dipole (MN) varies from 1 to 4 m, depending on the increase of AB. The borehole data are processed with the Ix1d software. It allows the plotting and interpretation of electrical sounding curves. It is an inversion algorithm that is based on the superposition of the theoretical curves with the pre-calculated models from the real data included in the software (**Figure 3c**). This operation is an iterative calculation technique that uses the gradient method to minimise the sum of the squared deviations between the two curves [10]. The interpretation is of good quality when the measured resistivity values coincide as well as possible with the pre-calculated curves.

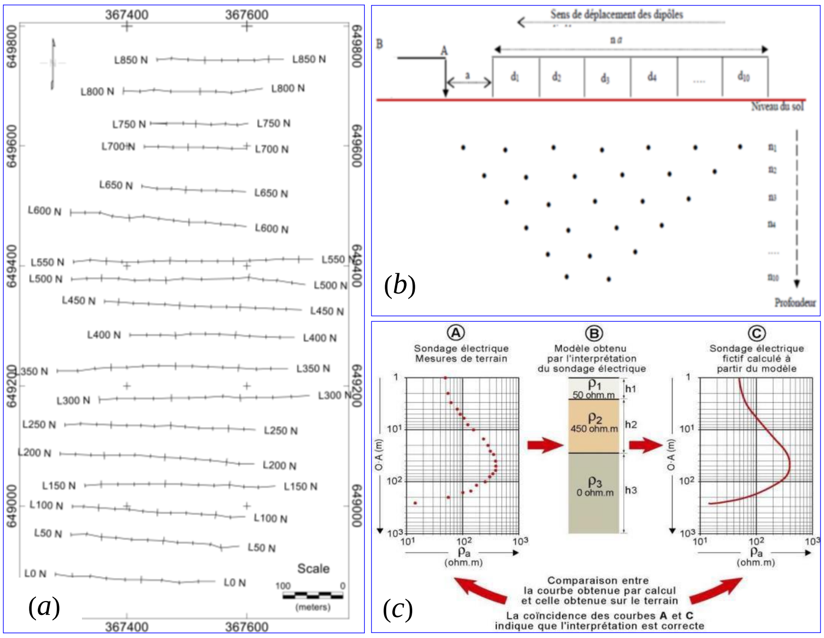

Figure 3: (*a*)-Profile positioning layout; (b)-Pôle-dipôle configuration;
(c)- Technic of electrical survey curve inversion

IV. RESULTS AND DISCUSSION

4.1 Analysis and interpretation of 2D sections

Figure 4 shows the stack of 2D resistivity sections of four profiles, L150N, L300N, L500N and L700N. These sections are on average 350 m long with a depth of around 80 m. The true resistivities range from 73 to 5300 Ω.m. Overall, the resistivities reveal three different terrains. The first terrain corresponds to the superficial and conductive layer marked by the colour blue (C1). It is characterised by resistivities below 700 Ω.m. It is found on all sections and its thickness increases from west to east. On sections L150N to L500N, the thickness of this conductive layer reaches more than 20 m in places, reflecting significant alteration. Field observations allow us to link this conductive layer to sandy clays and/or alteration. After this superficial layer lies a second layer with a resistivity of between 700 and 2200 Ω.m and is marked by the greenish to yellowish screen (C2). This set reflects a relatively deep lithology with a higher resistivity than the sandy-clay layer. From a geological point of view, this electrical signature has the characteristics of the saprolitic zone, when it is at depth, or of the indurated levels due to the effects of superficial armouring. Overall, this layer has an average thickness of 8 to 10 m. The third and final layer is marked by a red tinge and is characterised by resistivities above 2200 Ω.m. This set reflects the response of the healthy granite. Two sub-units are highlighted within the high resistivity structures, R1 and R2. The R1 structure corresponds to the electrical signature of the deep healthy granite. For most of the profiles, this unit is homogeneous in depth in its central and eastern parts. It is shallow to the west of profiles L 150N and L 500N and practically outcrops on L 300N and L 700N for about 60 metres. On the western edge of profiles L 150N, L 300N and L 700N, unit R1 is affected by two fractures, F1 oriented N-S on profile L 700N and F2 oriented NE-SW at profiles L 150N and L 300N. The second sub-unit R2 reflects the signature of isolated granite blocks resulting from dismantling due to supergene alteration. The typical example is the one observed at station 100 of the L500N profile. This has a subrounded shape and communicates with the healthy granite at depth. At the level of profiles L 150N and L300N, the R2 unit appears in the form of a slab and is translated by structures of high resistivity and lamellar form.

4.2 Analysis and Interpretation of Electrical Sounding

Electrical sounding 1 (SE 1/L150 N)

The SE1/L150 N electrical sounding curve has a "boat-bottom" appearance with a rising branch that shows irregularities. It reveals a characteristic succession of four geoelectrical terrains (**Figure 5a**). The first corresponds to the superficial cover, 1.5 m thick and with a resistivity of 515 Ω.m. This is followed by a set of alterite whose total thickness is around 17.7 m with resistivities that vary between 172.5 and 770 Ω.m. The third terrain has a thickness that varies between 8 and 10 m. It corresponds to the signature of the granitic saprolite. The last terrain has a resistivity that gravitates around 5200 Ω.m represents the granitic basement. The uniformity of the last rising branch reflects a sound basement with an absence of fractures. At the level of borehole SE1/L150 N, the top of the sound granite would be located at approximately 48 m.

Electrical borehole 2 (SE 2/L300 N)

The SE2/L300N electrical borehole also shows a "boat bottom" curve followed by a "single rising branch" which shows a slight inflection (**Figure 5b**). This curve indicates the succession of four geoelectric layers. The first layer is superficial and has a thickness of 0.8m. This is followed by a sandy-clay (alterite) layer which is 18.8 m thick and has a resistivity of between 440 and 680 Ω.m. The third layer is about 13 m thick and is associated with a poorly conducting complex with a resistivity close to 930 Ω.m. The last layer corresponds to the signature of the sound granitic basement with an estimated resistivity of 6140 Ω.m. It is surmounted by an alteration complex whose total thickness is close to 36 m. Hole SE2/L1300N shows an absence of fractures in the area of station 00.

Electrical borehole 3 (SE 3/L500 N)

The curve for borehole SE3/L500 N is a "step increase in resistivity" model (**Figure 5c**). It shows a characteristic succession of three geoelectric layers. The first layer corresponds to the 10.8 m thick surface cover with a resistivity close to 435 Ω.m. It is followed by a conductive complex with a resistivity close to 435 Ω.m. It is followed by a conductive complex probably consisting of alterite and/or saprolite with a total thickness of about 6 m and a resistivity approaching 470 Ω.m. The third and last terrain corresponds to the granitic basement. It is marked by a branch at an angle of 45° to the abscissa axis. It has a resistivity close to 4950 Ω.m and does not show any discontinuity. Hole SE3/L500 N indicates a sound granitic basement surmounted by an alteration whose thickness is approximately 18.4 m.

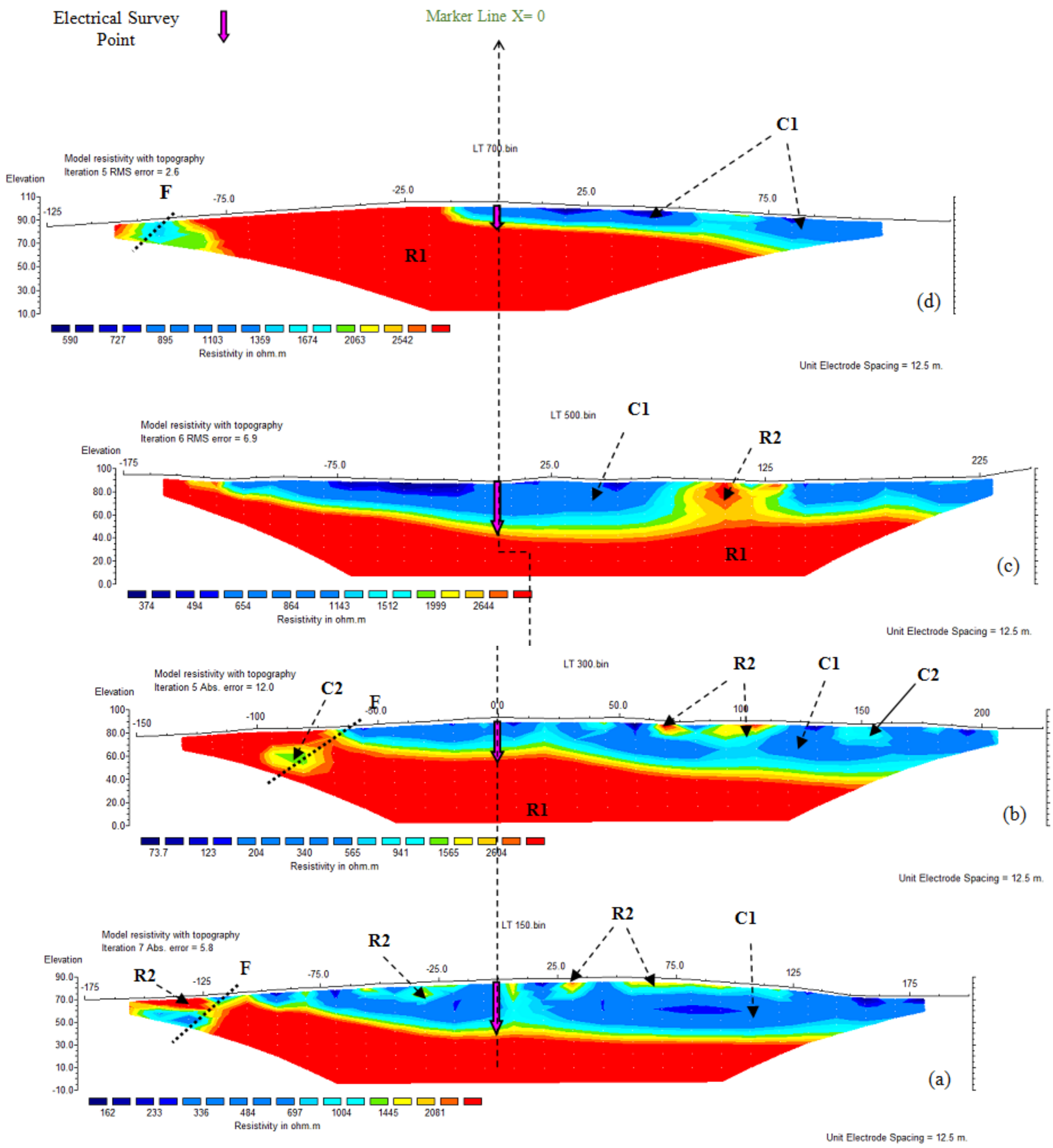

Figure 4: 2D section of selected profiles. (a) L150N, (b) L 300N, (c) L500N and (d) L 700N

Electrical Borehole 4 (SE 4/L700 N)

The curve of the electrical survey SE4/L700 N shows a "boat bottom" pattern with a rising branch that presents enough disturbances. Like borehole SE3, it reveals a characteristic succession of three geoelectrical terrains (Figure 5d). The first terrain corresponds to the superficial cover which has an average thickness of 1.2 m and a resistivity equal to 345 Ω.m. The second terrain is a set of altered rocks with a thickness of around 7.4 m and.

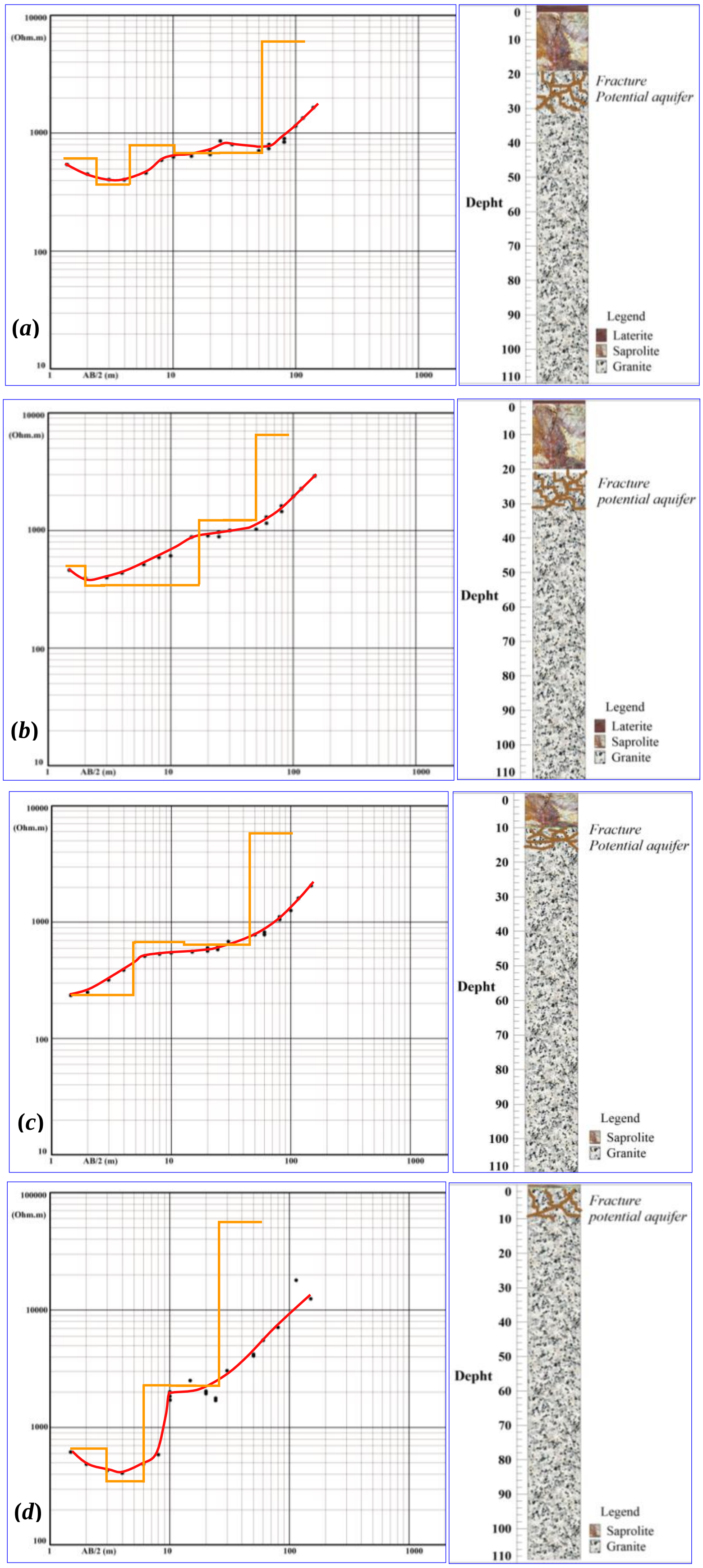

Figure 5: Electrical sounding curves and logs : (***a***) SD1/L150 N; (***b***) SD2/L300 N; (***c***) SD3/L500 N; (***d***) SD4/L700 N

resistivities ranging from 523 to 620 Ω.m. These first two terrains, which total a thickness of 8.6 m, correspond to the cuttings. The third corresponds to the signature of the granitic basement. It presents enough discontinuities in its superficial part that are due to the effects of fissures related to natural physical alteration processes. At borehole SE4, the granitic basement is shallow, between 8 and 9 m, and has a resistivity that gravitates around 5800 Ω.m. It also reveals an absence of fractures at depth.

4.2 Synthesis and Discussion

The 2D sections as well as the electric boreholes describe three stratigraphic units: a clayey-sandy layer (alterites) followed by a saprolitic level and finally a granitic base. The geo-electrical logs show superficial terrain that is less than 2m thick. They are not identifiable on the 2D sections because the surveys are carried out with a 25m step. The thicknesses of the sandy-clay complex are 28, 21, 13 and 8m respectively at SE1, SE2, SE3, and SE4. On the 2D sections, they are 24, 16, 14 and 10m at station 00 (baseline) of profiles L150N, L300N, L500N and L700N respectively. Similarly, the thickness of the saprolitic zone found on the 2D sections are corroborated by the geo-electrical logs (**see Figure 4 & 5**). Thus, the compilation of the thicknesses interpreted on all the 2D sections (16 profiles) allows the generation of a new database which, ingested in the Voxel module of Geosoft, proposes the 3D model of the exploitable granite (**Figure 6**). This model, which integrates the geometric parameters of the retained resistivities ($\rho_a \geq 3000$ Ω.m), estimates its volume at approximately 5.3 million m3 for a pit set at 100 m depth. The corresponding mass of exploitable granite is the product of this volume and the average density of the granite (2.67 T/m3). Thus, the total estimated reserve is around 14 million tonnes of aggregate. This is a significant amount, especially as it would correspond to approximately 26 years of mining at a rate of 2000 tonnes per day.

The results of the work carried out on this prospect have shown that the resistivities that characterise the basement are high ($\rho_a > 3000$ Ω.m). According to [11], in most cases when the resistivity of the last layer is above 1000 Ω.m, this generally reflects the response of the crystalline basement. This theory is consistent with the results obtained for the different boreholes carried out during this study. Furthermore, the boreholes carried out show "boat bottom", type H, and "step increase in resistivity", type A. This materializes a vertical succession that consists of a superficial layer, followed by a set of alterites and the crystalline basement. These shapes and patterns were also highlighted by [12] during his work in the Sikensi-Tiassalé region which is located to the west of the study area. Indeed, he showed that the weathering profile of his study area is presented as a succession of surface layer, a conductive complex associated with weathered horizons, fissured bedrock fringe and healthy bedrock. The 2D sections revealed, during this study, that the thickness of the overburden evolves from 0.15 m to a maximum of 52 m in places. However, some authors such as [3] and [12] have respectively shown that the thickness of alteration varied between 4 and 40 m in Agboville and could reach 70 m in places in the locality of Sikensi-Tiassalé.

Structurally, the Ery Makouguié 1 prospect is affected by NE-SW and N-S oriented fractures. The work of [13], which focuses on the mapping of structural discontinuities in southern Côte d'Ivoire, has also highlighted a predominance of N-S, NE-SW and NW-SE oriented fractures; directions that are consistent with those obtained on the prospect studied. Also, the Sikensi locality presents a highly fractured basement with predominantly N110° and N130° directions [12].

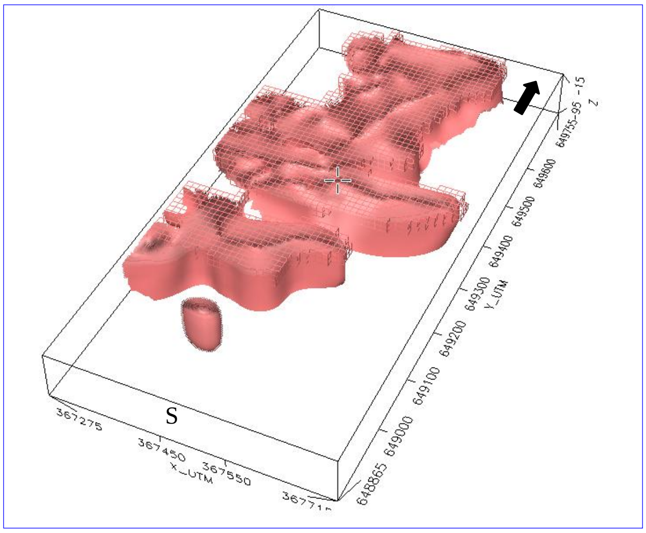

Figure 6: 3D model

The objective of this study was to evaluate the granitic potential for the implantation of an aggregate quarry. The methodology was based on the measurement of electrical resistivity contrasts with pole-dipole devices for profiling and Schlumberger for electrical drilling. The results of this study revealed that the depth of the granite roof varies between 0.15 and 52 m. The 2D sections show that the granite outcrops in places on the western edge of the prospect. The 3D model obtained by compiling the 2D sections shows an irregularly shaped underground massif and estimates its volume at 5.3 million m3. This volume corresponds to 26 million tonnes of mineable granite. However, the existence of two deep fractures could restrict its exploitation with the likely inflow of groundwater. The synthetic modelling of the resistivity from the 2D sections using Geosoft software is innovative and appears to be effective for the quantification of the volume and mass of underground materials. Mechanical drilling and geotechnical testing would be useful before sizing the quarry.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the general management of the Geophysical Research Office Côte d'Ivoire for agreeing to make available the data necessary for this research work.

REFERENCES

[1]. Ouattara, G. et Koffi, B. G., 2014. Typologie des granitoïdes de la région de Tiassalé (Sud de la Côte d'Ivoire -Afrique de l'Ouest) : Structurologie et Relations Génétiques. Afrique SCIENCE, Vol. 10, N° 2, 258–276. https://www.ajol.info/index.php/afsci/article/view/109667

[2]. Benbaqqal, H., Masrour, A., Benyassine, E.M., et Erragragui, M., 2016. Approche du SIG pour la valorisation des carrières de matériaux de construction. Cas d'étude : Ex-Région septentrionale de Meknès-Tafilalet, Maroc, Rev. J. Mater. Environ. Sci. N°7, 2342-2343.

[3]. N'go, Y.A., Gone, L. D., Savane, L. and Goble, M. M., 2005. Potentialités en eaux souterraines des aquifères fissurés de la région d'Agboville (Sud Est de la Cote d'Ivoire) : caractérisation hydroclimatique et physique. Afrique science 01 (1), 127-144.

[4]. Onep., 2017. Renforcement de l'alimentation en eau potable dans les centres urbains d'Agboville. Rapport final N°5929-CI, 170 p.

[5]. Ahoussi, K. E., 2008. Evaluation quantitative et qualitative des ressources en eau dans le Sud de la Cote d'Ivoire. Application de l'hydrochimie et des isotopes de l'environnement à l'étude des aquifères continus et discontinus de la région d'Abidjan-Agboville. Thèse de doctorat, Univ. Félix Houphouët-Boigny de Cocody (Côte d'Ivoire), 270 p.

[6]. Tagini, B., 1971. Esquisse structurale de la Côte d'Ivoire. Essai de géotectonique régionale. Thèse de Doctorat d'État ès Science Naturelle, Université de Lausanne (Suisse) et SODEMI, Abidjan, 302 p.

[7]. Mathieu, F. and Baïsset, M., 2015. Prospection géophysique par la méthode du panneau électrique sur les sites de Sparouine et de l'îlet Bastien du Maroni- Guyane. BRGM, France. Rapport final N° 64467,78 p.

[8]. Edwards L. S., 1977. Une pseudosection modifiée pour la résistivité et l'IP. Géophysique, Vol., 42 (5), 1020–1036.

[9]. Loke, M. A., 2015. 2-D and 3-D ERT surveys and data interpretation. Workshop outline, Piedmont Regional Order of Geologists Paris Geophysics, Turin, Italy, 10th. Sept. 2015.

[10]. Hacini, Y., 2006. Application des méthodes géophysiques à l'étude de deux sites (Kappelen et Grenchen) de l'aquifère poreux complexe du Seeland. Thèse de doctorat, Université de Lausanne.

[11]. Lavoie, A.C., 1998. Application de la méthode des sondages à la caractérisation des aquifères et des dépôts meubles, Basse-Terre du St- Laurent, région nord de Montréal. Mémoire de Maîtrise en Sciences de l'eau, Institut National de la Recherche Scientifique-Eau, Montréal, Canada, 151 p.

[12]. Sombo, A.P., 2012. Application des méthodes de résistivités électriques dans la détermination et la caractérisation des aquifères de socle en Côte d'Ivoire. Cas des départements de Sikensi et de Tiassalé (Sud de la Côte d'Ivoire). Thèse de doctorat, Univ. Félix Houphouët Boigny Abidjan, Côte d'Ivoire, 170 p.

[13]. Assoma, T.V., Koudou, A., Adiaffi, B., Koffi, F. K., 2018. Caractérisation des structures géologiques par analyse morphostructural d'image d'ombrage (ASAR ENVISAT Et MNT SRTM) et géostatique du Sud de la Cote d'Ivoire. European Scientific Journal, vol.14, N°15, 208-209. https://doi.org/10.19044/esj.2018.v14n15p197