The Effect of Corrosion in Soil Layers Determination along Adibawa-Zarama Pipeline Route

***Zorasi, C.B., Nyodee, G.T., & Nwiyor, P.S.**
School of Applied Sciences,
SLT Dept.
Ken Saro-Wiwa Polytechnic,
Bori.
*collinzi4u@yahoo.com

Falogun S.B.
Geogreatotechnics and Geodreels limited,
Port Harcourt.

ABSTRACT
Schlumberger Vertical electrical sounding (VES) was applied for investigation of soil layer corrosion along Adibawa-Zarama pipeline situated in the SW Niger Delta. Data collection was aided by Abem Terrameter SAS1000 equipment, employing the schlumberger method of a maximum half current electrode spacing of 50m. The outcome determined the maximum and minimum of seven and four geoelectric layers respectively. The result of the geoelectric survey was correlated with different lithologies by calibrating the geoelectric values with borehole data and electric cone penetration test results. The resistivity variation at various depths along the pipeline route was profiled and the soils within the depth range of 1m to 3m were classified based on the design and engineering code of Shell Petroleum Development Company (SPDC) standard practice to be slightly corrosive. The 1st, 2nd, 3rd, 4th, 5th and 6th geoelectric layers were contoured and the final 2D model to a depth of 40m was produced using Resist Software. For the total depth probed, transverse resistivity was noticeably higher than longitudinal resistivity; hence anisotropy value range within 1.06 to 1.5 existed. The generated 2D geoelectric model shows that the first layer has a resistivity of 19Ωm to 25Ωm but highest distribution is in the range of 101Ωm to 150Ωm.

Keywords: *Corrosion, Soil layer; geoelectrical resistivity; pipeline; subsurface model.*

INTRODUCTION

Soil scientists define soil as the unconsolidated layer on the earth's surface that contains living matter capable of supporting plants. Soils typically have an approximate depth of 1.5m (Busby et al., 2012). The buried soil environment is a confusingly complex environment; structures placed therein affecting the properties of one another in a very complicated manner (Parker, 1962). Hembara and Andreikiv (2011) regarded soil corrosion as one of the most important factors undermining the reliability of pipeline. Corrosion is the deterioration of materials by chemical interaction with their environment which affects almost all metals (Bradford, 2001; Mak, 2002; Andrew et al, 2005; Pritcard et al., 2013). Once corrosion occurs along pipeline an anodic-cathodic condition is created, which leads to the fast transfer of electrons from the cathode to anode. Figure 1.A shows the presence of an anode, cathode and subsequent paths for ionic conduction within the soil as a result of corrosion effect. Conductive soils provide an external link between any two sections containing an anode and a cathode (Alaminiokuma et al., 2016). The consequences of corrosion are many and vary. The effect of corrosion on safe reliable and efficient operation of equipment or structures are often more serious than the simple loss of metal mass. Failure of various kinds and the need for expensive replacements may occur even though, the amount of metal destroyed is quite small (Pritchard, Stephen and Timothy, 2013) Thus, with most underground services being at depths between 40 and 100cm, near surface soil interact with buried soil.

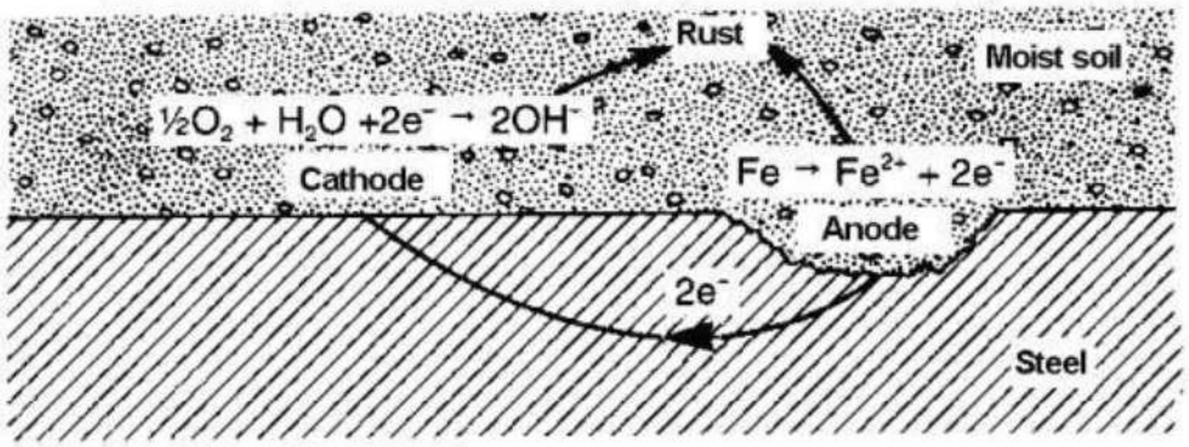


Figure 1.A **Representation of electro-chemical reaction in one corrosion cell (After: Camitz, 1998)**

The failure of pipes carrying fuels and other potentially hazardous liquids can result in ecological disasters due to the contamination of both soil mass and associated ground water from which ecosystem services arises, or potable water supplies are extracted (Cooper et al., 2000). The impacts of soil corrosion on buried infrastructure (pipeline) can be economically, environmentally and socially detrimental. The water, gas and highways sectors appear the most susceptible to soil corrosion processes within Nigeria.

This paper is aimed at carrying out the investigation of geoelectric layer depths of soils along Adibawa-Zarama pipeline route using Vertical Electrical Sounding (VES) method to identify geoelectric properties. This method addresses the determination of soil depth, thickness and lateral extent of conductive layers in the subsurface within the study area, through 2D simulation of the geoelectric layers model of the subsurface along the pipeline route. The interpretation and delineation of corrosive layers from the geoelectric model is effectively done. This research is significant because pipelines are the major means of crude oil and gas transportation and are liable to get corroded as a result of age. Soil survey design and subsequent soil mapping is established to aid in asset (pipeline) management and economical replacement of buried critically damaged infrastructure (pipelines). In addition, once corrosion commences from a point on a pipeline it led to oil seepage or spillage to nearby environment, making it vulnerable to fire outbreak and if it seep or spill to rivers it kills marine lives and if it seep into water aquifers it pollute the potable water. Soil properties contributing to soil corrosivity do not occur in isolation and are often interrelated. It is often a combination of soil processes with human activities that culminates in infrastructure (pipeline) failure. Thus, pipelines can be protected fully after the electrical properties of the contacting soil have been investigated since the corrosive action of soil cannot be eliminated but can be managed.

GEOLOGY OF THE STUDY LOCATION

This research is carried out in the Niger Delta region, in an area encompassing two local government areas in Rivers and Bayelsa States. Fig 1B shows the map of the Niger Delta and the study area. The location is the site of proposed Associated Gas (AG) pipeline route along the Shell Petroleum Development Company (SPDC) of Nigeria Right of way (ROW) from Adibawa flow station in Rivers State to Zarama field in Bayelsa State (Falodun, 2014) The vegetation is evergreen thick forest type completed with raffia palms. Prominent superficial soil types is silty-clay which is underlain by sand. This project route is a flat terrain with sparse undulations caused by seasonal water channels. The general physical geography of the area essentially reflects the influence of movements of flood water in the Niger Delta and their search for lines of flow to the sea, hence depositing their transported sediments along the paths of flow in the Rivers (Short and Stauble, 1967).This area lies within the humid tropical climate zone due to its proximity with the Gulf of Guinea. Geologically, the entire site and its environments lie within fresh water zone of the Niger Delta and they are of Miocene era. This zone is generally known to be characterized by considerable thickness of grayish silty-clay (mostly active) with intercalation of coastal plain and of the Benin geologic formation. (Short and Stauble, 1967). Benin formation is the most recent of the three lithostratographic units of the Niger Delta basin. The coastal plain is overlain by various quaternary deposits (Short and Stauble, 1967).

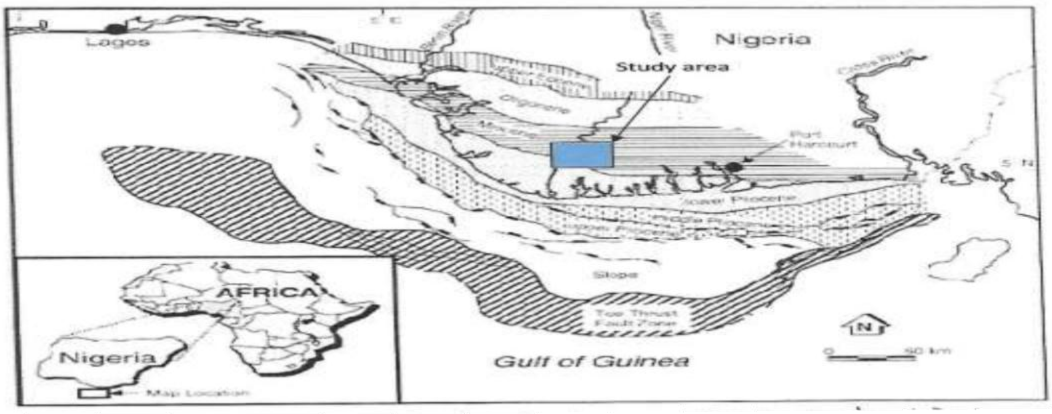


Fig 1B: Map of the Niger Delta showing the area of study in blue box

METHODOLOGY

This study utilizes surface electrical resistivity survey which is based on the principle that the distribution of electrical potential in the ground round a current–carrying electrode, depends on the electrical resistivity and distribution of the surrounding soils and rocks. The usual field practice is to apply an electrical direct current (DC) between two electrodes implanted in the ground and to measure the differences in potential between two additional electrodes that do not carry current. Two common techniques were used in this resistivity survey for vertical boundary delineation and horizontal electrical profiling (HEP) for horizontal boundaries delineation.

Vertical Electrical Sounding (VES)

Data were acquired using the appropriate VES equipment and configuration. The current and potential electrodes were maintained at the same relative spacing and the whole spread is progressively expanded about a fixed central point. Consequently, readings are taken as the current reaches progressively greater depths. This technique is extensively used in geotechnical surveys to determine overburden thickness and also in hydrogeology to define horizontal zone of porous strata. The schlumberger array configuration was employed to achieve vertical variation in resistivity as well as horizontal variation in resistivity distribution at defined depths and distances respectively (Lowrie, 1997)

Workflow

The workflow applied for this survey involved thirty (30) VES at specified locations, identified with the aid of global positioning satellite system (GPS) including total station survey equipment located at an interval of 250m apart, to record any change in lithology as a result of electric properties effect, along the Adibawa-Zarama pipeline route to be detected and classified into geoelectric layers. Data obtained from the field work include the resistance of the ground between the two inner electrodes, electrode spacing, date of survey, location and generation of physiographic information about the survey environment. The current and potential differences generated by the instrument were used to calculate the resistance of the ground to the flow of electric current. The appropriate formulas were then applied to get the geometric factors which are also multiplied by the resistance values to get resistivity. The resistivity with corresponding was then uploaded into the resist software for analysis to generate apparent resistivity curves from which the geoelectric layers of the areas were delineated.

Interpretation Techniques

Curve match

The schlumberger sounding curves obtained in this work were interpreted by one-dimensional inversion using the schlumberger automatic programme. The curves fall into the following categories: H, K HK, KH, A and Q types and its subsequent geoeletric sections in square graphs. These curves portrayed the different geological features encountered in the study area. The results of the interpretations of the schlumberger data required are presented here as Iso-patch, 1so-resistivity contour/image maps as well as the geoelectric sections of the fields data (Fig 1.8-1.14) In horizontally stratified formations, the shapes and types of the curve depends on the electrode configuration, resistivity and thickness of formation beneath the sounding points.

Whereas in a simple case of a single homogeneous isotropic layer of infinite thickness, the curve for apparent resistivity versus electrode spacing is a straight line , for two layers of upper homogeneous /isotropic with thickness h_1 and resistivity ρ_1 underlain by infinitely thick (h =) lower layer of resistivity ρ_2, the initial trend of the curve resembles the one for a simple layer, but the later trend departs from it depending on the relative resistivity and electrode configuration used: For multiple layers the letters H, A, K and Q are used in combination to indicate the type of geoelectric layered properties encountered.

Automatic interpretation of the subsurface

Zohdy (1989) described a fast iterative method for the automatic interpretation of Schlumberger and Wenner sounding curves which is based on obtaining interpreted depths and resistivity respectively. The method is fully automatic. It does not require an initial guess of the number of layers, their thickness or resistivity and it does not require extrapolation of incomplete sounding curves. The number of layers in the interpreted model equals the number of digitized points on the sounding curve. The resulting multilayer model is always well behaved within thin layers of unusually high or unusually low resistivity.

RESULTS

After carefully processing and noise elimination of data acquired, the results are presented in figures 1.1-1.14 and Table 1.1.The delineated geoelectric layers were used to plot resistivity profiles at 1m, 2m and 3m.The resistivity at the respective distances are written as ρ1m,ρ2m,ρ3m……ρnm (Fig.1.1).While in Fig. 1.2 series 1,2,3 represents resistivity profiles at 1m,2m and 3m depth respectively are mainly damp clay but areas on the profile where the resistivity fall within the range of 0Ωm to 50Ωm may be classified as soft/wet, clay/silt (where wetness is influenced by the closeness to ground water table, a river crossing or borough pit, valley or topography whose slope creates channel for water movement.) Regions on the profile which overlap are indications of soils with the same geoelectric resistivity values. This overlap is very prominent at the depth of 5m and 6m; and depth of 6m to 12m.Figures 1.3-1.4 shows sequential disappearance of some series from the profiles which represents various depths and distances along the pipeline route. This is as a result of an overlap in some of the profile series. It could also be due to geoelectric resistivity values being the same and having same geological lithologies of same age. This implies that as we go deeper in depth, soil homogeneity increases, whereas in upland Niger Delta, after the first surface to shallow blanket of clay, there is very high tendency to intercept sand or sandy lithology which maintains a considerable depth before transiting to a clear marked lithology. However, in the swampy area, it is possible to intercept marked lithologies at every short distance drilled.

Iso-Resistivity Map

1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th} and 6^{th} geoeletric layers were contoured as shown in (Figures 1.8 – 1.13) respectively. Figure 1.14 is a 2D model which shows the lithology and colour identification on the map. Colour is an important factor to recognizing the various geoelectric bands. This 2D geoelectric section distinguishes chronologic bands of lithology of probably the same age into various geoelectric units. The geoelectric layers interpreted varies from clay, silt-clay, sandy clay or firm silty clay, clayey silty sand, fine silty sand, very fine sand, fine sand to medium to coarse, coarse sand to dense coarse sand and sand gravel intercalation depth wise when calibrated with the resistivity of the study area. These resistivities are 17-100Ωm, 100-300Ωm,300-400Ωm,400-600Ωm,600-800Ωm,800-1000Ωm,1000-2000Ωm,2000-3000Ωm,3000-4000Ωm and above 4000Ωm respectively. Water table in this area is within 5m to 6m. Transverse resistivity generated is generally higher than their corresponding longitudinal resistivity shown in Table 1.1.

Geoelectric Layer Parameter Distribution

Geoelectric modeling based on the geophysical characteristics of the soil with depth is a dependable tool for lithologic characterization. Since every geoelectric layer has its own peculiar electrical properties, depending on its physical and chemical properties. The first geoeletric layer resistivity are mostly in the range of 101 to 150Ωm, while second geoeletric layer resistivity fall mostly within the range of 51 – 100Ωm.The third geoeletric layer resistivity is mostly within the range of 401 to 500Ωm, while fourth and fifth layers mostly distributed resistivity values fall within 601 to 700Ωm and 3001 to 4000Ωm respectively. The fifth layer has a close distribution to the 6th layer. It is pertinent to mention that the resistivity of soil can vary greatly with its water contents and the nature of the dissolved salts in the water.

DISSCUSION

Data obtained from 30 vertical electrical sounding (VES) points were interpreted starting first with the plotting of the apparent resistivity computed from field measurements versus electrode spacing in a Resist Software environment, The sounding curve is then compared with the internally built standard curve generated by the software program to obtain the parameters of the geoelectric layers in terms of layer resistivity, depth and thickness. The delineation of geoelectric layers and thickness was done with the software while geological stratigraphy was carried out based on geoelectric resistivity range of lithology and the knowledge of the geology of the area. Further parameters were derived from the resistivity and thickness of the geoelectric layers delineated. These parameters derived are transverse resistivity, longitudinal resistivity, anisotropy, curve types and conductivity as shown in Table 1.1.

The delineated geoelectric layers were used to plot resistivity profiles at the range of 1m-3m with its resistivity, written as ρ_1m, ρ_2m, ρ_3m, … ρ_nm, respectively. Further breakdown of the 30 VES profiles were grouped into (1m to 6m), (6m to 11m), (11m to 16m), (16m to 21m), (21m to 26m) and (26 to 30m) depths at 1m intervals as shown in Fig.1.1. This study is important as most pipelines in the Niger Delta are hardly buried beyond 5m depth within the soil but for scholarly purposes, the scope of this depth was increased to group (11-16m) (Fig 1.2-1.4) as soil layer serves as an important medium for transportation of crude oil and other human activities such as planting etc.

Geoelectric analysis incorporated with the knowledge of geology was derived by direct borehole drilling and through the application of cone penetration testing with pore pressure (CPTU): strength of the soil was also derived with proper calibration of the formation lithostratigraphy. Therefore, the soil in terms of degree of density or softness can be fathomed. The delineated geoelectric layers were further broken down into various geologic sections in relation to the degree of density derived from the CPTU plot. The stratigraphy was classified based on

Roberson (1990) shown in Figure 1.5. This CPTU log correlates well with the boreholes drilled (Fig. 1.6-1.7).

CONCLUSION

In this study, the application of VES led to the delineation of maximum and minimum of seven and four geoelectric layers. Prominent among these curves is HH. The result of the geoelectric survey was tied to various lithologies by calibrating the geoelectric values with borehole data and electric cone penetration test result. The resistivity variation at various depths along the pipeline route was profiled and the soil classified based on Design and Engineering code as slightly corrosive. 1st, 2nd, 3rd, 4th, 5th and 6th geoelectric layers were contoured and the final 2D model was up to a depth of 40m and was outputted using Resist software. The 2D geoelectric model generated shows that the first layer has a resistivity range of 19Ωm to 250Ωm but highest distribution is in the range of 101 to 150Ωm. This is classified as clay to silty-clay lithology. Clay is seen at the depth of 0m to 3m. However, beyond this depth to a depth of about 10m, it is likely to intercept silty to sandy clay. This investigation shows that VES can be used to achieve both horizontal profiling and vertical profiling. Further derived geoeletric parameters like transverse resistivity and longitudinal resistivity can serve as input for Earthing engineers, cathodic protection, drillers and geoscientists.

Table 1.1 ***Summary of geoelectric layers parameters for 1 – 6m depth***

VES point	Coord	Total thickness (m)	Curve	T(Ω)	S(Ω)	Anisotropy	ρl	ρt
1	4	22	HH	8570	0.10227	1.35	215.12	389.55
2	4	21.5	HH	9279.875	0.07879	1.26	272.88	431.62
3	5	34	HKA	30650.94	0.11578	1.75	293.65	901.50
4	6	35	HKA	32564.048	0.09235	1.57	378.98	930.40
5	5	28	AH	13031.535	0.07724	1.13	362.51	465.41
6	6	28.8	AAH	26779.62	0.04916	1.26	585.81	929.85

REFERENCES

Alamimokuma, G.I Isikpor, J., Emudianughe, J.E and warmate, I. (2016). Delination of soil corrositivity regimes along petroleum pipeline routes in the geomorphine zones of the Niger Delta using 2D Resitivity Tornography.Petro tech. Development journal Vol. 6 (2) 1-14.

Alex, M. (2002) corrosion of steel Aluminium and copper in Electrical application

Andrew E.R, Graham, E.C.B, Steven, J. D., Foreman S. and American Water works Association Research foundation, (2005). External Corrosion and Corrosion control of buried water mains. Amer water works Asso. 159.

Bradford, S.A. (2001.) Practical handbook of corrosion control in soils; Pieplines, tanks, casings, cables….Casti Publishing Ltd, Edmonton, Canada.

Busby, J.P, Entwistle , D., Hobbs, P., Jackson, P., Johnson, N., Lawley, R., Kinley, K., Mayr, T., Palmer, R.,Raines ,M., Reeves, H., Tucker, S., Zawadzka, J. (2012). A GIS for the planning of electric earthing. *Journal of Engineering Geology and Hydrogeology*. 45, 379-390.

Camitz, G., Vinka, T.G. (1989). Corrosion of steel and metal coated steel in Swedish soils – effects of soil parameters. In: Chaker V, Palmer DJ. (Eds.). *Effects of soil characteristics on corrosion.* American Society for Testing and Materials, Philadelphia, 37-53.

Cooper, N.R., Blakey, G., Sherwin, C., Ta T, Whiter, J.T., Woodward, C.A. (2000). The use of GIS to develop a probability-based trunk mains burst risk model. *Urban Water*. 2, 97-103.

Falodun, S.B (2014). Determination of Geo electric layers of soil along Adibawa – Zarama Pipeline route using vertical Electrical sounding method. Msc Dissertation RSUST.

Hembara,O.V. and Andreikiv ,O.E. (2011). Effect of hydrogenation of the walls of oil-and-gas pipelines on their soil corrosion and service life. Materials Science. 47, (5), 598-607.

Lowrie,W (1997) Fundamentals of Geophysics. Press syndicate of the University of Cambridge.214-215.

Parker, M.E. (1962). *Pipe line corrosion and cathodic protection: A field manual*. Gulf Publishing Company, Houston, Texas.

Pritchard,O.,Stephen, H.H.,and Timothy,S.F.(2013). Soil Corrosivity in the UK-Impacts on critical infrastructure.EPSRC.Cranfield University.

Short K.C and Staulde , A (1967). Outline of geology of Niger Delta, America Association of Petroleum Geologist Bull Vol. 51, PP 761 – 779.

Zohdy, A.A.R.(1968) The effect of current Leakage and electrode spacing errors on resistivity Measurements.USGS.

Annexure

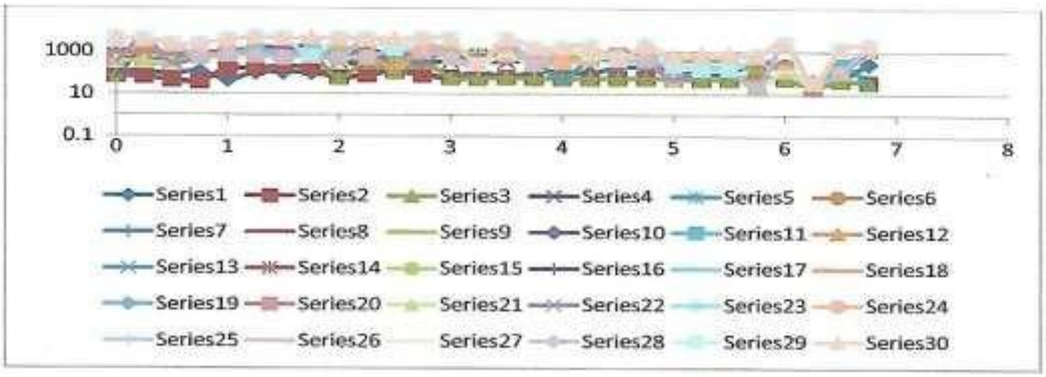


Fig. 1.1: Resistivity Profile of 1m, 2, 3..., 30m represented by series 1, 2, 3..., 30 respectively

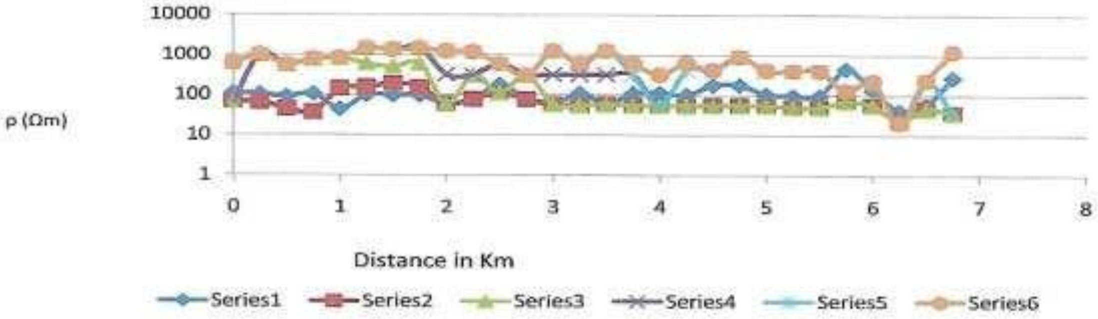


Fig. 1.2: Series 1, 2, 3....6representing resistivity profile at 1m, 2m...6m

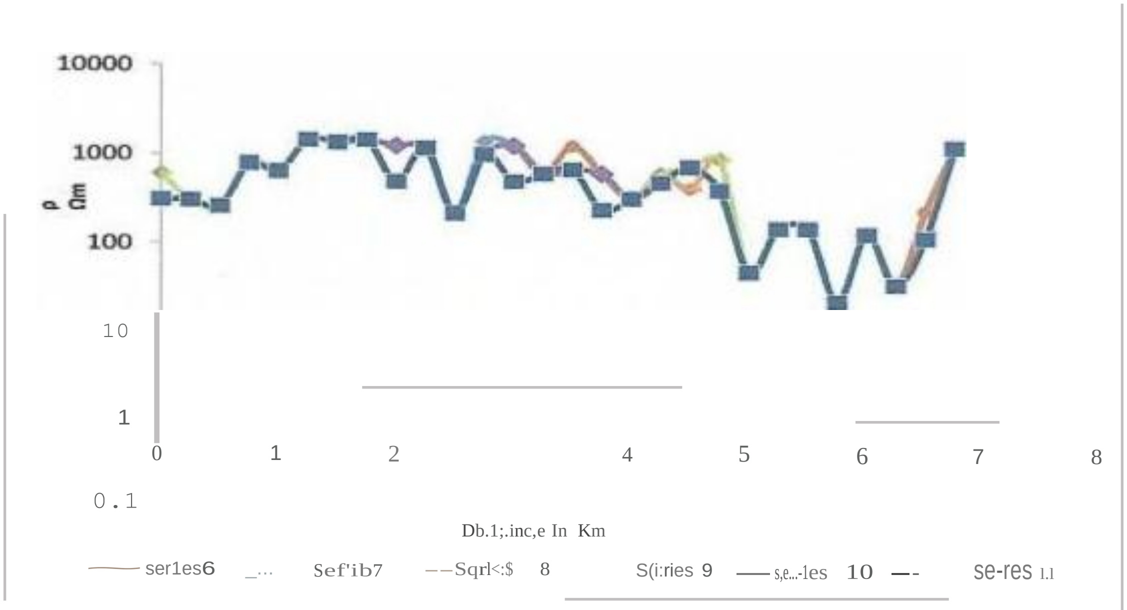


Fig. 1.3: Series 6, 7, 8............ 11 representing resistivity profile at6m, 7m, 8m, ...11m

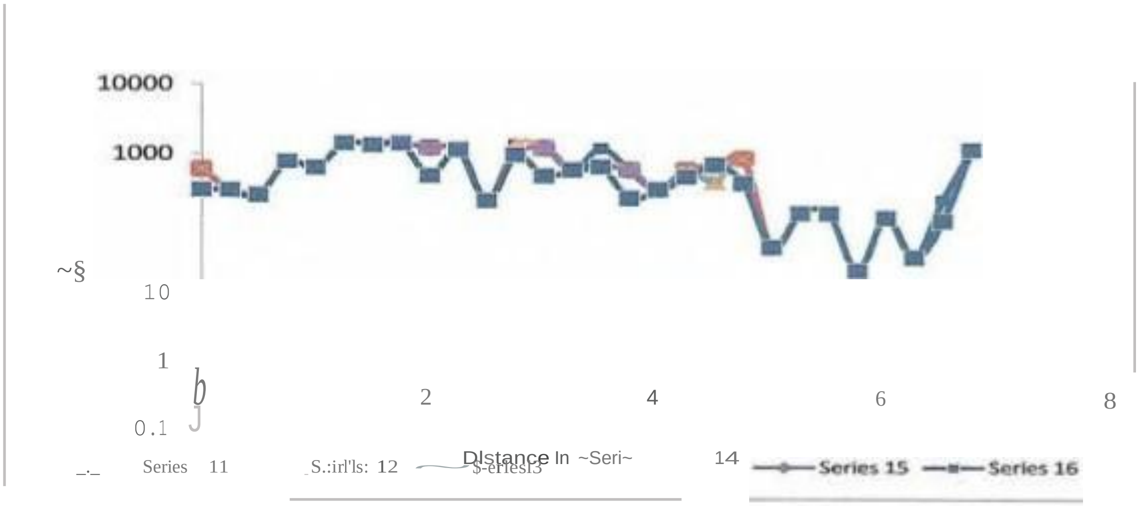


Fig 1.4: Series 11, 12, 13.......16 representing resistivity profile at11m, 12m, 13m...16m

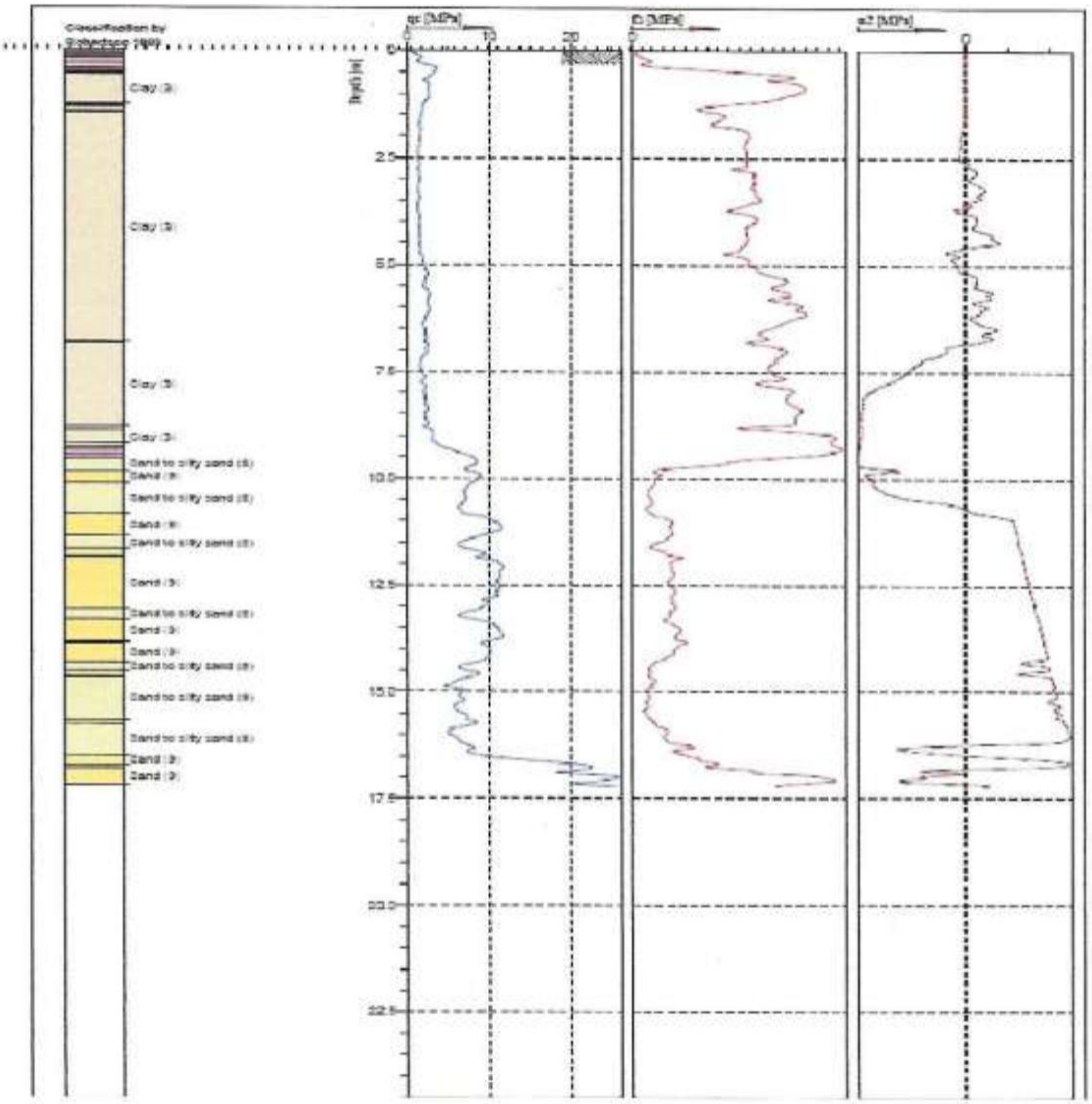
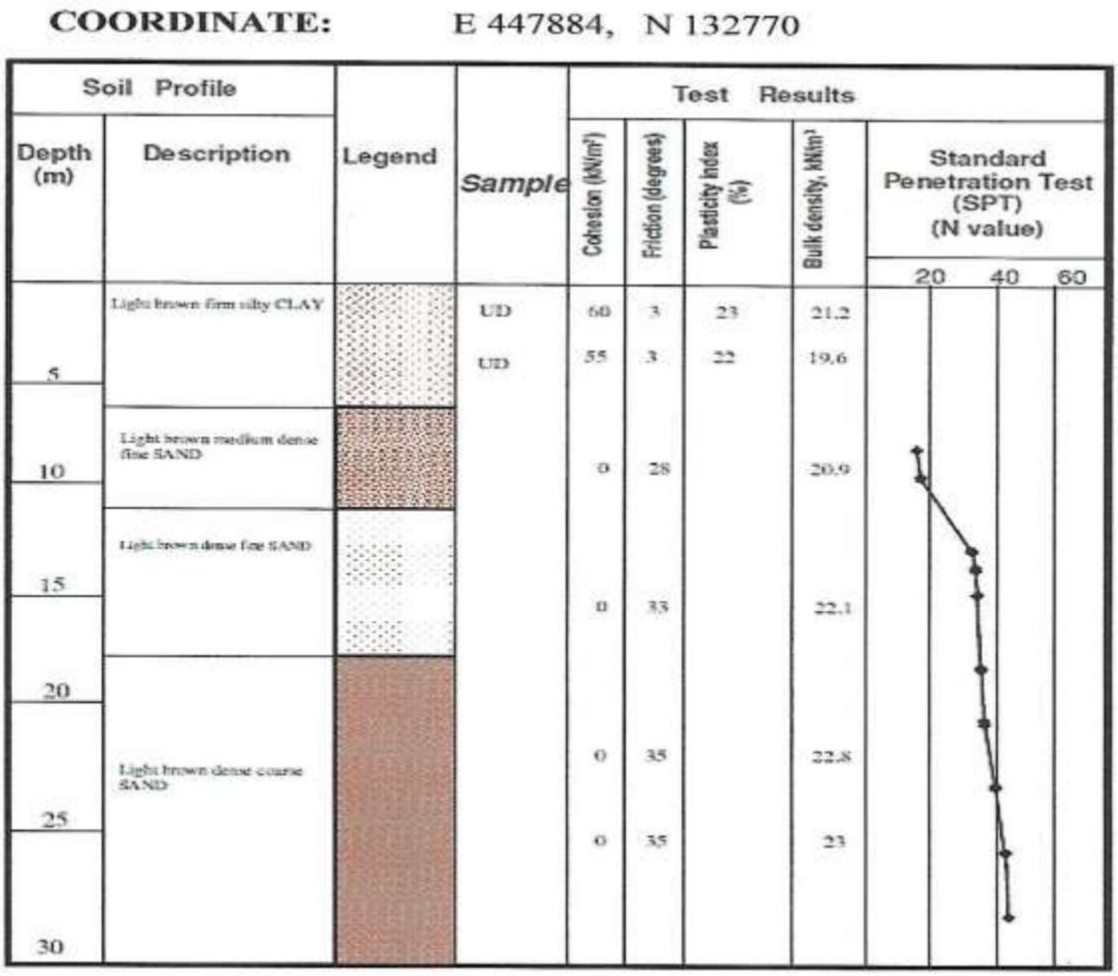


Fig. 1.5: CPTU log of a point along the pipeline route



COORDINATE: E 447884, N 132770

Soil Profile		Legend	Sample	Test Results				
Depth (m)	Description			Cohesion (kN/m²)	Friction (degrees)	Plasticity index (%)	Bulk density, kN/m³	Standard Penetration Test (SPT) (N value)
	Light brown firm silty CLAY		UD	60	3	23	21.2	
5			UD	55	3	22	19.6	
10	Light brown medium dense fine SAND			0	28		20.9	
15	Light brown dense fine SAND			0	33		22.1	
20	Light brown dense course SAND			0	35		22.8	
25				0	35		23	
30								

Fig. 1.6: Borehole Log by physical sampling during drilling 1.

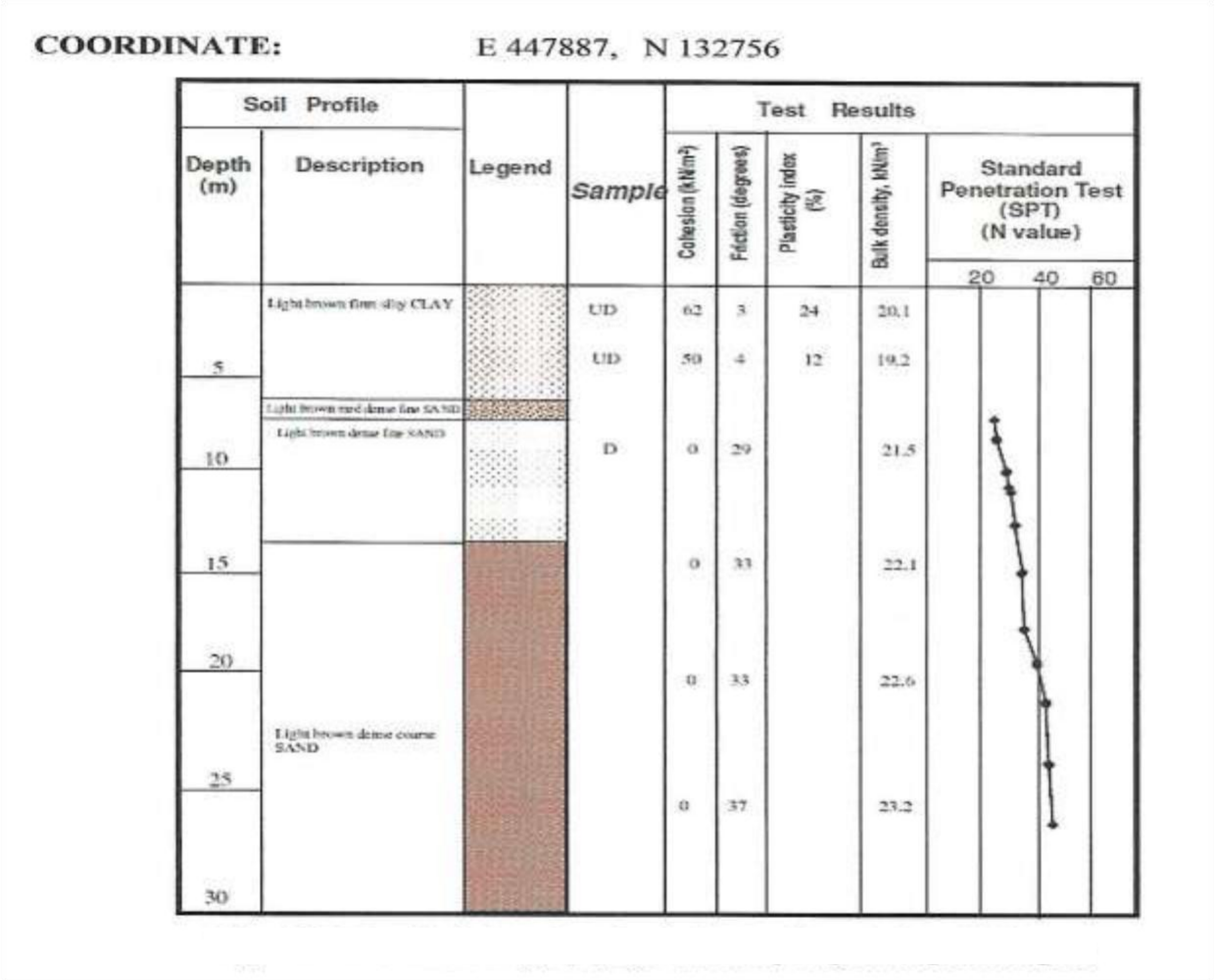


Fig 1.7: Borehole Log by physical sampling during drilling 2

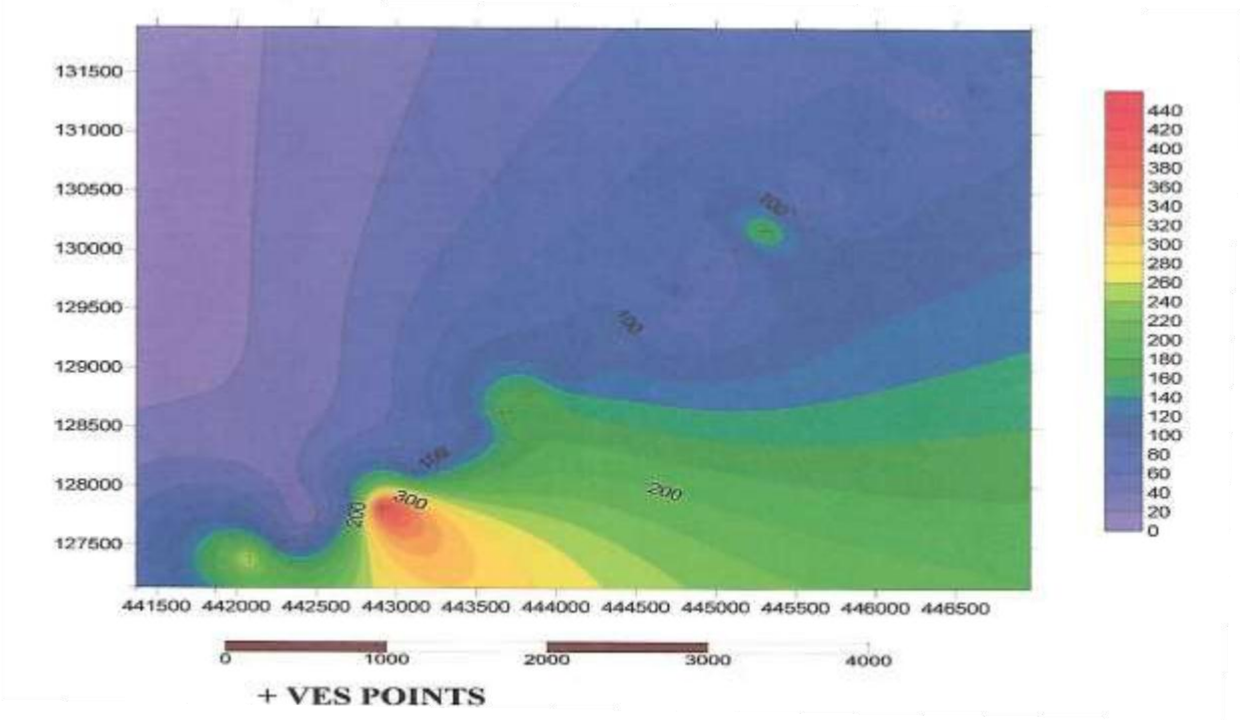


Fig. 1.8:1st geoelectric layer (Clay) Iso-resistivity Map

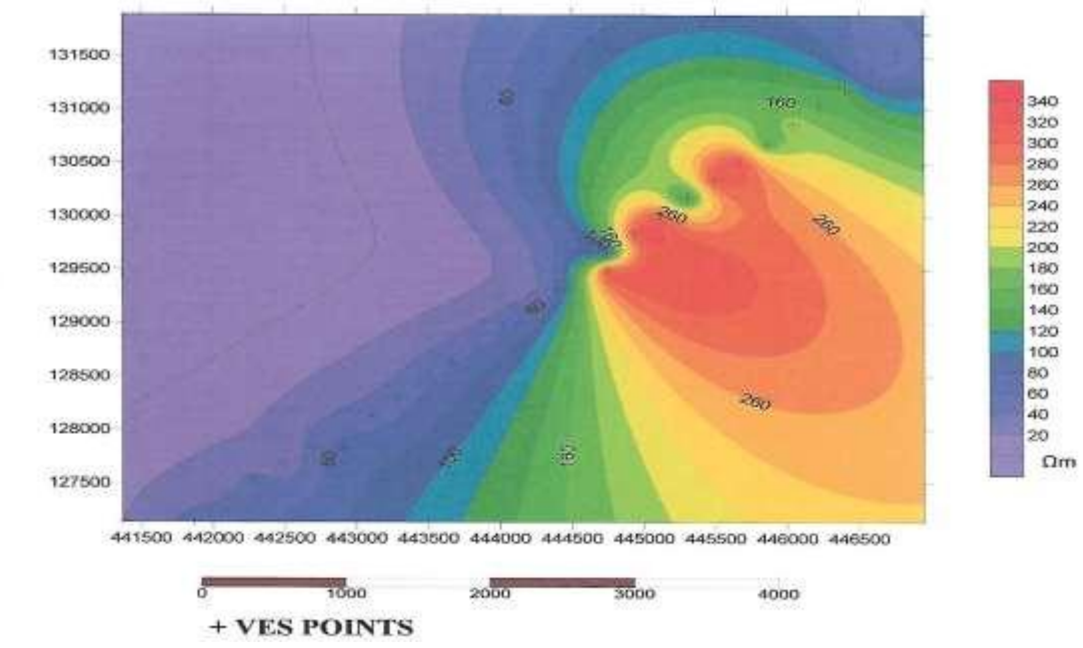


Fig. 1.9: 2nd geoelectric layer (sandy Clay) Iso-resistivity Map

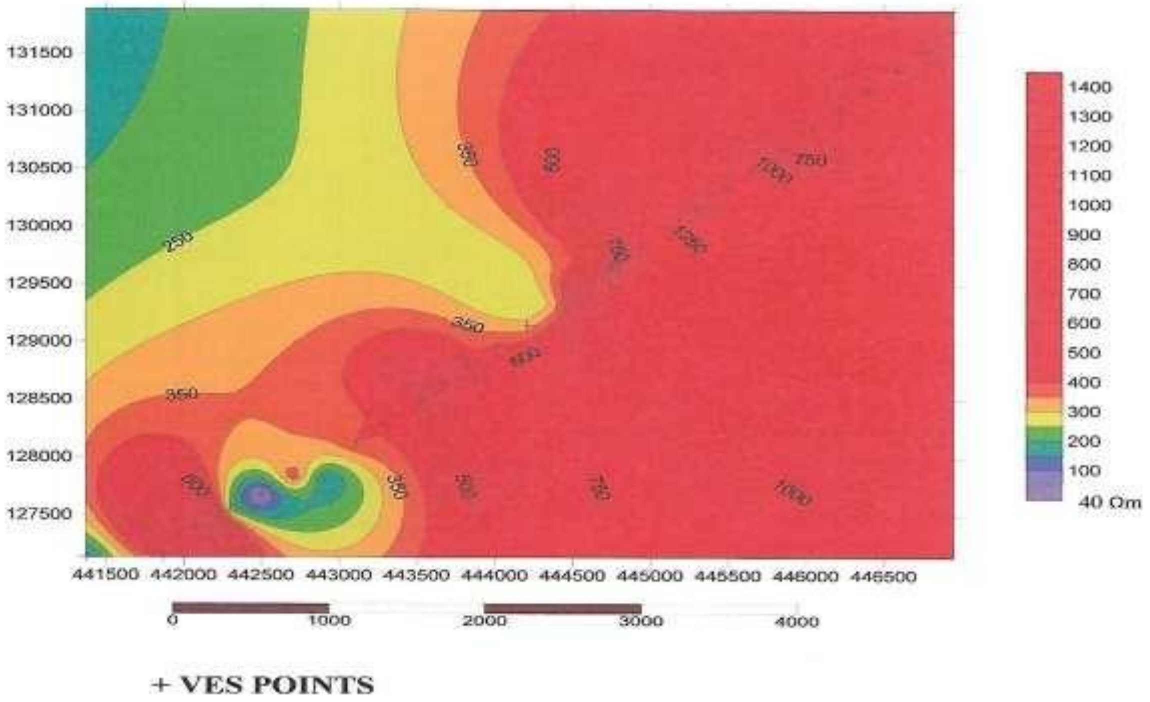


Fig. 1.10: 3rd geoelectric layer (sandy Clay) Iso-resistivity Map

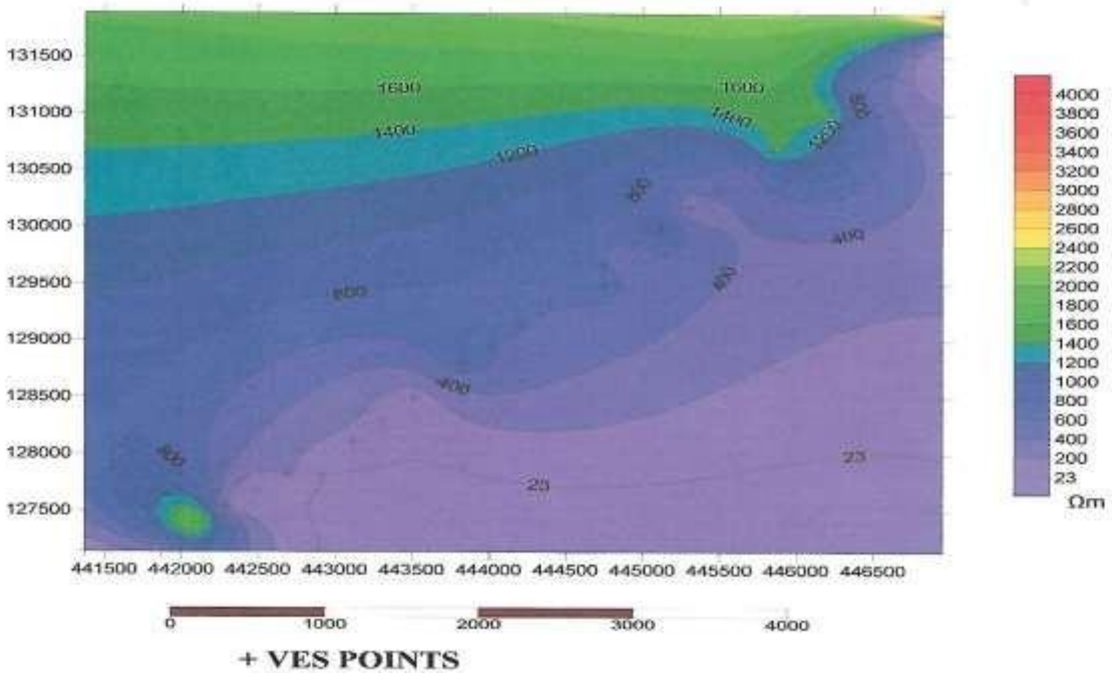


Fig. 1.11: 4th geoelectric layer (mainly sand and clayey sand few clay) Iso resistivity Map

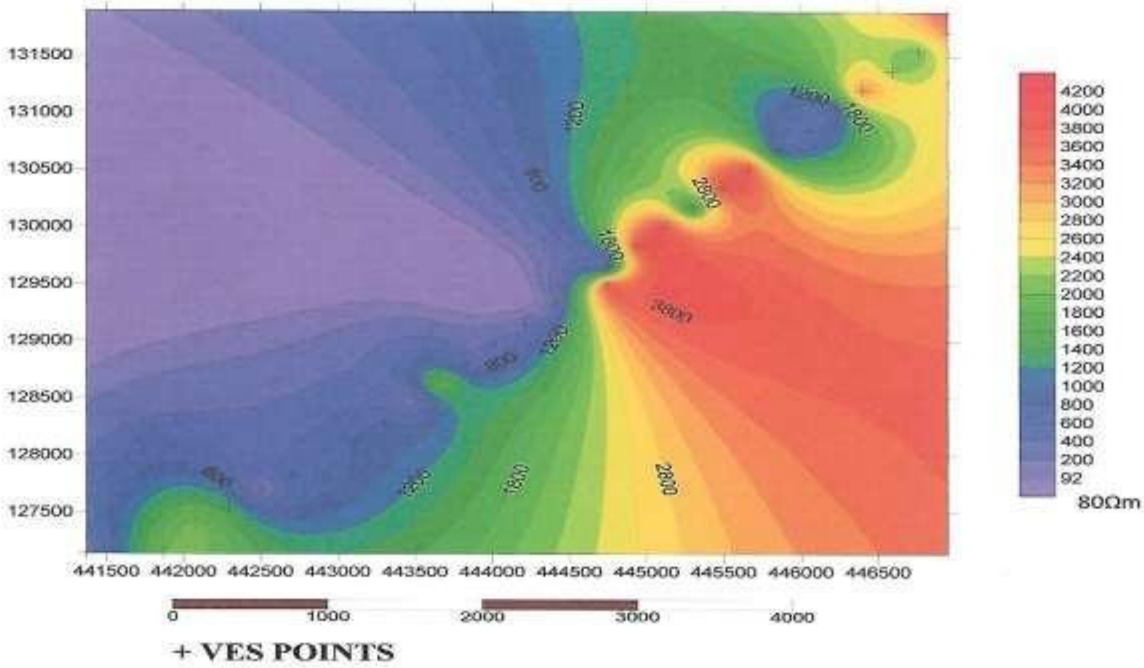


Fig. 1.12: 5th geoelectric layer (basically sand, little clayey to silty sand and little very few clay band) Iso-resistivity Map

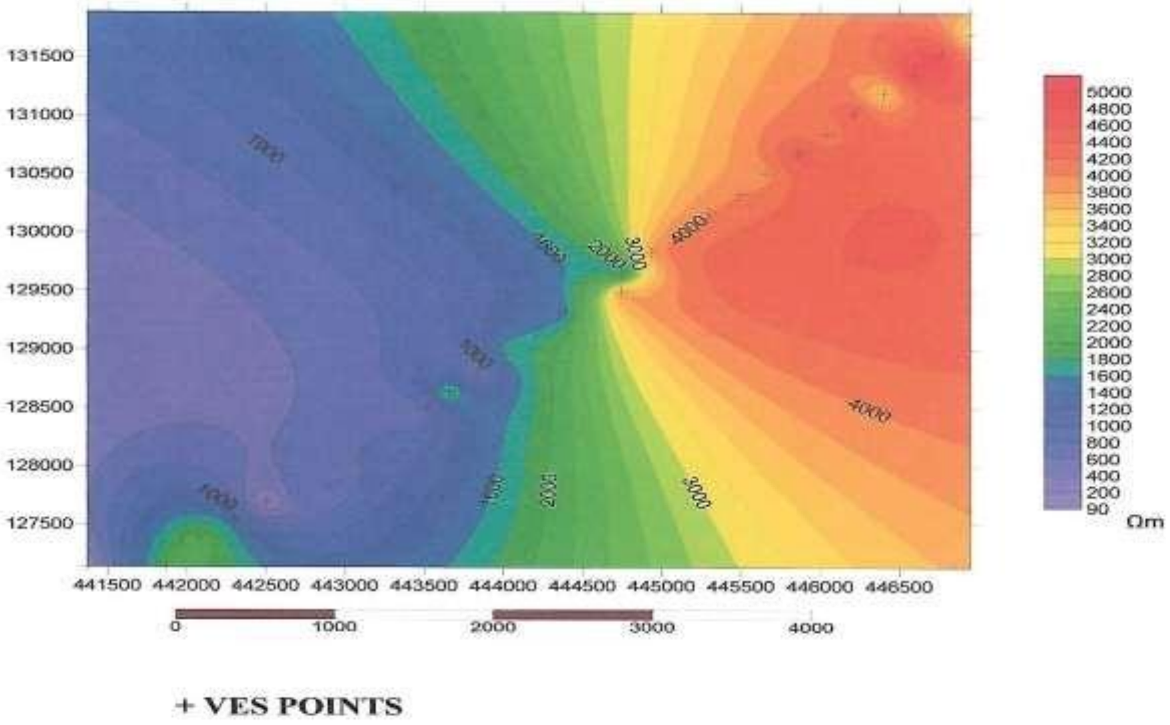


Fig. 1.13: 6th geoelectric layer (basically sand, only one to two clay band was captured here) Iso-resistivity Map

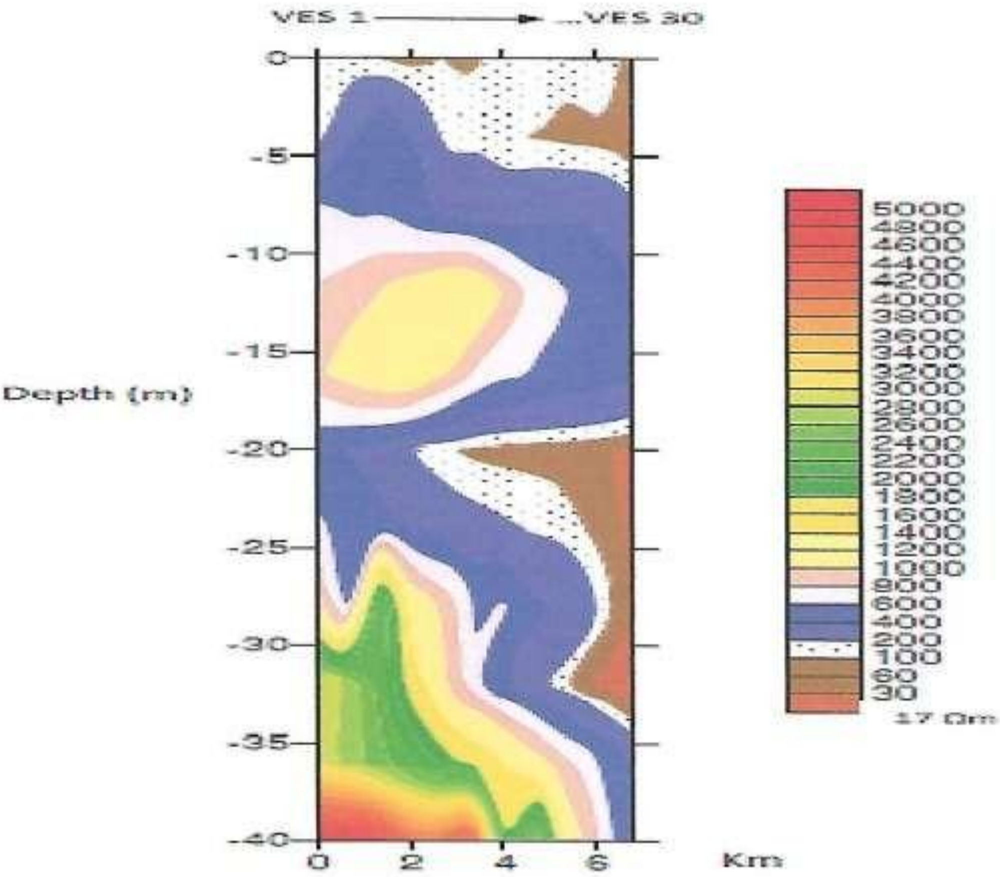


Fig. 1.14: 2D model of the geoelectric section