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Relevance of Integrated Geophysical Methods for Site Characterization in Construction Industry – A Case of Apa in Badagry, Lagos State, Nigeria

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ABSTRACT

Detailed geophysical investigations have been carried out using integrated geophysical methods with a view to characterising the subsurface lithologic features that might indicate suitable places for structural developments. An overview of the subsurface resistivity distribution has been achieved employing 8Vertical Electrical Soundings with the Schlumberger array and 4 2D resistivity imaging using Wenner array. In order to constrain the results of the electrical resistivity methods, we carried out a ground magnetic survey along E-W direction using the Proton precession magnetometer at 1m sampling interval. Analysis of well logs data available and VES results showed 4 to 5 geoelectric layers corresponding to sand, clayey sand, clay, silty sand and sandy clay. The 2D resistivity imaging sections showed relative decrease of apparent resistivity with depth implying a geological transition from sand with high resistivity value of about 508Ωm to clay with low resistivity value 16Ωm at depths of 0-20m and 25-50m respectively. The magnetic profiles showed that the study area was characterised by short wavelengths and amplitudes ranging from –3800 to 700 nT. The highs and lows of the magnetic responses occasioned by lithological variations and structural features were magnetically resolved. In view of the identified subsurface structures, the suggested depth to the competent layer is about 20m for low to medium structures while above 50m would be suitable for heavy or massive engineering structures. The use of integrated geophysical methods for the delineation, identification and imaging of the subsurface geological structures which could provide clues to the nature and type of foundation suitable for the development of the study area has been successfully achieved.

Keywords: Electrical resistivity, Wenner array, sand, magnetic anomaly, constrain, foundation design.

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INTRODUCTION

Lagos is a cosmopolitan city inhabited by millions of people from various parts of the world. At the economic level, it is Nigeria's economic capital as well as her financial and commercial nerve centre. The position of Lagos as a regional financial hub is universally acknowledged. Despite the relocation of Nigeria's capital from Lagos to Abuja, Lagos still holds so much potential that nowhere in Nigeria can be better suited (Peterside, 2007).

Recently, Lagos joined the Megacity group of cities like Tokyo, Bombay, New York and Los Angeles with a population estimation of about 18 million people. With such a dense population, Lagos can be said to have become a teeming tangle of humanity and enterprise (Dekolo & Oduwaye, 2011).Globally, megacities due to their huge population, have attendant issues and problems of inadequate socio-economic infrastructure necessary to sustain their population. For decades, the city of Lagos has grappled with problems such as gross shortage of housing, insufficient road networks and acute potable water supply.

In an effort to address this socio-economic malice, the state government through public and private partnership has embarked on various developmental programmes in the city with a view to drawing people away from the congested centre and have them shift to the suburbs. Badagry, one of the suburbs that is about 45km from the city, is expected to witness a huge influx of people not only because of its strategic location but also due to the fact that it isa trading outlet for Trans-Saharan Trade Routes and an inlet for the Trans-Atlantic Trade (Mabogunje, 1971).

Following this trend, and the fact that the number of people living in Lagos, Nigeria's fastest growing city, is expected to reach the 24 million mark in 2015 (Dekolo & Oduwaye, 2011), there is a need for adequate town planning projects in the suburbs of Lagos and Badagry, in particular, which should be focused on delivery of residential accommodation in addition to other social infrastructures.

Against this background, we embarked on the use of integrated geophysical methods involving electrical resistivity and magnetic methods to define the stratigraphy of the subsurface structural features and identified suitable place for housing developments in the study area. Although geotechnical methods may be used, the high cost of using such methods and the distortion of the subsurface compositions which might result compared to the outcome of using the geophysical methods employed in this study favour the latter.

SITE AND GEOLOGY

The study area was about 15km from the Badagry roundabout on the Seme Border route. It is located between longitudes2° 52'50" to 2°53' 40" East of the Greenwich meridian and latitudes 6°.24'30" to 6°25' 20"North of the Equator. It can be accessed via the Lagos-Badagry expressway, leading to Badagry Town. It is bounded on the westby Porto Novo and Weme; on the north by Ilogbo, Ipokia; on the south by the Osa lagoon and the Atlantic ocean and on the east by the Awori settlements of Ojo and Lagos (Akran,2001). The stratigraphy of the Dahomey Basin has been extensively discussed with various works, and several classification schemes have been proposed by notable authors (Jones & Hockey, 1964; Omatosola & Adegoke,1981; Coker *et al*., 1983; Billman 1992; Elueze & Nton, 2004).

The stratigraphy sequence is classified under 5major formations in terms of their geological formation age that include the Littoral and Lagoon deposits, Coastal Plain sand, the Ilaro formation, the Ewekoro formation and Abeokuta overlying the crystalline basement complex; their ages range from Recent to Cretaceous. With the exception of Ilaro, the other 4of these formations constitute aquifers in the Dahomey Basin from which the geological section of Lagos was drawn. Lagos state is underlain by a geological sequence composed of Sands, clayey sands, Clay/Shale, Sandy clay typical of Alluvium and Coastal plain sands (Fatoba *et al*., 2004).

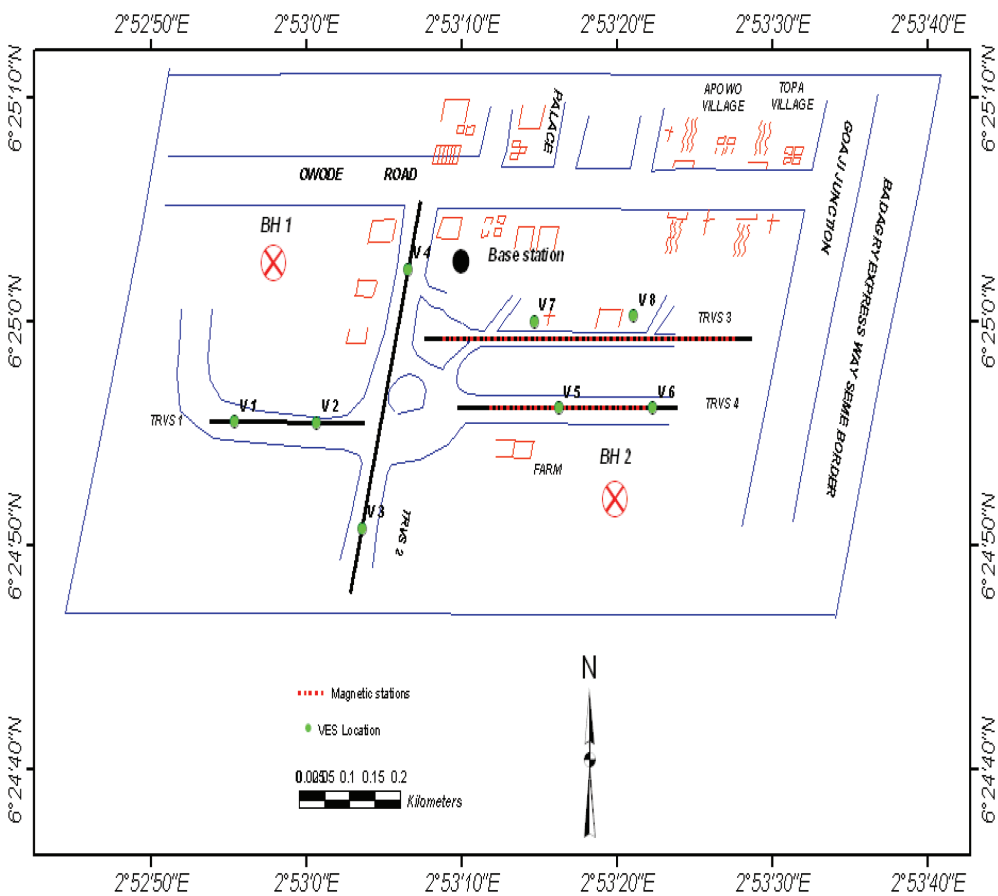


Fig.1: Location Map of the Study Area Showing the Traverses, VES Points and Borehole Locations

DATA ACQUISITION

Electrical Resistivity

In electrical resistivity method, electric current was injected into the ground through a pair of current electrodes. A second pair of electrodes was then used to measure the voltage resulting from the flow of current in the current electrode into the ground. Measurements were taken using Vertical Electrical Sounding and 2-D Electrical Resistivity Imaging techniques. Four traverses were established in the field of study (Figure 1). ABEM SAS 1000 Terrameter was used for the data acquisition. A total number of 8vertical electrical sounding (VES) positions were occupied using the Schlumberger electrode array. Along traverses 1,2 and 3we occupied VES points 1 and 2, VES 3 and 4, VES 7 and 8 respectively while VES 5 and 6werecarried out along traverse 4 (Fig.1). The current electrode spread (AB) varied from 2m to a maximum of 600m.

Current (I) was injected into the ground through two current electrodes and the resulting potential difference (V) was measured through another pair of electrodes called the potential electrodes. The obtained I and V were used to determine the apparent resistivity. The r.m.s error for iterations of resistivity data are shown in Figures 2a and2b. For the 2D survey, 4electrodes were used at electrode separation (a) of 10m. The Wenner array configuration was utilized for all the traverses. The midpoint of the 4electrodes was mapped i.e. measurements of the apparent resistivity values were taken at the mid-point of the four electrodes. Measurements were repeated as the array was moved along this profile while the electrodes were maintained at fixed separation until the end of the traverse (say, traverse 1). On completion of the data acquisition for a = 10 m, the four electrodes were moved to the starting point of the same traverse, and measurements were taken with a=20m, 30m and 40m. This process was repeated for the other 3traverses.This technique assisted in obtaining both the lateral and vertical changes in the subsurface formations.

The high resolution for imaging the subsurface and relative depth of penetration favoured the choice of Wenner electrode configuration (Loke, 2004). The apparent resistivity was obtained by using the equation:

$$\rho_a = 2\pi aR \tag{1}$$

where is the apparent resistivity measured in Ωm and a is the electrode separation and the measured resistance of the field is denoted by R measured in ohm (Telford *et al.*, 1990).

Magnetic Method

Since many geophysical interpretations may fit the observed data and a given interpretation may not be unique, it is always useful to use other methods in the same area to constrain the interpretation. Thus, we deployed the magnetic method as a reconnaissance tool to constrain the electrical resistivity method in order to give a clue to the number of the VES point to be sounded in the study area. Two magnetic traverses trending approximately in the E-W (Figure 1) directions were established. Magnetic survey involved taking the measurement of the total component of the earth's magnetic field using a G-856 Proton precession magnetometer. A base station, which is about 20m away from traverse 3,was established with readings taken before commencement of data capturing and immediately after the traverses had been occupied to allow for diurnal corrections. A total of 85 magnetic stations were covered with 3readings taken at each station and averaged. The operation and principles of the magnetometer are explained by Breiner (1973) and Telford *et al*. (1990).

DATA PROCESSING AND INTERPRETATION

Vertical Electrical Sounding

The VES curves shown in Figures 2a and2b were obtained by plotting the apparent resistivity against half electrode spacing (AB/2) and were interpreted by the partial curve matching method and computer iteration techniques. Theoretical derivations and practical tests (Barker 1989, Pozdnyakova *et al*., 1996, Banton *et al*., 1997) have shown that the approximate penetration depth can be considered as $^1/_6$ of the current electrode spread (AB) for the arrays of Schlumberger and Wenner types used on wide ranges of soils and grounds. The forward modelling computes the true resistivity of the models. This is accomplished by the programme RESIST using the linear filter theory (Ghosh,1971a,b) while the inverse modelling tries to obtain a theoretical model whose apparent resistivity curve matches a set of field data to a good approximation. The inverse modelling is carried out applying Marquardt's algorithm (Marquart, 1963) to an initial model which is modified repeatedly until it matches with the field curve.

2 D ElectricalResistivity Imaging

In order to convert the apparent resistivity data sets of the Wenner array into 2D resistivity images, the data sets were inverted using the DIPPRO inversion software. The programme algorithm calculates the forward responses using a finite element method. After the inversion process, the results were displayed as measured apparent resistivity pseudo-sections at the top and the resulting inverted true resistivity 2D section as the bottom panel. The result of the interpretation of the data acquired is presented as pseudo- sections shown in Figures 5 and 6. It uses the numerical approach to optimise the initial multilayer model constructed directly from the observed apparent resistivity values.

Magnetic Survey

The ground raw magnetic survey measurements were subjected to relevant corrections. Since the area is characterized by smooth terrain and no elevation differences were noticeable between the stations, terrain and elevation corrections were not applied. The international geomagnetism reference field (IGRF) value of 32000nT for the study area was subtracted from the readings of the survey stations. The data acquired from the field werefiltered using drift correction equations given as:

$$B_{drift} = B_e - B_s \tag{2}$$

$$\Delta T = T_e - T_s \tag{3}$$

where B_e and B_s and are the initial magnetic response and final magnetic response readings respectively, T_e and T_s are the initial and final time measurements and is the time difference.

The filtered data were plotted as magnetic profiles using the Microsoft Excel spreadsheet package. The plots were interpreted by visual inspection and done so quantitatively using Peter's slope index given by:

$$S = 1.6h \tag{4}$$

where S is the distance between the points of inflexion and h is the depth to the anomalous structure (Telford *et al*., 1990).

RESULTS AND DISCUSSION

Geoelectrical Sections

The 1-D geoelectric sections resulting from the interpretation of the resistivity data given in Figures 3 and 4 comprise VES 1- 8. These geo-electric sections revealed 4to 5geo-electric layers. The first layer, the topsoil, is characterised by resistivity values ranging from 334.7Ωm to 5167.0Ωm with associated thicknesses varying from 0.5m to 1.1m. The second substratum in VES 1, 3, 4 and 5 denotes silty sand with thicknesses between 0.3m and 4.3m, and resistivity values from 1232.5Ωm to 2577.6Ωm.The corresponding layer in VES 2, 6, 7 and 8 typifies sand with thicknesses ranging from 1.5m to 4.3m, and resistivity between 369.2Ωm to 912Ωm.The third horizon in all the VES is typical of sand with resistivity ranging from 350.7Ωm to 582Ωm except for VES 2,3 and 4, which is presumptuous of clayey sand. The associated thicknesses are between 4.9m and 14.0m.

On account of the resistivity and thickness, this layer is promising for citing engineering structures. The fourth layer in VES 1,2 and 3 is symptomatic of sandy clay with resistivity values of 132.7Ωm, 176.6Ωmand 99.4 Ωmand layer thicknesses of 49.1m,16.6m and 27.4m respectively. It can serve as a good layer for foundations. The corresponding layer in VES 6 and 8 is typical ofclay, with resistivity in the range of 50.3Ωm to 56.8Ωm, and thicknesses ranging from 12.6m to 15.7m.This same layer in VES 4, 5 and 7 denotes clay, with resistivity values ranging from 36.8Ωm to 40.5Ωm and thicknesses between 11.6m and 43.5m.

The fifth layer in all the VESs except VES 5 is characterised by high resistivity values especially VESs 3,4,7 and 8 with resistivity from 3633.0 Ωm to 6339.2 Ωm representative of gravelly sand. The resistivity value of the substratum of VES 5 is 807 Ωm indicative of sand while VESs 1,2 and 6 correspond to silty sand with resistivity of 1039.1 Ωm to 1231.5 Ωm. The current penetration terminated at this layer due to the limitation in the length of the traverses covered and consequently, the thickness of this layer could not be determined. However, for a deeper investigation of the subsurface, the length of the traverses should be increased.

By visual inspection, the second layer under VES points 1and 3 together with the first layer beneath VES 4 correlates well with the first layer of the borehole log (BH1) shown in Figure3. Also, on comparison of the geoelectric section B-B' with the borehole lithologic log (BH2) in Figure 1, it can be seen that the second layer for VES 6,7 and 8 has a similar soil type(sand) with the borehole at a depth of 12m. In addition, the fourth layer underneath VES 5, which matches with the third layer for VES 6, 7 and 8,has a similar composition with the second layer of the borehole.

2D Resistivity Imaging

A more accurate geological model has been established by means of a 2D resistivity imaging section (Figures 5 and 6). The resistivity cross sections resulting from the inversion of the geoelectrical data exhibit significant variations in resistivity values with depths. The inverted resistivity images made it possible to obtain information on the variations of resistivity to a depth of about 50m.The upper image is the pseudo-section data, while the lower one is the inverted image of the raw data. The models obtained for all the traverses show similar stratagraphical units corresponding to sand, sandy clay and clay deposits.

Traverse 1

The traverse is oriented in the NNE-SSW direction (Figure 1) and the lateral extent is 300m. The field data pseudo-section and 2D resistivity inverted section delineate 3distinct geoelectrical layers which are the topsoil sand, sandy clay and clay (Figure 5a). There is gradation in geological formation from sand (topmost) to clay (bottom) via sandy clay formation. The topsoil is characterised by high resistivity value 508 Ωm , average thickness of about 15m.It is representative of undulating sand mixed with stones at shallow depths used during filling of the area. The next layer has an average resistivity value 160 Ωm with an average thickness of about 35m; it is made up of sandy clay formation.

Towards the end of the traverse between electrodes 18 and 27, the third layer made up of subsoil associated with low resistivity value of about 16 Ωm and average thickness of 25m. It typifies clay. The presence of a clay subsoil indicates the incompetence of this layer to support a massive engineering structure. In addition, some structural geological features are noticed in the inverted resistivity section -- synclinal of the sandy clay formation and fracture between electrodes 8and 12. These could result in structural instability and foundation failure for any development erected on this part of the traverse. However, foundation structures would require special techniques (piling) extending down to the stable soil strata or bedrock to avoid foundation failure and structural damage in the proposed area.

Traverse 2

The traverse trends in the NE–SW direction. The lateral extent is about 280m. The pseudo-section and 2D resistivity imaging section (Figure 5b) are closely similar to traverse 1. The first part of the section (0-10m) shows a zone of relatively high resistivity value of about 465Ωm It is composed of unconsolidated sand mixed with stones used for filling at a shallow depth of about 15m. Its closeness to the surface shows that it can only support light to medium foundational structures. Overlaying the clay layer is the middle part of the profile with resistivity values of 195 Ωm to 113 Ωm that correspond to sandy clay formation. Due to its good engineering property and zone of deposition, it can support low to medium engineering structures. Beneath it is a low resistivity layer (resistivity 94 Ωm, thickness 30m) common to clay. The presence of a clay subsoil and a fracture noticed between the 9th and 12th electrodes makes this layer unsuitable for heavy engineering structures. Alternatively, a well-designed engineering foundation with proper piling would need to be taken into consideration for a good bearing layer.

Traverse 3

It runs from E-W direction and is about 240m long. It reveals (Figure6a) 3distinct layers with the topsoil made up of undulating sand mixed with stones that spans almost the length of the traverse. This layer is characterised by relatively high resistivity values of 398 Ωm with thickness of about 18m. The observed decrease in resistivity at a depth below the topsoil could be ascribed to change in subsurface geological formations. The second layer which typifies sandy clay with average resistivity of 135 Ωm and thickness of 15m could have good engineering properties for building construction. The third layer is similar to a formation beneath the afore-mentioned traverses. It is composed of clay with an anticline shape having average resistivity of about 29 Ωm and thickness of 25m. The low resistivity value of this formation and its structural form explain why it might be incompetent to support a massive engineering structure unless special foundation designs are taken into account prior to development.

Traverse 4

It is oriented in the E-W direction. The topsoil is made up of undulating sand mixed with stones at shallow depths (Figure 6b).The resistivity values ranges from 205-309 Ωm to a depth of about 18m. A basin-like structure which depresses throughout the section is observed between electrodes 5 and 10 possibly due to a fracture in the subsurface. The subsoil in this zone is sandy clay with average resistivity of 135 Ωm from a depth of 18m to the extent of investigation. The third layer which has a resistivity of 54 Ωm is about 27m thick. It is composed of a segmented clayey formation. It might be due to a fracture observed between the 5th and 12thelectrodes in the inverted section. As mentioned earlier, the development of this part of the site would also require special foundation designs.

Magnetic Survey

The magnetic data were interpreted using the total magnetic intensity profiles Figure 7a-d to identify possible anomalies. From visual inspection, the profiles show a number of marked anomalies with amplitudes ranging from -3800nT to 700 nT. Generally, in all the profiles the magnetic anomalies are associated with short wavelengths occasioned by near surface materials (Reynolds, 2011; Grant &West, 1965) suggestive of intercalations of sand and clay and pebbles or stones) which characterized the study area. The magnetic anomalies are located between 40-100m, 150-180m, 200-250m and 300-320m along the traverses. The high amplitude magnetic peaks noticed at 60-100m and 210-230m could be ascribed to a transition between geological formations (sand and clay due to a difference in their magnetic susceptibilities)and the presence of faults/fractures arising from the depositional nature of the study area. The low amplitude magnetic troughs identified between 40 m and 60m, 150 m and200m (Figure 7) may be due to undulating sand mixed with stones near the surface as observed in the 2-D resistivity sections.

INTEGRATION

An integrated interpretation of the acquired geophysical data shows that 3major resistivity zones were delineated from the resistivity sections. The presence of these zones is confirmed by variations observed in amplitude and size of the magnetic profiles. The depression observed in the2D sections might be due to a fault arising during the depositional period of the sediments or lithologic units at different depths in the subsurface. The variations in the amplitude of the magnetic profiles leading to peaks and troughs give indications of the presence of the alternating sequence of sand and clay formations in the study area.

A combination of electrical, magnetic and available well logs provides useful information of the subsurface geology of the area that is relevant to understanding and delineating the subsurface conditions for development of any category of engineering structure. The depth and extent of the magnetic responses are employed in constraining the depth obtained from the resistivity method, with both methods in good agreement.

Traverse 1

A combination of the 1-D geoelectrical section and the 2-D resistivity image shows the possibility that the VES 1 centre point was carried out between electrode positions 10 and 11while the start-off point for VES 2 was performed between electrodes 21 and 22. This is justified by the resistivity and depths obtained within this zone which correlate with that obtained from the geoelectric section for VES 1.It is evident that the third layer at a depth of about 2.2m with resistivity of 582.7Ωm matches that obtained in the 2-D resistivity imaging.

Traverse 2

In relating the geoelectric section and the 2-D resistivity structure, it is possible that VES 3 and VES 4 were carried out at the electrode positions 14 and between 9 and 10 respectively. This is evident from the resistivity and depths obtained for the layers beneath these locations agreeing with the results of the geoelectric sections. For example, at an approximate depth of 20m, clay with resistivity of 94Ωm, agrees with the fourth layer of VES 3.

Traverse 3

Using the 1Dgeoelectric section, the 2-D resistivity geoelectrical section, and the magnetic anomaly profiles, the depths to the competent layers estimated for the magnetic profiles match the sand layers obtained from the geoelectric section and the 2-D resistivity imaging. Furthermore, it can be inferred that the centre point for VES 7 was between electrodes 10 and 11.This is because all but the last layer are consistent with the resistivity of the layers shown in the 2-D resistivity section. For example, the 2-D resistivity section agrees with the fourth layer of VES 7at a depth of about 25m and with a resistivity of about 33Ωm. Also, the centre point for VES 8 which was conducted about 50m from VES 7 is between electrodes 16 and 17.

Traverse 4

On analysis of the geoelectric sections, the 2-D resistivity structure and the magnetic anomaly profiles, we noticed that the various depths to the anomaly estimated from the magnetic profiles presented in Table 2 were consistent especially with the sand layers obtained for both the geoelectric section and the 2-D resistivity structure. It then follows that VES 5 could have been performed between electrode points 8 and 9 andVES 6 between electrodes positions 14 and 15.

CONCLUSION AND RECOMMENDATIONS

This paper has discussed the use of integrated geophysical methods in the delineation and identification of geological structures which can guide the nature and type of foundations for the development of the study area. The qualitative interpretation of the 2D resistivity sections showed that the area is characterised mainly by sand, sandy clay and clay materials with the sand and sandy clay formations at shallow depths. Also, structural features mainly of fractures and synclinal were observed. This illustrates one of the advantages of 2-D resistivity imaging over the 1D geoelectrical section since none of the VES points could identify the fracture region on the 2-D imaging sections.

The undulating sand at shallow depths, the clayey materials as well as the fracture identified shows the incompetence of the subsurface in supporting massive or heavy engineering structures that could be developed in the study area. Worthy of note is the clayey materials present in the third layer of all the resistivity imaging sections. Its nature makes it highly incompetent for massive engineering structures except for proper foundation designs. Erecting structures could lead to differential settlement as clay has little or no integrity to support massive engineering structures because of its low shear strength. Since the clay layer extends to a substantial depth below the surface, a situation such as fluctuation in the water level could cause the clay to become oversaturated, leading to uplift of the ground's surface.

The presence of sandy materials near the surface suggests the suitability of this stratum (soil) for shallow foundations. The sandy clay formation observed in the second layer of the inverted 2-D resistivity sections reaching to an average depth of 20m offers good engineering properties such that the formation can support low to medium engineering structures. Deep foundations may not be feasible or convenient in the survey area owing to the presence of clayey materials in all the sections. It is strongly recommended that reinforcement and concrete packing should be done in parts of the study area where there is need for massive engineering structures. This is imperative in preventing tilting of buildings and cracks surfacing on the walls and floor as that would besigns of differential settlement and subsequent collapse of such structures in the future. Also, foundation footing should not be placed on clayey material. Foundations of large engineering structures around the study area should be sited on competent material via pilings. This study has demonstrated the usefulness of both the electrical resistivity and magnetic methods in characterizing subsurface soil for citing engineering structures.

TABLE1
Summary of VES Model Resistivity Values and Their Corresponding Thicknesses

Ves Point	Layer 1 (Topsoil)		Layer 2 (Clayey/Sand)		Layer 3 (Sand)		Layer 4 (Sand/Sandy Clay)		Layer 5 (Clayey and/Sand)		Curve Type
	Resistivity	Thickness	Resistivity	Thickness	Resistivity	Thickness	Resistivity	Thickness	Resistivity	Thickness	
	(Ωm)	(m)	(Ωm)	(m)	(Ωm)	(m)	(Ωm)	(m)	(Ωm)	(m)	
VES 1	5167.0	0.9	2171.5	1.4	582.7	7.3	132.7	49.1	1119.2	-	QQH
VES 2	2809.1	0.9	912.0	3.2	205.0	7.3	176.6	16.6	1039.1	-	QQH
VES 3	2314.5	0.9	1596.1	1.2	296.9	14.0	99.4	27.4	6339.2	-	QQH
VES 4	334.7	0.5	2577.6	0.3	200.6	9.3	40.5	43.5	4702.2	-	KQH
VES 5	1897.0	1.1	1232.5	1.9	375.8	8.0	36.8	22.7	807.5	-	QQH
VES 6	1581.2	1.1	844.0	2.5	423.5	6.4	56.8	15.7	12331.5	-	QQH
VES 7	1054.6	0.8	426.9	4.3	350.7	4.9	40.5	11.6	3633.0	-	QQH
VES 8	1003.0	1.0	369.2	1.9	459.1	5.4	50.3	12.6	4001.0	-	QQH

TABLE 2
Depth, Extent and Nature of Magnetic Anomaly

S/N	Traverse (m)	Depth (m)	Anomaly Range(m)	Nature of Anomaly
1	3(10)	3.15	100 - 120	Negative
		3.15	250 -270	Positive
		4.5	260 - 280	Negative
		4.5	310 - 330	Positive
		6.25	30 - 50, 150 - 200	Negative
		12.5	60 - 90, 220 - 250	Negative
2	3(20)	4.5	250 - 270	Positive
		5.1	130 - 180	Positive
		5.2	100 - 120	Negative
		9.5	220 - 240	Negative
		15.5	30 - 50, 280 - 300	Negative
3	4(10)	5.3	50-70	Positive
		21.5	100 - 120	Negative
		25.2	130 - 150	Negative
		9.7	180 - 200	Positive
		19.8	210 - 230	Negative
		5.1	240 - 250	Positive
4	4(20)	13	60 - 100	Negative
		9.2	110 - 140	Negative
		9.7	150 - 170	Negative
		17	200 - 240	Negative

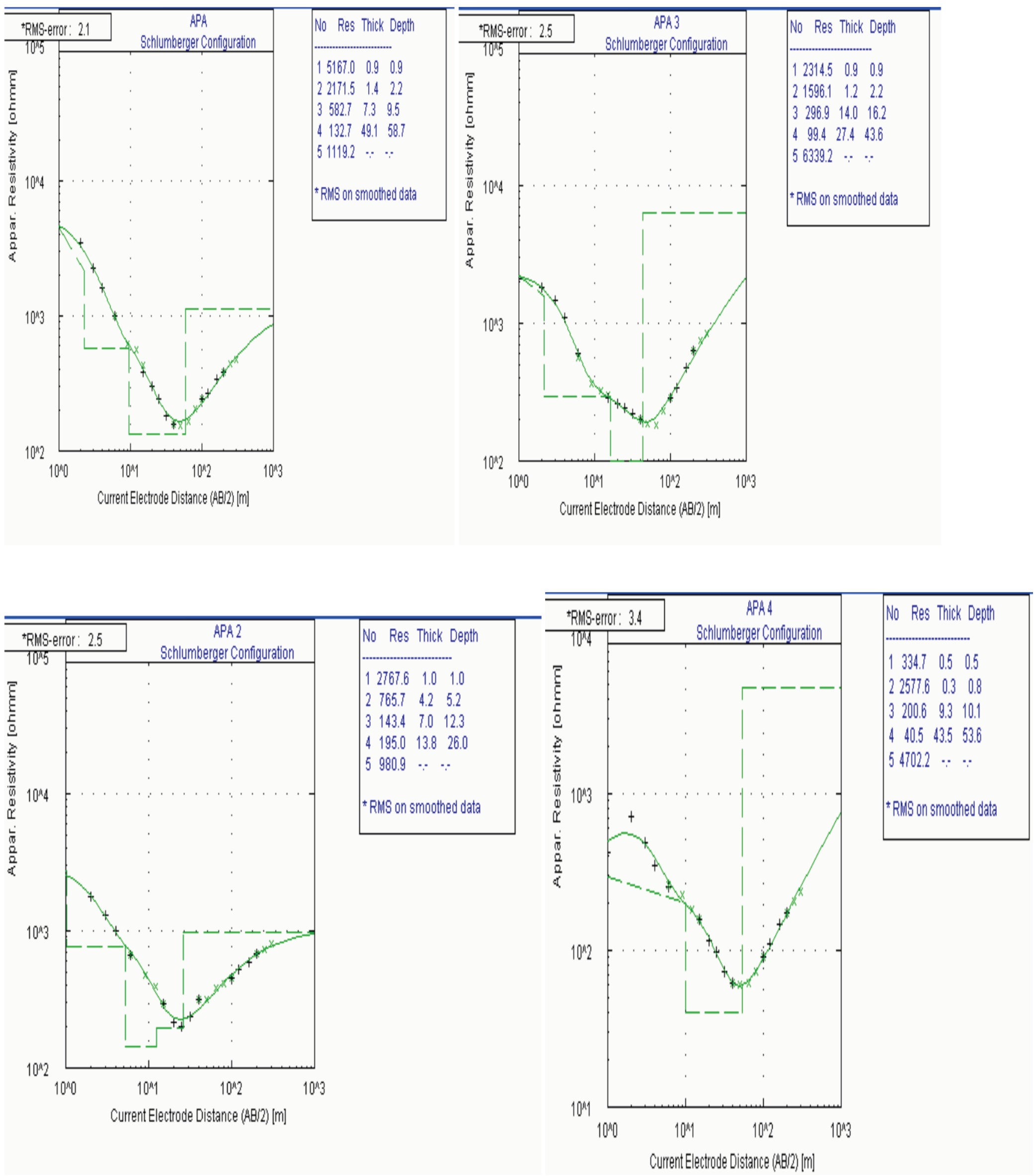


Fig.2a: Observed, Computed VES Points (1-4) and Layered Inversion Model

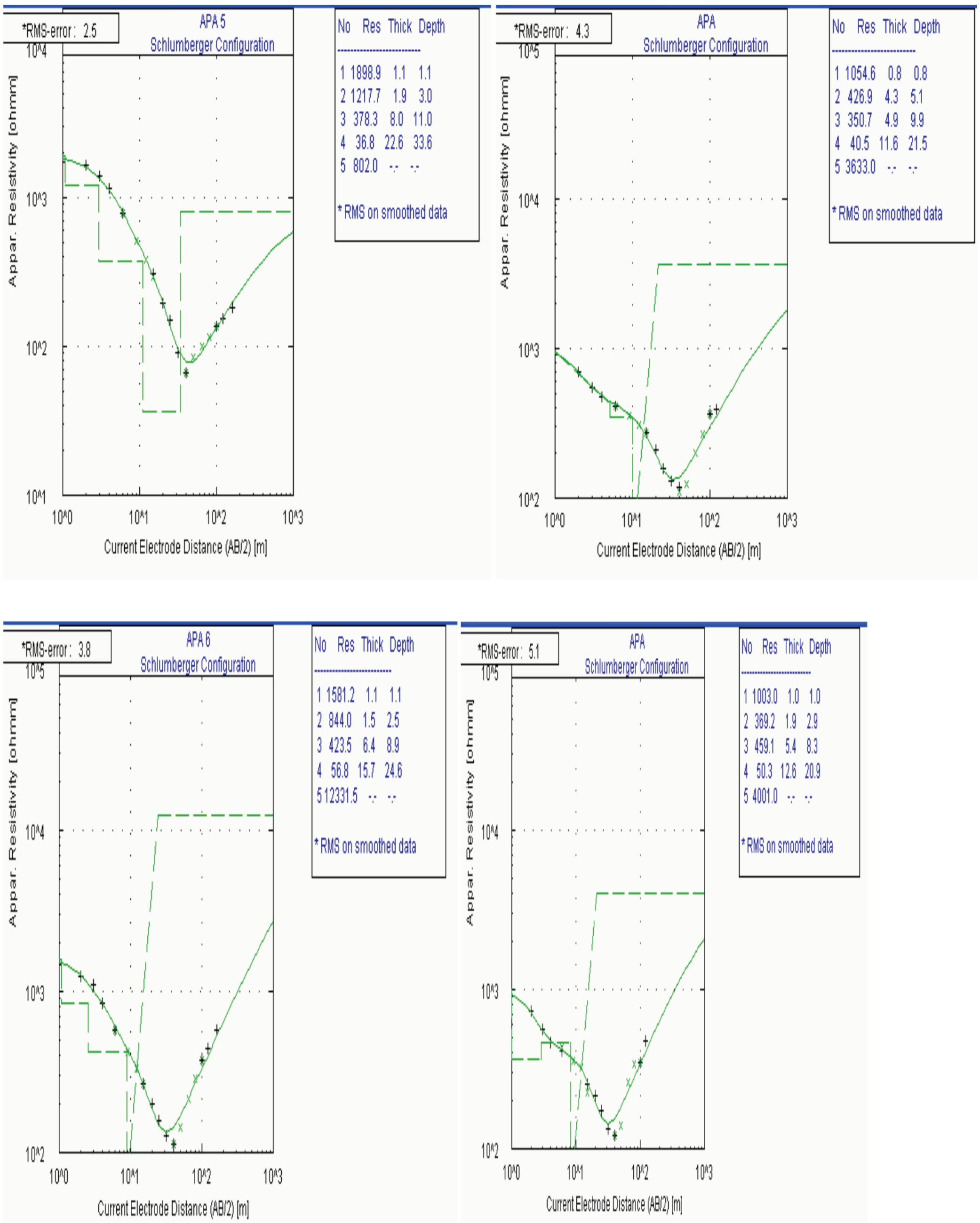


Fig.2b: Observed,Computed VES Points(5-8) and Layered Inversion Model

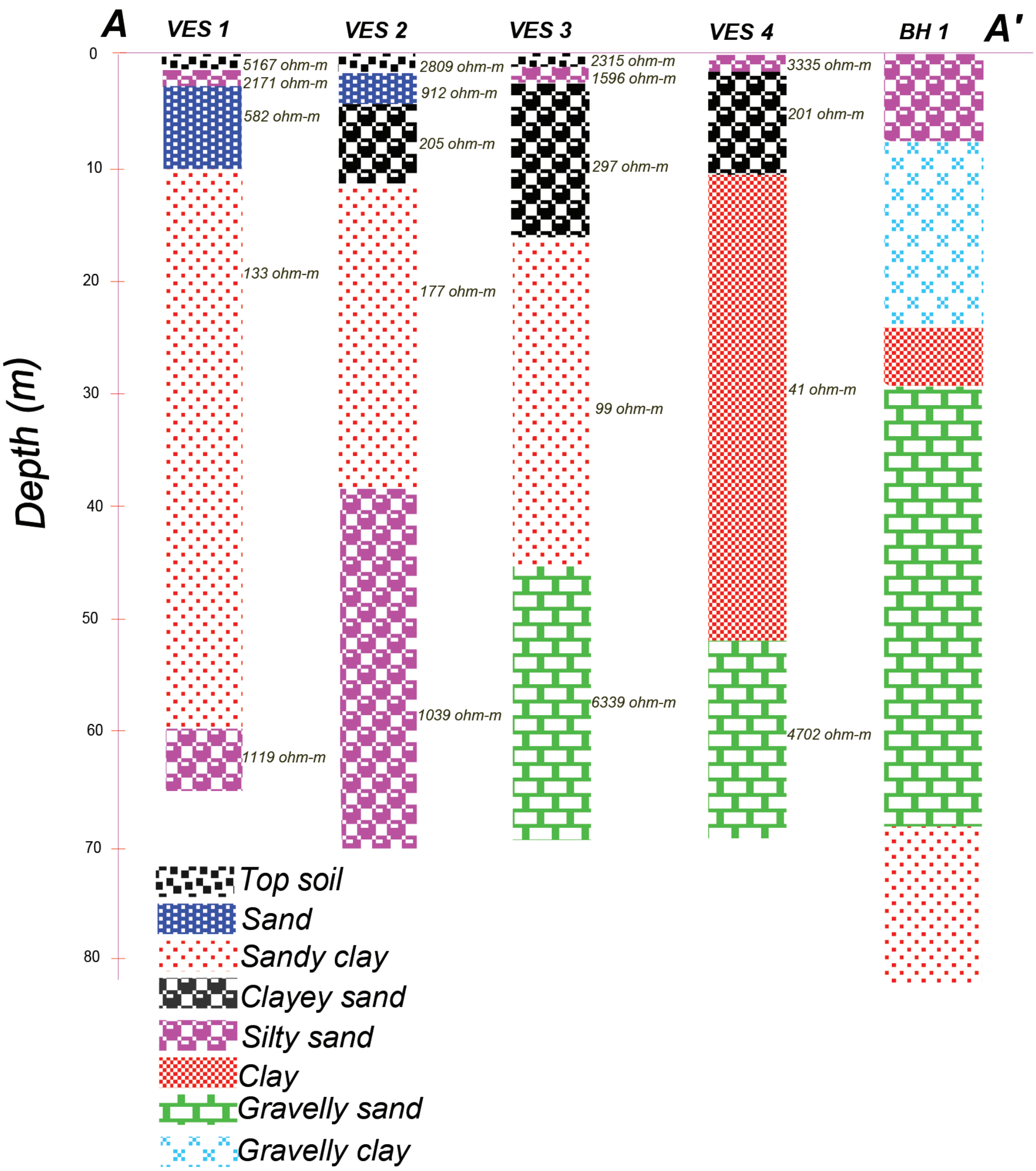


Fig.3: Geoelectric Section Along AA'

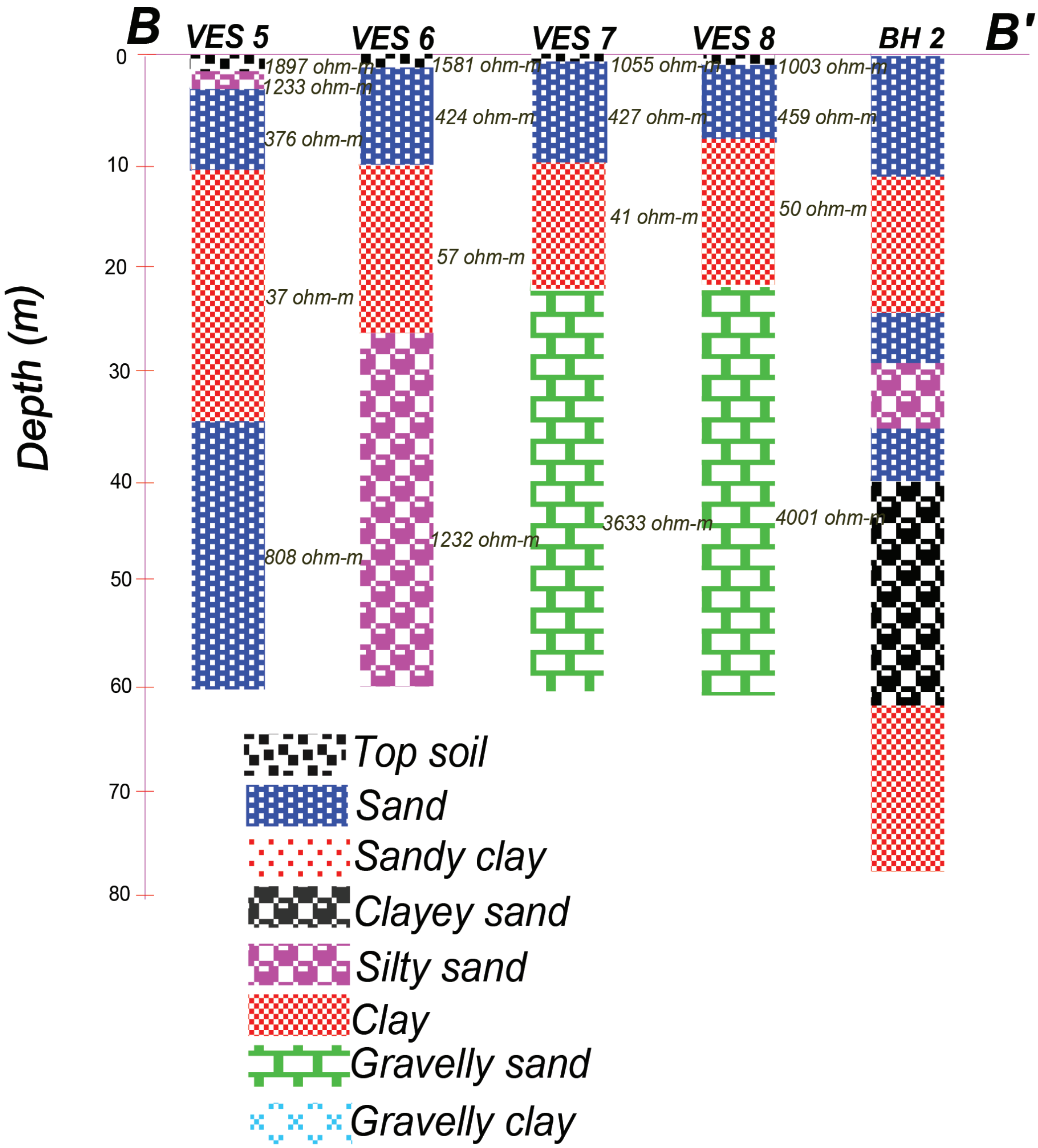
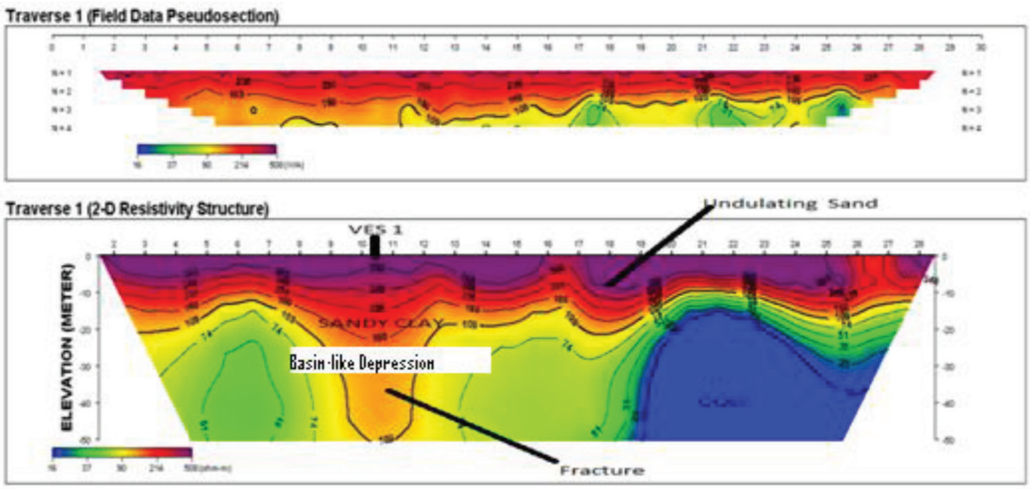


Fig.4: Geoelectric Section Along BB'

(a)



(b)

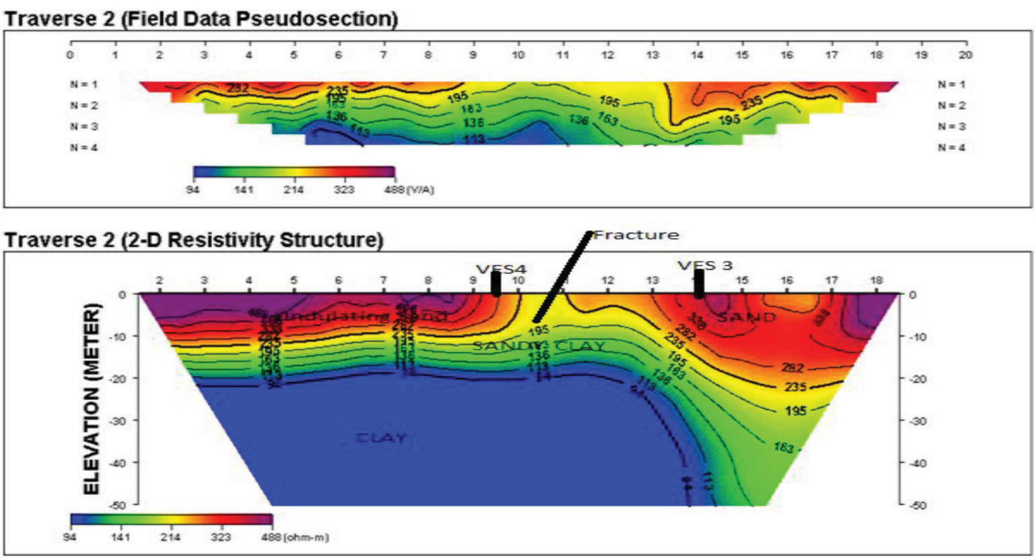


Fig.5: (a)Measured Apparent Resistivity Pseudosection(top) and Inverse Model Resistivity Section (bottom)Along Traverse 1 (b) Measured Apparent Resistivity Pseudosection (top) and Inverse Model Rresistivity (bottom) Along traverse 2.

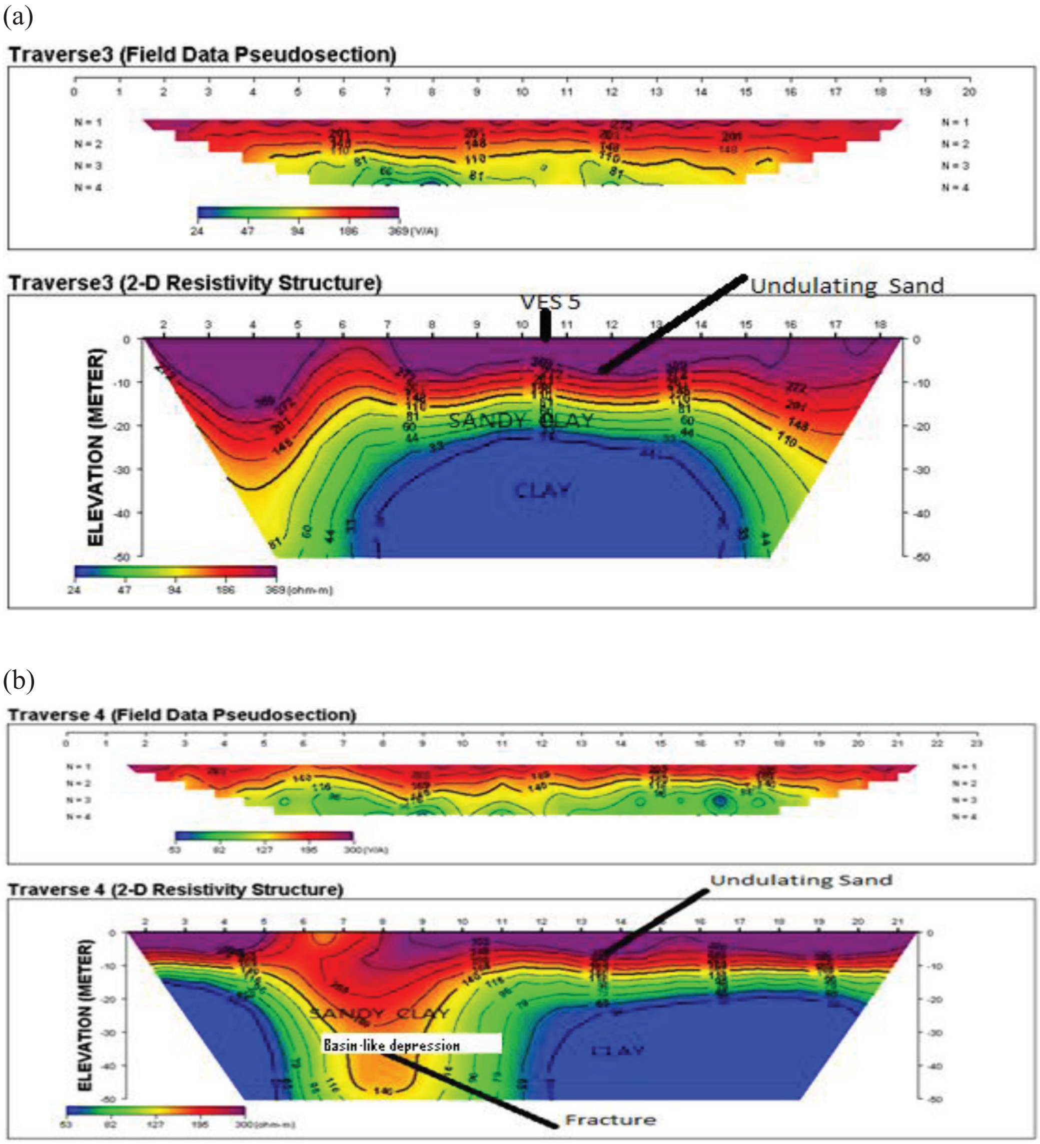


Fig.6: (a) Measured Apparent Resistivity Pseudosection (top) and Inverse Model Resistivity Section (bottom) Along Traverse 3 (b) Measured Apparent Resistivity Pseudosection (top) and Inverse Model Resistivity (bottom) Along Traverse 4.

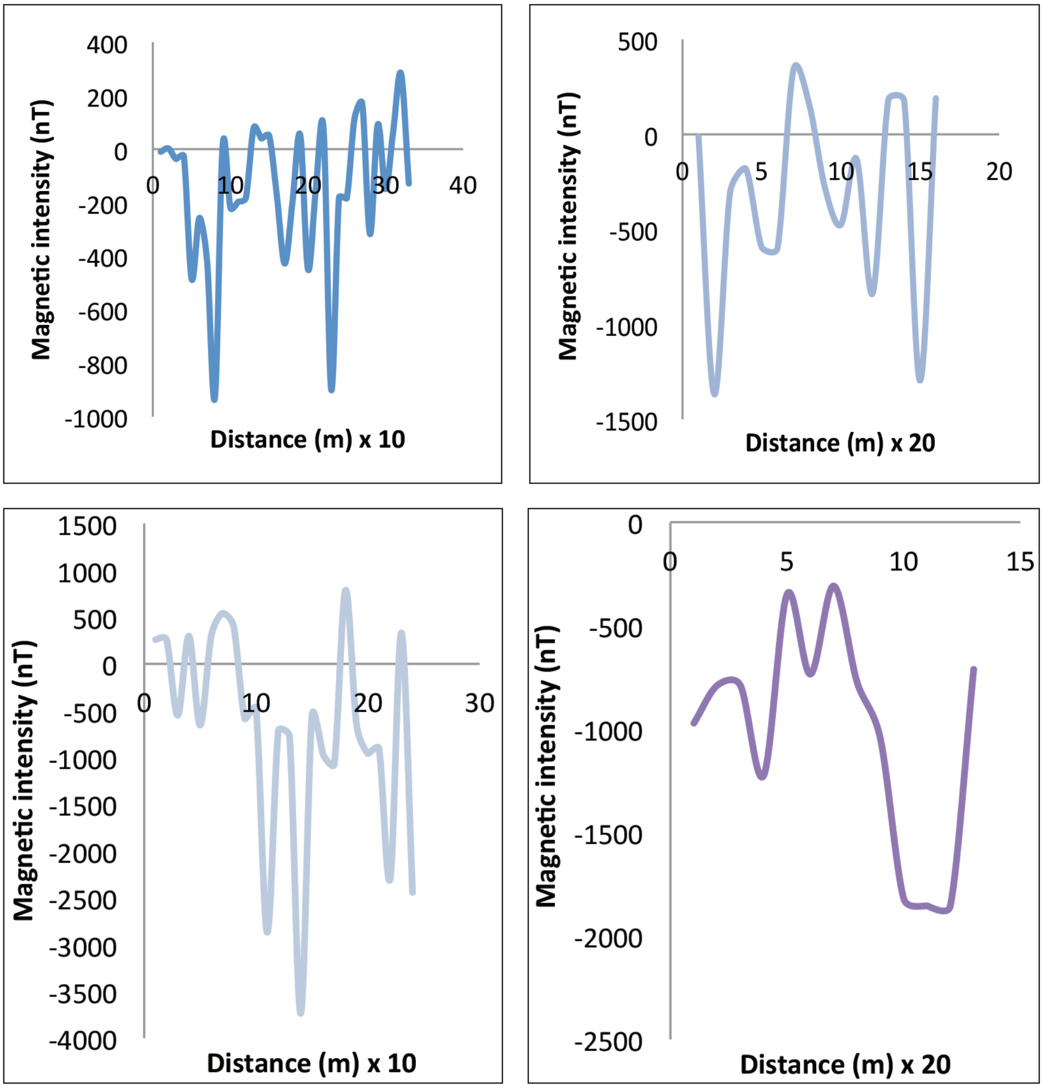


Fig.7: Magnetic Anomaly ProfilesAlong (a) Traverse 3 at 10m Spacing (b)Traverse 3 at 20m Spacing (c)Traverse 4 at 10m Spacing (d) Traverse 4 at 20m Spacing

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