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Integration of Geophysical, Geochemical and Geotechnical Methods to Prospect for Bentonite in Afuze, Southwestern Nigeria

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Abstract

This research was aimed at integrating geophysical, geochemical and geotechnicalmethods to prospect for bentonite.The research methodology involved conducting a geophysical survey (electrical resistivity imaging technique) using the dipole-dipole array with interval spacing of electrodes 5 m and inter-traverse spacing of 10 m,collection of samples from areas with resistivity signatures corresponding to target mineral (bentonite), conducting a geochemical analysis using x-ray florescence test to determine elemental distribution of sample, digestion and titration to determine sodium, calcium percentage present in sample and to conduct a geotechnical analysis to with reference to Liquid limit in order to identify the clay mineral (bentonite). Bentonite was identified along three traverses (traverses 1, 5 and 6) by the signature of resistivity values ranging from 10 Ωm-100 Ωm. Geochemical anlysis using the x-ray florescense test and Digestion and titraton test was able to capture the main elements that makes up bentonite (sodium, calcium, aluminium and silicon) and their content as well as sodium and calcium percentages. Result from digestion and titration test showed Sample obtained from Traverse 1 had higher calium percentage 158 parts per million (ppm) and had a sodium percentage of 48 parts per million (ppm). Sample obtained from Traverses 5 and 6 had calium percentage of 93 parts per million (ppm) and had a sodium percentage of 41 parts per million (ppm).Sample obtained from traverse 1 had a liquid limit of 176 and samples obtained from traverses 5 and 6 had liquid limit of 177.

Key words : geophysical, geochemical, geotechnical, liquid limit, x-ray florescense, digestion and titration, electrical resistivity

1 Introduction

Geophysical mapping plays a key role in “mineral target generation”[1]. This is because invasive techniques such as expensive drillings and direct sampling can provide very accurate one - dimensional information about the subsurface, but only for sampling location and for a limited volume of the subsurface. Geophysical mapping also saves money and time compared to drilling [2]. When geophysical mapping, geotechnical test and geochemical test are integrated, a detailed view of the quality and properties of a mineral is established.

The term “bentonite” is ambiguous. As defined by geologists, it is a rock formed of highly colloidal and plastic clays composed mainly of montmorillonite, a clay mineral of the smectite group and is produced by in situ devitrification of volcanic ash and weathering of sedimentary rocks [3].Empirical formula for Bentonite is given as: $Na_{0.2}\,Ca_{0.1}\,Al_2\,Si_4\,O_{10}\,(OH)_2(H_2O)_{10}$ [4]**.**Bentonite is one of the most sort after mineral in the world due to its many uses e.g. as insulators in civil engineering, as bleaching clay in oil refining, used in the treatment of indigestion, as filtering agent for clarifying wine and treating waste water, as drilling mud for oil well drilling etc. Bentonite belongs to the group of clays whose technical properties are controlled by the proportion of Montmorillonite a sub-group within the Smectitic clay [3]. It is clay derived from deposits of weathered volcanic ash. The transformation of ash to bentonite takes place only in water (majorly seawater, probably alkaline lakes, and possibly other fresh water) during or after deposition. Bentonite can also occur as a result of weathering of sedimentary rocks such as shale or the chemical weathering of feldspar.

There are two principal types of bentonite namely[3]:

(i) natural sodium bentonite or sodium montmorillonite .

(ii) natural calcium bentonite or calcium montmorillonite.

Natural sodium bentonite occurs with sodium as the predominant or main exchange cation. They are characterized by high swelling, high liquid limit and high thermal durability. It is usually used for oil and gas drilling mud. The vast majority of the montmorillonite occurring in abundance worldwide is of the calcium type and is referred to as calcium bentonite[5,6,7]. It has much lower swelling and liquid limit values compared to natural sodium bentonite. Calcium bentonite is used as a bleaching agent in lubricant oil recycling, as a catalyst, absorber, filler etc.

The present level of consumption or use of bentonite is about 200,000Mt (for oil well drilling only), much of this is sourced from the foreign market (Bilal *et al.,* 2016). The U.S.A is the major producer of bentonite. Approximately 90% of world bentonite production is concentrated in 13 countries: the USA, Greece, The common wealth of Independent states, Turkey, Germany, Italy, Japan, Mexico, Ukraine, Bulgaria,Czech Republic, South Africa, and Australia (Amoco, 1994).

Though, not much is known about the bentonite deposit in Nigeria, hence exploration for this mineral has not commenced in Nigeria which leads to high importation of this mineral from other countries [8]. Marine shale units that are highly enriched in montmorillonite are found in Nigerian sedimentary basins [9]. Notably among these are the Agwu Shale in Eastern Nigeria, the Imo shale that forms a belt across Southern Nigeria, the FIka shale in the North-eastern parts, aDankumaje and Kalambaina formations in the North-west. Many sections of these formations are said to possess mineralogical compositions of more than 80% montmorillonite. Bentonite clays also exist in the North-east quadrant of Nigeria (Borno, Yobe, Taraba and Adamawa) where a probable reserve of more than 700 million tones has been indicated. Of recent bentonite have also been reported found in Afuze, Ekpoma-igunebon road, Ovibiokhuan and Okpebho areas of Edo state, Nigeria holding about 70-80 million tons [8] hence the necessity for investigation into its occurrence at Afuze..

The complex nature of chemical composition of bentonite affects its method of exploration. Therefore, for the purpose of this research work an integration of geophysical, geochemical, geotechnical methods shall be adopted in prospecting for bentonite deposit in Afuze.

The geophysical method adopted is the 2D electrical resistivity imaging involving dipole-dipole Wenner array techniques, whichgives resistivity variation laterally and vertically.

Geochemical analysis is the process through which scientists determine the chemical compound that constitutes Earth, its atmosphere and its seas [10].Geochemical anlysis using the x-ray florescense test and Digestion and titraton test was able to capture the main elements that makes up bentonite (sodium, calcium, aluminium and silicon) and their content as well as sodium and calcium percentages.The geotechnical method was used to determine the plastic and the liquid limit of the sample investigated.

2 Site Description and Geology of the Study Area

Afuze lies withinit lies within latitude 06°058‘- 07°10‘North and longitude 06°01‘and 06°04‘East on the eastern sector of the Dahomey Basin (Figure 1) that extends from the Nigerian border with the Benin Republic to the so-called Benin Hingeline. The oldest rocks within the Eastern Dahomey Basin are the Abeokuta Group which is composed of three formations; Ise, Afawo and Araromi Formations by [11].The sedimentary rocks in Afuze belong to the upper part of the Araromi Formation of the Abeokuta Group. Geological reconnaissance mapping of the Afuze area shows that the area is underlain by a sedimentary sequence containing shales, clays, siltstone and ferruginizedsiltstone that occur as the topmost layer (Figure 2) by [12].

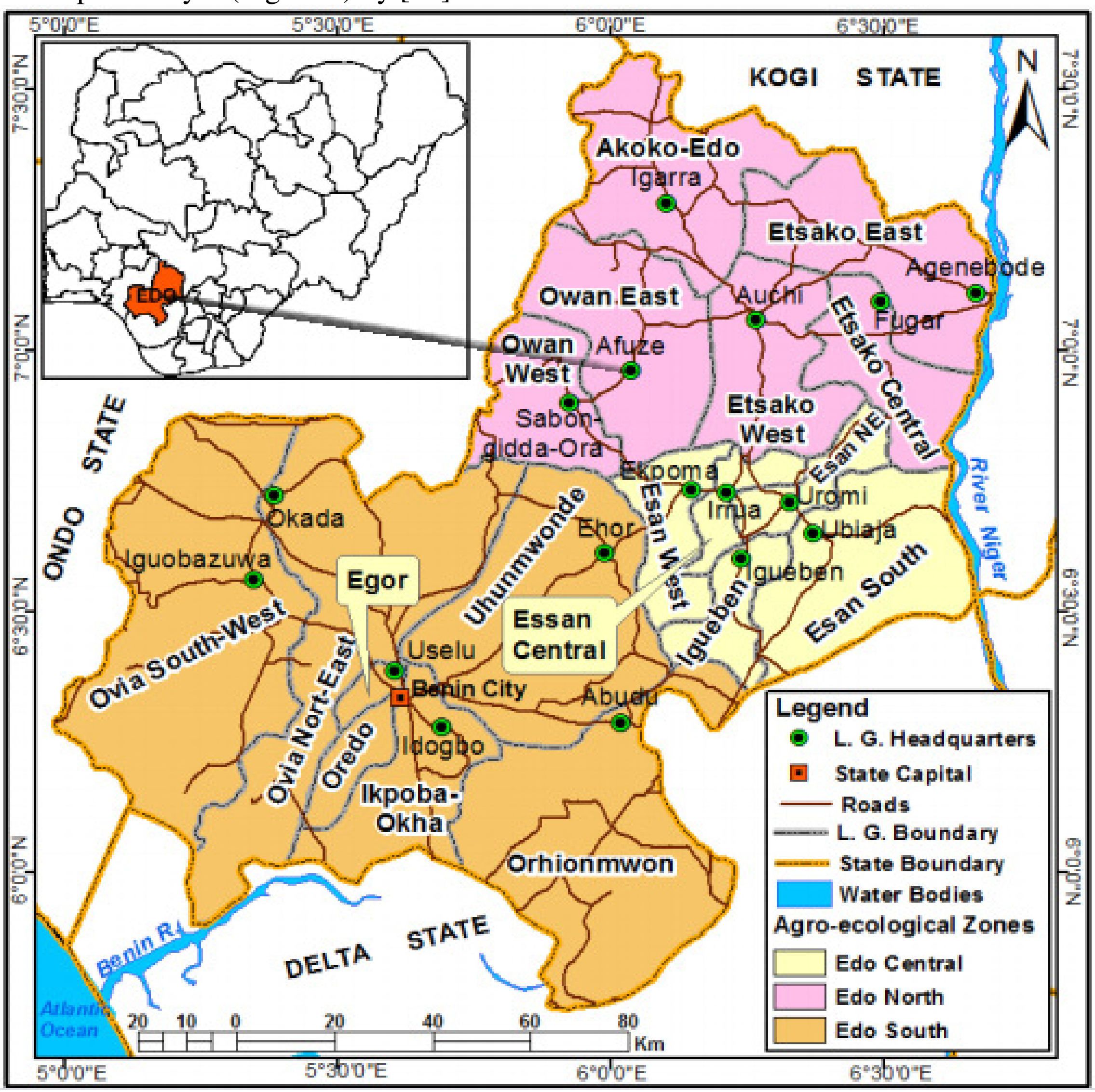


Figure 1: Map of Nigeria Showing Edo State and the Study Area [13]

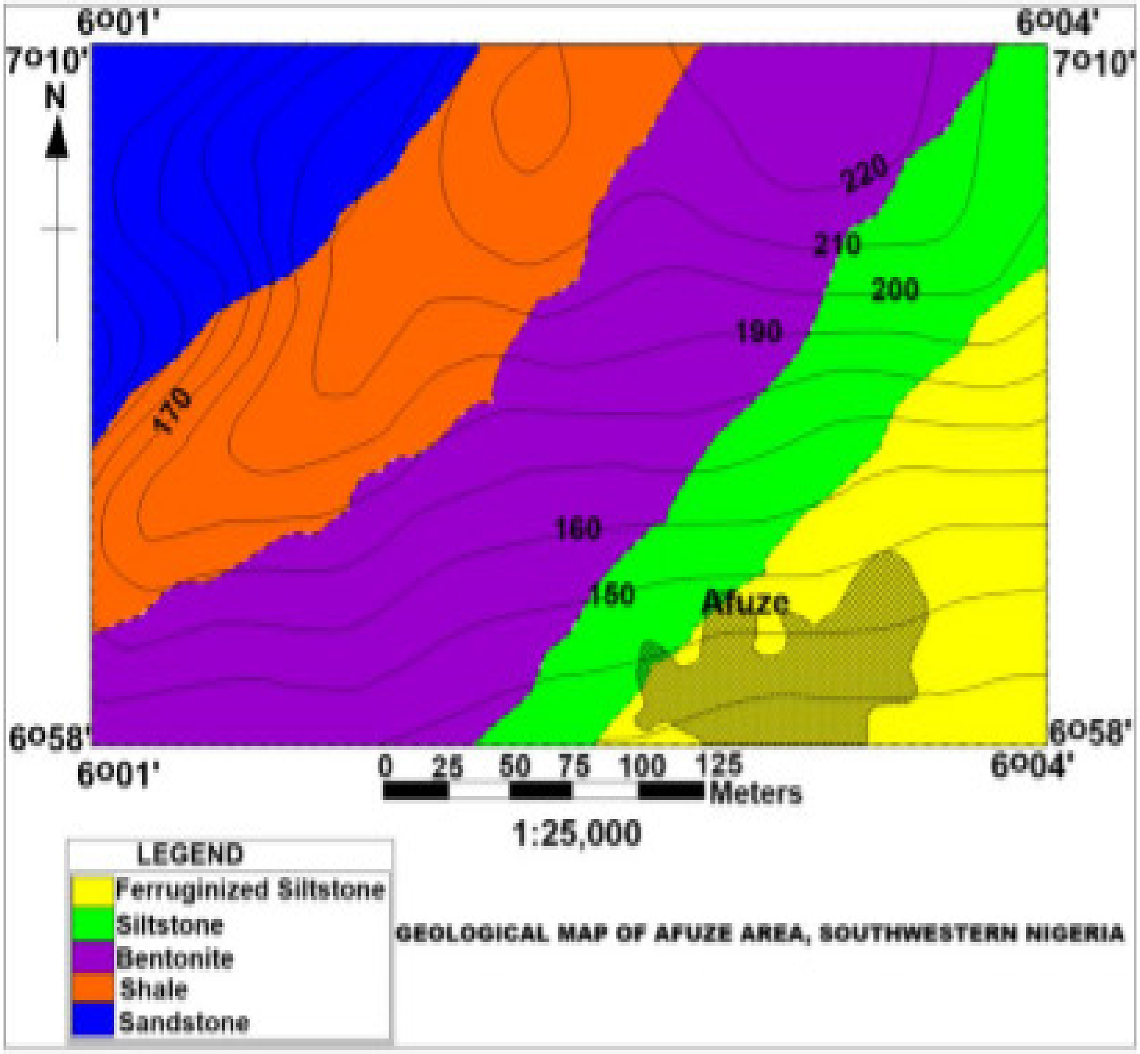


Figure 2: Geological map of Afuze area showing the distribution of the lithologic units and the following description is from oldest to youngest [12]

3 MATERIALS AND METHODS

The data set for this study comprised the use of Dipole-Dipole data acquisition (electrical resistivity prospecting technique), geochemical test (use of X-RAY florescence test and flame photometer, retort stand and burette for determination of calcium) and Geotechnical test (atterberg limit: main emphasis to the liquid limit).

3.1 Geophysical Data Acqusition (Electrical Resistivity Imaging)

Dipole-Dipole Array

The dipole-dipole array is one member of a family of arrays using dipoles (closely spaced electrode pairs) to measure the curvature of the potential field.

The research methodology involved establishing 10 traverses east to west direction, 20 m away from the Afuze-Auchi road, using the dipole –dipole array with interval spacing of electrodes 5 m and inter-traverse spacing of 10 m (Fig.3). Data is then presented in the form of a pseudo-section. The resulting image plots the apparent resistivity with depth, which is then contoured (commonly krigged) using a software known as Dipro-win. The color contoured image displays the distribution of apparent resistivity values and associated gradients within the area of interest (Fig. 4 to 13). In order to convert the apparent resistivity data to true resistivity, the data are inverted. The numbers presented at the bottom of the inverted section display goodness of fit criteria used to assess the accuracy of the calculated resistivity model.

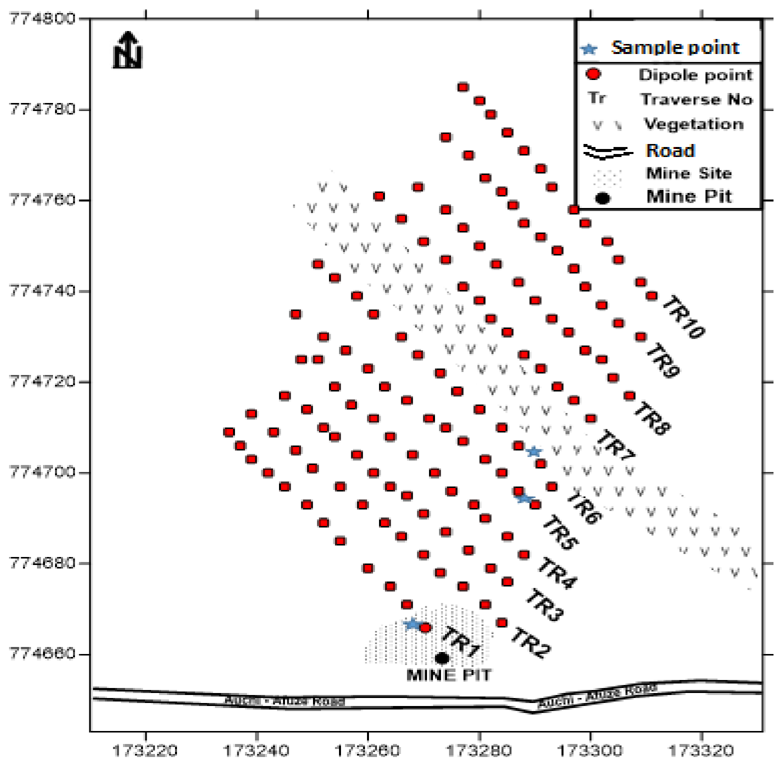


Figure 3: base-map of project location

3.2 Geochemical Analysis:

3.2.1 The EDX3600B X-ray Florescence Spectrometer:

The EDX3600B x-ray florescence spectrometer applies XRF technology to conduct fast and accurate analysis of complex composition. The sytem detect elements between magnesium (Mg, z = 12) and uranium (U, z = 92) with high resolution and fast analysis. Meaning elemts from 1 to 11 cannot be detected which implies test cannot test for sodium or detect sodium which is a major element in Bentonite, this problem was corrected for by digestion test .

3.2.1.2 Titrimetry Analysisand Digestionof Sample (Bentonite)

Procedures to Determine Calcium Percentage:

A small portion of sample (bentonite) was cut with hammer on a metallic plate and crush to powdery form using agate mortar and pestle. Carefully weigh out 2g, digest with concentated HNO_3 in excess until dissolution is clear, then sieve it, and Make the filtrate up to 50ml with distill water.

3.2.2 Proceduresto Determine Sodium Percentageor Solution

Sample (bentonite) was put in flame photometer.The flame photometer was used to check for sodium percentage. The samples obtained from traverse 5,6 and 1 were digested using Aqua Rhagae. After the digestion process samples where filtered. For determination of calcium, titration method was employed using retort stand and boret. The digestion and titration method was able to correct for the defect of x-ray floresence test as it showed the presense of soduim (Na) (through the use of the flame photometer) which is a major element in bentonite.

3.3 Geotechnical Test

The various geotechnical analysis carried out includes;

Grain size analysis:This test is performed to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis was performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method was used to determine the distribution of the finer particles.

3.3.1 Atterberg Limits :

This labouratory test was performed to determine the plastic and liquid limits of a finegrained soil. The liquid limit (LL) is arbitrarily defined as the water content, in percent, at which a part of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (1/2 in.) when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second. The plastic limit (PL) is the water content, in percent, at which a soil can no longer be deformed by rolling into 3.2 mm (1/8 in.) diameter threads without crumbling. Soil scientist (Albert Atterberg) defined seven "limits of consistency" to classify fine-grained soils, but in current engineering practice only two of the limits, the liquid and plastic limits, are commonly used. The Atterberg limits are based on the moisture content of the soil. The plastic limit is the moisture content that defines where the soil changes from a semi-solid to a plastic (flexible) state. The liquid limit is the moisture content that defines where the soil changes from a plastic to a viscous fluid state. A wide variety of soil engineering properties have been correlated to the liquid and plastic limits, and these Atterberg limits are also used to classify a fine-grained soil according to the Unified Soil Classification system..

Equipment: Liquid limit device, Porcelain (evaporating) dish, Flat grooving tool with gage, Eight moisture cans, Balance, Glass plate, Spatula, Wash bottle filled with distilled water, Drying oven set at 105°C.

4RESULTS AND DISCUSSION:

4.1 Geophysical Data Interpretationof Electrical Resistivity Survey

Information obtained from electrical resistivity survey (dipole - dipole) was used to create a pseudosection which were used for the interpretation.

4.1.1Traverse 1

Along traverse 1 (Figure 4), electrode spacing of 5 m was used with a total length of 60 m and the apparent resistivity values plotted against the pseudo-depth in the East-West direction. The resistivity distribution revealed the complex nature of the subsurface along the transverse which is highly heterogeneous. A four earth geologic layer were revealed along traverse 1. A low resisitivity zone with resistivity values ranging between 10 Ωm-100$\Omega m$is revealed almost uniformly distributed along the first layer between stations 0 to 60. It occurs at depth ranges between 0 to 4 m. For reasons of its low resistivity the zone is interpreted as bentonite bearing zone. The second layer is characterized by moderate resisitvity values to semi-high resistivity values. Resisitvity valuesranging from 100Ωm-350Ωm is interpreted as clay mixed with sand along station 0 to 20 at depth 5 m to 6 m. Resistivy values ranging from 350Ωm-500Ωm was also observed along station 35 to 60 and is interpreted as sand.Resistivty values ranging from 500Ωm-1000Ωm is interpreted as siltstone. The third layer is characterized by Resistivity values ranging from 1000Ωm-3000Ωm and 3000Ωm-8000Ωm and seems to be slightly intruded by the forth layer. Resistivity values ranging from 1000Ωm-3000Ωmat depth 6 to 9 m between station 0 to 20 is interpreted as ferruginous siltstone. Resistivty values ranging from 3000Ωm-8000$\Omega m$is interpreted as ferruginous siltstone or sandstone that is highly indurated. The fourth layer is characterized by Resistivity values ranging from 8000Ωm above and is interpreted as shale.

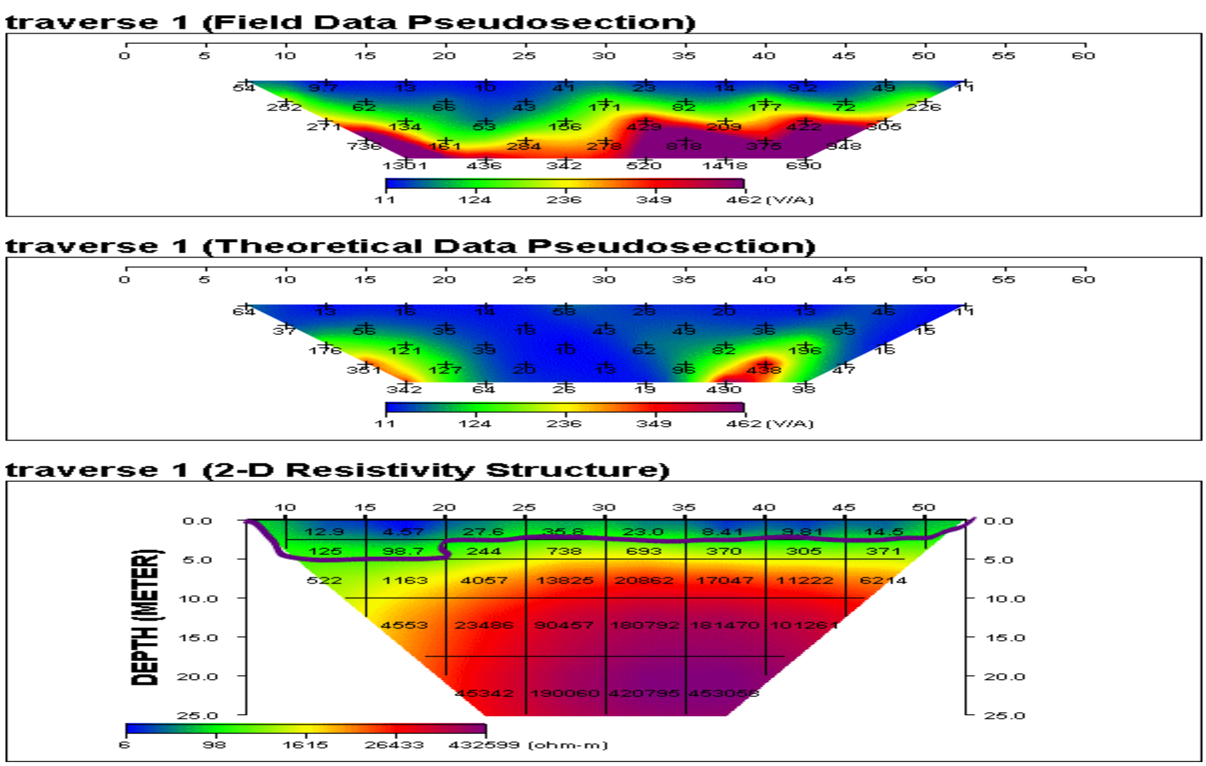


Figure 4: 2-D Resistivity Sections along Traverse 1

4.1.2 Traverse 2

Along traverse 2 (Figure 5), electrode spacing of 5 m was also utilized with a total length of 60 m and the apparent resistivity values plotted against the pseudo-depth in the East-West direction. The resistivity signature observed in traverse 2 indicated moderate to semi-high resitivity values. Semi-high resistivity signature was seen or observed in-between moderate resitivity signatures in traverse 2 (moderate resistivity signature is observed east and west direction in the traverse). This is as a result of diffential weathering of ferruginous siltstone (the semi-high resistivity signature).

Betweenstation 10 to 25 at depth 0-3 m, resisitivity value of 1000-2600Ωm is interpretted asferruginous siltston. At depth 5 m to 15 m between station 10 to 25 and station 35 to 60, resistivity values ranging from 350 Ωm-500 $\Omega m$was observed and interpreted as sand. Between station 35 to 40 at depth 5 m, resistivity value 269 Ωm is interpretted as a pocket of clay mixed with sand. At depth 20 m and below resisitivity values ranging from 1000Ωm-3000$\Omega m$is interpretted as ferruginous siltstone.

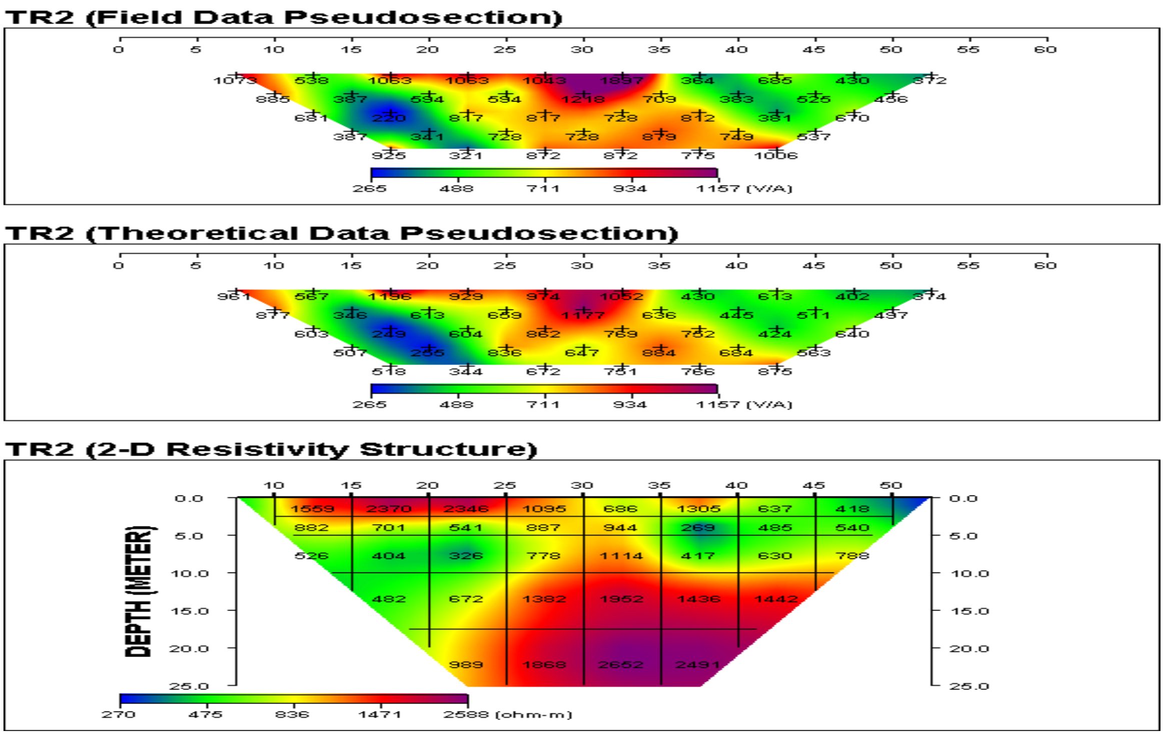


Figure 5: 2-D Resistivity Sections along Traverse 2

4.1.3 Traverse 3

Along traverse 3 (Figure 6), electrode spacing of 5 m was used with a total length of 60 m and the apparent resistivity values plotted against the pseudo-depth in the East-West direction. The resistivity distribution revealed something similar to that of traverse 2. A moderate resistiviy signature is in between a high resisitivy signature. This is suspected to be as a result of wearthering of ferruginous siltstone. Along station 10 to 20 at depth 0 to 3 m, resistivity values ranging from 6925 Ωm- 7036 $\Omega m$is interpreted as ferruginous siltstone highly indurated. Between station 20 to 30 at depth 0 to 3m, resistivity values ranging from 350 Ωm-500 Ωm is an indication of sand. At depth 8 m between station 10 to 20, resisitivy values ranging from 100 Ωm-350 Ωm is interpreted as a pocket of clay mixed with sand. Resistivty values ranging from 500Ωm-1000$\Omega m$is an indication of siltstone (as shown in Figure 6). Resistivity values ranging from 1000 Ωm -3000 Ωm is an ndication of ferruginous siltstone. Resistivty values ranging from 3000Ωm-8000Ωm an indication of ferruginous siltstone that is highly indurated.

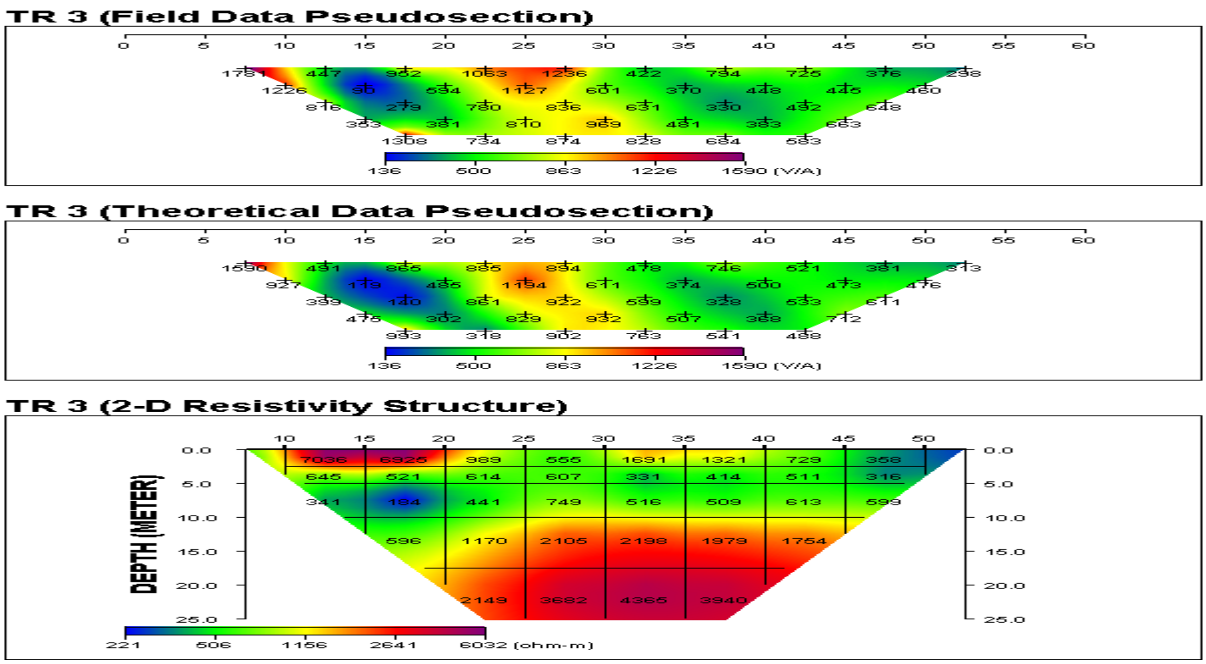


Figure 6: 2-D Resistivity Sections along Traverse 3

4.1.4 Traverse 4

Along traverse 4 (Figure 7), electrode spacing of 5 m was used with a total length of 60 m and the apparent resistivity values plotted against the pseudo-depth in the East-West direction. The resistivity distribution revealed the complex nature of the subsurface along the transverse which is highly heterogeneous.A three earth geologic layer were revealed along traverse 4. First layer is observed at depth 0 to 9 is characterized by moderate resistivity values and is slightly altered at station 30 to 60 to a lower resistivity signature. The first layer is also having a slight change in resistivity signature (becomes higher) as it approaches the second layer between station 35 to 60. The second layer is observed at depth 10 to 15 is characterized by a higher resistivity signature. The third layer is observed at depth 20 to 25 and is characterized by a very high resistivity signature. At the first layer between station 0 to 30 at depth 0 to 9 m , resistivity values ranging from 350 Ωm-500 $\Omega m$and 500 Ωm-1000 Ωm is interpreted as sand and siltstone respectively. At the first layer, at depth 2 m to 3 m at station 35 to 55, resistivity values ranging from 100 Ωm-350 Ωm is an indication of clay mixed with sand. At depth 8 to 10 m between station 35 to 60, resistivity values ranging from 1000 Ωm-3000 $\Omega m$is interpreted as ferruginous siltstone. At the second layer, resistivty values ranging from 3000 Ωm-8000Ωm is interpreted as ferruginous siltstone that is highly indurated. At the third layer resistivty values ranging from 8000Ωm above an indication of shale.

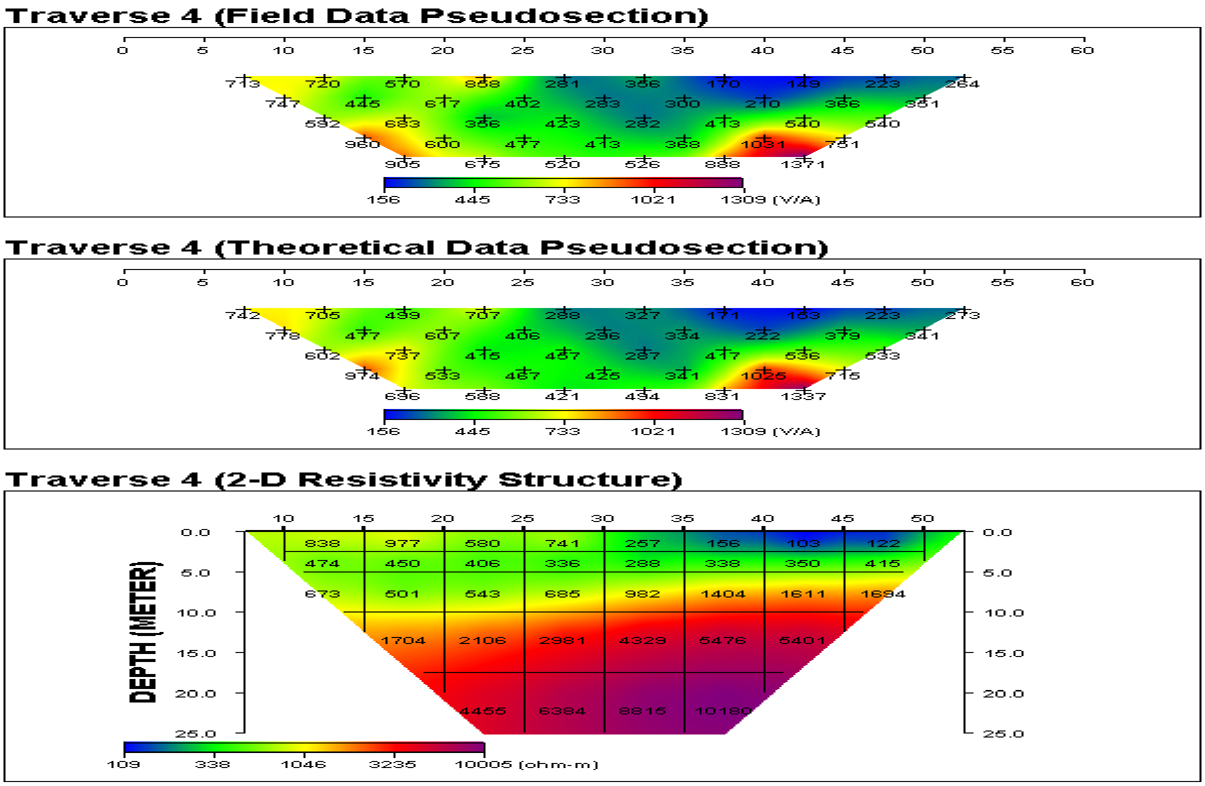


Figure 7: 2-D Resistivity Sections along Traverse 4

4.1.5 Travserse 5

Along traverse 5 (Figure 8), electrode spacing of 5 m was used with a total length of 60 m and the apparent resistivity values plotted against the pseudo-depth in the East-West direction. In traverse 5, resistivity distribution revealed the complex nature of the subsurface along the transverse which is highly heterogeneous. There is a rapid change of resistivity signature from East to West direction due to differential weathering of the ferruginous siltstone.In Travserse 5, between station 0 to 20 and depth 2 m-9 m, areas with resistivity values ranging from10 Ωm-100 Ωm in the east direction is in interpreted as bentonite. Areas with resistivity values of 100 Ωm-350 Ωm (as observed in station 20 to 45at depth 0 to 2.5 m) is interpreted as clay mixed with sand. Between station 25 to 60 at depth 3 to 5 m, resistivity values ranging from 350 Ωm-500 $\Omega m$is interpreted as sand. From station 25 to 40 at depth 8 m to 10 m, resistivity values ranging from 1000 Ωm-3000 $\Omega m$is an indication of ferruginous siltstone. At depth 15 m to 25 m, resistivty values ranging from3000 Ωm-8000$\Omega m$is an indication ferruginous siltstone that is highly indurated and resistivty values ranging from 8000Ωm above an indication of shale.

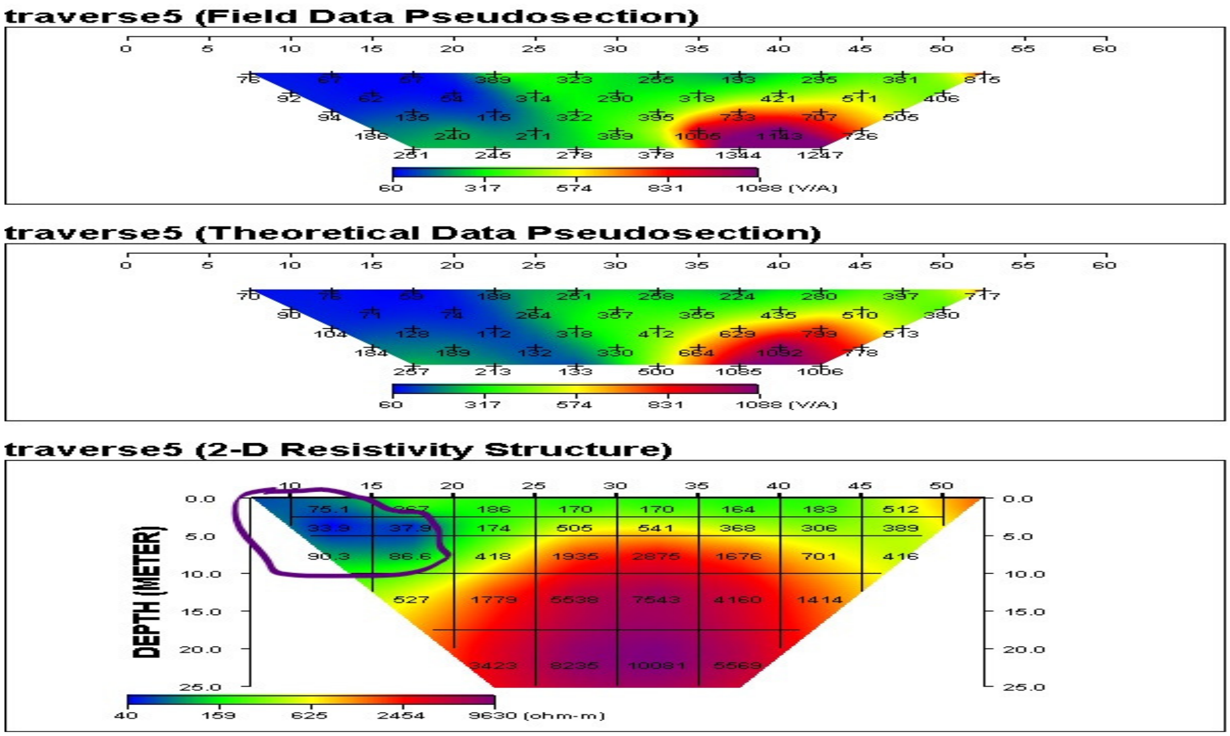


Figure 8: 2-D Resistivity Sections along Traverse 5

4.1.6 Travserse 6

Along traverse 6 (Figure 9), electrode spacing of 5 m was used with a total length of 60 m and the apparent resistivity values plotted against the pseudo-depth in the East-West direction.Traverse 6 has similar resistivity signature with that of travserse 5. There is a rapid change of resistivity signature due to the case of differential weathering of the ferruginous siltstone. It is important to note the change in resistivity signature from East to West direction (low to semi-high). The Eastern direction is characterized by extremely low to low resistivity signature while the west is characterized by moderate to semi-high resistivity signature.Between station 0 to 20 at depth 2 m- 9 m, areas with resistivity values ranging from 10 Ωm-100Ωm and is interpreted as bentonite and as we proceed westwards, there is an increase in resistivity values. Areas with resistivity values of 100 Ωm-350 Ωm (between station 20 to 25 at depth 2 m to 5m and station 25 to 30 at depth 2 m) is interpreted as clay mixed with sand. Between station 30 to 35 at depth 2 m , resistivy values ranging from 350 Ωm-500 Ωm is interpreted as sand. Between station 35 to 40 at depth 2 m, resistivty values ranging from 500 Ωm-1000 $\Omega m$is interpreted as siltstone. Between station 40 to 60, at depth 2 m, resistivity values ranging from 1000 Ωm-3000 $\Omega m$is interpreted as ferruginous siltstone. Between station 40 to 45 at depth 3 m and between station 45 to 50 at depth 3 m to 9 m, ranging from 500 Ωm-1000 $\Omega m$is interpreted as siltstone (this is as result of the differential weathering of the ferruginous siltstone above it). Resistivty values ranging from 3000 Ωm-8000 Ωm is an indication of ferruginous siltstone or sandstone that is highly indurated. Resistivty values ranging from 8000 Ωm above an indication of shale.

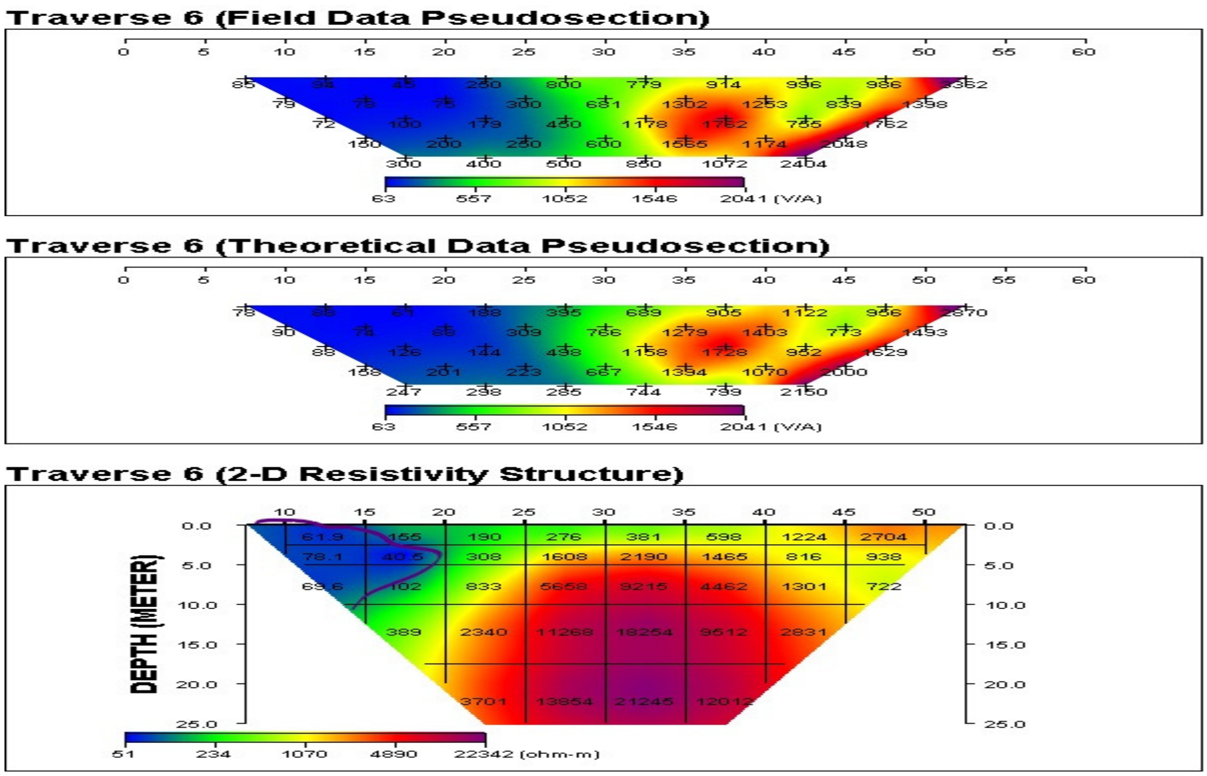


Figure 9: 2-D Resistivity Sections along Traverse 6

4.1.7 Travserse 7

Along traverse 7 (Figure 10), electrode spacing of 5 m was used with a total length of 60 m and the apparent resistivity values plotted against the pseudo-depth in the East-West direction.In traverse 7, moderate resistivity values are observed close to the surface or at shallow depth (0 to 5m) and semi-high resistivty signature are observed to be ocurring at same depth. High resistivity signature corresponding to the underlying rock (shale) is also observed to be occuring at shallow depth (at about 9 m), meaning the underlying rock (shale) is close to the surface. In traverse 7, areas with resistivity values ranging from 500 Ωm -1000 $\Omega m$is interpreted as siltstone. Areas with resistivity values ranging from 1000 Ωm-3000 $\Omega m$is interpreted asferruginous siltstone. Areas with resistivtiy values ranging from 3000 Ωm-8000 Ωm is interpreted as ferruginous siltstone that is highly indurated. Resistivty values ranging from 8000 Ωm above an indication of shale.

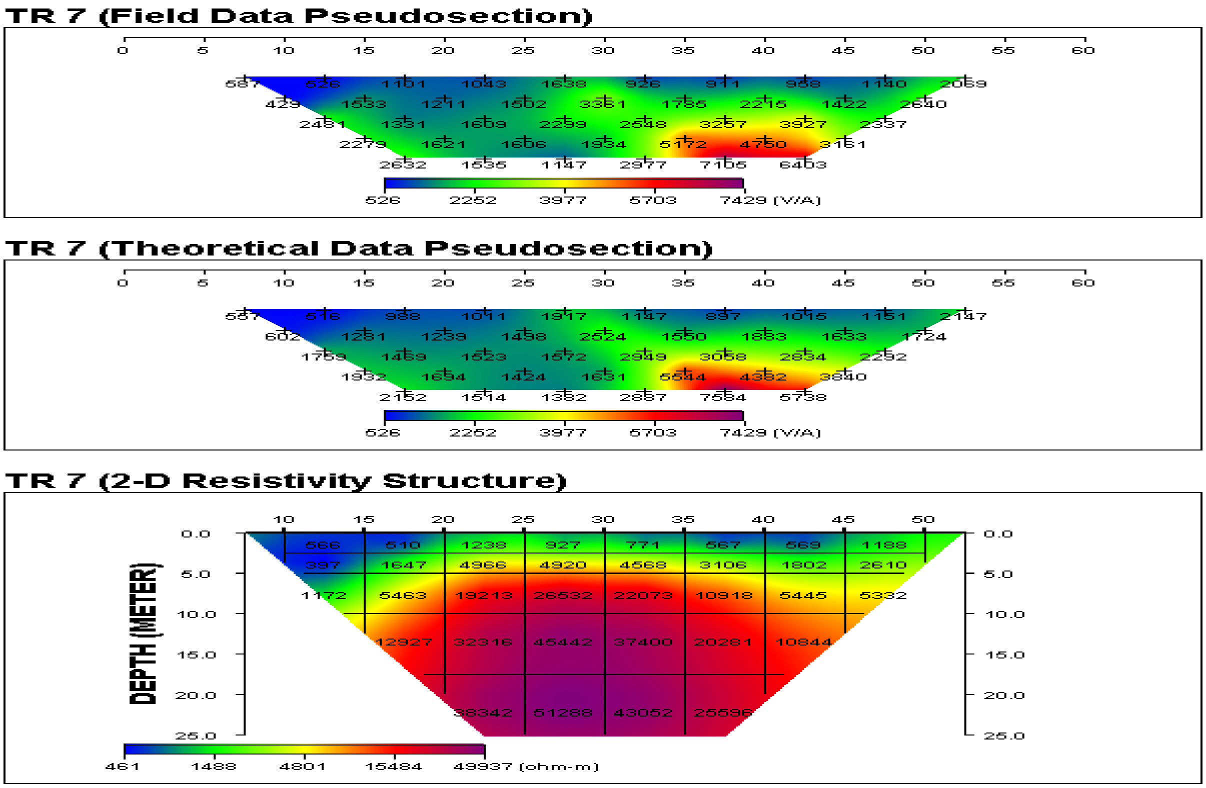


Figure 10: 2-D Resistivity Sections along Traverse 7

4.1.8 Traverse 8

Along traverse 8 (Figure 11), electrode spacing of 5 m was used with a total length of 60 m and the apparent resistivity values plotted against the pseudo-depth in the East-West direction. In traverse 8, moderate resistivity signature is seen near surface (0 to 5 m) in eastward direction (at station 0 to 15) and from station 20 to 60 semi-high resistivity signature corresponding to ferruginous siltstone is observed close to the surface (at the same 0 to 5 m). High resistivity signature corresponding to the underlying rock (shale) is also observed to be also occuring at shallow depth (at about 7 m). In traverse 8, betweenstation 10 to 15 at depth of 3 m to 5 m, resistivity values ranging from 333 $\Omega m$is interpreted as a pocket of clay mixed with sand. Areas with resistivty values ranging from 500 Ωm-1000 $\Omega m$is an indication of siltstone. Areas with resistivity values ranging from 1000 Ωm-3000 Ωm is an indication of ferruginous siltstone or sandstone .Areas with resistivity values ranging from3000 Ωm-8000 Ωm is an indication of ferruginous siltstone that is highly indurated. Resistivty values ranging from 8000 Ωm above an indication of shale.

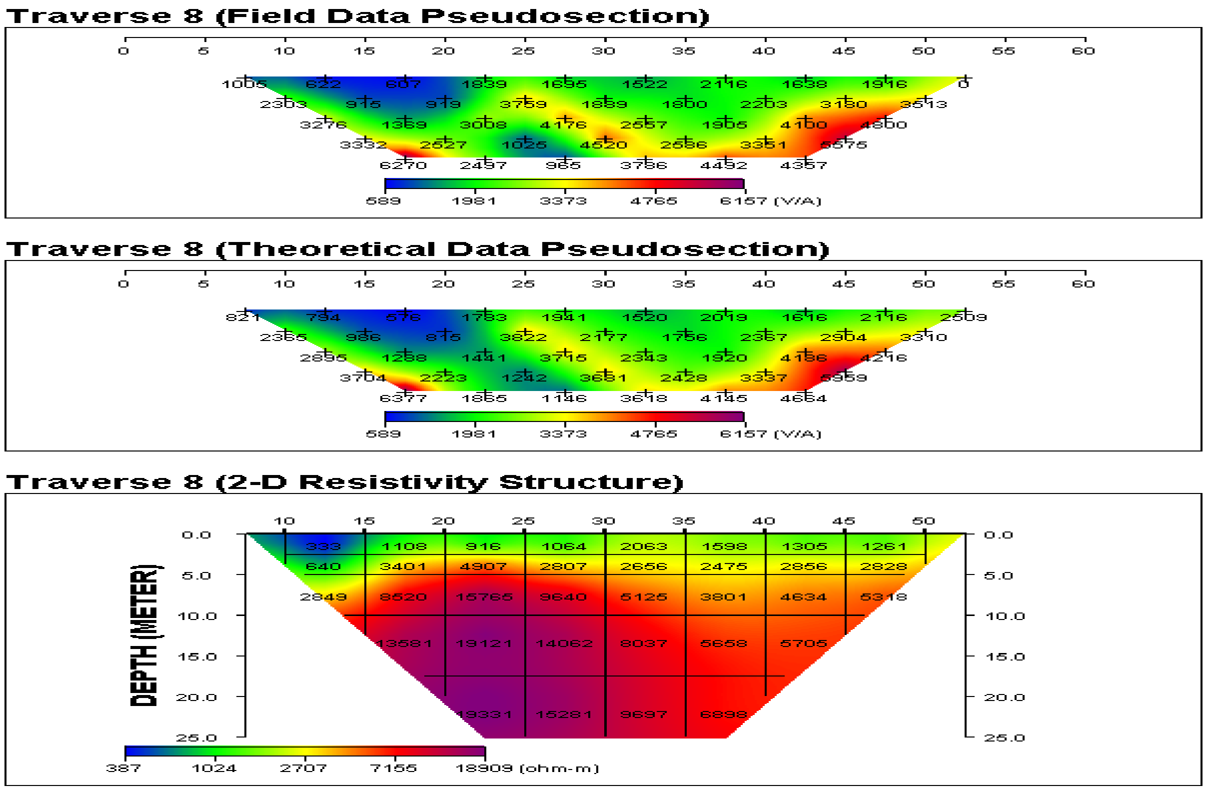


Figure 11: 2-D Resistivity Sections along Traverse 8

4.1.9 Traverse 9

Along traverse 9 (Figure 12), electrode spacing of 5 m was used with a total length of 60 m and the apparent resistivity values plotted against the pseudo-depth in the East-West direction. Traverse 9 is mostly characterized by resistivity signature corresponding to ferruginous siltstone. The In traverse 9, at station 0 to 10 at depth of 1m to 3m, resistivity values ranging from 500 Ωm-1000 $\Omega m$is interpreted as siltstone and from station 10 to 60 at same depth (1 m to 3 m) resistivity values ranging from 1000 Ωm-3000 $\Omega m$is interpreted as ferruginous siltstone. Between station 10 to 60 at depth 5 m to 25 m resistivity values ranging from 1000 Ωm-3000 $\Omega m$is observed and is interpreted ferruginous siltstone.

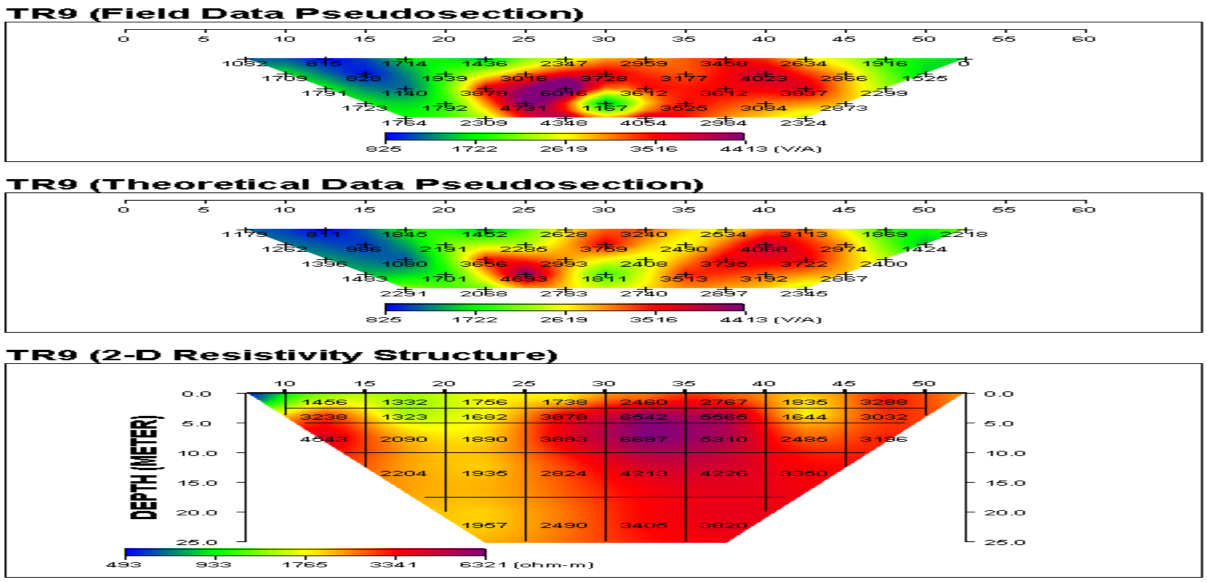


Figure 12: 2-D Resistivity Sections along Traverse 9

4.1.10 Traverse 10

Along traverse 10 (Figure 13), electrode spacing of 5 m was used with a total length of 60 m and the apparent resistivity values plotted against the pseudo-depth in the East-West direction. Resistivity values ranging from $1000\,\Omega m$-$3000\,\Omega m$ is observed from station 0 to 30 at depth 0 to 4 m. This changes as we proceed to the west as resistivity values drop to the ranges of $100\,\Omega m$-$350\,\Omega m$. This is as a result of differential weathering of ferruginous siltstone as at depth 5 m, resistivity values increases to the range $1000\,\Omega m$-$3000\,\Omega m$ (which is interpreted or corresponds to ferruginous siltstone).In traverse 10, from station 35 to 55 at depth 0 to 5 m in westward direction, resistivity values ranging from $100\,\Omega m$-$350\,\Omega m$ is interpreted as clay mixed with sand. At station 20 to 30, at depth 3 to 5 m, resistivty values ranging from$3000\,\Omega m$-$8000\,\Omega m$ is an indication offerruginous siltstone that is highly indurated. Resistivity signature corresponding to ferruginous siltstone is also observed at station 35 to 45 at depth 6 to 9 m. Resistivty values ranging from $8000\,\Omega m$ above an indication of shale.

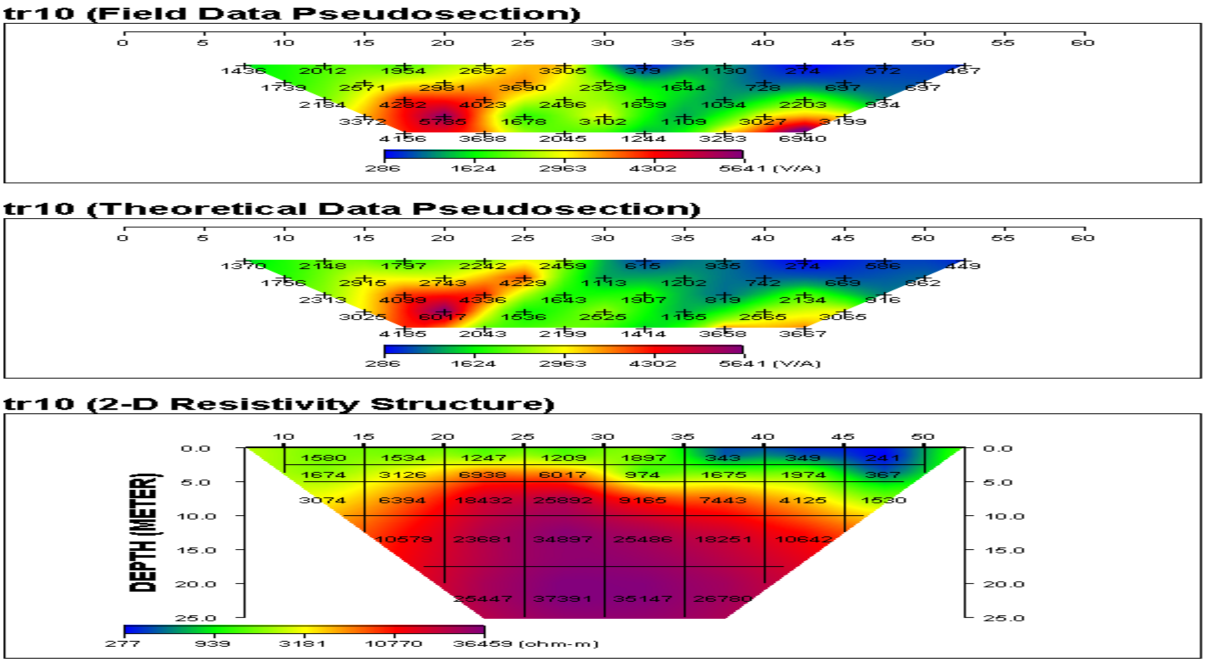


Figure 13: 2-D Resistivity Sections along Traverse 10

4.2 GEOCHEMICAL RESULTS

Samples were collected from traverse 1 , 5and 6, based on the interpretation of results obtained from dipole-dipole method. Areas with extremely low resisitivity was taken into consideration (traverse 1, 5and 6) and samples were obtained from areas with extremely low resistivity signatures which were interpreted to be associated with benotnite.

4.2.1 Use of X-ray Florescence to Determine Elemental Dispersion or Content:

Table 1: Table Showing Elemental Dispersion, Intensity and Content for Traverse 5 and 6

Sample obtained from Traverse 5 and 6	Sample Label: (sample A)	Test Time(s)
Suppliers		Work Curve:ORE
Voltage(KV)	40.0	Operator:001
Current(µA)	350	Date: 16/07/2019
Element	Intensity	Content(ppm)
Mg	0.0001	0.0043
Al	0.0735	15.0876
Si	0.3063	37.5238
P	0.0028	0.1292
S	0.0038	0.2417
K	0.0040	0.3183
Ca	0.0078	0.0878
Ti	0.0034	0.5207
V	0.0002	0.0098
Cr	0.0000	0.0000
Mn	0.0001	0.0000
Co	0.0001	0.0012
Fe	0.0065	0.6982
Ni	0.0012	0.0725
Cu	0.0021	0.0556
Zn	0.0030	0.0636
As	0.0005	0.0000
Pb	0.0004	0.0108
W	0.0004	0.1320
Au	0.0003	0.1762
Ag	0.0000	0.0000
Rb	0.0004	0.0015

Table 2: Table Showing Elemental Dispersion, Intensity and Content for Traverse 1

Sample obtained from Traverse 1	**Sample label: Sample B**	**Test Time(s)**
Suppliers		Work Curve: ORE
Voltage(KV)	40.0	Operator: 001
Current(μA)	350	Date: 16/07/2019
Element	Intensity	Content (ppm)
Mg	0.0001	0.0041
Al	0.1032	20.7770
Si	0.2352	27.6314
P	0.0029	0.1358
S	0.0052	0.3586
K	0.0041	0.3236
Ca	0.0057	0.1353
Ti	0.0057	1.0263
V	0.0005	0.0276
Cr	0.0000	0.0000
Mn	0.0001	0.0003
Co	0.0003	0.0051
Fe	0.0222	2.1869
Ni	0.0014	0.0822
Cu	0.0025	0.0686
Zn	0.0033	0.07 29
As	0.0006	0.0000
-Pb	0.0000	0.0000
W	0.0002	0.0575
Au	0.0001	0.0500
Ag	0.0000	0.0000
Rb	0.0003	0.0014

Use of x-ray florescence to determine elemental dispersion or content : The EDX3600B x-ray florescence spectrometer applies XRF technology to conduct fast and accurate analysis of complex composition. The sytem detect elements between magnesium (Mg, z = 12) and uranium (U, z = 92) with high resolution and fast analysis. Meaning elemts from 1 to 11 cannot be detected which implies test cannot test for sodium or detect sodium which is a major element in Bentonite this problem was corrected for by digestion test . The x-ray florescense test was able to capture the main elements that makes up bentonite (calcium, aluminium and silicon) and their content. Sample obtained from traverse 1 (sample B) had Aluminium (Al) content of 20.770 parts per million (ppm) , silicon content of 27.6314 parts per million (ppm) and calcium content with 0.1353 parts per million (ppm). Sample obtained from traverse 5 and 6 (sample MBL1) had Aluminium (Al) content of 15.0876 parts per million (ppm) , silicon content of 37.5238 parts per million (ppm) and calcium content with 0.0878 parts per million (ppm). (result shown in Table 2 and 3). Samples obtained were bentonite. Since the chemical formula for bentonite is $(Na_{0.2}\,Ca_{0.1})Al_2\,Si_4\,O_{10}\,(OH)_2(H_2O)_{10}$ (either sodium dominated or calcium dominated), both X-ray florescence test identified the presence of calcium and digestion test showed the presence of calcium and sodium (table 1, 2 and table 3) with calcium been dominate between them. Attapulgite was successfully eliminated as the chemical formula for Attapulgite is $(Mg, Al)_2\,Si_4\,O_{10}\,(OH)$ and magnesium detected was of extremely minute or extremely small percentage (was insignificant) in samples obtained.

Note: Tables 4.1 and 4.4 give a breakdown on the elemental composition of the samples obtained from study area.

4.2.2 The use of digestion and titration test to determine sodium and calcium percentage

The flame photometer was used to check for sodium percentage. The samples obtained from traverse 5,6 and 1 were digested using Aqua Rhagae. After the digestion process samples where filtered. For determination of calcium, titration method was employed using retort stand and burret and the results is shown in table.... Samples collected from traverse1(sample B), traverses 5 and 6(sample A) showed that the Afuze bentonite is a Calcium type of bentonite as it showed higher percentage of calcium .

Table 3:Result Obtained from Titration and Digestion Test Carried on Samples

Location	CALCUIM PERCENTAGE (ppm)	SODIUM PERCENTAGE (ppm)
Traverse 5and 6 (sample A)	93.024	48
Traverse 1 (sample B)	158.304	41

4.3 Geotechnical Result

Samples obtained from traverse 1 (sample B), traverse 5 and 6 (sample A) indicated that samples are calcium type of bentonite due to their range of liquid limit (according to White, 1949) of 177 and 176.5 respectively. Result of liquid limit for traverse 1 (sample B) is shown in Plate 1, result of liquid limit for traverse 5 and 6 (sample A) is shown in Plate 2.

ATTERBERG LIMIT TEST- BS 1377: Part 2:1990 (ASTM D4318)

Client: | Date : 25/06/2019

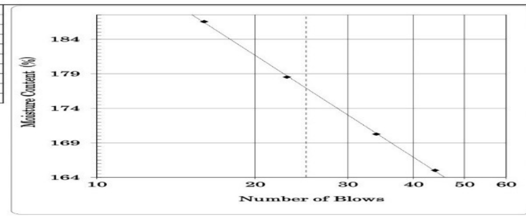
Project:

Location:

Sample No.: B | Boring No.: | Depth (mt):

Soil Description : Clay

LIQUID LIMIT, LL TEST			LL =	177.0 %
Test No.	1	2	3	4
Container No.	A	B	C	D
Wet Soil & Container g	52.07	51.80	55.70	54.88
Dry Soil & Container g	28.60	28.10	28.70	27.60
Container Empty g	14.40	14.20	13.60	13.00
Dry Soil g	14.20	13.90	15.10	14.60
Loss of Water g	23.47	23.70	27.00	27.28
Moisture Content %	165.30	170.54	178.79	186.82
Number of Blows	44	34	23	16



PLASTIC LIMIT, PL TEST		
Test No.	1	2
Container No.	A	B
Wet Soil & Container g	29.82	32.60
Dry Soil & Container g	24.40	26.70
Container Empty g	13.20	14.40
Dry Soil g	11.20	12.30
Loss of Water g	5.42	5.90
Moisture Content %	48.40	48.00
Plastic Limit, PL =	48.2 %	

LINEAR SHRINKAGE	
Original Length, L_o (mm)	140
Final Length, L_f (mm)	113
Linear Shrinkage = $(1-(L_f/L_o))*100$	19.3
Shrinkage limit =	2.5

MOISTURE CONTENT TEST		
Test No.	1	2
Container No.	A	B
Wet Soil & Container g	26.10	28.58
Dry Soil & Container g	24.40	26.70
Container Empty g	13.20	14.40
Dry Soil g	11.20	12.30
Loss of Water g	1.70	1.88
Moisture Content %	15.20	15.30
Moisture Content =	15.3 %	

USCS GROUP SYMBOL:	(CH)
Plasticity Index	128.80
Consistency Index	1.26
Liquidity Index	-0.26
Flow Index	6.59
Swell Index	0.09

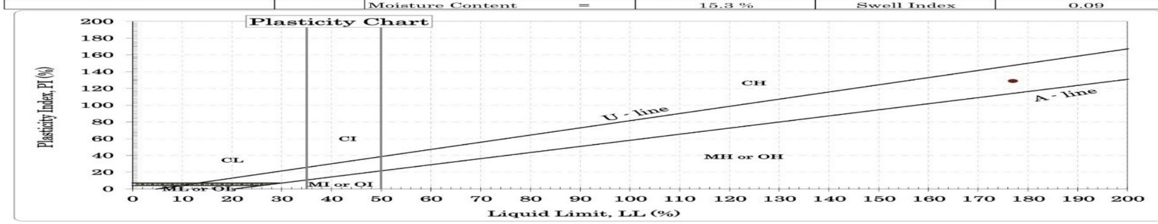


PLATE 1: Atterberg limit test of sample B(collected from traverse 1)

ATTERBERG LIMIT TEST- BS 1377: Part 2:1990 (ASTM D4318)

Client: | Date : 25/06/2019

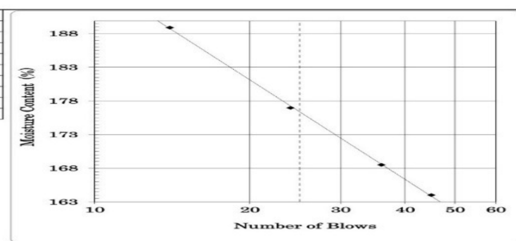
Project:

Location:

Sample No.: A | Boring No.: | Depth (mt):

Soil Description : Clay

LIQUID LIMIT, LL TEST			LL =	176.5 %
Test No.	1	2	3	4
Container No.	A	B	C	D
Wet Soil & Container g	51.88	51.51	55.41	55.16
Dry Soil & Container g	28.60	28.10	28.70	27.60
Container Empty g	14.40	14.20	13.60	13.00
Dry Soil g	14.20	13.90	15.10	14.60
Loss of Water g	23.28	23.41	26.71	27.56
Moisture Content %	163.92	168.40	176.87	188.79
Number of Blows	45	36	24	14



PLASTIC LIMIT, PL TEST		
Test No.	1	2
Container No.	A	B
Wet Soil & Container g	29.72	32.46
Dry Soil & Container g	24.40	26.70
Container Empty g	13.20	14.40
Dry Soil g	11.20	12.30
Loss of Water g	5.32	5.76
Moisture Content %	47.50	46.80
Plastic Limit, PL =	47.2 %	

LINEAR SHRINKAGE	
Original Length, L_o (mm)	140
Final Length, L_f (mm)	113
Linear Shrinkage = $(1-(L_f/L_o))*100$	19.3
Shrinkage limit =	2.5

MOISTURE CONTENT TEST		
Test No.	1	2
Container No.	A	B
Wet Soil & Container g	26.21	28.72
Dry Soil & Container g	24.40	26.70
Container Empty g	13.20	14.40
Dry Soil g	11.20	12.30
Loss of Water g	1.81	2.02
Moisture Content %	16.20	16.40
Moisture Content =	16.3 %	

USCS GROUP SYMBOL:	(CH)
Plasticity Index	129.35
Consistency Index	1.24
Liquidity Index	-0.24
Flow Index	6.59
Swell Index	0.09

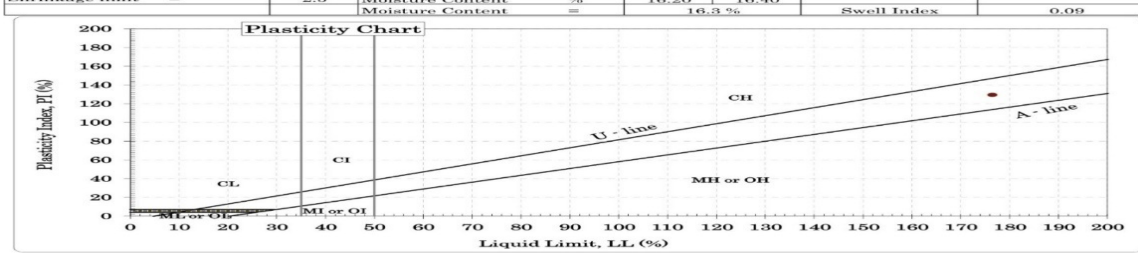


PLATE 2: Atterberg limit test of sample A (collected from traverse 5 and 6)

Table 4: Correlation of Geophysical, Geochemical and Geotechnical result

Traverse Number	Geophysical Result (Electrical Resistivity Value Depicting Bentonite)	Geochemistry Result (Digestion and Titration Result DepictingBentonite)	Geotechnical Result (Liquid Limit Result Depicting Bentonite)	Remarks
1. (Distance 0 to 60 m)	12.9 – 98.7 Ωm	Sample b : calcium 158.304 ppm , sodium 48 ppm	Sample b : 177	Bentonite present
2. (Distance 0 to 60 m)	Nil	Nil	Nil	Bentonite absent
3.(Distance 0 to 60 m)	Nil	Nil	Nil	Bentonite Absent
4.(Distance 0 to 60 m)	Nil	Nil	Nil	Bentonite Absent
5.(Distance 0 to 18 m)	33.9-90.3 Ωm	Sample A : calcium 93.024 ppm , sodium 41 ppm	Sample a: 176	Bentonite Present
6.(Distance 0 to 18m)	40.5- 79.1 Ωm	Sample A: calcium 93.024 ppm, 41 ppm	Sample: 176	Bentonite Present
7.(Distance 0 to 60 m)	Nil	Nil	Nil	Bentonite Absent
8.(Distance 0 to 60 m)	Nil	Nil	Nil	Bentonite Absent
9.(Distance 0 to 60 m)	Nil	Nil	Nil	Bentonite Absent
10.(Distance 0 to 60 m)	Nil	Nil	Nil	Bentonite Absent

5 CONCLUSION:

Electrical resistivity signatures of samples obtained from traverses 1, 5 and 6 (as shown in Figure 4.2, 4.6 and 4.7) showed extremely low resistivity which corresponds to that of bentonite with ranges between $10\,\Omega m$-$100\,\Omega m$. Profiles obtained from pseudosections showed that bentonite present in traverse 1 is not as thick (..m)as traverses 5 and 6 (..mand..m). Profile obtained from pseudosections also showed that bentonite occurring in traverses 5 and 6 to be having equal or very close thickness meaning they are same outcrop. From pseudosection it is observed that bentonitewas absent in traverses 2, 3,4,7,8, 9 and 10. From geochemical data it is evident that the bentonite found in Afuze is of calcium type since it is calcium dominated. Attapulgite can be confused or mistaken with calcium type of bentonite, due to their liquid limit range been very close and sometimes having similar values (calcium bentonite 117.48-175.55, Attapulgite 177.8). This problem was resolved by geochemistry test (using X-ray florescence test to determine elemental dispersion). Since the chemical formula for bentonite is $(Na_{0.2}\,Ca_{0.1})Al_2\,Si_4\,O_{10}\,(OH)_2(H_2O)_{10}$ (either sodium dominated or calcium dominated), X-ray florescence test identified the presence of calcium and digestion test showed the presence of calcium and sodium, with calcium been dominant element. Attapulgite was successfully eliminated as the chemical formula for Attapulgiteis $(Mg, Al)_2\,Si_4\,O_{10}\,(OH)$and magnesium detected was of extremely minute or extremely small percentage (was insignificant) in samples obtained. Kaolinite clay has close resemblance to bentonite due to its colour but its liquid limit range is far less compared to bentonite (34 – 59). Geochemical formula or chemical formula for kaolinite is $Al_2O_3(SiO_2)_2(H_2O)_2$ with no presence of calcium or sodium, meanwhile sodium and calcium was observed from geochemical results.

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