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Combined Geophysical and Geochemical Methods for Bentonite Prospecting in Afuze, Edo State, Nigeria

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ABSTRACT: In search for bentonite, geophysical and geochemical methods can be independently used to delineate for bentonite, although results and information from a single method might not be 100 % effective. For instance, it will be difficult to use resistivity values alone to identify a deposit as bentonite since most clay minerals have the same signature (extremely low resistivity values). Thus, this study integrates geophysical and geochemical methods to increase the accuracy of prospecting for bentonite in Afuze. The geophysical electrical method is used, with ten dipole-dipole traverses set up east to west direction, 20 m away from the Afuze-Auchi road. The dipole-dipole electrode spacing of 5 m and inter-traverse spacing of 10 m are used to acquire the electrical data. Geochemical anlysis using the x-ray florescense test and digestion and titraton test are able to capture the main elements that makes up bentonite (sodium, calcium, aluminium and silicon) and their content as well as sodium and calcium percentage. From the resistivity values of 10 Ωm-100 Ωm, bentonite has been identified in three traverses (traverses 1, 5 and 6). Results from digestion and titration test show samples obtained from traverse 1 has higher calium percentage 158 parts per million (ppm) and has a sodium percentage of 48 ppm. Samples obtained from traverses 5 and 6 have calium percentage of 93 ppm and have a sodium percentage of 41 ppm. This data set has been able to provide more details on bentonite having sedimentary origin and detailed information concerning bentonite occuring in Nigeria, serving as a guide for future researchers.

Keywords: Geophysical; geochemical; digestion and titration; electrical resistivity, x-ray florescense

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INTRODUCTION

The term “bentonite” is ambiguous. As defined by geologists, bentonite 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 (Christidis and Huff, 2009). Empirical formula for Bentonite is given as: $Na_{0.2}\,Ca_{0.1}\,Al_2\,Si_4\,O_{10}\,(OH)_2(H_2O)_{10}$ (Reade International Corp, 2018). Bentonite is one of the most sought-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 (George and Warren, 2009). 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. Bentonite are hosted and also associated with siltstone.

There are two principal types of bentonite namely (George and Warren, 2009):

i. natural sodium bentonite or sodium montmorillonite .

ii. natural calcium bentonite or calcium montmorillonite.

When geophysical and geochemical methods are integrated, a detailed view of the quality and properties of the mineral is established such as “Bentonite”. Geophysical methods have been used in the past to prospect for bentonite. Ahmed (2017), researched the electrical resistivity and rheological properties of bentonite on drilling muds modified with lightweight polymer. From his research it was stated that the addition of bentonite or presence of bentonite greatly reduced the electrical resistivity of the drilling mud and polymer. From his research it was stated that the addition of bentonite or presence of bentonite greatly reduced the electrical resistivity of the drilling mud and polymer. Therefore, this means bentonite is characterized with a signature of extremely low resistivity values. Geochemical analysis is the process through which scientists determine the chemical compound that constitute Earth, its atmosphere and its seas (encyclopedia.com, 2019). Geochemical analysis gives or can be used to identify elemental dispersion (using the x-ray florescence test) which will give the elements that make up a mineral. Geochemical methods have been employed in the time past to explore for bentonite. Federico (2009), was able to delineate the chemical properties of bentonite from the western interior Basin of Canada. Also, he was able ascertain the bentonite occurrence that was as a result of alteration of volcanic ash in the vicinity.

Although, both methods can be used to explore for bentonite independently, results and information from single method might not be 100 % effective. Resistivity values alone cannot be used to characterize bentonite as clay minerals have low resistivity value, meaning it will be difficult to use resistivity values alone to identity a deposit as bentonite.

In this research, the integration of both geophysical and geochemical methods have proven successful in delineating or prospecting for bentonite. However a combination of both gives more accuracy.

Geology of Afuze

Afuze lies within the eastern sector of the Dahomey Basin (Eastern Dahomey Basin) 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 Omatsola and Adegoke (1981).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 ferruginized ironstone that occur as the topmost layer (Figure 1) by Senbore and Akande (2016).

MATERIALS AND METHODS

Geophysical Data Acquisition (Electrical Resistivity Imaging) Dipole-Dipole Array

The dipole-dipole array is one member of a family of arrays using dipoles (closely spaced electrode pairs). It measures the curvature of the potential field. If the separation between both pairs of electrodes is the same a, and the separation between the centers of the dipoles is restricted to a (n+1). The “n” is a ratio of the distance between the current 1 and potential 1 electrodes to the current 1 and current 2 dipole spacing (Loke, 1999).

The research methodology entails 10 traverses east to west direction, 20 m away from the Afuze-Auchi road, then using the dipole – dipole array with interval spacing of electrodes 5 m and inter-traverse spacing of 10 m. 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 any modern inversion software (Aguisa.com, 2017) in this case the Dipro-win was utilized. The color contoured image displays the distribution of apparent resistivity values and associated gradients within the area of interest. In order to convert the apparent resistivity data to true resistivity, the data were inverted. The numbers presented at the bottom of the inverted section display goodness of fit criteria. This was used to assess the accuracy of the calculated resistivity model. Results obtained from geophysical interpretations was used to determine areas to collect samples for geochemical and geotechnical analysis.

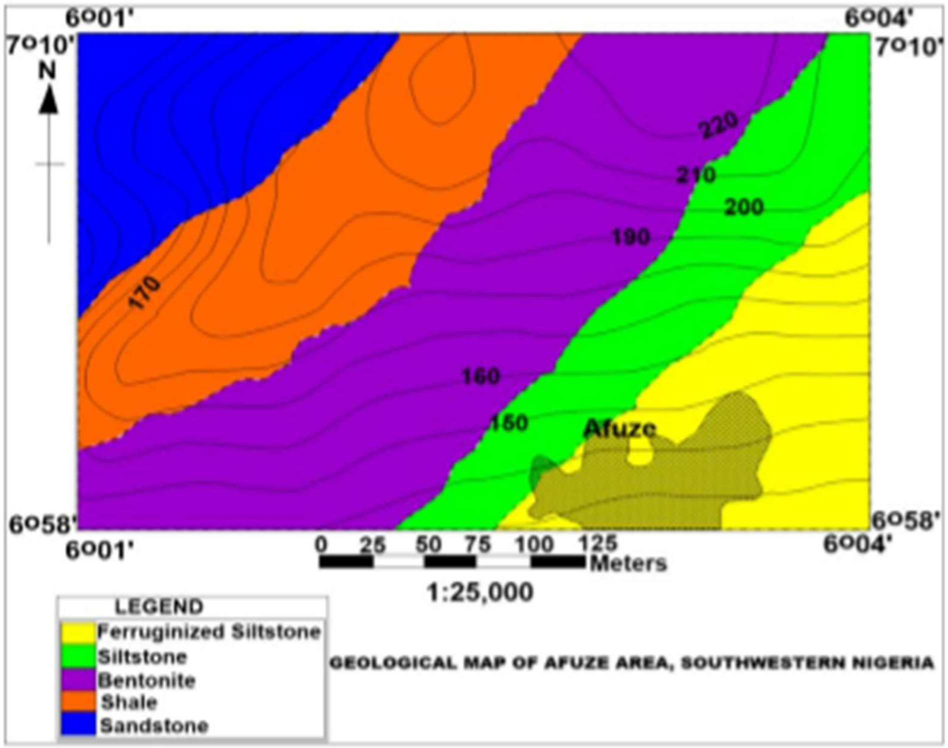

Figure 1: Geological Map of Afuze showing the Distribution of the Lithologic units (Senbore and Akande, 2016)

Geochemical Analysis

Samples were collected from traverse 1, 5and 6. This is as a result of the interpretation of results obtained from dipole-dipole method. Areas with extremely low resisitivity was taken into consideration (traverse 1, 5 and 6). This aided in the correlation of data. The geochemical analysis were conducted by digestion and titration as well as x-ray florescence test to determine presence of elemental components from the collected sample.

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. This means element from 1 to 11 cannot be detected which implies it cannot test for sodium or sodium cannot be detected, Sodium is regarded as a major element in Bentonite, this becomes a problem and have been corrected for by digestion test.

Titrimetry Analysis and Digestion of Sample (Bentonite)

The flame photometer was used to check for sodium percentage. The samples obtained from traverse 5, 6 and 1 was digested using Aqua Rhagae. After the digestion process samples were filtered. For determination of calcium, titration method was employed using retort stand and boret. Cut small portion of sample 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 .Make the filtrate up to 50ml with distill water

The procedures to determine sodium percentage or solution are

1. Cut small portion of sample with hammer on a metallic plate and crush to powdery form using agate mortar and pestle.
2. Carefully weigh out 2g, digest with concentated HNO_3 in excess until dissolution is clear, then sieve it .
3. Put sample in flame photometer.

Basemap of Study Location

Base-map of study location had been created approximately 20m away from the AFUZE-AUCHI road, Owan-East Local Government Area, Edo-State as shown below in Figure 2.

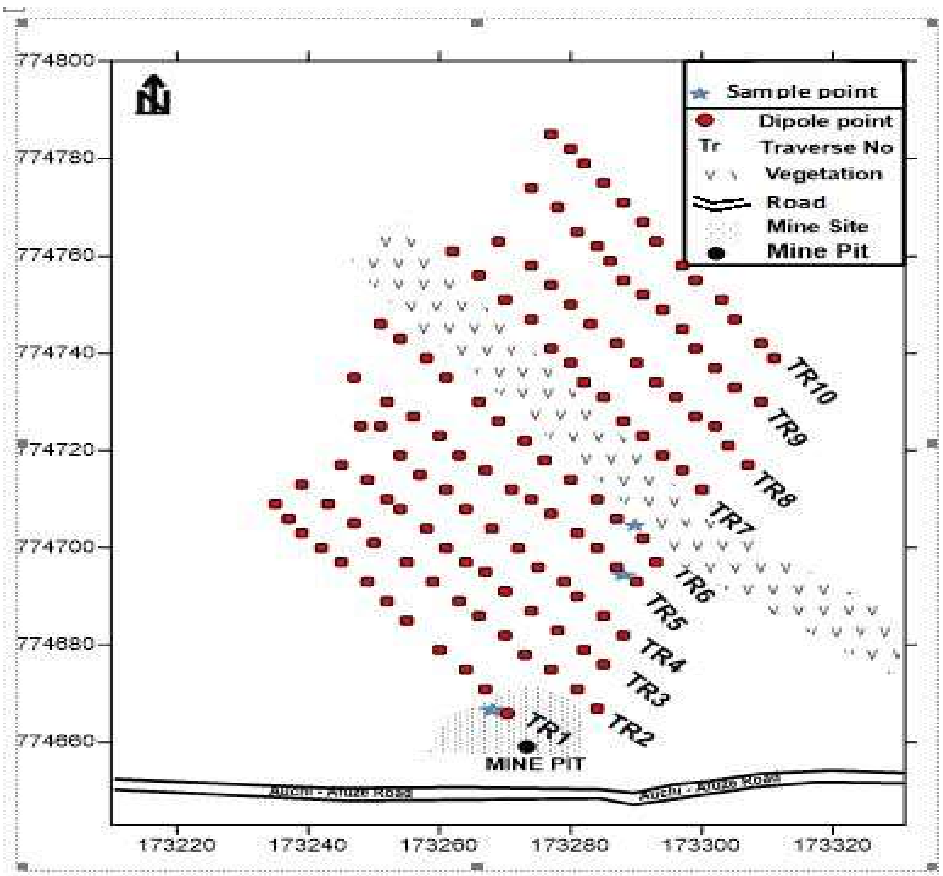

Figure 2: Base-map of project location

RESULTS AND DISCUSSION

Geophysical Data Interpretation of Electrical Resistivity Survey

Information obtained from electrical resistivity survey (dipole dipole) is used to create a 2-D Resistivity Structure. This indicates the presence of bentonite due to extremely low resistivity values ranging from 10 Ωm-100 Ωm. Moderate resisitvity values ranging from 100 Ωm-350 Ωm is an indication of clay mixed with sand. Resistivy values ranging from 350 Ωm-500 Ωm is an indication of sand. Resistivty values ranging from 500 Ωm-1000 Ωm is an indication of sandstone.

Resistivity values ranging from 1000 Ωm-3000 Ωm is an indication of ferroginized siltstone or sandstone. Resistivty values ranging from 3000 Ωm-8000 Ωm is an indicatiom ferroginized siltstone or sandstone that is highly indurated. Resistivity values ranging from 8000Ωm and above is belived to be shale (adapted from palacky, 1987). Areas marked or circled in traverses 1, 5 and 6 is an indication of bentonite due to their low resistivity value (<100 Ωm) . In traverse 1 (Figure 3), a low resisitivity zone with resistivity values ranging between 10 Ωm -100 Ωm 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. . 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 traverse 5 (Figure 7), between station 0 to 20 and depth 2 m - 9 m, areas with resistivity values ranging from 10 Ωm-100 Ωm in the east direction is in interpreted as bentonite. In traverse 6 (Figure 8), 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.. Other traverses (2,3,4,7,8,9 and 10) did not give resistivity signature corresponding to bentonite. In traverse 4 (Figure 6), 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. Results are displayed or shown below in Figure 3, Figure 4, Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10, Figure 11 and Figure 12.

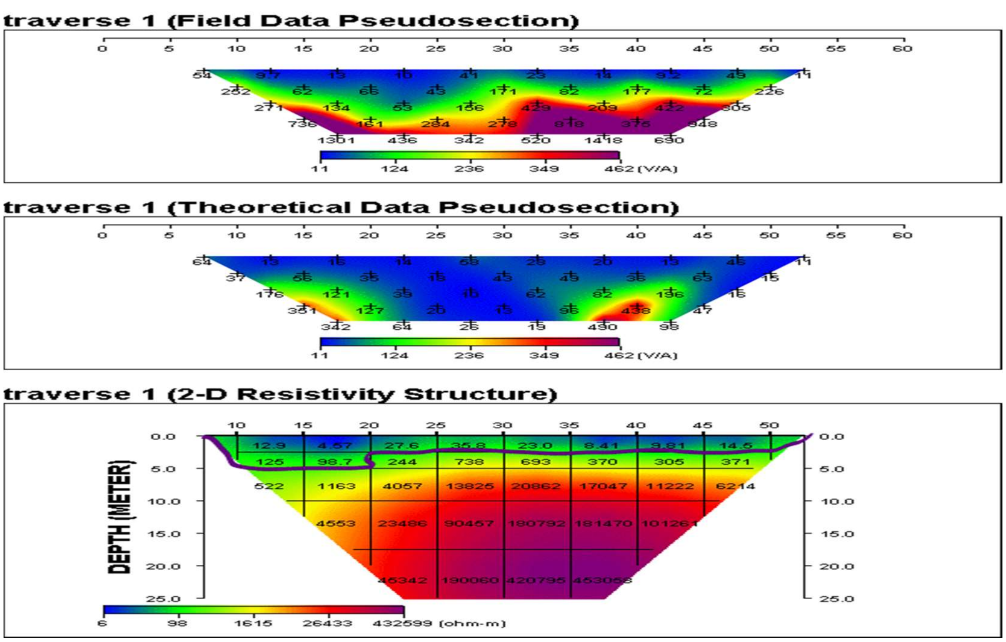

Figure 3: 2-D Resistivity Sections along Traverse 1

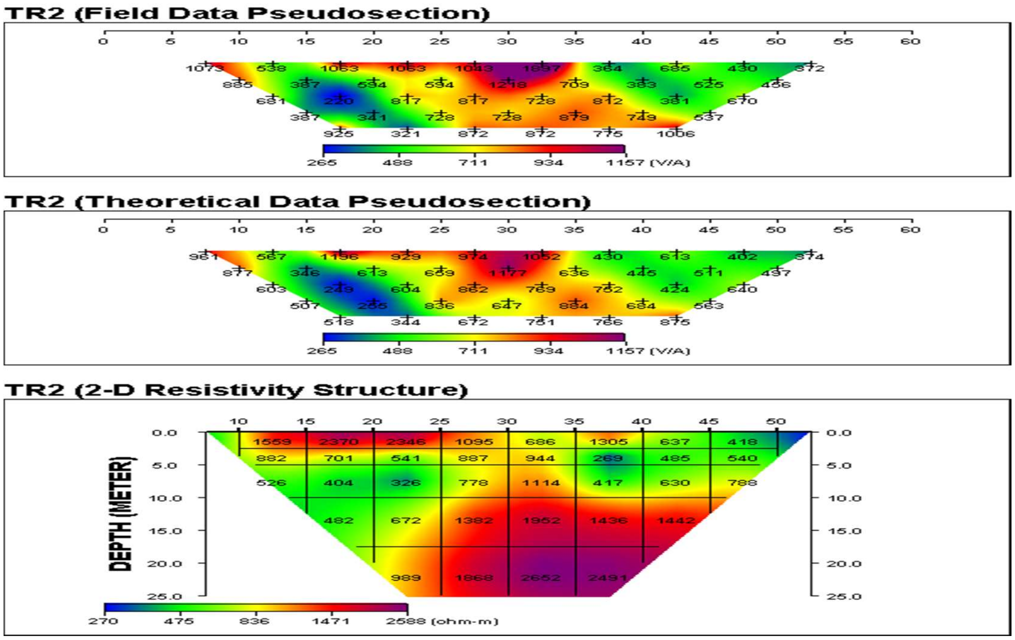

Figure 4: 2-D Resistivity Sections along Traverse 2

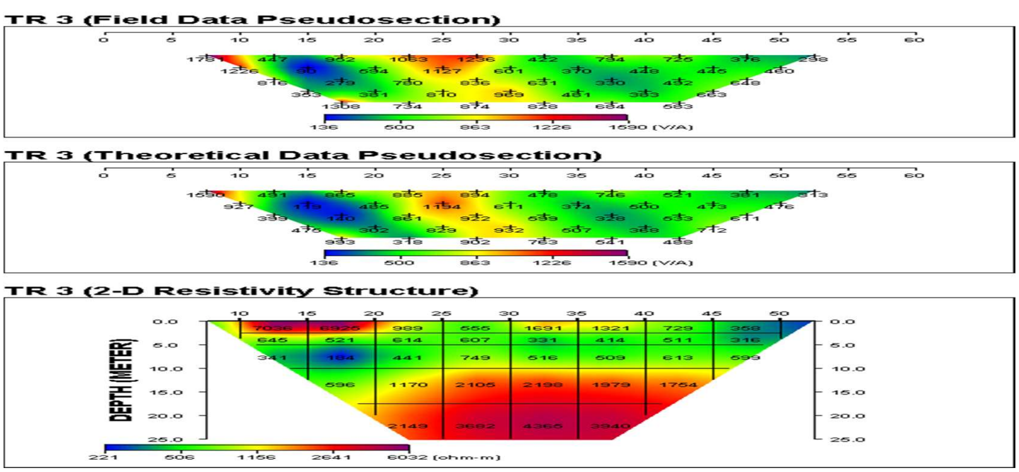

Figure 5: 2-D Resistivity Sections along Traverse 3

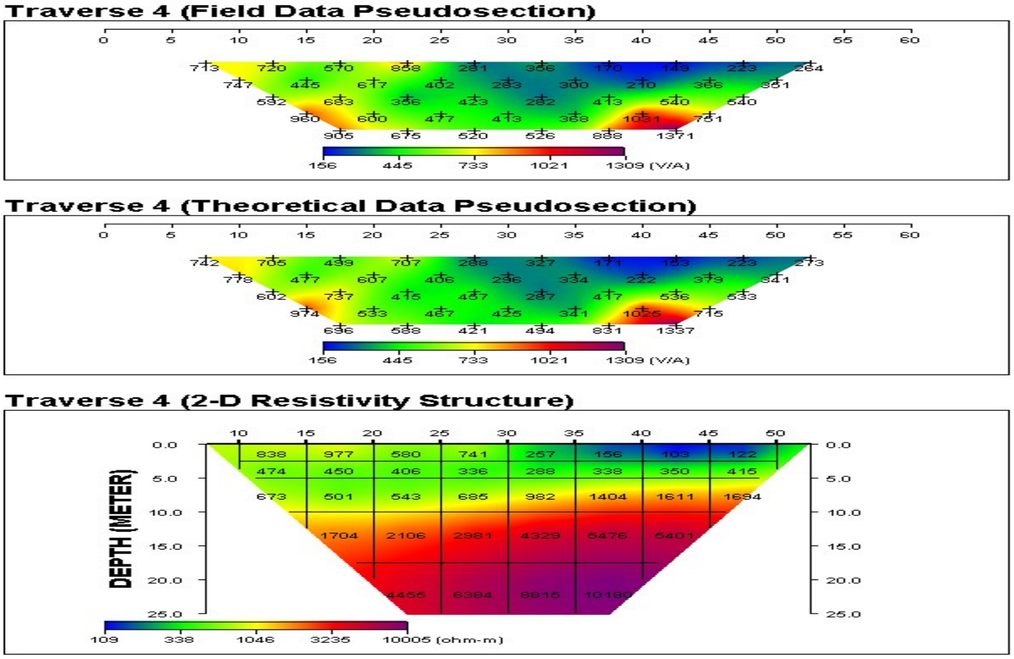

Figure 6: 2-D Resistivity Sections along Traverse 4

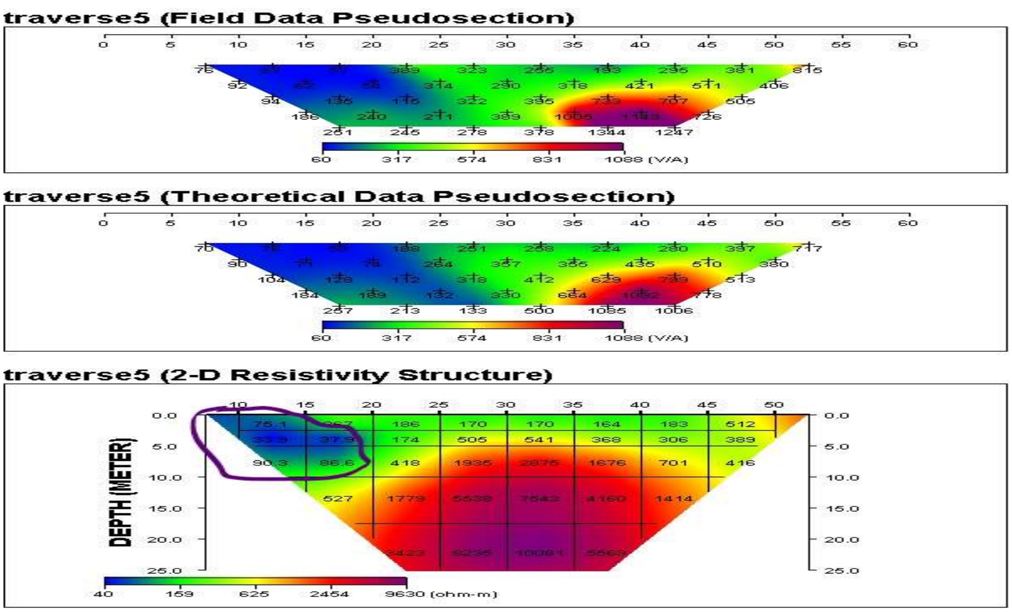

Figure 7: 2-D Resistivity Sections along Traverse 5

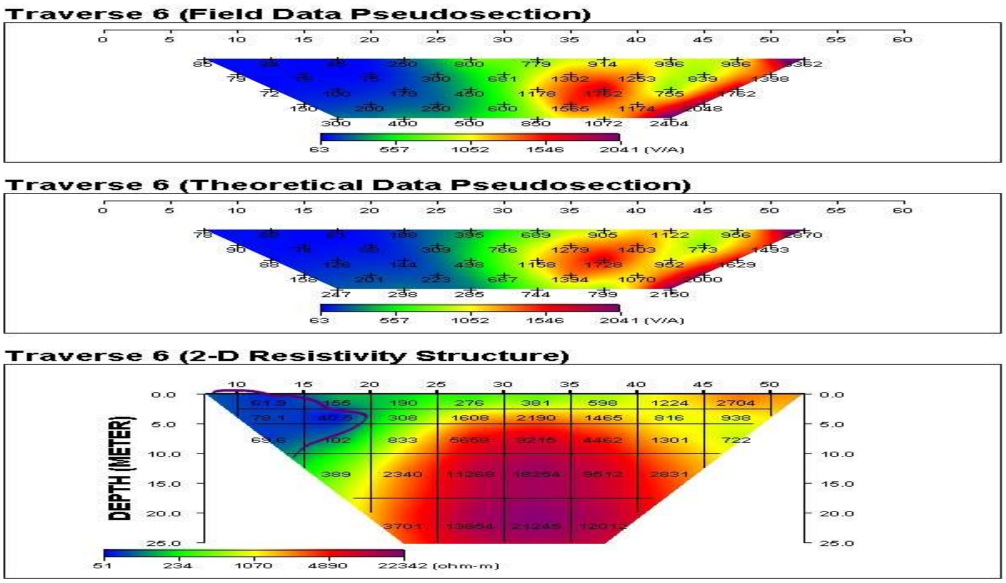

Figure 8: 2-D Resistivity Sections along Traverse 6

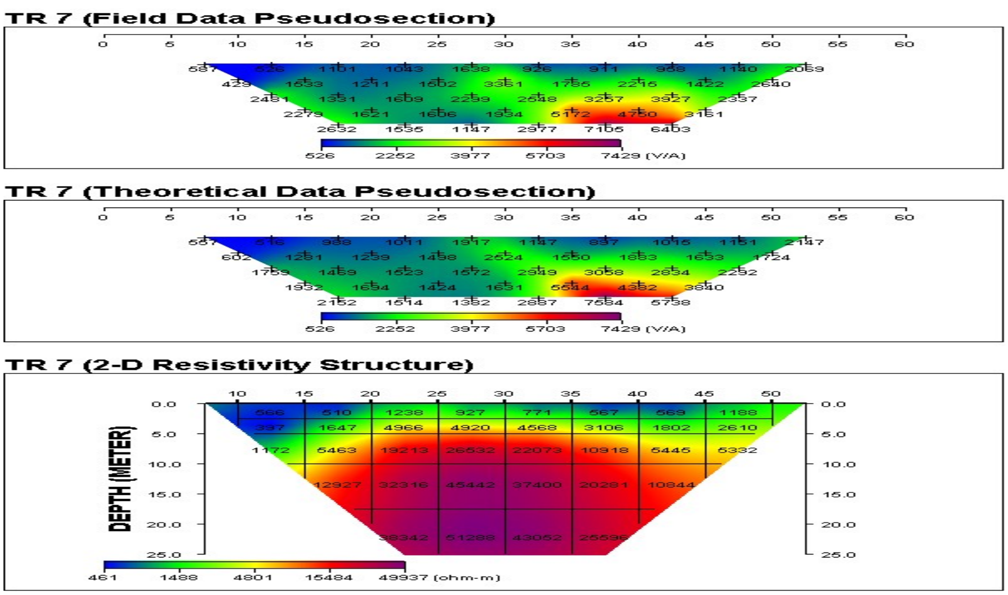

Figure 9: 2-D Resistivity Sections along Traverse 7

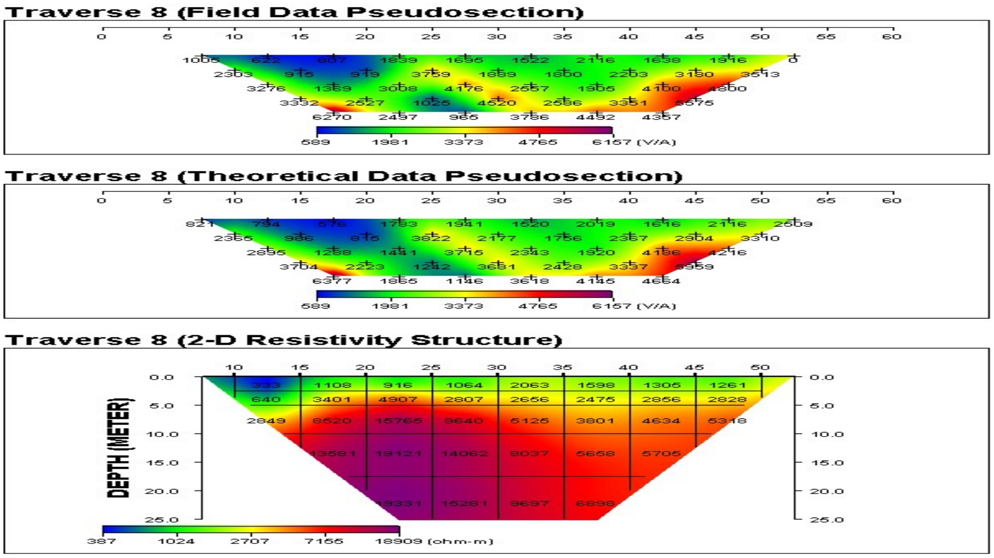

Figure 10: 2-D Resistivity Sections along Traverse 8

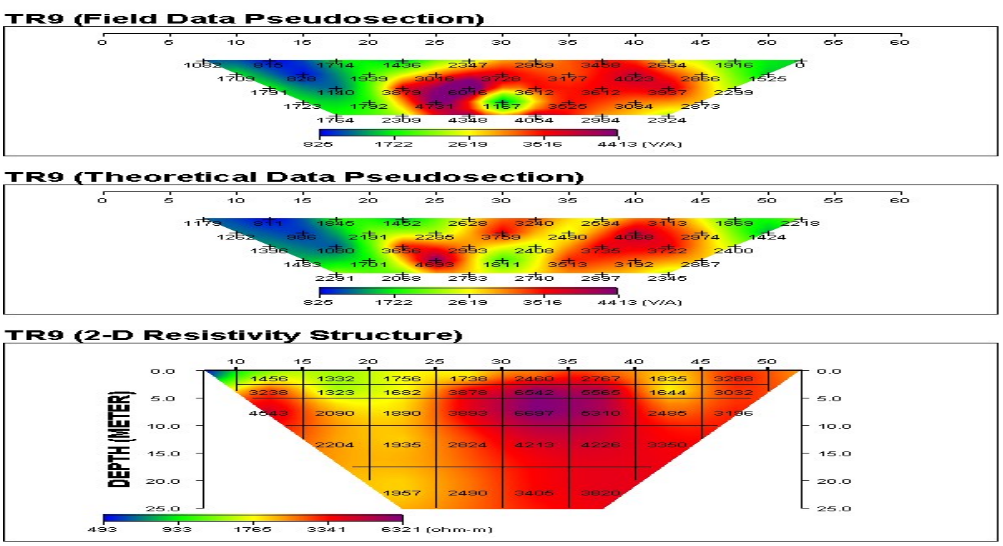

Figure 11: 2-D Resistivity Sections along Traverse 9

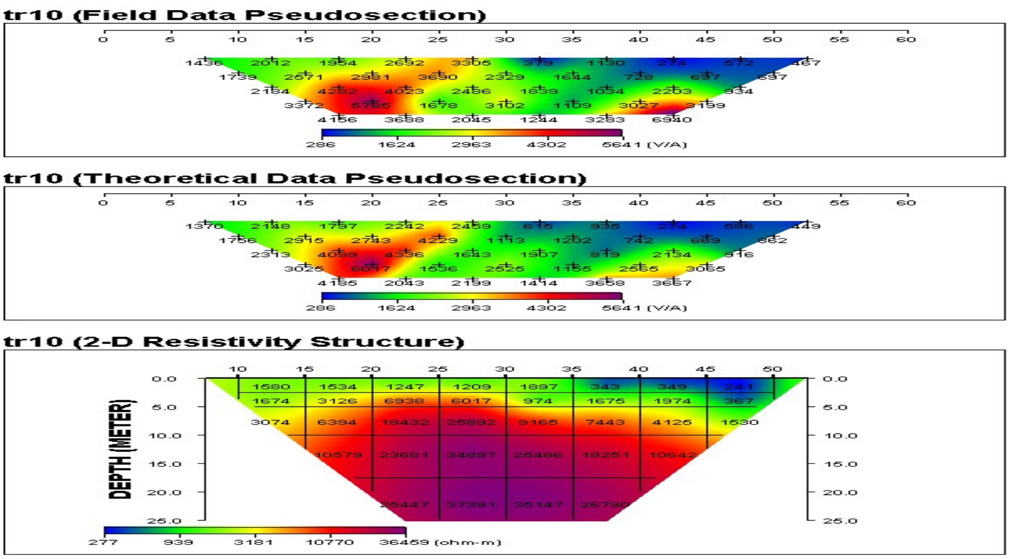

Figure 12: 2-D Resistivity Sections along Traverse 10

Geochemical Results

The digestion and titration test to determine sodium and calcium percentage

Samples collected from traverse 1(sample B), traverse 5 and traverse 6(sample A) showed that the Afuze bentonite is a Calcium type of bentonite with higher percentage of calcium . Sample obtained from Traverse 1 (sample B) have higher calium percentage of 158 parts per million (ppm) and have a sodium percentage of 41 parts per million (ppm). Sample obtained from Traverse 5 and 6 (sample A) have calium percentage of 93 parts per million (ppm) and have a sodium percentage of 48 parts per million (ppm). Result shown in Table 1 below.

X-ray florescence to determine elemental dispersion or content

The x-ray florescense test has been able to capture the main elements that makes up bentonite (calcium, aluminium and silicon) and their content. Sample obtained from traverse 1 (sample B) have 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) have 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). (shown in Table 2 and 3). These samples obtained are 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 dominant between them. Attapulgite have been successfully eliminated as the chemical formula for Attapulgite is $(Mg, Al)_2\,Si_4\,O_{10}\,(OH)$ and percentage of magnesium is insignificant.

Table 1: Result obtained from titration and digestion test carried out on samples

Location	Calcium Percentage (ppm)	Sodium Percentage (ppm)
Traverse 5 & 6 (sample A)	93.024	48
Traverse 1 (sample B)	158.304	41

Table 2: 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 3: Table Showing Elemental Dispersion in Traverse 5 and 6 (other elements with very minute concentration)

Sample obtained from Traverse 5 and 6	**Sample Label: (sample A)**	**Test Time(s)**
Nb	0.0005	0.0031
Mo	0.0044	0.1610
Cd	0.0000	0.0000
Sn	0.0106	2.0782
Sb	0.0156	1.9632

Table 4: 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

Note: Tables 2 and 4 give a breakdown on the elemental composition of the samples obtained from study area.

Table 5: Table Showing Elemental Dispersion in Traverse 1 (other elements with very little or minute concentration)

Sample obtained from Traverse 1	Sample label: Sample B	Test Time(s)
Nb	0.0003	0.0014
Mo	0.0016	0.2075
Cd	0.0000	0.0000
Sn	0.0098	1.8938
Sb	0.0146	1.8359

CONCLUSION

Electrical resistivity signatures of samples obtained from traverses 1, 5 and 6 (as shown in Figure 3, 7 and 8) showed extremely low resistivity. This corresponds to that of bentonite with ranges between 10 Ωm-100 Ωm. Profiles obtained from 2-D Resistivity Sections showed that bentonite present in traverse 1 (about 3 m thick) is not as thick as traverses 5 and 6 (about 8 m thick). Profile obtained from 2-D Resistivity Sections 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 bentonite did not appear in traverses 2, 3, 4, 7, 8, 9 and 10. This could be as a result of the differential weathering of ferruginous siltstone.

From geochemical data it is evident that the bentonite found in Afuze is of calcium type which is calcium dominated. Due to the combination of geophysical and geochemical methods, other clay minerals (attapulgite and kaolinite) with similar physical properties and range of electrical resistivity values were successfully eliminated. The chemical formula for attapulgite is $(Mg, Al)_2 Si_4 O_{10} (OH)$ and magnesium content detected was of extremely minute or extremely small percentage (was insignificant) in samples obtained. 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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