**2-D SUBSURFACE ELECTRICAL RESISTIVITY INVESTIGATIONS FOR MINERAL EXPLORATION OF UWANOBA, SOUTH-SOUTH NIGERIA**

**ABSTRACT**

Mineral exploration is a complete sequence of activities. It ranges between searching for a new mineral prospect (reconnaissance) and evaluation of the property for economic mining (feasibility study). It also includes augmentation of additional ore reserves and resources in the mine and total mining district. Most people in the Western World are environmentalists at heart whether engaged in the mineral exploration or extraction industries or not. The mining and quarrying companies are simply responding to *Society’s* desire and demand for houses, washing machines, and cars with roads on which to drive them, and so on. Two stark facts that the majority of ordinary people understand are first that ore bodies are wasting assets (that is, once an ore body is being exploited it has become a *wasting asset* and one day there will be no ore, no mine, and no further cash flow) and second that they are not evenly distributed throughout the Earth’s crust. The study area is Uwanoba and its environs, Edo state, Nigeria. The research in this environment unveiled the hidden rocks and minerals that were not captured during the conventional aeromagnetic and satellite imaging of rocks and minerals. The wenner alpha electrode configuration was deplored throughout in this study and Pasi Earth Resistivity Meter was utilized. Ten profiles were carried out; each profile is 200 metres long, and 50 metres apart. The low resistivity material with average apparent resistivity value below 1675 Ωm is interpreted to be clayey sand/ shalely sand, the medium (median) resistivity material with average apparent resistivity values between 1675 Ωm and 3500 Ωm which depicts coastal plain sand/ fine sand, and the high apparent resistivity material above 3500Ωm on the average is interpreted to be coarse dry sand.

**KEYWORDS**: Minerals, Inverse model resistivity, 2-D, Iteration, Wenner alpha array.

**INTRODUCTION**

“Nigeria is endowed with abundant mineral resources including gold, iron, lead, zinc, rare metals, coal and gemstones which could be harnessed for its development. These mineral deposits were formed at different stages in the geological evolution of Nigeria. Sadly, despite this mineral endowment, the country’s mineral sector has failed to meet public expectation of driving economic growth and generating employment of the teaming youth. Presently, the sector contributes less than 1% to the nation’s annual GDP. Paradoxically, the country is so much endowed yet so poor! This abnormality can be attributed to overdependence on oil, political instability ,poor legal, regulatory and institutional framework and lack of up to date geosciences data that can facilitate investment decision making We attempt to synthesize all the available data on Nigerian mineral resources including their geological setting, style of occurrences and highlight some new policies currently being promulgated by new government in order to woo key foreign investors who could be interested in investing in this vast, but yet grossly untapped mineral resources. In a broad sense, four important metallogenic and gemological “Eras” related to the formation of important mineral deposits corresponding to Paleoproterozoic, Neoproterozoic, Mesozoic and Cenozoic have been identified in Nigeria. The Paleoproterozoic synformational schist belts which resemble the Archean greenstone belt area associated with orogenic gold, manganese and Alogoma type banded iron formation. The Neoproterozoic Pan-African orogenic cycle related to amalgamation of western Gondwana culminated with the formation of some mineralized pegmatite fields in Nigeria. This broad pegmatite belt also refers to as “the Older Tin Belt” is rich in Sn, Nb, Ta and world class gemstones including tourmaline, aquamarine, kunzite and spessartine garnet. The emplacement of silica saturated A-type granites (the Younger Granites) generally believed to be roughly coeval with the opening of the Atlantic Ocean in Jurassic, led to the formation of significant (lead and zinc) mineralization and gemstones (emerald, topaz and fluorite). The Cretaceous Benue Trough in eastern Nigeria which forms the western part of the west and central African rift system (WCARS), hosts significant lead-zinc-barite mineralization and coal. Several tons of lead, zinc and barite have been mined from this rift basin. The Cenozoic alkaline volcanic rocks in Nigeria, like their counterparts in south eastern Asia, eastern Australia are also associated with some significant quality sapphire fields. Notable among these sapphire fields is the Mambilla sapphire field in north eastern Nigeria” (Olade, 2018).

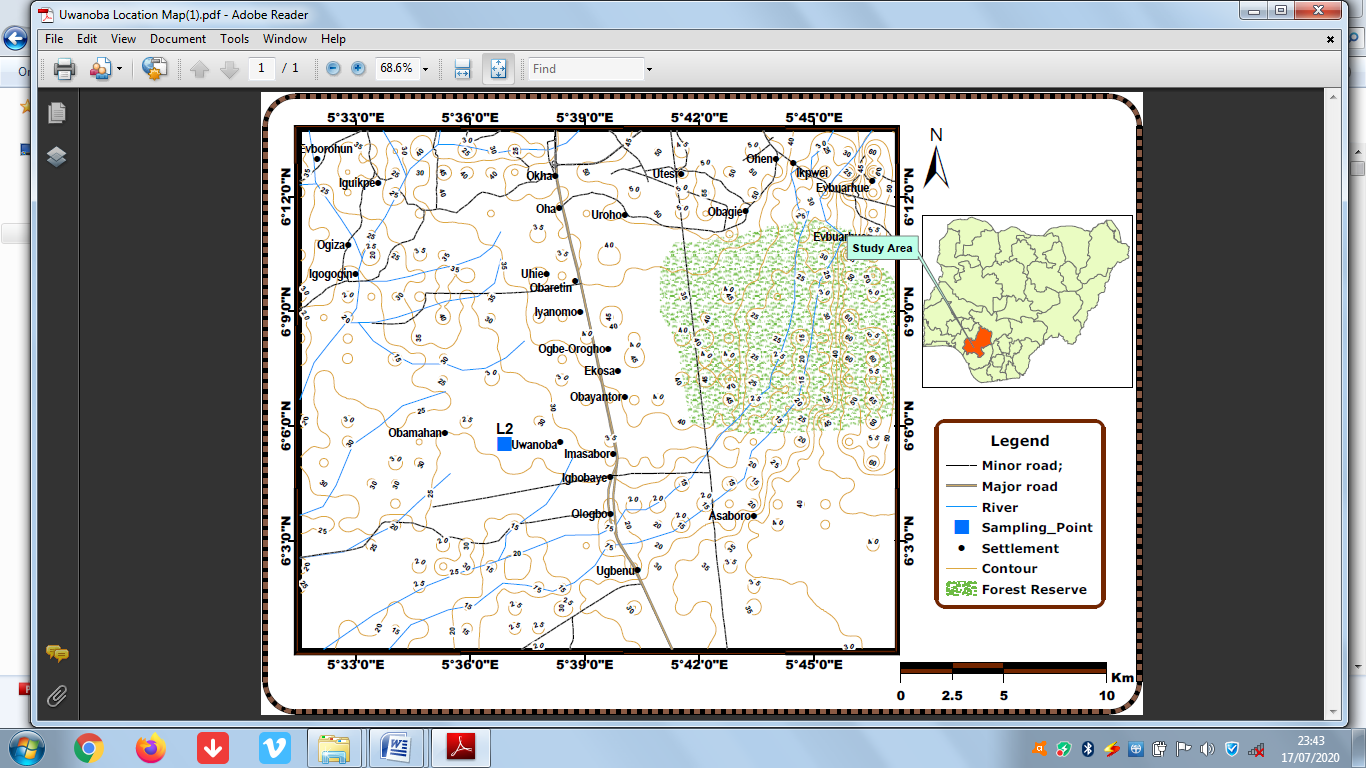
**GEOLOGICAL SETTING OF THE STUDY AREA**

Underlain by sedimentary formation of the South Sedimentary Basin is the Benin Region. The formation is about 1830 m thick at the seashore but thins landwards. The sedimentary suits of the Benin Formation dip 2˚ - 8˚ south. Geologically, the Benin Region comprises of (1) the Benin formation, (2) alluvium; (3) drift/top soil and (4) Azagba-Ogwashi (Asuba-Ogwashi) formation.

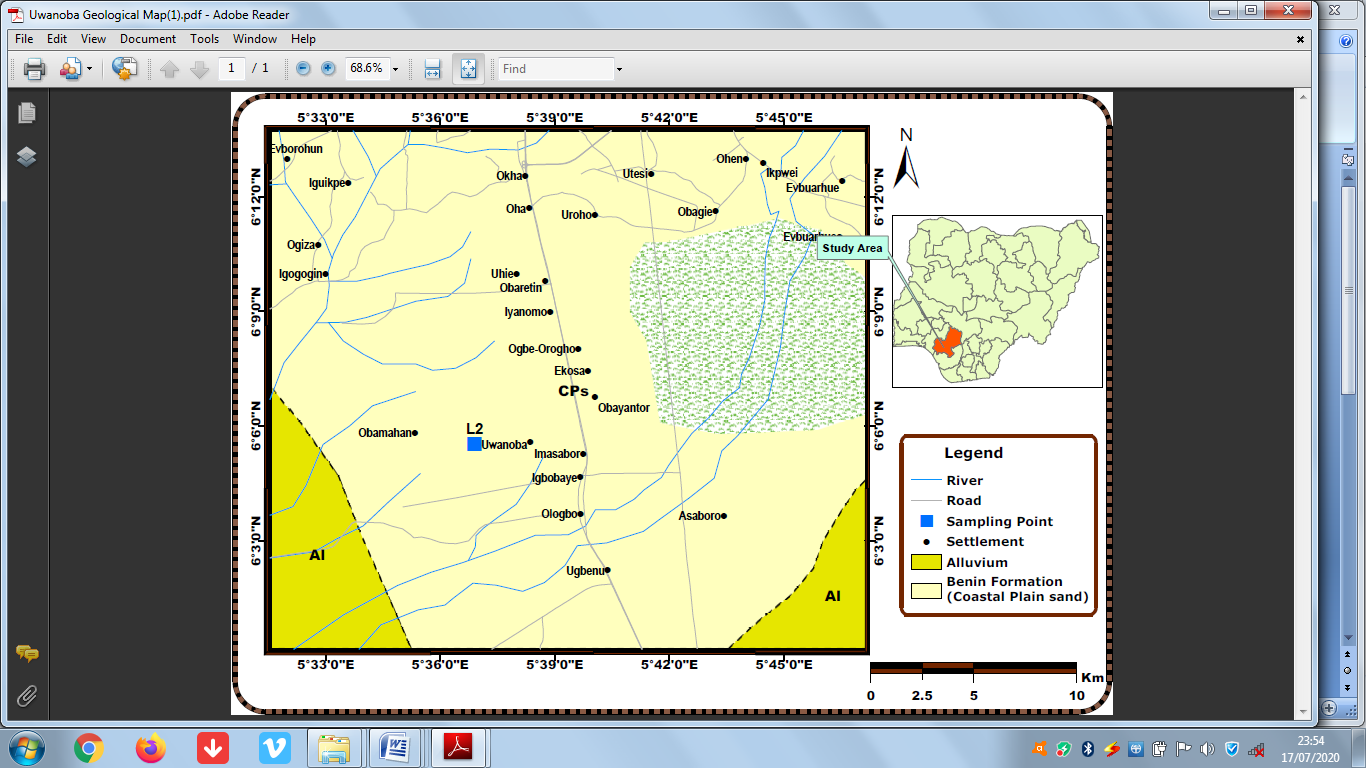
The formation is characterized by top reddish to reddish brown lateritic massive fairly indurate clay and sand. This is often marked with reticulate muderacks. This caps the underlying more friable pinkish-yellowish white often gravelly-pebble sands clayey soils, sands and clay Akujieze, (2004). The sedimentary sequences are poorly bedded with discontinuous clay horizons at various depths. It is estimated to be about 800m thick under Benin City and about 1,830 m near the sea shore sections of the formation. They are exposed at various erosion sites, sand quarry sites, and road cuttings. The Benin formation covers 95% of the region.

The Akata, Agbada and Benin formations overlie stretched continental and oceanic crusts (Heinio and Davies, 2006). Their ages range from Eocene to Recent, but they transgress time boundaries. These prograding depositional facies can be distinguished mainly on the basis of their sand-shale ratios, and the Benin Formation overlies the Agbada Formation. The Benin Formation consists of Late Eocene to Recent deposits of alluvial and upper coastal plain deposits that are up to 2000 m (6600 ft) thick.

The accurate destructive and wave dominated type Niger Delta Basin (in which Benin formation is inclusive) is believed to be one of the world largest Delta (Edward, 2006). It is situated at the north-eastern margin of the Gulf of Guinea on the west coast of Africa. The Okitipupa ridge separates the Niger Delta in the West from the Dahomey Basin. To the North, the Niger Delta is linked to the Benue Trough by the Cretaceous Anambra Basin. The Abakaliki uplift, the Cameroon Basement Complex and the Oban Massif bounds it to the northeast and east respectively and fed by the drainage systems of the Niger, Benue and Cross Rivers. The Niger Delta is considered structurally self-controlled since the structural features of the underlying Basement Complex do not seem to have directly influenced its tectonic development. Figures 1 and 2 show the location map and the geological map of study area.



**Figure 1: Location Map of the Study Area**



**Figure 2: Geological Map of the Study Area.**

**METHODOLOGY**

One of the new developments in recent years is the use of 2-D electrical imaging/tomography surveys to map areas with moderately complex geology (Griffiths and Barker, 1993). Such surveys are usually carried out using a large number of electrodes, 25 or more, connected to a multi-core cable. A laptop microcomputer together with an electronic switching unit is used to automatically select the relevant four electrodes for each measurement. At present, field

techniques and equipment to carry out 2-D resistivity surveys are fairly well developed. The necessary field equipment is commercially available from a number of international companies. Some institutions have even constructed “home-made” manually operated switching units at a nominal cost by using a seismic cable as the multi-core cable (Dahlin and Zhou, 2004). Two-dimensional resistivity surveys are usually carried out with a number of electrodes connected to a multicore cable. One of such a system is the Multi Abem Terrameter System where each electrode along the cable can be used as a current or potential electrode (Griffiths et. al., 1990; Griffiths and Barker, 1993). The smoothness-constrained least squares method was used. This consists of a number of 2-D rectangular blocks. We adopted the model used by (Barker, 1992) were the blocks are equal in number to the data points in the apparent resistivity pseudosection and are arranged in similar manner. The depths to the centres of the interior block are placed at the median depth of investigation (Edwards, 2006) for different electrode spacings used. The median depth of investigation is about 0.5 times the electrode spacing for the wenner array. The smoothness- constrained modification to the Gauss Newton method (deGroot-Hedlin and Constable, 1990) leads to the following system of normal equations:

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Where i is the iteration number, ji is the Jacobian matrix of partial derivatives, gi is the discrepancy vector which contains the the differences between logarithms of the measured and calculated apparent resistivity values, *λ*iis the damping factor and pi is the perturbation vector tothe model parameter for the ith iteration.

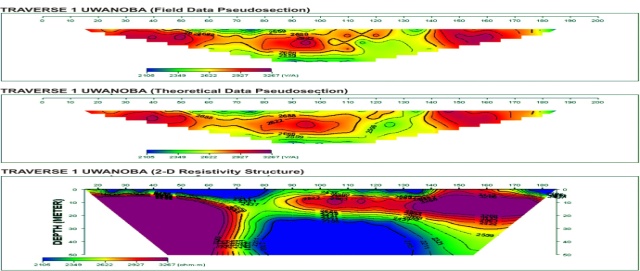
**RESULTS AND DISCUSSION**

The 2-D pseudosection plot serves as a useful guide for detailed qualitative interpretation. The observed apparent resistivity values are contoured with the intent of getting an approximate picture of the subsurface resistivity distribution. For this interpretation, the resistivity values are categorized into relatively low, medium and relatively high.

**Traverse line 1, Uwanoba**

In traverse 1 (Figure 3), the apparent resistivity range from 2105 Ωm to 3267 Ωm. The low resistivity values range from 2105 Ωm to 2321 Ωm, medium resistivity values are between 2321 Ωm and 2688 Ωm, while the high resistivity values are between 2688 Ωm and 3267 Ωm. The top left part and central zone denoted with blue colour is the low resistivity zone, and it has resistivity values which range from 2105 Ωm to 2321 Ωm, depths of 0 m to 20 m, and an average thickness of 30 m. This is characterized to be clayey sand. The green and yellow colours depict the medium resistivity zone, with resistivity values between 2321 Ωm and 2688 Ωm, thickness of about 15 m and depths ranging from between 0 m and 4 m. It is interpreted to be coastal plain sand/fine sand. The extreme left and right region of the 2-D profile with red and purple colours has the highest resistivity within the 2-D profile. This possesses apparent resistivity values which range from 2688 Ωm to 3267 Ωm, thickness of about 12 m and depths ranging from 0 m to 7 m. It is presumed to be coarse dry sand (Alile *et. al*, 2012).

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Clayey sand

Clayey sand

Coarse dry sand

Coarse dry sand

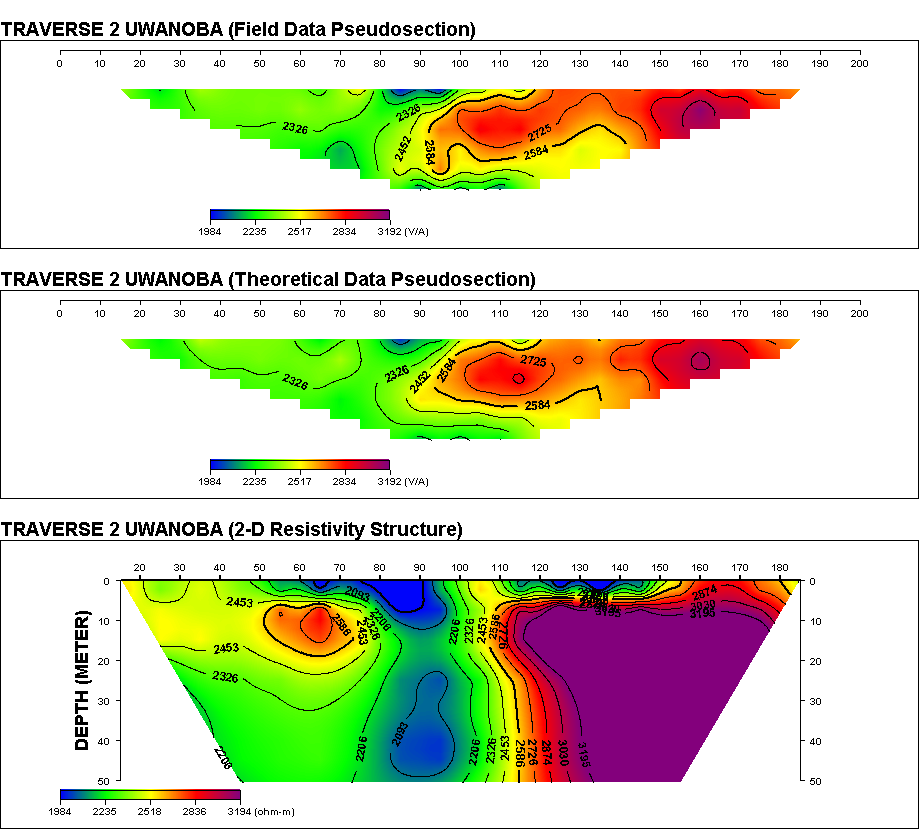
Longititude 0050 40’ 11.7’’E, Latitude 0060 07’ 17.8’’ N, Elevation = 51 m

Figure 3: The field data, the theoretical data, and 2-D resistivity structure for traverse 1 at Uwanoba

**Traverse line 2, Uwanoba**

In this traverse 2 (Figure 4), the medium resistivity zone is at the left, the low resistivity zone at the centre while the high resistivity zone is at the right. The low resistivity contour values range from 1984Ωm to 2206Ωm with thickness and depth of 11 m and 0.2 m respectively and it is suspected to be clayey sand. The medium contour resistivity value depicting coastal plain sand/ fine sand is between 2206 Ωm and 2588 Ωm, with depth of 0.3 m and thickness of about 30 m, while the high resistivity values coarse dry sand is between 2588 Ωm and 3194 Ωm with thickness of about 25 m and depth of 0.8 m (Loke, 2000).

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Fine sand

Clayey sand

Coarse dry sand

Clayey sand

Longititude 0050 40’ 19.2’’E, Latitude 0060 07’ 11.4’’ N, Elevation = 52.3 m

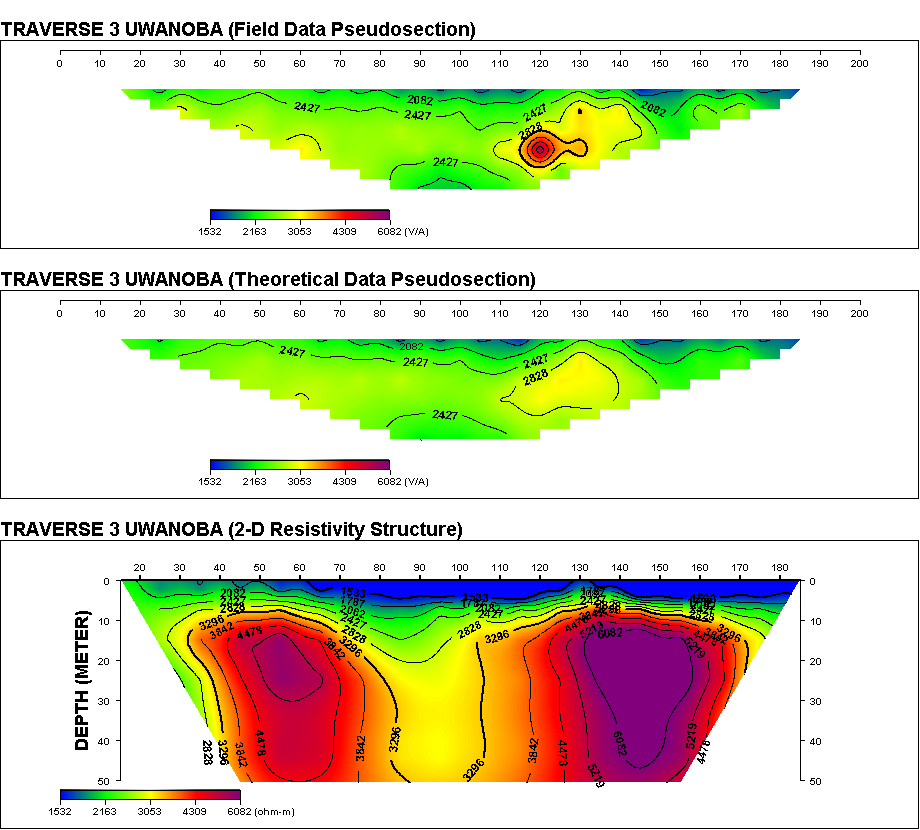
Figure 4: The field data, the theoretical data, and 2-D resistivity structure for traverse 2 at Uwanoba

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**Traverse line 3, Uwanoba**

Figure 5 (Traverse 3) represents the inversed model resistivity section along traverse line 3 with orientation in approximately north – south direction and represents resistivity variation with depth along the traverse line. The near-surface relatively has low resistivity contour values which range from 1535Ωm to 1787Ωm, depth of about 4 m, and an average thickness of 3 m. It signifies the presence of clayey sand. Beneath the low resistivity layer are the medium resistivity contour values ranging from 1787Ωm­ to 3926Ωm with thickness and depth of 3 m and 35 m respectively (Alile and Ehigiator, 2011).It depicts coastal plain sand/ fine sand. The high resistivity values at the left and right of the 2-D resistivity profile is between 3926 Ωm and 6082 Ωm with thickness of about 18 m and depth of 12 m. It is characterized to be coarse dry sand.

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Fine sand

Clayey sand

Coarse dry sand

Coarse dry sand

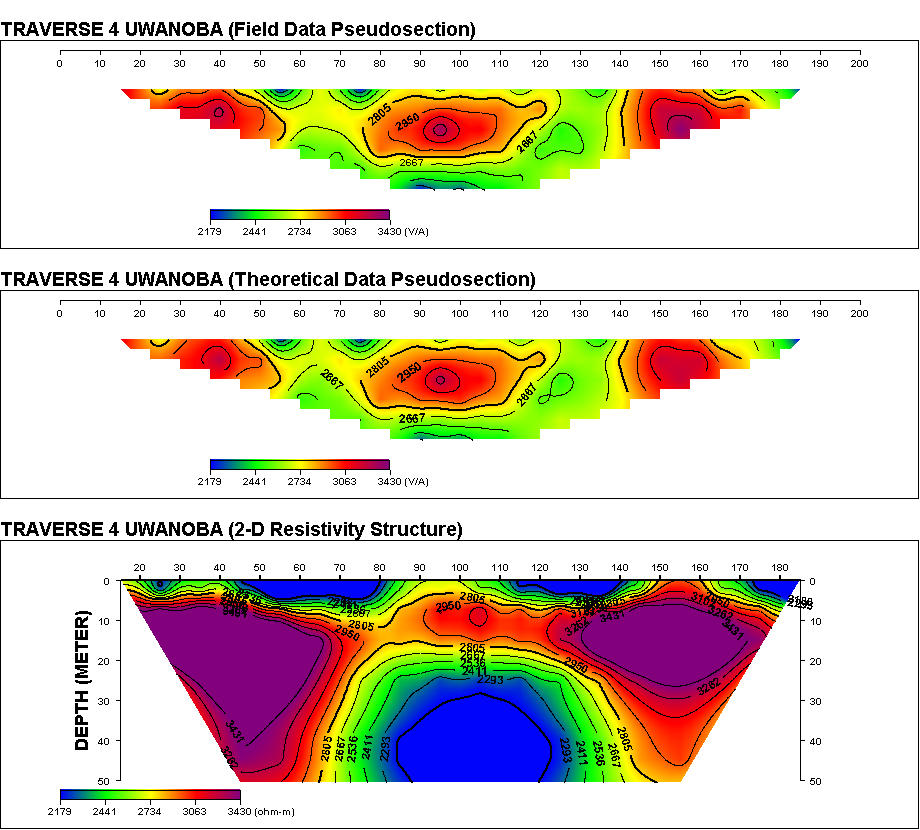
Longititude 0050 40’ 12.3’’E, Latitude 0060 07’ 11.2’’ N, Elevation = 30.1 m

Figure 5: The field data, the theoretical data, and 2-D resistivity structure for traverse 3 at Uwanoba

**Traverse line 4, Uwanoba**

In traverse 4 (Figure 6), three resistivity bodies were delineated. These have relatively low, medium and high resistivity values. The low apparent resistivity body range between 2179 Ωm and 2411 Ωm, and it is denoted with blue colour at the top and central part of the 2-D profile. It has thickness of about 30 m and depths which range from near surface to about 25 m indicating the presence of clayey sand. The medium resistivity body possesses resistivity values ranging from 2411 Ωm to 2850 Ωm as shown with green and yellow colours. Its thickness is about 10 m and has depths which range from near surface to 50 m. It is interpreted to be coastal plain sand/fine sand. The high resistivity body contains resistivity contour values between 2850 Ωm and 3430 Ωm, and it is denoted with purple and red colours with a lateral extent of 20 m to 80 m, and 120 m to 180 m. It has thickness of about 30 m and depth of approximately 10 m. It is made up of coarse dry sand (Martinez-Pagan *et al.,* 2013).

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Sand

Clayey sand

Clayey sand

Coarse dry sand

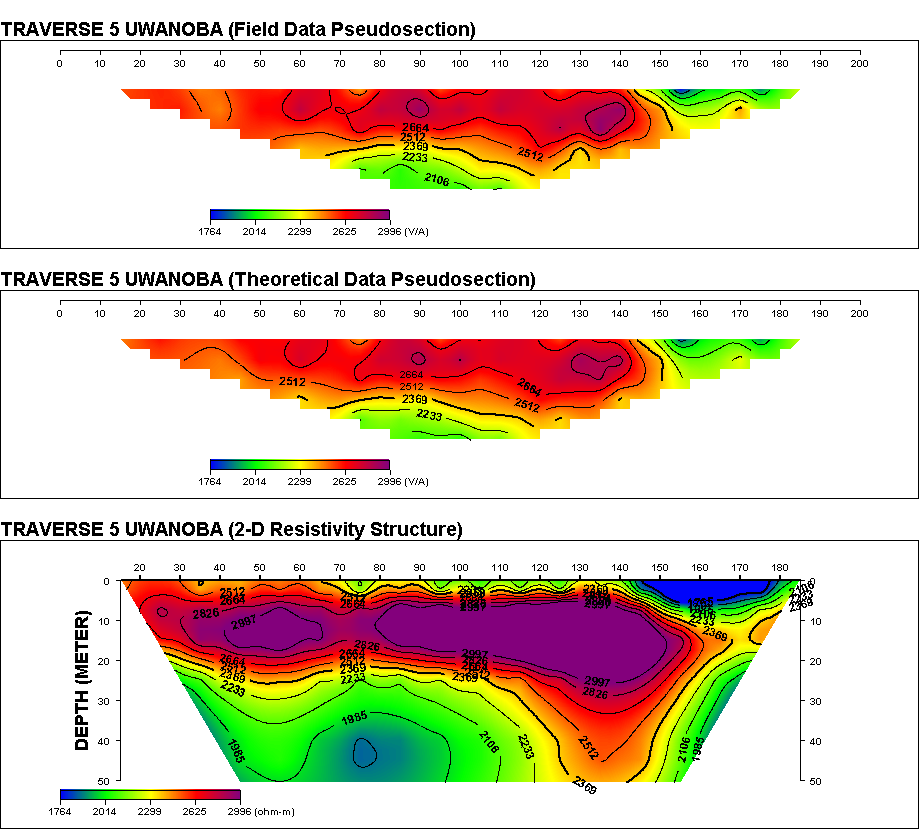
Coarse dry sand

Longititude 0050 40’ 11.7’’E, Latitude 0060 07’ 17.8’’ N, Elevation = 31 m

Figure 6: The field data, the theoretical data, and 2-D resistivity structure for traverse 4 at Uwanoba

**4.1.17 Traverse line 5, Uwanoba**

The interpreted 2-D resistivity profile of traverse 5 (Figure 7) has low resistivity at the top right and bottom left of the traverse, with lateral extents of 140 m to 180 m, and 30 m to 100 m respectively. The relatively low resistivity contour value (denoted with blue colour on the resistivity profile) is between 1764 Ωm and 1985 Ωm (Alile *et* al., 2020). It has thickness of about 10 m and depths ranging from 0 m to 32 m and it is suspected to be clayey sand. The yellow and green colours zone (or medium resistivity zone) has resistivity values between 1985 Ωm and 2512 Ωm, thickness of about 11 m and depths which range from 0 m to 21 m. It is composed of coastal plain sand/fine sand. The high resistivity contour is laterally extensive on the profile indicating coarse dry sand, and this possesses resistivity values which range from 2512 Ωm to 2997 Ωm. Its thickness and depth are 15 m and 3 m respectively.

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Fine sand sandsssssssssssssssssssss sassssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssand

Clayey sand

Clayey sand

sand

Coarse dry sand

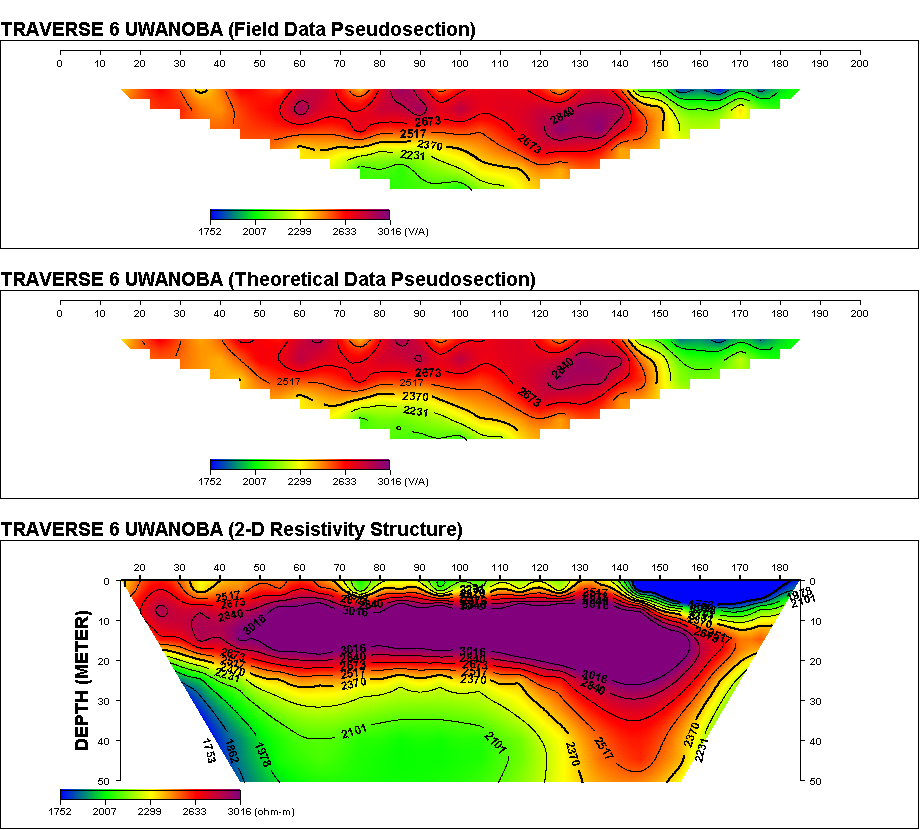
Longititude 0050 40’ 16.9’’E, Latitude 0060 07’ 18.7’’ N, Elevation = 29 m

Figure 7: The field data, the theoretical data, and 2-D resistivity structure for traverse 5 at Uwanoba

**Traverse line 6, Uwanoba.**

The interpreted 2-D resistivity profile of traverse 6 (Figure 8) has low resistivity at the top right, with values between lateral extents of 150 m and 180 m; and at the bottom left between 30 m and 50 m. It has depths of about 10 m at the top and 21 m at the bottom with thickness of approximately 3 m. This relatively low resistivity value (denoted with blue colour on the resistivity profile) is between 1753 Ωm and 1978 Ωm, and it is interpreted to be clayey sand. The yellow and green colours zone has resistivity values between 1978 Ωm and 2517 Ωm, and it is the medium resistivity zone with an average thickness of 25 m and depths ranging from 0 m to 50 m (Oyeyemi *et al.,* 2017). It is made up of coastal plain sand/fine sand. The high resistivity contour is laterally extensive from 20 m to 170 m and this possesses resistivity value which range from 2517 Ωm to 3016 Ωm indicating the presence of coarse dry sand. Its thickness and depth are 15 m and 5 m respectively.

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Clayey sand

Fine sand

Coarse dry sand

Clayey sand

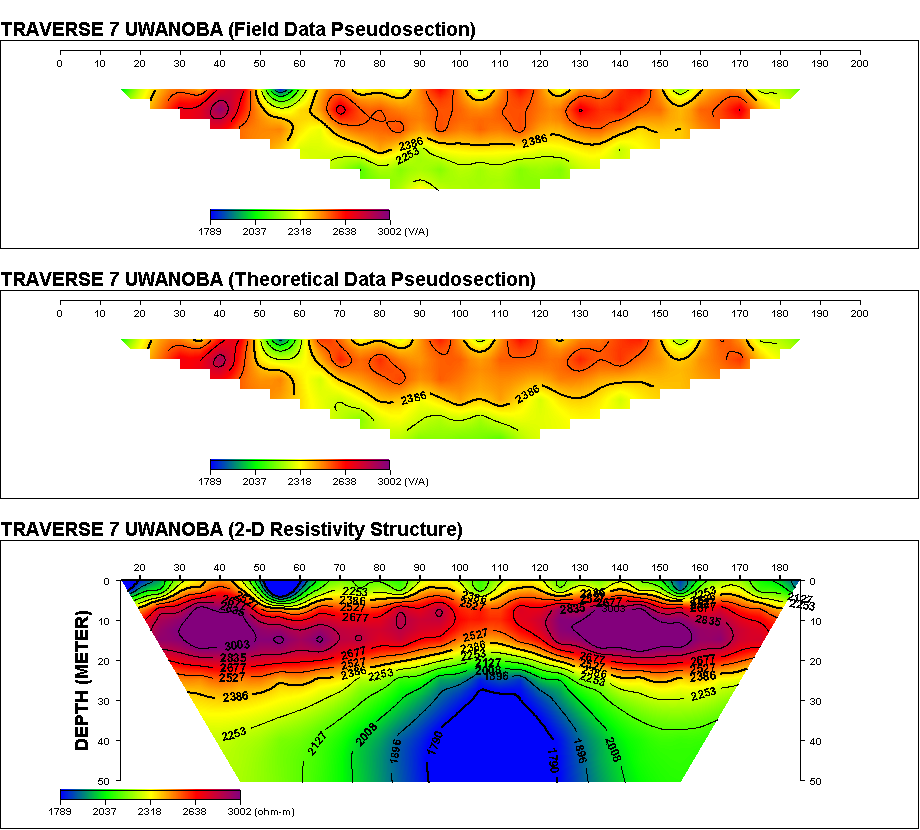
Longititude 0050 40’ 15.3’’E, Latitude 0060 07’ 18.4’’ N, Elevation = 28 m

Figure 8: The field data, the theoretical data, and 2-D resistivity structure for traverse 6 at Uwanoba

**Traverse line 7, Uwanoba.**

In Figure 9 (traverse 7), three resistivity bodies are delineated. The first relatively low resistivity body exists in three different tiny pockets at the near surface and at the bottom central of the 2-D resistivity profile. The low resistivity body (shown in blue colour and presumed to be clayey sand) has values between 1789 Ωm and 1896 Ωm, thickness of about 20 m and depth of approximately 25 m. The second resistivity body (denoted with green and yellow colours) categorized as medium resistivity zone depicts coastal plain sand/ fine sand with values ranging from 2008 Ωm and 2527 Ωm. Its thickness is about 10 m, depth of approximately 22 m, and is seen to be widespread across the entire profile. The third resistivity body has resistivity values between 2527 Ωm and 3002 Ωm, and it is shown by red and purple colours on the 2-D profile. It has thickness of 15 m and depth of about 5 m and it is suspected to be coarse dry sand (Beff *et al*., 2013).

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Fine sand

Coarse dry sand

Clayey sand

Clayey sand

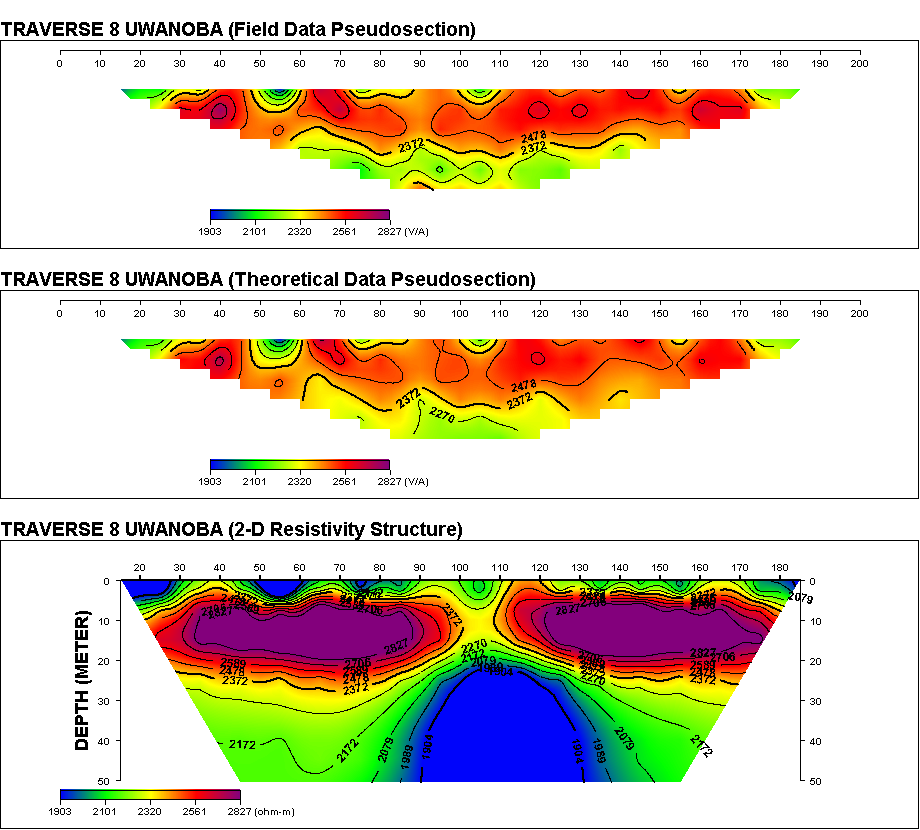
Fine sand

Longititude 0050 40’ 13.6’’E, Latitude 0060 07’ 18.2’’ N, Elevation = 50 m

Figure 9: The field data, the theoretical data, and 2-D resistivity structure for traverse 7 at Uwanoba

**Traverse line 8, Uwanoba**

In traverse 8 (Figure 10), the high resistivity body is split into two (from the left to the centre and from the centre to the right). The final inversion model for the profile reveals a high resistivity contour value (shown in red and purple colours) that range from 2478 Ωm to 2827 Ωm, thickness of about 12 m and depth of approximately 5 m. It is presumed to be coarse dry sand. The low resistivity body exists in four different pockets at the near surface and at the bottom central of the 2-D resistivity profile (Areghan *et al.,* 2015). The low resistivity body characterized to be clayey sand has values between 1903 Ωm and 2079 Ωm, thickness of 28 m and depth of about 5 m, as shown in blue colour. The yellow and green colours medium has resistivity values between 2079 Ωm and 2478 Ωm, thickness of 20 m and depths ranging from 0 m to 50 m. It indicates the presence of coastal plain sand/fine sand.

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Fine sand Sand

Clayey sand

Coarse dry sand

Clayey sand

Fine sand

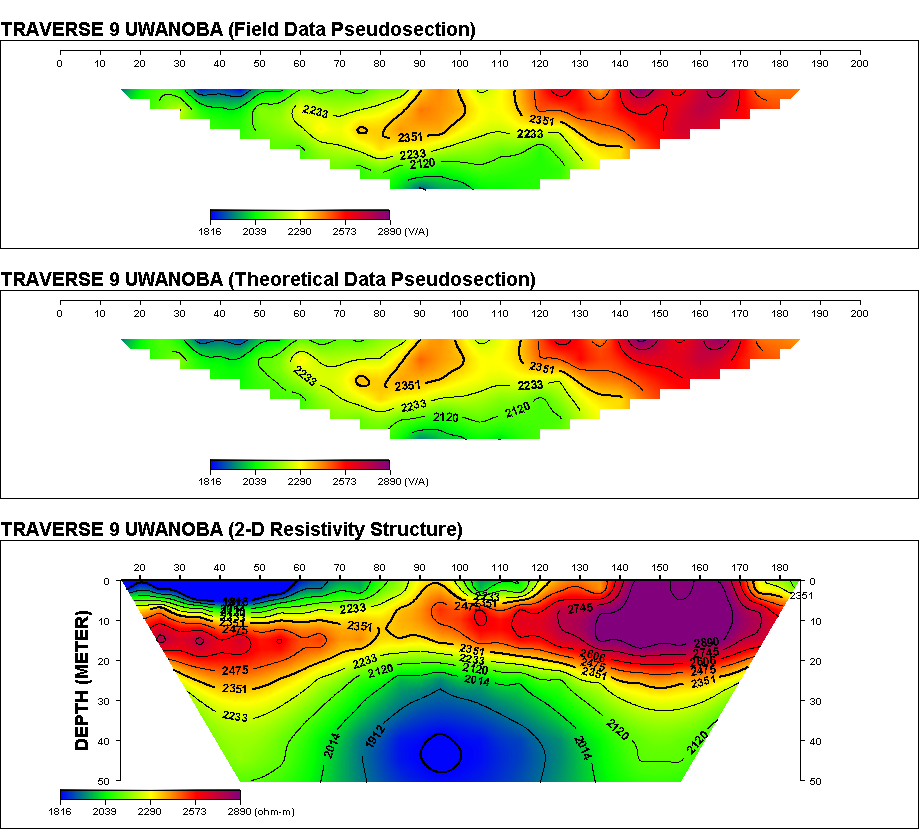
Coarse dry sand

Longititude 0050 40’ 11.9’’E, Latitude 0060 07’ 16.3’’ N, Elevation = 27 m

Figure 10: The field data, the theoretical data, and 2-D resistivity structure for traverse 8 at Uwanoba.

**4.1.21 Traverse line 9, Uwanoba**

In traverse 9 (Figure 11), the low resistivity body is split into two. It exists at the top-left and bottom-central of the 2-D profile. The final inversion model for the profile reveals a low resistivity contour value that range from 1904 Ωm to 2079 Ωm, with an average thickness of 20 m and depths ranging from 5 m to 25 m as shown in blue colour. It signifies the presence of clayey sand. The second resistivity body (denoted by green and yellow colours) is categorized as medium resistivity layer with values range between 2079 Ωm and 2372 Ωm, thickness of about 20 m and depths ranging between 0 m and 50 m; and it is seen to be widespread across the entire profile indicating the presence of coastal plain sand/fine sand (Olaseni *et al.*, 2018). The third resistivity body (denoted by red and purple colours) has apparent resistivity values between 2372 Ωm and 2827 Ωm depicting coarse dry sand. It also has thickness of 20 m and depths ranging from 0 m to 30 m.

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Fine sand

Coarse dry sand

Coarse dry sand

Fine sand

Clayey sand

Clayey sand

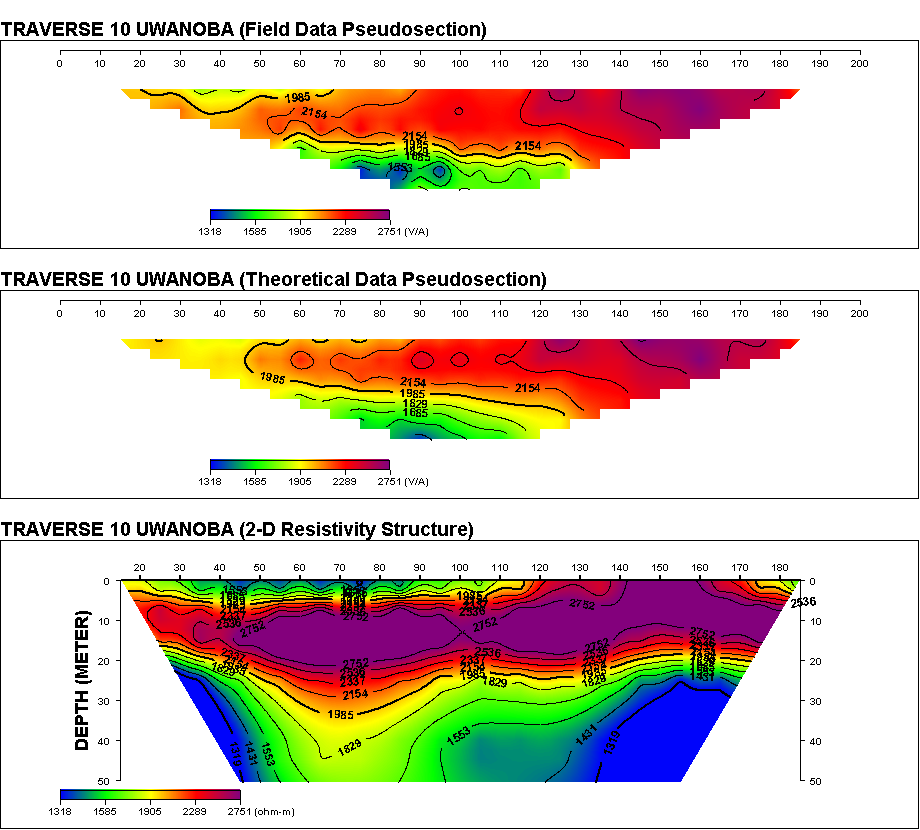
Longititude 0050 40’ 12.0’’E, Latitude 0060 07’ 14.6’’ N, Elevation = 28 m

Figure 11: The field data, the theoretical data, and 2-D resistivity structure for traverse 9 at Uwanoba.

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**Traverse line 10, Uwanoba.**

From the resistivity contour values of the 2-D profile obtain from traverse 10, Uwanoba (Figure 12), three categories of resistivity values are observed. These are the relatively low, medium (median) and high resistivity values. The final inversion model for the 2-D profile reveals a low resistivity contour value that range from 1318 Ωm to 1553 Ωm, shown in blue colour at the top-left, bottom right and bottom left. At the top left, its spread from the near surface to a depth of 3 m with thickness of about 2 m, while at the bottom, it has a depth of 20 m and an average thickness of 15 m (Ogunlana *et al*., 2019). This is suspected to be clayey sand. The second resistivity body is categorized as medium resistivity with values ranging from 1553 Ωm to 1985 Ωm, and is seen to be widespread across the entire profile depicting coastal plain sand/fine sand; this is denoted by green and yellow colours. It has depths which range from 0 m to 5 m at the top and 15m to 50 m at the bottom with an average thickness of 15 m. The third resistivity body has resistivity values ranging from 1985 Ωm to 2751 Ωm, and it is denoted by red and purple colours on the 2-D profile. It has an average thickness of 9 m and depths which range from 0 m to 8 m. It is characterized to be coarse dry sand (Aigbogun *et al.,* 2017).

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Coarse dry sand

Clayey sand

Clayey sand

Fine sand

Longititude 0050 40’ 12.2’’E, Latitude 0060 07’ 13.0’’ N, Elevation = 31m

Figure 12: The field data, the theoretical data, and 2-D resistivity structure for traverse 10 at Uwanoba.

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Figure 13: Lithology Logs of Uwanoba by Lacoon Drillers Company

**SUMMARY AND CONCLUSION**

From the results of 2-D inversed resistivity sections (2-D structures), the study area can be categorized into three geo-electric lithological settings. The first layer has relatively low resistivity material with average apparent resistivity value below 1675 Ωm and is interpreted to be clayey sand/ shalely sand (Usifo and Adeola, 2024). The second layer depicts coastal plain sand/fine sand which is the medium (median) resistivity material with average apparent resistivity values between 1675 Ωm and 2500 Ωm while the third layer with high apparent resistivity material above 2500Ωm on the average is interpreted to be coarse dry sandstone. These three materials can be found at any depth from the surface to a depth of 50 m on the ten (10) traverses under investigation. Materials of economic important and viable for industrial use were delineated: Clay from clayey sand is used in making ceramic, pottery both utilitarian and decorative, paper making, cement production and chemical filtering. It is also used as natural seals in cores of dams, barrier in landfills, removal of heavy metals from waste water and air purification.

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