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Geophysical Study of the Weathered and Near Surface Zone in Parts of Oru Area, Imo State Nigeria Using Seismic Refraction Method

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Abstract

Seismic refraction method has been used to map the near surface geological features in parts of the Oru Area. Ten seismic refraction profiles were surveyed within the Area. The instruments used were a 10 kg sledge hammer, Mark 6 digital 12-channel seismograph, Reflexw software was used to process the seismic data. A GPS system was used to obtain the co-ordinates of the profiles. Surfer 11 software was used to produce contours of the seismic velocities within the study Area. This research has established that the distribution of p-wave velocities within the subsurface of this area show a general increase of velocity with depth and velocity varying from 400 m/s to 770 m/s for the weathered layer. The thickness of the weathered layer is on the average 20.4 m. Field mapping shows that the Northern part of the study area rests on Ogwashi-Asaba formation. The area has mudstone, claystone, gritty claystone, carboniferous mudstone, massive sandstone facies whereas Benin formation is found to the southwest from Mgbidi. And also clay deposits are found within the boundary between the weathered layer and the consolidated layer. This research shows the presence of shallow and deep seated aquifers within the area. There are traces or channels of less dense materials which may be conduits for fluid movement within the consolidated layer. These channels suggest a defect in engineering capacity of this layer. Hence cutting and filling may be adopted even at great depths in the study area for the purpose of infrastructural development. The clay deposits within the Area can be exploited for industrial purposes. Also discovered in this research is a Batholitic structure along Nempi-Ibiasoegbe which permits the possibility of quarrying for crushed rocks along the section.

Keywords: Geophysical study; Seismic refraction method

Introduction

The weathered and near surface layer is the shallow subsurface layer composed of unconsolidated materials such as soil, sand and gravel. It is heterogenous in composition and is characterized by low seismic velocity which accounts for the delay experienced in travel times of the seismic waves [1-3]. The base of the weathered layer can be referred to as the interface between the weathered layer and the consolidated layer.

Seismic refraction method is a technique used to map the subsurface structure by analyzing waves that enter high velocity medium near the critical angle of incidence to the interface [4]. This method is based on the measurement of the travel time of seismic waves refracted at the interfaces between subsurface layers of different velocities. Seismic energy is provided by a source (shot) located on the surface or in a shot hole. For shallow applications this normally comprises a hammer and plate or weight drop.

This research article presents a geophysical study of the weathered and near surface layer in Oru Imo-State of Nigeria using seismic refraction method.

Location and Geomorphology of the Study Area

The study Area is located in Imo State of Southeastern Nigeria. It lies approximately between Latitudes $5^{0}37$ N and $5^{0}82$ N and longitudes $6^{0}50$ E and $7^{0}00$ E as shown in Figure 1 which is the map of the study Area. The Location Map Figure 1 is attached**.** The Oru Area has a daily temperature range of 31^{0}C to 33^{0}C during the dry season and a range of 24^{0}C to 26^{0}C during the rainy season. Most part of the Study Area is level land. It has the tropical Rain forest type of vegetation.

Geology and Hydrogeology of the Study Area

The Oru Area is made up of two geological formations, the Ogwashi – Asaba and the Benin formation. Ogwashi – Asaba formation is characterized by alternation of clays and sands and grits and lignites [5,6]. The formation occurs mainly in Asaba, Benin, Onitsha and Owerri Areas. Reyment [7] suggested Oligocene – Miocene age for this formation. The Benin formation consists of friable sand with intercalations of shale and clay lenses occurring occasionally at some depths [8]. The formation is partly estuarine, partly lagoon, partly

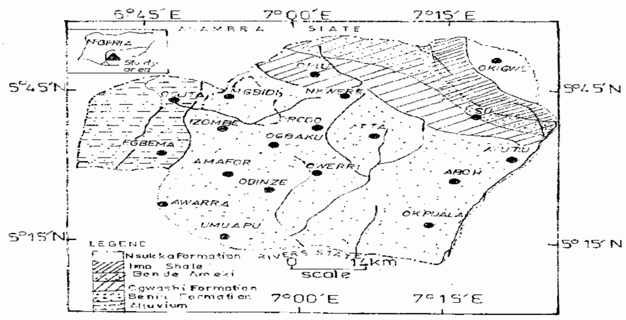

Figure 1: Location map of Oru Area from Imo State Ministry of Lands and Survey.

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deltaic and fluvid lacustrine in Origin [7].The shale are greyish, brown, sandy to silty and contains some plant remains and dispersed lignites [8]. The formation has an average thickness of 600 ft (196.85 m) [9].

Surface waters are not a major feature of the Oru area. The two formations are known to have reliable groundwater that could sustain borehole production. The high permeability of the Coastal Plain Sands, the overlying lateritic earth and the weathered top of this formation provide the hydrolic conditions favouring aquifer formation in the study Area. The copious rainfall that prevails in the area makes the aquifer prolific and continuously provides the groundwater recharge. It is indeed an excellent source of groundwater. The Figure 2 below shows the geological map of the study area.

Materials and Methods

The instruments that were used in this survey include a 12-channel Abem Terraloc Mark 6 Digital seismograph. Vertical geophones, reels of cables with take-out points, trigger coil, ranging pole, sledge hammer base plate and sealed battery. The global position system GPS was used to measure the co-ordinates of the survey points.

The survey started at Nempi known as profile 1.A field layout geometry was designed which stipulated the positions of geophones and shot points. The shots consists of hitting sledge hammer on the base plate 5 times, consecutively and this is deployed along the profile at 10 m interval. The first geophone was at 30 m while the last geophone was 140 m. However there were shots at 0 m, 10 m, 20 m, 150 m, 160 m and 170 m along the profile. The traces were recorded at a sampling interval of 0.25 ms. The seismic refraction survey was done in profiles in other places such as Aji, Ibiasoegbe, Amagu, Akuma, Akatta, Ubulu, Eleh, Omuma and Mgbidi named profiles 2 to 10 respectively. For each of these profiles the co-ordinates were obtained at the start and endpoints using a GPS instrument. These values are as follows as shown on the Table 1 below.

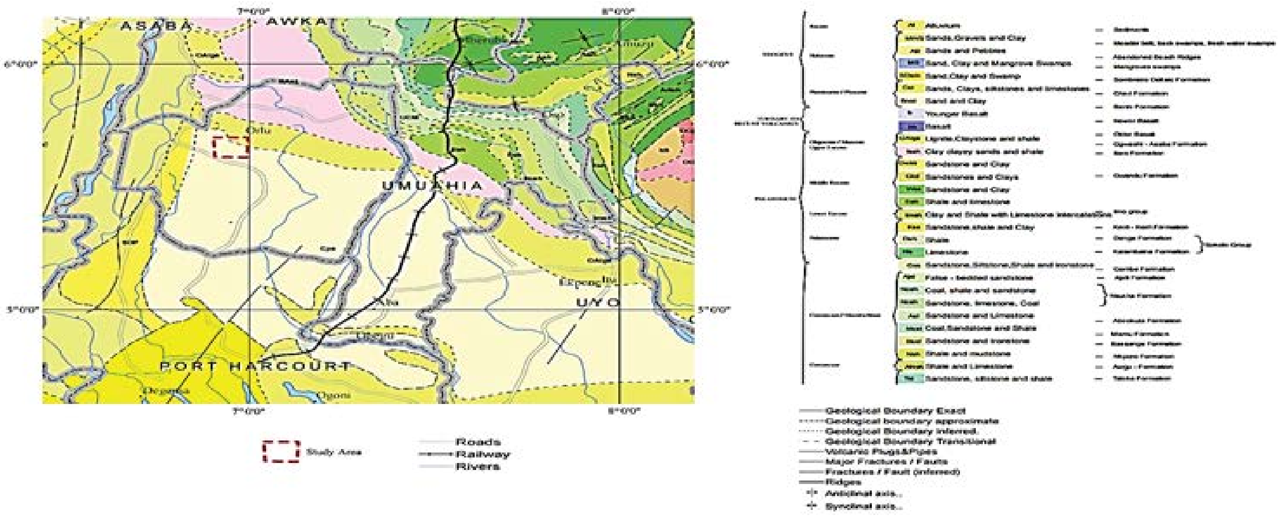

Figure 2: Geological map of Nigeria showing the study Area from Nigerian Geological Survey, Abuja.

Profile	Name of Town	Elevation (M)	Direction of Profile	Start Point	End Point
1	Nempi	142	NE –SW	N05^{0}46□42.0□□	N05^{0}46□36.8□□
				E 006^{0}55□46.7□□	E006^{0}55□44.7□□
2	Aji	127	NE – SW	N 05^{0}45□12.6□□	N 05^{0}46□09.5□□
				E 006^0 55□32.1□□	E 006^0 55□ 27.8□□
3	Ibiasoegtbe	140	SE – NW	N 05^0 46□35.8□□	N 05^0 46□36.8□□
				E 006^0 54□37.6□□	E 006^{0}54□32.3□□
4	Amagu	142	SW – NE	N 05^{0}47□38.7□□	N 05^{0}47□44.1□□
				E 006^{0}56□06.4□□	E 006^{0}56□06.7□□
5	Akuma	162	SW – NE	N 05^{0}48□42.0□□	N 05^{0}48□44.6□□
				E 006^{0}56□31.7□□	E 006^{0}56□37.0□□
6	Akatta	159	SE – NW	N 05^{0}47□32.2□□	N 05^{0}47□37.5□□
				E 006^{0}57□40.3□□	E 006^{0}57□38.3□□
7	Ubulu	145	SW – NE	N 05^{0}47□34.1□□	N 05^{0}47□38.0□□
				E 006^{0}55□06.0□□	E 006^{0}55□09.9□□
8	Eleh	138	NW – SE	N 05^{0}46□00.6□□	N 05^{0}45□55.8□□
				E 006^{0}55□34.0□□	E 006^{0}55□36.6□□
9	Omuma	127	NE – SW	N 05^{0}45□33.4□□	N 05^{0}45□31.1□□
				E 006^{0}56□00.5□□	E 006^{0}55□55.4□□
10	Mgbidi	82	NW – SE	N 05^{0}43□40.2□□	N 05^{0}43□39.0□□
				E 006^{0}54□13.7□□	E 006^{0}54□08.1□□

Table 1: Profiles and coordinates.

Data Processing

The seismic refraction data was processed using the reflexw software which is a windows TM 9X/NT/XP/VISTA computer programmer for the processing and interpretation of reflection and transmission data with special applications in ground penetrating radar (GPR), reflection and refraction seismic ultrasound and tomography. It was produced by K.J. Sand Meier in Germany. The processing of the seismic refraction data began with the downloading of the data from the Mark 6 Terraloc Abem seismograph. Processing starts with importation and conversion of the raw data into the Reflexw format. The next stage of processing was the application of filtering processes. An upper cut off frequency and the lower cut off frequency were set to 100 Hz and 5 Hz respectively. The next stage of processing was the application of gain in order to enhance the data quality. Other processing steps include picking first arrivals, assigning the picked travel times into layers and generating velocity models. P-wave, velocity was then obtained at various depths at the surface: 0 m, 10 m 20 m, 30 m, 40 m, 50 m and 60 m beneath the earth surface.

Results and Discussions

The survey results shall be presented and discussed using the following figures. Figure 3 represents the elevation model of the study area Figure 4 shows the location of seismic lines in the study area. Figures 5-14 are velocity models for each of the profiles. The velocity models are shown in shades of different colors. The models depict velocity distribution that shows a general trend of increase of velocity with depth. The various velocity models have a color bar attached to each model and are interpreted based on the velocity values attached to a particular color on the scale bar. The models are displayed with a horizontal distance along the profiles in meters and with a vertical distance which represent depth of probe measured in meters. P- wave seismic velocity distribution within the study area was derived and contoured for the depths at the surface 0 m, 10 m, 20 m, 30 m, 40 m, 50 m, 60 m and labeled Figures 15-21. Figure 22 is a contour of the depth to the top of the consolidated layer. The reference diagrams are shown below.

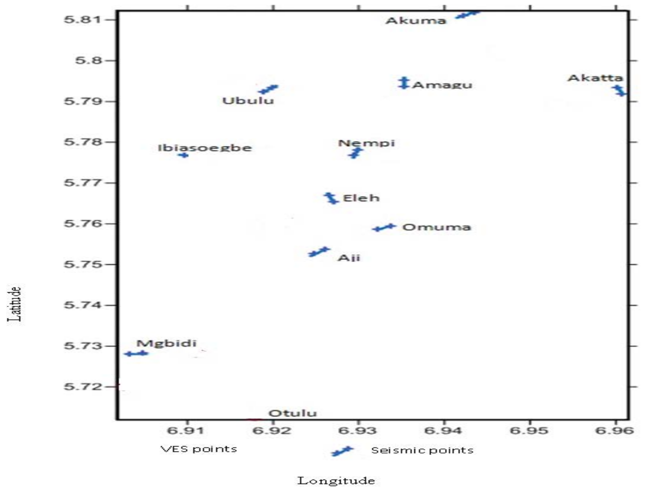

Figure 4: Showing profiles for seismic sounding.

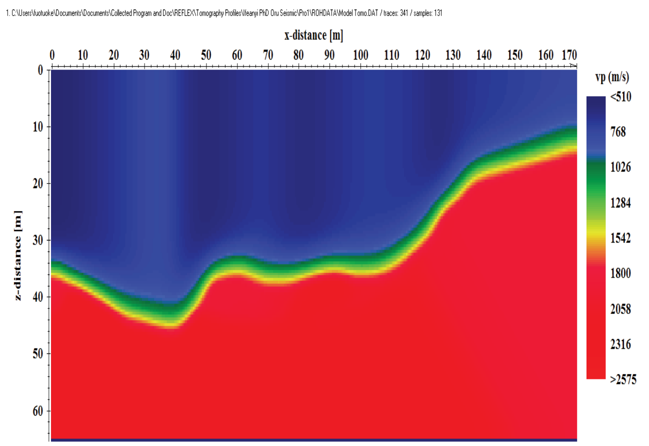

Figure 5: Showing velocity cross section at Nempi village.

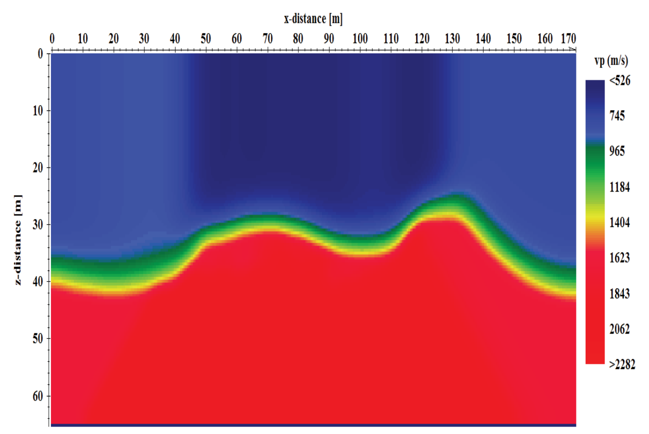

Figure 6: Showing velocity cross section at Aji.

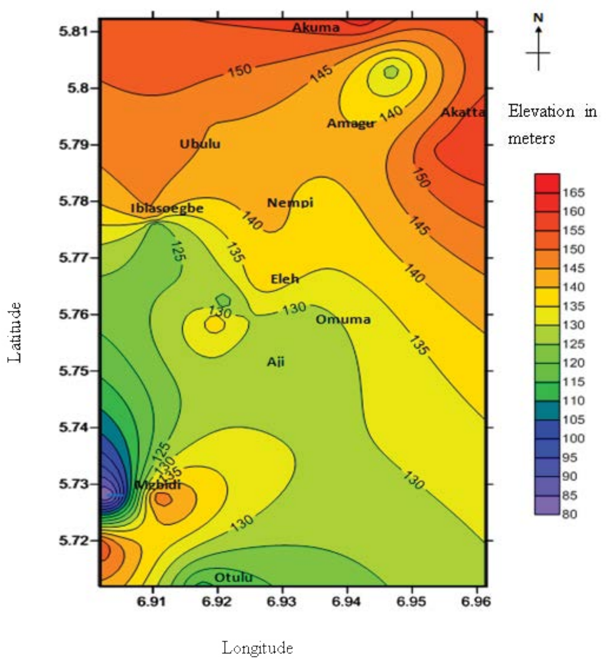

Figure 3: Elevation model of the study area showing the high lands oriented in NW-SE.

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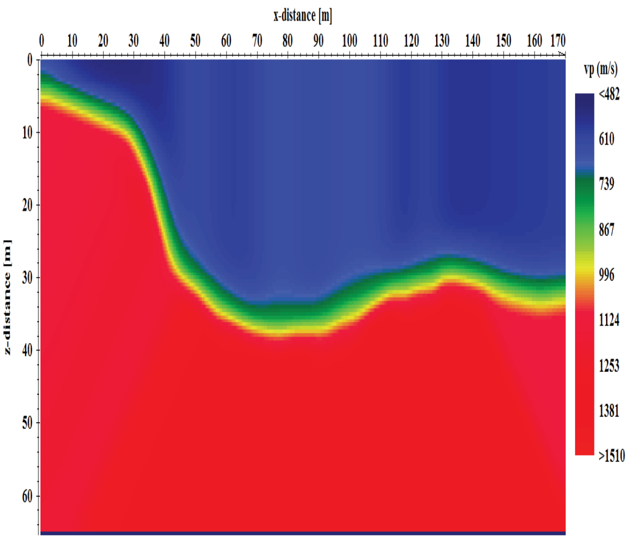

Figure 7: Velocity cross section at Ibiasoegbe.

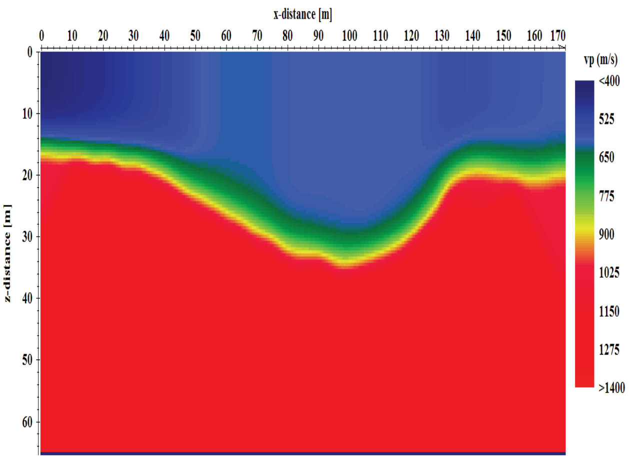

Figure 8: Velocity cross section at Amagu.

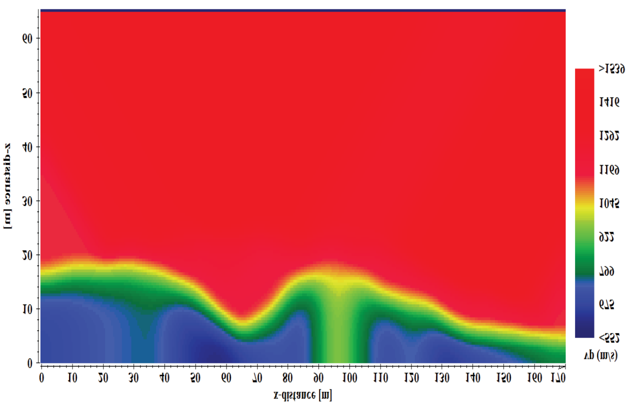

Figure 9: Showing velocity cross section at Akuma.

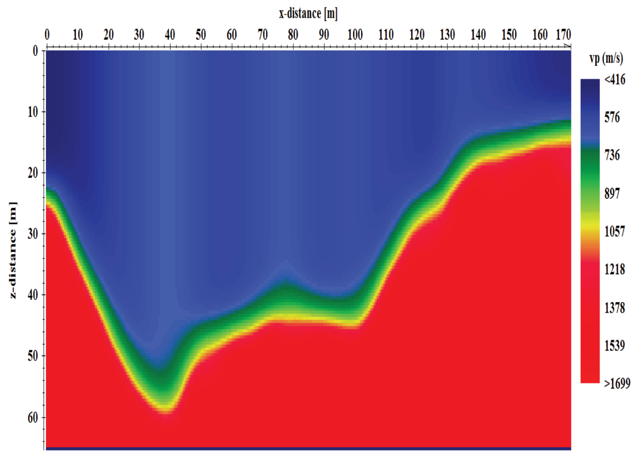

Figure 10: Showing velocity cross section at Akatta.

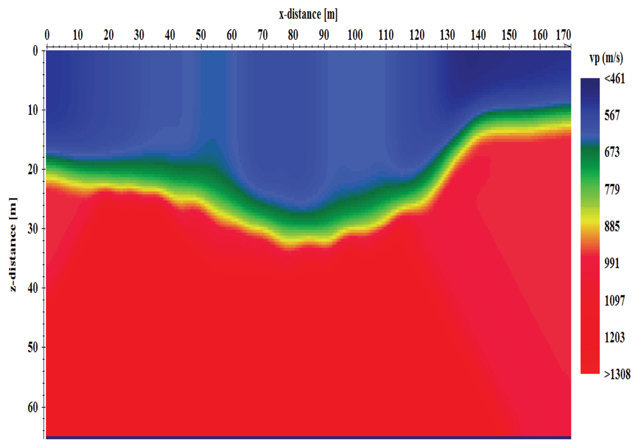

Figure 11: Showing velocity cross section at Ubulu.

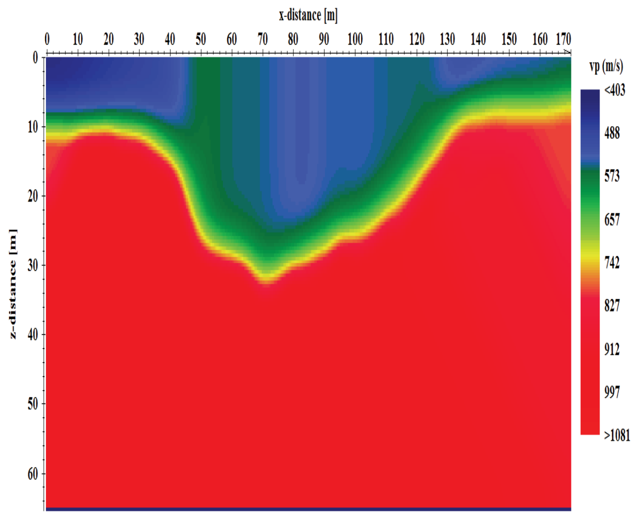

Figure 12: Showing velocity cross section at Eleh.

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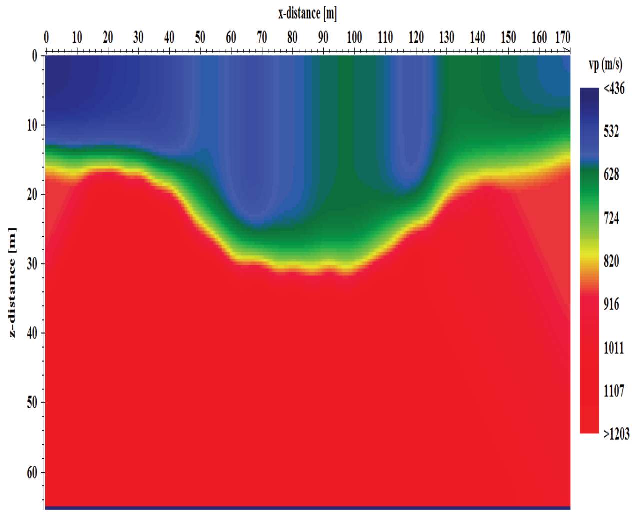

Figure 13: Showing velocity cross section at Omuma.

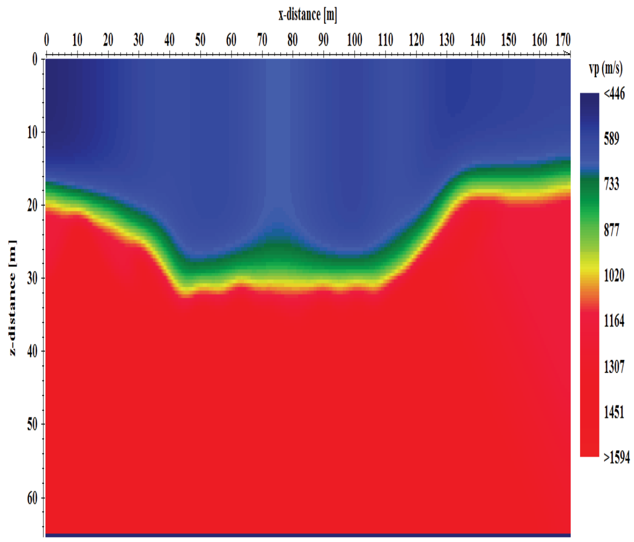

Figure 14: Showing velocity cross section at Mgbi.

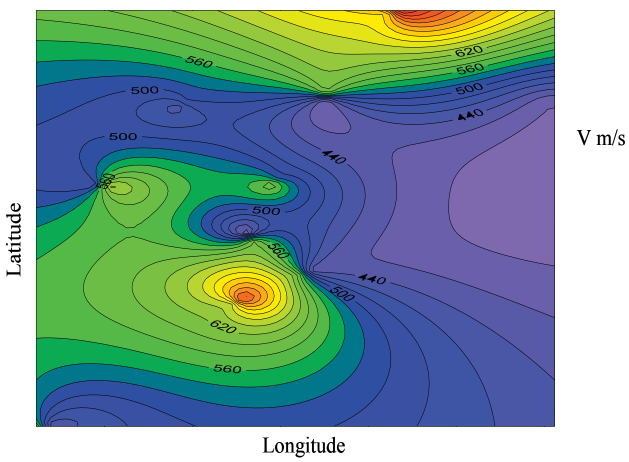

Figure 15: Velocity distribution at the surface of the study area.

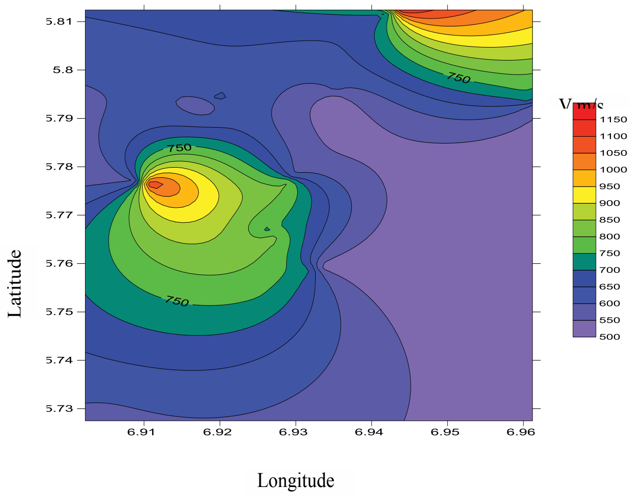

Figure 16: Velocity distribution at 10 m depth in the study area.

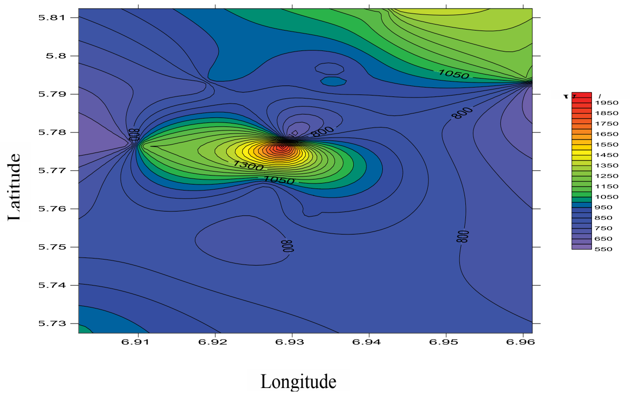

Figure 17: Velocity distribution at 20 m depth.

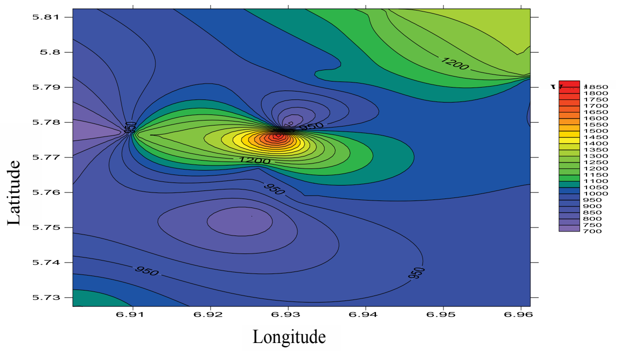

Figure 18: Velocity distribution at 30 m depth.

Looking at Figure 5 which is the p-wave seismic velocity distribution along the profile at Nempi, we discovered that the range of velocity from the top to the total depth of probe is between 500 m/s and 2600 m/s. The range of velocity for the weathered layer is between 500 m/s and 770 m/s.

The survey brought out a clear demarcation between the overburden (weathered layer) and the consolidated layer. The thickness

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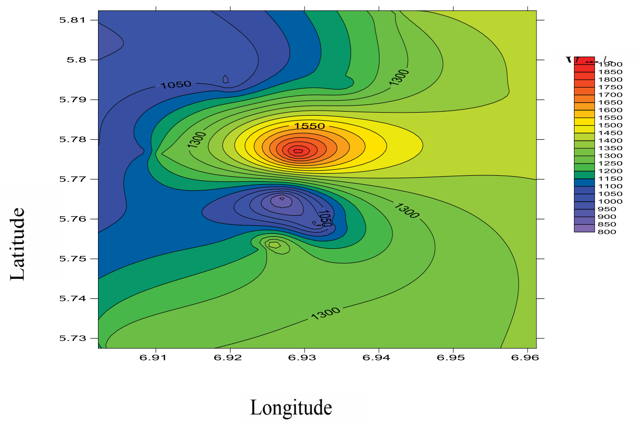

Figure 19: Velocity distribution at 40 m depth.

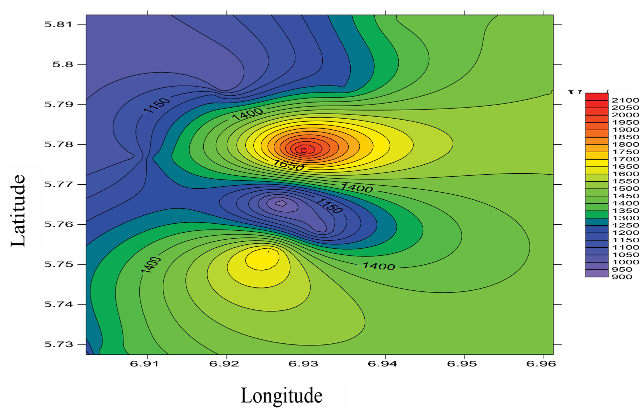

Figure 20: Velocity distribution at 50 m depth.

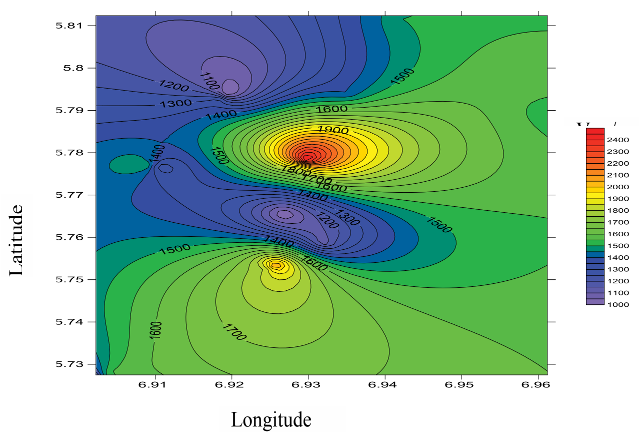

Figure 21: Velocity distribution at 60 m depth.

of the weathered layer ranges from 34 m at the beginning and at the midpoint of the profile and 10 m at the end of the profile. With an average weathered layer thickness of 26 m.

Figure 6 is the model of seismic p-wave velocity distribution along profile 2, the range of velocity from the top to the total depth of probe is between 500 m/s to 2300 ml. The range of velocity for the weathered

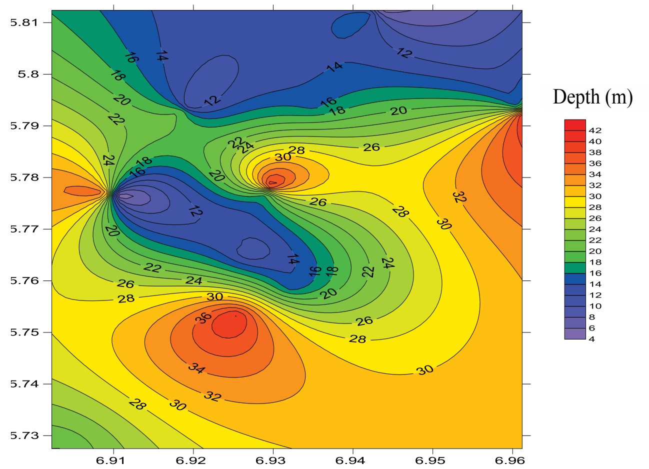

Figure 22: Showing depth to the top of the consolidated layer.

layer is between 500 ml to 750 ml. The survey was able to delineate clearly the contact point between the overburden and the consolidated layer. The thickness of the weathered layer ranges from 35 m at the start of the profile with 30 m at the midpoint and 35 m at the end. The average thickness of the weathered layer along this profile is about 33.3 m. Figure 7 depicts the distribution of p-wave velocity along profile 3. The velocity ranges from 400 ml to 1600 ml from the top to the depth of probe. The p-wave velocity for the weathered layer is within the limits of 400 ml to 600 ml. The thickness of the weathered layer ranges from 2 m at the beginning of the profile to 32 m at the midpoint and 32 m at the end of the profile. The average thickness of the weathered layer stands at 22 m for profile 3.

The range of velocities for the weathered/near surface layer for each profile and the average thickness for the weathered layer and their co-ordinates are in the Table 2 below.

Deductions from the results reveal a number of geological features. Some of the features noted from the results include the evolution of the sediments in the study area, Geologic intrusions and lineaments, clay zones, subtle structures, voids, thickness of weathered layer depth to consolidated layer and depths to aquiferous layers.

Three distinctive layers were revealed by the velocity models of Figures 5-14. The velocity models were displayed in rainbow color, ranging from dark blue to red with the two colours depicting lowest velocity values and highest velocity values respectively. These models suggest two main geological domains in the area. Area of high velocity and that of low velocity reflecting the nature of the domains. The nature of geological materials in these domains is responsible for this situation. Also noted is a lateral variation in geological materials for instance a minimum velocity response of about 380 ml came from the topsoil around Akatta village whereas the same topsoil recorded a velocity of about 850 ml within Akuma village as in Figure 15. The seismic velocity models for the different towns revealed the undulating nature of the topsoil thickness and underlain geologic structures across the entire area. Velocity responses from Akuma and the boundaries of Akatta, Amagu and Ubulu suggest the top soil thickness at the said locations to be very thin as compared with other locations surveyed as in Figure 22. Also the same Figure 22 indicates that Eleh and Ibiasoegbe villages recorded a very thin thickness to the second layer flanked by thick sedimentary pills at Nempi and Aji. Other parameters associated with

Profile/Town	Average Velocity of the weathered Layer (m/s)	Average Thickness of weathered layer (m)	Average velocity from the surface to the total depth of probe	Range of Velocity of the weathered layer (m/s)	Range of velocity from the surface to the total depth of probe	North (Degree)	East (Degree)
Profile 1/ Nempi	635	26	1550	500 -770	500 to 2600	5.777619444	6.929394444
Profile 2/ Aji	625	33.3	1400	500 -750	500 to 2300	5.753027778	6.924975
Profile 3/Ibiasoegbe	500	22	1000	400 -600	400 to 1600	5.776725	6.909672222
Profile 4/Amagu	465	20	950	400 -530	400 to 1500	5.794847222	6.935133333
Profile 5/Akuma	590	7	1050	500 -680	500 to 1600	5.812063889	6.942916667
Profile 6/Akatta	490	31.8	1050	400 -580	400 to 1700	5.793008333	6.960894444
Profile 7/Ubulu	485	17.3	850	400 -570	400 to 1300	5.793372222	6.918875
Profile 8/Eleh	450	11.6	750	400 -500	400 to 1100	5.766158333	6.926461111
Profile 9/Omuma	465	14.6	800	400 -530	400 to 1200	5.758966667	6.932755556
Profile 10/Mgbidi	500	20.6	1000	400 -600	400 to 1600	5.7277	6.903038889

Table 2: Extracted velocities, thicknesses and coordinate points of weathered layer from 2D velocity models in Oru LGA.

the thin surface like shape and size along Ibiasoegbe and Eleh village also suggest the material responsible for the velocity signature may be a massive intrusive body of higher density relative to the unconsolidated host sediments of the topsoil [10]. Mineral vein traces can be seen within the third bed, especially within the flanks of Ibiasoegbe, Ubulu and Nempi as in Figures 5, 7 and 11. These geologic features were revealed by the velocity models as channels of less dense material. They may be conduits of invasion within the consolidated layer [11]. The channels suggest inconsistency of the engineering capacity for the promising layer more suitable for high rising storey building. Hence, cutting and filling may be adopted even at great depths in the study area for the purpose of infrastructural developments.

Figures 15-21 show a contouring of the velocity distribution at different depths (0 m, 10 m, 20 m, 30 m, 40 m, 50 m and 60 m). High velocity materials dominated the east section of the study area compared to the western Section. This accounts for the depositional current regimes responsible for the transportation of geological materials within the study area.

Evolution of the sediments in the study area

A tidally influenced coastal plain depositional environment saw to the deposition of sediments within the Northern part of the study area which may be described as mudstone, carboniferous mudstone, clay stone, gritty clay stone and massive sand stone faces [12].

These materials are suggested to be deposited during the late phase of miocene-oligocene after which the Benin formation deposition covering the south end of the study Area through Ibiasoegbe and parts of Nempi broke in during the Pleistocene. Signatures from the velocity distribution Maps Figures 15-21 are predominantly in N-S predominant orientation.

Structural lineaments and intrusions

Velocity distribution map of Figure 16 revealed a sudden high in velocity of about 1100 m/s against the host materials with 600 m/s velocity between Ibiasoegbe and Nempi village. The geologic Materials responsible for this anomaly revealed consistency and suggested to have been, plunged or faulted by the remaining velocity distribution maps Figures 16-18 maintaining Nempi as the relative location of the batholith structure. The prominent intrusion intruded through the 60 m depth of probe by the seismic refraction survey and has a width of about 500 m. A closer look at the geological feature can be seen at the ends of the 2D velocity model along Ibiasoegbe Figure 7, 2D velocity model along Nempi (Figure 5). Subtle structures known to characterize the Ogwashi Asasba formation, north of the study Area [13] can be seen at depth 10 m as in Figure 16 of the velocity distribution map within Ubulu and at Amagu villages. Subtle structures also are found in Figure 5 which is 2D velocity model at Nempi. Figure 9 also reveals minor intrusions at depth of 30 m and 100 m along the Akuma velocity profile. Minor and major voids also were revealed clearer by the distribution maps. Slightly below Aji village is a massive velocity low, suggesting lateral inhomogeneity which could either be a void or intrusive material with less engineering capacity.

Clay zones

High thermal maturity affected shale content at the location due to intrusions mostly at Akuma. Akatta and ubulu villages. The shale content as suggested by seismic survey is a thin sheet sandwiched between sandstone materials and unconsolidated topsoil [14].

Depth to consolidated zone/layer

The geophysical results suggest the consolidated layer is directly overlain by thin sheet of clay zone. The thin sheet of clay zone can be seen also in the velocity models of Figures 5-14. Akuma, north of Nempi and south of Aji recorded the areas with maximum depth to the consolidated layer about 42 m as in Figure 22.

Possible depth to aquifer

The survey revealed both shallow and deep seated aquifers in the study area. Seismic velocity models suggest that water can be located at depths before or beyond the thin layer of clay. The tables below Present borehole data in the area and depths to clay zones and aquifer zones compared with borehole data (Table 3) [15].

Looking at the first three layers in each of the boreholes especially Akwada-Aji borehole. It is observed that they are slightly heterogeneous in composition and therefore not very consolidated or cemented together. This means that they are likely weathered. The depth to these layers is greater than 30 m which falls within the derived maximum thickness of the weathered layer in the study Area.

A careful study of this table shows that there is a fair agreement in the range of depths to clay deposits and aquiferous zones as predicted by seismic data and borehole data. Therefore the findings in this research work are dependable (Tables 4 and 5).

Depth (m)	Lithology
0.0-6.9	Sandy Topsoil
6.9-14.7	Shaly Sandstone
14.7-33.8	Clay Mudstone
33.8-46.0	Silt Sand
46.0-60.3	Sand
60.3-120.0	Sand Stone Shale Prospective Unit

Table 3: Borehole data of Ura-Akatta in the study Area.

Depth (m)	Lithology
0.0-8.1	Sandy Topsoil
8.1-17.5	Clay Silty Sand
17.5-39.9	Sandstone and Shale
39.9-50.5	Sandstone
50.5-65.5	Sand/Gravel
65.5-92.2	Prospective Aquifer Sand

Table 4: Borehole data of Akwada-Aji in the study Area.

Town	Range of depth to aquifer zone by seismic data (m)	Depth to aquifer zone by borehole data (m)	Depth to clay-zone by seismic data (m)	Depth to clay-zone by borehole data (m)
Nempi	10–50		26	
Aji	25–60	8–90	33.3	8–40
Ibiasoegbe	5–50		22	
Akuma	5–40		7	
Akatta	15–60	14–20	31.8	14–40
Ubulu	10–50		17.3	
Mgbidi	10–50		20.6	
Amagu	Oct-40		20	
Eleh	5–40		11.6	
Omuma	Oct-35		14.6	

Table 5: Depths to clay-zones and aquifer zones compared with borehole data.

Conclusion

This research has established that the distribution of p-wave velocities within the subsurface of this area shows a general increase of velocity with depth and velocity values varied from 400 m/s to 770 m/s for the weathered layer. The thickness of the weathered layer is on the average 20.4 m. Field mapping shows that the northern part of the study area rests on Ogwashi-Asaba formation. The area has mudstone, clay stone, gritty claystone carboniferous mudstone, massive sandstone facies whereas Benin formation is found to the southwest from Mgbidi. And clay deposits are found within the boundary between the weathered layer and the consolidated layer. The research also captured voids and subtle structures in the area. It is also discovered that there are shallow aquifers within the area as well as deep seated aquifers. There are traces or channels of less dense materials which may be conduits for fluid movement within the consolidated layer. These channels suggest a defect in engineering capacity of this layer. Hence cutting and filling may be adopted even at great depths in the study area for the purpose of infrastructural development.

Recommendations

Looking at the results of this work, it is recommended that there should be further study of the clay deposits in this Area and see if it can be exploited for industrial purposes and hence enhance the economy of the Area.

Also for the batholitic structure along Nempi-Ibiasoegbe, it is recommended that a more detailed study be conducted over this section. There may be possibility of quarrying for crushed rocks along the section.

Finally, the channels of less dense materials which may be conduits for fluid movement within the consolidated layer suggest a defect in engineering capacity of this layer. Hence, cutting and filling may be adopted even at great depths in the study Area for the purpose of infrastructural development.

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