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Use of Seismic Refraction Tomography to Obtain velocity and Thickness of the Weathered Zone of Oru, in Imo State

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Abstract

Tomography is an imaging technique that makes use of a non destructive energy source to probe the sub surface and produce a tomogram which represents a model of the geologic structure that exists below the surface. The principles of tomography initially were applied in the medical field and in recent times applied in global and exploration geophysics. The Oru area has no baseline information on the velocity and thickness of the weathered zone in this area. A survey was therefore carried out to obtain these parameters. The results of this survey carried out in the Oru Area of Imo State of South Eastern Nigeria using seismic refraction tomography to determine the velocity and thickness of the weathered zone indicates that the distribution of seismic velocity within the subsurface showed a general increase of velocity with depth. The velocity of the weathered layer was found to vary from 400 ms-1 to 820 ms-1. The thickness of the weathered layer is on the average 19.5 m and this is also the average depth to the consolidated layer. Measurements were made along a total of ten profiles evenly distributed within the Area. The receivers were placed at 10 m interval; an offset distance of 30 m on both sides of the profile was used. A 10 kg sledge hammer was used to produce the seismic signals along a 170 m profile length. The sledge hammer was hit on the base plate 5 times consecutively at each shot position. Mark 6 digital 12- channel seismograph was used to record the seismic signal and traces. Seismic refraction tomographic data are generally collected as a series of profiles, employing a constant spread technique in which the receivers are deployed and not moved during the data collection process for each profile. This simplifies the acquisition process while maintaining data quality and coverage. The reflex software was used to process the raw data, while GPS was used to obtain the co-ordinates of the profiles. The knowledge of the thickness and velocity of the weathered zone could be useful in the oil and gas as well as ground water explorations. It could also be useful to groups interested in civil or geotechnical engineering.

1.0 Introduction

The word tomography is derived from the Greek words Tomos (section) and graphy (drawing). It is a method for obtaining models that adequately describe seismic data observations and show the effect of rock properties on the seismic wave propagation. The principles of tomography were borrowed from the medical field, precisely medical imaging such as CAT scanning and PET scanning. The acronyms CAT and PET stand for and respectively computer assisted tomography and positron emission tomography. Both are used as non invasive tools to investigate internal tissues in the human body, usually to obtain information about tumors. CAT scans use x-rays as an energy source with many different configuration between source and receiver. Computer programs are used to analyze the recordings of x-ray reception to provide a picture of the body or some part of it. In PET scans, the patient swallows radioactive material that emits positrons. A very large number of positron detectors are arranged in a ring through which the patient passes. Analysis of variation in positron reception provides a picture of the part of the body scanned (Gadallah & Fisher 2009).

These principles of tomography are now being applied in seismology.

Information derived from seismic refraction tomography may be used to predict spatial variations in for example lithology, pore fluids, or rock fracturing and the method is therefore of great value in a wide range of exploration and engineering applications. As with many geophysical methods, it can also be applied on a variety of spatial scales,

from ranges of hundreds of meters, down to engineering or archaeological investigations of single columns in ancient buildings (Cardarelli & De Nardis, 2001).

Seismic refraction tomography produces three dimensional picture of the earth unlike the ordinary conventional refraction method. It therefore gives a clearer presentation of the features. Seismic refraction tomography can be used to study both near surface and deep seated structures depending on the energy source in use.

Jegede *et al* (2008) carried out a near surface investigation of groundwater contamination in the Ragolith Aquifer of the Zaria basement complex using electrical resistivity and seismic refraction tomography. Osazuwa *et al* (2008) used seismic refraction tomography to delineate subsurface trough for the evaluation of the water potential in parts of Samaru, Zaria. Also Chiemeke & Aboh (2012) used joint inversion of seismic refraction tomography and high resolution 3D seismic reflection to delineate the aquiferous layers within the basement complex. Seismic refraction tomography relies on the travel times of seismic energies recorded at the surface by multiple receivers from many sources to generate an optimized model of the distribution of the seismic velocities in the subsurface. This velocity model can be used to map subsurface units/features having sufficient difference in elastic properties. Seismic refraction tomography makes use of sources that generate seismic waves which probe a geological target of interest (Tien-Wen & Philip, 2002).

The aim of this research is to investigate the thickness of the weathered layer and its velocity using seismic refraction tomography.
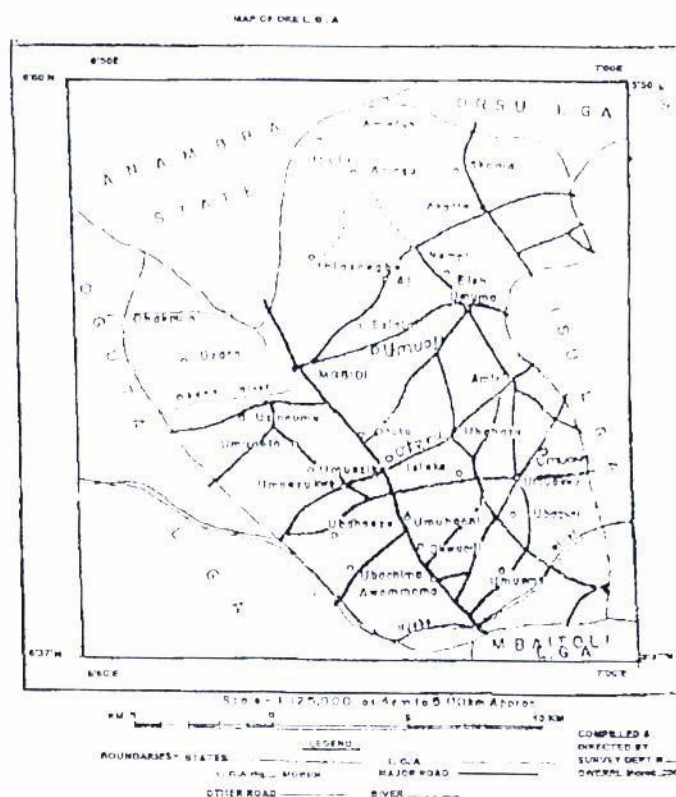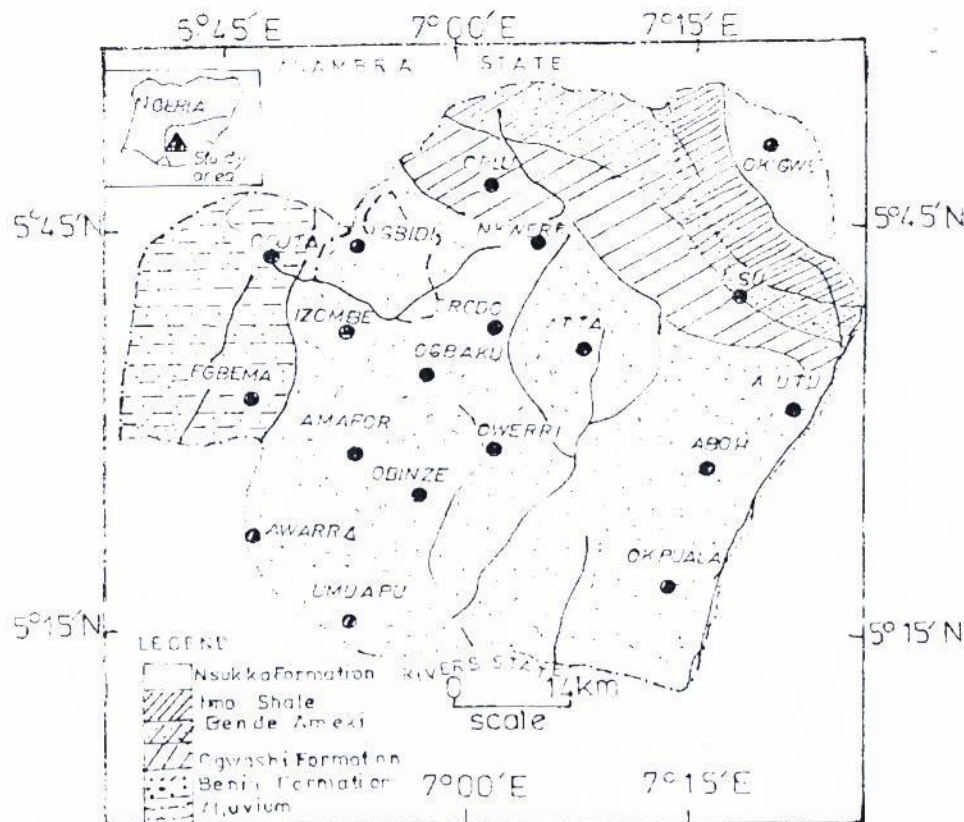

Figure. 1: Location map of the study area.

Figure. 2: Geological map of Imo State showing the study area.

2.0 Materials and Methods
2.1 Location And Geomorphology

The study Area is located in Imo-state of South Eastern Nigeria. It lies approximately between latitudes $5°37'$ N and $5°50$ N and longitudes $6°50'$ E and $7°00'$ E as shown on the map of the study area, Figure 1. Oru is bounded by the following towns from different directions, Oguta, Nkwerre , Orlu, and parts of Anambra State. The study area is made well accessible by quite a number of major, minor and track roads connecting the various villages and towns. The study area covers a landmass of about 315 km^2 Southeast of Nigeria. It is within the tropical rain forest which consists of two major seasons rainy season (March to October) and the dry season (November to February). The harmattan occurs within the dry season. The Oru area has a daily temperature range of 31 °C to 33 °C during the dry season and a range of 24 °C to 26 °C during the rainy season. Most part of the study area is level land. It has a vegetation made up of different species like palm trees, grasses of all types and food crops

2.2 Geology Of The Study Area

A study of the geology of Nigeria reveals that the Oru area lies within the Benin formation. It was formerly known as coastal plain sands (Reyment, 1965). The sands and sandstones are coarse to fine grained and commonly of granular texture. The formation consists of friable sand with intercalations of shale and clay lenses occurring occasionally at some depths (Short & Stauble, 1967). The formation has an average thickness of 600 ft (Kogbe, 1976). The coastal plain sand is highly permeable, having an overlying lateritic earth and a weathered top due to copious rainfall that prevails in the study area. The geological map of this area, Figure 2, is attached.

2.3 Data Acquisition

The basic instruments that were used for 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.

A field layout geometry was designed, which stipulated the positions of geophones and shot points. The geophones were placed at an interval of

10 m from each other. An offset distance of 30 m was used on both ends of the profile giving a total spread length of 170 m. The shots consist of hitting the sledge hammer on the base plates 5 times consecutively. The shots were fired at 30 m before the first receiver, at each receiver point and at 30 m after the last receiver. The generated data were recorded for onward processing.

2.4   Data Processing

A software known as the Reflexw was used in the data processing. It is a windows[TM] 9X/NT/XP/VISTA computer programme for the processing and interpretation of reflection and transmission data with special applications in ground penetrating radar (GPR) reflection and refraction seismics and ultrasound. It is authored by Sandmeier K. J. in Germany. Data processing started with importation of the raw seismic data and converting it to the Relexw format. The next step was the application of the Band pass filter. The upper cut off frequency and the lower cut off frequency were set to 100 Hz and 5 Hz respectively. This was to remove the effect of ground roll and improve the signal to noise ratio (S/N). Gain filter was applied to improve the amplitude of the weak refracted signals. The first arrival signal was picked by making use of the "Pick" option in the interpretative software. The picked travel time was inverted to produce an initial model, which was used in conjunction with the observed travel time to iteratively generate a tomographic model of the subsurface. The resulting information is a cross sectional map of the seismic velocity distribution in the subsurface.

2.5   Velocity Models

These velocity models were obtained after carrying out the processing techniques discussed in section 2.4. The velocity models show a distribution of p- wave velocity in each of the profile in the study area. In each of the model you will be able to see the length of profile, depth of probe and the velocity of each layer as indicated by the various colorations.
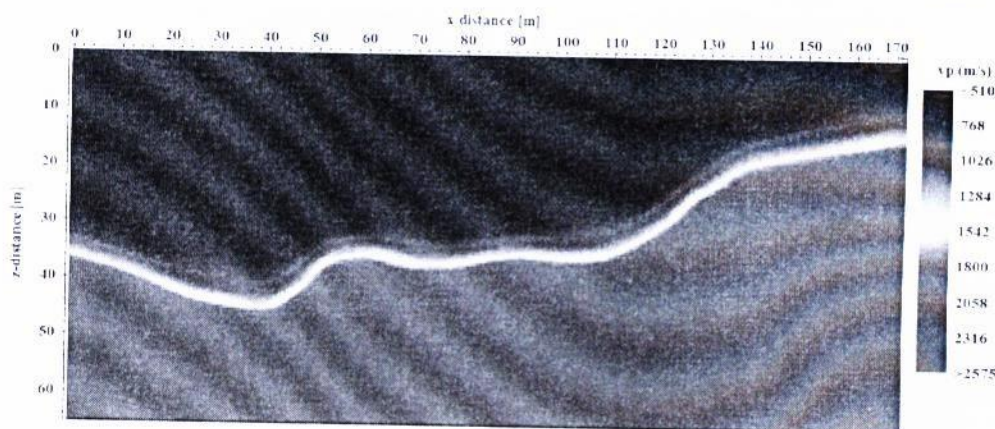

Figure 3: Model of velocity distribution along Profile 1 at Nempi.
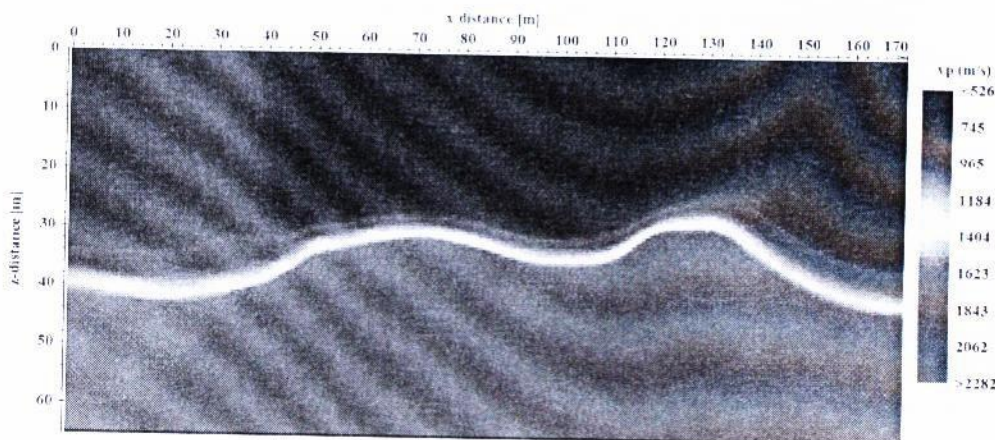

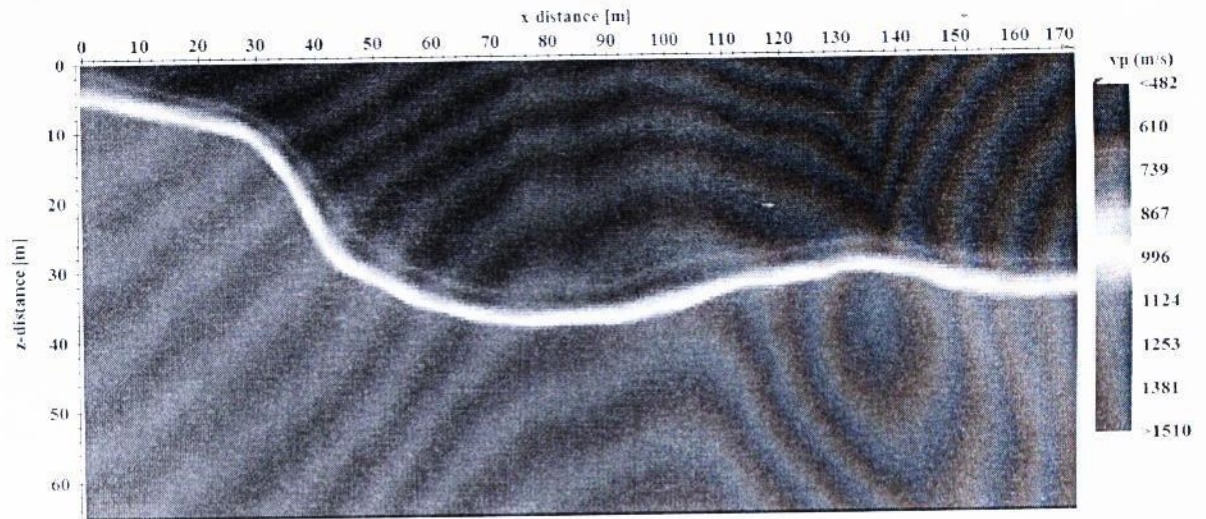Figure 4: Model of velocity distribution along Profile 2 at Aji.

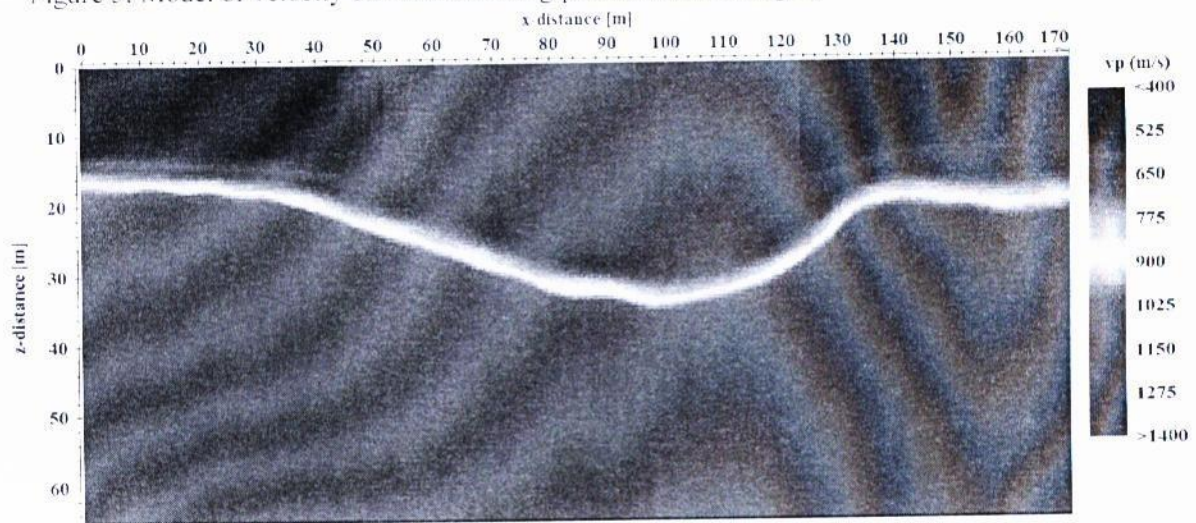Figure 5: Model of velocity distribution along profile 3 at Ibiasoegbe.

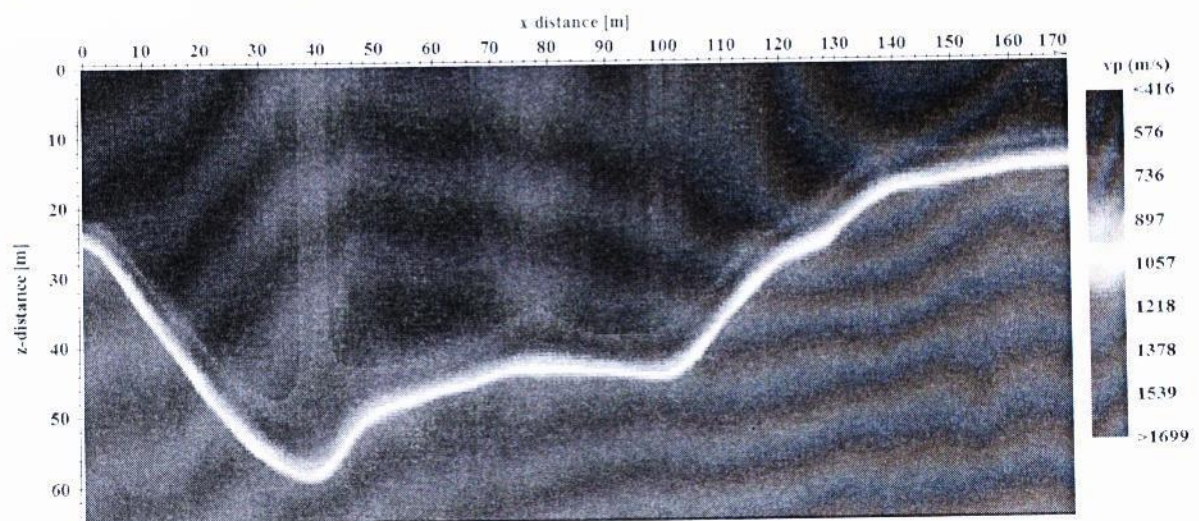Figure 6: Model of velocity distribution along profile 4, taken at Amagu.

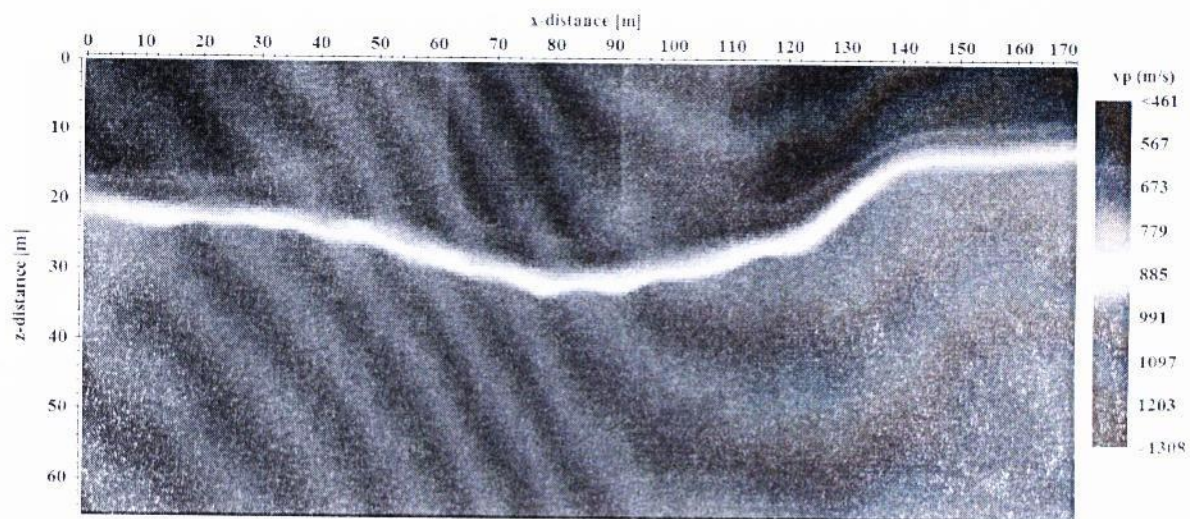Figure 8: Model of velocity distribution along profile 6, taken at Akatta.

Figure 9: Model of velocity distribution along Profile 7, taken at Ubulu.
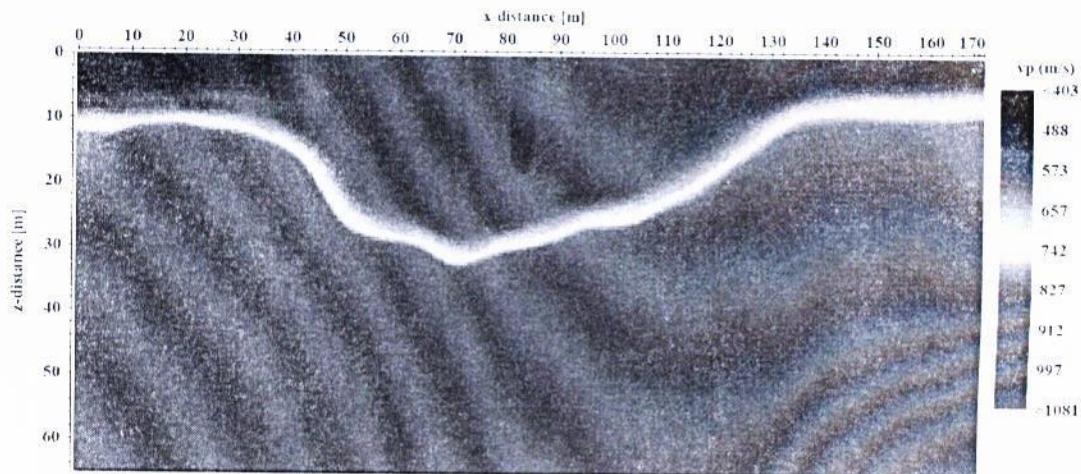
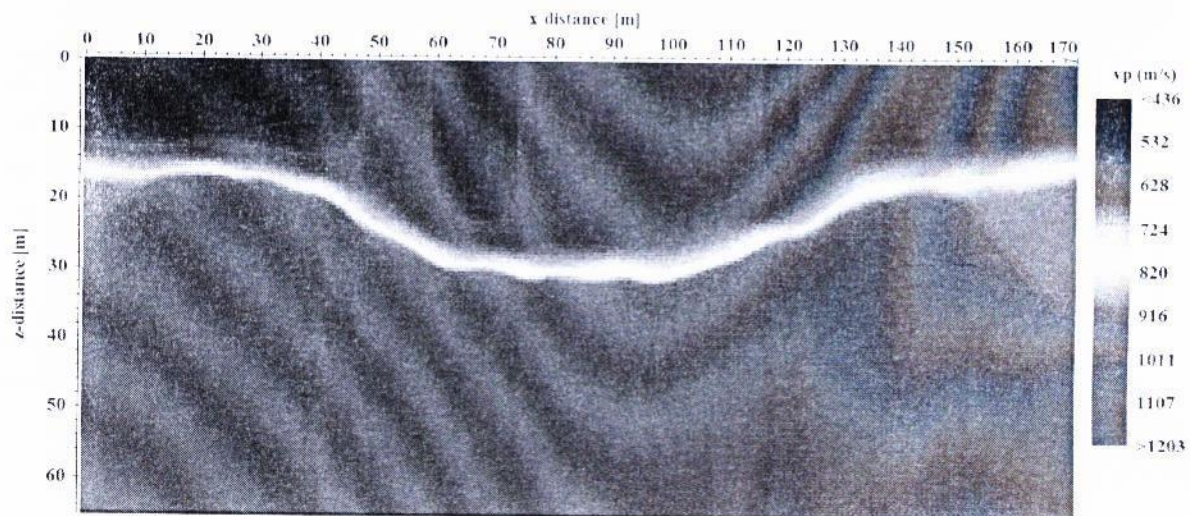Figure 10: Model of velocity distribution along Profile 8, taken at Eleh.

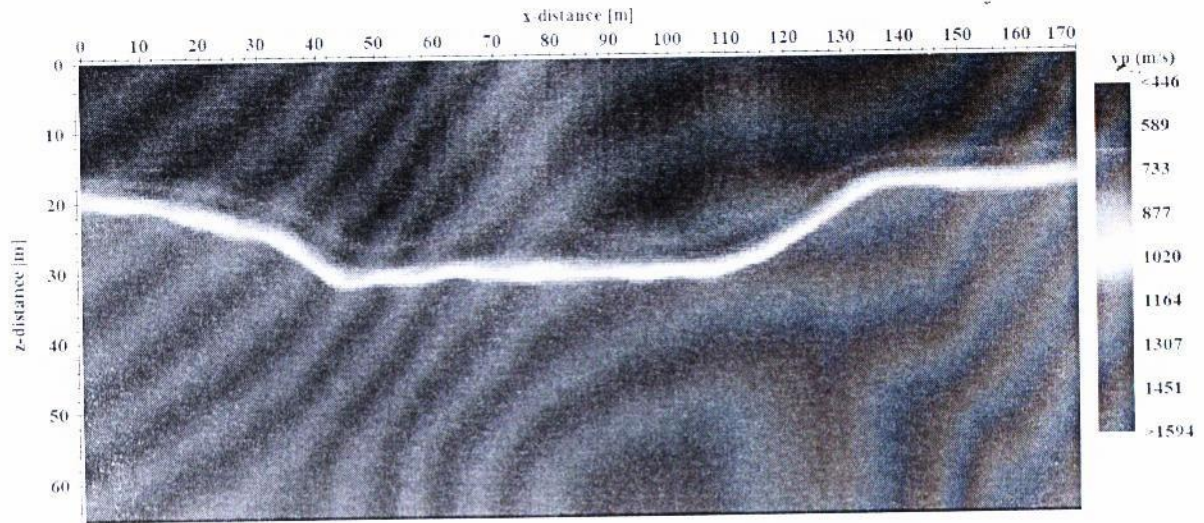Figure 11: Model of velocity distribution along Profile 9, taken at Omuma.

Figure 12: Model of velocity distribution along Profile 10, taken at Mgbidi.

3.0 Results And Discussion

The various velocity models for each of the profiles are shown from Figure 3 to Figure 12. The velocity models are shown in shades of different colors. The model depicts velocity distributions that show a general trend of increase of velocity with depth. There is no evidence of visible velocity anisotropy. This is a situation where a high velocity is underlain by low velocity. The various velocity models have a colour bar attached to each model. The models are interpreted based on the velocity values attached to a particular colour on the scale bar, not on the colour distribution within the models. 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.

For profile 1 at Nempi, the range of velocity from the surface to the total probe depth is between 500 ms^{-1} and 2,600 ms^{-1}. The velocity of the weathered layer varied from 500 m/s to 770 m/s. The survey brought out a clear demarcation between the overburden (weathered layer) and the consolidated layer. The thickness 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. The model showed high undulation of the topography of the consolidated layer. The profile sloped from the end towards the beginning of the profile.

The 2nd profile has a velocity range of between 500 ms^{-1} to 2,300 ms^{-1} from the surface to the total depth of probe and for the weathered zone the velocity varied from 500 m/s to 750 m/s. The survey was able to delineate clearly the contact point between the overburden and the consolidated layer. According to Parasnis (1986) the velocity of unconsolidated sand varies from 300 m/s to 800 m/s velocity of consolidated sand would be higher than these. 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. The contact point between the weathered and consolidated layer exhibited some level of undulation with no obvious direction of sloping along the profile. This procedure of interpretation is followed for all profiles. The table below shows velocities and weathered thickness from 2D velocity models with their co-ordinate points.

Table: Velocity and thicknesses of the weathered zone.

Profile/Town	Range of velocity of the weathered zone (m/s)	Range of velocity of the total probe depth (m/s)	Average Thickness of Weathered layer (m)	North Degree	East Degree
Profile 1|Nempi	500 – 770	500 to 2600	26	5.777619444	6.92939444
Profile 2|Aji	500- 750	500 to 2300	33.3	5.753027778	6.924975
Profile 3|Ibiasoegbe	400 – 600	400 to 1600	22	5.776725	6.909672222
Profile 4|Amagu	400 -530	400 to 1500	20	5.794847222	6.935133333
Profile 5|Akuma	500 -680	500 to 1600	7	5.812063889	6.942916667
Profile 6|Akatta	400 -580	400 to 1700	23	5.793008333	6.960894444
Profile 7|Ubulu	400- 570	400 to 1300	17.3	5.793372222	6.918875
Profile 8|Eleh	400- 500	400 to 1100	11.6	5.766158333	6.926461111
Profile 9|Omuma	400 820	400 to 1200	14.6	5.758966667	6.932755556
Profile 10|Mgbidi	400 600	400 to 1600	20.6	5.7277	6.903038889

These results show that the weathered layer thickness is lower in Profile 5/ Akuma, profile 8/Eleh, profile 9/ Omuma and profile 7/ Ubulu and higher in profile 4/ Amagu, profile 10/ Mgbidi, profile 3/ Ibiasoegbe, profile 6/Akatta, profile1/ Nempi and profile 2/ Aji. Also the weathered layer velocity is on the average 635 m/s for Nempi, 625 m/s for Aji, 500 m/s at Ibiasoegbe , 465 m/s at Amagu, 590 m/s at Akuma, 490 m/s at Akatta, 485 m/s at Ubulu, 450 m/s at Eleh, 610 m/s at Omuma and 500 m/s at Mgbidi

3.1   Three Dimensional Presentation Of The Results

The following Figures 13 and 14 are three dimensional presentations of the results of the survey. Figure 13 is the 3D view of Seismic wave velocity distribution within the survey area. Whereas Figure 14 is a 3D view of the thickness of the weathered layers within the survey area. This pictorial representation conveys the same results as discussed in section 3.0.
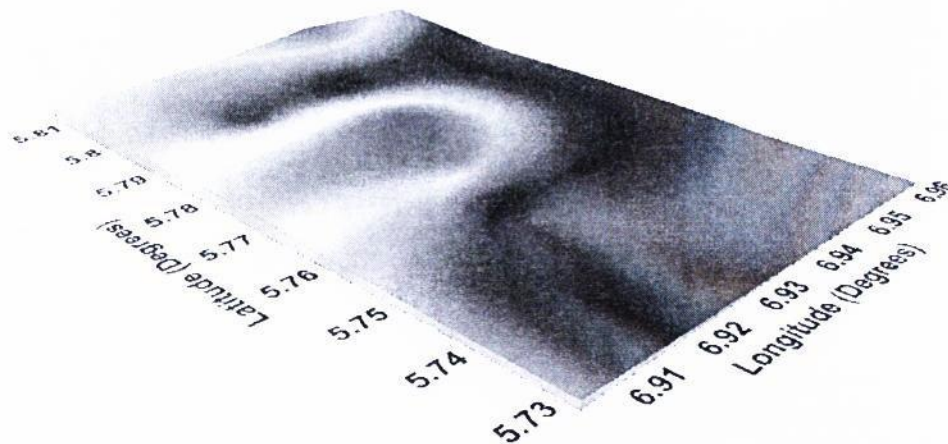

Figure 13: 3D view of seismic wave velocity distribution within the survey area.
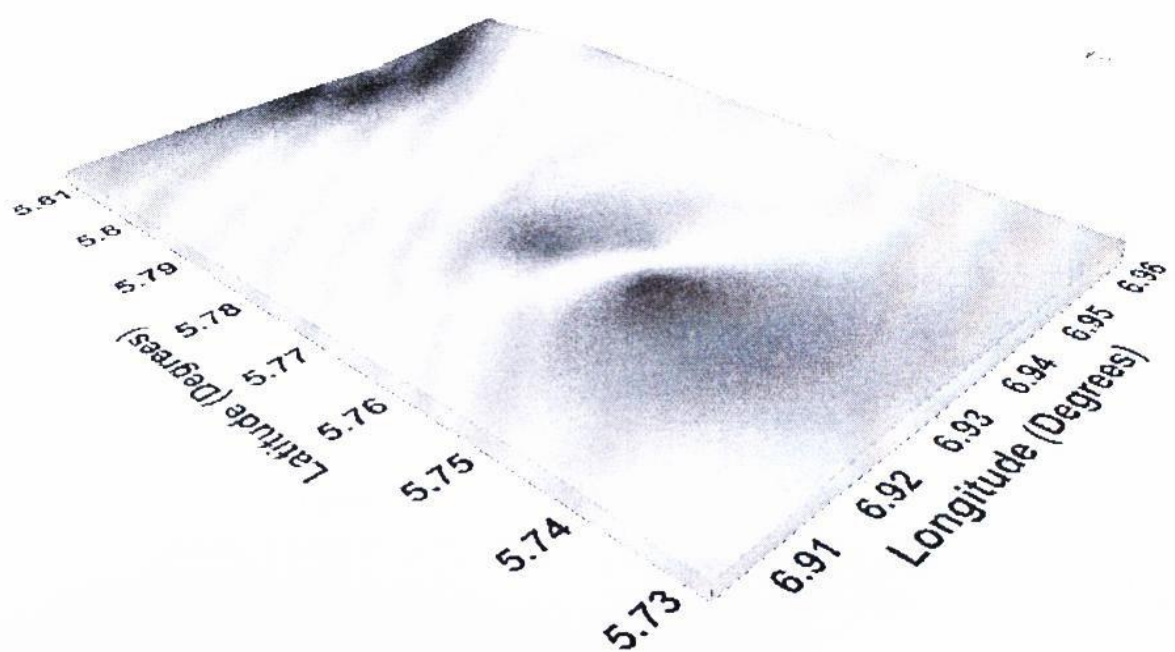
Figure 14: 3D view of the thickness of the weathered zone within the area.

4.0 Conclusion

In this research work seismic refraction tomography has been used to determine the average thickness and p wave seismic velocity distribution of the weathered zone of the Oru Area. The results obtained indicate that the distribution of seismic velocities within the subsurface showed a general increase of velocity with depth. The velocity of the weathered layer was found to vary from 400 m/s to 820 m/s. The thickness of the weathered layer is on the average 19.5 m and this is also the average depth to the consolidated layer.

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