



INTERNATIONAL JOURNAL OF SCIENCE FOR GLOBAL SUSTAINABILITY
Uses of seismic refraction tomography in investigation of groundwater potential in Kaduna millennium city, Kaduna Nigeria

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Received on: November 2018

Revised and Accepted on: September 2019

ABSTRACT

Seismic refraction tomography is unique in the sense that shot are taken at every receiver position along the spread. In that way, it becomes possible to conduct both forward and reverse shooting simultaneously along the profile lines. Therefore, every point within the subsurface along the profile lines is probed by both forward and reversed shots. This leads to what one might call the scanning of the subsurface. The data were processed with ReflexW software and a conventional forward and reversed travel time curve was plotted for each profile lines. Thereafter joint inversion of the travel time picks was carried out. This resulted in the generation of an iterative model, which was used to generate tomographic sections. The result of seismic refraction tomography showed lateral and vertical variation in velocity along most of the profile lines, thereby giving a true image of velocity distribution, both vertically and laterally within the subsurface. Refraction Tomography gave accurate depth and thickness of the overburden along the profile and to delineate aquifer potential in the basement topography. The aquifer is estimated to be around 45m to 60m along the entire profile line

Keywords: Seismic Refraction Tomography, Groundwater Potentials, Millennium city, Kaduna, Nigeria.

1.0 INTRODUCTION

Seismic refraction tomography is an imaging technique (Tien-When and Phillips, 2002), which applies the same basic principle as conventional refraction shooting, except for the fact that more shots are fired before the first geophone, at each geophone point, and beyond the last geophone, thereby having far more number of shots than the conventional seismic method. (Kearey and Brooks, 2002).

The conventional seismic refraction method which involves only shooting of a forward and reversed shot has long been used to determine depths and velocities within the subsurface. Experiments have shown that this can only be used to determine the velocities at the shot points not along the entire profile. This has in time past led to erroneous assumption of the same velocity across the entire profile within the

subsurface, thereby masking area of anomalous velocities and depth variations merely covered by a very thin overburden thickness (Dobrin, 1976). When the refractor is suspected to have a dip, the velocities of the beds and the dip of the interface can be obtained by shooting a second complementary profile in the opposite direction. (Lowrie, 1997). According to Osemeikhian and Asokhia (1994) the refraction method is mainly used for mapping of the weathered layer, for determining depth to water table and for engineering purposes, also for applying correction to reflection data.

Objectives of this work include:

- (i) To image the subsurface and determine the nature of the strata,
- (ii) To determine the image of the aquifer,
- (iii) To determine the depth to the refractor and the overburden thickness at the shotpoints and along the entire profile.

2.0 INSTRUMENTATION

The major instruments employed in this survey include the 24 channels digital seismograph (Terraloc Mark 6), sets of 25 vertical geophones, reels of cables and sledgehammer. The multi-channel digital seismograph records 24 traces at the same time. It has a very high dynamic range that gives a very high resolution for both refraction and reflection survey. It can be used anywhere in the world and in all weather conditions (Sandmeier, 2003). The sets of 25 vertical geophones with one acting as the trigger geophone, has a frequency range of 4 -100Hz. It is used to pick the seismic signals generated by the energy source (the sledge hammer).

3.0 METHODOLOGY

Seismic refraction survey is a geophysical method to map geological structures by using head waves. Head waves involve energy which enters a high velocity medium near a critical angle and travels in the high-velocity medium nearly parallel to the refractor surface. The main

quantity measured in the seismic refraction method is the time between the ignition of the seismic wave and the first arrival of energy along the path between the shot point and detectors. The first arrivals are evidences of the fastest traveling waves which are longitudinal waves. By observing first arrivals for a variety of shot detector distance, a time-distance curve can be constructed. The time-distance relations can be analyzed in terms of the variation with distance of minimum time paths. Then the elastic discontinuities can be deduced from these variations, and can be interpreted in terms of the nature, depth and attitude of geologic units below the surface (Keary *et al.*, 2014). The objective is to determine the arrival times of the head waves to map the depth to the refractors in which they travel. It is a faster method that often finds application in locating the ground water table, determining depth to bedrock and configuration, mapping near-surface poorly consolidated/slow velocity layer, among other uses.

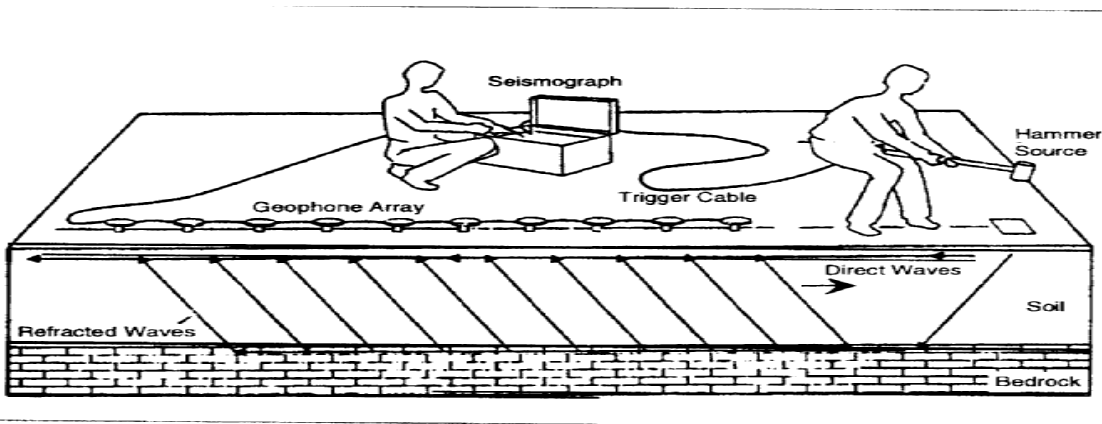


Figure 1.1a: Field lay out showing the path of directed and refracted seismic waves (EPA, 2002; Benson *et al.*, 1984)

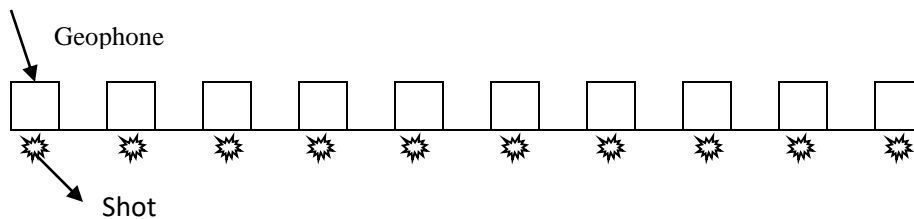


Figure 1.1b: Field lay out for the seismic refraction tomography survey.

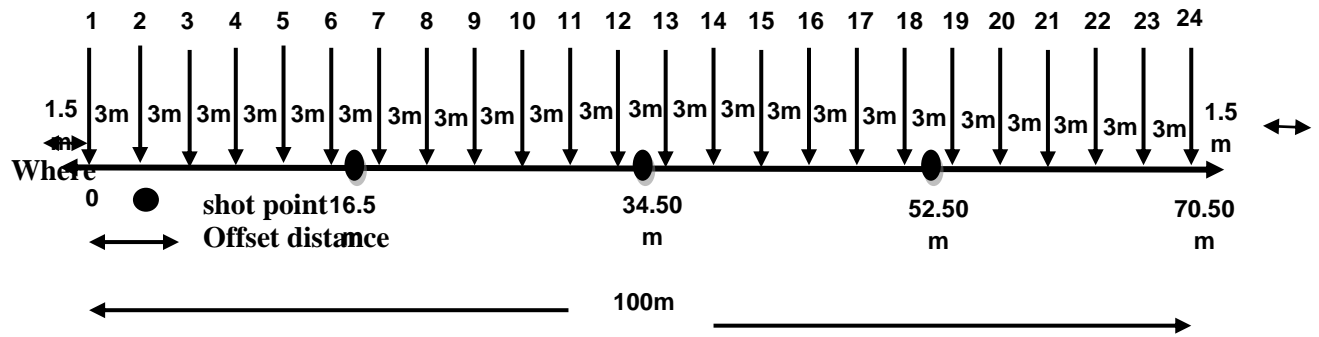


Figure: 1.1a, b: General Field set up of the geophones



PLATE I: Seismic Refraction Tomography in Millennium City

3.1 STUDY AREA DESCRIPTION

Kaduna state millennium city, was created in 1999, following the decision to expand the city in other to build more house for both federal and Kaduna state civil servants. The millennium city lies in the north-west part of Nigeria with latitude of 10°31" N and longitude 07° 30" E,

with elevation of 619 m, (Figure. 2). Showing 3D Map of Millennium City (Relief),while (figure 3) shows the study area and it is accessibility through major and minor roads, (figure .4). shows geological maps of Nigeria showing the study area and (figure .5). Shows geological map of Kaduna State (NGSA 2007).

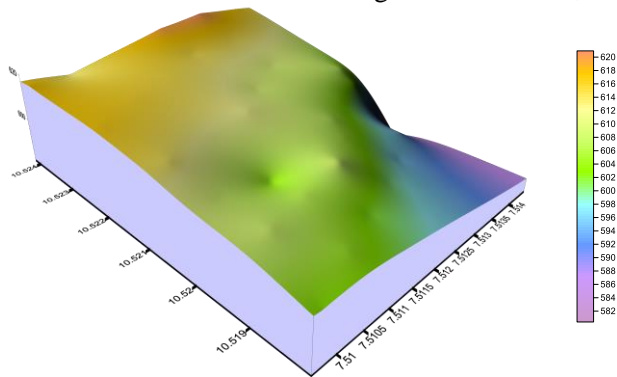


Figure 2: Showing 3D Map of Millennium City (Relief)

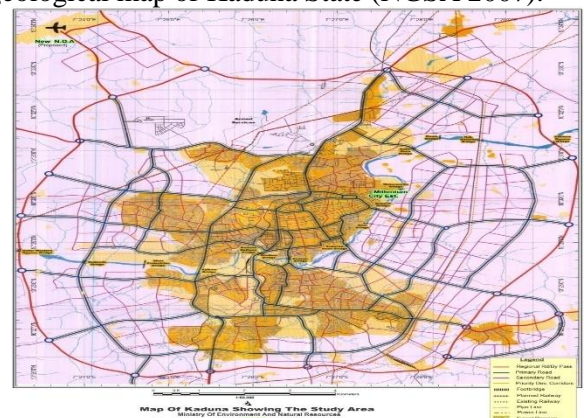


Figure 3. Map of Kaduna showing the accessibility of the study areas

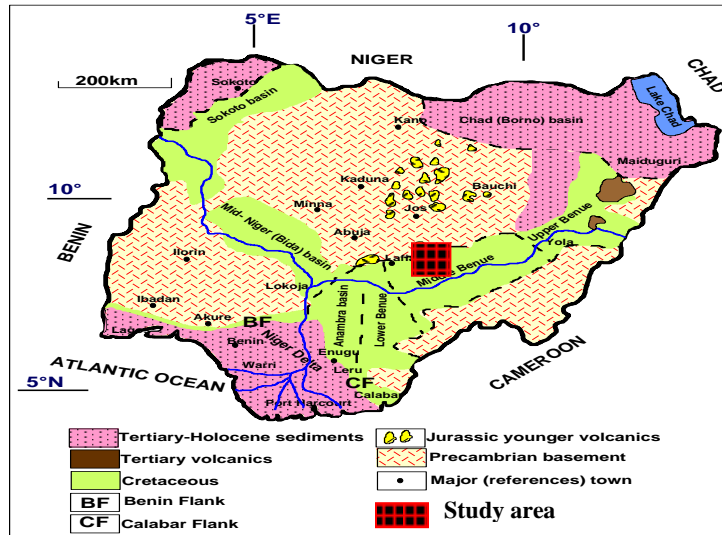


Figure 4: Geologic map of Nigeria showing the Study Area

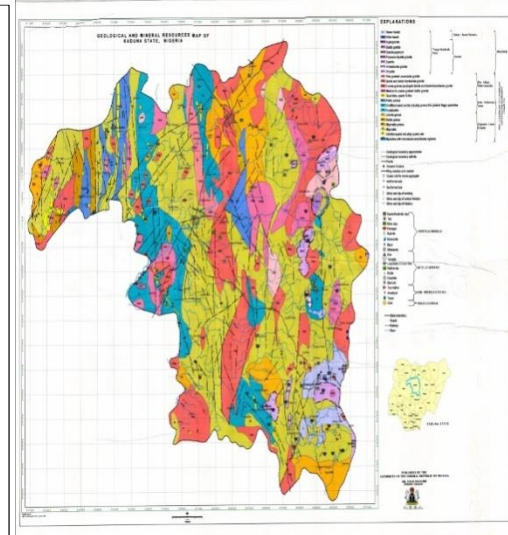


Figure 5: Shows geological map of Kaduna State (NGSA 2007)

3.2 GEOLOGY OF THE AREA

The study area lies within the Basement Complex of Northern Nigeria (Figure 3). The Basement Complex includes all rocks older than the late Proterozoic (McCurry., 1976) and is composed mainly of gneisses, migmatite, granites, and some extensive areas of schist, phyllites and Quartzites (Baimba.,1978),(Perez and Barber.,1965) according to (McMcCurry.,1976).The whole Basement has been through at least two tectonic-metamorphic cycles and consequent metamorphism, magnetization and granitisation have extensively modified the original rocks so that they generally occur as relict rafts and xenoliths in migmatite and granites. Two groups of granites are present and these are the Older Granites and the Younger Granites. The Older Granites are Widespread and often give rise to smoothly domed hills which typically rise to about 170 m above the surrounding plains.(Russ.,1957).The Younger granites which include granites,syenites and rhyolites cover extensive areas in the plateau.

The area lies entirely within the Basement Complex of Northern Nigeria (Figure 3). The rocks consist of series of granites, gneisses, migmatite, low-grade schist, quartzite and amphibolites that have been grouped by the British authors as “Basement Complex of the Precambrian age” (Olugboye., 1975). The

topsoil varies in composition, colour and texture at most places. They are predominantly laterite and quartz grains (deep browns or reddish brown soil). Geophysical investigation reports of (Eduvie., 2005) and (Dan –Hassan., 1999) showed that Kaduna is underlain by 3 to 5 geologic layers; the top lateritic soil, clayey sand/sandy clay, weathered transition zone, the fractured bed rock and the fresh bedrock.

Geophysical investigation and borehole drilling reports have clearly established two major aquifers. These are the overburden weathered aquifer and the fractured crystalline aquifer (Dan-Hassan and Olarufemi.,1999) at some locations these aquifers are interconnected and form a hydrogeological unit of water table surface.

3.3 DATA COLLECTION

In seismic refraction tomography, there are many shots along each profile. The seismic sources and receivers are arranged so that multiple seismic rays pass through each elements of that volume. The total travel-time for each ray are the basic data acquired for interpretation. The refraction tomography profiling adopted for this research work, seismic refraction shooting along the profile, A, B, C, D, E, D and F, of the field layout, with the 24 geophone equipment will be used in the survey. At first, measurement of geophone spacing kept at 3 m interval along each profile line will be carried out. Then the geophones were planted

firmly to the ground. They were connected to the recording instrument (Seismograph) placed between the 12th and 13th (34.50 m) and (106.50 m) geophone respectively (mid-point of the layout) and amplifiers filters and gains will be accurately set. Source will be placed at 1.5 m offset away from the first geophone and the first shot is made. Then shots are made between the 6th and 7th geophone, 12th and 13th geophone, 18th and 19th geophone and 1.5 m offset away from 24th geophone. Then the resulting signals will be recorded in the Seismograph. The signals will be stored on the hard disk of the Seismograph. They will be 360 shot points for the dumpsite and 200 shot points for control site, the total shot points will be 560 shot points. Figure 3.9a, 3.9b and 3.9c is the field set up for the geophones and the field layout for the data collections.

3.4 SEISMIC REFRACTION DATA PROCESSING

Seismic refraction data analysis and interpretations such as delay time method, plus-minus method and the generalized reciprocal method suffer near surface attributes, such as lateral discontinuities and heterogeneity and gradients. Therefore, the analytical method used in this particular research work is refraction

tomography, which is not subject to these constraints. The seismic refraction tomography is able to resolve velocity gradients and the lateral velocity differences or velocity changes which may be applied where conventional refraction methods fail, such as area of compaction, fault zone and karst, Zhang and Toksoz (2002), the seismic tomography method was successful in smothering lateral variations and velocity model provided by it. The software used for the seismic refraction tomography is called (ReflexW) is a full refraction modeling and integrated software package that runs on geometric seismograph, it is an inversion routine software package. The raw data is normally stored in SEG formats were opened with Reflex W and the first particular breaks were recognized or identified and picked from wiggle mode with an automated picker, Figure 6 and adjusted manually with an interactive cursor. The first break pick files for each station were saved to plot. The tomogram through inversion was transformed into velocity models in this research works and figure 6: Representative of the seismic arrival signal in a wiggle form and picking of the first arrival were also used in this research work.

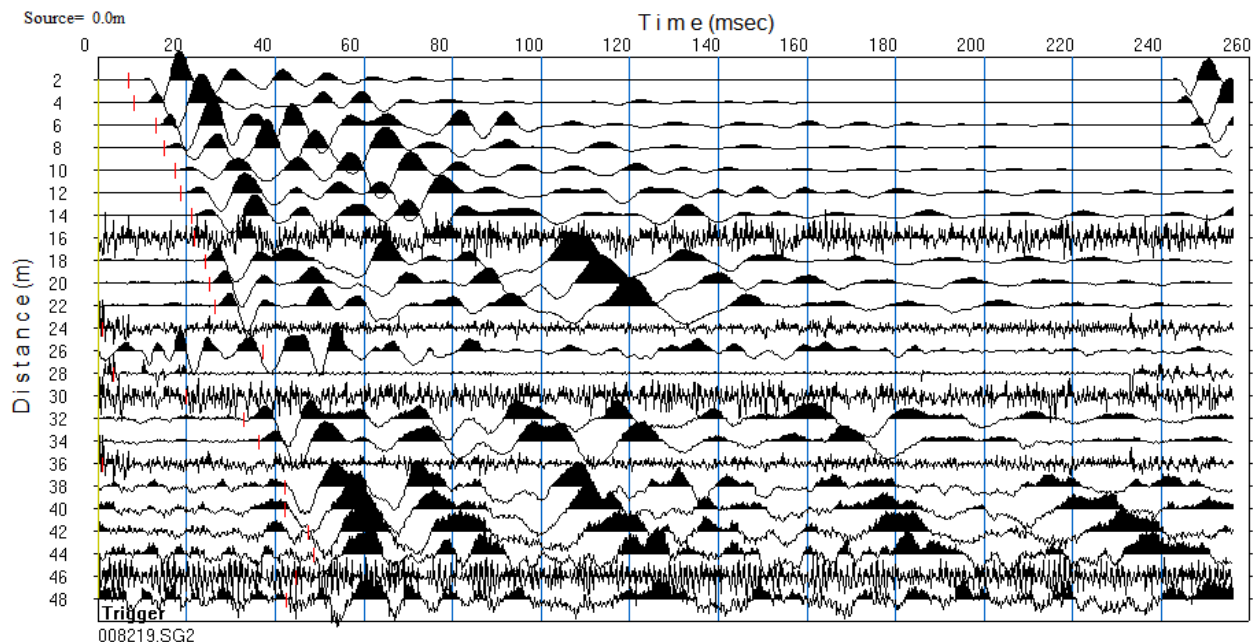


Figure 6: Representative of the seismic arrival signal in a wiggle form and picking of the first arrival

4.0 RESULTS AND INTERPRETATION

Three seismic profiles (Figure 7, 8 and 9), were analyzed for the seismic refraction tomography techniques in other to determine the fracture zones called aquifer.

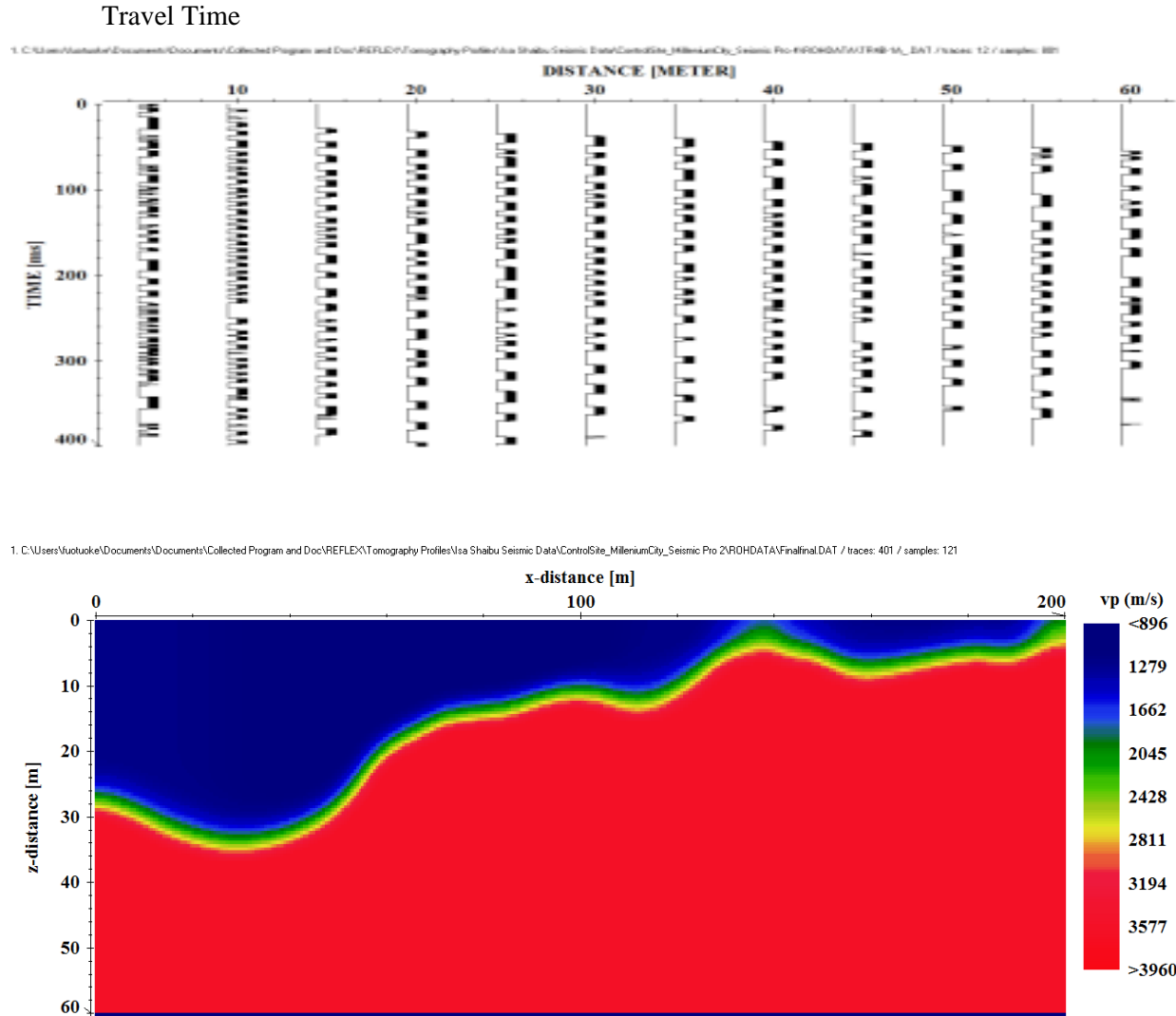


Figure 7: Seismic Tomographic Model in Millennium city Kaduna profile 1,

The tomography model (Figure 7.) showed a general increase of velocities with depths. The profile extends 200 m and above along the surface, the tomography models in figure 7 were able to delineate the overburden with velocity of 600 m/s to 1400 m/s and depth range of 0.7 m to 2.3 m with average thickness of 0.7 m to 2.3 m .The velocity of this indicate presence of much loose material around this zones. The contact area between the overburden and the basement showed no much undulation within the

subsurface, and slope is not sharp down from the end of the profile toward the beginning of the profile. The weathered basement with velocity range of 1500 m/s to 2000 m/s and average depth of 13.2 m to 16.4 m with average thickness of 11.0 m to 15.7 m, and the fresh basement with velocity range 2400 m/s above with average depth of 36.7 m above, with average thickness of 21.1 m above, which are within aquifer potential zone.

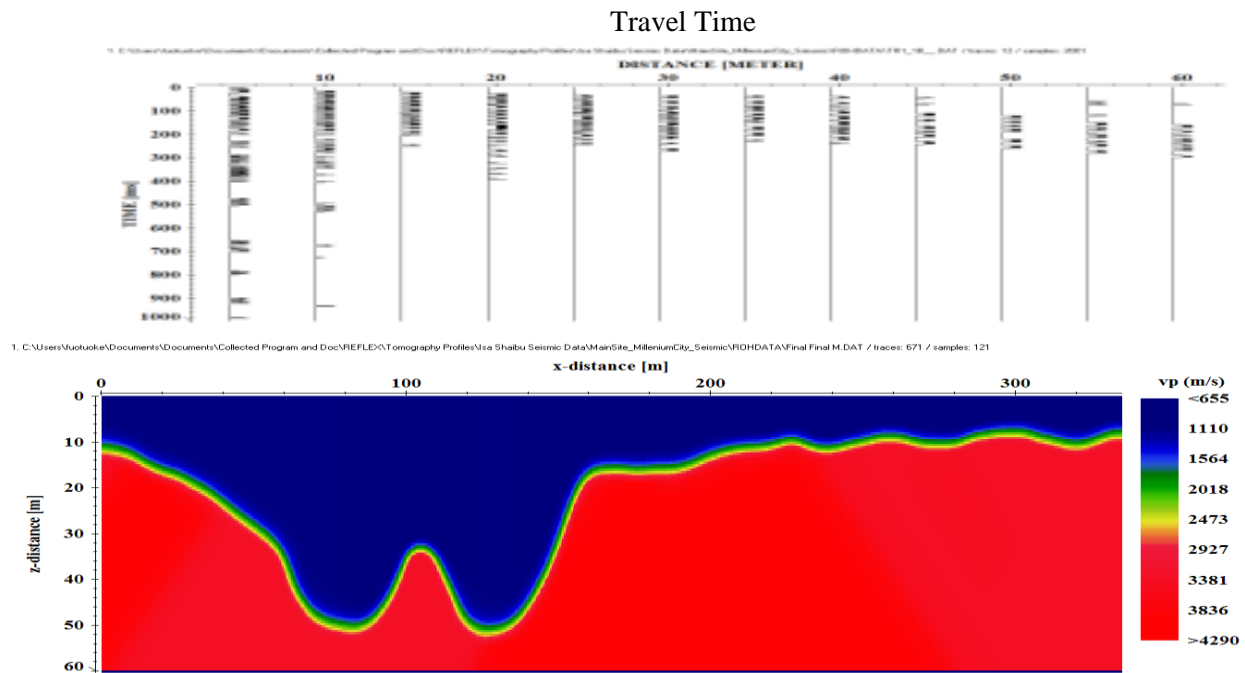
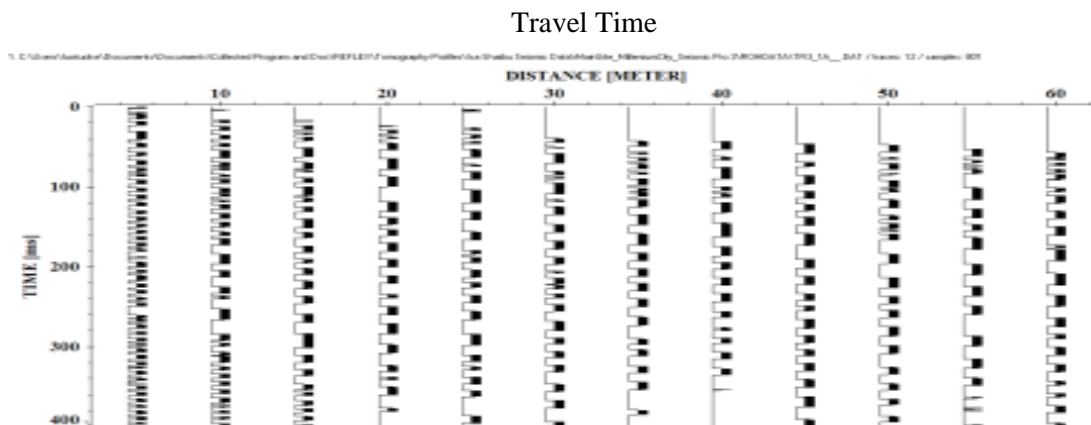


Figure 8: Seismic Tomographic Model in Millennium city Kaduna profile 2

The tomography model (Figure 8.) was able to delineate the overburden with velocity range of 400 m/s to 1400 m/s and depth range of 1.1 m to 1.7 m and average thickness of 1.1 m to 1.7 m, the contact area between overburden and the basement showed very much undulation, the weathered basement with velocity range of 1600m/s to 2500 m/s with average depth of 10.5 m to 15. 7 m, the average thickness of 8.9 m to 14.6 m, while fresh basement velocity range is

3300 m/s with depth of 19.6 m above with average thickness of 8.9 m. Comparison of the difference in depth to weathered basement and depth to the fresh basement, which represent the thickness of the weathered basement, showed that, profile 1 have thicker weathered basement (35.1 m) which is about 18.3 m and much thicker at the beginning of the profile lines. This also indicated much pronounced aquifer zones very good for industrial uses.



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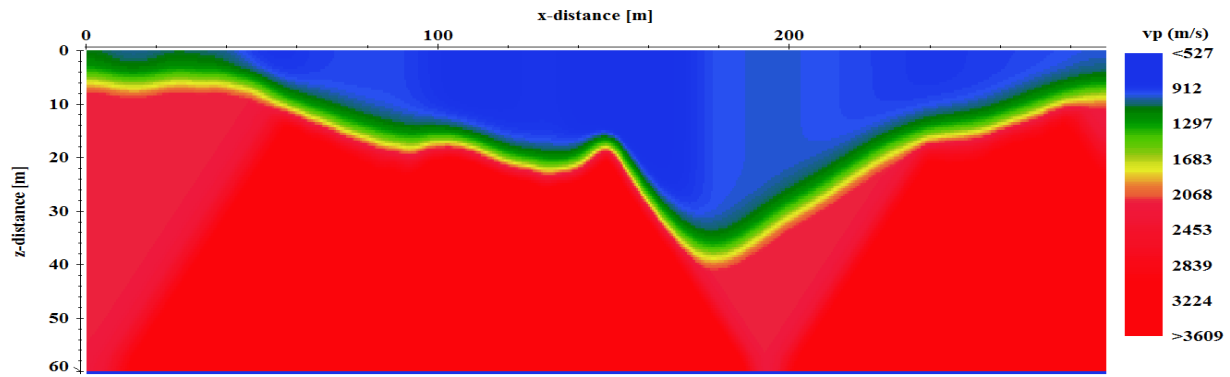


Figure 9: Seismic Tomographic Model in Millennium city Kaduna profile 3,

The tomography model (Figure 9.) was able to delineate the overburden with velocity range of 250 m/s to 1000 m/s and depth range of 0.9 m to 1.6 m and average thickness of 0.9 m to 1.6 m, the contact area between overburden and the basement showed very much undulation, the weathered basement with velocity range of 1200m/s to 1500 m/s with average depth of 8.0 m to 14. 5 m, the average thickness of 6.3 m to 13.6 m, while fresh basement velocity range is

3000 m/s, with depth of 23.1 m above with average thickness of 8.6 m. Comparison of the difference in depth to weathered basement and depth to the fresh basement, which represent the thickness of the weathered basement, showed that, profile 3 have thicker weathered basement (6.3 m) and much thicker at the centre on this particular profile line with a very good aquifer at the center.

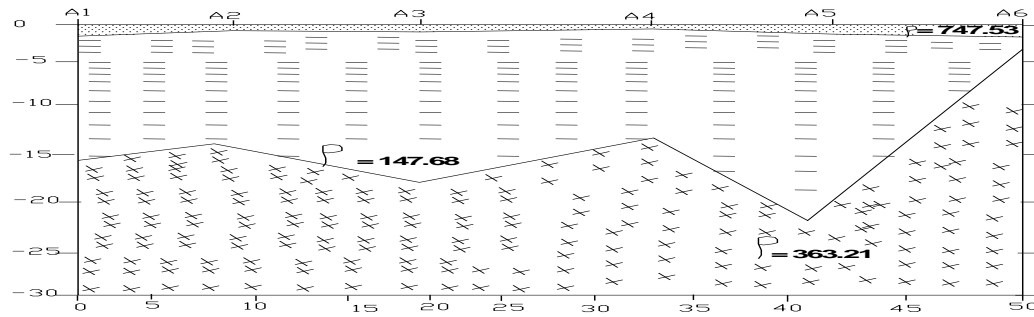


Figure 10 a: Geologic section of profile 3

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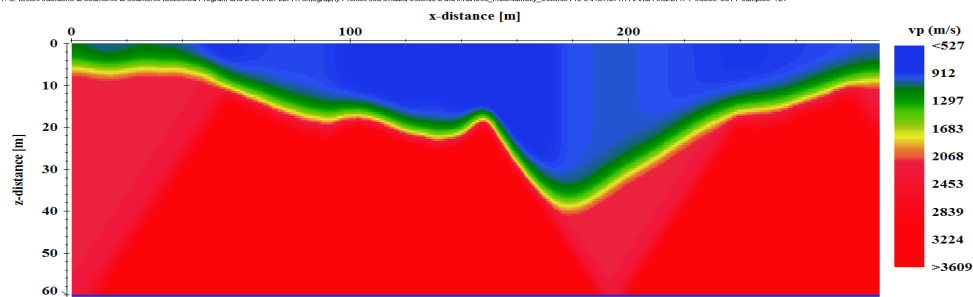


Figure 10 b: A Tomogram of Sub profile 3

5.0 DISCUSSION

The tomographic section of figure 8, showed how velocity varied with depth along the entire

profile. It would have been very erroneous to have assumed the velocities at a distance of 10 m and 50 m along the profile, at the same depth of 10m are the same, similarly for a depth of 15 m at the same distance along the profile. Figure 9 depicts clearly how velocities vary along the entire profile at the same depth.

Seismic refraction tomography method also delineated three to four velocity layers with different thickness and various compositions of lithology. The velocity then increases down the depth. The seismic refraction tomography indicates that even though the same number of layers is delineated. Variations in thickness also exist due to different properties.

The geologic sections indicated areas or zone with very good aquifer potentials in the entire profile lines.

6.0 CONCLUSION

Data analysis and the interpretation of this survey have indicated the suitability and efficiency of the Seismic Refraction tomography methods in probing subsurface structures and delineating groundwater potential in basement terrain like Kaduna. These particular methods have delineated variations in velocity distributions. Fractures observed suggests geological feature that could facilitate a very

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good aquifer reservoir. The seismic refraction tomography has shown three to four velocity layers with different lithological compositions and thickness. The velocity increases down the depth, velocity models were used to image the subsurface geology of the entire study areas. Maximum of four layers were also delineated.

From Figure 7 above, sub-profile lines, the velocity range of the first layer is 600 m/s to 1400 m/s, the thickness range of the first layer is 0.7 m to 2.3 m, the velocity indicates loose materials around the zones. The velocity range of the second layers is from 1500 m/s to 2000 m/s, with thickness range of 11.0 m to 15.7 m. The third layer is characterized by velocity of 2400 m/s which is the fresh/fractured basement with good aquifer potentials.

7.0 RECOMMENDATION

The present study uses of seismic refraction tomography in investigation of groundwater potential in Kaduna millennium city, Kaduna Nigeria. The study became necessary due to the increase in population of the area and the incessant water scarcity experienced by the occupants of the estate, A total drill depth of 45m to 60 m was recommended for optimum groundwater yields in the area with a good industrial borehole if need be.

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