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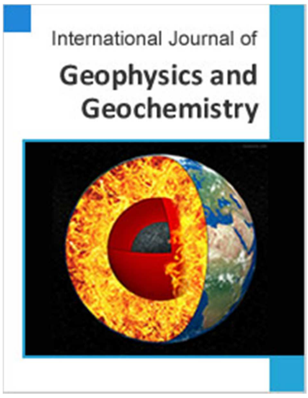

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Geoenvironmental Investigation of Subsurface Structure in Parts of Calabar South, Southeastern Nigeria: Seismic Refraction Approach

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Abstract
This study examines the application of refraction profiling using the in-line method to interpret the subsurface structure in Anantigha and Unical farm in Calabar South. This involves the mechanical generation of seismic waves using a sledge hammer on a steel plate and a seismograph to record the arrival times of critically refracted waves. Graphical treatment of data shows the subsurface to be a two layer model. The overburden velocity in the three locations are in the range of 200m/s and 300m/s. The refractor velocities ranged between 400–500m/s ands. The calculated dipshave a maximum angles of 2.6° in location 2 and 2.1° in location 1 and 3. The depth to the interface in the down dip and up dip in location 1 are 8.6m and 7.8m respectively. Location 2 has down dip of 6.7m and up dip of 8.6m. Location 3 has the intermediate depth to the interface of 7m down dip and 7.5m in the up dip. Geological interpretation of results based on the comparison of velocity ranges for lithology shows a weathered surface material and dry sandy clay lithology for the overburden refractor respectively.

1. Introduction

The basic techniques of seismic exploration consist of generating seismic waves near the surface of the earth by exploding a small dynamite charge or by impact of a heavy weight. The resulting shockwaves spread out through the earth in all directions from the source, the time of arrival of the wave refracted by the discontinuities between different rock formations is recorded at nearby points on the surface by small detectors usually disposed on a straight line directed towards the source. From the knowledge of travel times to various detectors the speed of the waves through the medium is calculated. The nature of the subsurface material influences the part taken by and speed of travel of the seismic waves. The travel times and velocities of waves enable s one to reconstruct the paths seismic waves and hence the structure of the subsurface (Keary and Brooks, 1991, Musset and Atab Khan, 2000, Reynolds, 1997).

Seismic refraction is mostly applied as a reconnaissance tool in newly explored areas. It is mostly useful in situations where there is at least one high speed bed having geological interest extending without perceptible change over an extensive area. For a bed to be map able by refraction such a bed must be overlain by a formation which have a lower speed (Dobrin, 1976). The data acquired from seismic refraction method can be used to determine the precise depth to weathered basement and the overburden thickness such that the different lithologies within the subsurface can be easily predicted (Adeoti, et al., 2012).

Seismic refraction method has been used variously in determining depth to bed rock in foundation studies at construction and building sites, investigation of subsurface structure and determination of depth to water table in different parts of the world. Details of this can be found in (Dawood, et al., 2012, Venkateswara, et al., 2004, Seimetz, et al., 2013, Al-Garni and El-Behiry, 2010). Seismic refraction surveys have been carried out in the study area by Umoren, (1980) and Lecky (1981) to investigate the subsurface structure in the University of Calabar. The methods deployed were limited in extent and crustal depth. The depth of the interface was calculated to be 1.5m for forward shooting and 1.52m for reverse shooting. Comparison of the velocities obtained showed that the first layer was sand and the second layer was probably sand and laterite. The aim of this study was to investigate subsurface structure in University of Calabar farm and some parts of Anantigha in Calabar South.

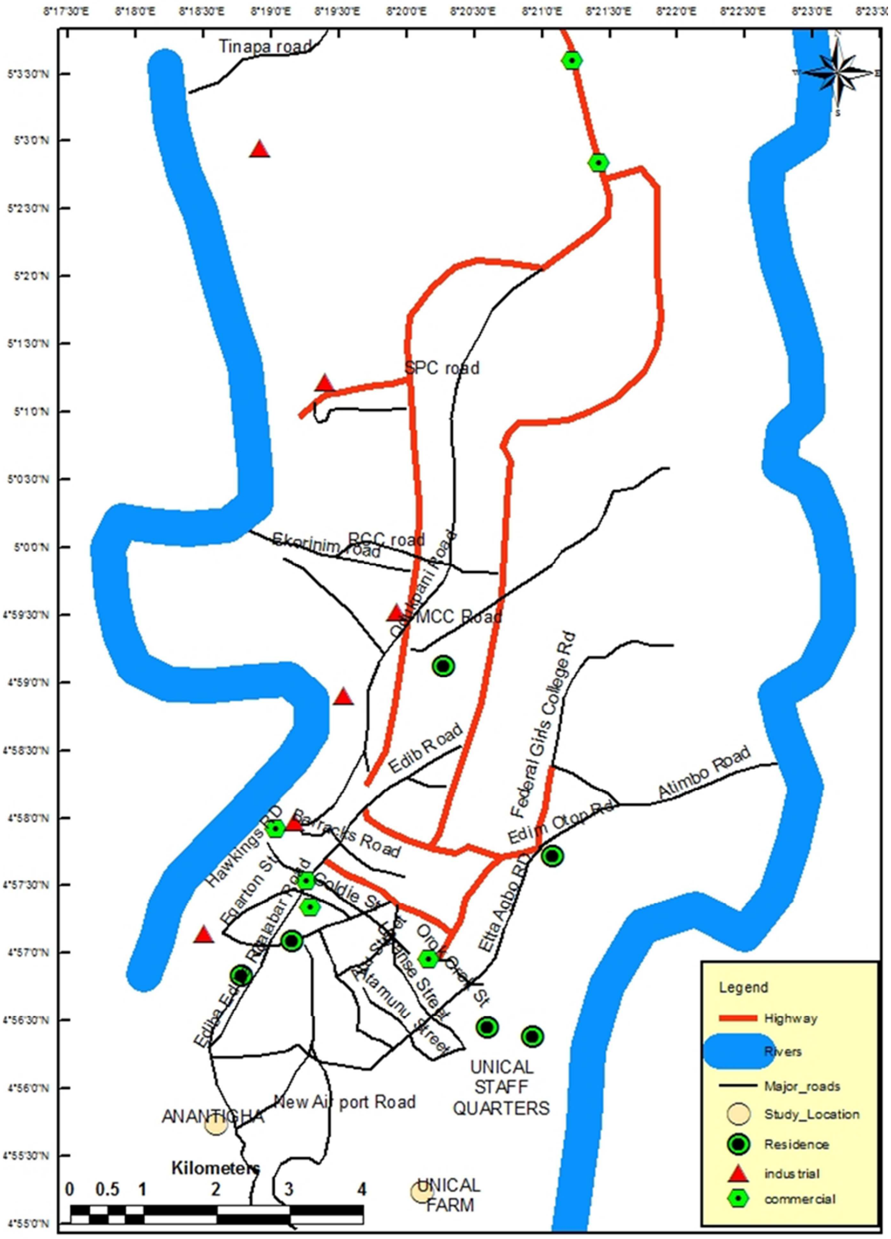

Figure 1. *Map of Calabar showing study area locations.*

1.1. Study Area Description

The study area can be described based on its location and access roads to the area of study.

1.2. Location and Accessibility

The study area lies in the southern part of Calabar area in south eastern Nigeria, within longitudes 8° 17’ to 8° 20’ and latitude 4° 55’ to 4° 56’ (Figure 1). Location 1 and 2 were shot at Anantigha area in Calabar South Local Government area, while location 3 was sounded at University of Calabar farm near the staff quarters. Notable features in the area are Calabar South Local Government Headquarters secretariat, residential houses and a productive hand dug well within the school premises. The tarred Calabar New Airport leads to the study area. At a junction along New Airport road an untarred road leads to the Council Headquarters. Access roads used as footpaths also leads to the study area. The study area is accessible by the use of taxi, motorcycle and foot.

1.3. Physiography and Climate

The Anantigha area in Calabar south is a level land covered with grassland. The level land is truncated by erosion in some areas characterized by depressions known as gulley. There some undulating areas caused by weathering and erosional processes. The surficial soil type is sandy loam which is vulnerable to erosion. The level land is extensive in area. The existing nearby Cross River Prograde to shore and make the surrounding area swampy. There are threes of average heights of 15m and the presence of elephant grasses helping to minimize erosion.

The study area record high rainfall, the climate is humid. The area is characterized by two seasons; the rainy or wet season and the dry season. The rainy season has a relatively longer period than the later. The rainy season starts from the month of April and peak in August and terminates in November. The dry season commence from this period to March.

2. Geology

According to Murat, (1970), the sedimentary fill of the south eastern Nigeria basin which Calabar Flank is a part was controlled by three main tectonic phases namely: Albian, Upper Santonian, Lower Campanian and Eocene. The first tectonic phase occurred in the Albian times (107ma) Murat, 1970) and was characterized by NE-SW trending faults resulting in the formation of the Benue-Abakaliki rift. The Benue Abakaliki-rift is considered to be the failed arm of the triple junction. The basin was delimited to the NW by the Benin Benue Hinge line and between this hinge and the Abakaliki Trough Shelf deposits were laid down on the Anambra Platform. Continued tensional regimes might have produced the smaller continental margin Toughs of the Benin and Calabar Flank areas (Figure 2). In the second tectonic phase Upper Santonian –Lower. Campanian (76-88). There was uplifting and folding of the Abakaliki-Benue folded belt Murat, (1970). The NW-SE trend of the Calabar Flank was preserved during this phase. The third tectonic phase occurred towards the end of the Eocene (540ma). The Abakaliki plunge and the Calabar Flank experienced repeated periods of erosion and non-deposition during the middle and upper Eocene, while large deltaic complex was deposited in the down dip of Anambra Basin, the boundaries being the Niger Delta Hinge line and the Calabar Flank. By the late Eocene, the deltaic sediments had spread onto the oceanic crust. The Niger-Benue drainage system and the Cross River united by the end of the Oligocene (38ma). The deeply entrenched erosion surfaces observed in the Niger Delta Basin downlip of Abakaliki plunge and the Calabar flank were subsequently filled by clayey marine sediments such as Afam clay member and Kwa Ibo clay member.

The Epierogenic movements resulted in major transgressive (Albian) led to the deposition sediments of the Asu River Group consisting of shale, sandstones and limestone. The second sedimentary cycle in the Turonian transgression deposited Eze Akushales.

Essien, (1995) asserted that five major transgressive phases are recognized during the mid Albian, late Albian to Cenomanian, Turonian, early Coniacian and late Campanian. This corrects the work of Ramanathan and Fayose, (1990) which said that only four transgressive cycles were recognized (Figure 2).

Calabar is located in the extreme south east of Nigeria on a Peninsula between the Calabar River and Great Kwa River. The city is built on a sandy terrace and rise to heights of about sixty meters near Calabar River and fall gradually eastwards to the Great Kwa River. The geology of Calabar is built on the Tertiary and Quaternary sediments of the Niger Delta basin. The basin consist of alternating sequence of sand, gravel, silt, clay, alluvium, which are most likely derived from the adjoining Precambrian Basement Complex of the Oban Massif and Cretaceous rocks. The basement complex is made up of gneisses, schist, granite, pegmatite and a host of ultramafic suites (Ekwueme, 2003), while the cretaceous sedimentary unit (Calabar Flank) is made up of limestone, sandstones, shale and marls (Reijersand Petters, 1997).

The higher lands in Calabar are composed of Tertiary sands which occur as fluvial marine terraces (Lecky, 1981). Most of Calabar consist of these terraced deposits which drops to the plain level at an average slope of 10%. In the wide valleys formed by the Great Kwa River and the Calabar River the Tertiary sands have been eroded, and the recent valleys are filled with Quaternary alluvium. This alluvium is composed of sand, silts and clays containing significant amounts of organic debris (Reijers and Petters, 1997).

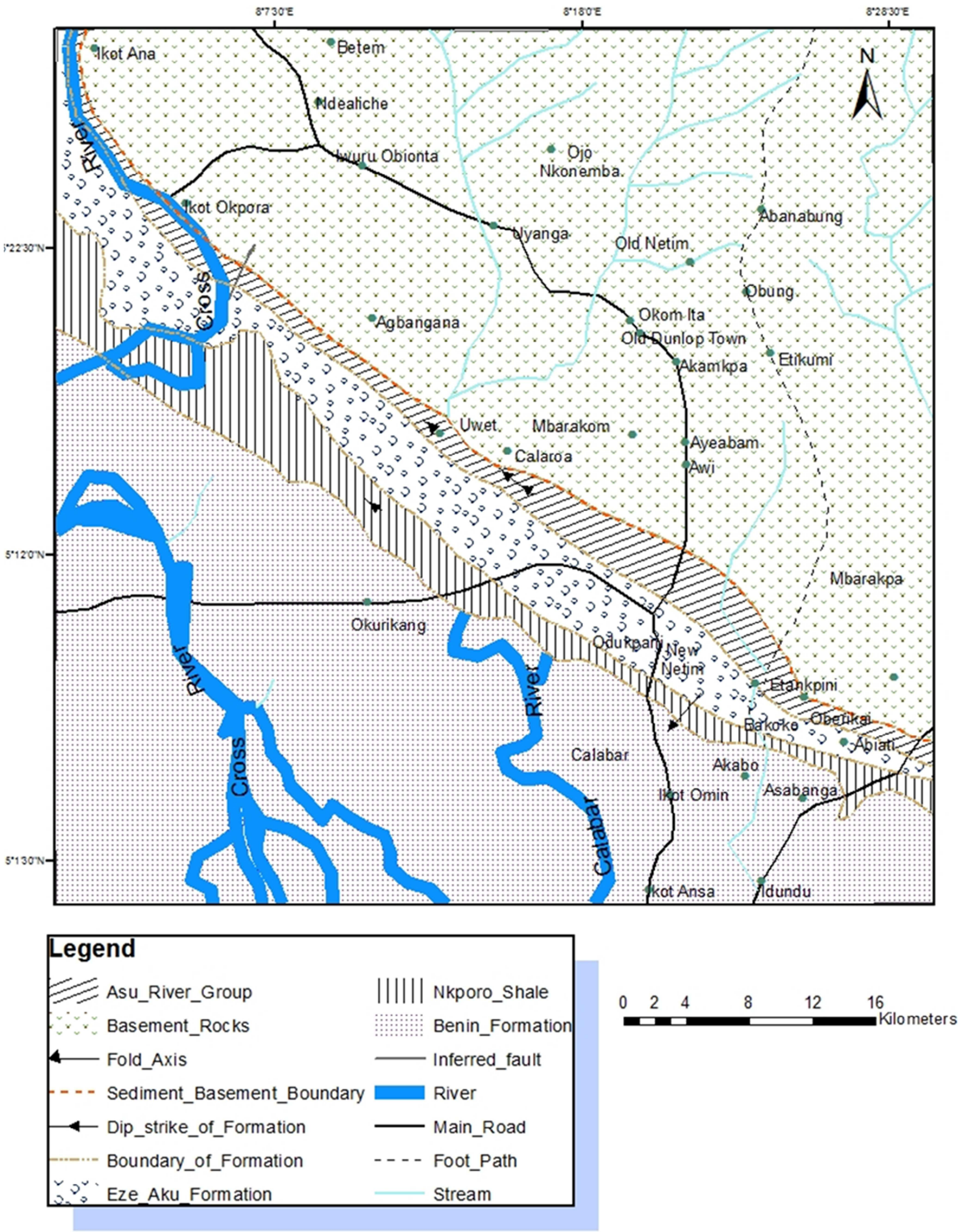

Figure 2. Geological map of Calabar and environs.

3. Methodology

3.1. Instrumentation

The equipment used in seismic refraction differ from those of reflection in having high sensitivity to low frequencies. Since only first arrivals need to be faithfully recorded, the use of Automatic Gain Control or large dynamite range is not essential. However, the same characteristics that make possible the recording of reflections among strong interfingering events have now been usefully employed also in recording refraction events other than first arrivals (Hobson and Jobin, 1973).

For a small scale refraction survey of a construction site to locate the water table or rock head, recording out to an offset distance of about 100m normally suffice, geophones are being connected via a multi core cable to a portable 3 -24 channel seismic recorder (Kearey and Brooks 1991).

A sledge hammer was impacted on a steel plate and provided sufficient energy to traverse the short recording range. The dominant frequency of this energy source exceeded 10Hz and the required accuracy of such travel times was about 0.5ms (Keary and Brooks 1991). The difficulties associated with the cable connection between a detector spread and a recording unit limited the conventional refraction survey to a maximum short-detector offsets of about 1km, and henceto a depth of investigation of a few hundred meters. This explains why for a larger scale refraction survey it is necessary to dispense with a cable connection.

Refraction method is used for relatively shallow depth than reflection method. It is therefore, very important in the areas of hydrogeological surveys and most recently in shallow depth investigation for civil engineering purposes. The source of energy for such shallow investigations can be a much lighter explosion or even drop of a heavy weight, as applied in this study. The geophones spacing is often determining by the purpose of the study. The instruments used in this study include: a three channel seismograph and geophones. Others were; a cable, sledge hammer and steel plate. Geophones are very sensitive transducers capable of picking and converting into an electric signal slight movements of the earth beneath it (Figure 3).

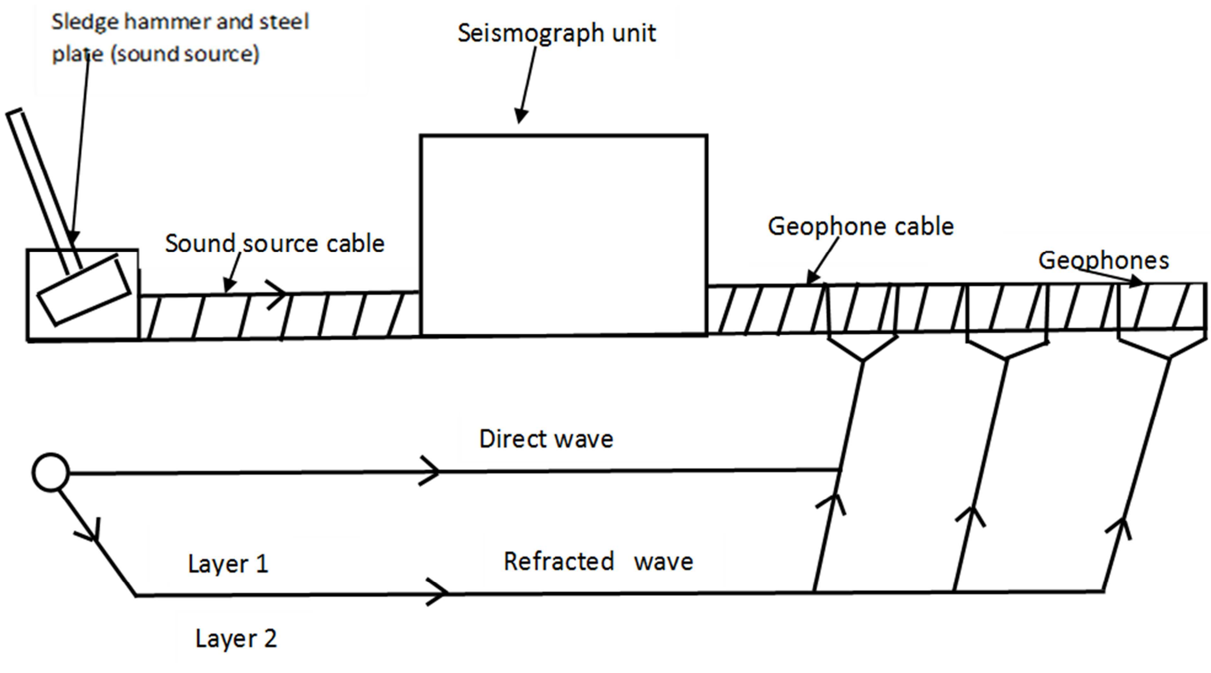

Figure 3. *Block diagram of seismic refraction system.*

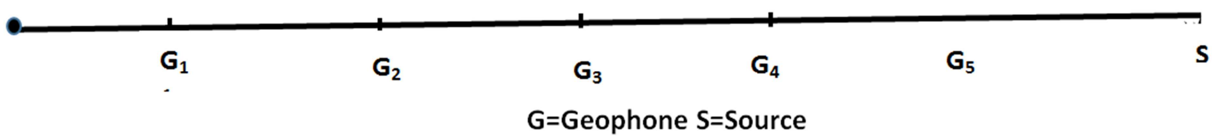

Figure 4. *Typical shooting and receiving arrangement along on-line refraction survey method.*

The basic refraction method involves shooting reverse refraction profiles. The layout of the traverses varies with the purpose and technique. The choice of shot to geophone interval depends on the required depth of exploration and the subsurface. The various profiling techniques include the arc or fan shooting, in-line shooting and broadside shootings described by Dobrin, (1976).

In fan shooting, the geophones are located in different directions from the shot point at roughly the same off set distance. In-line profiling (Figure 4) is the most widely used of all the field techniques in seismic refraction work. Successive shots are taken at uniform or almost uniformed intervals along each line, and successive detector spreads are shifted about the same distance as the corresponding shot points. The shots are gradually received from opposite directions on each detector spread. Broadside shooting is applied to second event (Dobrin, 1976). The shot points and detector-spreads are laid out along parallel lines which are generally across strikes. The method yields information about refractors. The kind of profiling technique employed in this experiment was the in-line shooting.

3.2. Field Layout and Procedure

The set up equipment consisted of a single seismic source S with a set of detectors arranged in a straight line from the source and a seismograph (Figure 4). An electronic device was incorporated in the seismograph to filter out unwanted noise such as wind induced noise, footsteps from field workers, shops, road traffic etc. from the surrounding that can degrade data quality. The frequencies of these noise generally tend to be above the frequency band of the seismic signal and can be filtered out with no loss to the seismic signal (Asokhia, 1984). On this line marked on the ground with the help of a measuring tape, the geophones were planted firmly on the ground at uniformed intervals. The arrangement is known as single profile. For a dipping interface, a single profile will give a false determination of velocity and layer thickness. To surmount this difficulty, the reverse profile was employed. This was done by simply interchanging the position of the shot from one end to the other.

The profiling was done on a considerably flat area in order to avoid complications in calculations due to elevation differences between source and receivers. Also the profile configuration was determined by a number of factors such as the terrain and facilities available.

A total of three spreads were taken at three different locations. Field data was acquired in three different locations. Two locations (1 and 2) at Anantigha and location 3 in Unical farm. A total of 10 readings were taken for each spread due the limitation of the source of generating seismic energy using a sledge hammer and steel plate which is at shallow depth. The offset distance interval was taken at 5m.

The method of shooting was by mechanical impact; that is by using a sledge hammer of about 2kg to strike a steel plate placed flat on the surface of the ground. The record time was set at 250ms. The values of the arrival time with respect to the geophone distances were recorded. The dominant frequency of geophones was about 100Hz. A 3-channel seismograph recorded time–distance data generated and a printout was of the output was produced. The offset distance interval was taken at 5m between geophones. The layer velocities were determine using computer excel program. The spreads are indicated in map of the study area (Figure 1). Geosections of the three locations are presented in Figure 3.

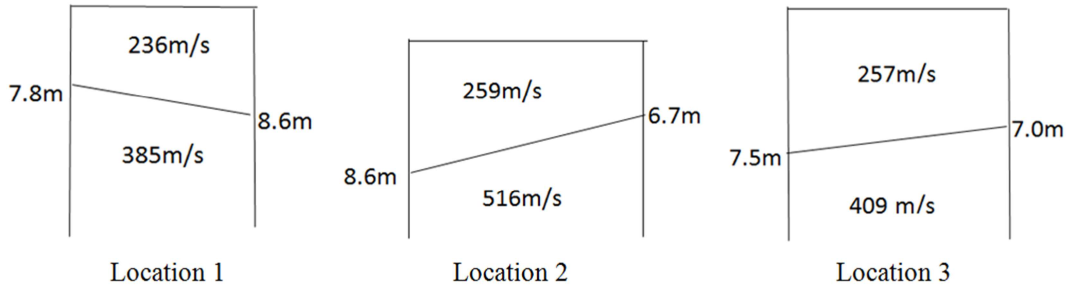

Figure 5. *Seismic geosection of the three locations (not to scale).*

3.3. Data Reduction

The acquired field data for three spreads were plotted into conventional time- distance graphs and refraction curves were obtained (Figure 6, 7, 8). The travel times are determined from the breaks of the traces represented on the graph. The first breaks are also known as the first arrivals. From the graph, direct wave slope, $1/V_1$ and the refracted wave slope, $1/V_2$, were drawn. The depth or thickness of each layer earth can be obtained by taking the average velocities of the forward and reverse curves (V_1 and V_2 respectively) and the intercept time (t_0). Substituting these values in the equation below the value of the thickness or depth to the refractor can be calculated Available empirical formula given below were used to calculate certain parameters namely: overburden and apparent refractor velocities, actual velocity, critical angle, magnitude of dip and perpendicular distance in the up dip and down dip directions.

Actual velocity is given by $1/V_2=1/2(1/V_{2D}+1/V_{2U})$ where V_{2D}=down dip apparent velocity, V_{2U}= up dip apparent velocity

Magnitude of dip is given by $\phi=1/2(\mathrm{Sin}^{-1}V_o/V_D-\mathrm{Sin}^{-1}V_o/V_u)$

Critical angle given by $\Theta=1/2(\mathrm{Sin}^{-1}V_o/V_D+ \mathrm{Sin}^{-1}V_o/V_U)$

Intercept time (t_{in}) $t_{in} = 2Z_D\mathrm{Cos}iC/V_0$

Perpendicular distance to the refractor $Z_D=V_0t_{iD}/2\mathrm{Cos}iC$ where CosiC is cosine of critical angle, t_{iD} is down dip of intercept time.

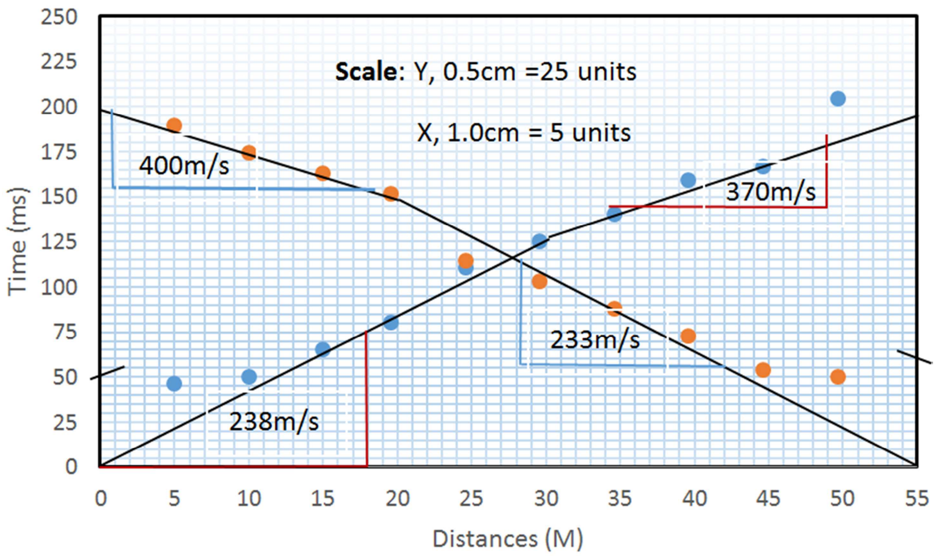

Figure 6. *Plot of seismic refraction data in location 1, time versus distance.*

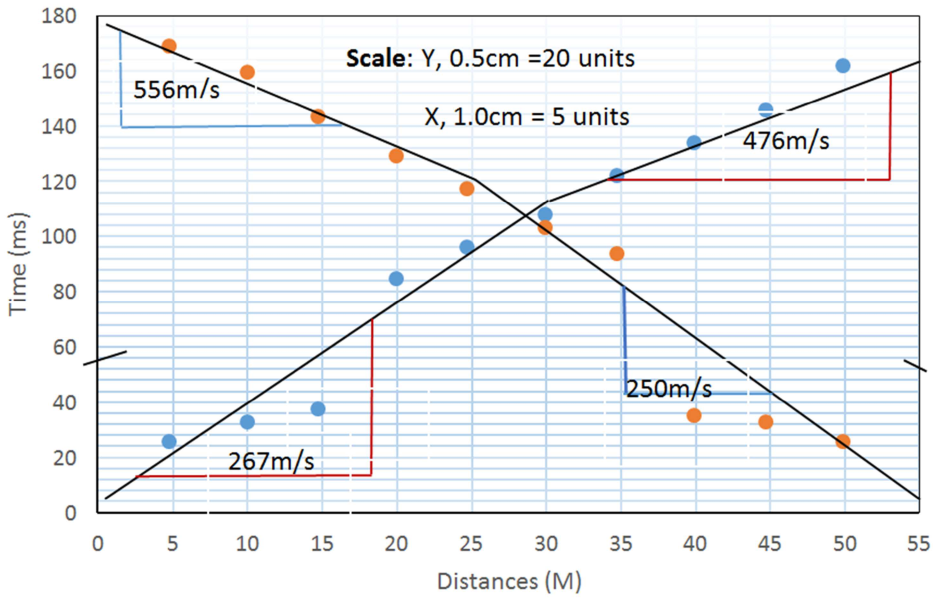

Figure 7. *Plot of seismic refraction data in location 2, time versus distance.*

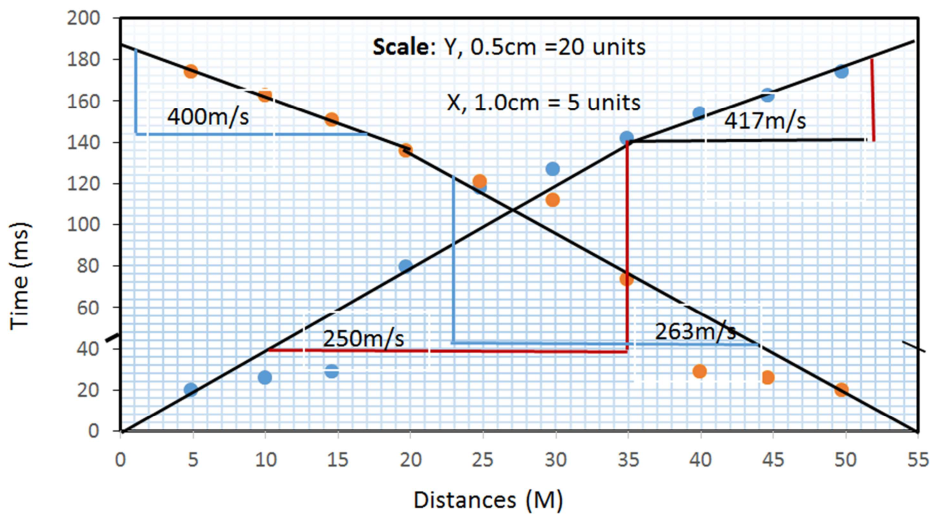

Figure 8. *Plot of seismic refraction data in location 3, time versus distance.*

4. Results and Discussion

4.1. Results

Field data was acquired in three different locations. Two locations (1 and 2) in Anantigha and location 3 in University of Calabar farm. A summary of results of the refraction survey is presented in table 1.

The calculated velocities for forward and reverse shooting from the slopes of the plotted graph in location 1 at Anantigha recorded 238m/s for forward shooting and 233m/s for reverse shooting Figure 5 and Table 1). These are known as the overburden velocities. The refractor velocities are 370m/s and 400m/s for forward and reverse shootings respectively (Table 1). The actual velocity of the refractor is 384m/s. The actual velocity is the average of the down dip and up dip velocities of the refractor and is computed using the relation: 1/V2=1/2(1/V2D+1/V2U) where V2D = down dip apparent velocity, V2U = up dip apparent velocity. The subsurface is dipping at an angle of magnitude 2.10 in the SW direction with a critical angle of 37.80. The depth to the interface in the up dip direction is 7.8m and 8.6m in the down dip. Values of dip, depth to interface in the up dip and down dip directions and critical angles obtained in locations 1, 2 and 3 respectively are presented in figures 9, 10, and 11 respectively. The letters FS and RS on the figures stands for forward and reverse shootings respectively while VO and V1 represents overburden and refractor velocities in that order.

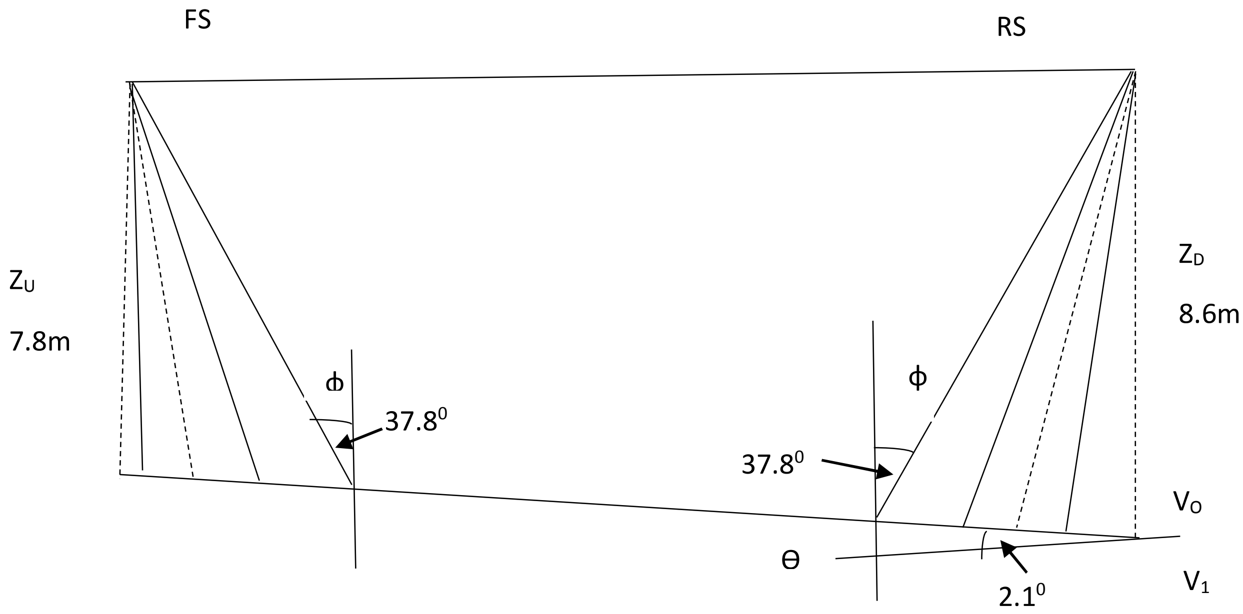

Figure 9. *Subsurface structure in location 1.*

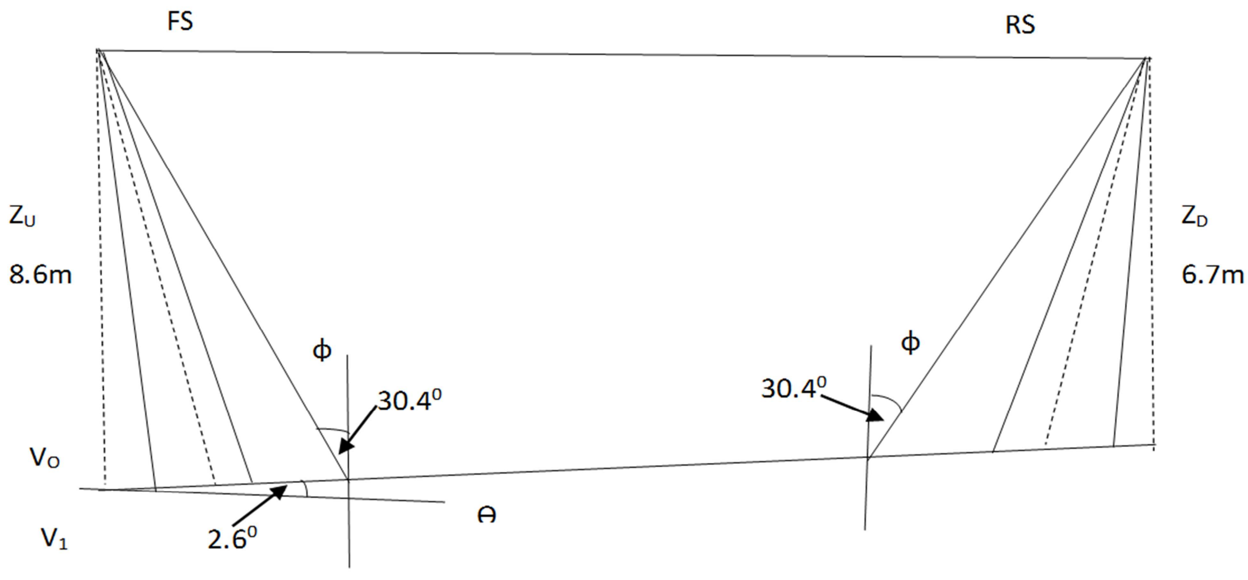

Figure 10. *Subsurface structure obtained in location 2.*

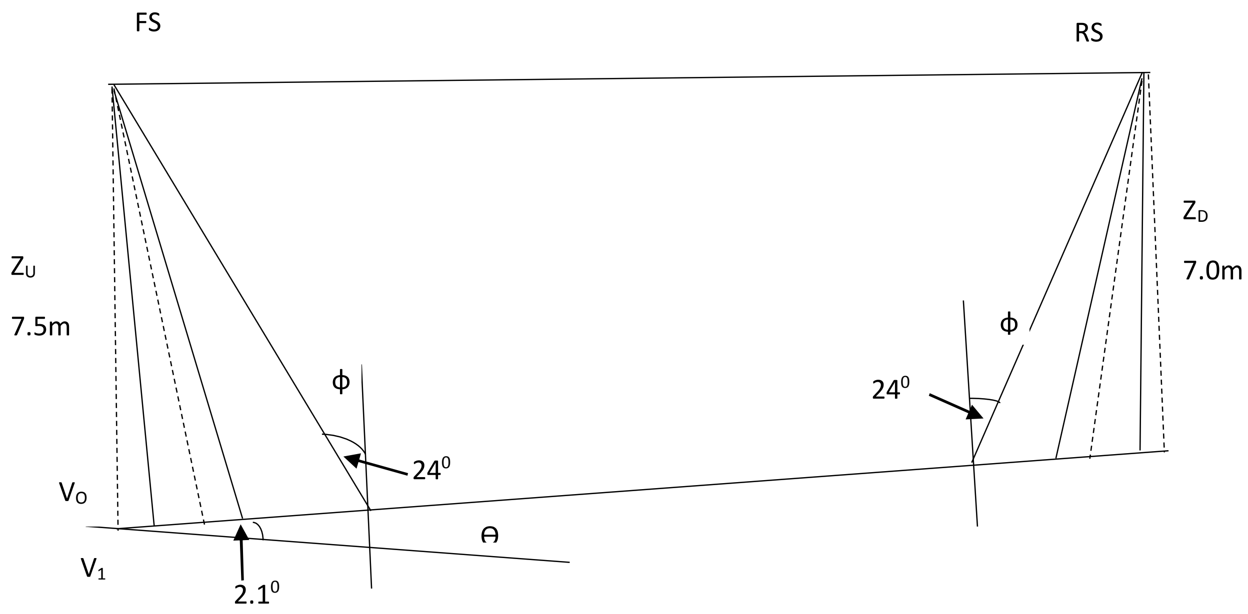

Figure 11. *Subsurface structure obtained in location 3.*

Table 1. *Summary of calculations from seismic plots. (F and R stands for forward and reverse shooting velocities respectively).*

Location	Overburden velocity (m/s)		Refractor velocity (m/s)		Actual velocity (m/s)	Critical angle	Magnitude of dip	Perpendiculardistance tothe interface (m)	
	F	R	F	R				Z_u (m)	Z_D (m)
Location 1	238	233	370	400	384	37.8°	2.1° SW	7.8	8.6
Location 2	267	250	476	556	512	30.4°	2.6° NW	8.6	6.7
Location 3	250	263	417	400	408	24°	2.1° NE	7.5	7.0

When the velocity values are compared with standard velocity values in Kearey and Brooks (1991), the lithology can be interpreted as weathered material for the overburden lithology with refraction range of 360-430m/s. The overburden velocity also compares favourably with dry sand in the velocity range of 100-200m/s (Mooney, 1973).

In location 2 seismic shooting at Anantigha, the overburden velocities in the forward and reverse shootings are 237m/s and 217m/s respectively. The refractor velocities are 476m/s and 556m/s for forward and reverse shooting in the order (Table 1). The actual velocity from calculation gives 512m/s. The value of magnitude of dip is about 2.6° in the NW direction. The critical angle is 30.4°. The depth to the interface at the up dip end is 8.6m and 6.7m at the down dip end. Results from the calculated velocities subsurface shows that the subsurface in this location is weathered material when compared with standard velocity value range of 305-610m/s, and 360-430m/s (Mooney, 1973: Keary and Brooks, 1991).

The refraction survey at location 3 in Unical farm, from calculation of overburden velocities shows that the velocities for forward and reverse shootings are 250m/s and 263m/s respectively (Table 1). The apparent refractor velocities show values of 417m/s and 400m/s for forward and reverse shooting respectively. The actual velocity equals 408m/s. The subsurface structure has a magnitude of dip 2.1° in the NE direction. The value of the critical angle equals 24°. The depth to the interface at the up dip end is 7.5m and 7m for the down dip end. Comparison of refractor velocities with standards given by Schepers, (1975) in the range of 360-430m/s-430-690m/s shows that the subsurface ranged from sandy clay to gravelly dry sands.

4.2. Discussion

From the three locations where the profiling was carried out, there is close similarity in the results obtained. This shows an agreement on the subsurface structure of Unical farm and Anantigha both in Calabar south area (Figure 1). The depth of investigation in this study is almost uniformed. In Unical farm, the depth ranged from 6.7- 8.6m while at Anantigha the depth ranges from 7.8-8.6m. The dip s of the subsurface structures has the same values in Unical farm and location 1 at Anantigha. Whereas, the magnitude of dip in location 2 doubles that in location 1 at Anantigha (Table 1).

The geologic interpretation of the study area as being composed of weathered surface materials and sandy clay is countenanced by previous seismic refraction survey results in Unical farm by Lecky, (1981) and Umoren, (1980). These workers reported the geology of the study area to be composed of tertiary sandy clay.

The depth of investigation in this study could not sampled down to the water table because of the facilities available. In ground water survey in the area in previous works, the water table was established to be within 12-16m, depending on the magnitude of the dip of the area. The source of energy for seismic wave generation in in this experiment was too low to permit investigation into the deeper part of the crust, hence only two layers were possible to study. The high noise level from passing vehicles, noise from birds in the sky led to wrong picking of the arrival time. Also, lack of prints to actually record the arrivals and find their values were sources of errors associated with this survey.

5. Conclusion

The subsurface structure of Calabar south is composed mainly of weathered materials and dry sandy clay. The seismic refraction survey identified a two-layer model from the refraction curves. The energy source was insufficient to sample deeper than too layers, hence the inability of the method to penetrate up to the water table. The findings are in consonance with previous investigations in the study area using the same seismic refraction technique deployed in this study.

To enhance proper understanding of the subsurface structure of Calabar area, a higher energy source that can penetrate deeper in to the subsurface should be employed. The application of seismic refraction study is useful as a subsurface geophysical investigation to substantiate surface geological findings. Seismic refraction is extensively used to provide subsurface information on the depth to basement, depth to water table, engineering geological situation of a proposed site and as a reconnaissance survey in geological mapping. In the light of the foregoing it is gainful to invest in seismic refraction survey.

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