Petroleum and Coal

Article Open Access

Seismic Refraction and Downhole Surveys for Delineation of Geomorphic Features in Parts of the Eastern Niger Delta, Nigeria

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Received September 6, 2019; Accepted February 4, 2020

Abstract

A seismic survey using down hole and seismic refraction surveys was carried out in parts of the Niger delta to delineate the geomorphic features and their effects on the low velocity layer. The study area is demarcated into the western and eastern portions by the Sombreiro River with an elevation of 12m to the west and 50m to the east. The aim of this study is to investigate the weathering and sub-weathering thicknesses and velocities and to relate them to the two distinct elevations and physio-graphic profiles of the area under investigation. Using the time-intercept method for inter-pretation, weathering thicknesses ranges from 1.3m to 4.7m while sub- weathering thicknesses range from 11.4 to 35.7m in the area. Similarly, weathering velocities varies between 119m/s to 941m/s, with the sub – weathering velocities having values between 425m/s and 1665m/s. Similarly, the consolidated layer velocities ranges from 1610m/s to 2208m/s. Geological interpretation of the results west of the Sombreiro River (with lower elevation) revealed a thicker sub- weathering zone and higher sub-weathering velocity profile compared to the east. The disparity in weathering thicknesses and velocities between the two sections of the study area was revealed by the interpretative contour maps as a closure with a defined north- south (N-S) trend along the escarpment as defined by the river. The Sombreiro River is therefore believed to be a fault or erosion controlled escarpment.

Keywords: *Geomorphic features; Seismic refraction; Down hole; Low velocity layer; Sombreiro River; Niger Delta.*

1. Introduction

Seismic velocities that are lower than the velocity in water usually imply that gas is present and (air or methane resulting from the decomposition of vegetation) fills at least some of the pore spaces [1-2]. Such low velocities are usually seen only near the surface of the Earth's crust in a zone called the weathered layer or the low-velocity layer [3-5]. This layer, which is usually 4 to 50m thick is characterized by seismic velocities which are not only low (usually between 250 and 1000m/s) but at times highly variable [2,4,6]. The characteristics of this layer include the high absorption of seismic energy, the low-velocity and the rapid changes in velocity which have a disproportionately large effect on travel times, the marked velocity change at the base of the LVL and the very high impedance contrast at the base of the LVL [2,4,7-8]. Opara *et al.*, [4] and Olumide *et al.*, [5] explained that the near-surface of the earth has been described as a nuisance to seismic reflection exploration for several reasons which may include the following low velocities that cause large time delays to reflected signals. Also, high absorption of seismic waves by this layer causes attenuation of reflections and lateral variations that causes relative time delays. Similarly, most failures of buildings and road constructions today are signs of the failures of the structural engineering designs in addressing the issue of the LVL. Determination of the velocity and thickness of the LVL is also very important in the design of pattern shot and establishing the base where the shot will be fired. It is also very important in a static correction in seismic exploration work.

Weathering depths and layer thicknesses can be investigated by a number of geophysical techniques such as electrical resistivity, down hole and uphole surveys. However, recent improvements in the down hole method have given it an edge over other methods. Down hole shooting is a reliable and acceptable method of determining weathering depth and velocities during seismic surveys for petroleum exploration. Variations in thickness and velocity of layers are most pronounced near the surface because of the process of weathering which produces a layer of non homogenous and unconsolidated materials at the earth's surface. Seismic shooting within the low velocity layer therefore results in low energy penetration of the subsurface for a given source – energy level thus exciting a greater proportion of boundary waves [8].Variations in the elevation of the surface affect travel times of seismic waves and it is necessary to correct for such variations as well as for changes in the low-velocity layer. Usually, a reference datum is selected and corrections are calculated so that in effect the shot points and geophones are located on the datum surface. Occasionally, special studies are made of the weathering layer to determine more accurately the depth and velocities of the weathered and consolidated layers respectively. These were done in the present study by the means of the seismic refraction and down hole surveys. In uphole surveys, a hole is drilled well below the suspected level of the weathering and charges are set off at intervals up the hole into a short spread of geophones. On the other hand, in an LVL survey, a single charge near the surface is shot into a short geophone spread from both ends.

In general, uphole surveys gives a much better result when compared to other refraction seismic methods, and is therefore preferred. Both methods however, use single geophones per trace, spaced so that several others are within 20 to 30 metres of the hole and the next group are spaced further away up to a maximum of about 200m. The first breaks are then plotted in various ways to determine the number of layers of weathering, depth of weathering, and velocities of the various layers. The plot for the up hole geophone changes abruptly where the shot enters the low velocity layer (LVL); the slope of the portion above the base of the LVL gives the velocity of the weathered layer and the break in slope usually defines the depth of the weathered layer clearly. For the distant geophones, the plot is almost vertical at first since the path length changes very little as long as the shot is in the high speed layer. However, when the shot enters the LVL there is an abrupt change in slope and the travel time increases rapidly as the path length in the LVL increases. The refraction velocity at the base of the LVL is obtained by dividing the time interval between the vertical portions of the curves for two widely separated geophones.

The present study therefore exploited the inherent attributes of the down hole seismic surveys to identify the weathering profile of the study area and to relate it to the sharp and steep escarpment defined by the Sombreiro River. This approach is expected to reveal any possible relationship between the identified geomorphic features and the weathering characteristics of the earth's surface in the study area.

1.1. Location and physiography of the study area

The project area lies within latitudes $05^0\ 00^1$N and 05^030^1N and longitudes $06^0\ 10^1$E and $07^0\ 10^1$E. It covers an approximate surface area of about 468.50 sq km (Figure 1). The area is located approximately 100km northwest of Port Harcourt and 70km from Owerri. It is bounded in the north by the Assa and Ibigwe Oil Fields, the Ahia Field in the south, and the Obagi Oil Field in the west. There is a good network of both tarred and motorable earth roads within the prospect area. The major ones are the Port Harcourt/Owerri Road and the Elele/Omoku Road. Two major pipelines bearing oil and gas traverse the prospect from north to south. The oil pipeline belongs to the Shell Petroleum Development Company (SPDC) while the gas pipeline which connects from the Obrikom gas re-injection plant is owned by the Nigerian Agip Oil Company (NAOC). The project area is differentiated into two distinct elevations and physiographic profiles: a western and eastern portion separated by the Sombreiro River with an elevation of 12m to the west and 50m to the east. The Sombreiro River runs from north to south of the project area with several tributaries. It stretches to a distance of about 4 km dividing the area into two with about one third to the western portion. The area west of the Sombreiro River is characterized by low elevations and swampy terrain. This area is merged with the relatively higher topography east of the river by a sharp but steep escarpment (Figure 2).

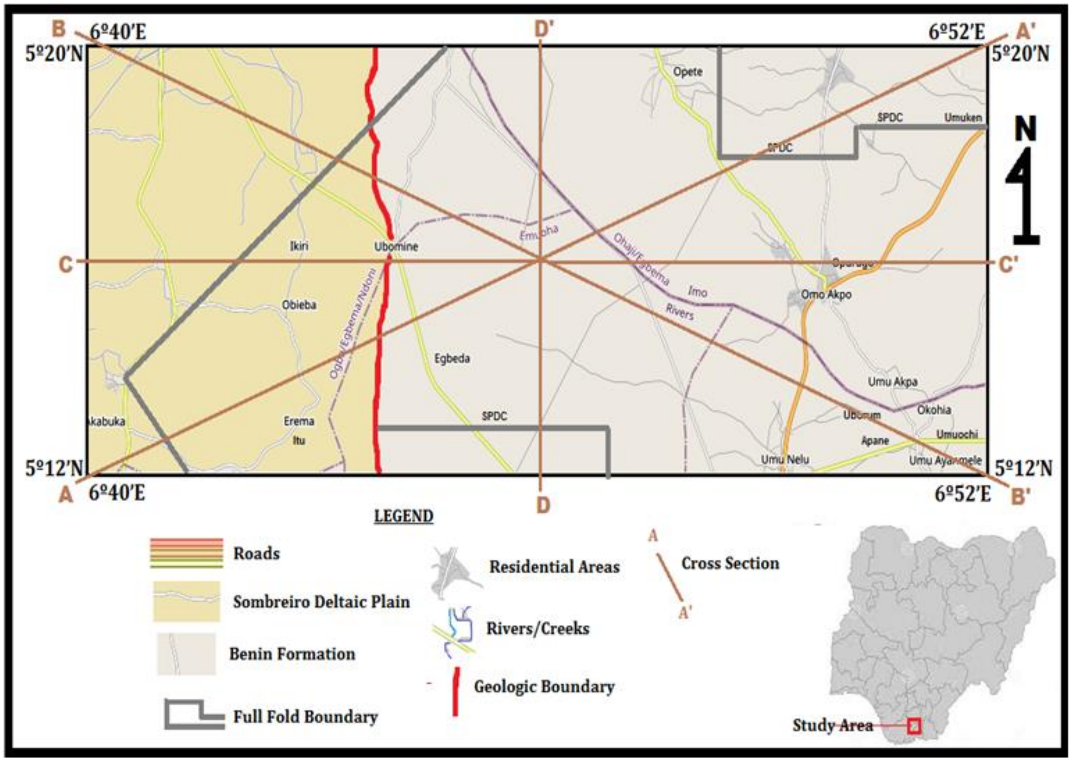

Fig. 1. Geology/location map of the study area

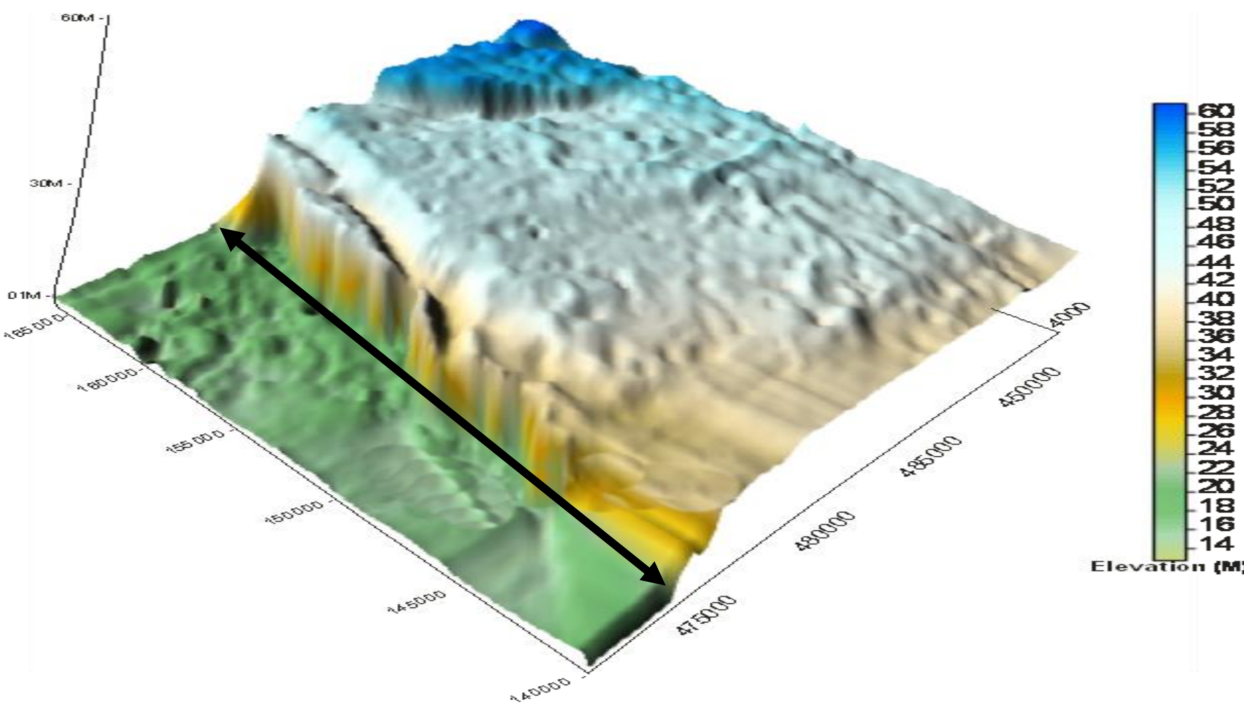

Fig.2. Surface elevation plot of the survey area showing an escarpment (The thick black line indicates where the basin of the Sombreiro River started)

1.2. Geomorphology and local geology of the study area

The main vegetation of the area is the secondary re-growth forest. However, there exists a large proportion of thick uncultivated bush with wooded vegetation and extensive raffia palm forest especially around the Sombreiro river flood plain and river bank typical of the tropical rain forest. The vegetation consists generally of trees, shrubs, herbs, and grasses.

The geomorphology and geology of the Niger delta have been extensively described by various authors [28-32]. The formation of the present-day Niger delta started during Early Paleocene and it resulted mainly from the buildup of fine-grained sediments eroded and transported by the River Niger and its tributaries. The subsurface geology of the Niger delta consists of three litho-stratigraphic units (Akata, Agbada, and Benin Formations) which are in turn overlain by various types of quaternary deposits [34].The Quaternary Deposits (normally 40–150m thick) generally consist of rapidly alternating sequences of sand and silt/clay with the latter becoming increasingly more prominent seawards [31,34-36]. The surface distribution of the various geological units of the Niger delta is shown in Table 1 and Figure 3.

Table 1. Geologic and geomorphic units of the Niger delta basin [34]

Geologic/geomorphic units	Lithology	Age
Alluvium(general)	Gravel, sand, silt	Quaternary
Freshwater backswamp, meander	Sand, clay, some silt, gravel	Quaternary
Mangrove and salt water/back-swamps	Medium – fine sands, clay and some silt	Quaternary
Active/abandoned beach ridges	Sand, clay, and some silt	Quaternary
Sombreiro –warri deltaic plain	Sand, clay, and some silt	Quaternary
Benin Formation	Coarse to medium sand with subordinate silt and clay lenses	Miocene
Agbada Formation	Mixture of sand, clay and silt.	Eocene
Akata Formation	clay	Paleocene

Geologically, the area is underlain by the Benin Formation also known as the coastal plain sands. Some of the geomorphological units found in the area include the Sombreiro deltaic plain of the Quaternary sediments of the Niger Delta. The Sombreiro deltaic plain is made up of sand/clayey sand and consists of intercalations of silt, clays and peat clays. The topmost portions of the sediments are often lateralized [37]. The Niger Delta is made up of three generalized lithostratigraphic units (from oldest to youngest) namely Akata, Agbada, and the topmost Benin Formation [31,33]. The Akata Formation is the basal unit of the Niger Delta and consists of massive monotonous and generally dark grey marine shales. The formation is generally very rich in fauna and flora remains [33]. Sandstone lenses (rings) occur near the top of the formation, particularly at the contact with the overlying Agbada Formation. Akata Formation is the major source rock for the hydrocarbons of the Niger delta [31-33]. Its thickness is uncertain but may reach 7000m in the central part of the delta with the age ranging from Paleocene to Holocene [32,38]. The Agbada Formation that overlies the Akata (basal) Formation is a paralic sequence represented by an alternation of sandstones and shales in various proportions [31].

This formation forms the hydrocarbon prospective sequence (reservoir) in the Niger Delta and most exploration wells are terminated in this formation [31-32,38]. The sandstones are the main hydrocarbon reservoirs while the shales constitute the cap rocks or seals [32,39]. The age of the formation decreases from *Eocene* in the north to *Pleistocene* in the south and *Recent* at the delta surface. The Benin Formation is the youngest and the shallowest part of Niger Delta's lithostratigraphic sequence. It is composed almost entirely of non-marine sands and gravels. The formation has high sand content (over 90 %) and little shale. The sands have shale intercalations that become more abundant towards its base [31-33]. To date, only oil shows have been found associated with this highly porous and generally fresh water-bearing sand formation [33,40]. The formation reaches a maximum thickness of 2,100m in the central Niger Delta where there is maximum subsidence of the basement [32]. The age ranges from *Oligocene* in the north to *Recent* in the distal part of the Niger Delta.

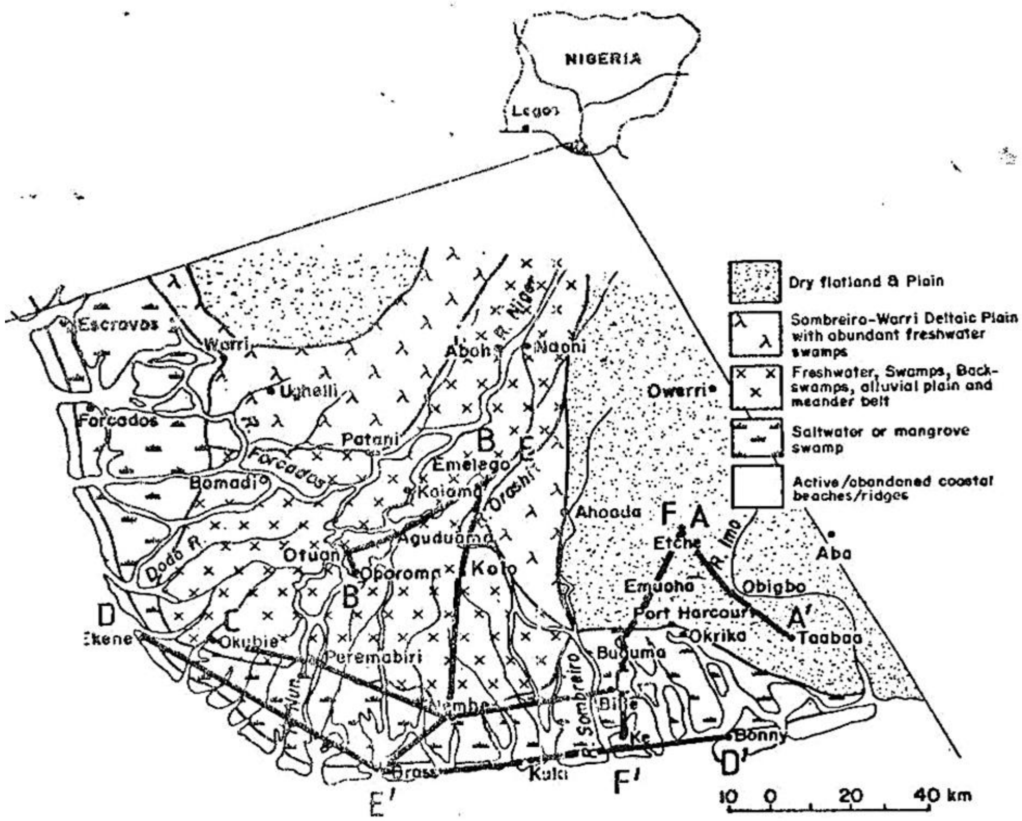

Fig. 3. The major geomorphological units of the Niger delta basin (after [34])

2. Data acquisition and reduction

This study used two seismic data acquisition methods which include the down hole seismic survey and the surface refraction seismic survey. The downhole survey was initially intended to be used entirely for this project as it is one of the best methods of investigating the near-surface and finding the thickness and velocity of the low-velocity layer. However, surface LVL refraction survey was incorporated due to the challenges of lack of access road to the planned shot location points and the near absence of surface water in many of the proposed down-hole shot point locations. The down hole is preferred to the conventional surface refraction method because it uses less number of shots and therefore suffers less shot variation errors. Source/shot point is usually close to the surface while a single or array of receivers (hydro-phones) are placed down the hole. The entire project covers an estimated 468.50 sq.km of surface area. The shot points are distributed over the 4.0 X 4.0 sq.km grid system. The shot points were located at the interception of source and receiver lines used for the normal seismic reflection recording of the study area. A total of 36 shot points (30 downhole and 6 seismic refraction shot points) were used for the data acquisition of the study area. For the surface LVL refraction survey, 1m holes were drilled on either side of the geophone spread. Shots were separated at 5m, 70m, and 135m intervals from the last geophones on either side of the spread. Between 5 and 10 electric detonators were used as energy sources while 12 pieces of 10 Hz SM4 geophones were centered on the shot point. Six shots (3 forward and 3 reverse) were taken for this study.

A depth of 63m was drilled for each downhole point with measurements stopped at the depth of 60m. The holes were drilled using the rotary drill method with water used in the drilling of the short holes. Water mixed with drilling muds helped to soften the soil, acted as a weight upon the drill bit as it rotated inside the ground and helped to flush out the drill cuttings into the mud pit. Lithologic samples (from the drill cuttings) were collected at interval depths of 3m, washed, and placed in the sample box. The reason for the collection was to use them to reconstruct the vertical profile of the soil of the uphole point. This was used to correlate velocity changes with changes in lithology as depth increases. The following pieces of equipment were used during the drilling operation: Each of the down-hole survey locations was drilled to 63 m depth. The recording hole was cased with plastic casings and logged to a maximum depth of 60 m; the extra 3m is to allow for possible backfilling of the hole due to collapsing. An energy source hole of 1 m depth was drilled 2 m away from the recording hole and was used to bury the explosive charges. Drilling was by the semi-manual, engine-powered rotary method. This involves rotating the drill stem by manual labour and pumping water through to flush out cuttings. Drilling mud was formulated from drilling chemicals (bentonite and EZ mud) to provide borehole stability and transportation of cuttings to the surface. A downhole cable with 11 hydrophones positioned at different intervals was used. The first hydrophone was separated 1 m from the top of the hole while the next two were separated 2 m from each other. The next five were separated 5m from each other, followed by the next 3 separated 10m from each other. Each of the hydrophone depths was marked with tape on the cable/rope. After the drilling of the hole at the intersection of the source and receiver, an explosive (dynamite) of 0.1kg was buried at a depth of 1m close to the drilled hole (about 1m offset from the hole). The detonation of the explosives released a huge amount of energy which vibrated the ground and was subsequently transmitted into the ground as wave energy. This energy was detected by the receivers (hydrophones) and transmitted to the seismogram, which recorded the signals as travel time signals. In processing the data, first break arrival times were picked for various shots. First break time is the first pick up time recognized for any trace, and it is a parameter of interest in the interpretation of down hole data [41]. Near-surface depth models were computed from picked first break time, and to achieve this, the time was plotted against each hydrophone position in the drilled well [42].

The recording intervals were graduated in such a manner to ensure that none of the subsurface layers were missed out. This configuration yielded the following sample points: 1m, 3m, 5m, 10m, 15m, 20m, 25m, 30m, 40m, 50m, and 60m from the surface. The data for both the downhole and refraction survey was acquired with the OYO GEOSPACE MCSEIS Model 160MX V5.42 portal digital recorder. This instrument is a 24 channel signal enhancement seismograph that has a combination of features such as speed, accuracy, and lightweight, with visible CRT display and electro-sensitive plotter. This instrument automatically stores data for subsequent hard copy printouts. The data acquisition electronics allows selection of sample rates from 1/8 of milliseconds to 4 milliseconds and also incorporates both high cut and low cut filters to provide cleaner signals and extended ranges. The data for both the downhole and surface refraction profiling were recorded on the data sheet and the magnetic tape for further play back. The sample plot of the time-distance graph for the forward and reverse shooting of the surface refraction profiling survey is shown in Figure 4. The trace size and appearance were easily adjusted to meet specific requirements for immediate display.

The surface refraction profiling spread consists of 12SM4, 10HZ geophones laaid on the surface but centered about the intersection. The total spread length was 70 m with the complete acquisition consisting of 6 shots, 3 forward shots, and 3 reverse shots. Shots were recorded at 135 meters, 75 m, and 5 m off each end of the spread. This was to ensure that deeper information on the subsurface was obtained. For each of the shots recorded, holes were drilled to the depth of 1 m, while 5 to 10 caps (detonators) were used as the energy sources. The first breaks (arrivals) were picked from each monitor record either manually by visual inspection or with McSeis Up-hole software. First break travel time can be picked up automatically by the use of artificial intelligence [42-43]. The geophone spacing in a refraction survey generally depends on the depth of exploration and the subsurface details required. As a rule of thumb, the total spread length should be three to five times the maximum depth anticipated [43-45]. For this project, the interpretation method used for the intercept-time method assumed that the subsurface layers are present with uniform velocity. Velocities for the overburden and refractor layers were calculated as distance travelled divided by time elapsed for each portion of the time-distance plot using cross-over distance(critical distance) and intercept time techniques. Because both the intercept time and the critical distance are directly dependent upon the velocities of the two materials and the thickness of the top layer, they can be used to determine the depth to the top of the second layer using equation1:

$$z_1 = \frac{x_c}{2}\sqrt{\frac{v_2 - v_1}{v_2 + v_1}} \qquad (1)$$

It can also be calculated using intercept time as given below

$$z_1 = \frac{T_1}{2}\frac{v_1 v_2}{\sqrt{v_2^2 - v_1^2}} \qquad (2)$$

For the two-layer case, the sub-weathering depth is given by the formula

$$z_2 = \frac{1}{2}\left(T_2 - 2Z_1\frac{\sqrt{V_3^2 - V_1^2}}{V_3 V_1}\right)\frac{V_3 V_2}{\sqrt{V_3^2 - V_2^2}} \qquad (3)$$

The critical ingredients for successful refraction profiling include accurate placing of sensors, the timing of relative arrivals to precisions of milliseconds, and the calculation of the bedrock depths and velocities. The refraction survey is a good tool for continuous profiling and helps to determine lateral changes in the refractor velocity.

3. Results interpretation and discussion

The acquired data were analyzed using an advanced Microsoft Excel based processing software. The weathered layer model and its calculated values were generated using the intercept method which applied the time-distance plot (Figure 4). Contour maps and interpretative cross-sections of the various variables were also generated to appreciate their spatial variation across the study area.

The results of the downhole and surface refraction survey revealed that the area is dominated by a two (2) layer velocity model with one (1) layer models observed in only five locations along the escarpment (Figure 2). Weathering layer velocities ranged from 119m/s to 941m/s with a mean value of 341.14 m/s while the sub-weathering velocities ranged from 425m/s to 1665m/s with a mean value of 776.48 m/s (Table 2). The consolidated layer velocities ranged from 1610m/s to 2208m/s with a mean value of 1791.22 m/s. Similarly, weathering thicknesses ranged from 1.3m to 4.7m with a mean value of 2.49 m while sub-weathering thicknesses ranged from 11.4 to 35.7m with an average of 18.56m.

Table 2. Summary of interpreted results of the weathered layer in the study area.

Shot point	Sil/sub-soil classification	Data type
1	0 - 6 m (clayey sand), 6 - 3 6 m (sand), 3 6 - 4 8 m (gravel/hard clay), 4 8 - 6 0 m (sand/hard clay)	Down hole
2	0 - 6 m (sandy clay), 6 - 2 7 m (sand/coarse sand), 2 7 - 6 0 m (coarse sand/clay)	Down hole
3	0 - 3 m (clayey sand)/pebbles), 3 - 6 m (sandy clay), 6 - 6 0 m (coarse sand/clay)	Down hole
4	0 - 2 m (sandy clay), 2 - 9 m (silty sand), 9 - 2 4 m (sandy clay), 2 4 - 3 0 m (sand), 3 0 - 6 0 m (sandy clay)	Down hole
5	0 - 1 2 m (clay), 1 2 - 2 7 m (sandy clay), 2 7 - 6 6 m (medium m coarse sand	Down hole
6	0 - 9 m (hard clay), 9 - 2 1 m (clayey sand), 2 1 - 2 4 m (sandy), 2 4 - 6 0 m (coarse sand)	Down hole
7	0 - 6 m (clay), 6 - 1 8 m (clayey sand), 1 8 - 5 1 m (coarse sand/hard clay), 5 1 - 6 0 m (coarse sand)	Down hole
8	0 - 3 m (clay), 3 - 1 2 m (clayey sand), 1 2 - 4 5 m (coarse sand), 4 5 - 6 0 m (sand)	Down hole
9	0 - 3 m (clay), 3 - 1 2 m (clayey sand), 1 2 - 4 5 m (sand), 4 5 - 6 0 m (coarse sand)	Down hole
10	0 - 1 2 m (clay), 1 2 - 1 8 m (clayey sand), 1 8 - 2 7 m (sand), 2 7 - 6 0 m (coarse sand)	Down hole
11	0 - 3 m (clay), 3 - 9 m (clayey sand), 9 - 2 7 m (sand), 2 7 - 3 6 m (coarse sand), 3 6 - 6 0 m (sand)	Down hole
12	0 - 1 5 m (clayey sand), 1 5 - 3 0 m (sand), 3 0 - 4 5 m (coarse sand), 4 5 - 6 0 m (coarse sand & clay).	Down hole
13	0 - 1 m (clay).	LVL
14	0 - 3 m (silt sand), 3 - 1 8 m (sand), 1 8 - 3 9 m (coarse sand), 3 9 - 6 6 m (med - fine sand).	Down hole
15	0 - 1 m (clay).	LVL
16	0 - 9 m (clay), 9 - 1 5 m (clayey sand), 1 5 - 3 5 m (sand), 3 5 - 5 0 m (coarse sand) 5 0 - 6 0 m (sand).	Down hole
17	0 - 1 m (clay).	LVL
18	0 - 1 m (clay).	LVL
19	0 - 3 m (clay), 3- 25 m (clayey sand), 2 5 - 3 6 m (sand), 3 6 - 6 0 m (coarse sand mixed with clay).	Down hole

Shot point	Sil/sub-soil classification	Data type
20	0 - 6 m (clay), 6 - 1 2 m (clayey sand), 1 2 - 3 3 m (sand), 3 3 - 6 0 m (coarse sand)	Down hole
21	0 - 1 2 m (clayey sand) 1 2 - 3 9 m (sand), 3 9 - 4 5 m (coarse sand), 4 5 - 6 0 m (coarse sand and clay	Down hole
22	0 - 6 m (silty sand) 6-1 8 m (medium sand) 1 8 - 4 8 m (coarse sand),4 8 - 66m (fine-medium sand)	Down hole
23	0 - 9 m (clay) 9 - 2 1 m (clayey sand), 21 - 27 m (sand), 2 7 - 4 2 m (coarse sand and clay) 4 2 - 6 0 m (coarse sand)	Down hole
24	0 - 9 m (sandy clay) 9 - 4 5 m (sand), 4 5 - 6 0 m (coarse sand)	Down hole
25	0 - 6 m (silty sand) 6 - 1 2 (sandy clay) 12 - 51 m (fine-medium sand) 5 1 - 66m (coarse sand)	Down hole
26	0 - 1 m (sandy clay)	LVL
27	0 - 1 2 m (clay), 1 2 - 26 m (coarse sand), 2 6 - 3 6 m (sandy clay), 3 6 - 5 0 m (coarse sand), 50 - 66 m (sand).	Down hole
28	0 - 9 m (clay), 9 - 2 7 m (sand), 2 7 - 6 6 m (coarse sand).	Down hole
29	0 - 6 m (sand), 6 - 9 m (clay), 9 - 3 0 m (sandy clay), 3 0 - 4 5 m (sand), 4 5 - 6 6 m (coarse sand).	Down hole
30	0 - 3 m (silt), 3 - 6 m (sandy clay), 6 - 1 2 m (sand), 1 2 - 1 8 m (fine sand), 1 8 - 3 6 m (medium m sand), 3 6 - 6 0 m (coarse sand).	Down hole
31	0 - 9 m (sandy clay), 9 - 1 5 m (coarse sand), 1 5 - 1 8 m (med. grain sand), 1 8 - 3 3 m (coarse sand), 3 3 - 4 2 m (sand), 4 2 - 6 6 m (fine sand).	Down hole
32	0 - 3 m (silt), 3-6 m (sandy clay), 6 - 1 5 m (coarse sand), 1 5 - 3 0 m (fine sand), 3 0 -3 3 m (coarse sand),3 3 - 6 0 m (medium - fine sand).	Down hole
33	0 - 3 m (silt), 3 - 6 m (sandy clay), 6 - 1 2 m (gravel), 1 2 - 2 4 m (fine sand), 2 4 - 6 0 m (coarse sand.	Down hole
34	0 - 1 m (clay)	LVL
35	0 - 1 2 m (clayey sand), 1 2 - 1 8 m (sand & clay), 1 8 - 2 7 m (fine sand), 2 7 - 4 5 m (sand), 4 5 - 6 0 m (fine sand).	Down hole
36	0 - 9 m (clayey sand), 9 - 1 5 m (coarse sand & clay), 1 5 - 3 0 m (sand), 3 0 - 6 0 m (coarse sand).	Down hole

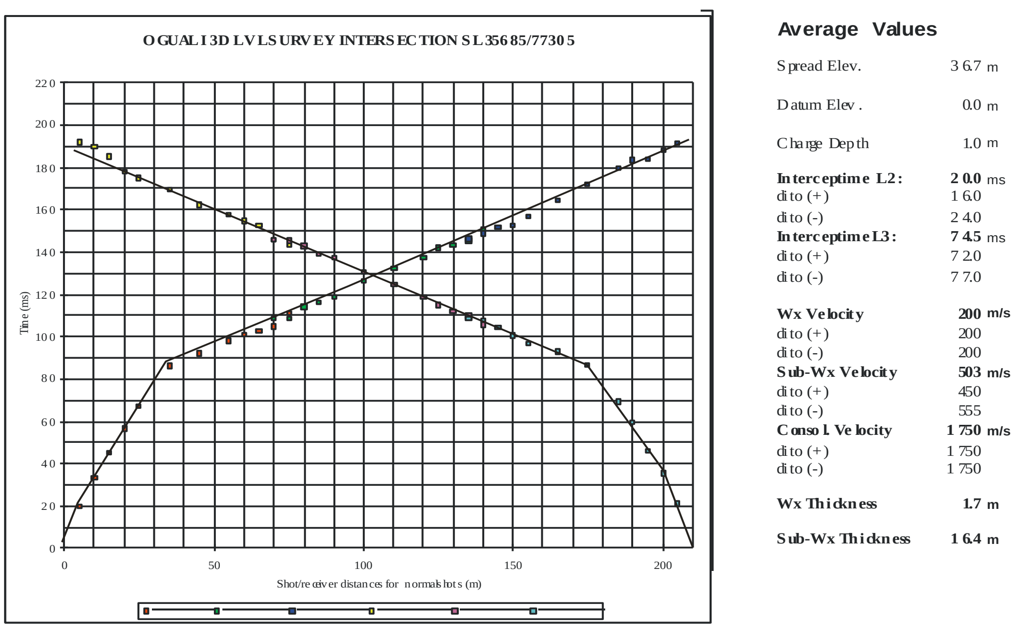

Fig. 4. Typical Time-Distance Plot for LVL survey recorded during the study

The elevation data across the study area, the weathered layer, the sub-weathered layer, and the consolidated layer velocities were used to generate contour maps as shown in Figures 5,6,7 & 8. Similarly, the weathered layer and sub-weathered layer thicknesses were plotted as contour maps in Figures 9 and 10 respectively. There seems to be a substantial variation in the thicknesses of the weathered layer across the areas with different elevations. This shows that elevation has a strong effect on seismic velocities and thicknesses of the subsurface layers in the study area. However, there were no consistent and significant variations in the seismic velocities with lithology. This is because velocity is a function of the degree of compaction (density) rather than lithologic changes.

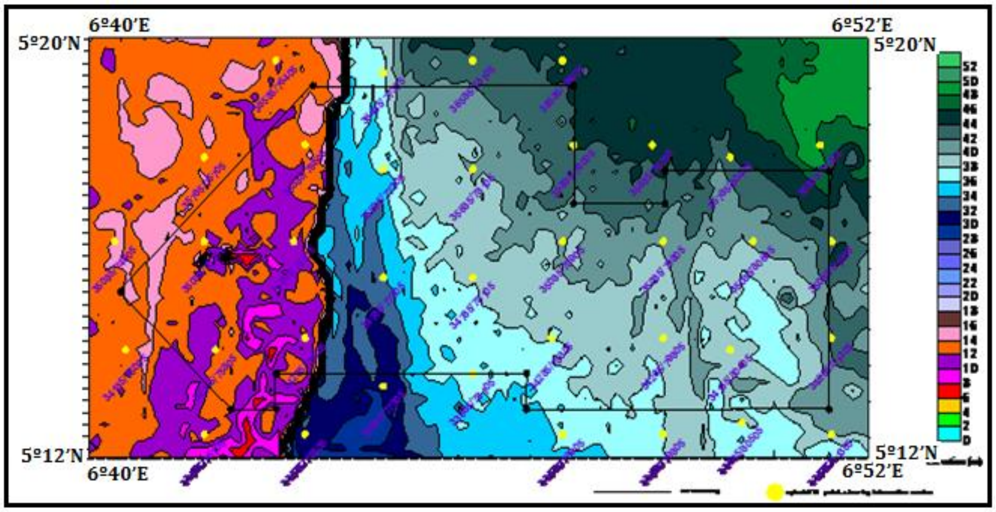

Fig.5. The elevation map of the study area (The black coloured line is the Sombreiro River)

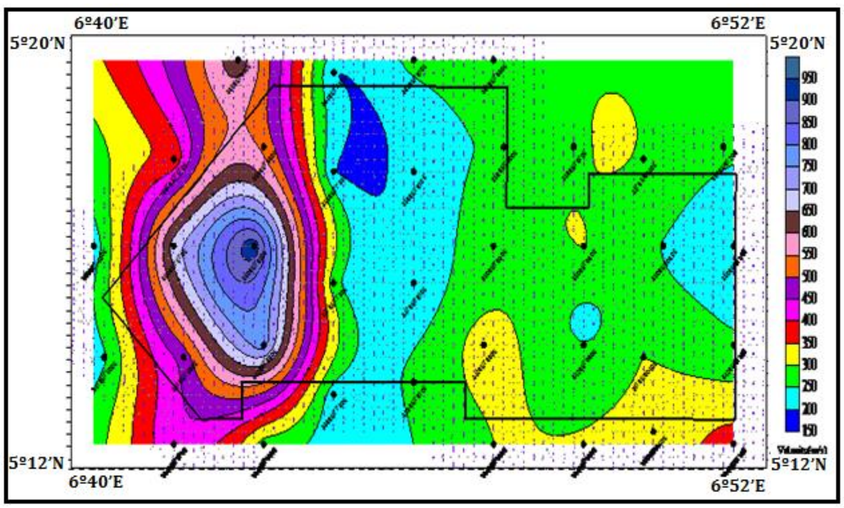

Fig.6. Weathering layer velocity field contour map of the study area

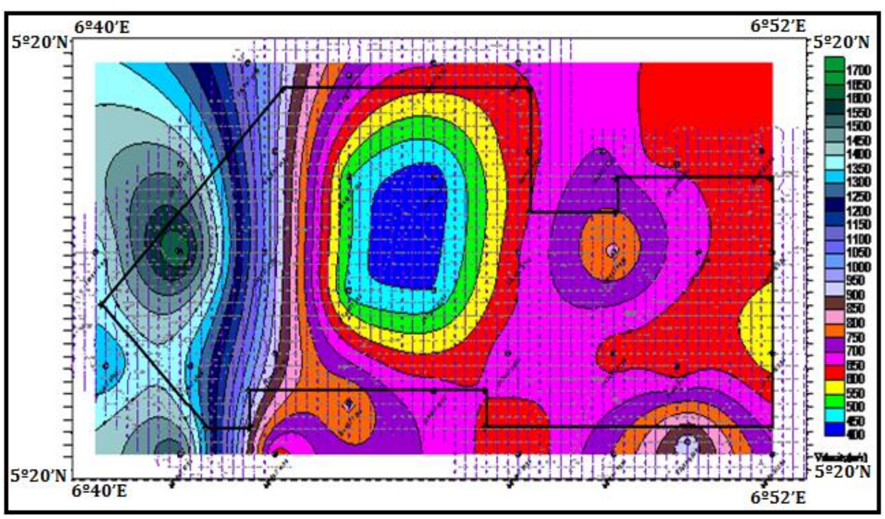

Fig.7. Sub-weathering layer velocity field of the study area

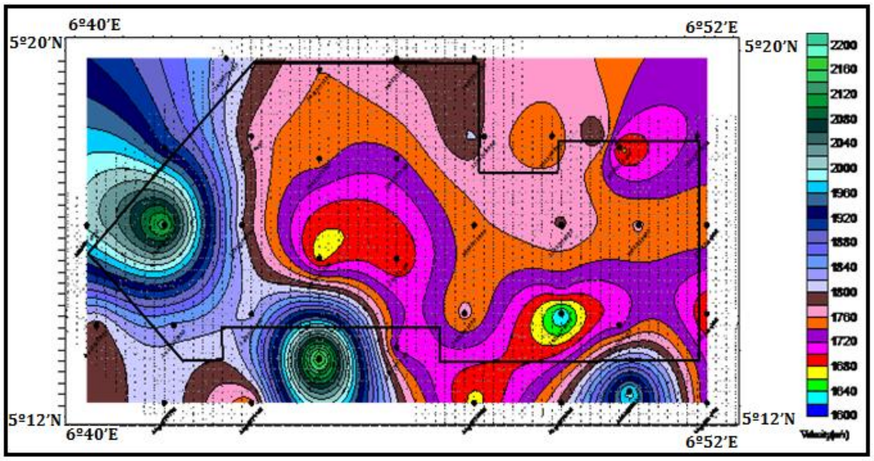

Fig.8. Consolidated layer velocity field of the study area

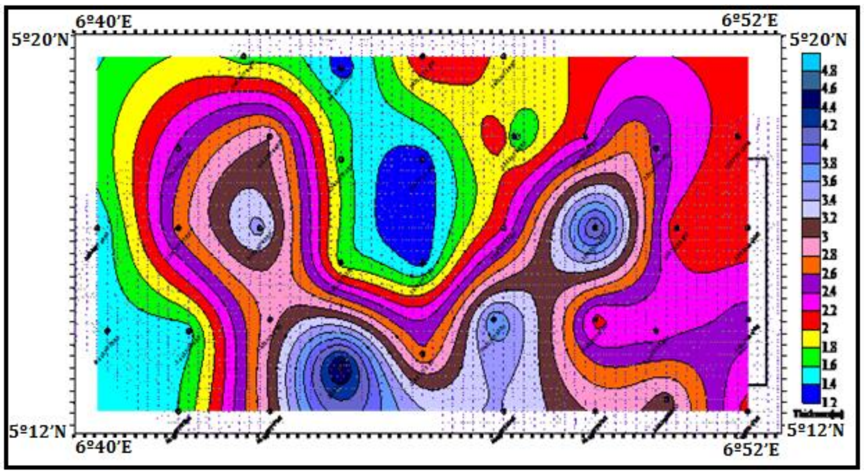

Fig. 9. Weathering layer thickness contour map of the study area

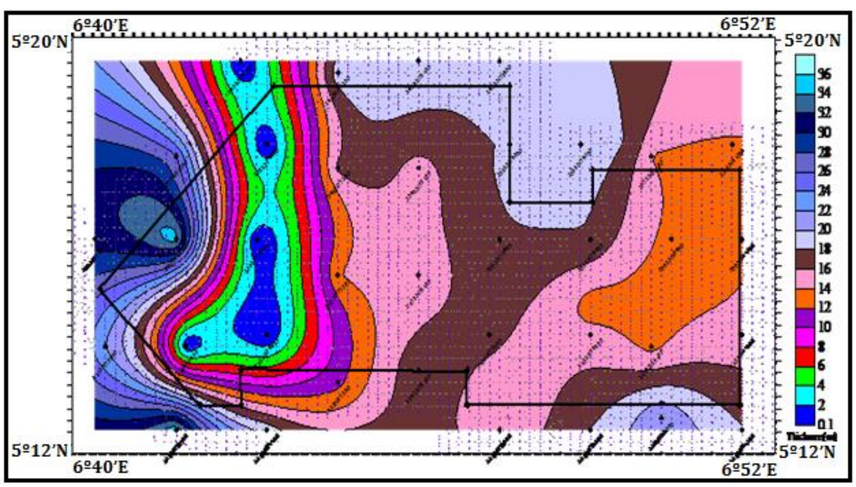

Fig. 10. Sub-weathering layer thickness contour map of the study area

The result of the study as shown in Table 2 and depicted by the contour maps of the weathering layer velocity fields and weathering layer thickness maps revealed an escarpment defined by the Sombreiro River which is shown in black colour (Figure 5) The contour maps show a high degree of spatial variation of the weathering depths and thicknesses around the

Sombreiro Riverbank. This is due to the effect of deposition and compaction of sediments around the river area. The area west of Sombreiro River has higher weathering thickness and weathering velocities compared to the eastern portion. This may be due to the presence of extensive compacted clay materials in the area. A comparison was also made between the total weathering thickness and elevation on the western portion, eastern portion, and from west to east across the Sombreiro River (Figures 11-13).

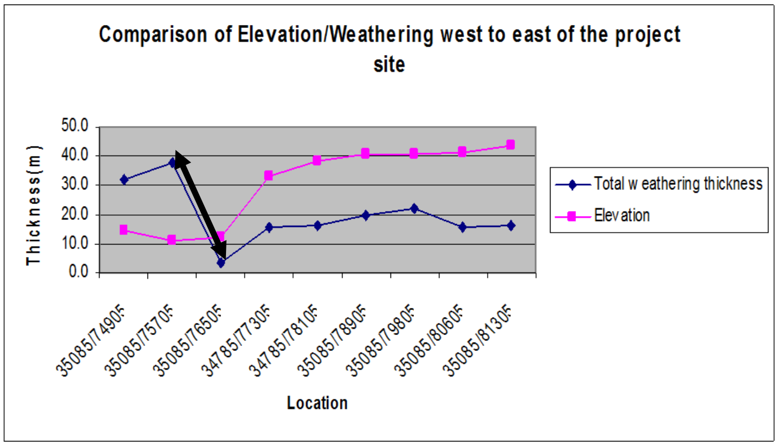

Fig. 11. Comparison of elevation/weathering thickness, west to east of the project area (The black the arrow shows the position of the Sombreiro River)

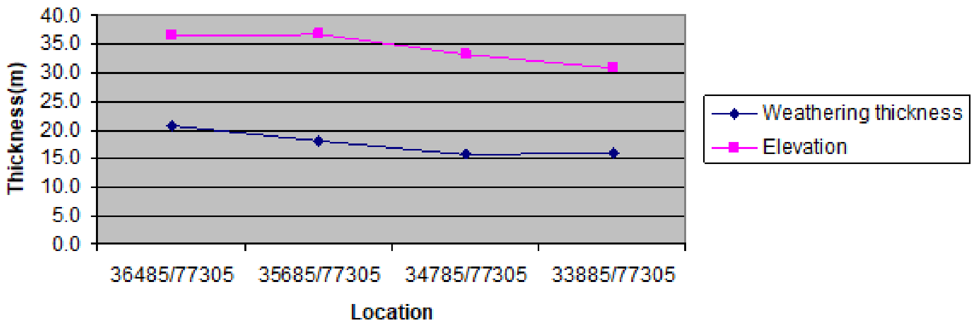

Fig.12. Comparison of elevation and weathering thickness from north to south (east of Sombreiro River)

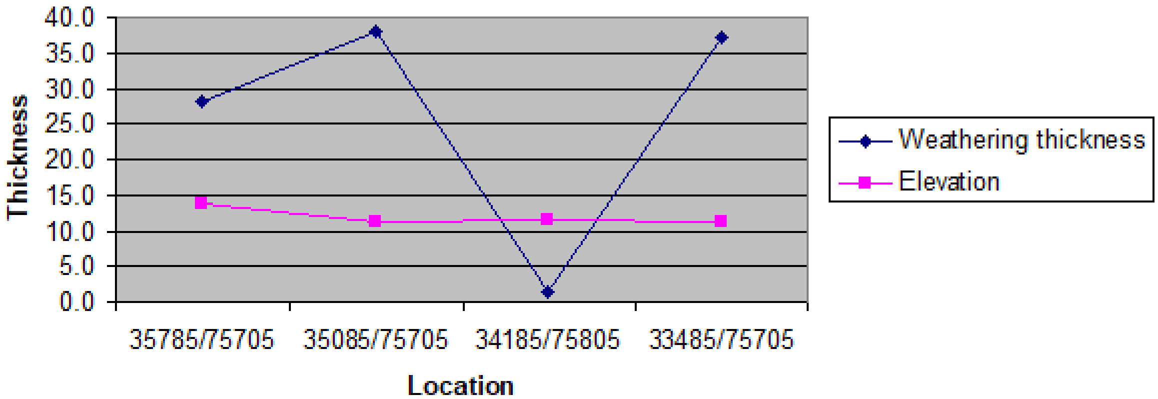

Fig.13.Comparison of elevation and weathering thickness from north to south (west of Sombreiro River)

Similarly, the interpretative cross-sections A- A^1, B- B^1, C-C^1 & D-D^1 showing the depth to the weathered layer across the study area are shown in Figure 14. The result of the interpretation of the cross sections revealed that the western portion with lower elevation has higher sub weathering thickness while the eastern portion with higher elevation has lower sub-weathering thickness. There appears to be a zone of structural weakness across the Sombreiro River which is represented by a sharp drop in both the elevation and sub weathering thickness. This zone of weakness is believed to be an erosional surface or may have been tectonically (fault) controlled. However, faults are generally difficult to map within sedimentary formations because they are usually masked by thick overburden [46]. The sudden increase in weathering depth across the zone especially close to the Sombreiro River suggests relatively high porosity and permeability. Since porous and permeable rocks have a greater ability to hold water, the low seismic velocities explain why seismic wave velocity is markedly attenuated in those areas. In many areas, weathering depth usually corresponds to the groundwater table [2]. Because of the unconsolidated nature of the weathered layer, the high porosity values and presence of fluids in the pore spaces, seismic shooting in the weathered layer usually results in low energy penetration of the subsurface for a given source energy level thus exciting a greater proportion of boundary waves [4-5,8].

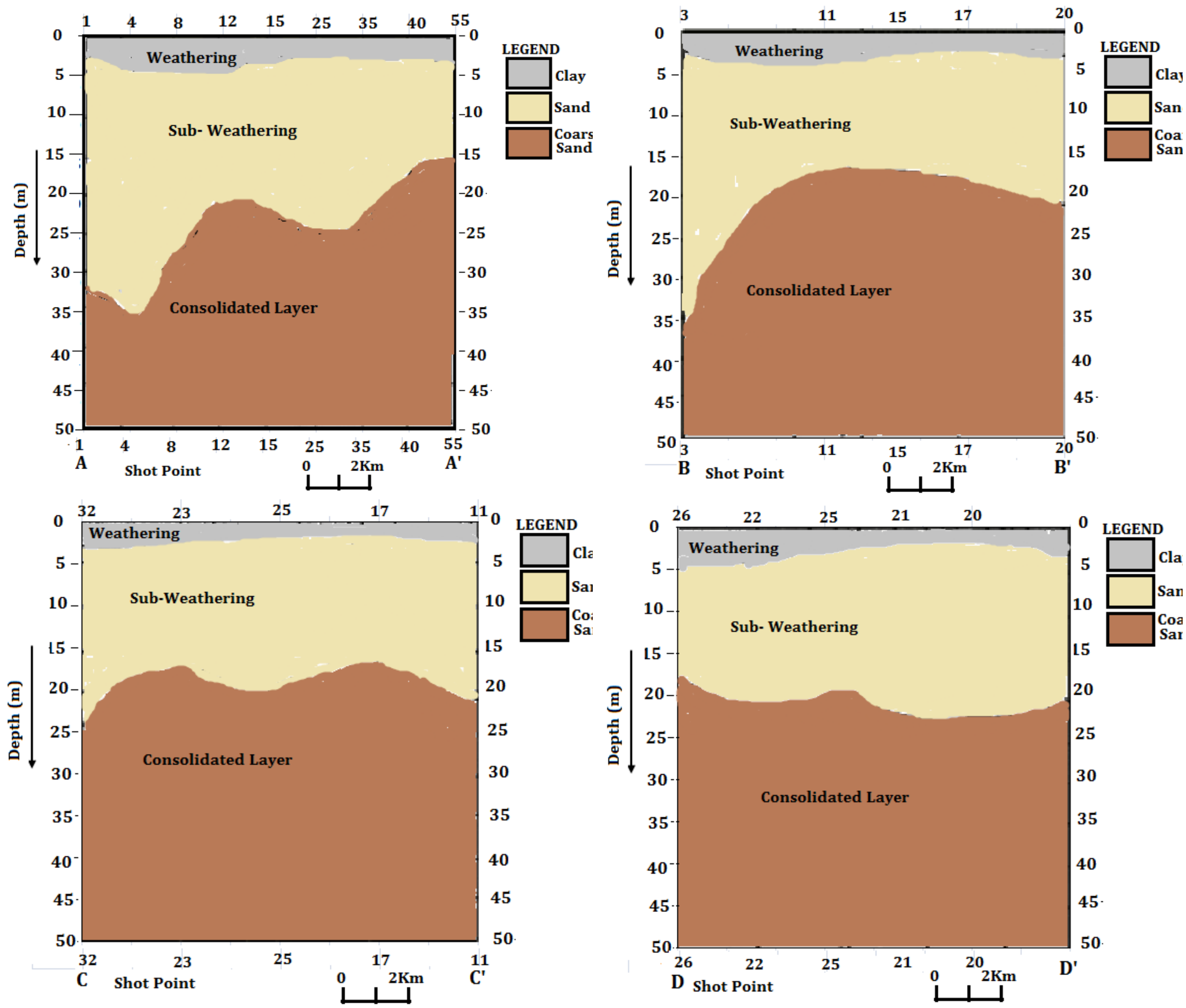

Fig.14. Interpretative cross-sections A- A^1, B- B^1, C-C^1 & D-D^1 showing the depth to the weathered layer across the study area

The range of velocities for the weathered and consolidated layers obtained in this study are in agreement with the findings obtained from previous studies carried out in the Niger Delta [3-5,18,47]. Studies carried out at Sg. Udang, Melaka., have revealed that the velocities of the weathered and consolidated layers are respectively in the range of between 450 and 900m/s and between

1600 and 2000m/s respectively with the weathered layer having a regional average thickness of approximately 6m [27]. Results of the study in the southeast Niger delta revealed an average weathered layer velocity of 500m/s and an average consolidated layer velocity of 1736m/s [23]. Similarly, in another study in the Southern Niger Delta, the velocity of the weathered layer in the area was estimated to be between 250m/s and 800m/s [47], while the study in north-central Niger delta estimated the weathered layer velocity to vary between 119m/s to 941m/s [27]. Studies on the effects of the weathered layer carried out in the Niger Delta revealed that the velocity of the low -velocity layer ranged between 144 and 996m/s with a regional average of 407m/s while the thickness of the low-velocity layer varied between 3.0 and 9.6m with a mean value of 5.0m. Also, the velocity of the consolidated layer was observed to be between 1449 - 1812m/s with an average value of of1738m/s [4]. Opara *et al.*, [4] further recommended that shots for reflection seismic surveys in the area should be located at a minimum depth of 9.6m in the area to eliminate the effects associated with the low-velocity layer. These findings, therefore, show that the velocity of the weathered layer obtained in this study is practically within the range obtained from the previous studies in the Niger Delta.

4. Summary and conclusion

Detailed down hole and seismic refraction profiling survey studies of the study area revealed that the area is dominated by a two (2) layer velocity model with one (1) layer models observed in only five locations along the escarpment. Weathering layer velocities ranged from 119m/s to 941m/s with a mean value of 341.14 m/s while the sub-weathering velocities ranged from 425m/s to 1665m/s with a mean value of 776.48 m/s. The consolidated layer velocities ranged from 1610m/s to 2208m/s with a mean value of 1791.22 m/s. Similarly, weathering thicknesses ranged from 1.3m to 4.7m with a mean value of 2.49 m while sub-weathering thicknesses ranged from 11.4 to 35.7m with an average of 18.56m. In conclusion, the down hole and seismic refraction survey revealed predominantly a two-layer geologic model for the weathering thickness and velocity. Hence, the combination of the two methods has been found very useful in studying subsurface characteristics of the area for application in engineering foundation studies by site civil engineers [3]. Its application in reflection seismic data acquisition and processing by geologists, geophysicists, and seismologists are also well documented [4-5,25]. Finally, the information provided by this study can be used to infer the presence of subsurface structures in the study area as well as determine the depths below the weathered layer that are most suitable for the acquisition of good quality seismic data in the area [4-5,25].

Similarly, the uphole and seismic refraction profiling surveys were used to map the subsurface to determine the weathering and sub-weathering thicknesses and velocities within the study area. The top of the consolidated layer and weathered zones were also defined. Good data quality was obtained throughout the survey which allowed reliable interpretation to be achieved. Contour maps of the seismic models were created to show the location of the erosional lineament running across the study area. The contour maps revealed a correlation of the geomorphic features with the Sombreiro River. The subsurface linear features defined by the contour maps have a north-south (N-S) orientation. The study area is divided into two structural regions: the western portion of the Sombreiro river which has a low elevation, thick sub-weathering layer, and high sub-weathering velocity and the eastern portion which has a high elevation, low sub-weathering layer thickness, and low sub-weathering velocity.

It can be concluded from the findings of this study that the down hole and refraction (LVL) survey methods were very useful in providing subsurface information over large areas at a reasonable cost and were therefore very effective for investigating geomorphic features within the study area.

5. Recommendation

Based on the above findings, we, therefore, recommend as follows:

1) The data points on the acquisition grid should be established at a closer interval to obtain a better subsurface definition of the geological structures.

2) Seismic reflection data acquisition should be carried out across the area below the average weathered layer thickness of 2.493 m.
3) Uphole and seismic refraction surveys can be used to establish the water table in most cases.

Acknowledgements

The authors extend profound gratitude to the Management of United Geophysical Nigeria Ltd, for providing the enabling environment during the entire period of the data acquisition and Interpretation. The support of the Management of the Federal University of Technology, Owerri is is also highly appreciated.

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