A Comparative Study of Down - Deep Hydrophone Seismic Refraction Survey and Drill Logs for the Determination of Near Surface Layer Velocity and Thickness Over 'Galos' Field, Niger Delta, Nigeria

Ofomola M. O.
Department of Physics, Delta State University, Abraka
Email: ovirimerrious@yahoo.com

ABSTRACT
Uphole acquisition was conducted to determine the weathering thickness and velocity of strata layer, in essence obtain values for static correction to be used in the processing of reflection data. Drill logs from each Uphole point was used in conjunction with the theoretical interpretations as a physical set of data to aid in making inferences for boundary distinction. Fifty two (52) Uphole locations were drilled and logged. Each location was drilled to 66m and logged to 60m. Litho logy from the bore samples reveals dominantly sand and clay units. The sand sizes ranges from fine to coarse.The records / playbacks have good signal quality with distinct first break times. The UDISYS interpretation software guided by surface (shot depth) correction and shot offset correction displayed a two-layered case. Analysis on the weathering thickness and velocities within the prospect area reveals that uphole locations have weathering thickness ranging from 2.7m to 11.0m. The highest velocity within the weathering layer is 924m/s (254m/s to 924) while the velocity of the consolidated layer ranges from 1528ms to 1927ms. Appreciably, this correlates with the formation samples collected at various uphole lithology logs. More so, it is of interest to note that low velocity layer / weathering thickness within the prospect area synchronized with previous study of the Niger Delta weathering velocity layer.
Keywords: Drill-hole, down-deep, Critical angle, Near surface, weathering layer.

1. INTRODUCTION

The weathering layer is a critical zone in all seismic operations. It is characterised by loosed and unconsolidated materials, thereby having low transmission of seismic waves, which results at the generation of multiples (at the base of the layer) during seismic reflection/refraction survey. Shots taken in this layer tend to be of low frequencies because the layer is capable of absorbing high frequency signals and releasing lower frequency ones (Ogagarue, 2007). However, since this higher frequency signals gives the subsurface information required, it is appropriate that shots are taken below this unconsolidated layer in order to acquire good quality data.

There is a great disparity in the velocity of the weathered layer (Low Velocity Layer) and that of the underlying consolidated strata, and this variation causes error in the arrival time of the reflected/refracted vibrations associated with the small changes in thickness of the weathered layer. Consequently, the low velocity layer data is important in removing the effect of topographic differences for the various shot points taken on a spread, thereby aiding the processed data produce a true picture of the subsurface.

In order to determine the thickness and velocity of the weathering layer, the uphole seismic refraction survey is carried out. This will help in taking a decision on the drilled and charge depths on any seismic operation. Uphole data are also utilized in the computation of statics during subsequent processing of seismic reflection data.
In a typical uphole survey, the hole is drilled to a depth of 63 m and then logged to about 60 m where shots are laid (in the case of offset-geophone) or where hydrophone is lowered (in the case of down-deep hydrophone).

2. LOCATION AND GEOLOGY

The study area (Figure 1) lies within the jurisdiction of Bayelsa and Delta state in the Niger Delta of south central Nigeria. The project spans nine (9) Local Government Area. These are Southern Ijaw, Sagbama, Yenegoa, Kiama, Ekeremor, Kolokuma / Opukuma, Patani, Ughelli south, and Bomadi. Fishing, farming, logging and palm oil processing are the major occupation of the people. The language spoken by the people within the block are Ijaw, Ewu and Urhobo.

The concession is in the Nigeria West Belt between latitude 10° 00'N and 14° 00'N and longitude 39° 00'E and 42° 50'E (Figure 2). The vegetation of the area is high forest, generally dominated by dense rain forest with light shrub at the riverbank. Many oil palm, raffia palm, bamboo trees and cane rope can be observed within the project block.

Three distinct facies belts have been identified in the Niger delta (Short and Stauble, 1967; Asseez, 1989). The Benin Formation consists of predominantly massive, highly porous fresh water-bearing sandstone, with local interbed of shale. The sand and sandstone are coarse-grained, very granular and pebbly to fine-grained. It is a continental deposit of Miocene to younger age and has a thickness of up to 2,100 meters.

The Agbada Formation consists of alternating sandstones and shales of the delta front, distributary-channel and delta plain origin. The sandstones are medium to fine grained, fairly clean, locally calcareous, glauconitic and shelly with dominantly quartz and potash feldspar with subordinate amounts of plagioclase, kaolinite and ellite. It constitutes the main hydrocarbon habitat in the Niger Delta.

The Akata Formation is made up of a sequence of under-compacted marine clays with minor sandy and silty beds. The shales are dark grey, medium hard and may contain lenses of abnormally high-pressured siltstone or fine-grained sandstone. It is thought to be the main hydrocarbon kitchen of the Niger Delta (Doust and Omatsola, 1990).

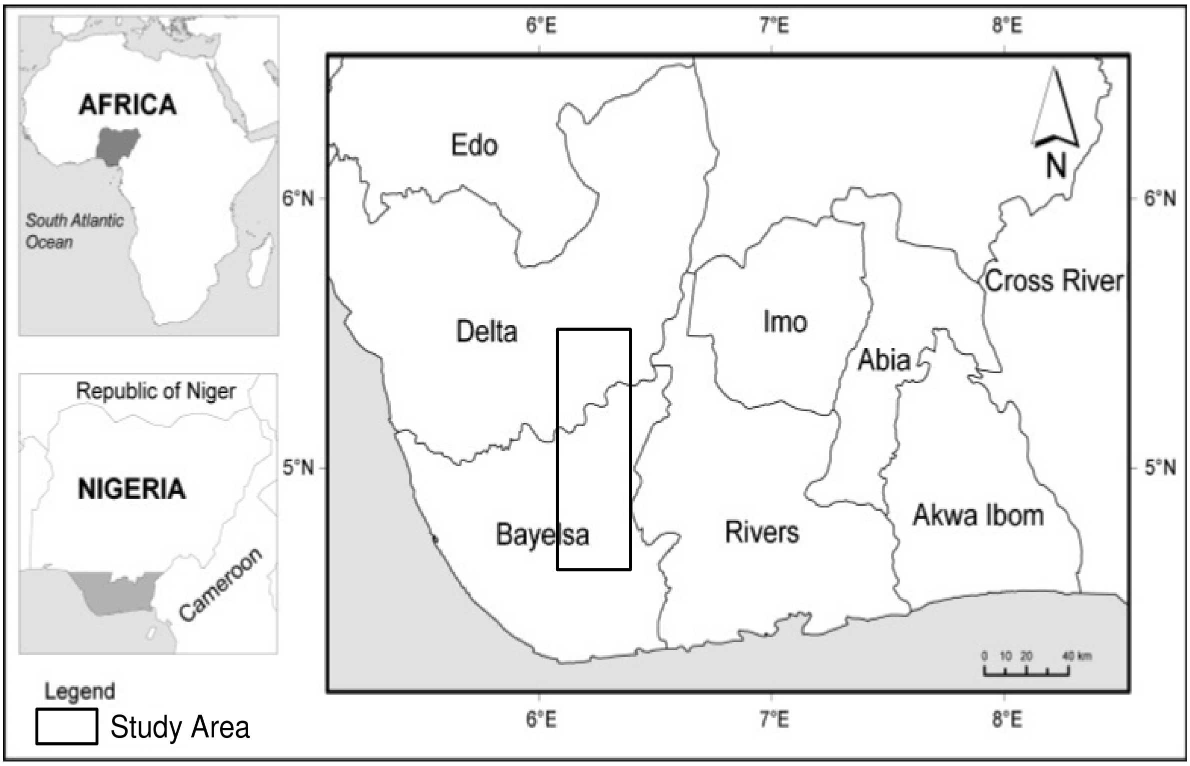

Figure 1: Location map of the study area

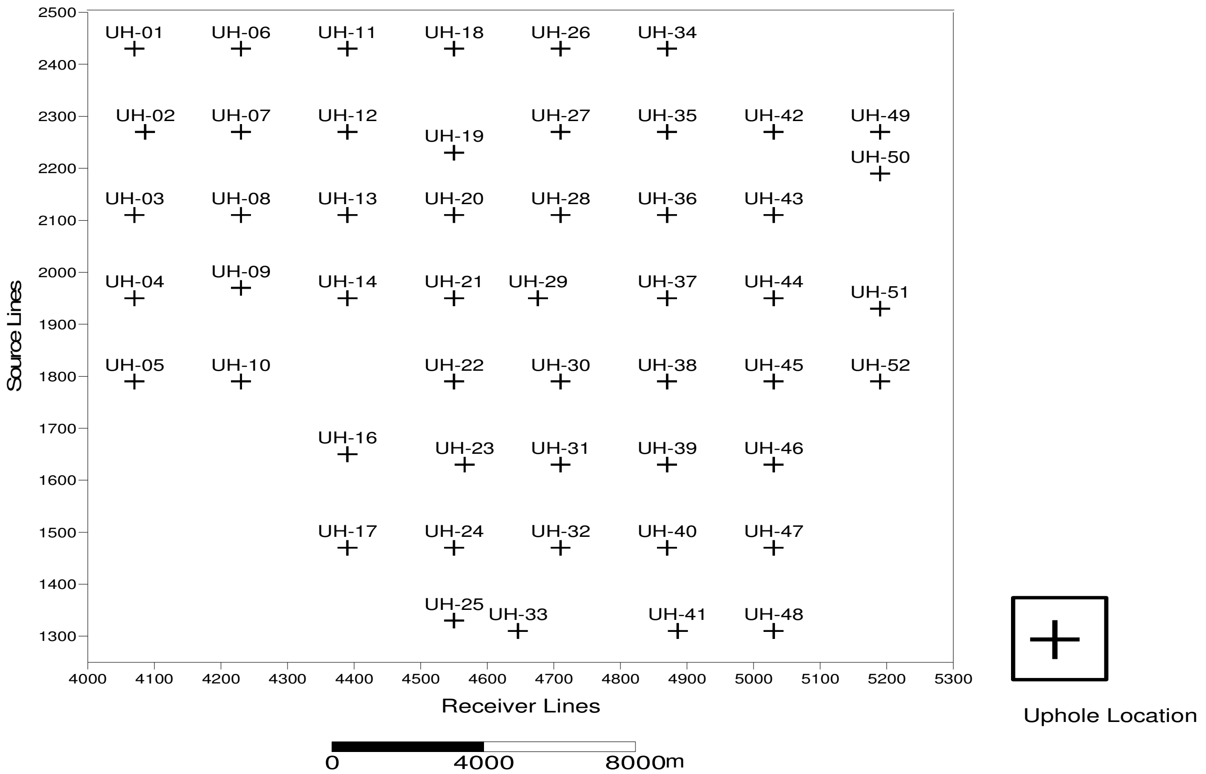

Figure 2: Data acquisition map of the study area

3. THEORY

The seismic refraction technique is based on the refraction of seismic energy at the interfaces between subsurface/geological layers of different velocity. The seismic refraction method uses very similar equipment to seismic reflection, typically utilizing geophones in an array, and a seismic source (shot). The schematic diagram (Figure 3a) illustrates the path of seismic waves propagating from a source at the surface. Some of the seismic energy travels along the surface in the form of a direct wave. However, when a seismic wave encounters an interface between two different soil or rock layers a portion of the energy is reflected and the remainder will propagate through the layer boundary at a refracted angle. At a critical angle of incidence the wave is critically refracted and will travel parallel to the interface at the speed of the underlying layer. Energy from this critically refracted wave returns to the surface in the form of a head wave, which may arrive at the more distant geophones before the direct wave. By picking the time of the first arrival of seismic energy at each geophone, a plot of travel-time against distance along the survey line can be generated. This type of graph is shown in the Figure 3b. The gradients of the lines in this type of plot are related to the seismic velocity of the subsurface layers. The final output is a velocity/depth profile for the refractors as shown.

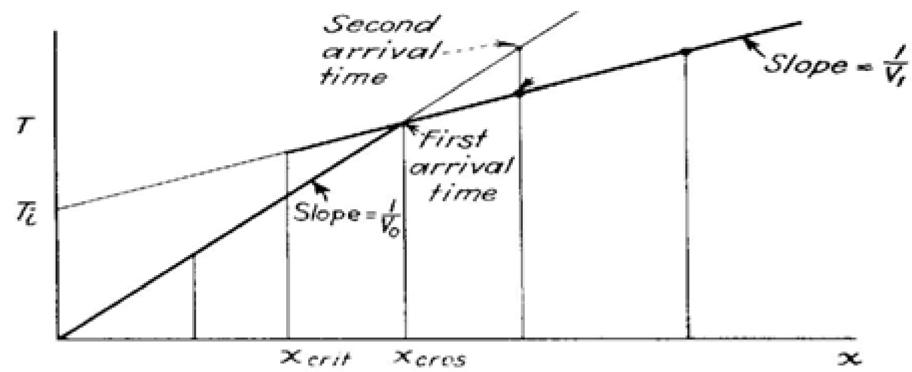

Figure: 3(a) Simple two-layer case with plane, parallel boundaries and (b) corresponding time- distance curve

Considering two media case as shown in figure 3(a) of respective speed of V_o and V_1, separated by a horizontal discontinuity at depth z. The direct wave travels from shots to detector near the earth's surface at a speed of Vo so that T=x/Vo. The total time, T of wave travel is the summation of the time TAB, TBC, TCD and TDA, and this is given as

$$T = \frac{x}{V_1} + \frac{2z\sqrt{V_1^2 - V_0^2}}{V_1 V_0} \qquad 1$$

On a plot of T versus x, this is the equation of a straight line and has the slope 1/V1 and which intercepts the T axis (x=0) at a time

$$T_i = \frac{2z\sqrt{V_1^2 - V_0^2}}{V_1 V_0} \qquad 2$$

Where Ti is the intercept Time. Also a distance X_{cross}, the two linear segments cross and at distances less than this, the direct wave travelling along the top of the Vo layer, reaches the geophone first. It is noted that at greater distances, the wave refracted by the interface arrives before the direct wave. The X_{cross} is therefore called the crossover distance (Dobrin, 1988).
Also from the intercept time, the depth z to the interface can be calculated as

$$z = \frac{T_i}{2} + \frac{V_1 V_0}{\sqrt{V_1^2 - V_0^2}} \qquad 3$$

This analysis of depth and velocity determination can be carried out for any number of layers.
Similarly, the velocities of the weathered layer, the bedrock and thickness of the weathered layer (V_W, D_W, and V_B) can be deduced from the uphole survey data (Figure 4). Here the reciprocal of the slopes of the segments OA and AB equals V_W and V_B respectively, while OD is the thickness of the weathered layer, where D is the base of the LVL. The uphole data information usually serve as control to the surface refraction data and is often more reliable (Ofomola, 2012).

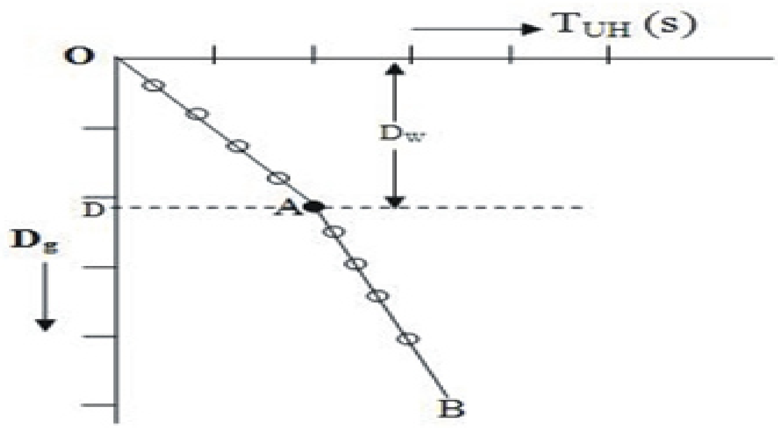

Figure 4: Uphole survey time depth relationship

4. RESEARCH METHODOLOGY

Uphole data were acquired using GEOMETRICS STRATAVISOR NZ11 seismograph connected to the harness. At every Uphole location, a hole was drilled to 66 meters depth at an intersection point between source and receiver lines using rotary method, and flushed continuously for 20 minutes to enhance stability for smooth and effective casing (Figure 5).

Samples were collected at every 3m-depth interval. Drill cuttings were described based on field observations and classified based on Wentworth grade scale.

To maintain formation strength once the drilling is completed, the drilled hole is aligned to TVD (True Vertical Depth) with plastic casings. For effective safety management, the drill crew pulls and evacuates their drilling equipment from shot point thereby making the location free for logging. The uphole Seismologist sets up the instrument at a safe distance away from the shot hole while a licensed shooter prepares the charge, and loads the shot hole with pre-defined number of caps to 2m bottom of charge.

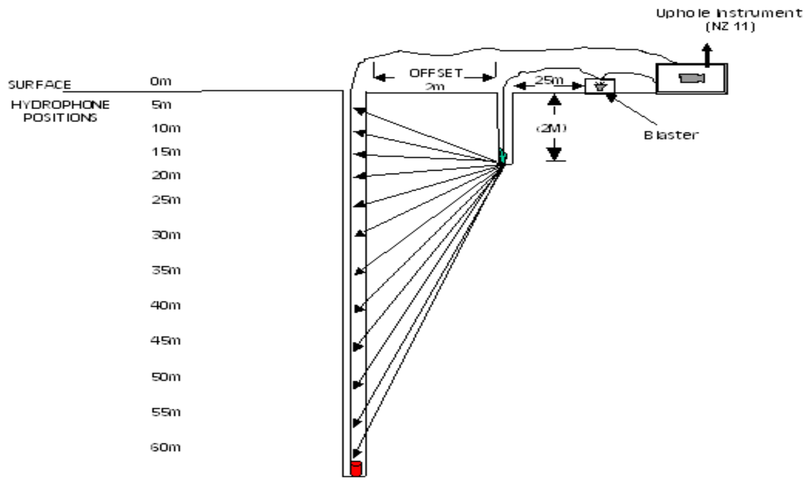

Figure 5: Uphole equipment Set – up

The shot hole is loaded with detonators varying from 1 to 10 caps depending on the depth of sensor and the quality of first breaks. The hydrophone harness is lowered into the cased hole filled with water to the required depth and properly secured to a peg to maintain stability.

After completing the safety procedure detailed under Safety Measures herein, the firing command is sent from the blaster unit, which then provides the voltage discharge needed to explode the detonators (energy source). The blasting unit produces a field time signal simultaneously with the firing pulse to the caps. This signal is fed back and recorded into the instrument to produce the arrival time sequence. Once a shot is successful (the output data is printed out in hardcopy, saved into hard disc and diskette), the harness is raised to the next calibrated depth. This process and procedure would be repeated till the last depth is logged. The hydrophone is positioned at 0m depth (surface level) but submerged in water to record the surface signal for comparison of the first breaks as well as instrument performance.

Uphole data were recorded on field worksheets; hard disk and the monitor record were printed out as backups against data loss. First breaks were picked manually and automatically with Strata visor NZ11 in the field, and crosscheck manually as well as with BDE software. The raw arrival time(Tm) read from the monitors were corrected for offset and shot depths using the steps detailed below:

$$Tc = Tm * (Dc / (Offset^2 + Dc^2)^{1/2}). \qquad 4$$

Where Tc=Offset corrected time
Tm=Raw pick time
Dc (corrected depth) = Depth (receiver) – Depth (source)
The time is finally corrected or reduced to surface, using
Ts (surface corrected time) = Tc – Tc (0)
Where Tc (0) = Offset corrected time at the surface.
The corrected first break times are plotted against depths and interpreted using to calculate the velocity and thickness of the subsurface layers.

5. DISCUSSION OF RESULTS

5.1 Velocity and Weathering Thickness

First-break time is the first pick-up time recognised for any trace, and it is the parameter of interest in the interpretation of uphole data (Ojo, 1993). Near-surface depth models are computed from picked first-break times (Taner *et al.*, 1998) and to achieve this, a plot of the corrected time is made against each channel for every shot in the case of the offset geophone. For the down-deep hydrophone data, the time is plotted against each hydrophone position in the hole. A graphical plot of surface corrected arrival time was made against corresponding depths from which velocity is obtained; the gradient represents the velocity while the thickness is calculated from the point of intersection of the two slopes (point of inflexion). Summary of the calculated velocities and thicknesses of the weathered and consolidated layers is given in table 1.

Statistics within the prospect area reveals that the consolidated layer velocities ranged from 1528m/s to 1927m/s while the highest velocity within the weathering layer is 924m/s (i.e. 254m/s to 924m/s). Also, the weathering thickness ranges from 2.7m to 11.5m. Apparently because of formation peculiarity, some uphole points recorded less than what is obtainable in the normal Niger Delta velocity / thickness statistics.

It was also observed from the velocity plots that all the uphole locations maintained and exhibited two layers.

Table 1: Summary of the Interpretation Statistics of the Uphole survey in the area

Serial No.	Location (Sps)	Elevation (m)	First layer report		Second layer report	
			Thickness (m)	Velocity (m/s)	Thickness (m)	Velocity (m/s)
1	2430-4070	4.1	2.7	766		1724
2	2270-4086	5.5	2.9	368		1799
3	2110-4070	6.9	4.9	308		1897
4	1950-4070	7.1	2.8	308		1774
5	1790-4070	6.8	4.8	386		1774
6	2430-4230	5.3	4.9	924		1705
7	2270-4230	5.5	5.2	567		1785
8	2110-4230	7.2	3.0	426		1681
9	1970-4230	8.3	4.6	254		1799
10	1790-4230	5.7	4.5	660		1699
11	2430-4390	5.6	2.7	364		1668
12	2270-4390	8.2	4.2	420		1688
13	2110-4390	7.9	5.4	293		1898
14	1950-4390	6.1	10.5	782		1528
15	1790-4390	7.3	6.0	592		1584
16	1650-4390	7.7	4.9	307		1714
17	1470-4390	7.6	3.7	364		1718
18	2430-4550	8.2	4.1	510		1719
19	2230-4550	7.2	8.9	587		1827
20	2110-4550	9.7	7.8	640		1896
21	1950-4550	8.9	6.5	336		1804
22	1790-4550	8.5	4.8	226		1760
23	1630-4566	7.3	8.6	447		1802
24	1470-4550	6.8	9.1	606		1707
25	1330-4550	7.5	4.4	380		1732
26	2430-4710	9.2	7.0	648		1953
27	2270-4710	7.9	5.1	399		1898
28	2110/4710	9.2	6.6	520		1708
29	1950-4676	6.2	8.9	620		1759
30	1790-4710	5.2	10.1	717		1888
31	1630-4710	8.3	5.3	577		1679
32	1470-4710	5.1	5.2	530		1663
33	1310-4646	6.9	6.2	692		1812
34	2430-4870	10.8	4.6	477		1771
35	2270-4870	9.6	8.7	409		1811
36	2110-4870	8.7	7.0	450		1796
37	1950-4870	6.0	5.8	777		1858
38	1790-4870	8.5	8.7	644		1802
39	1630-4870	8.5	9.3	737		1840
40	1470-4870	6.5	11.0	725		1767
41	13104886	7.8	7.0	634		1914
42	2270-5030	7.9	9.9	714		1955
43	2110/5030	6.9	9.8	606		1927
44	1950-5030	5.2	6.3	467		1928
45	1790-5030	6.2	7.9	462		1673
46	1630-5030	8.9	6.2	433		1693
47	1470-5030	7.9	7.3	546		1765
48	1310-5030	6.0	10.7	641		1704
49	2270-5190	6.8	6.4	466		1909
50	2190-5190	6.2	5.1	507		1599
51	1930-5190	9.8	6.2	365		1710
52	1790-5190	5.9	6.9	401		1861

5.2 Weathered layer Thickness Map

The weathered layer thickness which is the thickness of the first layer in all the uphole points was contoured in order to determine its distribution in the study area (Figure 6). The values range from 2.5 to 11 m, with the lowest thickness in the western flank of the area. However, a bigger part of the study area has thickness ranging from 6.5 to 8.5 m. The implication is that this weathering thickness will be used to eliminate the effect of low velocity layers during static and elevation correction.

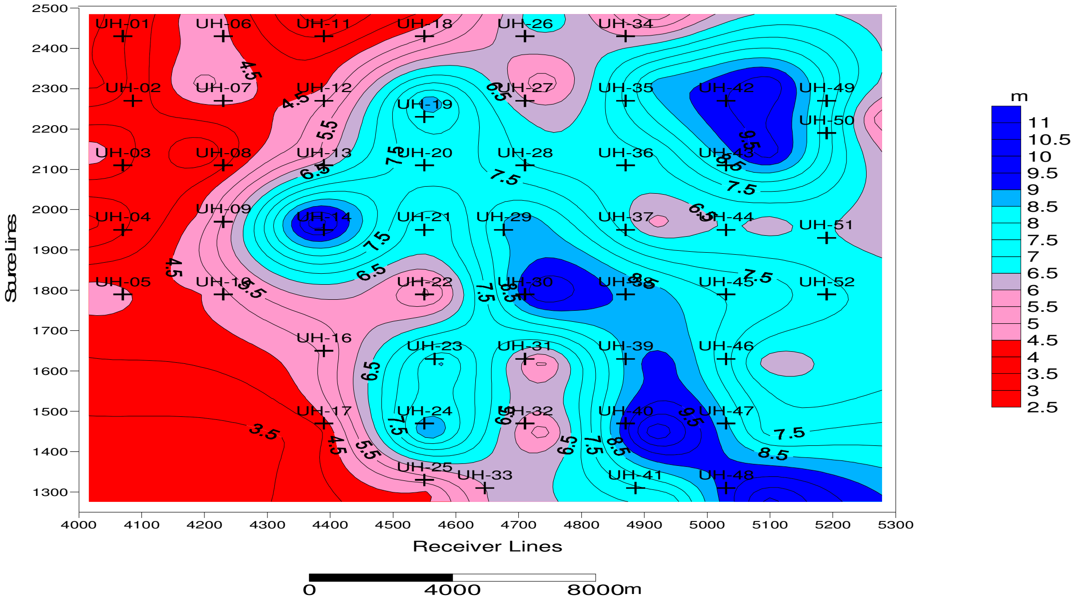

Figure 6: First layer/Weathered layer thickness map of the study.

5.3 Weathered Layer Velocity Map

The velocity of the weathered layer ranges from 200 to 950 m/s (Figure 7). This marginal variations in these near-surface seismic velocity is indicative of the high degree of homogeneity of the layer and underscores the possibility of a smooth statics behaviour in case of any seismic reflection data likely to be acquired in the study area (Ofomola, 2012).

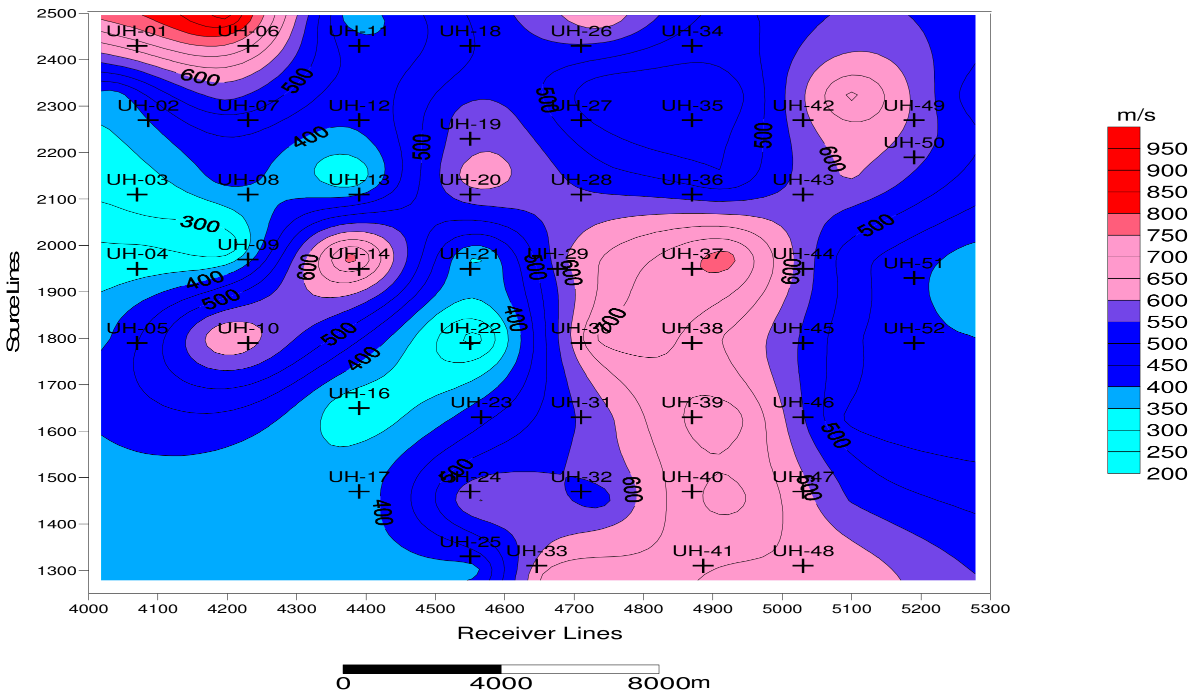

Figure 7: First layer/weathered layer velocity of the study.

5.4 Consolidated Layer/Bedrock Velocity Map

The consolidated layer velocity ranges from 1520 to 1940 m/s as shown in Figure 8. Judging from the seismic velocity distribution of this layer, it is observed that the layer is sufficiently competent

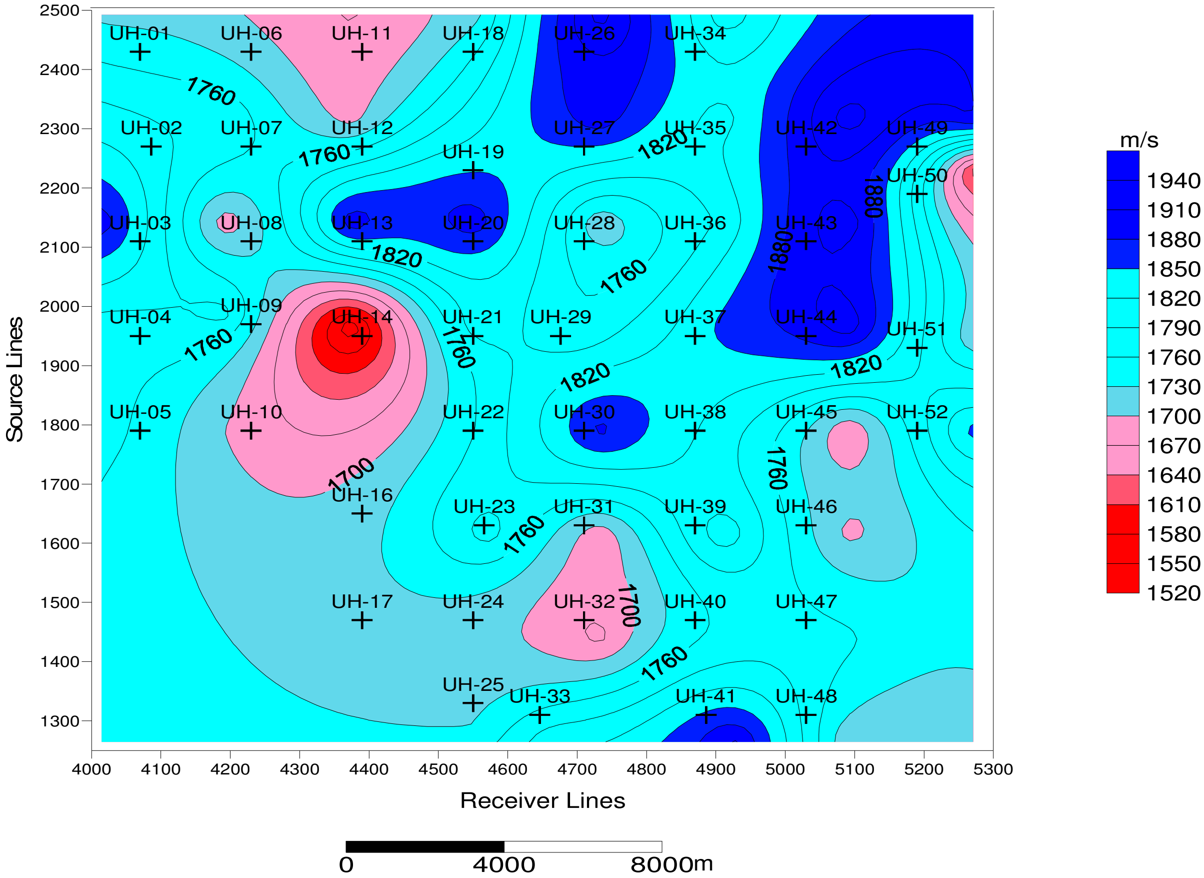

Figure 8: Consolidated layer velocity map of the study

5.5 Comparison of the uphole results with Lithology logs

Drill logs data were obtained in all the uphole points and examined based on Wentworth grade size classification. This is done in conjunction with the theoretical interpretations as a physical set of data to aid in determining the boundary distinction in the study area

For Uphole location 1, Formation samples showed that the topmost sample, 0m to 3.0m recorded overburden clay. Depths 3m to 24m had fibrous clay formation while depths 24m to 66m had fine to coarse sand traces. Close examination showed predominantly sand, coarsening downwards the sequence with little traces of white particles recorded between 27m and 57m depths (Figure 9). Total depth of 66.0m was drilled to make room for convenient logging depth of 60 m.

Also Uphole 2 was drilled to the depth of 66.0m to give room for convenient logging depth of 60m. Cuttings from the formation were sampled at 3.0m intervals, and observations on their physical field properties showed that the topmost 3.0m recorded black fibrous organic matter overburden. Depths 3m to 15m consists mainly medium grain size while depths 15m to 66 delineate predominantly fine sand with traces of white particles (Figure 10).

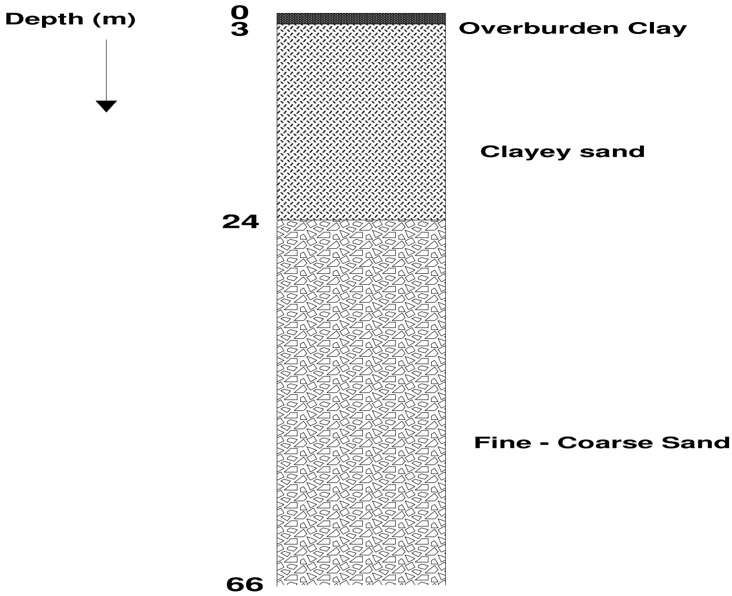

Figure 9: Drill log in Uphole location 1

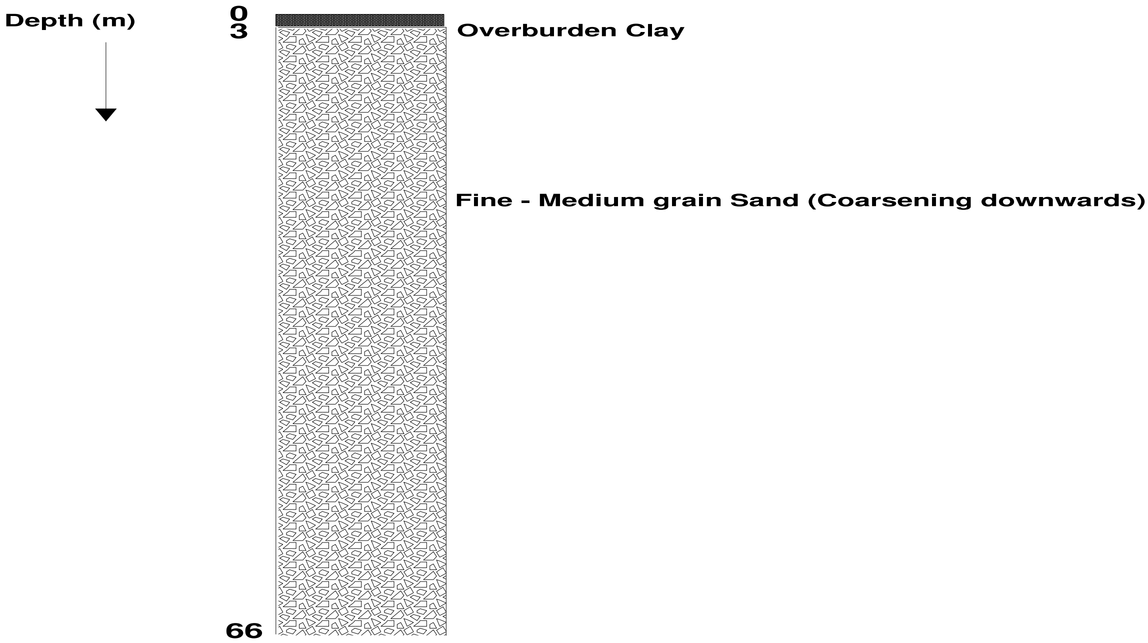

Figure 10: Drill log in Uphole location 2

Total depth of 66m was drilled to give room for a convenient logging depth of 60m for uphole location 3 (Figure 11). The formation samples collected delineates clay with traces of lignite material depths 0m to 4m. Depths 4m to 66m delineate fine sand to medium grain size. The lithological prognosis is displayed in figure 11 below.

Figure 11: Drill log in Uphole location 3

This was done for all the uphole points and it was observed that the result with regards to depth of the unconsolidated topsoil of 3, 3 and 4 m for uphole 1, 2 and 3 respectively correlates closely with the weathering layer thicknesses of 2.7, 2.9 and 4.9 m in the theoretical interpretation. It was generally observed that there was a correlation of the theoretical interpretation results with the drill hole logs in all the points.

6. CONCLUSION

A comparative study of Down - deep Hydrophone Seismic Refraction survey and Drill Logs for the Determination of Near Surface Layer Velocity and Thickness Over 'Galos' Field, Niger Delta, Nigeria has been conducted. Analysis on the weathering thickness and velocities within the prospect area reveals that all uphole locations have weathering thickness ranging from 2.7m to 8.2m, apart from uphole locations 14, 30, 40 and 48 having weathering thickness ranging from 10.5m to11.0 The highest velocity within the weathering layer is 924m/s (254m/s to 924) while the velocity of the consolidated layer ranges from 1528ms to 1927ms. The records / playbacks from the single channel seismograph (Strata-visor) used during the uphole survey displayed good signal quality with distinct first break times. The theoretical interpretation displayed a two-layered case, and this appreciably correlates with the formation samples collected at various uphole lithology logs.

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