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Uphole Seismic Refraction Survey for Low Velocity Layer Determination Over Oga Field, South West of Niger Delta, Nigeria

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Abstract

Uphole seismic refraction shooting experiment aimed at investigating the subsurface layers, was carried out using a three dimensional (3D) approach, to evaluate the weathering parameters in prospect areas, such as weathering thickness or Depth (D_w); weathering velocity (V_w) of the low velocity layer (LVL) and Velocity of sub-weathering or consolidated layer (V_c) in OGA field located South West of Niger Delta. Six uphole locations were drilled using a rotatory (hand operated) drilling machine in the study area. The time-offset curve of the first arrivals for shots from different charge depth inside the borehole was used and time-intercept techniques of seismic refraction interpretation were employed for the different locations (A – F). The weathering thickness was found to vary from 6.0m to 10.0m.The P-wave velocity of the LVL ranges from 328msec^{-1} to 444msec^{-1}, with an average value of374.3msec^{-1}. Sub-weathering was found in all locations. The velocity of the consolidated zone was found to vary from 1666msec^{-1} to 1785msec^{-1} with an average velocity of 1714msec^{-1}.Using the result, the effect of weathering on refraction data was eliminated during seismic data processing .The record playback has a good signal quality with distinct first break times. An Interpretation Software designed by Integrated Data Service Limited (IDSL) a subsidiary of Nigeria National Petroleum Cooperation (NNPC) was employed. A two-layered case was displayed from the graph of each uphole point analysis and the sub-weathering parameters were obtained. Therefore, the weathering velocity and thickness on the prospect area are in correlation with what is obtainable in the Niger Delta weathering statistics.

Keywords: Uphole, Seismic, Refraction Survey, Low Velocity, Layer Media

1.0 Introduction

The up-hole method of seismic refraction survey is a field seismic technique which makes use of geophones as sound detector devise or receivers, planted on the ground surface and an underground seismic source to obtain information about the lithology of the sub-surface. Artificial vibrations induced by explosives (dynamites or detonators) source are used to generate seismic wave energy.When this energy is incident at a critical angle to a reflector with a positive reflection coefficient, it is refracted along the interface at the velocity of the second layer.Each point on the interface excited by the refracted wave radiates upwards with hemispheral divergent, causing wavefronts to travel to the surface, with ray paths that intersect theinterface at the critical angle. This emerging wave energy are picked by sensors on the ground surface which in turn convert this mechanical vibration generated by the seismic source into varying electrical wave pulses and transmit it to a seismograph machine (McSeis)which will display this seismic data in the form of wiggles or repetitive signature. The low velocity layer(also known as the weathering layer) which often correspond to the upper region of the sub-surface layer is characterized by low transmission of seismic waves energy, with high absorptivity of sound wave and high rate of scattering of these waves energy due to the presence of low velocity materials (anomalies) underlying this region. It is therefore appropriate that in order to obtain a good quality reflection data or to increase the signal to noise ratio, shot have to be taken at the base or below the base of the weathering layer. The hidden (low velocity zone-LVZ) layer can of course be detected by shooting from a borehole to the seismic spread geophones [1].Hence it is important to carry out this preliminary

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uphole method of seismic refraction survey to determine the weathering parameters across OGA field which covers 127.40 square kilometers in the subsurface area of the Warri North Local Government Area in Delta state in the western part of the Niger-delta. Exploration geophysics involves the use of geophysical theory, methods and instrumentation to locate hydrocarbon and other mineral sources. Exploration geophysics generally concentrates on finding lateral heterogeneities in the earth crust.

2.0 Location of Study Areas

The survey area lies in Western part of Niger Delta area. The Niger Delta is located between longitude $04^0$00' and $06^0$00' north of the equator and between longitudes $04^0$00' and $09^0$00' east of the Greenwich meridian. The total survey area covers about 127.40 square kilometers.

3.0 Local Geology of the Study Area.

The total survey area covers about 127.40 square kilometers. The Niger Delta is situated in the Gulf of Guinea[2]. From the Eocene to the present, it has prograded south-westward, forming depobelts that present the most active portion of the Delta at each stage of its development [3].These depobelts from one of the largest regressive deltas in the world with an area of 300,000km^2 [4],a sediment volume of 500,000km^3[5],and a sediment of over 10km in the basin depocenter [6].The three major depositional environments (marine mixed and continental) that are observable in the Niger Delta are represented by the Benin, Agbada and Akata formations, which have been deposited in high energy deltaic environment sediments in the basin which exceed a thickness of about 35,000ft between the upper and lower deltaic plain.

The structural and tectonic frame work of the modern Niger delta basin is related to opening of the Atlantic Ocean and the accompanying structural evolution of the Gulf of Guinea migeosyclineshows that the Niger delta overlies the early stage [7]. Beneath what is now known as the delta area, plume activities had occurred followed by lithospheric plate thinning and associated Hermotectonic uplift. The first phase (stage) was probably reached by early cretaceous time because by Albian times, marine sediments were being laid down in the Abakiliki and Benue troughs [8]. Thereare three subsurface stratigraphic units in the modern Niger Delta Benin, Agbada and Akata formations [9]. These three formations were laid down under the marine transitional and continental environments respectively.

4.0 Theory

The quantity that is observed in the refraction survey is the time between generation of seismic wave of the shot point by dynamite and its first arrival time at the detector placed at a measured distance from the shot point. The first arrival to the geophone is the wave which has travelled the minimum time path between shot and detector.The seismic path for minimum travel time can be traced by applying the Snell's law.

Refraction Path for a 2-Layer Case

Shot in the weathering layer$D_W > D_S$

Consider a single shallow shot taken at a depth $D_S$within the weathering layer where $D_w$is the thickness of the weathering layer.

The total travel time, T between the shot point S and receiver at R is given by:

$$T = T_{SA} + T_{AB} + T_{BR} \tag{1}$$

$$T = \frac{SA}{V_w} + \frac{AB}{V_e} + \frac{BR}{V_w} \tag{2}$$

Where, V_w = weathering layer velocity, and

V_e = consolidated layer velocity.

Therefore,

$$T = \frac{D_w - D_s}{V_w \cos\theta} + \frac{AB}{V_e} + \frac{D_w}{V_w \cos\theta} \tag{3}$$

Where, θ is the critical angle of incidence

Now, $AB = X - [FD + CR]$

$$\frac{FD}{D_w - D_s} = \tan\theta \tag{4}$$

Therefore,

$$FD = (D_w - D_s)\tan\theta \tag{5}$$

Similarly,

$$AB = X - [FD + CR]$$

$$\frac{CR}{D_w} = \tan\theta, \therefore CR = D_w \tan\theta \tag{6}$$

Hence

$$AB = X - (D_w - D_s)\tan\theta - D_w \tan\theta$$

$$= X - (2D_w \tan\theta - D_s \tan\theta) \tag{7}$$

Therefore, the travel time equation becomes:

$$T = \frac{D_w - D_s}{V_w \cos\theta} + \frac{2D_w \tan\theta - D_s \tan\theta}{V_e} + \frac{D_w}{V_w \cos\theta}$$

$$= \frac{X}{V_e} + \frac{2D_w}{\cos\theta}\left[\frac{1}{V_e} - \frac{V_w}{V_e^2}\right] - \frac{D_s}{\cos\theta}\left[\frac{1}{V_w} - \frac{V_w}{V_e^2}\right]$$

$$T = \frac{X}{V_e} + \frac{2D_w\sqrt{V_e^2 - V_w^2}}{V_e V_w} - \frac{D_w\sqrt{V_e^2 - V_w^2}}{V_e V_w} \tag{8}$$

The weathering depth is obtained from the last equation by setting the offset to zero, i.e., x=0. At zero offset, the total travel time T=T. where T, is the intercept time. From (8) we therefore have that

$$T = \frac{2D_w\sqrt{V_e^2 - V_w^2}}{V_e V_w} - \frac{D_w\sqrt{V_e^2 - V_w^2}}{V_e V_w} \tag{9}$$

From which the weathering depth can be obtained as:

$$D_s = \frac{T_i V_e V_w}{2\sqrt{V_e^2 - V_w^2}} + \frac{D_s}{2} \tag{10}$$

Snell's law

$$\sqrt{1 - \frac{V_e^2}{V_w^2}} = \cos\theta, \therefore \frac{1}{\cos\theta} V = \frac{V_w}{V_w^2 - V_e^2} \tag{11}$$

Hence

$$D_w = \frac{T_i V_w}{2\cos\theta} + \frac{D_x}{2} \tag{12}$$

In a 3-layer case (i.e. two layers of weathering), the total depth of the weathering layer is given by

$$D_w = Z_0 + Z_i \tag{13}$$

The T-X plot for this case is shown in figure 4 and the travel time equation is given by:

$$T = \frac{X}{V_e} + \frac{2Z_0}{V_2 V_0} - \frac{2Z_i\sqrt{V_2^2 - V_1^2}}{V_2 V_1} \tag{14}$$

At X = 0

$$T = T_{12}$$

$$T_{12} = \frac{2Z_0\sqrt{V_2^2 - V_0^2}}{V_2V_0} - \frac{2Z_i\sqrt{V_2^2 - V_1^2}}{V_2V_1} \tag{15}$$

$$Z = \frac{T_iV_0}{2\cos\theta} + \frac{D_s}{2}$$

Where

$$\cos\theta = \sqrt{1 - \frac{V_0^2}{V_2^2}} \tag{16}$$

Therefore, with T_{i2} read from the T-X plot calculated as above, the total depth of weathering can be determined as given in equation 10.

Shot at the base of weathering layer ($D_s = D_w$)

The total time for this case is given by;

$$T = T_{SA} + T_{AR} = \frac{SA}{V_e} + \frac{AR}{V_w} \tag{17}$$

Therefore,

$$T = \frac{D_w\tan\theta}{V_e} + \frac{D}{V_w\cos\theta} = \frac{X - D_w\sin\theta}{V_e\cos\theta} + \frac{D}{V_e\cos\theta} \tag{18}$$

Following the procedure for the 2-layer case, we have that;

$$T = \frac{X}{V_e\cos\theta} + D_w\frac{\sqrt{V_e^2 - V_w^2}}{V_eV_w} \tag{19}$$

At $X = 0, T = T_i$, so that

$$T_i = D_w\frac{\sqrt{V_e^2 - V_w^2}}{V_eV_w} \tag{20}$$

Therefore, the weathering thickness is obtained as;

$$D_w = \frac{TV}{\cos\theta} \tag{21}$$

Shot taken in the consolidated layer $D_s > D_w$

Under the distance time intercept of the slope, the arrival curve from which the velocity of the low velocity zone is determined disappears when the shot is taken below the weathering layer. This is why it is impossible to determine the weathering thickness or depth when a shot is taken below the weathering layer.

For a shot $D_s > D_w$, the thickness of the first sub-layer of weathering, Z_o is obtained as:

$$Z_0 = \frac{T_aV_0}{2\cos\theta_1} + \frac{D_s}{2}, where, \cos\theta_1 = \sqrt{1 - \frac{V_0^2}{V_2^2}} \tag{22}$$

Therefore, with T_{12}, T-X plot (figure 4) calculated as above, the total depth of weathering can be determined as given in Equation 10.

5.0 Interpretation of Seismic Data by their Compression Wave Velocity.

Rocks differ in their elastic moduli and densities due to a number of factors; the most important are composition, texture (gram shape and sorting) and porosity. They will thus differ in their wave velocities of rock layers encountered by seismic survey. This is important for two main reasons;

1. It is necessary for the concession of seismic wave travel times.
2. This provides an indication of the lithology of a rock and in some cases the nature of pore fluids contained within it.

Gas in pores reduces the elastic moduli, hence a drop in the velocity of the rock so the presence of gas is directly detected in seismic survey.
Typical compression wave velocity values of earth materials are given in Table 1.

6.0 Acquisition Method (Field Procedure)

Uphole data were acquired using (McSeis) seismograph connected to the harness. At every uphole location, a hole is drilled to 66meters 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 loading.To maintain formation strength, once the drilling was completed, the crew pulled out and evacuated drilling equipment from shot point thereby making location free for logging. The uphole supervisor would then set up the instrument at a safe shooting distance of 25m minimum away from the shot hole while the assistant and other uphole crew load the drilled hole with pre-defined number of caps down to depth (bottom of change). The drilled hole would be loaded with detonators varying from 1 to 10 caps depending on the depth of calibration and the quality of first breaks.
After the initial set-up of equipment and safety procedure consideration, the firming command later would be sent from the blaster unity, which would provide required voltage discharge needed to trigger the detonators a field time signal simultaneously with the firming pulse to caps this signal would be feedback and recorded into the instrument to produce the arrival time sequence. Once a shot was successful, the output data would be printed in hardcopy and saved into compact disc. This process and procedure were repeated till the last depth was logged.

7.0 Instrumentation

Material Used: Recording instrument McSeisSX 24XP Seismograph, Blaster Unit, Big Umbrella, Marine Rope 100m Length, Metal weight, Plastic clips, Firing line plus connecting cables,two 12 volts dry cell batteries.
Consumables: Plotter paper rolls, Masking tapes, Cutter knife, Venture tapes, Hand Napkin, Screw drivers, Digital multi-meter

7.1 Uphole Design/ Geometry

The uphole design comprises of harness made up of marine rope graduated in the appropriate calibration where explosives can be attached and weighted on the lower end of a heavy metal. The marine rope was recalibrated at each depth point and logged up to twelve channels as illustrated on the geometry diagram in Fig 8.

7.2 Equipment Set Up: The calibrated depths of 60m, 50m, 40m, 30m, 25m, 20m, 15m, 10m, 5m, 3m, and 1m were employed for data acquisition in 3 dimensions, prior to acquisition there was an instrument test carried out at 0m on the ground level (Fig. 8).

8.0 Presentation of Field Data

Uphole locations A-F, as seen in Table 2, were acquired using this harness geometry as follows: 60m, 50m, 40m, 30m, 25m, 20m, 15m, 10m, 5m, 3m, 1m. The drilled hole was loaded with detonators varying from 1 to 10 caps depending on the depth of calibration and quality of the first break. The corresponding table of values was recorded for arrival time against geophones offset.

9.0 Interpretation and Discussion of Results

By quantitative interpretation of uphole location 1316/5398 (Plate 1), we have the weathering velocity V_o represented by the slope of the 1st segment as $(8 - 2)/(24 - 6) \times 10^3 = 333$m/s.
The consolidated velocity,V_2 represented by the slope of the 2nd segment is given as$(60 - 18)/(56 - 32) \times 10^2 = 1750$m/s
The depth of weathering $Z_o = 9.0$m.
Similar values were obtained for V_o , V_2 and Z_o in Plates 2,3,4,5 and 6.
Uphole seismic refraction survey conducted in the study area showed that two layers were penetrated by seismic wave velocities with an average weathering (LVL) velocity of 374.3msec^{-1} and consolidated velocity of 1714msec^{-1}having a regional weathering depth of 8msec^{-1}.
Since velocity varies with depth, the weathering information obtained can be used to eliminate the effect of the low velocity layer.
Result from the analysis indicates that the velocity of seismic wave propagating through the weathering layer $V_o$ranges from 328msec^{-1} to 444msec^{-1} and the velocity of the lower layer (consolidated zone), V_2 ranges from 1666msec^{-1} to 1785msec^{-1}.

Also from Table 4, the result showed that the first layer of velocity 432msec^{-1} is silt (dry sand) the second layer of velocity 873msec^{-1} consists of silt and gravel.

11.0 Conclusion

The velocity of the weathered layer (LVL) in OGA field,south western part of the Niger delta region was found to vary from 328m/sec to 444m/sec having a weathering depth or thickness variation from 4.0m to 10.0m.The lithology from the bore samples revealed dominantly sand and clay unit. Therefore, for seismic reflection planning and design, prospective explorationist/geologist for a drill log of 10.0meters at the base or below base of weathered layer is recommended in other to eliminate the effect of travel times in the low energy zone in other to produce a better reflection data and less noise.

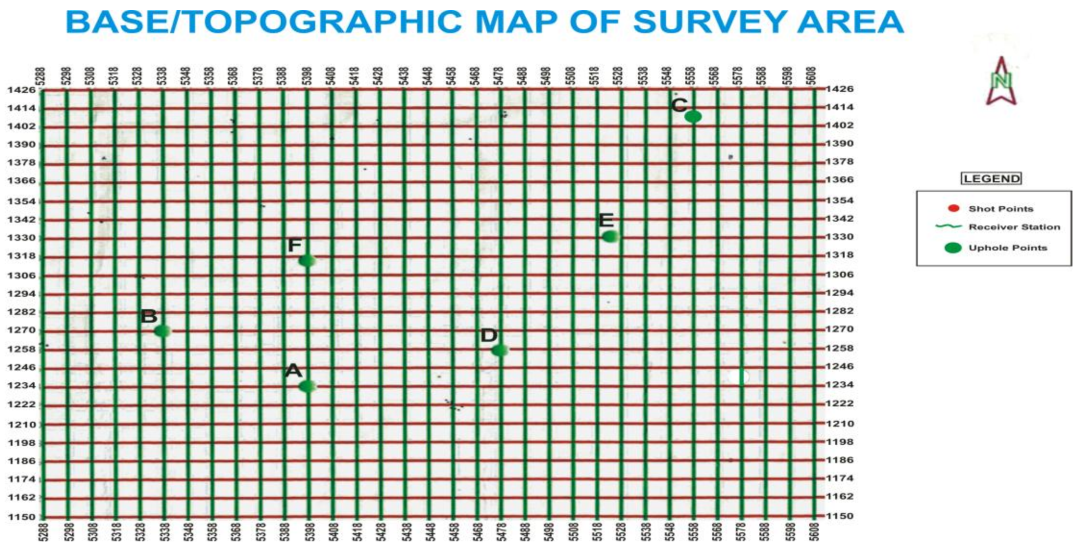


Figure 1: Base and Topographic Map of Survey Area

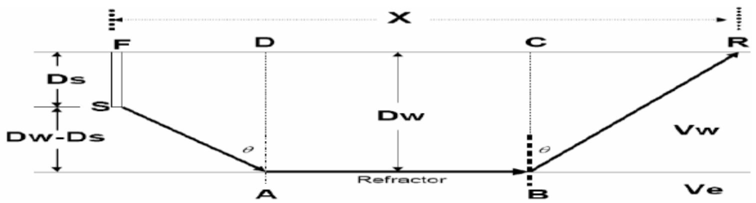


Figure 2: Refraction path for a 2-Layer Case

Figure 3: Refraction path for a 2-Layer Case

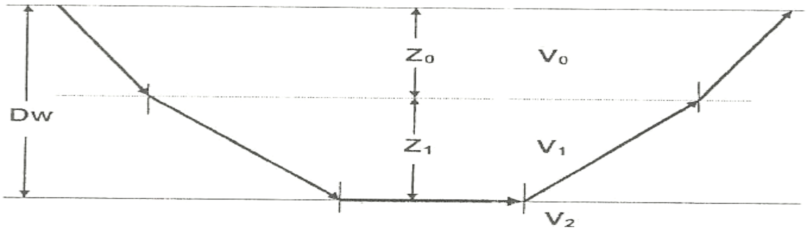


Figure4: Refraction path for a 3-layer Case.

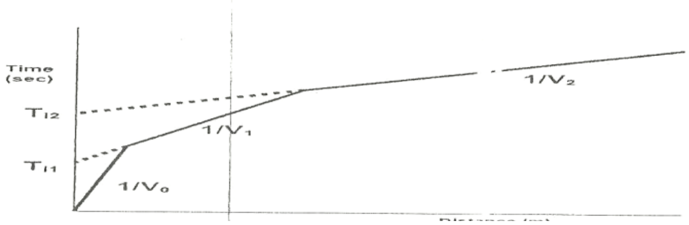


Figure 5: T-X plot for 3-Layer case.

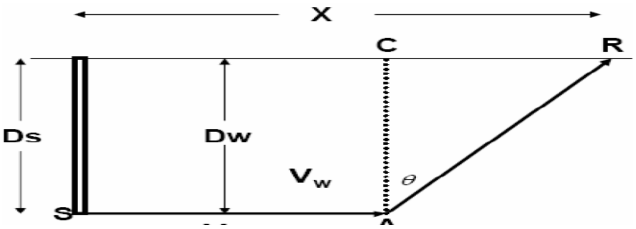


Figure 6: Raypath for a shot at Base of Weathering

Table 1: Seismic compressional wave (P-wave) Velocities in earth materials (Shell Intensive Training Programme, 2002).

Earth materials	**Vp(ms^{-1})**	**Earth materials**	**Vp (ms^{-1})**
Unconsolidated materials		Igneous/metamorphic rock	
Soil	100 – 190	Granite	5500 – 6000
Sandy (dry)	190 – 1000	Gabbro	6500 – 7000
Sand(water saturated)	1500 – 1900	Utramatic rock	7500 – 8500
Clay	1000 – 2500	Serpentinite	5500 – 6500
Glacial till (water saturated)	1500 -2500	Slate	3500 – 4500
Permafrost	3500 – 4000	Quartzite	5500 -6000
Sedimentary rocks		Pore fillings	
Shale	1500 - 4190	Air	300
Sand stone	1900 – 6000	Water	14 00 – 1500
Limestone	1900 – 6000	Ice	3400
Dolomites	2500 – 6500	Petroleum	1300 -1400
Salt	4500 – 6500		
Anhydrite	4500 – 6500		
Gypsum	1900 – 3500		

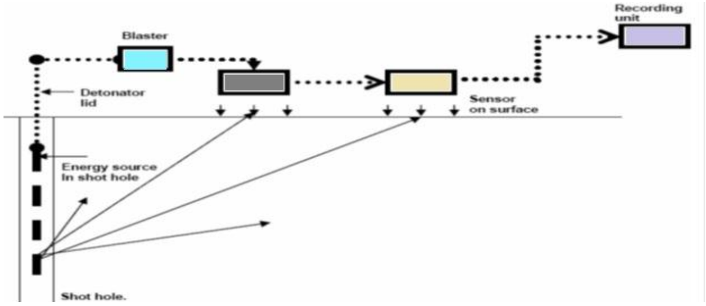


Figure 7; Field Layout for Offset-Geophone Data Acquisition

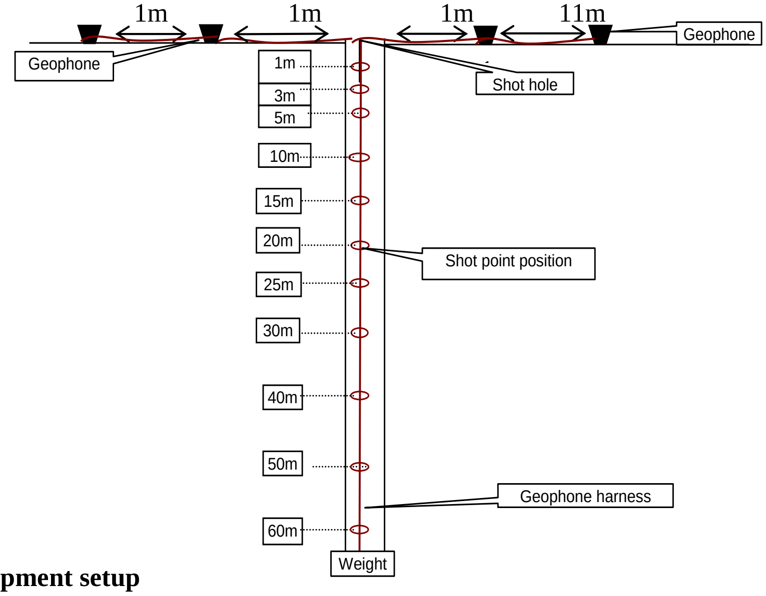
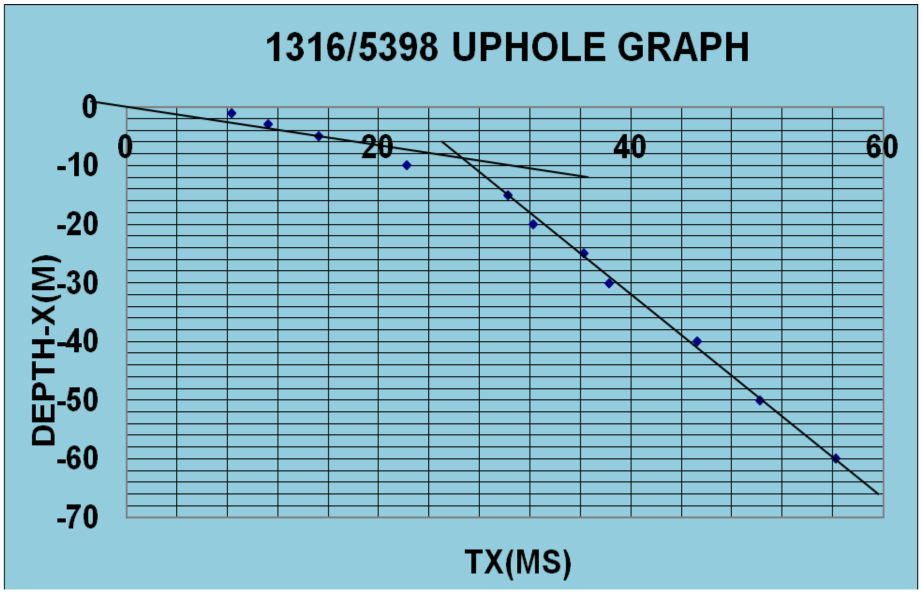


Figure 8: Equipment setup

Table 2: Arrival Time at Different Depth in the UpholeSurvey

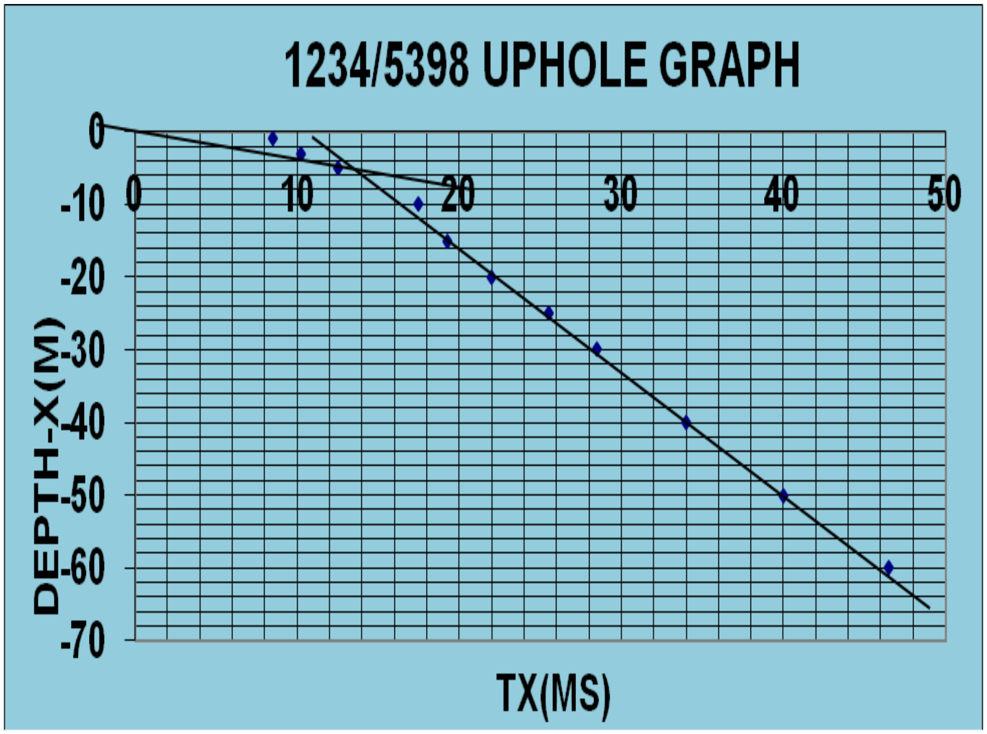
Depth X(M)	Location A Elevation (15.5m)	Location B Elevation (18.6m)	Location C Elevation (15.6m)	Location D Elevation (26.0m)	Location E Elevation (30.7m)	Location F Elevation (22.3m)
-1	8.50	7.50	7.75	6.50	8.50	6.50
-3	10.25	9.75	12.75	10.00	12.0	10.0
-5	12.50	13.25	14.00	12.50	13.0	12.0
-10	17.50	21.25	20.00	20.00	21.0	20.0
-15	19.25	27.00	21.00	28.00	30.0	28.0
-20	22.00	29.00	25.00	0.0	36.0	0.0
-25	25.50	31.00	28.00	33.00	37.0	33.0
-30	28.50	34.00	30.00	28.50	40.0	28.0
-40	34.00	39.00	36.00	42.25	45.0	42.0
-50	40.00	45.75	41.25	48.63	50.0	48.0
-60	50.00	51.00	48.00	53.75	57.0	53.0



TX(ms)	DEPTH-X(m)
8.375	-1
11.25	-3
15.25	-5
22.25	-10
30.25	-15
32.25	-20
36.25	-25
38.25	-30
45.25	-40
50.25	-50
56.25	-60

V_o = 333m/s
V_2 = 1750m/s
Z_o = 9m

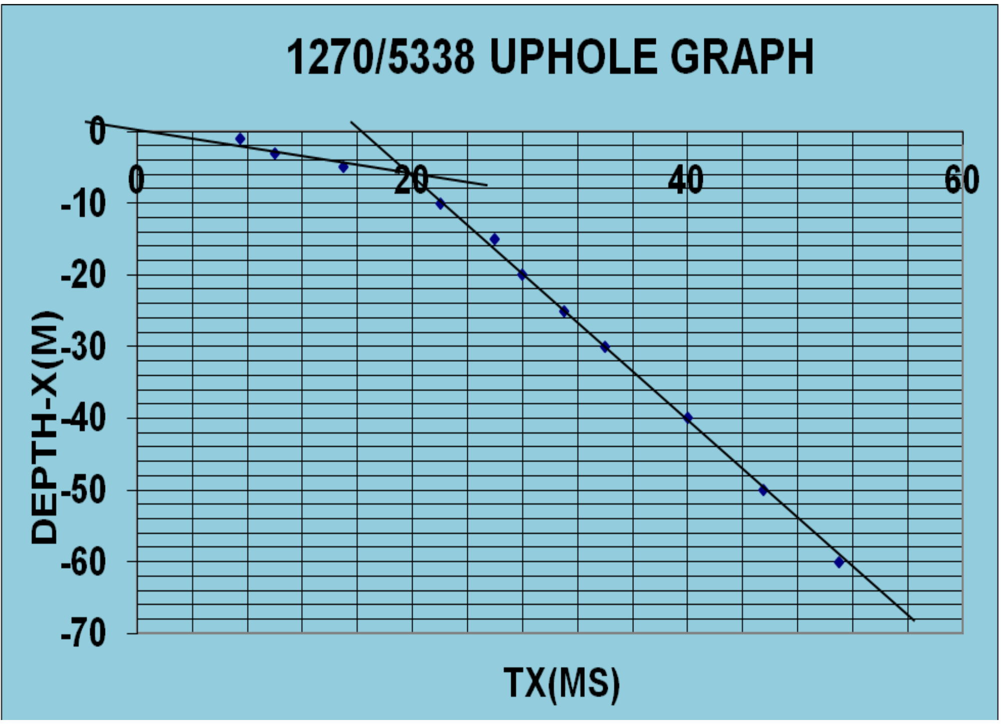
PLATE 1:1316/5398 UPHOLE DATA/GRAPH



TX(ms)	DEPTH-X(m)
8.5	-1
10.25	-3
12.5	-5
17.5	-10
19.25	-15
22	-20
25.5	-25
28.5	-30
34	-40
40	-50
46.5	-60

V_o = 400m/s
V_2 = 1689m/s
Z_o = 6m

PLATE 2: 1234/5398 UPHOLE DATA/GRAPH

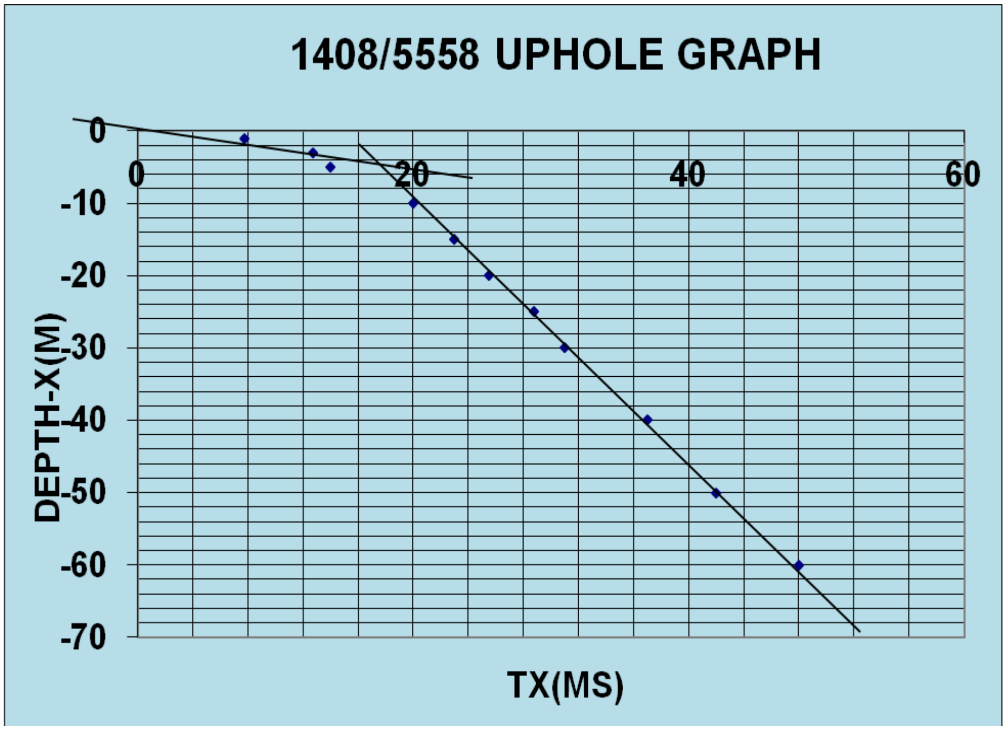


P

TX(ms)	DEPTH-X(m)
7.5	-1
10	-3
15	-5
22	-10
26	-15
28	-20
31	-25
34	-30
40	-40
45.5	-50
51	-60

V_o =	333m/s
V_2 =	1724m/s
Z_o =	6m

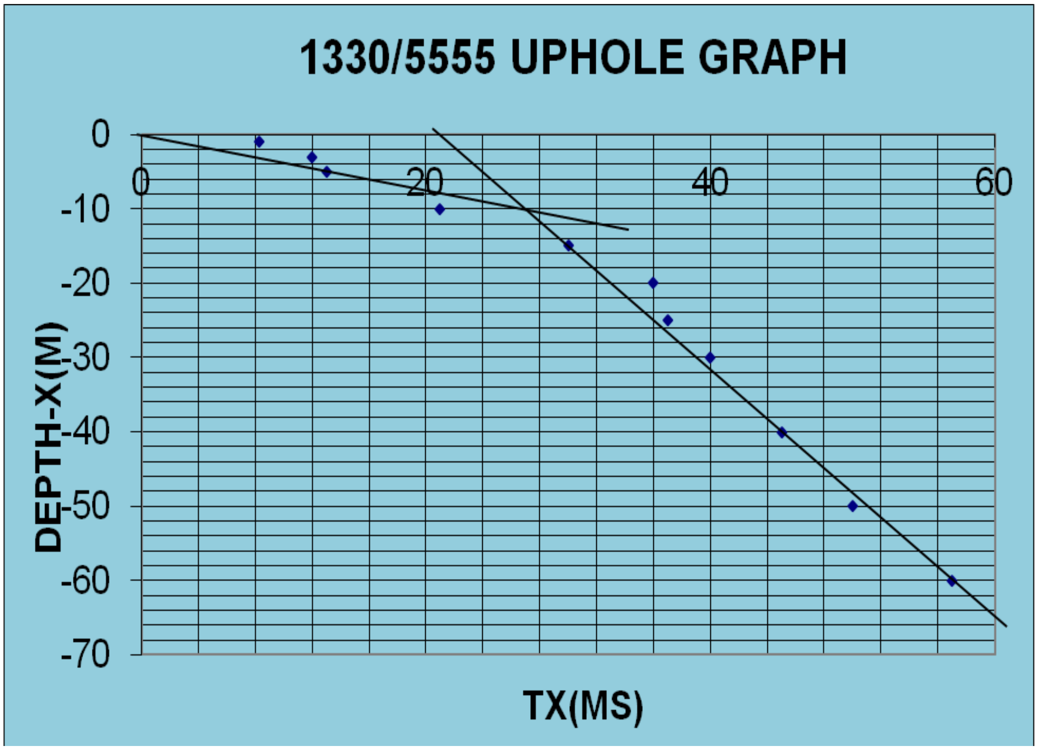
PLATE 3: 1270/5338 UPHOLE DATA/GRAPH



TX(ms)	DEPTH-X(m)
7.75	-1
12.75	-3
14	-5
20	-10
23	-15
25.5	-20
28.75	-25
31	-30
37	-40
42	-50
48	-60

V_o =	357m/s
V_c =	1785m/s
D_o =	5m

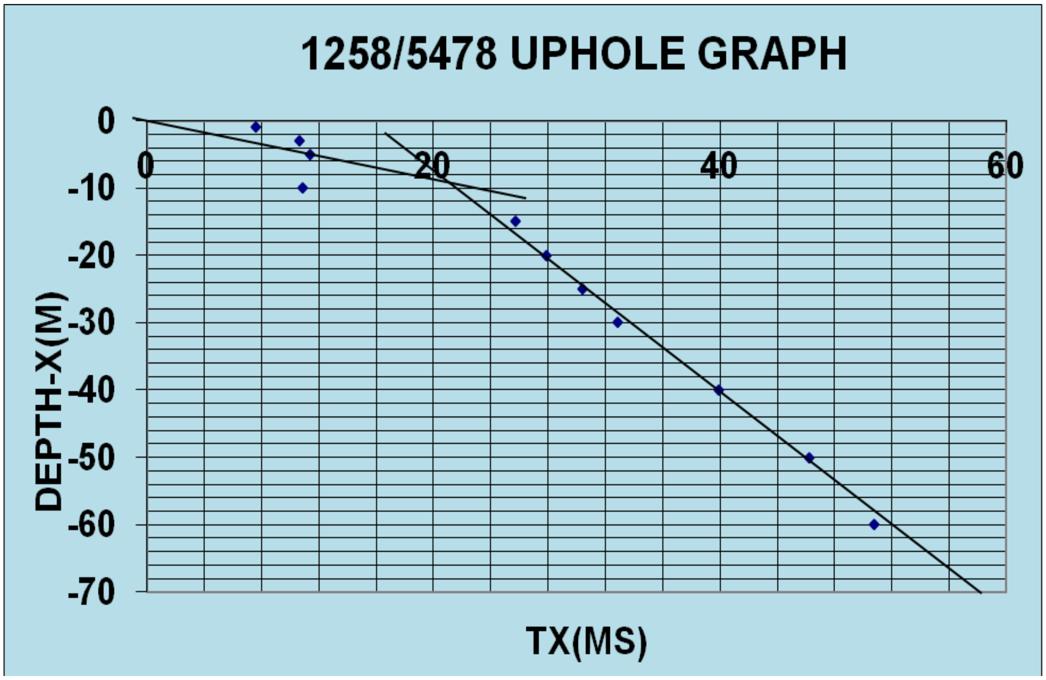
PLATE 4: 1408/5558 UPHOLE DATA/GRAPH



TX(ms)	DEPTH-X(m)
8.25	-1
12	-3
13	-5
21	-10
30	-15
36	-20
37	-25
40	-30
45	-40
50	-50
57	-60

V_o = 384m/s
V_c = 1666m/s
D_o = 10m

PLATE 5: 1330/5555 UPHOLE DATA/GRAPH



TX(ms)	DEPTH-X(m)
7.625	-1
10.625	-3
11.375	-5
10.875	-10
25.75	-15
27.875	-20
30.375	-25
32.875	-30
39.95	-40
46.25	-50
50.75	-60

V_o = 428m/s
V_c = 1,714m/s
D_o = 9.8m

PLATE 6: 1258/5478 UPHOLE DATA/GRAPH

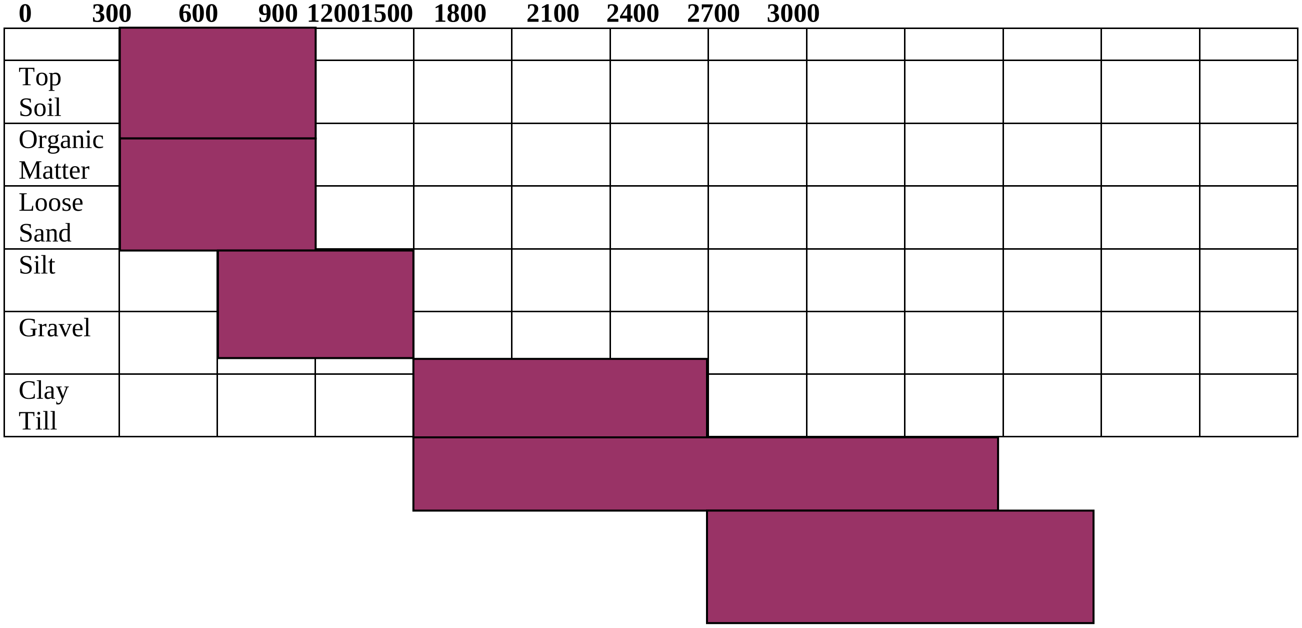
10.0 Discussion

Using equation (1), the depth of consolidated layer can be calculated as shown in Table 3

Table 3 Layer model of study area

Uphole Location	Shot points (SPs)	Elevation (m)	Thickness (m)	Velocity (m/s) Weathered layer	Velocity(m/s) consolidated layer
A	1234/5398	15.5	6.0	400.0	1692.0
B	1270/5338	18.6	7.0	333.0	1724.0
C	1408/5558	15.6	6.0	357.0	1785.0
D	1258/5478	26.0	10.0	444	1667.0
E	1330/5578	30.7	10.0	384	1666.0
F	1316/5398	6.0	9.0	328	1750.0
Total		112.4	48.0	2246	10284
Average		18.7	8.0	374.3	1714

Table 4: Classification of Geological Materials by Seismic Velocities



Reference

[1] Dobrin M.A (1988). Introduction to Geophysical prospecting. McGraw-Hill New York (4th Education) pp 1-9, 33 – 49, 59-61, 461 – 480.

[2] Klett, T.R.,Ahlbrandt , T.S., Schmopker, J.W., And Dolton, J.L., (1997). Ranking of the world's oil and gas provinces by known petroleum volumes: U.S. Geological Survey Open-file Report-97-463, CD-ROM.

[3] Doust, H., And Omatsola, E.,(1990). Niger Delta, *in*, Edwards, J. D., and Santogrossi, P.A., eds., Divergent/passive Margin Basins, AAPG Memoir 48: Tulsa, American Association of Petroleum Geologists, pp 239-248.

[4] Weber, K.J., (1987). Hydrocarbon distribution patterns in Nigerian growth fault structures controlled by structural style and stratigraphy: Journal of Petroleum Science and Engineering, Vol. 1: pp 91-104.

[5] Hospers J. (1965). Gravity field and the structure of the Niger Delta Nigeria, Geo. Soc. Am. Bull Vol.76: pp 407 - 422.

[6] Igboekwe, M.U, GurunadhaRvvs, Okwueze, E.E., (2008). Ground water flow modeling of Kwa-Ibo River watershed south East Nigeria. Hg drol process: Vol. 22: pp 1523 -1531

[7] Burke, K., (1972). Longshore drift, submarine canyons, and submarine fans in development of Niger Delta: American Association of Petroleum Geologists, Vol. 56, pp 1975-1983.

[8] Stacher, P.,(1991). Present understanding of the Niger Delta hydro carbon habitat, *in*, Oti, M.N., and Postma, G., eds., Geology of Deltas : Rotterdam, A.A. Balkema, pp 257-267.

[9] Short, K. C., And Stauble, A.J., (1965). Outline of geology of Niger Delta: American Association of Petroleum Geologists Bulletin, Vol. 51: pp 761-77.