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Analytical determination of low velocity layer in 4-D hydrocarbon prospecting in parts of Imo State

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Abstract

Generally, Seismic reflection surveys are done in the oil sectors to determine commercially viable hydrocarbon reservoirs but in most cases reflection records are obscured by wave behaviours in weathering layer. Hence, Up-hole refraction surveys are carried out in 3-D and 4-D prospects with a view to delineating the accurate depth or location of hydrocarbon reservoirs with least distortion by precise determination of the low velocity layer (LVL).Thus, Up-hole survey was done here using a 24-channel Seismograph OYO Mcseis 160mx which prints the seismometer responses from geological structures beneath in waveforms. These waveforms were studied and plotted to obtain the layer velocities of the waves and their corresponding layer thicknesses from fifteen randomly selected sites in the field. Analyses of results show that the field of study is basically a 3-layer zone in which the weathering layer thicknesses varied from 2.0m to 3.5m with velocity ranging from 340m/s to 1000m/s The consolidated layer velocities range from 1750m/s to 2050m/s which fall within the range used for static correction on the reflection records. Thus weathering/static corrections here may be eliminated at about 3.0 m deep and at elevation of 20m to 40m above sea level in this field and similar fields.

1.0 Introduction

Acquisition of data for hydrocarbon exploration in most multinational oil companies is done by the application of geophysical methods. The most commonly employed geophysical method to compliment reflection survey in the oil and gas industries is the seismic refraction method (Doyen, et al) [5]. The method involves the use of vibrations generated from an energy source usually dynamite, vibrosis, or dropping of heavy weight on the ground and the use of aqua pulse in the case of offshore or marine seismic. The seismic refraction method is utilized here in a 4-D prospect to effectively determine the yield of some wells in a field in part of Imo state. The four-dimensional (4-D) or time-lapse seismic monitoring is a new technology with a determined commercial value aimed at monitoring changes in seismic data by repeating a 2-D or 3-D seismic survey. It sets out to determine seismic changes in relation to fluid, and stress changes during production stage of a field. (Dunlop et al, 1991 [3], Archer et al, 1993 [1]). In the past once a field starts producing, no further survey or check is done. This usually results to failed reservoirs but with 4-D survey, reservoir recharge and viability of a producing field are adequately monitored. The 4-D seismic survey allows field comparison within and between wells and away from wells, making oil/water and gas/oil fluid fronts visible (Johnstad et al, 1993 [6]). 4-D monitoring improves the knowledge of saturation and pressure distribution, resulting in improved dynamic reservoir models and optimal recovery (Blonk and Calvert, 1997 [2]). The study is aimed at critically delineating the low velocity layer in a 4-D prospect in order to reassess the reservoir yield to ascertain its continued viability. The low velocity layer of the earth crust corresponds to the topmost layer of the earth's surface which is characterized by presence of loose, unconsolidated or weathered sedimentary materials or an exfoliated material of metamorphic or igneous rock. Acquisition of Low velocity layer data facilitates corrections in the processing centre and eliminates errors of convolution and distortions of Normal Move Out (NMO) and Common Depth Point (CDP) stacking. Essentially, knowledge of the thickness and velocity of this layer (LVL) increases the accuracy and validity of the static time shift applied in processing field data. Hence an empirical knowledge of the depth of the LVL of any field as a compliment to reflection studies is of great importance to oil prospecting and producing sectors. This is the thrust of this work.

The study in this case was done using a sensitive Seismograph and 0.2 kg dynamite as detonators to obtain the seismic wave forms from which the first breaks of the receiver responses were plotted and analyzed.

2.0 Location and access

The study Area lies within Imo state between latitude 04^0 55' N and 05^0 02' N and longitude 07^0 03' E and $07^0$14' E as established using the Global Positioning System (GPS). These are Imo River and Nkali fields. It is drained by two major rivers – Imo River and River Otamiri. River Otamiri which is located in the Western part of the prospect flows North-West to South-East to merge with the River Imo located on the Eastern part. Both rivers are fast flowing and generally navigable.

3.0 Research Methodology

Generally, the operation is carried out by drilling a single deep hole of about 60m in a selected site near a 4-D reflection survey for which safety from structures such as pipeline, buildings, oil wells *etc* is guarantee and the availability of water or access for water trucks to pump water for drilling is ensured. The drilled hole was then logged using seismograph and detonators. Logging involves a record of all the drill cuttings while drilling. There after, 10-11, Hz electromagnetic hydrophones/geophones were laid at intervals along the receiver line as shown in Figure 1. An offset of 2 metres from the shot hole was taken, thumped to a depth of 2 meters and then loaded with the already prepared charge (dynamite). A shot was taken by detonating the dynamite in the 2 metres deep hole which courses compressional and shear waves to propagate through the medium or lithology that has varying densities, bulk and shear moduli (Phillip Kearey et al, 2002 [8]).

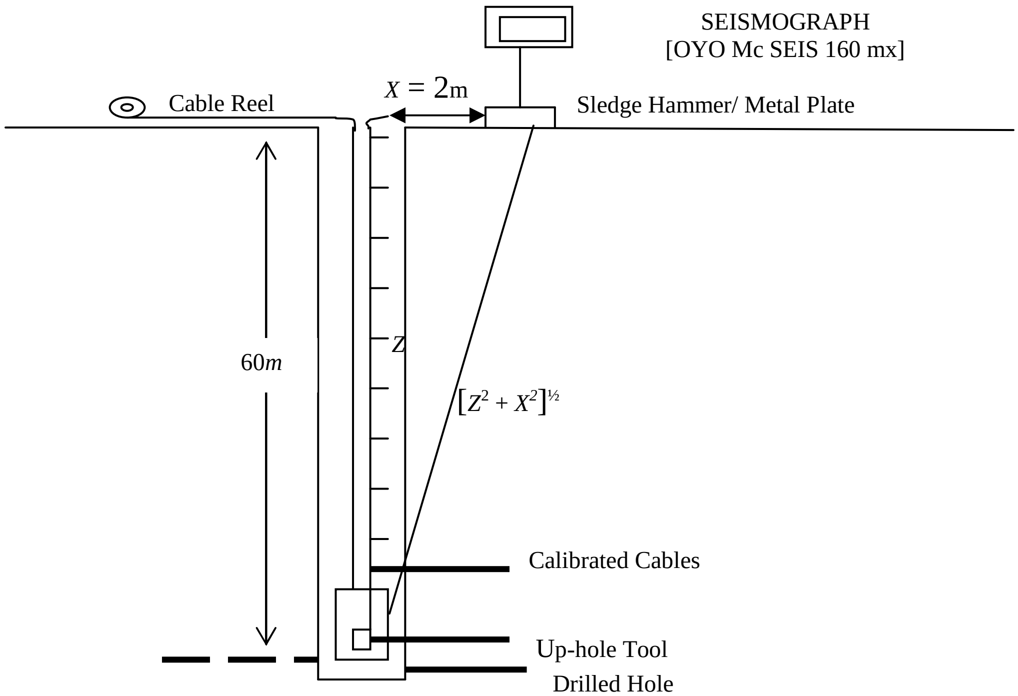


Figure 1: Field Equipment Setup for Up-Hole Refraction Survey

3.1 Theory of Low Velocity Layer

The theory of low velocity layer is based on common physical principles of reflection and refraction. Considering a two-layer earth medium, (weathered and consolidated layer) through which seismic signals travel with reflection velocity, V_1 and refraction velocity, V_2 as shown in the theory below,

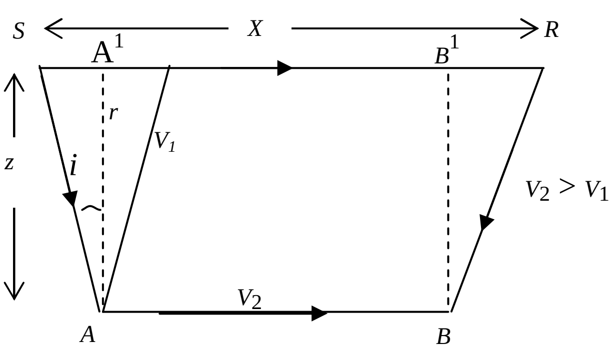


Figure2: Geometry of Refracted Ray-path

We recall that

$V = x/t \Rightarrow t = x/v$

From Snell's law, $$\frac{Sin\, i}{Sin\, r} = \frac{V_1}{V_2} \quad (3.1)$$

At critical angle of incidence, i, the refracted ray lies on the interface, that is $r = 90^0$

$$\Rightarrow Sin\, r = Sin\, 90^0 = 1 \Rightarrow Sin\, i = \frac{V_1}{V_2} \quad (3.2)$$

Considering Figure 2 above, $Sin \quad i_c = \frac{SA^1}{SA}, Cos \quad i_c = \frac{AA^1}{SA}, \tan i_c = \frac{SA^1}{AA^1}$. The travel time of the refracted wave is, $t = \frac{SA}{V_1} + \frac{AB}{V_2} + \frac{BR}{V_1}$

$$t = \frac{2SA}{V_1} + \frac{AB}{V_2} \tag{3.3}$$

(Since SA = BR). But $t = \frac{AA}{SA} + \frac{Z}{SA}$ where ($AA^1 = Z$) $\Rightarrow SA = Z/\cos i_c = Z \sec i_c$. Also,

$AB = x - (SA^1 + B^1R) = x - 2SA^1 \Rightarrow AB = x - 2Z \tan i_c$ (Since $SA^1 = Z \tan i_c$)

Substituting for the value of AB and SA into equation 2.2, 2.1, 2.3,

$$t = \frac{2Z_i \sec i_c}{V_1} + x - \frac{2Z \tan i_c}{V_2}$$

$$t = \frac{2Z}{V_1 \cos i_c} + \frac{x}{V_2} - \frac{2Z \sin i_c}{V_2 \cos i_c}$$

$$t = \frac{x}{V_2} + \frac{2Z}{V_1 \cos i_c}(1 - Sin^2 i_c) = \frac{x}{V_2} + \frac{2Z \cos i_c}{V_1}$$

But, $\cos i_c = \sqrt{1 - \left(\frac{V_1}{V_2}\right)^2}$

$$\Rightarrow t = \frac{x}{V_2} + \frac{2Z\sqrt{V_2^2 - V_1^2}}{V_1 V_2}. \tag{3.4}$$

(Dobrin, 1976) [4].

Equation 3.4 gives the arrival time of the refracted wave.

For the direct wave; $t = x / v$

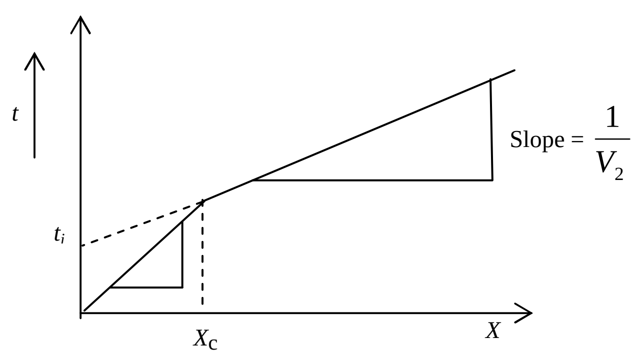


Figure 3: Generalized plot of t and *X*.

Intercept time

$$t_i = \frac{2Z}{V_1 V_2}\sqrt{V_2^2 - V_1^2}. \tag{3.5}$$

But at X_c, time for refracted wave = time for direct wave arrival.

That is,

$$\frac{X_c}{V_1} = \frac{X_1}{V_2} + \frac{2Z}{V_1V_2}\sqrt{V_2^2 - V_1^2} \Rightarrow \frac{X_c}{V_1} - \frac{X_1}{V_2} = \frac{2Z}{V_1V_2}\sqrt{V_2^2 - V_1^2} \Rightarrow \frac{X_c}{V_1V_2}(V_2 - V_1) = \frac{2Z}{V_1V_2}\sqrt{V_2^2 - V_1^2}$$

$$\Rightarrow X_c = \frac{2Z\sqrt{V_2^2 - V_1^2}}{V_2 - V_1}. \quad (3.6)$$

and, $Z_i = \frac{X_c}{2}.\frac{V_2 - V_1}{\sqrt{V_2^2 - V_1^2}} \qquad \Rightarrow Z_i = \frac{X_c}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}}.$ (3.7)

where X_c = Cross-over distance.
Z_i = Depth of first layer
V_1 = Velocity of first layer
V_2 = Velocity of second layer

For the sub-weathering zone, if the arrival times are plotted versus shot-receiver distance, the time where the best line through the points intercepts the time axis is proportional to layer thickness as follows:

$$Z = \frac{V_2V_1t_i}{\sqrt{V_2^2 - V_1^2}} \quad (3.8)$$

A general wave equation can be obtained from Hooke's relation.

The responses (wiggle traces) from the receivers were displayed on the seismograph (OYO McSeis 160mx), printed and recorded on a diskette for use.

3.2 Field significance of low velocity layer data

The most common purpose of all data processing is to increase the signal-to-noise ratio. The signals obtained along side the low velocity data consist of unfiltered primary reflections. These are seismic waves which have been reflected only once by rock bedding underneath the seismic line. This method of enhancing the signal-to-noise ratio in primary reflected data using low velocity layer data is called static correction.

Static correction is used to correct two irregularities associated with the acquisition of seismic data. These include Elevation and weather layer correction.

3.2.1 Elevation correction:

This correction eliminated the undulating topography of the earth crust. Graphically, the method involves drawing a graph of the elevation (*E*) and thickness of the first weathered layer (*Z)* using all uphole points on the x-axis. The reflection times are then adjusted by assuming a datum on top all shot points and by putting all geophones and shots points on the same datum.

The values of the elevation at top of shot, *e* and datum plane elevation *d*, are determine from graph and the elevation correction time (*EC*) is then computed using the formula

$EC = (E + e\text{-}h\text{-}2d)/V_1$ (3.9)

Where V_1 is the mean velocity of the first layer and the time difference obtained is then added to or subtracted from the reflection data to get the actual correction elevation.

3.2.2 Weathering correction

Weathering correction is carried out to eliminate the effect on travel times of variations in the thickness of the low-speed-zone (LVL). The correction is carried out graphically using the same graph of elevation and layer thickness. The intercept time T_i of the first layer is computed from the up-hole graphs and then used to calculate the time (Δt) difference using the mean velocities (V_1 and V_2) on the relation below,

$$\Delta t = T_i = \sqrt{\frac{V_2 - V_1}{V_2 + V_1}} \quad (3.10)$$

The value of Δt is then used to determine the various corrected weathered depth. The depth values are then again plotted on the elevation and layer thickness graph. A line joining these points (line of best fit) together represents the corrected weathering datum.

4.0 Data presentation

A total of twenty up-hole sites were surveyed in the field of study. Five sample locations are registered in this research project. The obtained field data for the sample sites are presented in table 1.

Table 1: Sample Field Data

Location A (UMUDU)		**Location B (ULAKWO)**		**Location C (OPIORO)**		**Location D (EGBELU)**		**Location E (EDEGELOM)**	
D(m)	***T(m/s)***	***D(m)***	***T(m/s)***	***D(m)***	***T(m/s)***	***D(m)***	***T(m/s)***	***D(m)***	***T(m/s)***
2	2	2	9	2	10	2	9	2	8
3	3	3	10	3	12	3	8	3	10
5	6	5	12	5	14	5	11	5	12
6	6	6	10	6	18	6	14	6	14
11	8	11	20	11	24	11	20	11	18
16	11	16	28	16	28	16	27	16	22
21	14	21	36	21	30	21	3	21	25
26	17	26	39	26	32	26	34	26	28
36	23	36	46	36	38	36	37	36	33
46	28	46	52	46	44	46	44	46	38
56	33	56	56	56	50	56	50	56	44

5.0 Data Analysis

The field data obtained from the up-hole survey were analyzed using a computer based interpretation software. However, in this project, the graphical method is employed to determine the depth of the first layer by plotting a graph of time (*t*) versus depth (*x*) Figures 4 to 8.

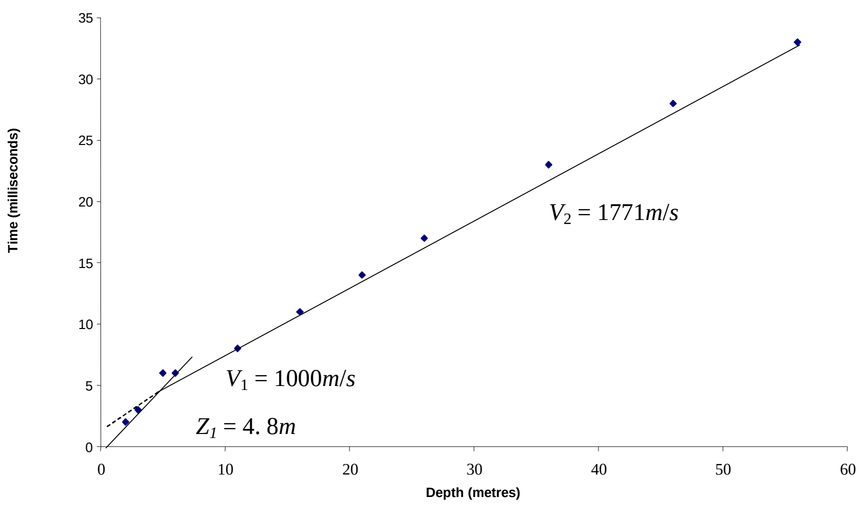
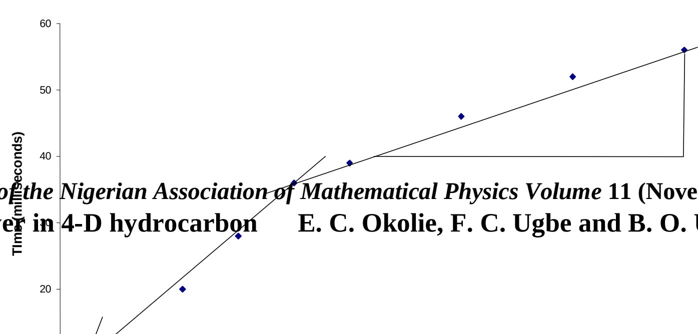


Figure 4: Graph of Uphole Location A



$V_3 = 2125 m/s$

$V_2 = 720 m/s$

$Z_2 = 383\ m$

$V_1 = 250 m/s$

$Z_1 = 2.6 m$

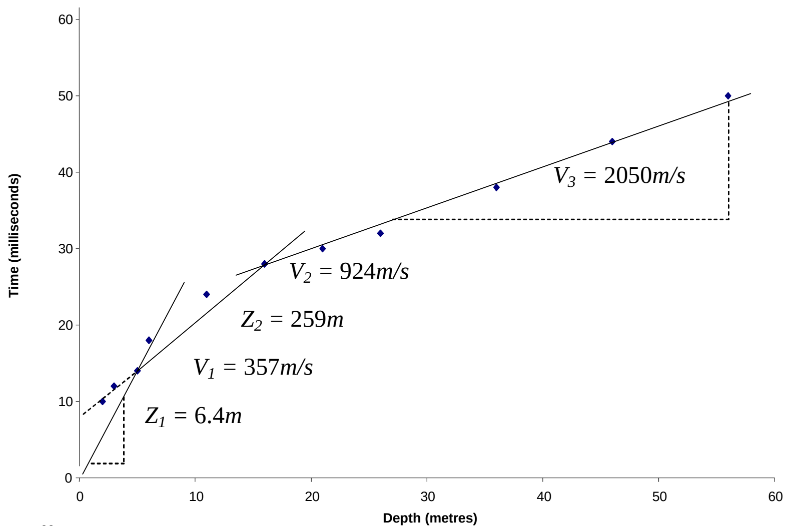


Figure 6: Graph of Uphole Location C

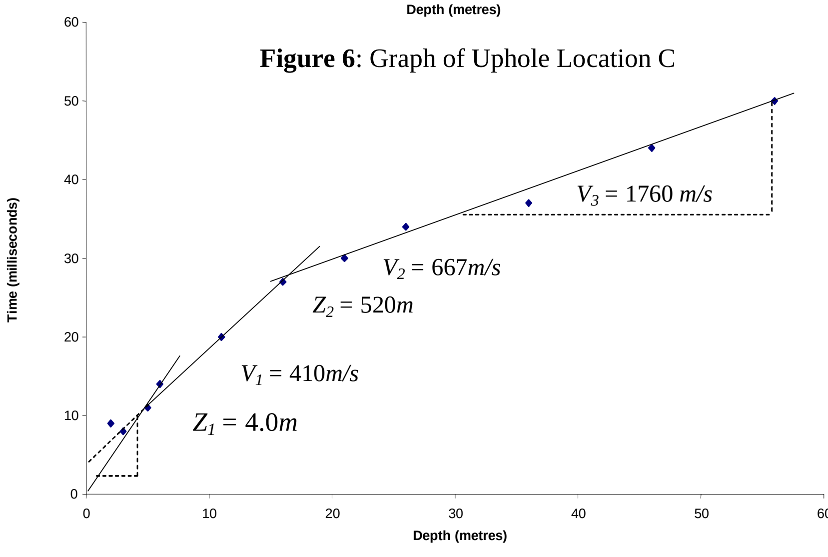


Figure 7: Graph of Uphole Location D

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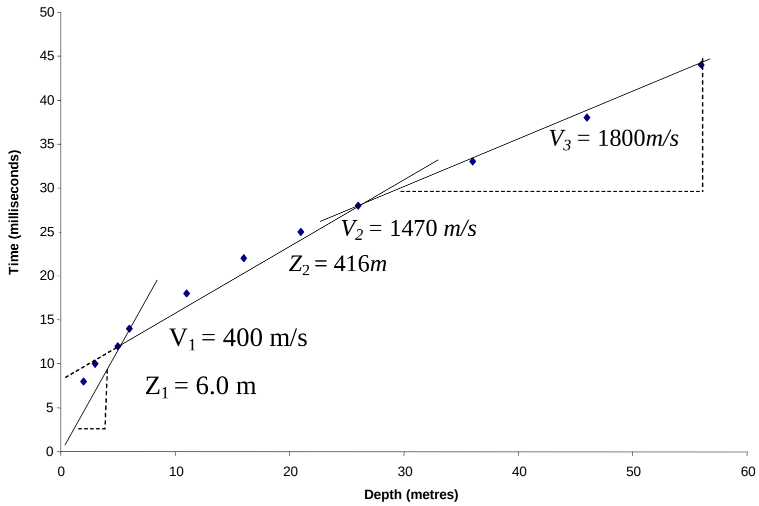

Figure 8: Graph of Uphole Location E

6.0 Discussion

From the plots (Figure 4 to 8), it was observed that, sites B, C, D and E, have a three layers - the weathered layer, sub-weathered layer and consolidated layer with velocities, $V_{1,}$ and V_2 for the weathered layers and V_3 consolidated layers as shown in the table 2 below. From the velocities it is obvious that the first weathering layer in the field consists mainly of dried weathered rock particles. They are immediately underlain by closely packed sub-weathered lateritic soil to far depth. The consolidated layer which is mainly made up of medium grain sand to gravely sand is generally saturated with water as indicated by its high layer velocity of 1700 ms and above (Table 2) (Osemeikhian and Asokhia 1994) [7].

Table 2: Layer Model

Uphole Location	**Elevation (*m*) Above Sea Level**	**Weathering Layers**				**Consolidated Layer Velocity (V_c)(ms^{-1})**
		Depth $D_1(m)$	**Depth $D_2(m)$**	**Velocity $V_1(ms^{-1})$**	**Velocity V_2 (ms^{-1})**	
A	20.4	2.8		1000		1771
B	40.2	9.6	383	250	720	2125
C	30.4	6.4	259	357	924	2050
D	33.6	4.0	520	410	667	1760
E	20.7	6.0	416	400	1470	1800
Mean Value				**354**	**956**	**1900**

Table 3: Calculation of Elevation correction

Site	**Shot Elevation (*e*) (*m*)**	**Depth Charge (*h*) (*m*)**	**First Break (*ms*)**	**Datum Plane Elevation (*d*) (*m*)**	**2*d* (*m*)**	**Detector Elevation (E) (*m*)**	**(*E + e – h* - 2*d*) = *X***	**Elevation correction (Delay Time) X/V_1 (ms)**
A	19.8	2	2.8	1.4	2.8	20.4	20.4 + 19.8-2-2.8 = 35.4	35.4/1000 = 0.035
B	0.0	2	9.6	21.2	42.4	40.2	40.2 + 0-2-42.4 = -4.2	-4.2/250 = -0.017
C	9.8	2	6.4	11.4	22.8	30.4	30.4 + 9.8-2-22.8 = 15.4	15.4/357 = 0.043
D	6.6	2	5.0	14.6	29.2	33.6	33.6 + 6.60-2-29.2 = 9.0	9.0/410 = 0.022
E	19.5	2	8.2	1.7	3.4	20.7	20.7 + 19.5-2-3.4 = 34.8	34.8/416 = 0.084

Thus, adding or subtracting the Delay Time from the reflection time (First break) in Table 3, we have real travel time t_r as

For Site A $\Rightarrow t_r = 2.8\text{-}0.035 = 2.765ms$

But, $X = vt$

$X_A = 2.765 \times 1000/1000m = 2.77m$

For Site B $\Rightarrow t_r = 9.6 + 0.017 = 9.617ms$

$X_B = 9.617 \times 250/1000 = 2.40m$

For Site C $\Rightarrow t_r = 6.4 - 0.043 = 6.357ms$

$X_C = 6.357 \times 357/1000 = 2.27m$

For Site D $\Rightarrow t_r = 5.0 – 0.022 = 4.978ms$

$X_D = 4.978 \times 410/1000 = 2.04m$

For Site E $\Rightarrow t_r = 8.2 – 0.084 = 8.116ms$

$X_E = 8.116 \times 400/1000 = 3.25m$

7.0 Conclusion

This study was undertaken to determine the Low Velocity Layer (LVL) of the study area using Up-hole survey in a 4-D prospect. 4-D surveys are usually carried out in producing field where 2-D or 3-D had earlier been made to ascertain its continuous viability or otherwise. Such information is often obscured by the adverse effect of the Low velocity layer (LVL). Hence, Up-hole survey was used to empirically determine the weathering layer or LVL so as to eliminate its effect on arrival time. The obtained data were generally good and were subjected to calculations and graphical interpretations. The results from interpretations showed that the area is basically a three layer model. Only location A showed two-layer formations. From calculations, the weathering thickness of the first layer was found to be from about 2.0 to 3.5 m with velocity from 250 ms^{-1} to 1000 ms^{-1} and mean value of 354ms^{-1} while the sub-weathering layer velocity of 720 to 1470 m/s with a mean of 956 m/s was also obtained in the set of up-hole data with the exception of location A. The consolidated layer velocities range from 1750 m/s to 2050 m/s with an average velocity of about 1900ms^{-1} which fall within the range used for static correction on the reflection records. We therefore infer that weathering/static corrections here may be effected at about 3.0 m deep and at an elevation of 20 m to 40 m referenced to sea level by placing all detectors on the same datum of 3.0 m deep in this field and similar fields. It is however, recommended that 2000 m up-hole separation used here be reduced to 1000 m so that more up-hole stations could be surveyed for increased accuracy.

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