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Uphole Seismic Refraction Survey for Low Velocity Layer Determination over Yom Field, South East Niger Delta

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Abstract: The uphole refraction survey was carried out in YOM field 4-D prospect to evaluate the weathering thickness and velocity of the Low Velocity Layer (LVL). Five uphole locations were occupied in the study area and the time intercept technique of the seismic refraction interpretation was employed. For the different locations (A-E), the weathering thickness was found to vary from 0.9-1.9 m with velocity from 250-800 m sec^{-1}. A sub weathering layer was also observed in all locations except A. Also, the velocity of the consolidated layer was found to vary from about 1750-1800 m sec^{-1} with a mean velocity of 1766 m sec^{-1}. Using this result to eliminate the effect of LVL on reflection data from the graphical approach, it was observed that the elevation and weathering correction (static correction) was found to be eliminated at a datum of 2 m deep.

Key words: Low velocity layer, uphole, seismic refraction, elevation correction, YOM, eliminated

INTRODUCTION

The low velocity layer of the earth crust correspond to the topmost layer of the earth's surface which is characterised by the presence of loose, unconsolidated or weathered sedimentary materials or an exfoliated materials of metamorphic or igneous rocks. There is a great disparity in the velocity of the weathered layer (LVL) 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. These time delays if not allowed for degrade the reflection seismic section by improper alignment of traces after Normal Moveout (NMO) corrections.

Low velocity layer can be eliminated by correcting for the near surface velocity and topographic differences. Differences in arrival time due to differences in the elevation of the geophone will have the effect of positioning a syncline under a hill or an anticline under a valley or a fault under a cliff.

It is therefore, required that low velocity layer data acquired during seismic prospecting be corrected to take care of this anomaly. The 1st calculation of corrections for elevation and weathering is carried out in the field. The distance of the geophone from a layer under investigation is measured and divided by the velocity of the wave in the consolidated layer near the surface and adding or subtracting this time from the time of arrival of reflected data at the geophone stations. These field statics are based on the uphole survey and 1st break information and are subsequently used in processing as the 1st estimate.

The static time shift corrections is also carried out and this associates a common layer to all waves which passes through that portion of the earth. Taner *et al.* (1974) and Hatherly *et al.* (1994) give good synopses of a simple approach of carrying out seismic refraction statics corrections. 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. Also, it facilitates later manipulations and corrections in the processing centre and eliminates other errors in acquisition through computation caused by the recording system such as convolutions and distortions due to the physical properties of reflected waves such as Normal Moveout (NMO) and Common Depth Point (CDP) stacking. This study sets to examine critically, the method of acquiring uphole data in a 4-D seismic survey as compared with other methods thereby, revealing shortfalls in low velocity layer determination and ways of reducing risk of a repeat survey. An uphole survey is a seismic refraction procedure which aims at determining the thickness and velocity of the weathering layer.

The survey is therefore, a good tool in making decisions on drilled and charge depths in any seismic operation. Uphole data are also utilized in the computation of statics during subsequent processing of seismic reflection data.

Location and geology: The study area (Fig. 1) is a 4-D prospect which is located within an area approximately between latitudes 4.92-5.05°N and longitudes 7.05-7.24°E

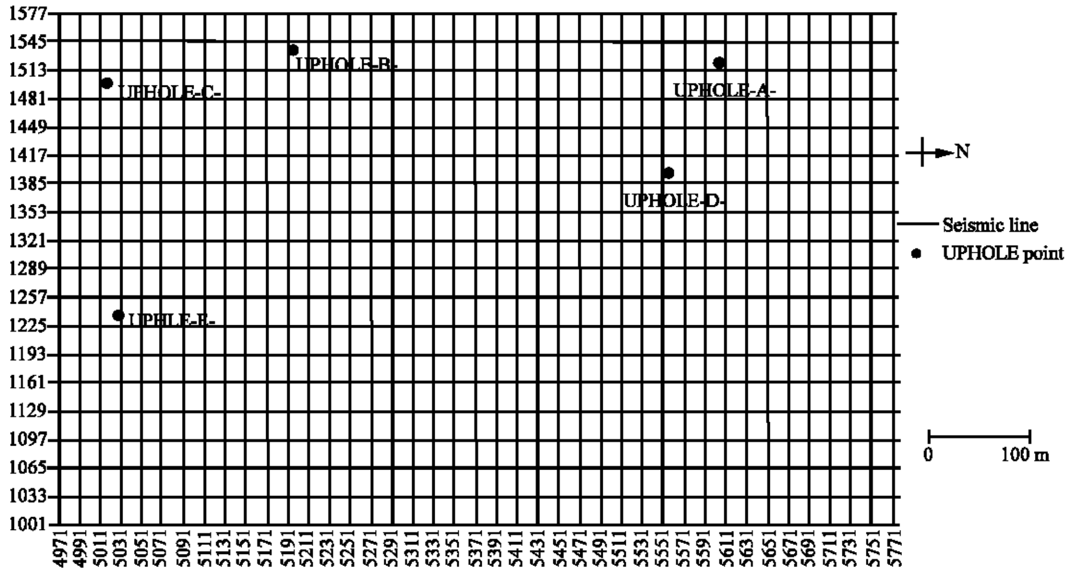

Fig. 1: Base map of the study area showing uphole location

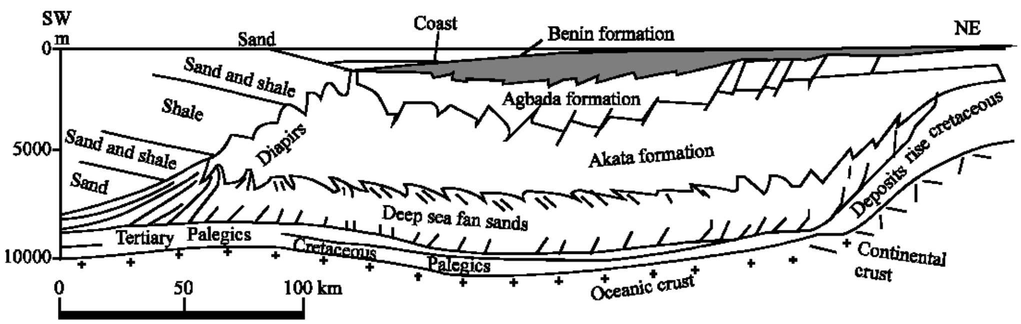

Fig. 2: Stratigraphy/structure of the Niger Delta (Asseez, 1989)

of the Niger Delta complex, Nigeria. The area is characterised by grassland vegetation interspersed with farms of cassava and maize with the northern part having thick vegetation. The terrain is flat but allows for a good drainage pattern as the land slopes into two major rivers which flood at the peak of the rainy season. The prospect traverses two major oil fields and is criss-crossed by a network of roads.

Three distinct facies belts (Fig. 2) have been identified in the Niger Delta (Short and Stauble, 1967; Asseez, 1989). The Benin formation (Miocene to Recent) within which the study is housed, 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 >2,100 m (Weber and Daukoru, 1975; Ejedawe, 1981). The Agbada formation between lower/middle Miocene to Pliocene, 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 (Evamy *et al.*, 1978).

The Akata formation aged eocene to recent 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.

Theory: Seismic refraction surveying measures the 1st arrivals of seismic energy from a seismic source. The exact time, the source is produced and when the energy reaches the receiver need to be determined to analyse the 1st arrival travel times.

The 1st arrival of seismic energy is always the direct wave or the refracted wave, the direct are refracted waves are shown perivous (Fig. 3).

The direct wave travels from A-D at the slower velocity V_1 and the refracted wave travels from A-D via B and C where, it is critically refracted and travels at V_2 between B and C. This means that at short AD distances the direct wave arrives 1st because it has a shorter travel but when the separation between A and D increases the refracted wave will arrive 1st because of the faster travel time between B and C will overcome the difference in distance travelled. This means that the velocities of the layers can be analysed and so can the depth to the interface.

Velocities are commonly calculated by plotting a travel time vs. distance between source and receiver plot, shown in Fig. 4a. The velocity of the top layer (weathered layer) can be calculated from the reciprocal of the gradient of the direct arrivals and the velocity of the 2nd layer (bedrock velocity) can be calculated from the reciprocal of the gradient of the refracted arrivals. The depth to the interface can be calculated from the intercept time of the refracted arrivals and the two calculated velocities and the equation to calculate depth to interface is:

$$Z = \frac{t_i v_1 v_2}{2(v_2^2 - v_1^2)^{1/2}}$$

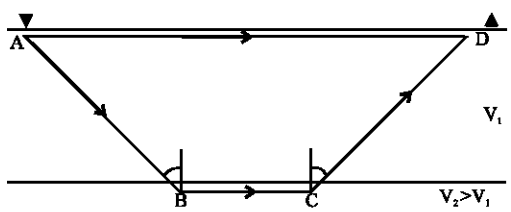

Fig. 3: Direct and refracted waves in a two layer medium

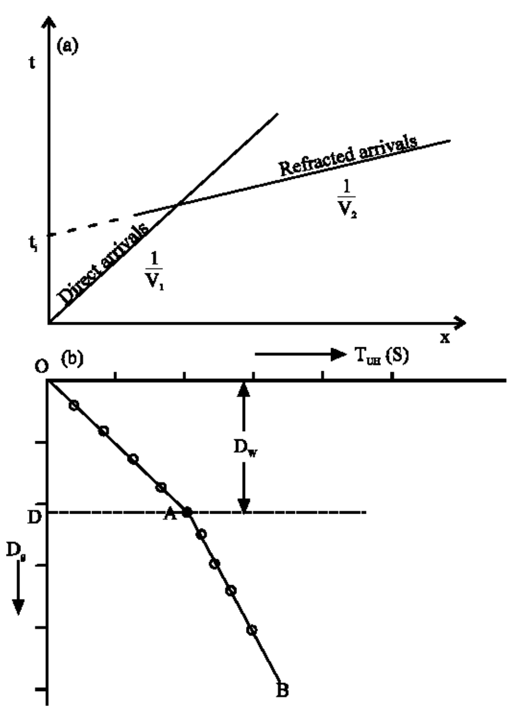

Fig. 4: a) Travel time vs. distance plot; b) uphole survey time depth relationship

Similarly, the parameters (V_W, D_W and V_B) can be deduced from the uphole survey data (Fig. 4b). 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.

MATERIALS AND METHODS

When energy is incident at the critical angle to a reflector with a positive reflection coefficient, it is refracted along the interface at the velocity of the 2nd layer. Each point on the interface excited by the refracted wave radiates upwards with hemispherical divergence causing wavefronts to travel to the surface with raypaths that intersect the interface at the critical angle (Asor, 2000). It follows that on a seismic record, a reflection ceases to exist at the critical distance and is succeeded by a refraction.

In an uphole survey, a hole is essentially drilled (up to about 63 m depth) where shots are laid (in the case of offset-geophone) or where, hydrophone is lowered (in the case of down-deep hydrophone). The procedure for determining the LVL in many seismic surveys is well defined. The single deep hole of 60 m is done by digging a mud pit and connecting the drill head to it with hoses. Flushing is achieved when metallic drill are screwed to the drill bit and rotating steel casing by hand connected to a drill head and pumping water, drilling mud from mud pit with hoses through the casing to flush the hole to 60 m. At the end of the drilling, the hole is cased by a 4 bar PVC casing. The logging involves a record of all the drill cutting while drilling is ongoing with a weight being attached to the bottom end of the down hole cable. The cable is then lowered into the hole to the correct depth with 10-11, 10 Hz electromagnetic hydrophones inserted at intervals. The uphole cables and geophones are laid out at line intersections along the receiver line. The licensed shooters clear the uphole position before bringing the seismic explosives (detonators and dynamite). A shot hole is positioned 2 m away from the drill hole (i.e., offset is 2 m), thumped to 2 m depth and then loaded with the already prepared charge, properly tamped with sand. The charge used consists of one cap and 0.2 kg dynamite or a total of 47 caps/detonators when a single hydrophone is used and shots are taken at each interval. Using the down hole cable, the hole is then shot and the output signal like wiggle traces are recorded into a 3.5 diskette in the uphole recording instrument (OYO McSeis 160MX).

RESULTS AND DISCUSSION

After a shot is taken, a plot of arrival times versus geophone stations (in the case of offset-geophone) and hydrophone depth (in the case of down-deep hydrophone) is made on a monitor record and this constitutes the data set. In processing of the data, 1st break arrival times are picked for various shots. First-break time is the 1st pick-up time recognised for any trace and it is the parameter of interest in the interpretation of uphole data. It is worth pointing out that a good and reliable quantitative interpretation of the uphole data is made only from shots taken well within the weathering layer. This is as a result of the fact that here, the ray crosses the weathering layer twice and this gives a proper representation of the ray path in the weathering layer (Ogagarue, 2007). Five uphole locations were used for this study and the results of the survey showing arrival time vs. depth is shown in Table 1.

Calculation of weathered layer velocity/thickness from the time/depth graph: For the analysis of this data, the graphical method was employed to determine the depth of the 1st layer by plotting a graph of time against depth. The slope inverse of the curve obtained gives the velocity of the seismic wave of the layer in question. The graphs were plotted for each uphole points and the velocities of the weathered and consolidated layers obtained, respectively. The graph of time in milli sec against uphole depth in meters in location A is shown in Fig. 5 with the computation of the weathered layer velocity (V_1), consolidated layer velocity (V_2) and the depth to the weathered layer. From the graph:

$$\text{Slope of the 1st segment} = \frac{1}{v_1} = \frac{7-2.5}{7.5-1.5} \times 10^3$$

$$V_1 = 800 \text{ msec}^{-1}$$

Also from the 2nd segment of the graph:

$$V_2 = 1771 \text{ m sec}^{-1}$$

Now using Eq. 1, the depth to the consolidated layer can be calculated, thus carrying out this procedure on the other uphole locations B-E, gives a layer model of the earth around the study area as shown in Table 2:

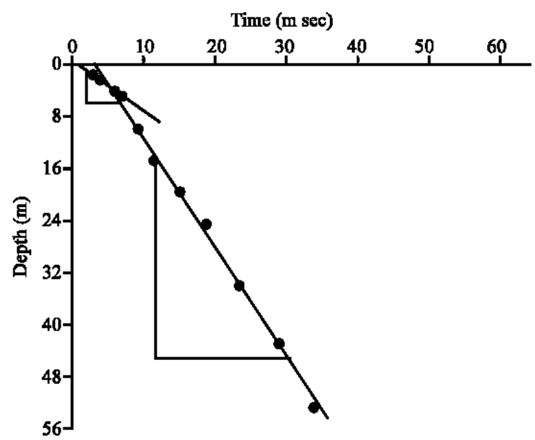

Fig. 5: Graph of time vs. depth of uphole location A

Table 1: Arrival time at the different depth in the uphole survey

Location A (elevation 20.4 m)		Location B (elevation 40.2 m)		Location C (elevation 30.4 m)		Location D (elevation 33.6 m)		Location E (elevation 20.7 m)	
Depth (m)	Time (m sec)	Depth (m)	Time (m sec)	Depth (m)	Time (m sec)	Depth (m)	Time (m sec)	Depth (m)	Time (m sec)
2.0	2.0	2.0	9.0	2.0	10.0	2.0	9.0	2.0	8.0
3.0	3.0	3.0	10.0	3.0	12.0	3.0	8.0	3.0	10.0
5.0	5.5	5.0	12.0	5.0	14.0	5.0	11.0	5.0	12.0
6.0	6.0	6.0	10.0	6.0	18.0	6.0	14.0	6.0	14.0
11.0	8.0	11.0	20.0	11.0	24.0	11.0	20.0	11.0	18.0
16.0	11.0	16.0	28.0	16.0	28.0	16.0	27.0	16.0	22.0
21.0	14.0	21.0	36.0	21.0	30.0	21.0	3.0	21.0	25.0
26.0	17.0	26.0	39.0	26.0	32.0	26.0	34.0	26.0	28.0
36.0	23.0	36.0	46.0	36.0	38.0	36.0	37.0	36.0	33.0
46.0	28.0	46.0	52.0	46.0	44.0	46.0	44.0	46.0	38.0
56.0	33.0	56.0	56.0	56.0	50.0	56.0	50.0	56.0	44.0

Table 2: Layer model of the study area

Uphole location	Elevation (m)	Weathered layer Thickness (m)	Weathered layer Velocity (m sec^{-1})	Consolidated layer velocity (m sec^{-1})
A	20.4	1.8	800	1771
B	40.2	0.9	250	1750
C	30.4	1.9	333	1750
D	33.6	1.8	410	1760
E	20.7	1.9	400	1800

$$Z = \frac{6 \times 800 \times 1771}{2(1771^2 - 800^2)^{\frac{1}{2}}}$$

$$Z = 1.8 \text{ m}$$

Generally, the weathered layer seismic velocity ranges from very low 250 m sec^{-1} around location B of the study area to 800 m sec^{-1} around location A. These 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 (Enikanselu, 2008). Also, the weathered layer thickness ranges from very low 0.9 m around location B of the study area to 1.9 m around locations C and E. Also, the consolidated layer seismic velocity ranges from 1750 m sec^{-1} around location B of the study area to 1800 m sec^{-1} around location E. It could be observed that the layer is sufficiently competent judging from the seismic velocity distribution across the study area.

Static correction: The most common purpose of all data processing is to increase the signal-to-noise ratio. The signal 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. It is used to correct two irregularities with the acquisition of seismic data. These include elevation and weathering correction.

Elevation correction: Elevation correction eliminates the undulating topography of the earth crust. The method involves drawing a graph of the Elevation (E) and thickness of the 1st 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 on the same datum followed by another arbitrarily chosen datum below the shot as shown in Fig. 6. From the graph, the values of elevation at top of shot, e and datum plane elevation, d is determined.

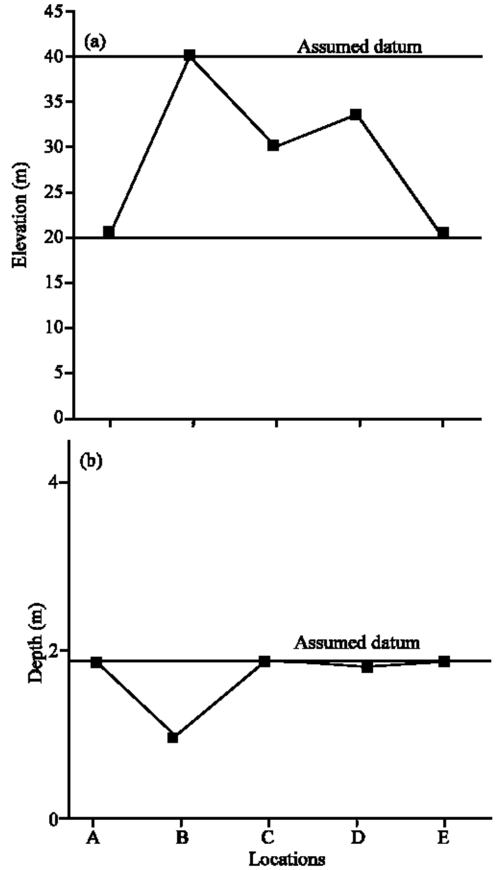

Fig. 6: Graph of elevation correction

Table 3: Delay time computation

Shot elevation (e)	Depth of charge (H)	Datum plane elevation (d)	2d	Detector elevation	E+e-h-2d = X	X/V1 (m sec)
19.8	2	1.4	2.8	20.4	35.4	0.081
0	2	21.2	42.4	40.2	-4.2	-0.010
9.8	2	11.4	22.8	22.8	15.4	0.035
6.6	2	14.6	29.2	29.2	9.0	0.021
19.5	2	1.7	3.4	3.4	34.8	0.079

Table 4: Depth to sea level

Location	A	B	C	D	E
First break time (m sec)	2.8	9.6	6.4	5.0	8.2
Final datum (m)	2.0	2.0	2.0	2.0	3.0

The elevation correction is then computed from the equation; E.C = E+e-h-2 d/V_1 where, V_1 is the mean velocity of the 1st layer and the excess time obtained is then subtracted or added to the reflection data. The final datum is therefore, determined from the calculation (Table 3 and 4). Thus, adding or subtracting the delay times from the reflected time picked as the 1st break time, the final datum is approximately 2 m depth taking the line of best fit with elevation of 20 m referenced to sea level.

Table 5: Weathering correction

Locations	A	B	C	D	E
Ti (m sec)	3.0	6.0	7.0	3.0	8.0
Δt (m sec)	2.3	4.7	5.4	2.3	6.2
Depth values, X (m)	2.0	1.0	2.0	1.0	2.0

Weathering correction: Weathering correction is carried out to eliminate the effect on arrival times of variations in the thickness of the Low Velocity Layer (LVL). The correction is carried out graphically using the same graph of elevation and layer thickness (Fig. 6). The intercept time T_i of the 1st layer is computed from the uphole graphs and then used to calculate the excess time (Δt) using the average velocities (V_1 and V_2) with the equation below:

$$\Delta t = T_i \sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$$

The value of Δt is then used to determine the various corrected weathered depth. The depth values are then again plotted on the elvation and layer thickness graph as shown in Table 5. Therefore, taking the line of best fit, this removes the weathered layer altogether, putting all detectors effectively on a datum below its base.

CONCLUSION

This study has analysed the weathering characteristics of the study area using the uphole survey techniques. The results show mainly a three layer model (except uphole location A) in almost all the interpreted low velocity layer data. The weathering thickness was found to vary from 0.9-1.9 m with velocity ranging from 250-800 m sec^{-1}. Also, the average consolidated layer velocity is about 1766 m sec^{-1} and falls within the range used for static correction on the reflection record as this removes its effect on the arrival time.

Although, velocity varies with depth, the weathering thickness information obtained is used to eliminate the effect of low velocity layers. Also, the elevation and weathering correction was found to be eliminated at a datum of 2 m and elevation of 20 m referenced to sea level so as to remove irregularities by placing all detectors on the same datum.

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