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Velocity profile and subsurface stratification in oil and gas exploration in parts of Niger Delta Nigeria

E. C. Okolie,
Department of Physics
Delta State University, Abraka, Nigeria.

In prospecting for crude oil and gas (hydrocarbon), the most useful and most reliable applicable seismic approach is the reflection method because of its high resolution and deep penetration when seismic shots are taken. However, land surveys require the use of pattern holes for logistic reasons as against deep shooting in swamps and seas. With the use of pattern hole shots, there is the need for further investigation of the stratification of the subsurface structure in a particular field as near surface coherent and random noise tend to obscure useful signals on records. One reliable means of subsurface investigation is by running a velocity profile. Velocity profiles of part of Delta South senatorial district were carried out in swats using seismograph Oyo Mc Seis-160mx from which the subsurface structure of the fields were stratified to enhance interpretation of true hydrocarbon traps. The results show that the consolidated region is mainly compact clay, sand stone, shale argillite and weathered fractured rocks which is indicative of possible hydrocarbon reservoir at far depth. However, in computing for the real hydrocarbon depth, an obscuring depth of up to 20 metres need to considered.

1.0 Introduction

Seismic exploration is usually employed in prospecting for oil and gas since it has deeper penetration and high resolution factor. In land survey, there are basically two complimentary approaches; the reflected waveform and the uphole refraction studies.

Although waveform studies give details deep down, it is difficult to distinguish waves particularly near the earth surface. The latter approach therefore compliments (*i*) during interpretation by stratifying the superficial layers of the subsurface. This is important as near surface coherent and random noise tend to obscure useful signals or records. In the oil industries therefore, it is of utmost importance that uphole surveys are made. Hence velocity profiles of two fields in Niger Delta basin of Delta State were carried out using uphole refraction survey from which the superficial layers were stratified for the purpose of interpretation of possible oil traps [3].

2.0 Location of study area

The area is within Latitude $5^{o}50^{/}$E and $6^{o}10^{/}$E, and Longitude $5^{o}00^{/}$N and 5 $^{o}15^{/}$N It is situated in the Delta South senatorial district. It is within the Benin formation but remarkably

Telephone: +324-0803-678-4353

characterised by very low elevation and flat topography as evident by numerous flowing rivers, streams which empty in river Niger and water log terrain. It is basically a sedimentary region.

3.0 Materials and methods

Twenty-seven uphole survey sites fill two fields in the central zone of Delta south were used. The fields have a characteristic Niger Delta geological setting which is an indication of hydrocarbon reservoirs. Two well survey approaches are possible (*i*) the up-hole refraction method and (*ii*) the horizontal profiling. The first was used in preference because of its accuracy, deep penetration and available measuring instrument – the seismograph 160mx [10].

Each site was programmed and drilled to 60 metres by the flushing method with twenty 3-metre drill casings of 0.12*m* diameter.

Shooting and Recording: On attaining 60m depths, the casings were removed a reliable pressure resistant geophone encased in a steel cylinder (uphole tool) was lowered into the deep hole using calibrated marine rope. The up-hole tool was equipped with a mechanical appendage which suspended the tool freely at any required depth while recording. The geophone cables were connected to a 24-channel seismograph model (Oyo Mc Seis-160*mx*) which records and prints out seismic traces. Sledge hammer and metal plate source positioned two metres away from the hole were used as energy source. A geophone, the trigger to the seismograph buried under a metal plate served as the short point (Figure 3.1) [8].

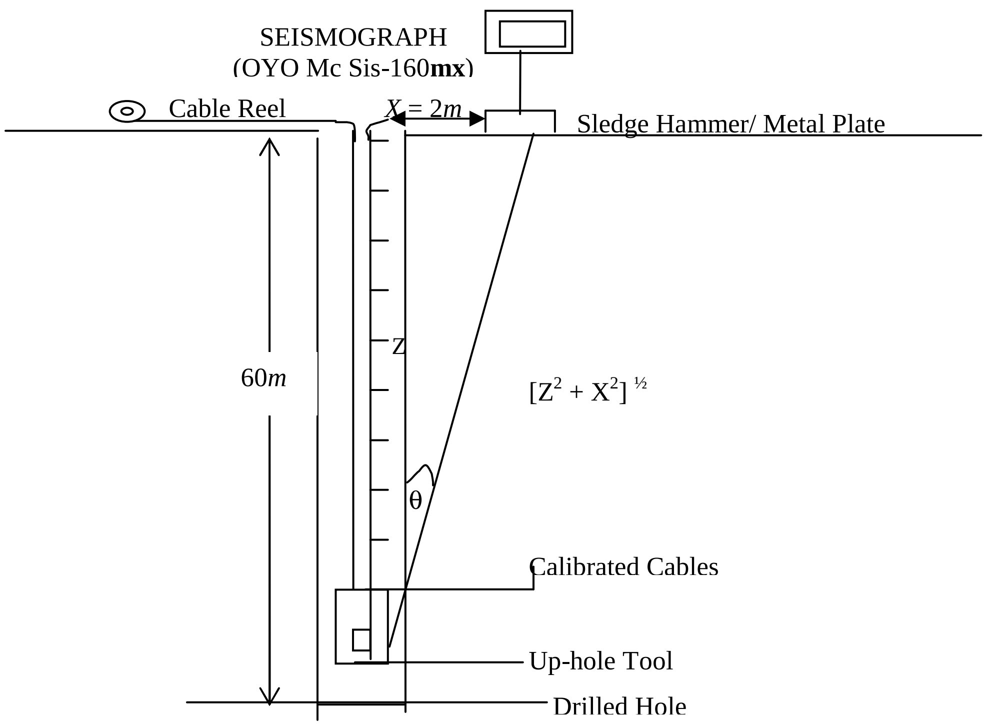

Figure 3.1: Up-hole refraction survey field equipment setup

4.0 Theory

The basic assumptions relating to refracted ray path geometries of horizontal interfaces are that the subsurface is composed of a series of layers separated by plane and possibly dipping interfaces, the seismic velocities increase with depth and ray paths are restricted to vertical plane containing the profile line. These imply that there is no cross dip component within the subsurface [3].

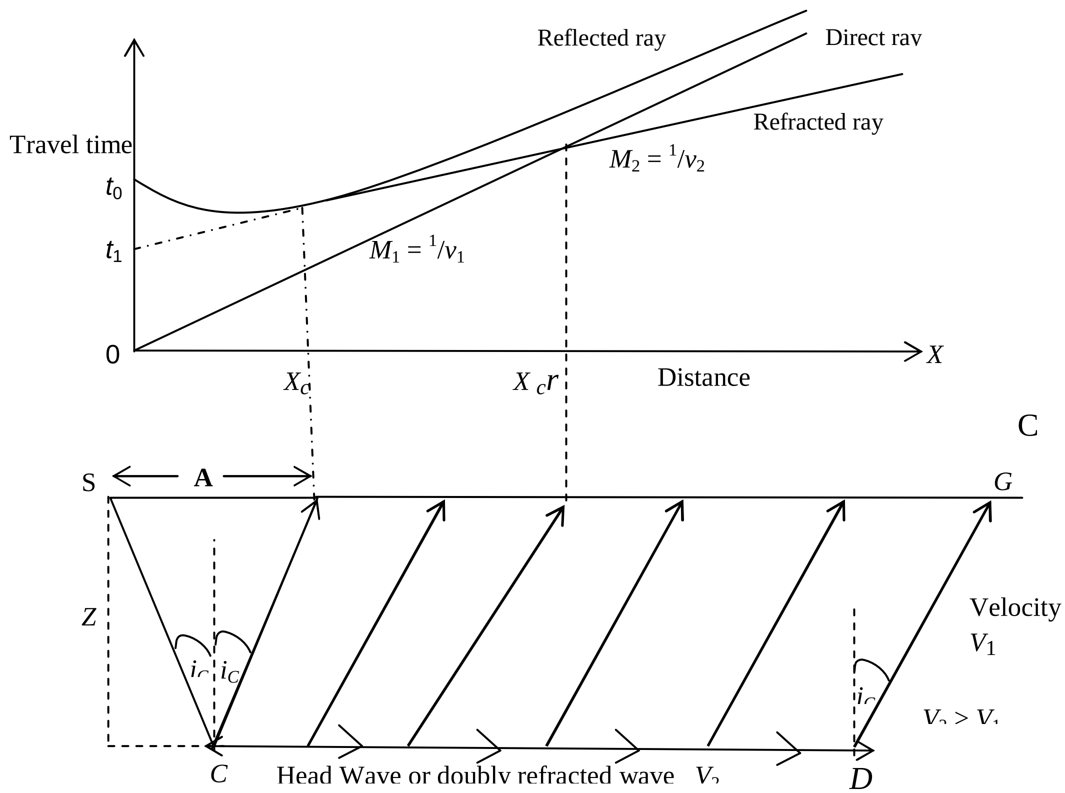

Figure 4.1: Application of Huygens' principle to the critical refraction at the interface between two horizontal subsurface layers at Z metres apart showing travel – time versus distance curves for direct, reflected and refracted rays through them with seismic velocities V_1 and V_2 for which $V_2 > V_1$ [5]

The doubly refracted waves through SCDG in Fig 2 are specifically important for the information they reveal about the layer structure of the earth. In a two – layer horizontal interface, the wave-fronts are associated with energy travelling directly through an upper layer to detector at G, a distance X from the source, with the energy critically refracted in a lower layer. The layer velocities are V_1 and V_2, ($V_2 > V_1$) and the refracting interface is at a depth Z (Figure 4.2). The direct rays travel horizontally through the top of the upper layer from S to G with velocity V_2 while the doubly refracted ray travels through path SC with velocity V_1 at critical angle i_c to the interface, passes through to D with greater velocity V_2 and then to geophone (detector) "G" with velocity V_1 [5] and [1].

Thus, $SC = DG$ and $CD = SG - X$

The sonic travel time of wave through path *SCDG* by definition is,

$$t = \frac{2SC}{V_1} + \frac{CD}{V_2} \tag{4.1}$$

$$t = \frac{2Z}{V_1 \cos i_c} + \frac{X - 2Z \tan i_c}{V_2} \tag{4.2}$$

Applying Snell's law, $\sin i_c = V_1/V_2$ the travel time becomes [5].

$$t = \frac{X}{V_2} + \frac{2Z\cos i_c}{V_1} \tag{4.3}$$

A plot of *t* against *x* gives a straight line (linear) graph with $slope = {}^{1}\!/_{V_2}$

and $$\text{intercept} = \frac{2Z\cos i_c}{V_1} \tag{4.4}$$

$$\text{initial time, } t = \frac{2Z\cos i_c}{V_1} \tag{4.5}$$

$$t = \frac{2Z\sqrt{V_2^2 - V_1^2}}{V_1V_2} \tag{4.6}$$

where, $$\cos i = \sqrt{\frac{V_2^2 - V_1^2}{V_2}}$$

If geophone is close to shot point, the direct ray is expected to arrive first but this is not the case practically because the doubly refracted ray travels faster and eventually overtakes the direct ray to become the first (break) arrival. By the above calculation,

$$\frac{x}{V_1} = \frac{x}{V_2} + \frac{2z\sqrt{V_2^2 - V_1^2}}{V_1V_2} \tag{2.7}$$

where $$X_{cd} = \frac{2Z\sqrt{V_2^2 - V_1^2}}{V_1V_2} \tag{2.8}$$

X_{cd} is defined as cross over distance and the velocities of the subsurface layers are directly obtained from reciprocal slopes of the straight lines corresponding to the direct and doubly refracted rays [6].

The thickness of the interface by [5] and [9] is,

$$Z = {}^{1}\!/_{2}\,\frac{V_1V_2t_1}{\sqrt{V_2^2 - V_1^2}}. \tag{4.9}$$

$$Z = \frac{1}{2}\chi_{cd}\sqrt{\frac{V_2^2 - V_1}{V_2 + V_1}} \tag{4.10}$$

Thus, shots were taken at different depths (Figure 3.1). Each time the seismograph was automatically triggered while the waves generated travelled through the layers of the soil to the tool. The seismograph therefore records the shot time and the “first break” of the signals from the tool. Thus, the one dimensional travel times of the generated waves and their waveforms were recorded into the designated channel in the seismograph Twenty-four convenient depths were shot corresponding to 24 channels of the seismograph. Time delay and filters introduced eliminated noise of uncertain origin which would have obscured useful signals [4]. Signals showing waveforms were displayed on the screen [7]..

A print of the recorded wave forms for each site was then produced for study (Figure 4,2 3).

Time correction: All recorded first break times on seismograph were corrected to vertical one-way travel times to account for the 2 metres surface offset of shot point from drilled bole aimed at preventing hole noise and ensuring that generated waves travel through soil layers to tool instead of water in the hole [11]. This corrected time from Figure 3.1 is

$$tv = tr \frac{z}{(z^2 + x^2)^{1/2}} \qquad (4.11)$$

Therefore $tv = tr\cos\theta$, but $\theta = \tan^{-1} x/z$

Therefore $$tv = tr\cos(\tan^{-1} x/z) \qquad (4.12)$$

where tv = corrected one way travel time

tr = recorded one way travel time

x = 2m = offset of shot point

z = Depth of uphole tool in nature

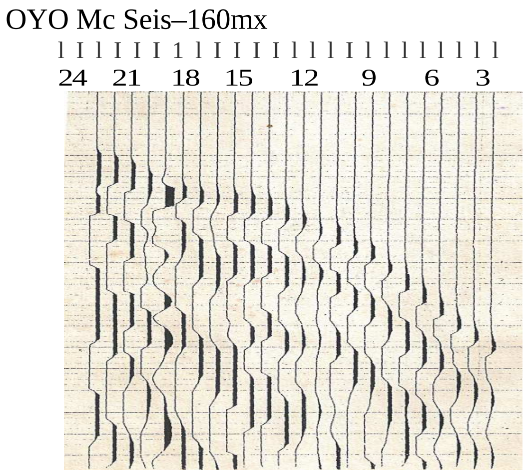

Figure 4.2: Seismograph printout for computation of first break

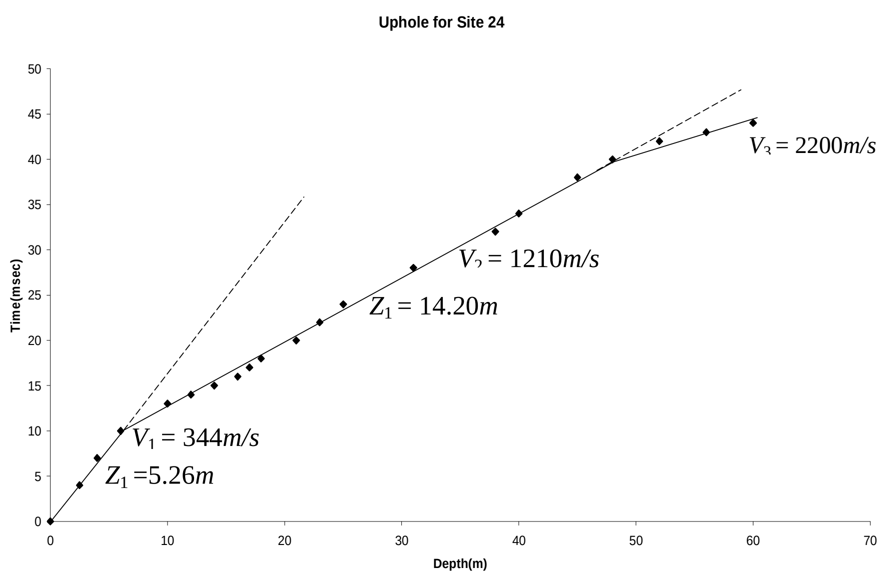

Figure 4.3: Sample plot of time-depth for three layer sites

5.0 Results and conclusion

Analysis of the data indicates that the area of study is made up of unsaturated materials.. It also shows that some sites have single weathering layer while others have double weathering layers (Figures 4.3 and 4.4). The velocities of shock waves in the weathering layers range from 350*m/s* to 625*m/s* with thickness ranging from 2.0 *m* to 6.5*m*, mean of 4.15*m* and standard deviation 0.88. This is followed by a region of consolidated layer. For sites with two layers, the velocities in the second layer range from 1000 m/s to 1400 *m/s*.

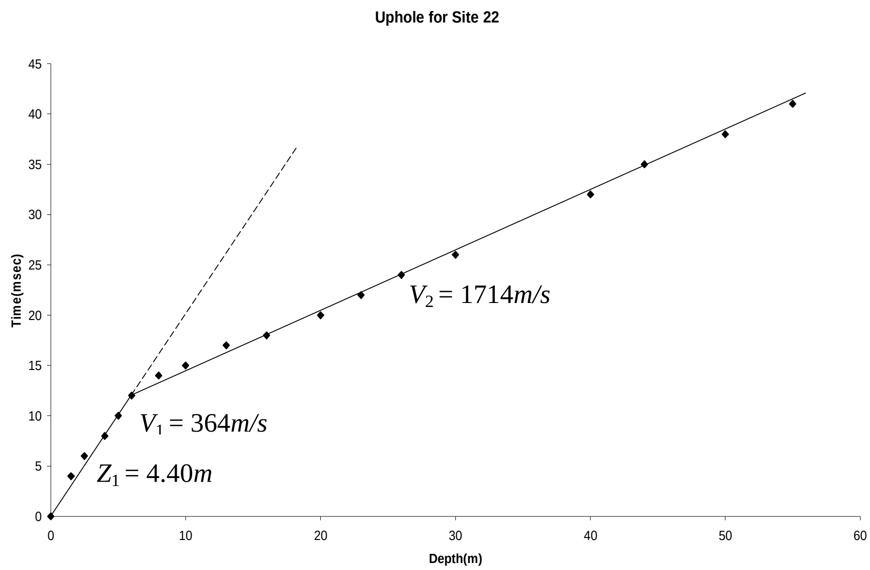

Figure 4.4: Sample plot of time-depth for two layer sites

Table 4.1: Layer Velocities and Thicknesses deduced from Plots

Shot Location	$V_1(m/s)$	$V_2(m/s)$	$V_3(m/s)$	$Z_1(m)$	$Z_2(m)$
1.	383	1721		4.25	
2.	364	703	1640	3.20	7.80
3.	400	1640		3.00	
4.	333	1750		3.80	
5.	475	1000	1900	3.50	11.00
6.	380	1042	1903	3.30	9.00
7.	380	1870		4.50	
8.	339	1700		4.30	
9.	351	1764		5.60	
10.	400	1700		5.40	
11.	363	1750		4.30	
12.	377	1089	1715	3.80	11.90
13.	338	1000	1810	4.50	12.30
14.	380	1531		4.80	
15.	600	1388	1174	2.00	12.50
16.	428	1333	1786	2.70	8.50
17.	625	1706		2.30	
18.	389	1182	1655	4.00	12.30
19.	364	1579		5.40	

20.	458	1105	2167	6.70	20.80
21.	375	1820		4.80	
22	364	1714		4.40	
23.	476	1713		3.00	
24.	344	1030	2170	5.26	
25.	554	1068	2018	5.10	12.70
26.	368	1848		3.80	8.90
27.	614	1706		3.60	

V_1 = Velocity of First Weathering layer

V_2 = Velocity of Second Weathering Layer
V_3 = Velocity of the Consolidated depth
Z_1 = Thickness of First Weathering layer
Z_2 = Thickness of Second Weathering layer

The three layered consolidated zones have velocities of 1700*m/s* and above with the thickness of the second layer between 13 and 21 metres (Table 4.1). These velocity values in such sedimentary terrain indicate that the first weathering layer consists of loose sand with patches of silt, while the second weathering layers has high presence of clay and gravel and the consolidated layer consists mainly of shale and weathered rock. In conclusion, the consolidated region is mainly compact clay, sand stone, grey wreck conglomerate, shale argillite and weathered fractured rocks which is indicative of possible hydrocarbon reservoir at far depths (Figure 5.1). These results are clear evidence of possible hydrocarbon traps beneath. However, in computing for the real hydrocarbon depth, an obscuring depth of up to 20 metres need to considered.

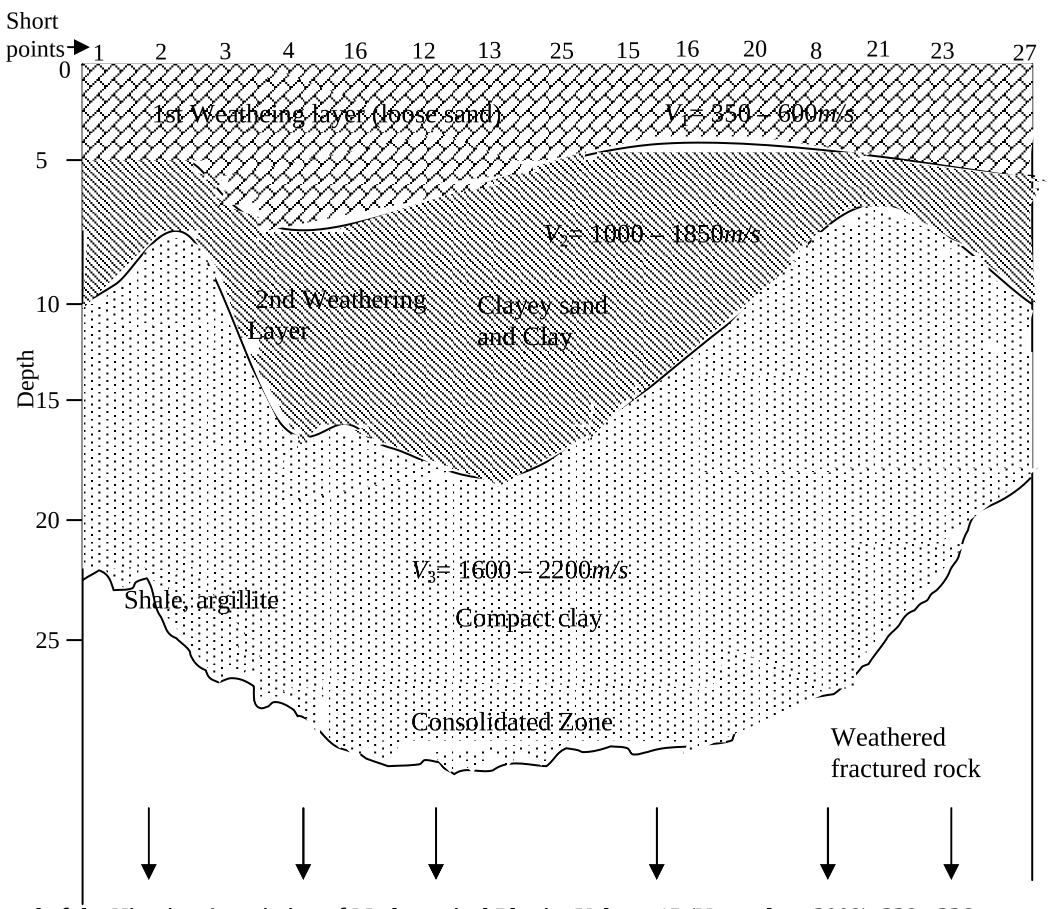

Figure 5.1: Geoelectric Section of Study Sites

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