Geophysical Seismic Refraction and Uphole Survey Analysis of Weathered Layer Characteristics in the “Mono” Field, North Western Niger Delta, Nigeria.

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ABSTRACT

A total of twenty-nine (29) reverse-shooting seismic refraction lines and uphole survey data from one well have been analyzed, aimed at unraveling the weathered layer geophysical characteristics in “Mono” field, onshore NW Niger delta, Nigeria. The time-intercept technique of seismic refraction interpretation was employed while the conventional method of well shooting analysis used in the uphole well surveys. Results of data interpretation revealed that the thickness of the weathered layer is fairly uniformly thin in the area, ranging from 3.50m around the western and eastern flanks to 5.30m at the north central location with a regional average of 4.4 m. The average weathered layer compressional wave velocity was about 525 m/s; ranging from 300 m/s to 750 m/s around the north west and south eastern flanks and central portion of the study area respectively. The underlying consolidated layer has an average velocity of about 1800 m/s adjudged sufficiently competent to withstand engineering structures.

(Keywords: seismic refraction, uphole, time-intercept, weathered layer and reverse-shooting)

INTRODUCTION

On land, there is generally a surface “weathered layer” or “low velocity layer” (LVL) whose seismic velocity is much lower than normal. These top sediments are usually highly aerated and unconsolidated. This layer is usually some few metres thick, but may occasionally reach a thickness of several tens of metres depending on the geologic nature. Often, the thickness of this layer is both laterally and vertically highly variable along a line, leading to significant seismic time delays of magnitude dependent on the positions (elevations) of the shot and detector. These time delays, if not allowed for, degrade the reflection seismic section by improper alignment of traces after normal moveout (NMO) correction. Much more sinister, M^{c}quillin (1979), is the effect of more gradual changes in shift along a line, which introduce entirely spurious structures into the section.

The low-velocity-layer is generally characterized by zone of high seismic energy absorption, disproportionately large effect on seismic wave travel times arising from the low velocity and its rapid rate of change, sharp bending of seismic rays into near vertical due to large impedance contrast at the base of the layer and high amplitude of reflection at its base due to the large impedance contrast thereby making it very important in multiple reflection and wave conversion. The first calculation of corrections for elevation and weathering is carried out in the field. These field statics are based on survey, uphole and first break information and are subsequently used in processing as the first estimate.

A good knowledge of the thickness distribution of the layer is often of immense advantage to engineering geophysical studies as well as in seismic reflection data acquisition ventures. The process of correcting for these time delays is known as statics correction or simply statics. Taner et al., (1974) and Hatherly et al., (1994). give good synopses of a simple approach of carrying out seismic refraction statics corrections. Marsden (1993) reviews statics corrections.

The seismic refraction method, Docherty (1992) and Boschettin et al., (1996) is usually employed in the structural configuration of this layer. Louis et al., (1995) employed the seismic refraction method to investigate the low-velocity surface layer parameters at a dam site on the Nestos river in northern Greece. A fast example of a rapid method of statics determination has been given by Zanzi and Carlini (1991). The uphole survey information provides a direct and veritable control on the seismic refraction method.

In this study, the author attempts to determine the average weathering thickness and the near surface compressional velocity variation pattern using detailed analysis and interpretation of refraction seismic data and uphole survey measurements acquired over the study area. A two-layer earth model was assumed. The results are important in the eventual accurate mapping of the underlying structures required for petroleum and groundwater exploration as well as civil engineering projects in the study area.

LOCATION AND GEOLOGY

The study area (Figure 1) is located within an area approximately between latitudes 5.7° – 6.2°N and longitudes 5.6° – 6.3°E northwest of the Niger delta complex, Nigeria. The area is characterised by fresh water and mangrove swamps with relief that increases towards the north, Uko et al., (1992). Three distinct facies belts have been identified in the Niger delta, Short and Stauble (1967):

(i) 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 up to 2,100 meters, Weber and Daukoru (1975) and Ejedawe (1981).

(ii) 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).

(iii) 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 (Doust, 1990).

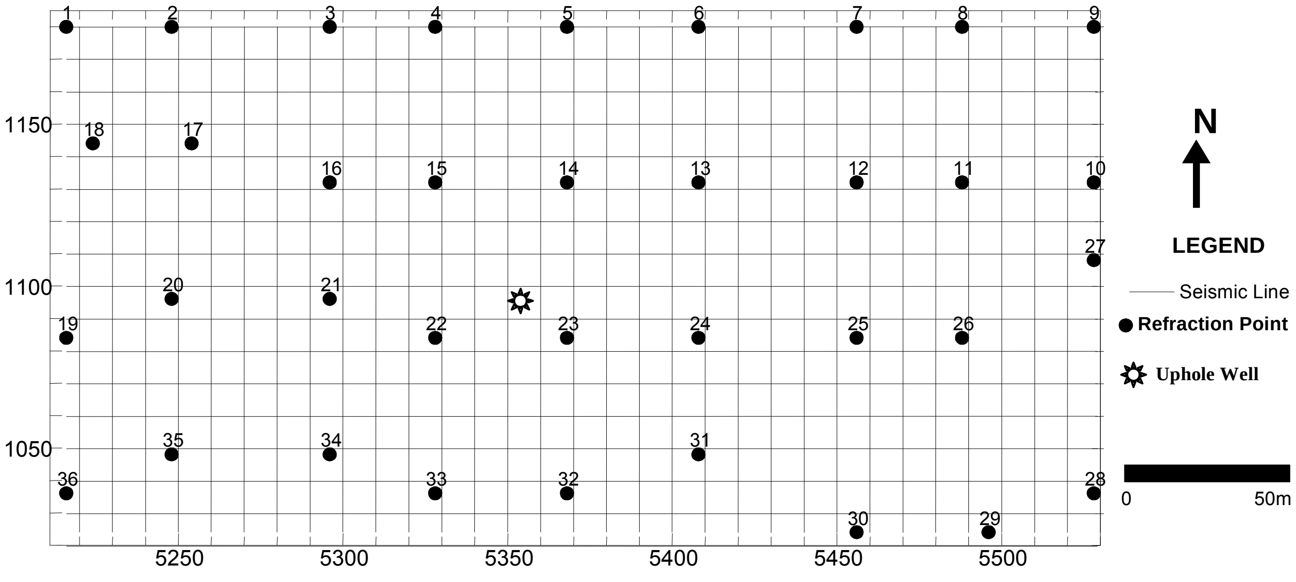


Figure 1: Base Map of the Study Area Showing the Refraction Points and Uphole Well Location.

THEORY

A shallow-layer refraction survey entails the generation of seismic wave energy and determining the travel time (first breaks) of sound energy from a known source location through a refractor and back to a surface geophone. First break times, T of the records are plotted against offset, X as shown in Figure 2(i).

According to M^{c}quillin et al. (1979), Knox (1967) and Dobrin and Savit (1988), for a two-layer medium (Figure 2) in which the energy source is located in the weathered zone, the travel time T is given by:

$$T = \frac{X - 2D_w \tan\theta_c + 2D_w}{V_B} + \frac{2D_w}{V_w \cos\theta_c} \qquad \mathbf{(1)}$$

Thus at X = 0, i.e. at shot point location,

$$T_i = \frac{2D_w}{\cos\theta_c}\left(\frac{1}{V_w} - \frac{-\sin\theta_c}{V_B}\right) \qquad \mathbf{(2)}$$

and since, by Snell's law,

$$\theta c = \arc\sin\frac{V_w}{V_B}$$

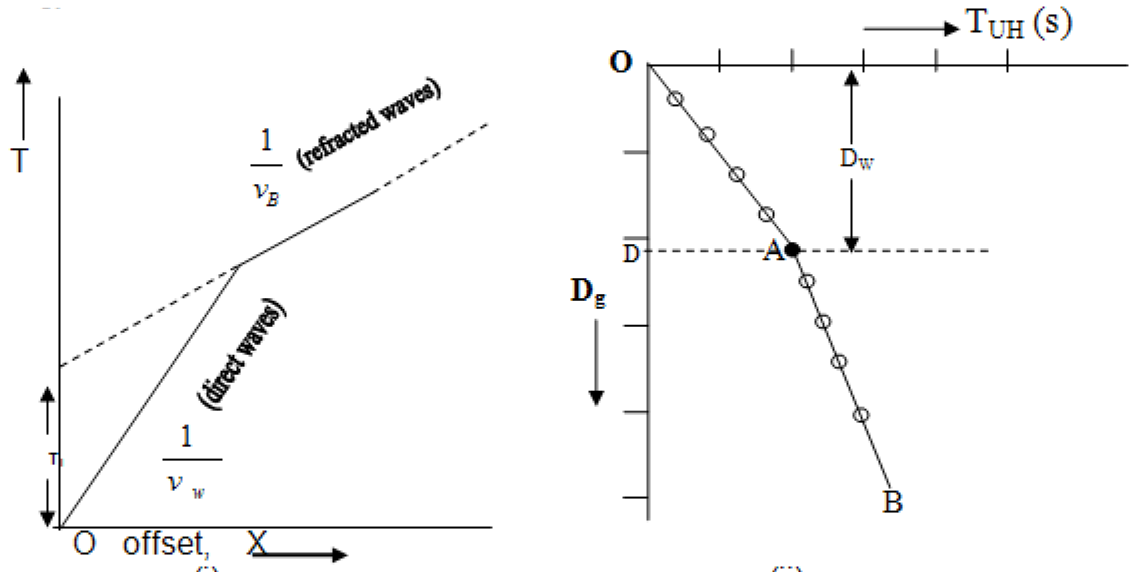
Then $T_i = \frac{2D_w \cos\theta_c}{V_w}$

$$= \frac{2D_w (V^2_B - V^2_W)^{1/2}}{V_B V_W} \qquad \mathbf{(3)}$$

where V_w is the weathered layer seismic velocity; D_W, the depth to base of the weathered layer; θ_c, the critical angle of incidence of the wave and T_i, the intercept time.

In Figure 2 (i), the reciprocal of the slope of the lower segment, equals the weathered layer velocity, V_W ; while that of the upper gives the bedrock velocity, V_B. By plotting all first breaks and inserting the appropriate values of T_i, V_B and V_W, depth to bedrock refractor, D_W, can be computed using equation 3.

Similarly, these parameters (V_W, D_W, and V_B) can be deduced from the uphole survey data, figure 2(ii). 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.



(i) (ii)

Figure 2: (i) Time-Offset Configuration for a Two-Layer Seismic Refraction Profile (ii) Time-Depth Relation for the Uphole Survey.

MATERIALS AND METHODS

The seismic refraction investigation was carried out using the ‘Geospace Miseis 160 MX’ seismograph model 1115 recording equipment via a 105 telemetric cable. The seismic energy was provided through the detonation of explosives. The refracted arrivals were detected using the vertical electromagnetic type geophones appropriately arranged along the ground surface. The source- geophone array, Figure 3, has the first geophone, comprising six serially-connected jugs bunched one meter away from the shot point. Thereafter, five (5) geophones were linearly planted at 5m inter-geophone separation. These were followed by another four (4) geophones with 10m inter-geophone separation and finally by another two at 20m separation.

The explosives were detonated at the ends of each traverse, resulting in forward and reverse propagation of seismic energy. The travel time curves obtained were processed using the popular slope/intercept method. Generally, two seismic layers were obtained from the interpreted curves: the near-surface low velocity layer and the sub-weathering consolidated layer.

The uphole survey required a shot-hole, usually deeper than the base of the LVL, in which shots were fired in order of suitably decreasing depth, D_s and a surface uphole geophone, *(*usually within 3 m of the shot-hole). Shots are fired at various depths in the hole, beginning at the bottom until the shot is just below the surface of the ground. First break times, T_{UH} were plotted against shot depths, D_s. The straight line changes direction abruptly where the shot enters the near-surface layer. The slope of the straight-line segment above the base of the LVL gives V_w and the point of break in slope usually defines the base of the low velocity layer, D_w. The consolidated layer velocity, V_B, can be deduced from the slope of the lower segment, Figure 2(ii).

For the field configuration of the uphole survey, the shot hole was 63 meters deep; three meters being lost to infilling of sand. Loading of the charges was carried out from depth 60m up to 30m with 0.2-kg dynamite and from 25m up to 3 m with 0.1kg dynamite.

DISCUSSION OF RESULTS

The results were presented in the form of maps and tables. The geophysical properties of interest were the seismic velocity distribution of the weathered layer, its thickness variations and the competence (in terms of seismic velocity) of the supporting consolidated (sub-weathering) layer. The detailed discussion is presented in the following.

The determination of the weathering characteristics of the study area was hinged on the critical analysis of the variations in the magnitudes of the near-surface seismic velocity, V_w and the thickness of the low velocity layer, $D_{w.}$ The variations of seismic velocity of the consolidated (sub-weathering) layer (V_B) immediately underlying the LVL was also analyzed for engineering site investigation purposes. Finally, the results of the above surface techniques were correlated with the subsurface uphole data. The overall results were compared with a similar study, Uko et al., (1992), some kilometers away from the study area. For the purpose of these, three maps (Figures 4, 5, and 6) were prepared.

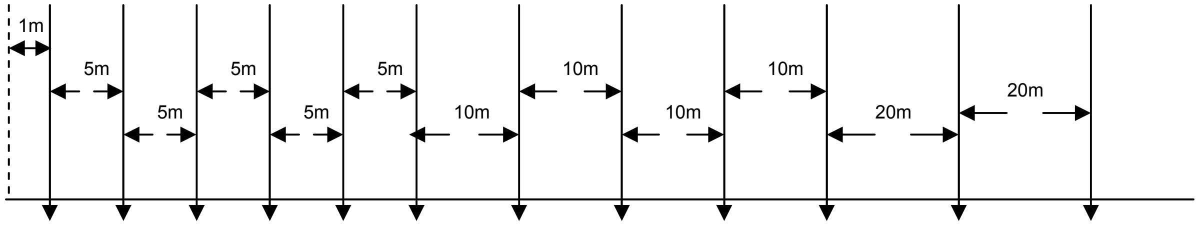


Figure 3: Refraction Source-Geophone Array.

⊗
▼ Geophone location

The results of the uphole survey from the only available well served as control in the estimation and distribution of the above parameters.

Weathered Layer Velocity

Figure 4 is the seismic weathered layer velocity variation map of the study area. Generally, the weathered layer seismic velocity ranges from very low 300 m/s on shot location 5528/1046 (south East) and around 5456/1180 North Eastern portion of the study area, to 750 m/s on shot location 5328/1084 in the south central flank. Along the western flank, the velocity values vary from 350 m/s to about 300 m/s on the upper north central portion (see Figure 4). These marginal variations in both 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.

Weathered Thickness layer

The relative dense coverage of the survey enables the preparation of the isopach map of the weathered layer in the study area, Figure 5. The layer thickness ranges from 3.5m around shot location 5528/1180 to 5.3 m on shot location 5408/1132 around the north central portion of the study area, Figure 5.

The map reveals that the LVL thickness decreases from the north eastern towards the south western flanks. A zone of fairly uniform thickness traverses the central portion along the east-west direction. This may have explained the uniform velocity (particle homogeneity) observed across the central portion of the study area.

The values of these parameters, as obtained by both the seismic refraction and up-hole surveys, were compared. In most locations, the thickness differs by less than 10%; considered reasonable within the scope of this study. The up-hole survey value which is expected to serve as control, often showed higher values than their surface refraction-derived counterparts.

Under favourable conditions, the uphole surveys are expected to provide more accurate values of seismic velocity and thickness of the weathered layer since the measurements were recorded *in situ*.

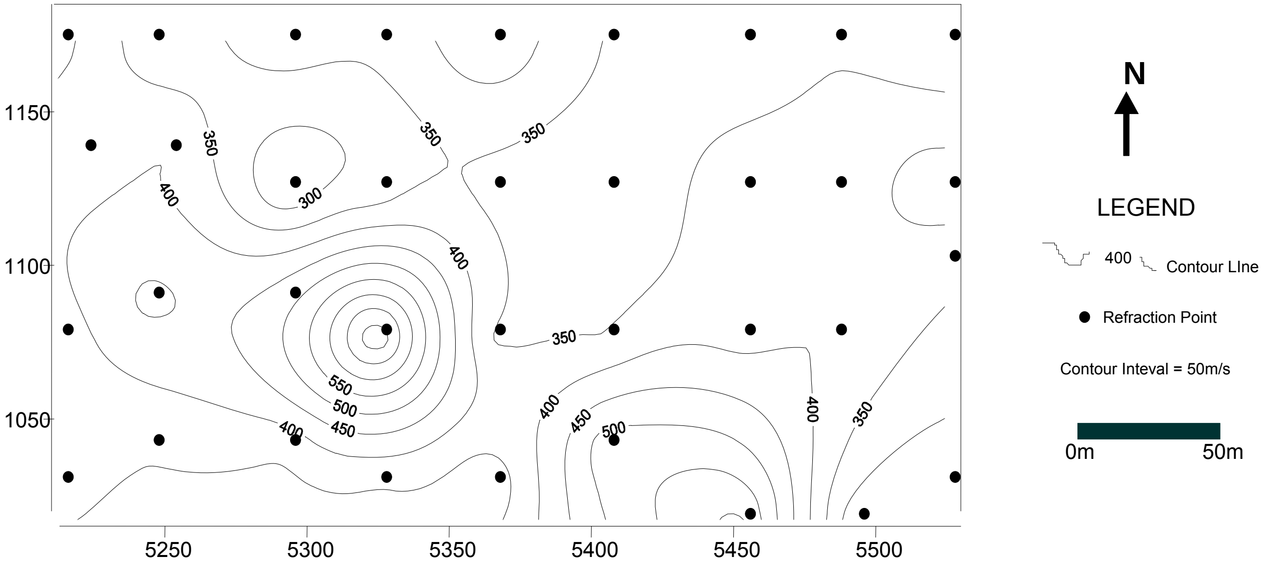


Figure 4: Iso-velocity Map of Weathered Layer.

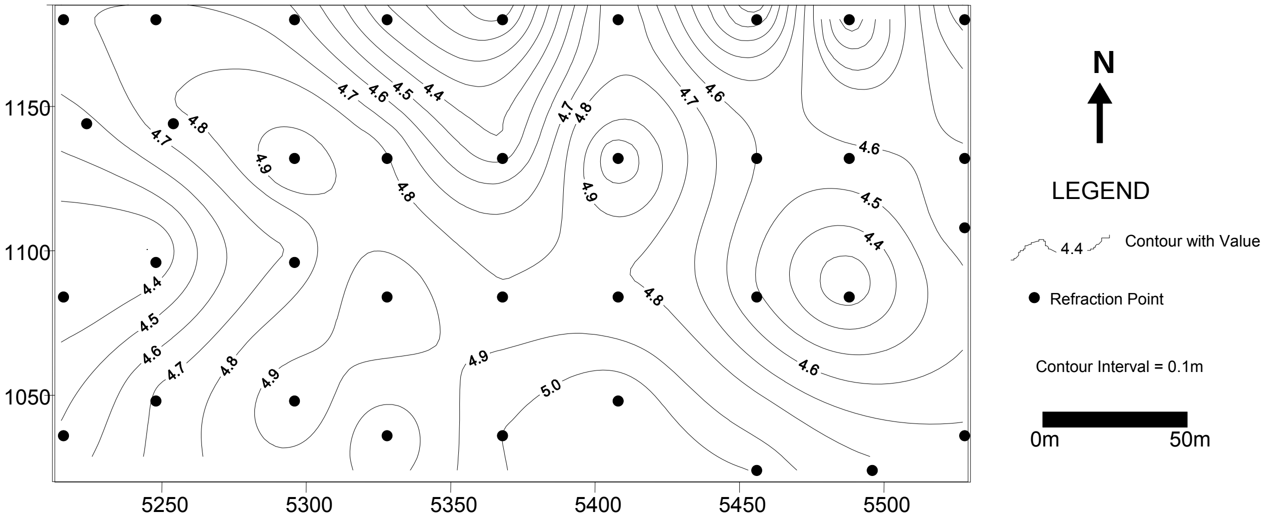


Figure 5: Isopach Map of Weathered Layer.

Consolidated Layer

Figure 6 shows the pattern of variation of the consolidated layer seismic velocity, ranging from 1100 m/s around the south-western portion of the area spanning 2100 m/s towards the north central segment. It could be observed that the layer is sufficiently competent judging from the seismic velocity distribution across the study area. The south eastern portion has the most competent bedrock depicting a maximum velocity of 2500 m/s. The velocity contrast of about 1400 m/s showed that the layer is, like the overlying weathered layer, rather inhomogeneous probably arising from varying degree of compaction of the constituent sediments. The scope of this work does not extend to the determination of the thickness of the consolidated layer substratum.

The results of this study were compared with a similar work, Uko et al. (1992), around east central Niger Delta. There, the average weathering thickness was determined to be about 20.0 metres as against 5.57 metres in this study. This wide variation could be attributed to the observed North-South increase of weathering thickness. In both studies however, a north-south increase in thickness was observed. It can therefore be stated that the weathering layer thickness increases as one moves southwards towards the coast. The average weathered layer velocity of 500 m/s was observed in the east while in the North West (this study), it was about 432 m/s. Both studies still correlate reasonably. The average velocity of the sub-weathered layer correlated reasonably: 1732 in the east and 1694 m/s (this study). The observed fair correlation attests to the observed similarity in the near surface (onshore) geology of the Niger Delta.

Uphole Survey

The results of the uphole survey however revealed some sharp contrasts from that of the surface refraction. From the former, the weathered layer seismic velocity was 435 m/s; the thickness of the weathered layer 5.2 metres and the consolidated layer seismic velocity 1700 m/s. Table 1 was generated from the spatial distribution of the weathering parameters in order to compare the surface refraction values (R_S) with their uphole-derived counterparts (U_D).

It could be observed that the percentage deviation between them is highest with the weathered layer seismic velocity distribution, ranging in magnitude from 0.004% to 29.20%; the thickness distribution of the layer ranging from 1.92% to 17.31% and least with the consolidated layer velocity distribution from 3.31 to 12.98%. The standard deviation of R_S (V_W, D_W and V_B) across the study area were 6.8 m/s, 0.3 and 1819 m/s respectively while the coefficient of variation – ratio of standard deviation to the mean – were correspondingly 19%, 6.2% and 7.3%.

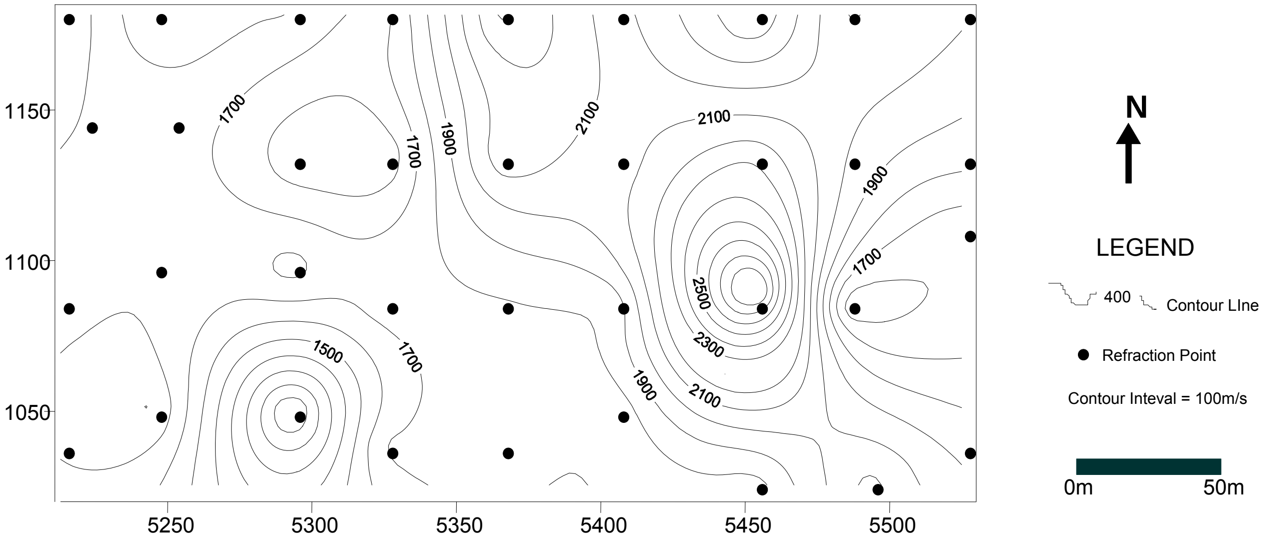


Figure 6: Iso-velocity Map of Consolidated Layer.

Table 1: Comparison of Weathering Parameters as Obtained from Refraction and Uphole Data.

S/N	**Refraction Point**	**V_w (m/s)**		**% Deviation**	**D_w (m)**		**% Deviation**	**V_B (m/s)**		**% Deviation**
		R_S	**U_D**		**R_S**	**U_D**		**R_S**	**U_D**	
1.	1	437	435	0.004	5.0	5.2	-3.85	1667	1810	-7.90
2.	3	458	-	5.28	4.7	-	-9.62	2045	-	+12.98
3.	5	460	-	5.74	4.3	-	-17.31	1731	-	-4.36
4.	7	318	-	-26.89	4.3	-	-17.31	1876	-	+3.65
5.	9	308	-	-29.20	5.1	-	-1.92	1691	-	-6.57
6.	11	380	-	-12.64	4.6	-	-11.54	2000	-	+10.49
7.	13	308	-	-29.20	5.3	-	1.92	2010	-	+11.04
8.	15	400	-	-8.04	4.9	-	-5.72	1833	-	+1.27
9.	17	370	-	-14.94	4.8	-	-7.69	1880	-	+3.86
10.	20	485	-	11.49	4.5	-	-13.46	1833	-	+1.27
11.	22	355	-	-18.39	5.0	-	-3.85	1750	-	-3.31
12.	24	350	-	-19.54	4.8	-	-7.69	2000	-	+10.49
13.	26	400	-	-8.04	4.4	-	-15.38	1722	-	-4.86
14.	30	615	-	41.37	5.0	-	-3.85	1750	-	-3.31
15.	32	314	-	-27.81	5.0	-	-3.85	1730	-	-4.42
16.	34	360	-	-17.24	5.0	-	-3.85	1600	-	-11.60
17.	36	371	-	-14.71	4.8	-	-7.69	-	-	-

R_S = Surface Refraction U_D = Uphole Data

CONCLUSION

This study has analysed the weathering characteristics of the study area using the seismic refraction and uphole survey techniques. The analysis is hinged on the determination of the pattern of variation of the seismic velocity, the thickness of the low velocity layer (LVL) as well as the seismic velocity of the consolidated layer. The refraction analysis assumed a two-layer earth model of seismic velocity increase with depth as well as planar refracting interface.

In a nutshell, the thickness of the weathered layer ranged between 4.3 to 5.3 m. and decreases from the north eastern to the south western flanks. Also, the weathered layer velocity varies from 300 m/s on the south western flank to 750 m/s on the north central flank. The average consolidated layer velocity is 1800 m/s and also follows a north-south decrease. The statistical analysis has revealed that the weathered later was relatively heterogeneous and loose as revealed by the coefficient of variation of 19.5% values vis-à-vis the consolidated layer, 7.3%. The results obtained from the uphole survey was central to the refraction's and lends credence to the reliability of the latter.

The findings in this study have shown that any meaningful seismic reflection work in the study area required substantial static corrections, owing to the high variability of weathered layer seismic velocity and thickness. The determined depths to the base of the LVL is a vital information for the proper location of energy source for 'noise' reduction and a resultant improvement in the signal to noise ratio. In most cases, locating the source below the LVL bypasses the layer thereby maximizing energy transmission.

It is expected that information on the sub-weathering velocity will be of interest in the location of civil engineering structures via the determination of the level of bedrock competence in the study area.

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REFERENCES

1. Boschetin, F., Dentith, M.C., and List, R.D. 1996. "Inversion of Seismic Refraction Data Using Genetic Algorithms". *Geophysics*. 61: 1715 – 1727.

2. Dobrin, M.T. and Savit, S.V. 1988. *Introduction to Geophysical Prospecting, (4th edition)*. McGraw Hill: New York, NY.

3. Docherty, P. 1992. "Solving for the Thickness and Velocity of the Weathering Layer Using 2-D Refraction Tomography". *Geophysics*. 57:1307 – 1318.

4. Doust, H. and Omatsola, E. 1990. "Niger Delta References". Unpublished Shell Petroleum Company Report. 1:201 – 237.

5. Ejedawe, J. E. 1981. "Patterns of Incidence of Oil Reserves in Niger Delta Basin". *American Association of Petroleum Geologists (AAPG) Bulletin*. 65:1574 – 1585.

6. Evamy, B.D., Haremboure, J., and Kamerling P. 1978. "Hydrocarbon Habitat of Teriar Niger Delta". *American Association of Petroleum Geologists (AAPG) Bulletin*. 62:1-39.

7. Hatherly, P.J., Urosevic, M., Lambourne, A., and Evans, B.J. 1994. "A Simple Approach to Calculating Refraction Statics Corrections. *Geophysics*. 59(1):156 – 160.

8. Knox, W.A. 1967. "Multilayer Near-Surface Refraction Computations". In: *Seismic Refraction Prospecting*: Musgrave, A. W. (ed.) Soc. Expl. Geophysics. 197 – 296.

9. Louis, J., Papadopoulos, T., Drakatos, G. and Pantzartzis, P. 1995. "Conventional and Modern Seismic Investigations for Rock Quality Determination at a Dam Site – A Case History". *Geophysical Prospecting*. 43(6):779 – 792.

10. Marsden, D. 1993. "Static Corrections – A Review". *The Leading Edge*. 12(2):43-49, 115-20.

11. Mcquillin, R., Bacon, M., and Barclay, W. 1979. *An Introduction to Seismic Interpretation*. Gulf Publishing Co.: Houston, TX.

12. Taner, M.T., Koehler, F. and Alhilali, K.A. 1974. "Estimation and Correction of Near-surface Time Anomalies". *Geophysics*. 39: 441 – 463.

13. Telford, W.M., Geldart, L.P., and Sheriff R.E. 1990. *Applied Geophysics*. 2nd edition. Cambridge Univ. Press: Boston, MA.

14. Uko, E.D., Ekine, A.S., and Ebeniro, J.O. 1992. "Weathering Structure of the East-Central Niger Delta, Nigeria". *Geophysics*. 57(9):1228-1233.

15. Weber, K.J. and Daukoru, E.M. 1975. "Petroleum Geology of the Niger Delta". 9th World Petroleum Congress Proceedings: Tokyo, Japan. 2:209 – 221.

16. Zanzi, L. and Carlini, A. 1991. "Refraction Statics in the Wave Number Domain". *Geophysics*. 56(10):1661 – 1670.

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