

Original Research Paper

# Assessment of Weathering Layer Characteristics over OPL-135 in the Western Part of the Niger Delta Basin, South-South, Nigeria

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**Abstract:** An up-hole seismic refraction survey was carried out in OPL-135 in the Western part of the Niger Delta Basin, (SS) Nigeria. A total of thirty seven (37) up-hole locations in a (4.0×3.750) km grid configuration were drilled and logged over the prospect. The focal objective for the study was to assess the weathering layer characteristics over the prospect, specifically, to estimate the weathering and sub-weathering layer thicknesses and velocities, in a bid to better understand the near-surface properties and to enhance the subsequent acquisition and processing of 3 D seismic reflection data of the prospect. From the data acquired, time-depth plots for each up-hole shot point were derived, which was used to determine the velocities of the underlying layers for each point. Depth to the refractor distance were computed to determine the thickness of the weathered layers. The result obtained gave an overview of the lateral variation in the thicknesses and velocities of the near subsurface over the prospect. The thickness of the weathering layer obtained ranged from 3.1 m at up-hole point 21 and 28 to 6.8 m at up-hole point 12, with an average value of 4.7 m across the prospect. The weathering layer velocity ranged from as low as 210 m/s at up-hole point 4 to as much as 593 m/s at up-hole point 29, with an overall average value of 361 m/s. The sub-weathering layer velocities ranged from 1131 m/s at up-hole point 32 to a maximum of 1987 m/s at up-hole point 3, with an overall average of 1707 m/s across the prospect. The results from this study would aid proper planning/implementation of the 3 D seismic acquisition program for the prospect and would as well be an indispensable tool in the pre/main and post processing of the acquired seismic reflection data.

**Keywords:** Weathering Layer, Low-Velocity Layer (LVL), Up-hole Geometry, Geophones, Seismic Refraction, First Break Time, Statics Correction

## Introduction

The near-surface also known sometimes as the Low-Velocity Layer (LVL) or the weathered/weathering zone, or in some instances, called the unconsolidated (loosed) layers is the shallow part of the earth subsurface, usually the first few tens or hundreds (in rare cases) of meters, whose properties smear the response from deeper subsurface targets in the processing of seismic reflection data (Adizua *et al.*, 2019a). A near-surface Low-velocity

layer according to (Sheriff, 1991), is usually the portion where air rather than water fills the pore spaces of rocks and unconsolidated earth. This portion of the near-surface is termed the weathering layer in seismic parlance and differs remarkably from the geologist's perspective of weathering which is as a consequence of rock decomposition. The term Low-Velocity Layer (LVL) is often used to connote the seismic weathering. Frequently, the base of the weathering layer is the water table. Sometimes the weathering velocity is gradational,

sometimes it is sharply layered. Weathering velocities typically range from 500 to 800 m/s (although they could be as low as 150 m/s for the first few metres) compared to sub-weathering velocities of 1500 m/s or greater (Sheriff, 1991).

The Low-Velocity Layers (LVL) is majorly known for their low seismic velocities and varying or irregular thicknesses. This variation affects travel-times along elevation changes and results to slow transmission of seismic waves and generation of some form of seismic noise (surface waves). There exist a great disparity in the velocity of the seismic weathered Layer (LVL) when compared to that of the underlying consolidated strata. This disparity causes errors in the arrival time of the reflected/refracted signals (waves) associated with the small changes in the thickness of the weathered layer. This poses a challenge in processing and interpretation of seismic reflection data for deeper targets as earlier stated. It is pertinent therefore, to ascertain (estimate) the depth to the base of the weathered layer before a seismic acquisition survey. Such information would enable in the right placement of shots at the appropriate depths so as to reduce ground roll interference with actual subsurface reflection during seismic acquisition projects. It aids 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. It equally allows for the reduction of seismic reflection/refraction data to a specific reference or fixed datum (Marsden, 1993).

The assessment of the near-surface weathering characteristics, therefore, finds very useful applications in seismic data processing (Cox, 1999; Yilmaz, 2001; Opara *et al.*, 2018; Adizua *et al.*, 2019a-b) and other applications like in geotechnical investigations, civil and mining engineering projects (Gouly and Brabham, 1984; Steeples and Miller, 1988; Bükér *et al.*, 1998; Juhlin *et al.*, 2002). The conventional approaches to near-surface characterization include inversion of refracted arrivals, up-hole survey techniques and more recently tomography. These approaches have been extensively discussed and applied in different basins around the world (Hampson and Russell, 1984; Zhu *et al.*, 1992; Belfer and Landa, 1996; Lanz *et al.*, 1998; Martí *et al.*, 2002; Bergman *et al.*, 2004; Yordkayhun *et al.*, 2007; Guevara *et al.*, 2013). The up-hole survey technique have equally been tested and applied within the Niger Delta Basin, Nigeria (Enikanselu, 2008; Igboekwe and Ohaegbuchi, 2011; Ofomola, 2011; Adeoti *et al.*, 2013; Anomohanran, 2014). In the present study, the up-hole survey technique is applied in the assessment of the

weathering layer characteristics over OPL-135 in the western part of the Niger Delta Basin, South-South, Nigeria, to better understand the near-surface characteristics and to enhance the subsequent acquisition and processing of 3 D seismic reflection data of the prospect.

The up-hole survey is a viable means of determining the thickness of the near-surface layers and the time for seismic energy to travel through these layers and hence their velocities (Cox, 1999). The information obtained from up-hole surveys provide complementary details that aids in the interpretation of conventional seismic refraction/reflection data. The up-hole survey locations serve as control points and when tied to seismic data extends the well location (up-hole survey point) information away from the hole or to interpolate between two or more holes across the seismic volume. (Sheriff, 1991) defines an up-hole survey as; “successive sources at varying depths in a borehole in order to determine the velocities of the near-surface formations, the weathering thickness and (sometimes) the variations of record quality with source depth”. In continuation, he stated further that “sometimes a string of geophones is placed in a hole of the order of 200 ft deep to measure the vertical travel times from a nearby shallow source”. Up-hole surveys are not used universally and their expensive cost of deployment is a critical factor that limits its wide range of application. Two common techniques or configurations exist for data acquisition during up-hole refraction surveys, they are:

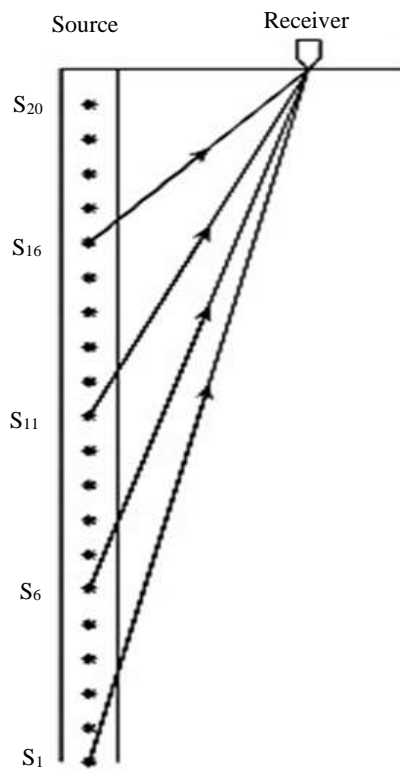
- i) Source in borehole and receivers at the surface
- ii) Receivers in borehole and source at the surface

Both configurations are illustrated in Figs. 1 and 2 respectively.

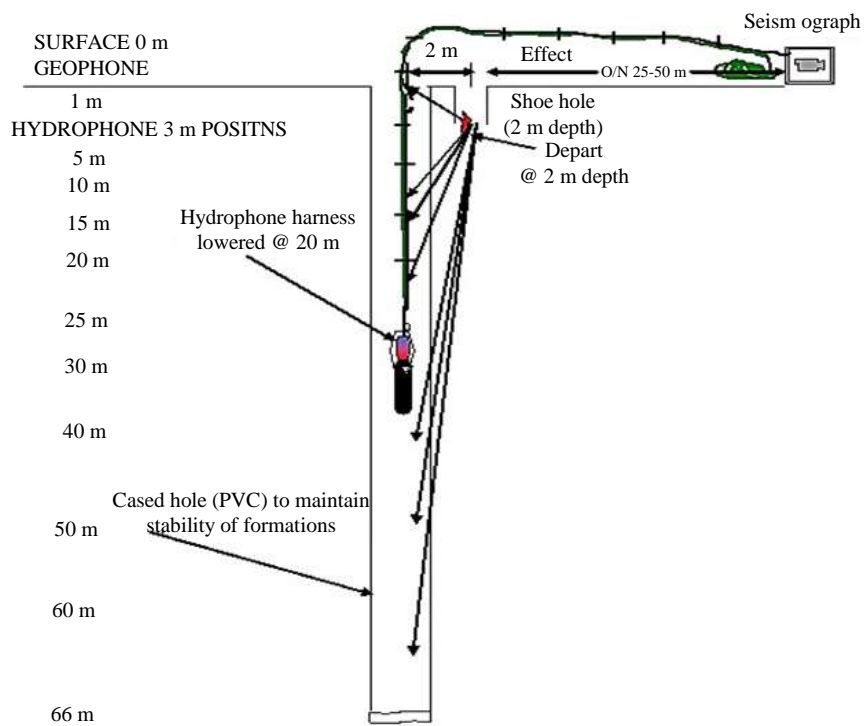
Regardless of the method or configuration adopted to acquire the data, with either sources (up-hole recording) or receivers (downhole recording) in the borehole, the basic procedure is the same. Once the up-hole data is acquired, the interpretation usually entails:

- i) Picking the first arrivals from each depth level
- ii) Applying any necessary corrections to these times
- iii) Plotting the data and estimating the velocities and thicknesses of the various layers identified

By so doing, a near-surface assessment of the weathering layer characteristics would have been obtained. Details on the underlying principles, methods of implementation of up-hole surveys, data collection, reduction/conversion and correction as well as interpretational approaches to up-hole survey models have been well documented in (Franklin, 1982; Wong *et al.*, 1987; Hunter and Burns, 1990; Whiteley *et al.*, 1990a-b; Cox, 1999).



**Fig. 1:** Up-hole survey configuration for sources in borehole, receiver at the surface (Cox, 1999)



**Fig. 2:** Up-hole survey configuration for receivers in borehole, source at the surface (CNPC/BGP Technical Report, 2014)

## Location of Study Area and Geologic Settings

The study area covers four Local Government Areas (LGAs) in Delta State, Nigeria. The LGAs are; Aniocha South, Ndokwa East, Oshimili North and Oshimili South. Figure 3 shows the location and boundaries of the study area.

The vegetation in the prospect area varies from farm lands, light vegetation and grass lands in the western and central part of the prospect to raffia flooded plains and tropical rain forests at the eastern region. The prospect area is subceptible to heavy flooding and erosion in the wet seasons. Numerous small lakes and fish ponds which are all of economic value, through fishing to the local communities are situated within the prospect. The Iyesse River runs through the central part, dividing the prospect into approximate halves and the Umomi River, a tributary of the River Niger, aligns almost parallel with the prospect on the northern part while the River Niger bounds the prospect on the east. Accessibility in the prospect area is quite fair. The major Ughelli - Asaba road runs almost centrally through the prospect with other minor linked roads. Access over the north to north-western part is good. However, some difficulty exist at the north-southern and central parts where the roads terminate at creeks. The area is a part of the Niger Delta Basin. The sediments are unconsolidated and have a

highly variable thickness throughout the region. It is made up of fresh water swamps and mangrove swamps with relief that increases towards the north. The Niger Delta Basin is characterized by both marine and mixed continental depositional environments which is believed to have originated during the Eocene. Only three sedimentary formations (Fig. 4) have been identified in the Niger Delta Basin, namely; the Benin, the Agbada and Akata Formations (Short and Stauble, 1967).

The Benin Formation consists of predominately massive, highly porous fresh water-bearing sandstone with local interbed of shale. The sand and sandstone are granular and pebbly to fine-grained. It is a continental deposit of Miocene to younger age, with variable thickness in the order of >1,800 m. Typical outcrops of the Benin Formation can be seen around Benin and Onitsha. The Agbada Formation consists of alternating sandstones and shales and is of fluviomarine origin. It is Eocene in age in the north and Pliocene in the south. These sands, sandstones and marine shales which make up the Agbada Formation has a maximum thickness of about 3000 m. It constitutes the main hydrocarbon habitat in the Niger-Delta. The Akata Formation consists of shales with local interbedding of sands and siltstones. It was deposited in a marine environment and has a maximum thickness of about 5500 m. It is thought to be the main hydrocarbon kitchen of the Niger Delta Basin (Kulke, 1995; Klett *et al.*, 1997).

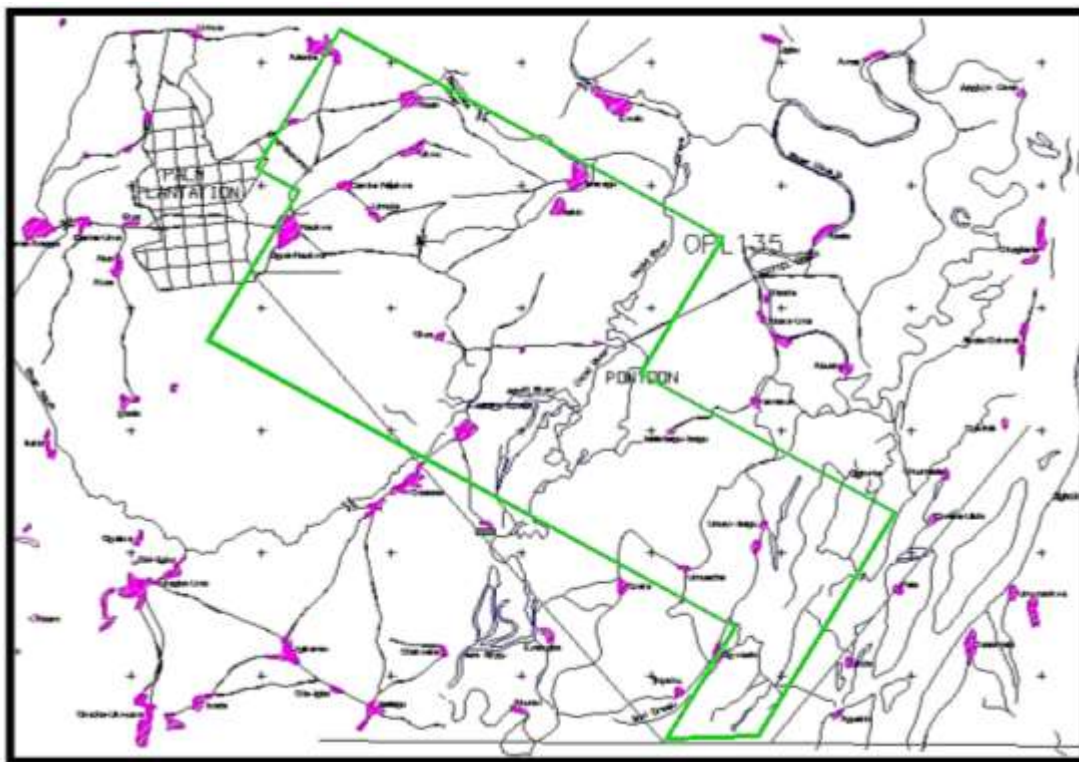
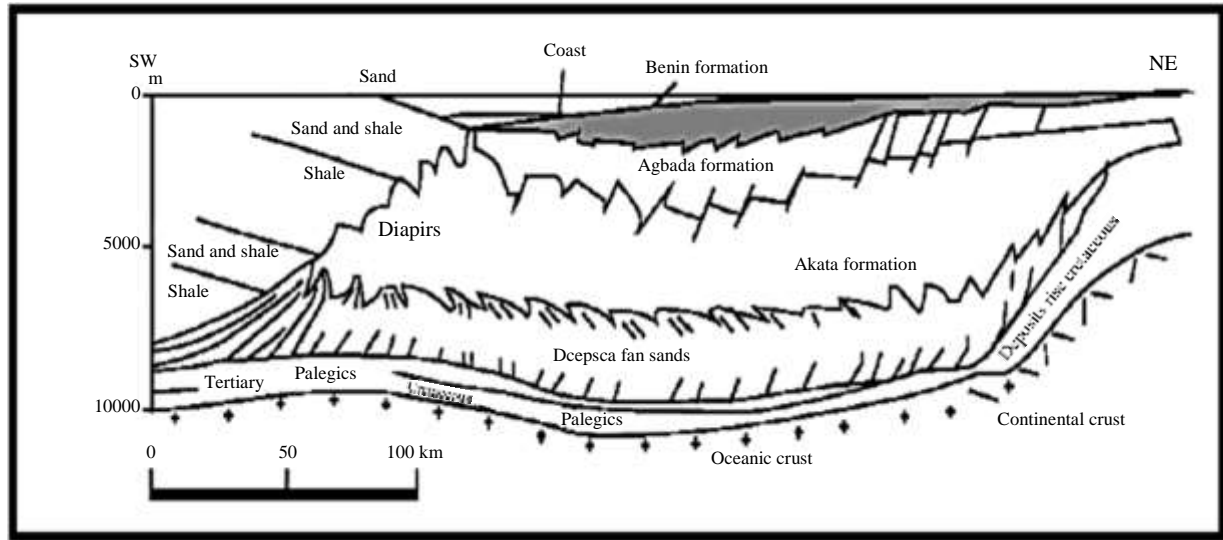


Fig. 3: Location of the study area with its dimensions bounded by the green lines



**Fig. 4:** Stratigraphy and depositional structure of the Niger Delta Basin

## Background Theory

A brief but concise description of the underlying principle of the up-hole refraction survey technique (slope-intercept technique of interpretation) is presented.

During an up-hole refraction survey, after the detonation of the shots, that is, generation of seismic wave energy, the travel time (first breaks) of seismic waves from a known source location through a refractor and back to a surface geophone could be determined. If a graph of first break times ( $T$ ) is plotted against the offset ( $X$ ) for each up-hole set up or configuration (Fig. 5).

The velocity of the weathered layer could easily be obtained for every up-hole point. Similarly, assuming a two-layer earth model in which the energy source is located in the weathered zones, the travel time  $T$  is given by:

$$T = \frac{X - 2Z \tan \theta_c + 2Z}{V_2} + \frac{2Z}{V_1 \cos \theta_c} \quad (1.0)$$

Where:

$X$  = The offset distance

$\theta_c$  = The critical angle of incident wave

$Z$  = The depth to base of the weathered layer or depth to interface

$V_1$  = The weathered layer velocity

$V_2$  = The consolidated layer velocity

From (1.0), if the offset is set at  $X = 0$  (that is at shot point location), it implies from Fig. 5 that time  $T = T_i$ :

$$T_i = \frac{2Z}{\cos \theta_c \left( \frac{1}{v_1} - \left( -\frac{\sin \theta_c}{v_2} \right) \right)} \quad (2.0)$$

Considering that from Snell's law,  $\theta_c = \sin^{-1} \left( \frac{v_1}{v_2} \right)$ , Eq.

2.0 modifies further to:

$$T_i = \frac{2Z \cos \theta_c}{v_1}$$

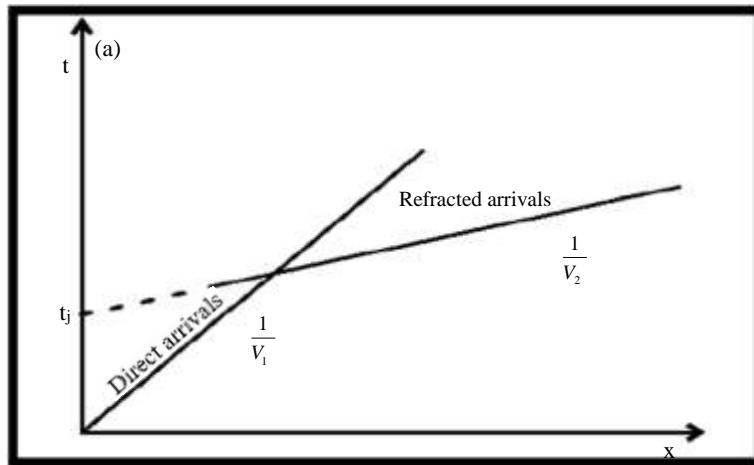
$$T_i = \frac{2Z (v_2^2 - v_1^2)^{1/2}}{v_2 v_1} \quad (3.0)$$

From the relations above, if  $T_i$  is known for all up-hole survey points, then  $Z$  which is the depth to the base of the weathered zone could be obtained as:

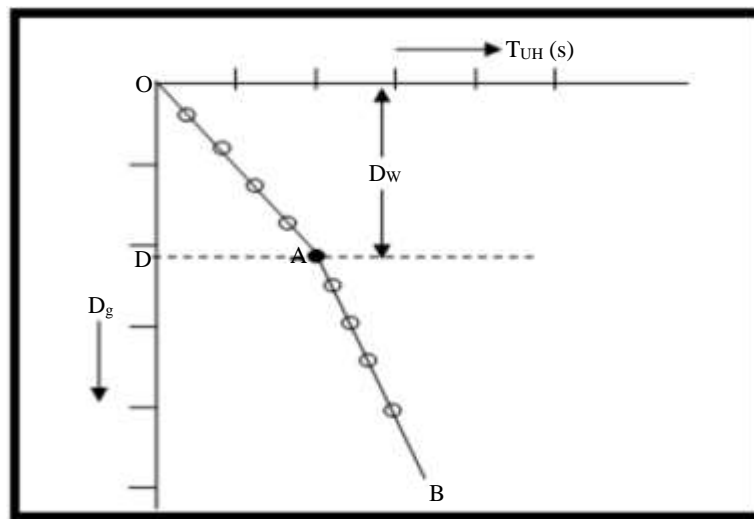
$$Z = \frac{T_i v_2 v_1}{2(v_2^2 - v_1^2)^{1/2}} \quad (4.0)$$

Figure 6, graphically shows how the weathered layer thickness can be estimated via the slope-intercept technique.

The thickness of the weathered layer is the path covered by line OA on the depth axis. Therefore, if the up-hole survey time versus depth graph is plotted for all survey measurements points, the distances OA in each case could easily be obtained to generate the thicknesses of the weathered layers for all the various survey points. The dotted lines at point A, marks the base of the Low-velocity layer, which in actual sense is, the base of the weathered layer.



**Fig. 5:** A plot of travel Time ( $T$ ) versus offset ( $X$ )



**Fig. 6:** Up-hole survey Time ( $T$ ) versus Depth ( $D$ ) relation for estimating thickness of weathered layers via the slope-intercept approach

### Materials, Data Acquisition Strategy and Processing

Materials deployed for the up-hole refraction survey included; a Geometrics Strata Visor NZ11 Seismograph recorder, blaster unit, wiring harness, 12V dry cell battery and consumables like, plastic casings, plotter paper rolls, masking tapes, bulldog tapes, knives and digital multimeters. A complete up-hole acquisition crew prosecuted the up-hole survey operation. A total numbers of thirty seven (37) up-hole locations in a (4.0×3.750) km grid specification were drilled and logged. They were arranged such that at least four up-hole locations were taken on each swath (Fig. 7).

Prior to acquisition, basic instrument tests were performed to ensure the instruments deployed to the field functioned optimally. The acquisition set up entailed placing receivers in the borehole with the source at the surface (Fig. 2). A firing command was then given from the blaster unit which provided the required voltage discharge needed to trigger the detonators (energy source). The blasting unit normally produces a field time signal simultaneously with the firing pulse to the caps. This signal would be fed back and recorded into the instrument to produce the arrival time sequence. Once a shot is successful, the output data is documented and the harness moved to the next calibrated depth. This procedure was repeated till the last depth was logged. A

block diagram showing the workflow for the processing of the acquired field data is presented in Fig. 8.

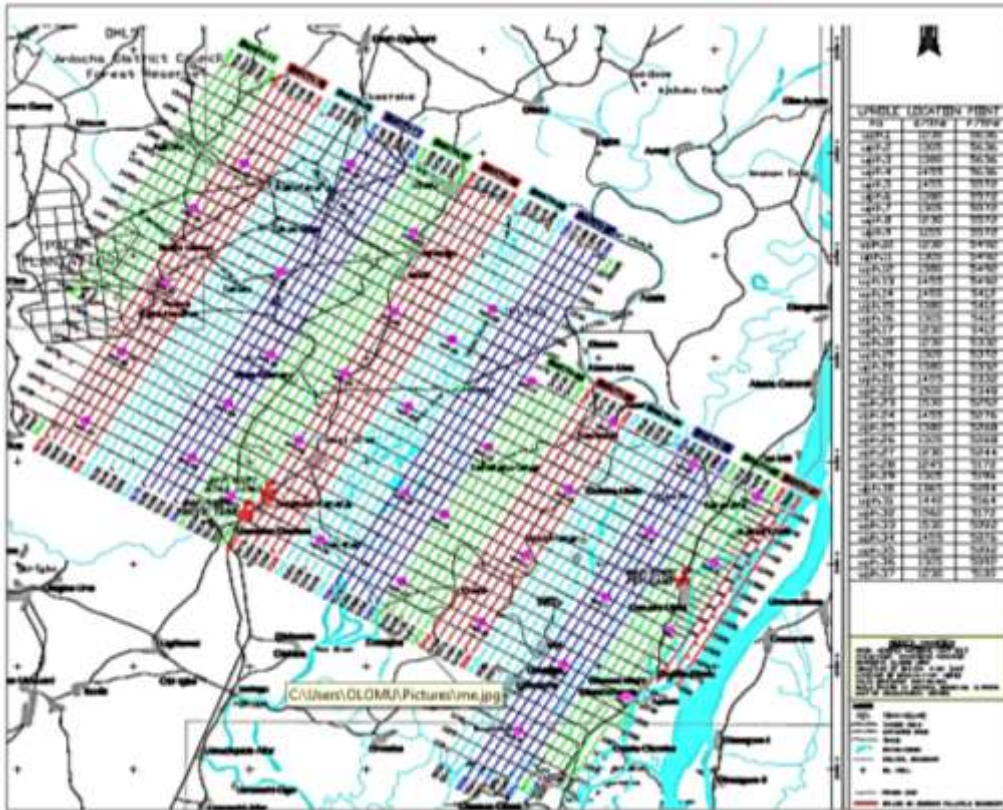


Fig. 7: Up-hole grid map of the prospect showing up-hole sample points with purple dots

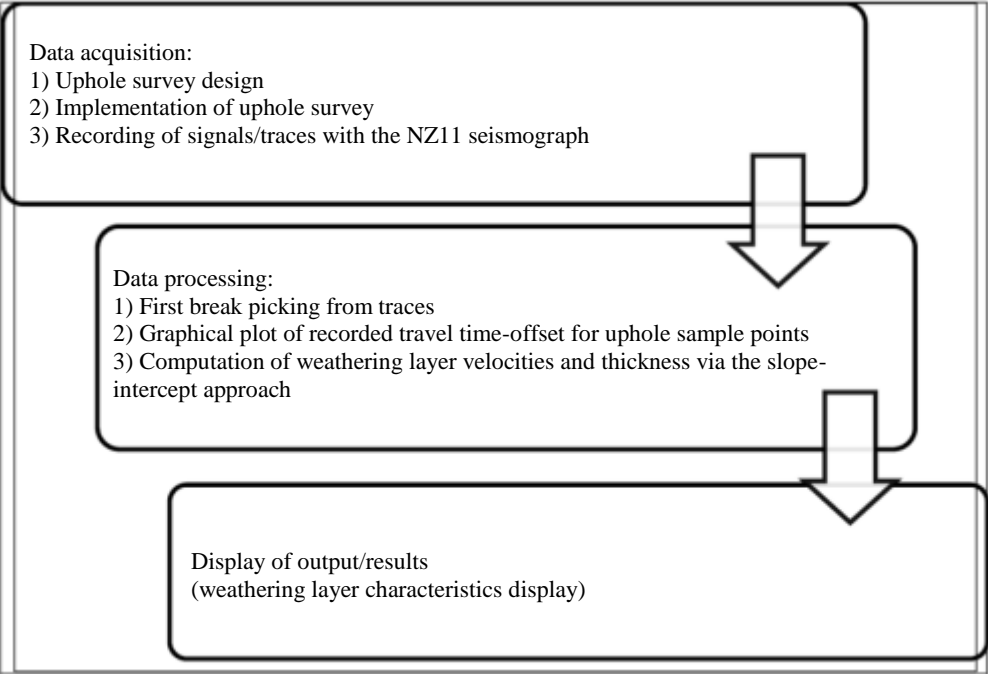


Fig. 8: The processing workflow adopted for the acquired up-hole survey data

## Results and Discussion

Presented in Figs. 9-11 are graphical plots of recorded travel times versus offset for some selected up-hole sample locations.

From the travel time versus offset plots, the layer model of the prospect was generated using the already established relations (Eqs. 1.0-4.0). This weathering layer model is given in Table 1.

The weathering layer velocity ranged from as low as 210 m/s around UPH-4 of the prospect to 593 m/s

around UPH-29. These relatively high variations in the near surface seismic velocity is indicative of the high degree of inhomogeneity of the layer (The Low-Velocity Layer-LVL, in this particular case). This remarkably reduces the possibility of obtaining a smooth statics response for any seismic reflection data likely to be acquired in the area. These values obtained were in close proximity (in agreement) to those obtained in the separate studies by (Adeoti *et al.*, 2013; Anomohanran, 2014) in other different locations within the Niger Delta Basin.

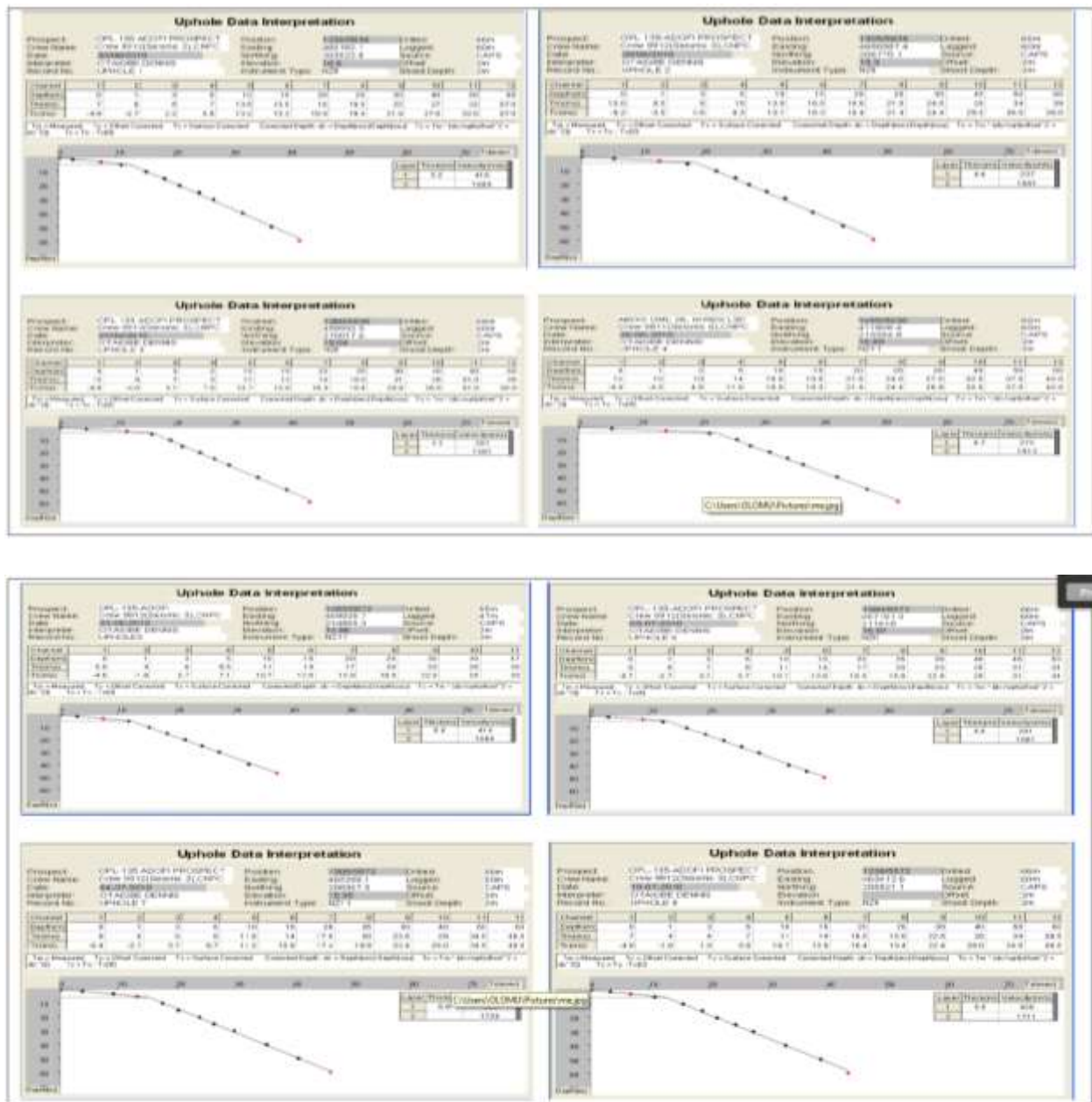
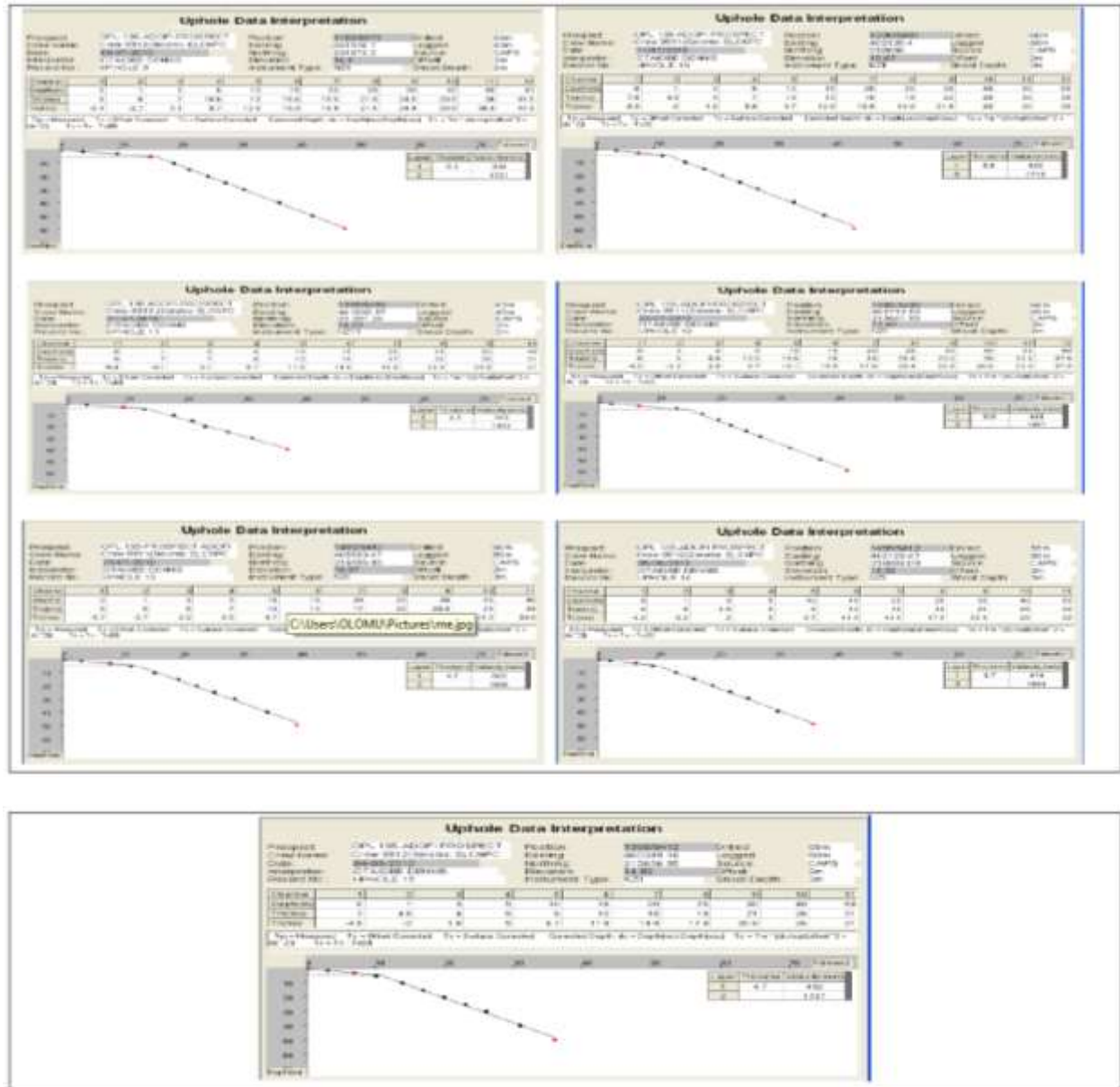


Fig. 9: Travel time versus offset plots for up-hole sample points 1-8





**Fig. 10:** Travel time versus offset plots for up-hole sample points 9-15

Also, the weathering layer thickness ranged from as low as 3.1 m around UPH-21 and UPH-28 of the area to 6.8 m around UPH-12. The average weathering thickness was approximately 4.7 m. The implication for these values obtained is that, for the soon to be deployed/executed 3 D seismic reflection acquisition program, the dynamite shots (energy sources) should be well placed below this average depth of 4.7 m (should be even deeper, above 7 m around UPH-12) across the entire prospect to grossly ameliorate and eliminate all the undesirable effects/problems of the low velocity layer-LVL (ground roll and their likes) on the eventual pre/main and post processing of the 3 D seismic

reflection data and its attendant adverse effect on the overall imaging quality (output) of the section, most of which have previously been highlighted in the introductory part of the paper. The sub weathering (consolidated) layer seismic velocity ranged from 1131 m/s around UPH-32 to 1987 m/s around UPH-3. Again these values obtained were in agreement to those obtained by (Enikanselu, 2008; Igboekwe and Ohaegbuchi, 2011; Adeoti *et al.*, (2013). This portion of the near subsurface layer is sufficiently compacted judging from the seismic velocity distribution across this section within the study area. The depth to the interface ranged from 0.45 m around UPH-28 to 1.50

m around UPH-33 within the prospect. The output of this study would serve as a very valuable input parameter and greatly enhance the elevation and weathering components of statics correction for the

eventual seismic reflection data that would be acquired in the prospect and would guide in the correct placement of shots as previously emphasized during the 3 D seismic reflection data acquisition campaign.

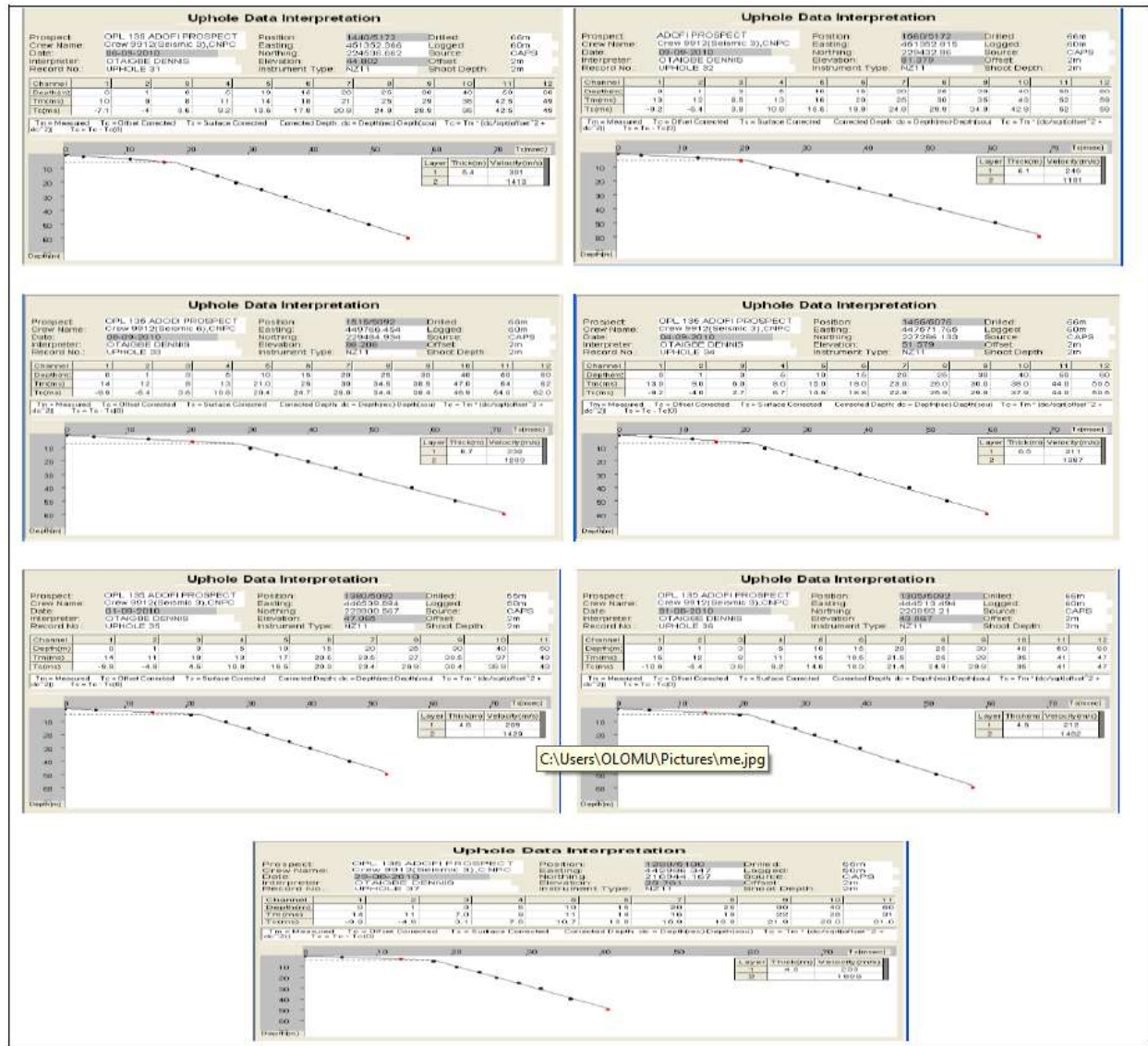


Fig. 11: Travel time versus offset plots for up-hole sample points 31-37

Table 1: Layer model of the weathering and sub-weathering zones over the prospect

Sample point	Elevation (m)	Thickness (m)	Weathering layer velocity (m/s)	Consolidated (Sub-weathering) layer velocity (m/s)	Depth to Interface (m)
UPH-1	16.60	5.2	415	1804	11
UPH-2	15.30	4.4	237	1851	17
UPH-3	15.04	4.1	261	1987	15
UPH-4	15.89	4.7	210	1810	21
UPH-5	14.86	5.0	414	1660	11
UPH-6	15.87	4.4	341	1691	12
UPH-7	15.96	5.6	384	1728	15
UPH-8	15.68	5.5	450	1711	12
UPH-9	14.50	5.3	334	1721	16

**Table 1:** Continue

UPH-10	15.69	5.0	425	1712	11	0.73
UPH-11	15.27	4.2	316	1463	13	0.74
UPH-12	17.62	6.8	444	1967	16	0.95
UPH-13	16.67	4.7	383	1596	11	0.70
Uph-14	15.52	4.7	474	1694	09	0.68
UPH-15	14.82	4.7	452	1737	10	0.70
UPH.16	13.59	4.3	382	1712	11	0.65
UPH.17	12.91	5.0	396	1801	12	0.69
UPH.18	19.23	4.2	392	1737	10	0.59
UPH.19	14.73	4.5	336	1943	13	0.58
UPH.20	15.35	4.5	570	1690	08	0.76
UPH.21	16.35	3.1	380	1895	09	0.47
UPH.22	16.12	3.7	375	1898	11	0.57
UPH.23	16.64	3.5	539	1856	06	0.48
UPH.24	21.78	4.4	303	1914	14	0.57
UPH.25	19.82	4.2	360	1689	12	0.67
UPH.26	17.39	4.5	278	1775	16	0.64
UPH.27	18.05	3.7	540	1746	07	0.60
UPH.28	18.29	3.1	381	1778	08	0.45
UPH.29	16.36	5.0	593	1726	09	0.88
UPH.30	20.53	3.8	237	1889	15	0.48
UPH.31	44.80	5.4	301	1413	17	0.95
UPH.32	81.38	5.1	245	1131	20	1.14
UPH.33	86.21	6.7	239	1203	29	1.50
UPH.34	51.58	6.5	311	1387	21	1.24
UPH.35	47.07	4.6	209	1429	22	0.82
UPH.36	43.07	4.5	212	1482	20	0.73
UPH.37	25.76	4.0	233	1929	18	0.55

## Conclusion

This study has successfully determined the weathering layer characteristics of the prospect (OPL-135) using the up-hole refraction survey technique. The results obtained revealed a two layer earth model. The weathering layer was relatively heterogeneous and loose, whereas, the sub-weathering layer was relatively compacted and fairly homogeneous. The results from this study has suggested that for any meaningful seismic reflection project to be embarked upon in the prospect, it would require a substantial amount of statics correction, owing to the high variability of the weathering layers in terms of velocity and thickness. The velocity estimate gotten from the survey were in close agreement with those gotten from literature and falls within the acceptable range for values used for statics correction in the seismic data processing sequence. The determined depths to the base of the LVL is a vital information for the proper placement of energy sources (dynamites) to ameliorate noise effects as a result of dispersive groundrolls associated with the weathering zone. This would in turn, improve the Signal to Noise Ratio (SNR) of the yet to be acquired seismic reflection data.

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useful insights. The University of Port Harcourt, Port Harcourt, Nigeria is worthy of mention, for providing the teaching and research platform.

## Author's Contributions

**Okechukwu Frank Adizua:** Coordinated data analysis, interpretation and discussion. He prepared, reviewed and revised the manuscript on behalf of the team for publication and served as the corresponding author.

**Adekunle Oyemade Sofolabo:** Designed research plan and organized the study for the team.

**Olomu Ivory Obi-Egbedi:** Played a major role in the data acquisition experiments and assisted in data analysis and interpretation for the team.

## Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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