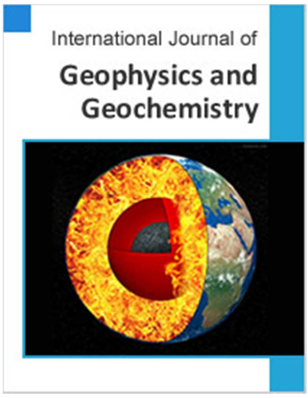
International Journal of Geophysics and Geochemistry
2018; 5(1): 9-18
http://www.aascit.org/journal/ijgg
ISSN: 2381-1099 (Print); ISSN: 2381-1102 (Online)

American Association for Science and Technology



Keywords
Elevation,
Weathered Layer,
Uphole,
Core Samples,
Niger Delta

Received: September 9, 2017
Accepted: November 1, 2017
Published: February 12, 2018

The Effect of Elevation and Weathered Layer on Seismic Data Quality: Case Study of Olo Field, Niger Delta

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Citation
Adikwu Onum Stephen, Okereke Chidinma, Anene Francis Chibuzor, Selemo Alexander Olusegun. The Effect of Elevation and Weathered Layer on Seismic Data Quality: Case Study of Olo Field, Niger Delta. *International Journal of Geophysics and Geochemistry.* Vol. 5, No. 1, 2018, pp. 9-18.

Abstract
Seismic data acquisitions in the study area have been faced with the challenge of high volume of weak shots recorded. The choice of 21m Single Deep Hole being deployed to the study area for the first time as opposed to the conventional Pattern-hole source, was geared at averting the effect high weathered layer thickness manifesting as a result of unusual elevation anomaly. This depth however still left the issue unresolved as the study area witnessed high volume of weak shots records. This research was therefore carried out using uphole seismic refraction data from twenty one borehole locations within the study area to analyze statistically the causes of these weak shots. The elevation which was estimated to range from 4m to 65m was sensed remotely using the SRTM which was used to generate a Digital Elevation Model. The weathered layer thicknesses and the velocities were found to range between 4.8m to 25.3m and 413ms^{-1} to 614ms^{-1} respectively. Several contour and analytical maps were generated for the weathered and consolidated area. A correlation of approximately one quarter of the shot point elevation was established to be the weathered layer thickness from a simple. Also, lithology analysis of core samples taken at explosive depth was conducted and revealed that shot hole depth within the weathered layer and some nature of geology of the formation was responsible for obtaining weak shots. Prediction from linear regression model in this research also indicates that at 21m explosive depth many of the shot that will be recorded will be weak hence, reducing the quality of seismic data to be acquired. Therefore it is recommended that there is need to review this depth in order not to compromise the quality of data.

1. Introduction

Seismic methods represent one of the most important geophysical techniques for oil and gas exploration due to its high accuracy, high resolution and deep penetration [6]. The presence of uneven surface topography in a prospect frequently constitutes a source of error in seismic data acquisition as well as datuming through an incorrect low velocity layer model which can introduce false structure into the deeper reflectors. Therefore it becomes important to correct for effect of elevation, variable thickness and lateral variation in velocities of the unconsolidated layers in any prospect. Statistical analysis for determining the degree of conformity between surface topography, weathered layer thickness/velocities and mapped structure is useful in gathering information on influence of elevation and weathering layers on qualityof seismic data acquisition.

The weathered layer or low velocity layer occur only near the surface, usually 4m to 50m thick. The characteristics of this layer includes the high absorption of seismic energy, the low velocity (Normally between 250 to 1000m/s) and rapid change in velocity which have a disproportionately large effect on travel times, the marked velocity change at the base of the LVL and the very high impedance contrast at the base of the LVL [10]. Weathering depths and layer can be investigated by a number of geophysical techniques. However, the merits of an uphole survey over other geophysical methods cannot be over- emphasized. Uphole survey allows for construction of a detailed map of the thickness and velocity of the weathered layer. With this information a statics model could be created and applied to the seismic data to remove the effects of the weathered zone. Besides providing means of identifying and defining velocity inversions or reversals situations where a stratum has a lower velocity than that of the overlying material which may not be identified by surface refraction surveys, it also gives an insight to other subsurface conditions that would be obscured to observer at the surface. Usually, a hole that penetrates below the weathering layer is drilled and geophones are placed at various known offset distances on the surface. It is therefore a good tool in taking decisions on drilled and charge depths prior to the commencement of any seismic reflection operation.

Several studies have been carried out on low velocity (weathered) layer using seismic refraction, aimed at determining specific characteristics of the layer [2]; [4]; [7]. Also a lot of downhole/uphole surveys have been carried out in Niger Delta in the course of acquiring reflection seismic data for oil and gas exploration [1]; [5].

The study area is a producing oil field situated in the Northern fringe of Niger Delta region of Nigeria. Seismic Exploration was last carried out about a decade ago with the pattern charge detonation method. With decline in oil production, there was need to re acquire higher quality of data with deeper horizon and resolution.

Recent development in seismic technology has shown that the single deep hole (SDH) charge method gives a better resolution and mirroring of a deeper reflector than the pattern holes charge method owing to the elimination of attenuation effect of low velocity layer (weathered layer). But there was still the problem of the occurrence of weak shots despite a well design survey layout compromises the objective. Considering that the cost and the logistics involved in retaking these weak shots are quite enormous, precautionary measures to avoid these occurrences in future prospects is eminent.

Hence, this research work was carried out using reflection and refraction seismic data to statistically analyze the effect of elevation and weathered layer on the quality of seismic shots and ascertain the suitability of these layers for seismic reflection data acquisition and engineering structures.

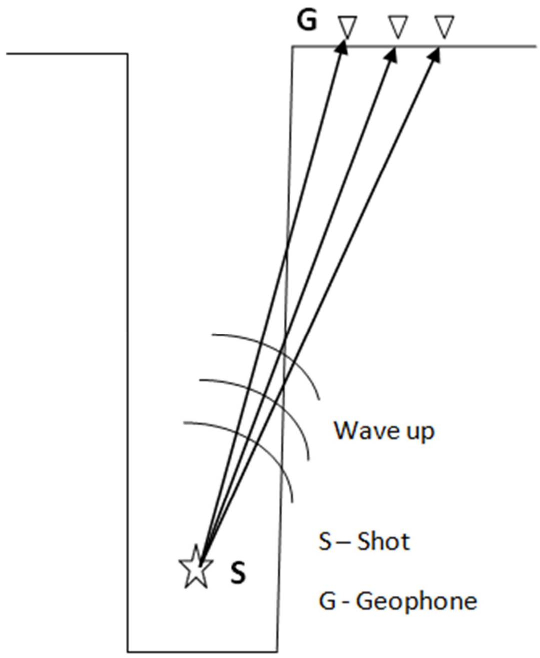

Figure 1. *Basic Geometry for uphole offset geophone. (SPDC Journal 2008).*

1.1. Location of the Study Area

The study area is producing oil field in the northern part of the Niger Delta basin that lies between longitude 5°33’30.26”E and 5°53’37.82”E and latitude 6°15’35.77”N and 5°56’38.32”N. The study area falls within part of Oredo LGA, Edo state and Ethiope East LGA of Delta State, covering an area of 523sqkm. Elevation varies from as low as 4m close to the river channel southward of the prospect area and as high as 76m North East of the prospect with predominate undulating terrains in the region. (Figure 2).

1.2. Geology of the Study Area

The area is characterised by an upward regressive sequence of tertiary sediments that progressed over passive continental sediments. Three major sedimentary cycles have occurred in the Niger Delta structural basin since the early Cretaceous, namely an upper sandy Benin Formation, an intervening unit of alternating sandstone and shale named the Agbada Formation, and a lower shaly Akata Formation [3, 8]. These three units extend across the whole delta and each ranges in age from Early Tertiary to Recent. Subsurface structures are described as resulting from movement under the influence of gravity and their distribution is related to growth stages of the delta.

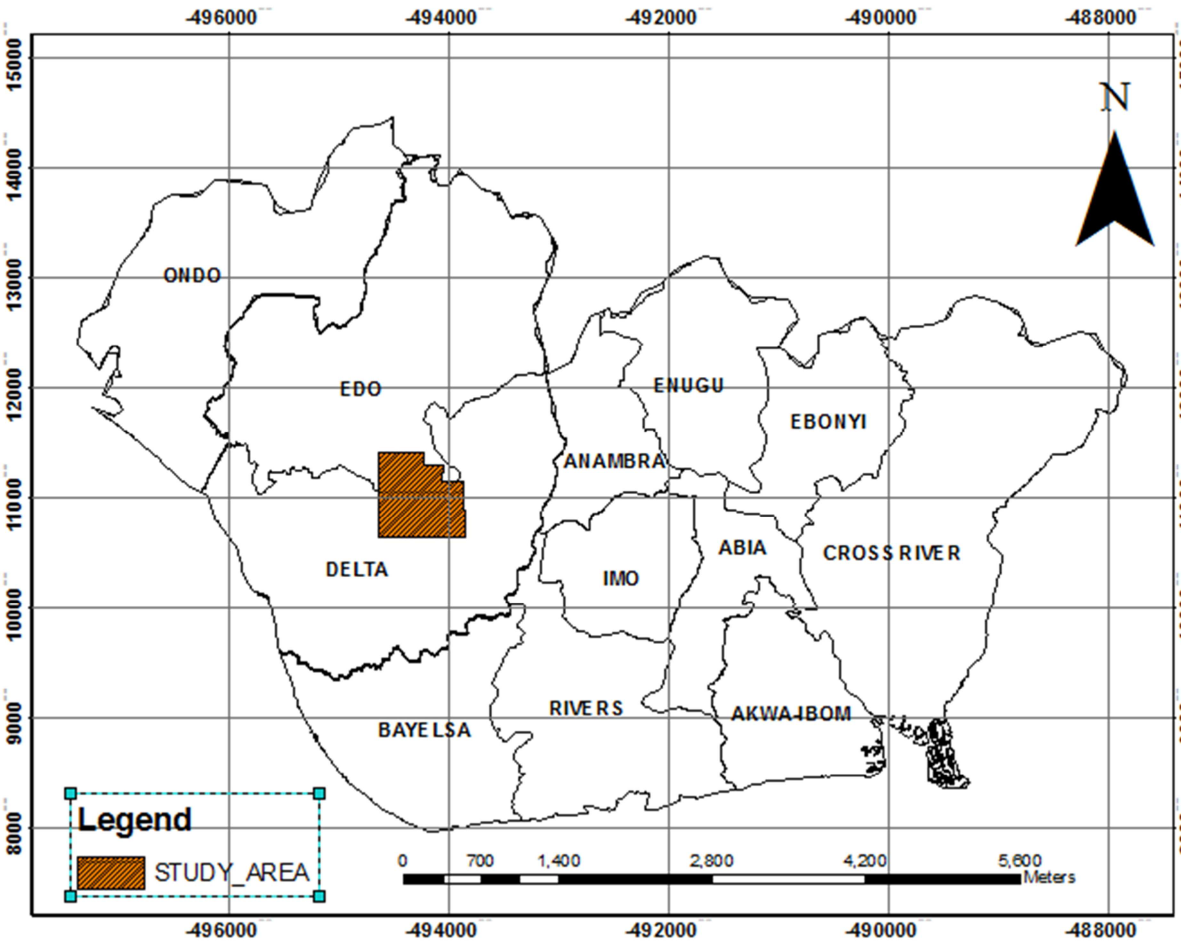

Figure 2. *Map of southern Nigeria showing the study area (Source: Nigerian Geological Survey 2010).*

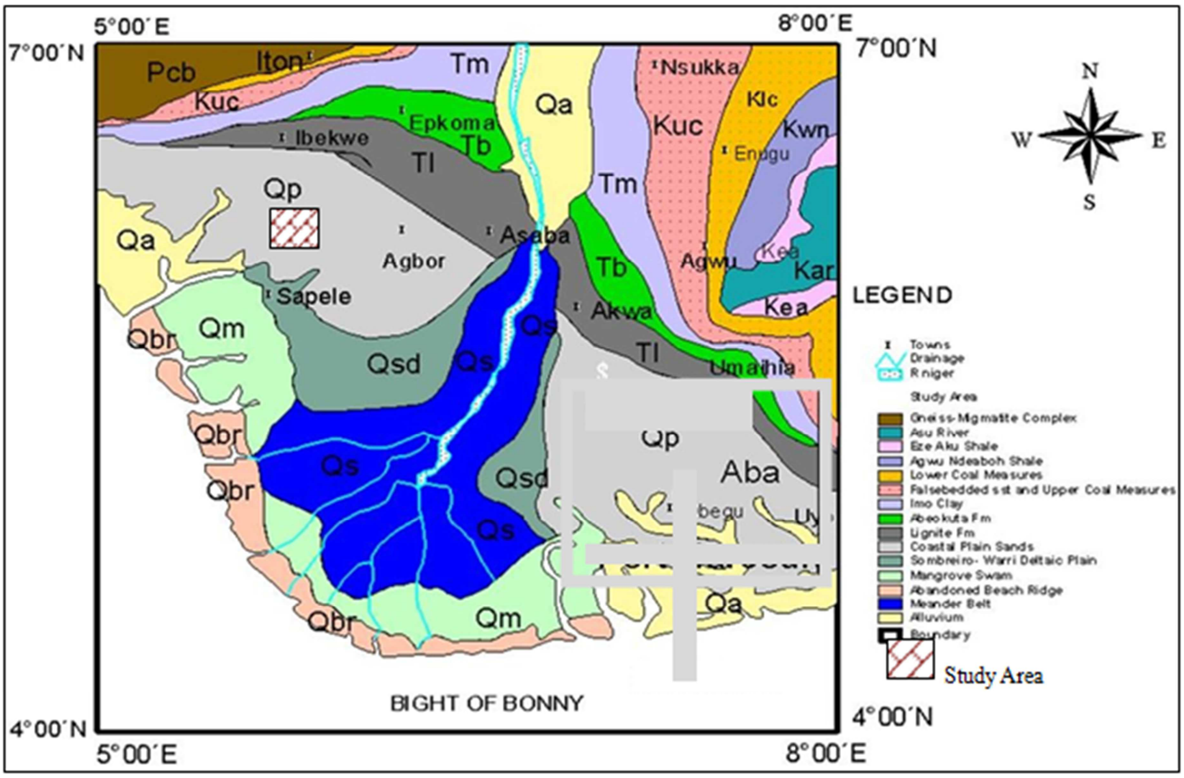

Figure 3. *Geologic Map of Niger Delta Showing the Study Area (Source: Nigerian Geological Survey 2010).*

2. Materials and Methods

2.1. SamplingTechnique

A total of 21 Up-hole surveys were carried out for the purpose of this research work. The field set-up is shown in figure 1. An uphole energy source lowered in the drill hole, a cable containing 12 geophones calibrated according tothe geometry was arranged at the surface. The data was acquired using a 24- trace OYOGEO-SPACE McSeis 160MX model 1115 portable digital recorder. The energy source used was 8 caps for a single shot. These waves travel to the surface and picked by each of the geophone channel at different times. The travel time recorded by seismograph or further processing for arrival time picking of the firstbreak time. The data is then used for velocity analysis and the estimation of low velocity layers thicknesses.

The study area was divided into 9 swaths. The research focused on swaths 1, 2 and 3 based on the availability and the variation in the quality of shot as at the time of the research. Similarly, for shot classification based on quality, samples of shots were drawn from the three swaths to achieve the objective of variation of shot quality with elevation and weathered layer thickness. A total number of shots taken were 24346. Experimental shots were taken at different depths, elevations and locations to examine these effects on the quality of shots.

2.1.1. Assessing Variation of ShotQuality with Elevation

The elevation data was remotely sensed using the SRTM imagery and was used as an input in generating the contourmap at 2m and 5m contour interval with ArcGIS10.1 software. An elevation model was also created with elevation ranges for ease of data analysis.

The seismic SegD data of each shot point drawn as a sample for the research was analysed using the Spectral Analysis Model in the Promax 3D seismic data processing software to determine the intensity of seismic energy return to the surface, frequency and amplitude of the shots. Three unique classes of shot identified are weak, fair and good as shown in Table 2 formed the classes of shot based on quality.

Classed post map was created in Surfer 12 showing spatial distribution of quality of shots. The class post map was then superimposed on the contour map to evaluate the effects of elevation on the quality of shots.

Table 1. *Elevation Classification.*

Elevation Range (m)	Elevation Class
0-9.9	Low Elevation
10.0-19.9	Moderate Elevation
20.0-29.9	Moderately High Elevation
30.0-39.9	High Elevation
40.0-50.0	Very High Elevation

Table 2. *Shot Quality classification.*

Quality of shot	Frequency Range (Hz)	Amplitude/dBpower peak Range
Weak	40-50	-5 and -10
Fair	30-40	-1 and -2
Good	20-30	-1 and -2

Source: (Petroleum Africa publication Dec. 2010)

2.1.2. Estimating Weathered Layer Thickness and ShotQuality

The uphole data was used for velocity analysis and the estimation of low velocity layers thickness. This data was then used to produce the contour map of the weathered layer thickness, isopach and isovelocity maps. Also the velocities of the low velocity layer (first layer velocity) as well as the consolidated layer velocity were plotted against the coordinates to form the velocity surface model of the area ofinterest. The classed post map created previously was superimposed on the isopach and isovelocity maps createdabove.

2.2. Determining the Subsurface Lithology Within the Study Area

Core samples from the individual borehole of the 21 uphole point was taken with sample thickness of 30cm each for the purpose of identifying the type of formation harboring the explosive at the 21m design depth by carrying out lithology analysis.

2.3. Shot Quality Forecasting

The shot quality model/ prediction was based on the entire prospect. An attempt was made to establish a relationship between the elevation (known independent variable, X) and the weathered layer thickness (unknown dependent variable, Y) using the mathematical expression Y=AX+B. Where A is the slope and B is the intercept.

3. Result

3.1. ElevationClassification

The elevation of the study area is as shown in the digital elevation model in Figure 4. A wide variation in elevation is observed on the DEM within the entire prospect. Elevation increases from the river course northward from 20m to 46m within swaths 1 to 3. The average elevation for the area under study is 25m which is above the design depth of 21m. This may be suggesting a high weathered layer thickness from the principle of Isostacy.

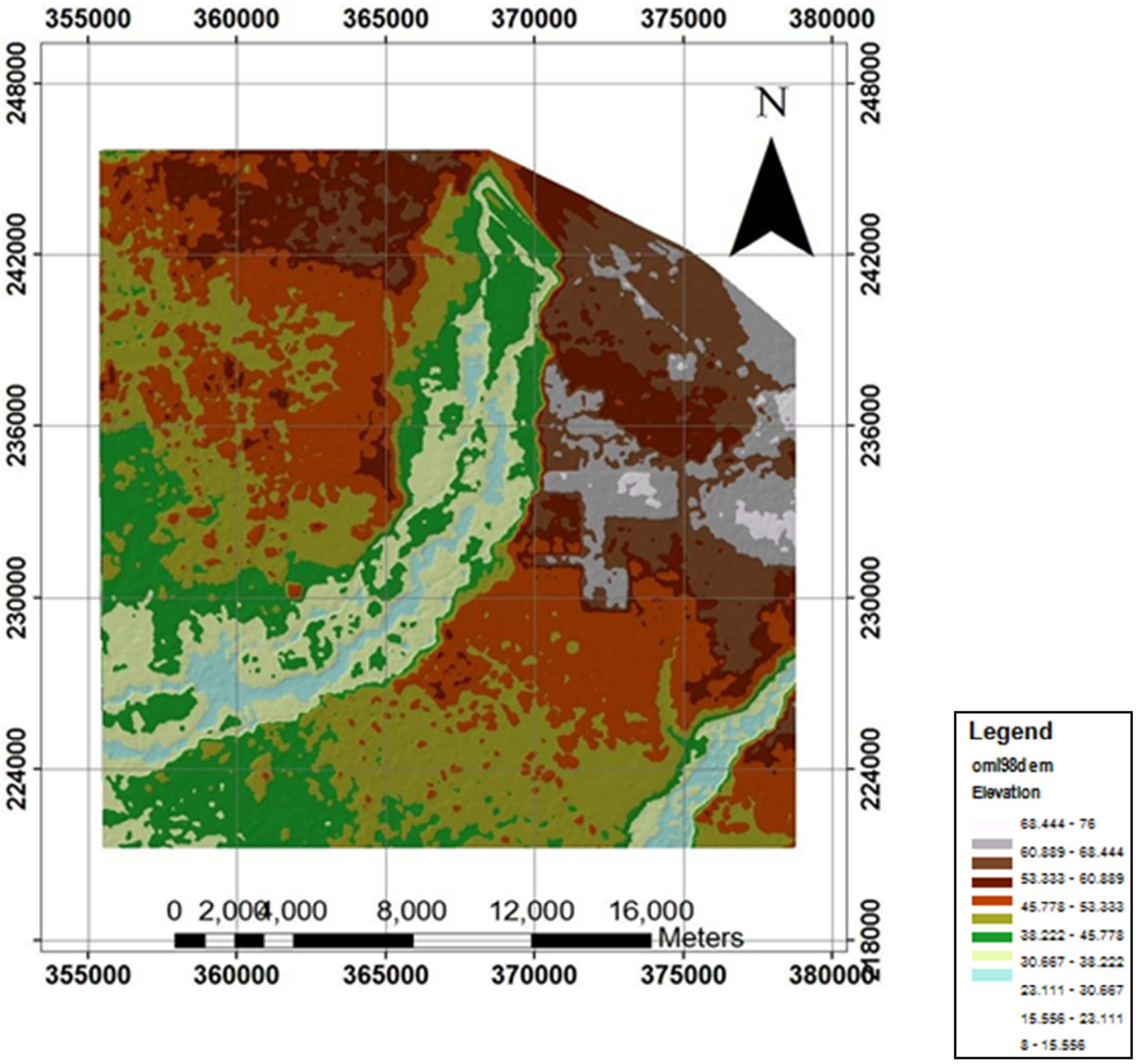

Figure 4. *Digital elevation model (DEM) of the study area.*

3.2. Elevation and Shot Quality Classification

The quantities of shots and corresponding percentages classified into Good, Fair and Weak based on spectral analysis were taken as shown in Table 3.

The histograms show normal distribution between the decline in quantities of good and fair shots with increasing elevation and conversely increase in the quantities of weak shot with increasing elevation. The trend was slightly uniform across the three swaths with percentage quality of shot decreasing with increase in elevation. The combined swaths profile indicates the point of intersection of these percentages coincide with approximately 30m (above 25m) depth.

Table 3. *Shot Quality Classifications with Elevation Variation.*

COMBINED SWATHS 1, 2 and 3						
ELEVATION	WEAK		FAIR		GOOD	
	QUANTITY	(%)	QUANTITY	(%)	QUANTITY	(%)
5m	118	11.48978	394	38.36417	515	50.14806
15m	284	13.94207	833	40.49347	920	45.16446
25m	1306	34.32326	1484	39.00131	1015	26.67543
35m	2182	55.80563	1116	28.5422	612	15.65217
45m	325	79.65686	67	16.42157	16	3.921569
55m	4		0		0	
TOTAL	4219		3894		3078	

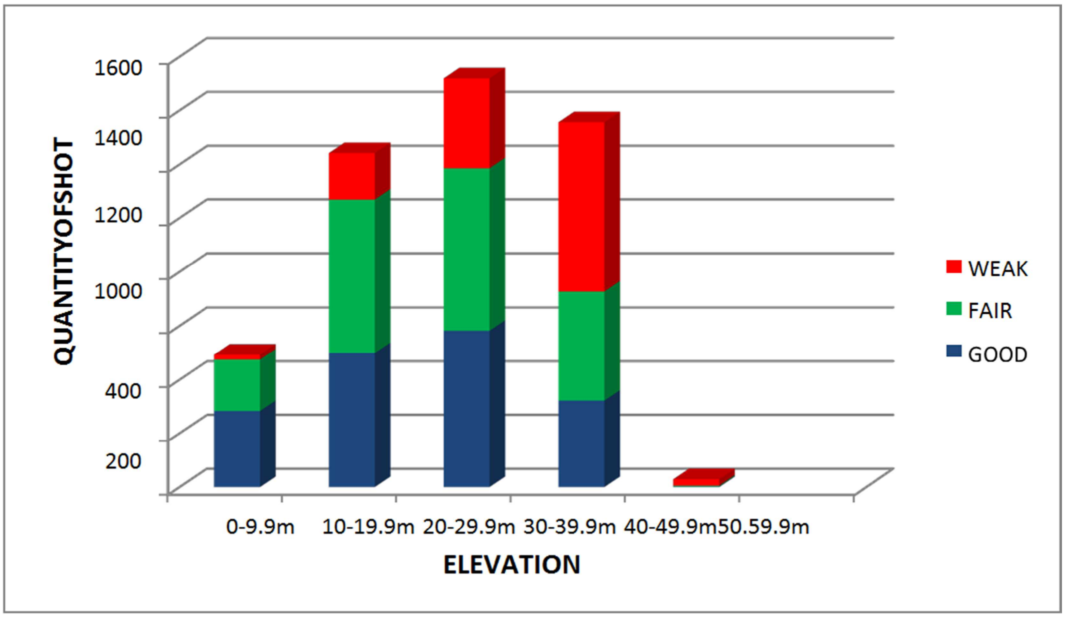

Figure 5. *Quantity Variation of Shot quality with elevation for swath 1.*

1cm represents 200 shots on the vertical (quantity of shot) axis.

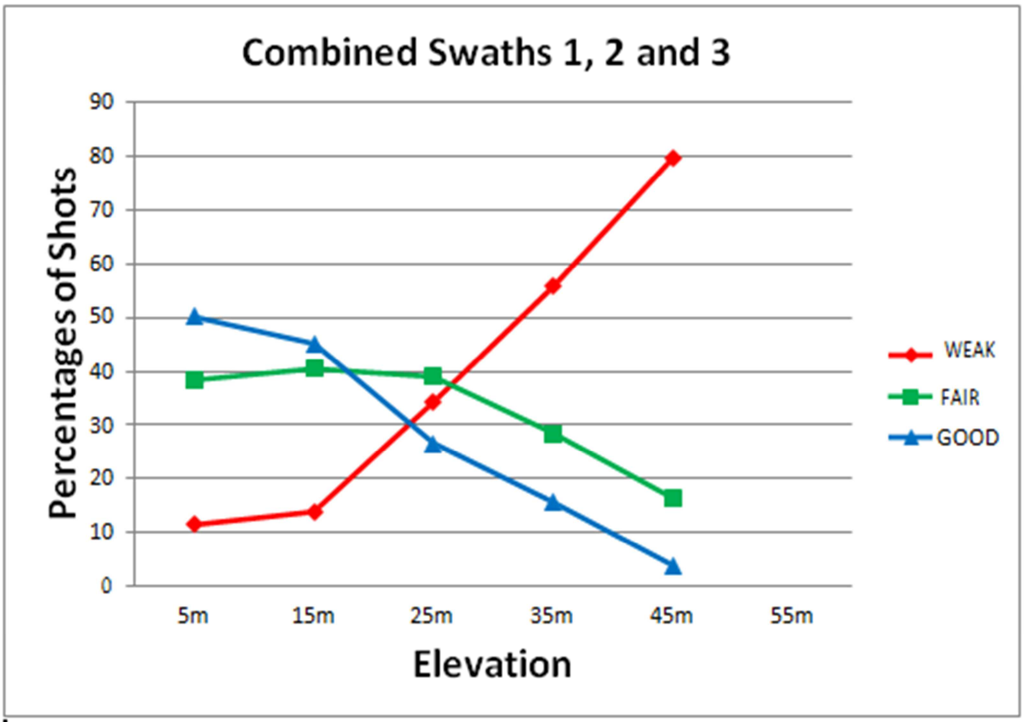

Figure 6. *Profile of Percentages of Shot Quality against Elevation for Combined Swaths 1, 2 and 3.*

4. Discussion

4.1. Effect of Weathered Layer Thickness on the Quality of Shots

Uphole analysis geared at estimating the lateral variation in weathered layer thicknesses were carried out and the result is represented in Table 4. The weathered layer thicknesses and the velocities of the unconsolidated layer are between 4.8m to 25.3m and 413ms^{-1} to 614ms^{-1} respectively. The second layer velocity is between 1520ms^{-1} and 1905ms^{-1} with indefinite thicknesses which were adjudged by [9]and [5]as competent enough for good seismic reflection data within the Niger Delta basin. However the high overburden thickness of the study area and the depth of Single Dip Hole deployed is still within the unconsolidated area, resulted in the persistence of weak shots.

Table 4. *Spatial and Geophysical details of Refraction (uphole) Points for Weathered Layer Thickness estimation.*

UPHNO	EASTING	NORTHING	ELEV. (m)	1STTHICK (m)	2NDTHICK (m)	LVL (m)	1ST VEL (m/s)	2ND VEL (m/s)
1	355483	220821.4	13	13.7		13.7	487	1651
2	355457.8	224444.7	3.1	6.6		6.6	426	1520
3	355458.6	228621	14.4	7.7		7.7	579	1718
4	355426.6	233423.2	25.3	13.2		13.2	548	1736
5	355431.9	237572.3	29.9	15.2		15.2	510	1692
6	355402.7	241775.5	31.8	15		15	510	1905
7	355459.6	246018	37.7	11		11	428	1657
8	359437.2	244998.3	38.3	12.5		12.5	497	1742
9	359422.9	241774.1	33.4	10.6		10.6	491	1760
10	359427.3	237572	34.9	17.9		17.9	614	1574
11	359428.3	232772.2	29	15.7		15.7	568	1732
12	359934.5	229172	18.5	7		7	421	1623
13	359433	224971.9	25.3	17.1		17.1	551	1697
14	359456.3	220795.8	18	17.1		17.1	551	1697
15	363458	220822	0	4	14.6	18.6	405	1706
16	363457.9	225021.4	28.1	3.4	15.8	19.2	420	1671
17	363458.2	229821.6	7.9	4.8		4.8	413	1675
18	363445.3	233397.6	35.5	3.2	18.2	21.4	423.5	1739
19	363456.7	237620.5	37.4	3.7	19.5	23.2	428	1637
20	363458.4	241822.6	42.5	3.9	19.2	23.1	421	1568
21	362957.6	246022.1	45.8	3.8	21.5	25.3	441	1630

The experimental shot analysis also reveals that all the shots with drilled depth between 9m to 15m except shot point were weak. The only exception with return of good energy was because of lower thickness of the unconsolidated layer at the point is about 7.5m, hence 12m drilled depth at that point falls in the consolidated layer. Similarly a few shots appeared fair despite the high elevation of the point on which they were established. At such positions explosive were presumably buried within the consolidated layer hence good energy return.

4.2. Effect of Explosive Host Formation on the Quality of Shot

The highest density of good and fair shots was present in swath 1 as compared to swaths 2 and 3. The weathered layer range is lower hence the explosive depth in this region is well established within the consolidated layer (figure 7).

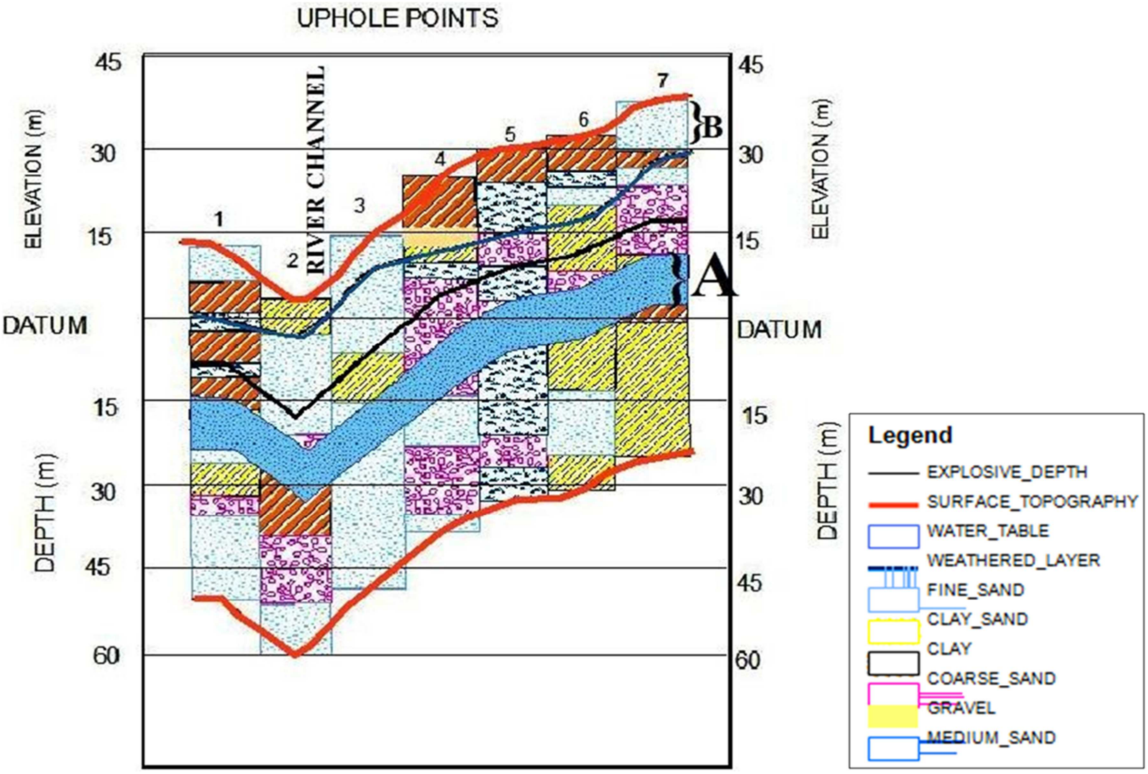

Figure 7. *Plot of Depth/ Elevation against Uphole Points in Swath 1.*

Some portion of the uphole point shave varying degree of geologic settings that contributed adversely to the quality of shots. In regions with explosive depth within the aquifer region, there is possibly explosive contact with water. Some areas have their explosive depths falling within a continuous clayey formation which has been proven to have a compacting effect on the explosive thereby reducing the potency of such explosive in the face of high sleep time. These two geologic phenomena are perhaps responsible for the record of some weak shots in some areas with explosive depth within the consolidated layer. A is the Zone of Water table fluctuations B is the Zone of dry thickness.

4.3. Shot Quality Fore Casting

Adeoti et al. (2013) in an attempt to predicting the thickness of weathered layer thickness fitted a linear regression model to velocities of layers and weathered layer. He concluded that in the absence of one parameter the other canbe estimated provided they are in the same geologic formation.

A regression profile plot as shown in figure 8 indicates that the correlation is well fitted into the data though the regression coefficient is middling (R2= 0.5029). This may be due heterogeneous nature of the earth crust and the fact that single point value was applied to the whole elevation data. The slope of the curve (M=0.5147) infers that the weathered layer thickness (Y) is a little more than half of the elevation of the point on thesurface.

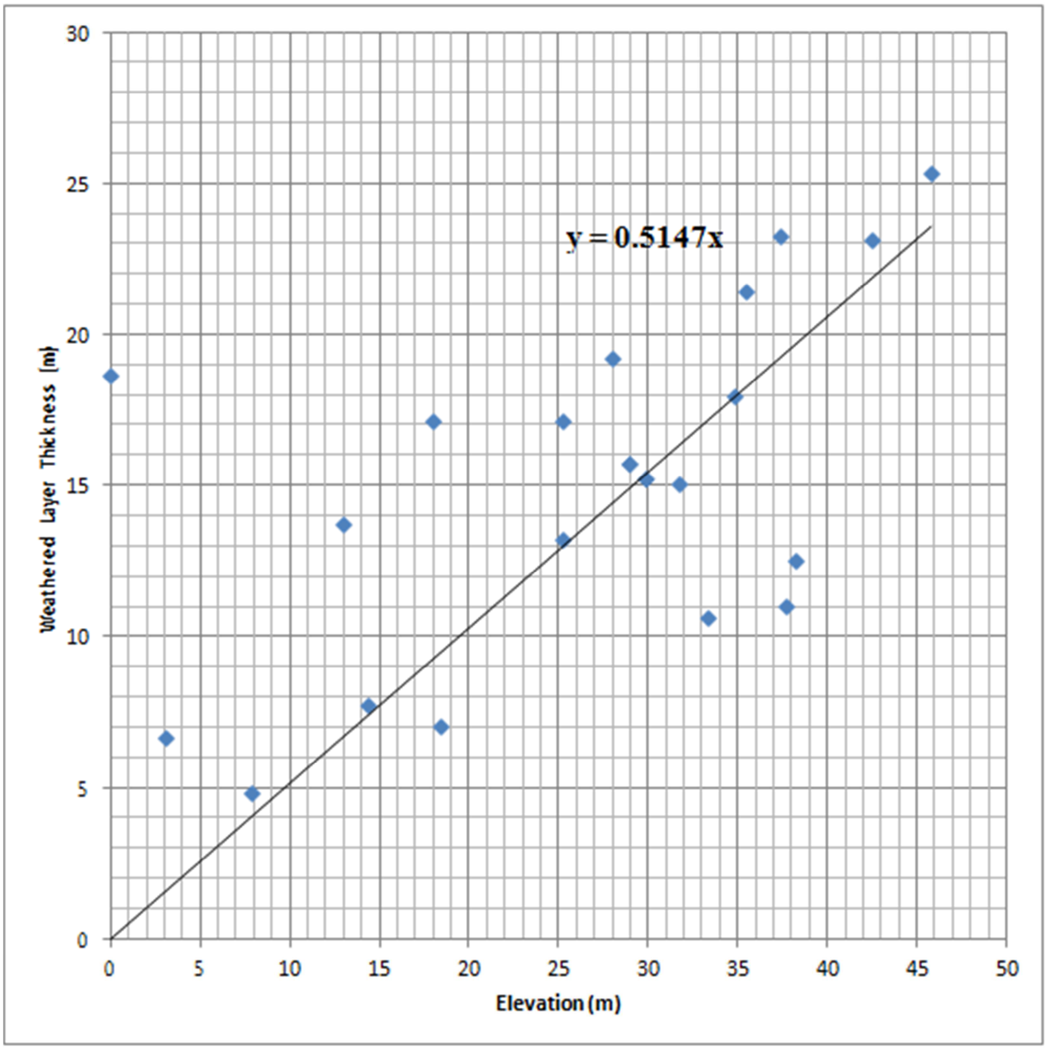

Figure 8. *Linear Regression Curve between Elevation and Low Velocity (Weathered) Layer.*

Based on the analysis of elevation on shot quality at 21m depth and the regression analysis, a model of expected quality of shots was generated. Digital elevation model of the entire prospect area has shown that the elevation of the area is undulating in the southern part of the area with a range from 8m to 76m. Analysis of elevation classification in this research shows that shot qualities change at two major elevation values of 18m and 30m for “Good”to“Fair” and “Fair”to“Weak” respectively. Figure 9 represents the shot quality prediction on elevation basis and it shows that between elevations 0m to 18m (Good Shot) covers an area 33.25Km^2 representing 6.33% of the prospect area, 19m-30m (Fair Shots) covers 124.18 Km^2 representing 23.7% of the prospect area while 31m-76m (Weak shots) has the highest area coverage of almost 70% of prospect area. The implication according to this research is that at 21m explosive depth, 70% of the shot that will be recorded will be weak as a result reducing the quality of seismic data to be acquired. There is need to review this depth in order not to compromise the quality of data.

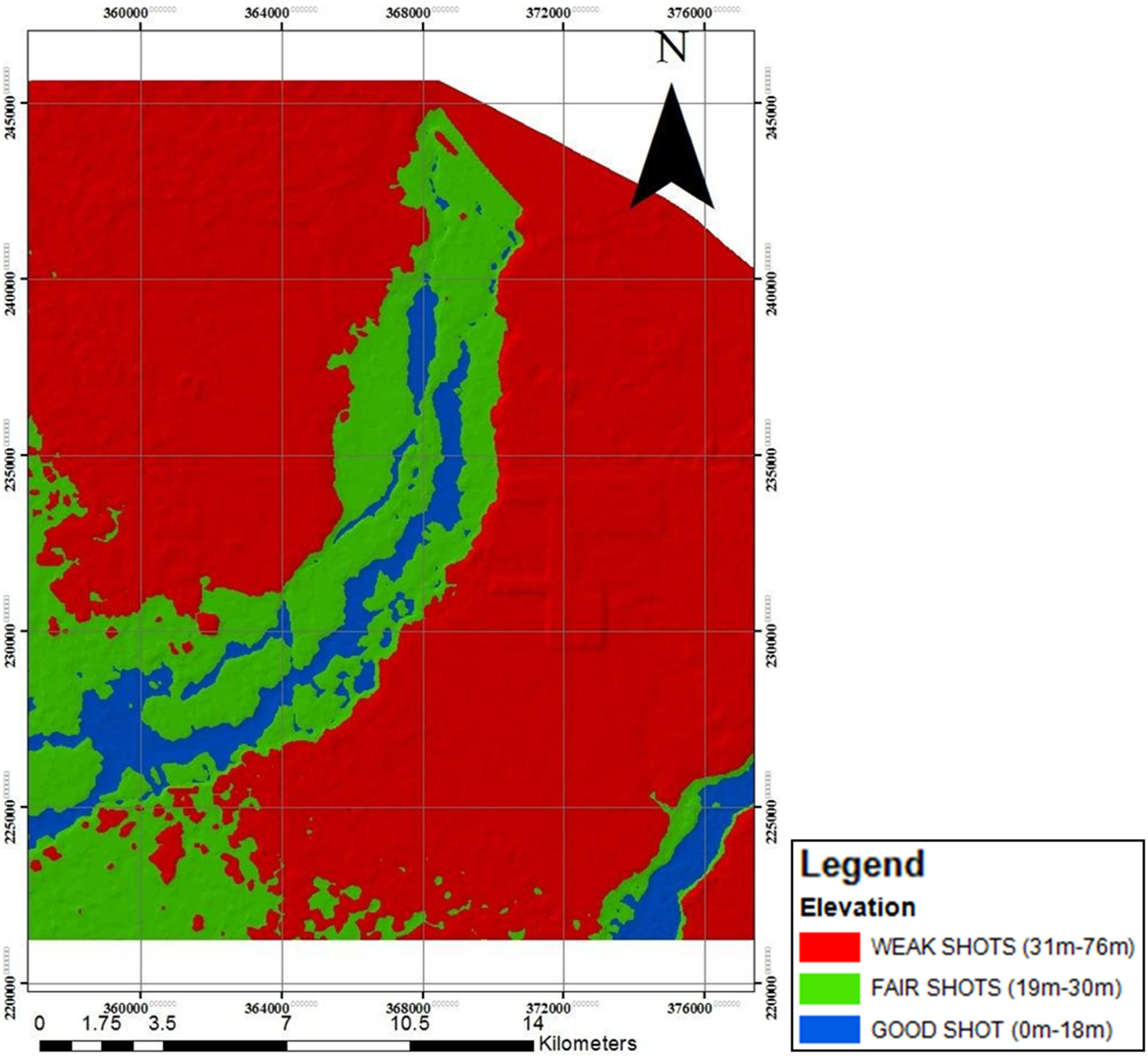

Figure 9. *Map of the Study Area Showing the Expected Quality of Shots at 21m SDH depth based on Elevation classification.*

Furthermore, composite analysis constituting DEM, ISOPACH and Spatial distribution of Shot Quality within the 3 swaths under consideration for the parameters reveals that high LVL thickness and elevation values are consequently returning low quality of shots which can be related to the fact that 21m depth of SDH at such points will still be within the weathered layer. Four (4) categories of relationships were identified among the three (3) parameters (i.e. elevation, weathered layer thickness and quality of shot) as follows;

i. High elevation and high weathered layer thickness as categoryA, gave predominantly bad shots.
ii. Low elevation and high weathered layer thickness as categoryB, gave predominantly fair shots
iii. High elevation and low weathered layer thickness as categoryC, gave predominantly fair shots
iv. Low elevation and low weathered layer thickness as categoryD, gave predominantly good shots.

Therefore better quality seismic data centers on establishing source below the LVL which can be pre-determined with the elevation model in this work for adequate depth of SDH to bedeployed.

5. Conclusion

In this research work, elevation and weathered layer thickness are proven to have effects on the quality of shots and return of seismic signal based on the analysis carried out in this research work. High elevations mostly coincide with high overburden thickness and vice versa inferring some certain degree of relationship existing between the two parameters as shown in the regression model.

The regression model further established a relationship between these parameters (within the context of same geologic environment and inhomogeneity) hence in the event of unavailability of uphole analysis, the DEM can guide in to estimate the weathered layer thickness if they have similar geologic setting with the study area. The adequate depth can be decided upon with the DEM in addition to gravity and magnetic geophysical survey in order to acquire quality data for better oil and gas exploration.

The effect of explosive host formation could not be clearly determined in this research but the analysis revealed that LVL thickness affects the quality of shot with respect to the SDH depth deployed. Based on the outcome of the experimental shot in this study and the range of elevation of the whole prospect a 30m depth hole would have turned out better quality seismic data at an economically reasonable cost. Recent improvement in resolution of data acquisition methods give rise to higher resolution images and more precision in interpretation and therefore recommended for further studies.

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