

Comparison of the Characteristics of Low Velocity Layer (LVL) in the Mangrove Swamp and in the Upper Flood Plain Environments in the Niger Delta, using Seismic Refraction Methods

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Abstract

Sixteen (16) surface-laid-geophones and fourteen (14) downhole-laid-hydrophones experiments were conducted in Upper Flood Plain and in Mangrove Swamp areas respectively in parts of the Niger Delta. The aim is to compare low-velocity-layer (LVL) characteristics in the two environments. The velocity and depth of the weathered layer and those of the consolidated layers were calculated using depth-time plots. The interpreted data showed a substantial variation of the weathered layer thickness and elevation in the two study areas. In the Upper Flood Plain, LVL thickness varies between 2.8 m and 40 m with an average of 21.46 m. In the Mangrove Swamp, the thickness varies between 2.0 m and 5.5 m with an average of 3.40 m. The weathered layer thickness in the Mangrove Swamp is fairly uniform having an average of 3.4 m. This highly variable LVL thickness indicates the necessity of correcting for this layer during seismic reflection processing.

A close study of the results reveals a thickening of the weathered layer northwards accompanying the increase in elevation. Elevations in Upper Flood Plain vary between 3.4 m and 156 m with average of 69.90 m; the elevations in Mangrove Swamp vary between -0.10 m (sub-sea) and 0.4 m with an average -0.0043 m implying that the topography of the Mangrove Swampy area is highly variable and undulated. The weathered layer velocity in the Upper Flood Plain varies between 313.67 ms⁻¹ and 984 ms⁻¹ with average of 438.80 ms⁻¹. In the Mangrove Swamp, weathered layer velocity varies between 294.5 ms⁻¹ and 863 ms⁻¹ with average of 524.10 ms⁻¹. The average velocities of the underlying consolidate layer in the Upper Flood and Mangrove Swamp are 1753.28 ms⁻¹ and 1603.51 ms⁻¹ respectively depicting a general increase in the velocity with amount of consolidation of the bedrock in the two areas. Analysis of the velocity spectra suggests that low air-blast velocity, of the order of laboratory velocity of sound in air of 343 ms⁻¹ at 20°C resulting from direct blast waves could have been drawn in. For the dry Upper Flood Plain and moist-laden Mangrove Swamp, the air-blast velocities are 346.80 ms⁻¹ and 539.70 ms⁻¹ respectively at 27°C which is the average atmospheric temperature in the Niger Delta. The results of this work compare closely with those of Uko et al., Eze and Okwueze, Enikanselu, Lazzari et al., Ibogboekwe and Ohaegbuchu, and Ofomola who worked on LVL characteristic in different environments in the Niger Delta. The results of this work can be used for static correction in seismic processing, for planning and assessing risk for engineering structures, and for groundwater exploration.

Keywords: Geophones; Hydrophones; Near-surface; Mangrove swamp; Flood plain; Seismic refraction; Time-offset depth-velocity conversions

Introduction

Seismic exploration involves the generation, detection, analysis and interpretation of elastic waves in the earth to study the sub-surface properties of the earth. A seismic section or profile should represent accurately the configuration of the subsurface. But due to topography and near-surface irregularities and other factors, this is not so. One of the factors is the weathered zone, otherwise called the low velocity layer (LVL) or weathered layer. This portion of Earth affects and is impacted by various human activities such as building, excavating, tunnelling, storing or accidentally releasing hazardous materials. Moreover many of the planet's minerals, groundwater, and cultural resources are located in the uppermost subsurface layers [1-10].

This layer effectively slows down the propagation of seismic waves through the earth and hence increases their travel times. This can lead to erroneous depth predictions of structures during final interpretation of seismic sections and reflections may appear deeper than they actually are [11,12]. In seismic reflection work, one very important method in eliminating this problem is the application of static corrections. But before static corrections can be determined and applied, the LVL characteristics of velocity, thickness of the LVL and its elevation must be known and thus incorporated into the processing programme

of seismic reflection data. The aims of this research are, therefore, to determine the LVL characteristics of thickness, weathering velocities and the consolidated layer velocities in the Upper Flood Plain and the Mangrove Swamp areas in the Niger Delta, and to make a comparison between these characteristics in the two zones. The study is of high significance in the sense that the computed results from the LVL can be used in static, elevation and dynamic corrections in reflection seismic survey [4,13] in water exploration [2]. The LVL characteristics can also be used in foundation studies for the design and construction of roads, bridges, high-rise buildings and dams [5].

Theoretical background

The weathered layer or low-velocity-layer: The weathered layer

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is the topmost layer of the earth's surface. It should not be confused with geologic weathering although it is often the result of it. For weathered or low velocity layer, seismic velocities which are lower than the velocity in the underlying consolidated layer imply that gas (air or methane resulting from the decomposition of vegetation) fills at least some of the pore space. This layer is usually made up of loose unconsolidated sedimentary materials although igneous, metamorphic, and consolidated sedimentary outcrops can have a weathered layer due to exfoliation and dilatation. Moreover, this layer, which is usually 4 to 60 m thick, is characterized by low seismic velocities which are not only low (250 and 1000 m/sec) but at times highly variable [2,6]. Velocities within the weathered layer vary both vertically and laterally.

The importance of the low velocity layer is four fold [14]: (1) the absorption of seismic energy is high in this zone causing false structures. It is therefore essential that the effects of the weathered layer be eliminated from the records, (2) the low velocity and the rapid changes in velocity have a disproportionately large effect on travel-times. Shooting in the weathering layer results in low energy penetration of the sub-surface for a given source energy level and also excites a greater proportion of boundary waves. These effects degrade the signal-to noise ratio of the resulting recording. Because of this, it is preferably economical to shoot beneath the weathering layer when possible, (3) the marked velocity change at the base of the LVL sharply bends seismic rays so that their travel through the LVL is nearly vertical regardless of their direction of travel beneath the LVL, and (4) the very high impedance contrast at the base of the LVL makes it even an excellent reflector, important in the generation of multiples (at the base

of the layer). Shots taken in this layer tend to be of low frequencies because the layer is capable of absorbing high frequency signals and releasing lower frequency ones. Since higher frequency signals contain more information on the subsurface, it is appropriate that in order to acquire good quality reflection data, shots have to be taken below the weathering layer. Because of the first factor, records from shots in this layer often are of poor quality and efforts are made to locate the shot below the LVL.

Surface-laid-detectors refraction method: Surface-laid-detectors refraction method is a technique to map near-surface geologic structure by using head waves that are detected by surface-planted geophone detectors. The source/shot point is close to the surface. Head waves from the source enter a high-velocity medium refractor at critical angle and travel in the high-velocity medium nearly parallel to the refractor surface and are detected by the surface-laid geophones. The objective is to determine the arrival times of the head waves to the refractors [7,8]. The velocity of seismic waves within overburden and rock layers is controlled by the important parameters of elasticity and density. The ground is generally assumed homogenous in its elastic properties, and its velocity will therefore vary both vertically (with depth) and laterally.

For a two-layer medium in which the energy is located at a depth of D_s in the first weathered layer and sub weathered layer [D_1] (Figure 1), the thickness of the first weathered layer (D_o) is given by Dobrin, Uko et al., [2,15]:

$$D_o = \frac{t_1}{2} \frac{v_0 v_1}{(v_1^2 - v_0^2)^{\frac{1}{2}}} + \frac{D_s}{2} \quad (1)$$

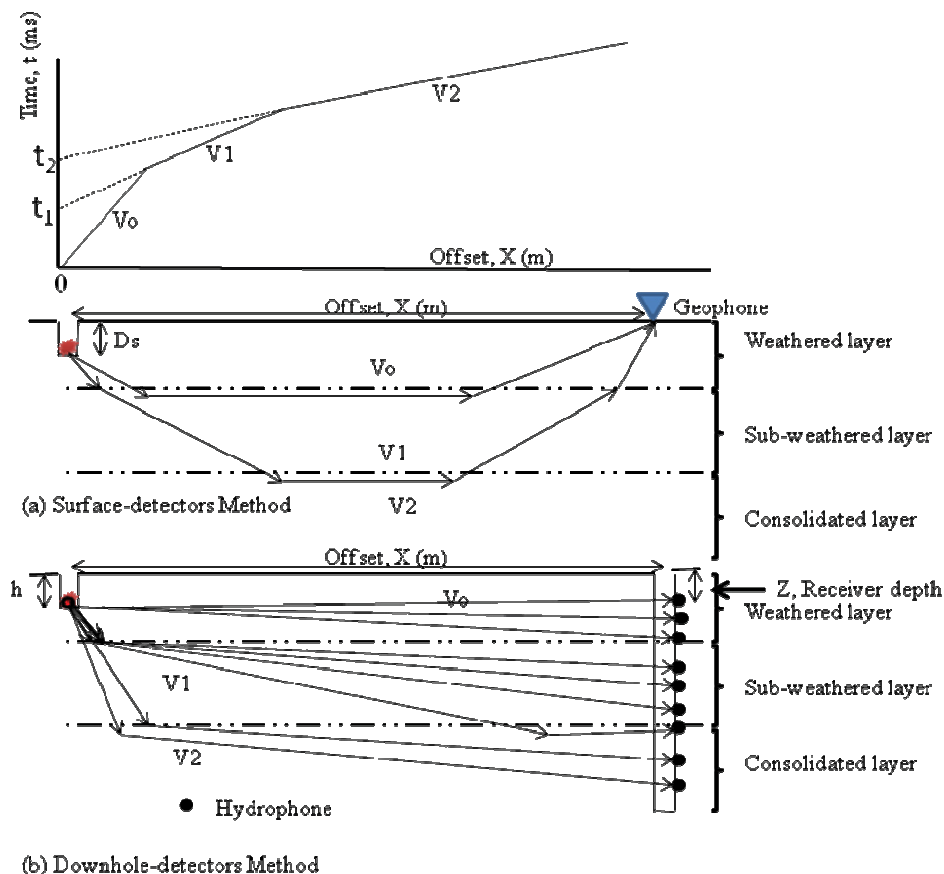


Figure 1: Schematic raypaths and travelttime graph for a two-layer model. Raypaths are exaggerated near the boundaries to separate the ray from the boundary.

$$D_1 = \left\{ t_2 - \frac{2D_o(v_2^2 - v_0^2)^{\frac{1}{2}}}{v_0 v_2} \right\} \frac{v_1 v_2}{2(v_2^2 - v_1^2)} \quad (2)$$

where t_1 and t_2 are the intercept times on the time-distance graph, and v_0 is the velocity of the first weathered layer. The velocities of the sub-weathered and consolidated layers are v_1 and v_2 respectively, and the sum of D_o and D_1 is the total thickness (D_w) of the weathered layer. For the derivation of these equations, the following assumptions were made. Seismic wave travels along straight raypaths with velocities that are constant within each layer that is isotropic and homogenous. The layers are horizontal bedding, velocity increases with depth, and only P-wave is considered. The recorded travel-time data may be interpreted by the use of graphical method.

Downhole-laid-detectors refraction methods: The features of the down hole include source/shot point is close to the surface; array of hydrophone-detectors are down the hole [3]. The hole is normally filled with water. In the early 1980s in Nigeria, the practice was to fire shots at various depths in the borehole beginning at the bottom and continuing upwards until the shot is just below the surface of the ground. The field challenge faced ranged from borehole wall collapses after some shots are taken at depth to shot-misfires. This results in the borehole caving-in and blocking the hole. Consequently, there are downtimes and extra costs in re-drilling new holes. Now an array of hydrophone receivers is fixed in the hole as shown in Figure 1. Uko et al. [16] observed that there exists a 7-18% difference between the velocities determined by the surface-wave and downhole methods. The surface-wave method gives spatially averaged velocities along the line of traverse coincident with the geophone spread. Downhole technique is mainly used in marshy swampy terrains where geophones planting become a problem that could lead noisy or dead traces for poor planting. In the case of downhole seismic method, velocities are specifically applicable only to the borehole location. The implication is that downhole measurements can be adversely affected by the local borehole factors and conditions resulting from plastic casings and excessive collapse around the flushed-zone of the borehole [16].

Measurements of arrival times of the seismic pulses to the

geophones at various depths give the velocity of the propagation of pulse in the ground. Since the elastic properties of the layer are assumed homogenous generally, the velocity of the ground motion will therefore vary both with depth and horizontal distance.

For a source depth of h , an offset of X , the vertical velocity t_v corrected for the source depth is [3]:

$$t_v = \frac{t_s(h-Z)}{\left\{ \left(\frac{hX - ZX}{h} \right)^2 + (h-Z)^2 \right\}^{\frac{1}{2}}} \quad (3)$$

where Z is the respective receiver depths, h is the source depth, X is the offset, t_s is travel time for slant path (the raw time picked from the seismogram). The velocities were computed from the reciprocals of the slopes of the straight-line segments based on the thickness equation, t_i is the intercept time.

Location, geology and geomorphology of study areas

The Niger delta is located at the southern end of Nigeria. It is a constructive lobate-arcuate delta situated between latitudes 4° - 6° N and longitudes 4° - 9° E (Figure 2). It covers a geographical area of 259,000 km² [17]. Its subaerial encompasses about 75,000 km² and extends 300 km from apex to mouth. It is predominantly a savannah covered lowland covering over a million square kilometres [18]. The basin is bounded on the south by the Atlantic Ocean, on the west by the Benin flank, on the north by the Anambra Embankment and the Abakaliki Anticlinorium and on the east by the Calabar Flank (Figure 2). The geology of the Niger Delta is only known through the numerous subsurface data acquired during oil prospecting. The history and structure of the Niger Delta are relatively known through several syntheses [19-22].

The survey areas (Figure 3) are parts of the Niger Delta complex which generally indicates beds of fine to coarse and typical of fluvial channel deposits. The areas are composed of mainly two distinct lithological formations: Quaternary Deltaic plain (upper and lower) and Tertiary Benin and Ameki Formations. The Deltaic plain is made up of units consisting of coarse to medium grained unconsolidated sands, forming lenticular beds with intercalations of peaty matter and

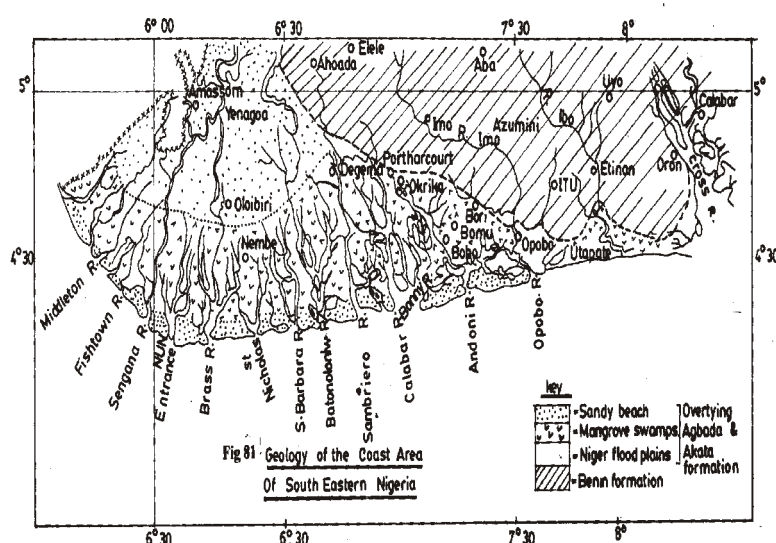
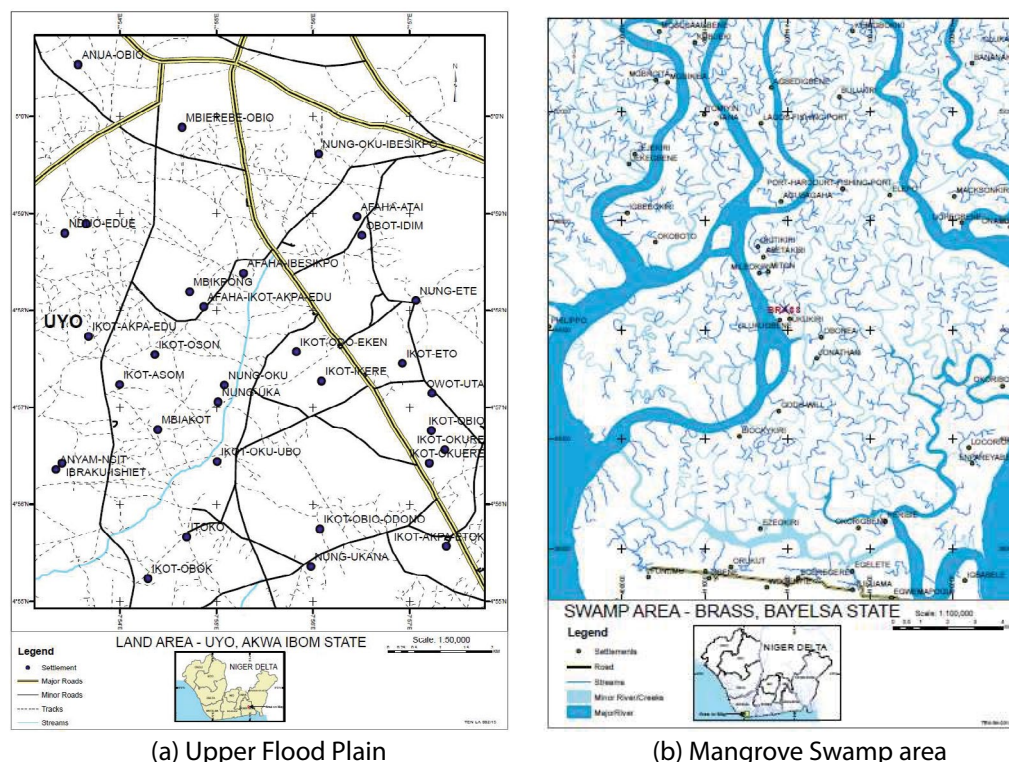


Figure 2: Geology of the Coast Area of South Eastern Nigeria.



(a) Upper Flood Plain

(b) Mangrove Swamp area

Figure 3: Map of the Upper Flood Plain and Mangrove Swamp areas.

lenses of soft, silt clay and shale. The lower most (Akata formation) is composed of uniform shale grading upwards to grey sandy silt shale [19-22].

It often contains sandstone lenses near the contact with the overlying (Agbada formation) and attains a minimum thickness of 1200 m [18,20]. The Agbada formation consists of upper predominantly sandy unit, minor shale intercalations and a lower unit which is thicker than the upper sandy unit. The sandy beds of the formation form prolific aquifers. The high permeability of the Benin formation, the overlying lateritic red earth and weathered top of the formation as well as the underlying clay-shale member of the Bende-Ameki and Ogwashi-Asaba series provide the hydrologic conditions favoring aquifer formation in the area.

Gravelly beds up to 9 m thick were reported by Amechi [23]. The top sediments are aerated unconsolidated sandstones and have a highly variable thickness throughout the region. This formation consists of sands, clay, lignite, peat and some granular gravel. The clay strata in this formation are of varying thickness from 3 m to 10 m. The sands and sandstone are coarse grained, gravelly and locally fine grained [24]. They range in color from white to yellowish brown. The high yielding permeable Benin formation, the overlying lateritic red earth and weathered top of the formation as well as the underlying clay-shale member of the Bende-Ameki series provide the hydrologic conditions favoring aquifer formation in the area. Generally, the sediments in the Niger Delta range in age from Paleocene to recent [18,20].

The climate of the study area is tropical and dominated by two main seasons: the dry and rainy seasons. Average mean annual rainfall is over 2400 mm and according to hydro-geological studies over 40% of this infiltrate and recharge groundwater [25]. The soil profile is remarkably

uniform throughout the area. Approximately, the whole areas consist of deeply weathered and intensely leached soil. The heavy rainfall coupled with the drainage nature of the sub soil is conducive for the high infiltration of rain water.

The proximity of Nigeria to the equator is responsible for the general high temperature. A mean annual temperature of 27°C is recorded in part of the Niger Delta Region. Minimum temperatures in the coastal states are highest in February, March and April and lowest in January and August. Relative humidity near the coast is about 80% to 100% at dawn and 70 to 80% in early afternoon at maximum temperature.

The vegetation cover is thick mangrove in a very swampy environment. Generally speaking, the topography of the Benin formation is flat lying with the greatest height not exceeding 180 m above sea level. The ground level however, slopes gently towards the Niger River flood plains, being directed mainly by the Cross, Imo, Kwaibo and Sambrario River systems. The vegetation is typically tropical rain forest.

Materials and Methods

In the downhole detector array method, hydrophone spread consisting of 24 hydrophones at specified interval was lowered into a hole drilled to 66 m deep. The drilling was by manual rotary method using steel pipes. Water and drilling mud were employed during drilling PVC casings were installed after the drilling was completed. This was to prevent the collapse of the hole. The hydrophone spread was then lowered into the hole. A heavy metal weight was attached to the end of the hydrophone spread to enhance the stability of the spread in the hole and to confirm that the spread reaches the bottom of the hole.

The hydrophones were spaced from the surface and were linked

with an electrical cable to the recording instrument. Energy source was 0.2 kg dynamite charge buried 1.5 m deep beneath the earth surface from an offset distance of 5 m from the downhole position. The charge was electrically controlled and recorded by the McSeis-160MX recording instrument. The observed travel times resulted in first breaks as shown in a sample of the monitor record. The picked travel times were corrected to account for the 5 m offset distance from the seismic source to the borehole head. This correction approximates as though the data were recorded with the seismic source placed exactly at the borehole head. The velocities and the LVL thickness were determined from the corrected travel times.

The field set-up of the survey for surface detectors, a spread of 12 geophones was planted on the earth's surface. Shots of 0.2 kg dynamite charge were exploded from offsets of 5 m. The average results for both direct and reverse shots represent the velocity structure of the location. The monitor records were first edited for dead and noisy traces. The arrival times were picked from the traces of the monitor records and used to compute the velocities, using Equation 3.

Results and Discussion

The sample monitor records for the two areas are shown in Figures 4 and 5. The computed elevations, velocities and LVL thickness are presented in Tables 1 and 2. Figures 6 and 7 show typical time-offset (T-X) profiles in Upper Flood Plain and Mangrove Swamp respectively. The velocity of the weathered zone was calculated from the reciprocals of the slopes of the various line segments of the plots using Equations 1 and 2 above. The computed thicknesses, velocities were used for interpretation. The interpreted data showed a substantial variation of the weathered layer thickness and elevation in the two study areas. In the Upper Flood Plain, thickness varies between 2.8 m and 40 m with an average of 21.46 m, while in the Mangrove Swamp, the thickness varies between 2.0 m and 5.2 m with an average of 3.40 m. This highly variable thickness indicates the necessity of correcting for this layer during seismic reflection exploration.

Elevations in the two areas were also compared. In the Upper Flood Plain, elevation varies between 3.4 m and 156 m with average

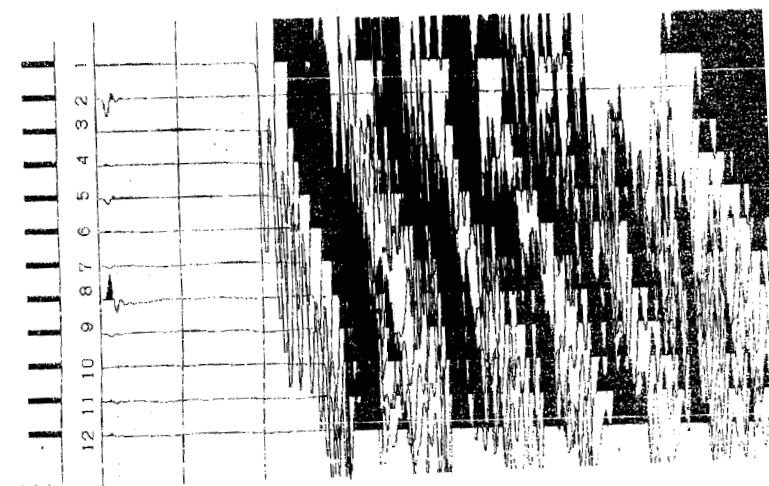


Figure 4: Sample of monitor records from surface-detector shooting.

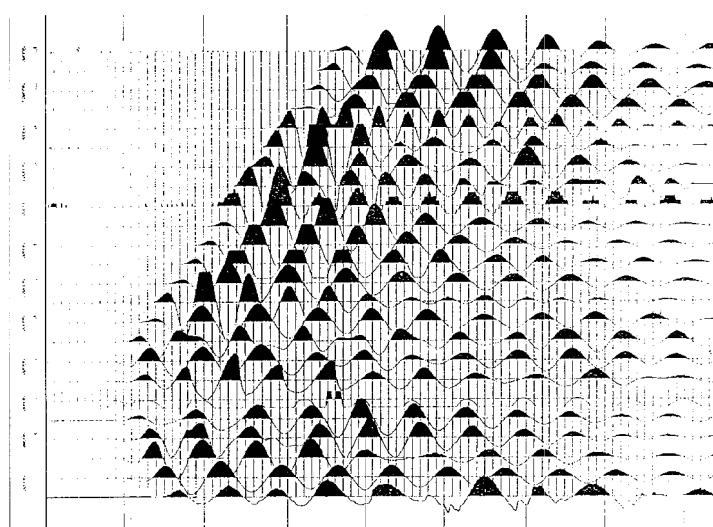


Figure 5: Sample of monitor records from downhole-detector shooting.

Station No.	Elevation (m)	Weathering Thickness, D_w (m)	Weathering Velocity, V_w (ms^{-1})	Consolidated velocity, V (ms^{-1})
1	7.90	5.20	477.00	1636.30
2	9.00	6.80	308.30	1892.50
3	3.70	4.50	494.60	1769.60
4	3.40	5.40	984.90	1801.00
5	3.80	5.20	510.90	1663.70
6	5.80	2.80	592.90	1602.50
7	4.70	3.40	492.20	1791.80
8	103.00	40.00	368.00	1819.00
9	111.00	17.50	346.83	1771.00
10	116.00	38.00	377.00	1732.00
11	156.00	40.00	353.00	1776.00
12	147.00	36.00	320.00	1716.00
13	129.00	40.00	362.00	1770.00
14	133.00	45.00	359.00	1760.00
15	135.00	24.00	360.50	1826.00
16	58.00	29.50	313.67	1725.00
Average	70.40	21.46	438.80	1753.28

Table 1: LVL results for Upper Food Plain area.

Station No.	Elevation (m)	Weathering Thickness, D_w (m)	Weathering Velocity, V_w (ms^{-1})	Consolidated velocity, V (ms^{-1})
1	0.4	4.0	656.8	1755.80
2	0.0	2.6	442.4	1566.50
3	0.1	4.0	520.7	1817.50
4	0.4	3.6	442.4	1502.30
5	0.2	5.1	294.5	1503.70
6	-0.50	2.0	544	1505.00
7	-0.10	5.5	417	1726.00
8	-0.10	2.4	457	1794.00
9	-1.50	2.0	727	1873.00
10	-0.10	3.0	765	1893.00
11	0.20	4.3	295	1578.00
12	0.30	3.5	349	1833.00
13	0.20	2.6	863	1889.00
14	-0.1	3.4	563	1716.00
Average	-0.043	3.40	539.70	1603.51

Table 2: LVL Results for Mangrove Swamp area.

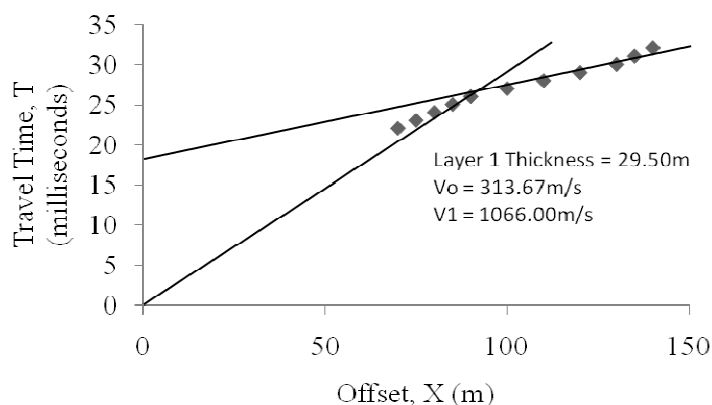


Figure 6: Sample surface-detector refraction profile in Upper Flood Plain.

of 70.40 m; the average weathered layer thickness I implying that the topography of the Swampy area is highly variable and undulated 21.46 m, while elevation in the Mangrove Swamp varies between - 0.10 m (sub-sea) and 0.4 m with average of - 0.043 m. In the Mangrove Swamp, the weathered layer thickness is fairly uniform having average

of 3.4 m. A close study of the results reveals a thickening of the weathered layer northwards accompanying the increase in elevation. The weathered layer velocity in the Upper flood Plain varies between 322.00 ms^{-1} and 984 ms^{-1} with average of 438.80 ms^{-1} . In the Mangrove Swamp, weathered layer velocity varies between 294.5 ms^{-1} and 863 ms^{-1}

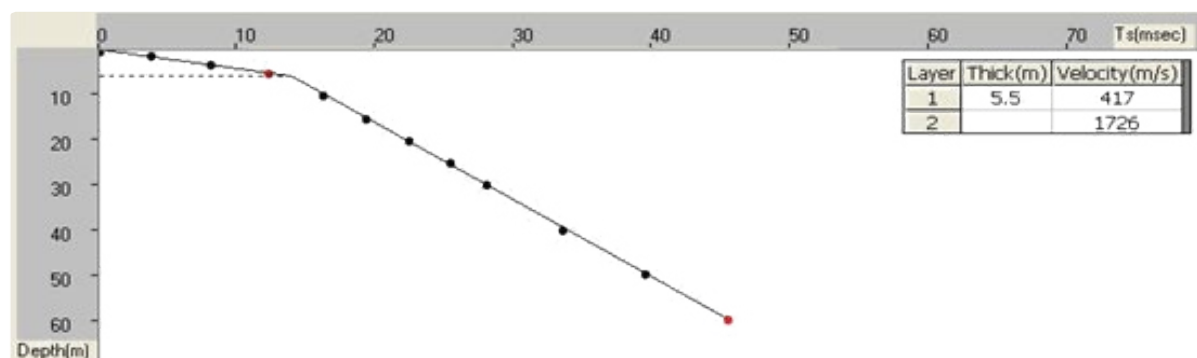


Figure 7: Sample downhole-detector refraction profile in Mangrove Swamp area.

with average of 539.70 ms^{-1} . The average velocities of the underlying consolidate layer in the Upper Flood and Mangrove Swamp are 1717.40 ms^{-1} and 1710.90 ms^{-1} respectively depicting a general increase in the velocity with amount of consolidation of the bedrock in the two areas. Analysis of the velocity spectrum suggests that low air-blast velocity, of the order of laboratory velocity of sound in air of 343 ms^{-1} at 20°C , resulting from direct blast waves could have been drawn in. For the dry Upper Flood Plain and moist-laden Mangrove Swamp, the air-blast velocities are 346.80 ms^{-1} and 539.70 ms^{-1} respectively at 27°C which is the average atmospheric temperature in the Niger Delta.

The results of this work compare closely with those of Uko et al., Eze and Okwueze, Enikanselu, Lazzari et al., Ibogboekwe and Ohaegbuchu and Ofomola [2-8] who worked on LVL characteristic in different environments in the Niger Delta. The results of this work can be used for static correction in seismic processing, for planning and assessing risk for engineering structures, and for groundwater exploration.

Conclusion

Based on analyzed results, the following conclusions are deduced for areas.

1. In the Upper Flood Plain, LVL thickness varies between 2.8 m and 40 m with an average of 21.46 m. In the Mangrove Swamp, the thickness varies between 2.0 m and 5.5 m with an average of 3.40 m. The weathered layer thickness in the Mangrove Swamp is fairly uniform having an average of 3.4 m. This highly variable thickness indicates the necessity of correcting for this layer during seismic reflection exploration. A close study of the results reveals a thickening of the weathered layer northwards accompanying the increase in elevation.
2. Elevations in Upper Flood Plain vary between 3.4 m and 156 m with average of 69.90 m; the elevations in Mangrove Swamp vary between -0.10 m (sub-sea) and 0.4 m with an average -0.0043 m implying that the topography of the Mangrove Swampy area is highly variable and undulated.
3. The weathered layer velocity in the Upper flood Plain varies between 313.67 ms^{-1} and 984 ms^{-1} with average of 438.80 ms^{-1} . In the Mangrove Swamp, weathered layer velocity varies between 294.5 ms^{-1} and 863 ms^{-1} with average of 524.10 ms^{-1} . The average velocities of the underlying consolidate layer in the Upper Flood and Mangrove Swamp are 1753.28 ms^{-1} and 1603.51 ms^{-1} respectively depicting a general increase in the velocity with amount of consolidation of the bedrock in the two areas.

4. Analysis of the velocity spectra suggests that low air-blast velocity, of the order of laboratory velocity of sound in air of 343 ms^{-1} at 20°C [1] resulting from direct blast waves could have been drawn in. For the dry Upper Flood Plain and moist-laden Mangrove Swamp, the air-blast velocities are 346.80 ms^{-1} and 539.70 ms^{-1} respectively at 27°C which is the average atmospheric temperature in the Niger Delta.
5. The results of this work are very important for static correction in seismic processing, for planning and assessing risk for engineering structures, and for groundwater exploration.

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