SITE CHARACTERIZATION USING UPHOLE SEISMIC REFRACTION TECHNIQUE IN PINDIGA, GOMBE IN NIGERIA

Asaha A. Emmanuel, Etim D. Uko, Olatunji S. Ayanninuola

Abstract

Six uphole seismic refraction profiles were acquired in Pindiga Field, Gombe in Nigeria, using seismic uphole refraction method. The aim of the study was to characterize the site of lithology, near-surface stratigraphy, and velocity for geotechnical and velocity regimes for seismic data processing. The data was recorded using Stratavisor Model NZXP Recorders, processed and interpreted using OMNI, Petrel, Landmark, UDYSIS, SeisIp, WavePack, Excel softwares. The results of the interpreted data reveal three-layer cases having dominant geologic lithologic sequences of sandstone, clay and silt, and intercalation of laterite, ironstone, coal and gravel up to a depth of 65m. The sand is an admixture of the various sizes but decarbonization is based on the size as defined by Wentworth scale of classification. In the First Weathered Layer, the velocity varies between 363ms⁻¹ and 453ms⁻¹ with an average of 391ms⁻¹. In the Second Weathered Layer, the velocity varies between 702ms⁻¹ and 870ms⁻¹ with an average of 834ms⁻¹. For the Third Weathered Layer, the velocity varies between 1012ms⁻¹ and 2104ms⁻¹ with an average of 1182ms⁻¹. In the Consolidated Layer, the velocity varies between 1012ms⁻¹ and 2104ms⁻¹ with an average of 1182ms⁻¹. Velocity regime varies between 1235ms⁻¹ and 2500ms⁻¹ with an average of 1556ms⁻¹. First Weathered Layer, the thickness varies between 2.6m and 4.7m with an average of 3.45m. Second Weathered Layer, the thickness varies between 0.9m and 41.5m with an average of 22.75m. Third Weathered Layer, the thickness varies between 12.5m and 45.9m with an average of 26.43m. The lithology, depth and velocity results of this work can be used to characterize a site, and also be applied in the processing of seismic reflection survey data.

Keywords

Weathered Layer, Up-hole, Seismic Refraction, Gombe, Nigeria

1. INTRODUCTION

Near-surface seismic optical and gas, and in determining the time delays needed for static corrections during seismic reflection data processing and in geotechnical engineering for the establishment of bedrock for foundation works in building houses, bridges, dams, and construction of highways as studied by (Akpan et al., 2018; Mbachi et al., 2019; Umoetok et al., 2019). These works are only in the Niger Delta where exploration for oil and gas had been an ongoing event. The aim of the present work is to characterize the near-surface in Bornu-Chad Basin Nigeria in terms of soil lithology, rock layer thicknesses and seismic velocities in these layers for similar applications.

The near-surface seismic properties can be used to design drilling and production programmes and in the design and construction of dams, roads, foundations for high-rise buildings and many other large construction projects in the area of study (Mbemere et al., 2018; Mbachi et al., 2019; Umoetok et al., 2019). Near-surface Velocity is used in static corrections for accurate mapping of structures in seismic reflection survey; the base of low-velocity-layer often coincides with Water table; this method can be used for groundwater exploration. Near-surface velocity and depth to bedrock information can also be applied in civil engineering for foundation works in high-rise buildings, dams, bridges, and highways (Akpan et al., 2020). Seismic velocities of rock layers are also computed using seismic reflection data (Lowrie, 1997). Seismic velocity can also be used to recognise lithology Zones of alternating sand and shale, the overall sand-shale ratio can be roughly determined by velocity (Omubo-Pepple et al., 2012). The aim of the present study is to determine lithology, near-surface stratigraphy, and velocity for geotechnical and velocity regimes for seismic data processing.

2. SITE AND ITS GEOLOGY

The Prospect area is the Kolmani South, East and North-East Prospect Field, which is located in Pindiga Town, Gombe State, Nigeria (Figure 1) in the Upper Benue Trough of Nigeria. The study area falls within the Upper Benue Trough of Nigeria. The northeastern most portion of the Benue rift structure that extends from the northern limit of the Niger Delta in the south to the southern limit of the Chad basin in the northeast (Obaje et al., 2004). This portion of the trough is made up of two arms: the Gongola Arm and the Yola Arm (although some authors have sub-divided the Upper Benue Trough to include a third central Lau-Gombe sub-basin) (Carter et al., 1965). In both arms of the basin, the Albanian Sandstone lies unconformably on the Precambrian Basement. This formation was deposited under continental conditions (fluvial, deltaic, lacustrine) and is made up of coarse to medium grained sandstones, intercalated with...
carbonaceous clays, shales, and mudstones. The Bima Sandstone was subdivided into a Lower, Middle and Upper Bima (Carter et al., 1963). The Middle Bima is reported to be shaley in most parts with some limestone intercalations and was assumed to be deposited under a more aqueous anoxic condition (lacustrine, brief marine). The Yolde Formation lies conformably on the Bima Sandstone. This formation of Cenomanian age represents the beginning of marine incursion into this part of the Benue Trough. The Middle Bima is reported to be shaley in most parts with some limestone intercalations and was assumed to be deposited under a more aqueous anoxic condition (lacustrine, brief marine). The Yolde Formation lies conformably on the Bima Sandstone. This formation of Cenomanian age represents the beginning of marine incursion into this part of the Benue Trough. The Yolde Formation was deposited under a transitional/coastal marine environment and is made up of sandstones, limestones, shales, clays and claystones. In the Gongola Arm, the laterally equivalents Gongila and Pindiga Formations and the possibly younger Fika Shale lie conformably on the Yolde Formation.

The Santonian was a period of folding and deformation in the whole of the Benue Trough. Post-folding sediments are represented by the continental Gombe Sandstone of Maastrichtian age and the Keri-Keri Formation of Tertiary age. The Gombe Sandstone is lithologically similar to the Bima Sandstone, attesting to the reestablishment of the Albian palaeoenvironmental condition. The Gombe Sandstone Formation, however, contains coal, lignite, and coaly shale intercalations which in places are very thick. The Keri-Keri Formation is made up of whitish grey sandstones, siltstones, and clay stones with the clay-stones dominating the lithology in most places (Carter et al., 1963; Benkhelil, 1982; Guiraud et al., 1990).

3. MATERIALS AND METHODS

3.1 Soil Samples Collection and Description

Each of the six (6) boreholes was drilled to 65m. Soil samples (Figure 2) were taken at the following depth intervals 0m, 1m, 2m, 3m, 4m, 5m, 7m, 10m, 15m, 20m, 25m, 30m, 35m, 40m, 45m, 50m, 55m, and 60m. The samples were described and classified using Wentworth Scale (Wentworth, 1922).

3.2 Determination of Layer Thicknesses and Velocities

The refraction recording spread consisted of a single SM4, 10Hz geophone positioned as shown in Figure 3. The holes were drilled to a depth 65m, out of which 60m was the maximum logger depth. The technique used was the down-hole receiver method with a surface energy source. This method allows for higher reliability of measurements and multiple records taken at multiple depths as the tool is pulled up gradually for the entire survey. A cylindrical weight of 5kg was attached to the end of the electrical cable with a rope to prevent loss or damage to the cable in case of hole collapse (Figure 2).
The energy source used is sledgehammer. The entire Uphole acquisition (UPH-01 – UPH-06) was carried out using the following calibrations: 0m, 1m, 2m, 3m, 4m, 5m, 7m, 10m, 15m, 20m, 25m, 30m, 35m, 40m, 45m, 50m, 55m, and 60m as receiver points. A hammer was used as the energy source and placed 3m away from the hole to obtain the first breaks. The recording parameters are shown in Table 1. The first break picks (Figure 3) were digitized and interpreted using UDISYS Version 1.0.0 software.

The thicknesses were computed automatically from the FACE programme.

For a source on earth’s surface, and receiver at depth z (Figure 3), the governing equations are:

\[ t_1 = \frac{2x(v_2^2 - v_1^2)^{1/2}}{v_1^2} \]  (1)
\[ t_2 = \frac{2x(v_3^2 - v_2^2)^{1/2}}{v_2^3} \]  (2)
\[ Z_1 = \frac{t_1v_1}{2(v_2^2 - v_1^2)^{1/2}} \]  (3)
\[ Z_2 = \frac{t_2v_2}{2(v_3^2 - v_2^2)^{1/2}} \]  (4)

where \( t_1 \) and \( t_2 \) are the intercept times; \( Z_1 \) and \( Z_2 \) are layer thicknesses; \( v_1 \), \( v_2 \), and \( v_3 \) are layers’ velocities. The velocities are computed from the reciprocals of the slopes of the straight-line segments of the graphs.

The results of the interpreted data reveal near-surface dominant geologic lithologic sequences of sandstone, clay and silt, and intercalation of laterite, ironstone, coal and gravels up to a depth of 65m (Figures 2, 4, 5, 7, 9, 11, 13, 15; Table 2). The sand is a mixture of the various sizes but demarcation is based on the size as defined by Wentworth Scale of Classification (Table 2).

### 4.2 Velocities and Layer Thicknesses

A graphical plot of surface corrected first breaks are made against corresponding depths (Figures 4, 6, 8, 10, 12, and 14) from which velocity is obtained; the inverse gradient represents the velocity while the thickness is calculated from the point of intersection of the two slopes (point of inflexion). The layer velocities and layer thicknesses are presented in Table 3. The velocity of the First Weathered Layer varies between 363ms\(^{-1}\) and 453ms\(^{-1}\) with an average of 391ms\(^{-1}\). The Second Weathered Layer velocity varies between 702ms\(^{-1}\) and 870ms\(^{-1}\) with an average of 834ms\(^{-1}\). The velocity of the Third Weathered Layer varies between 1012ms\(^{-1}\) and 2104ms\(^{-1}\) with an average of 1182ms\(^{-1}\). The sub-consolidated Layer has velocity variation of between 1012ms\(^{-1}\) and 2104ms\(^{-1}\) with an average of 1182ms\(^{-1}\). The velocity regime of the consolidated layer varies between 1235ms\(^{-1}\) and 2500ms\(^{-1}\) with an average of 1556ms\(^{-1}\).

The depths to refractors are also highly variable. The First Weathered Layer thickness varies between 2.6m and 4.7m with an average of 3.45m. The Second Weathered Layer thickness varies between 0.9m and 41.5m with an average of 22.75m. The Third Weathered Layer thickness varies between 12.5m and 45.9m with an average of 26.43m.

### Table 1: Uphole Acquisition Parameters

| Specific Parameter | Specification |
|--------------------|---------------|
| Recording System   | Stratavis NZXP |
| Source             | Iron base plate and Hammer |
| Detector Model     | SM4, 10Hz hydrophone |
| Record Length      | 512ms |
| Sample Rate        | 0.125ms |
| Offset             | 3m away from hole |

### Table 2: Core Samples descriptions from well-bore cuttings

| Depth (m) | Sample Description |
|-----------|--------------------|
| 0-10      | 98% Laterite; 02% Cobblestone. |
| 10-20     | 75% Laterite; 15% Cobblestone; 10% Pebble. |
| 20-30     | 94% Clay; 5% Silt; 1% Laterite. |
| 30-40     | 70% Clay; 10% Silt; 05% Laterite; 10% Coarse Sandstone; 05% Gravel. |
| 40-50     | 90% Clay; 10% Sandstone. |
| 50-60     | 85% Black Coal; 15% Shale. |
| 60-65     | 95% Shale; 05% Coal. |

### Figure 3: Monitor Record Printout, example.

### Figure 4: Traveltime-Offset Plot for UPH-11

### Figure 5: Lithological Log Description for Upholes UPH-11

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Table 3: Summary of Near-Surface Characteristics

| UPH Number | Layer Thickness (m) | Layer Velocity (m/s) |
|------------|---------------------|----------------------|
|            | L₁         | L₂         | L₃         | V₁         | V₂         | V₃         | V₄         |
| 11         | 3.0       | 3.2       | 29.1      | 363.0      | 702.0      | 1012.0     | 1235.0     |
| 13         | 3.0       | 3.8       | 41.2      | 400.0      | 820.0      | 891.0      | 1338.0     |
| 17         | 3.9       | 41.5      | 12.5      | 344.0      | 870.0      | 1178.0     | 2500.0     |
| 19         | 4.7       | 0.9       | 29.9      | 453.0      | 893.0      | 1109.0     | 1457.0     |
| 20         | 2.7       | 35.0      | -         | 413.0      | 860.0      | 1857.0     | -          |
| 21         | 2.6       | 22.9      | -         | 365.0      | 720.0      | 2104.0     | -          |
| 22         | 3.4       | 9.4       | 45.9      | 375.0      | 860.0      | 1045.0     | 1250.0     |
| Σ          | 20.7      | 136.5     | 158.6     | 2348.0     | 5005.0     | 7092.0     | 7780.0     |
| Average    | 3.5       | 22.8      | 26.4      | 391.3      | 834.2      | 1182.0     | 1556.0     |
5. **Conclusion**

The following conclusions are reached:

- The dominant geologic lithologic sequences of sandstone, clay and silt, and intercalation of laterite, ironstone, coal and gravels up to a depth of 65m. The sand is an admixture of the various sizes but demarcation is based on the size as define by Wentworth scale of classification.
- In the First Weathered Layer, the velocity varies between 363ms⁻¹ and 453ms⁻¹ with an average of 391ms⁻¹.
- In the second weathered layer, the velocity varies between 702ms⁻¹ and 870ms⁻¹ with an average of 834ms⁻¹.
- For the third layer, the consolidated layer, the velocity varies between 1012ms⁻¹ and 2104ms⁻¹ with an average of 1182ms⁻¹.
- Velocity regime varies between 12.35ms⁻¹ and 2500ms⁻¹ with an average of 1556ms⁻¹.
- The thickness of the first layer varies between 2.6m and 4.7m with an average of 3.45m.
- Second layer’s thickness varies between 0.9m and 4.15m with an average of 22.75m.
- The thickness of the third layer varies between 12.5m and 45.9m with an average of 26.43m.

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