Asian Journal of Applied Science and Technology (AJAST)
(Open Access Quarterly International Journal) Volume 2, Issue 3, Pages 83-93, July-September 2018

Near-surface Seismic Characteristics in Bornu-Chad Basin, Nigeria

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Article Received: 20 April 2018 *Article Accepted: 29 July 2018* *Article Published: 24 August 2018*

ABSTRACT

Uphole refraction survey was conducted in Borno-Chad Basin Nigeria, at 40 Uphole (UPH-01-UPH-40) locations, with the aim of ascertaining the low-velocity-layer (LVL) depth, velocity structure, and lithology of the near-surface layers using a single trace NZXP Stratavisor Refraction Seismograph. First break arrivals were picked and interpreted using UDISYS Version 1.0.0.0 software run on Excel Spreadsheet. The velocity and depth of the weathered layer and those of the consolidated layers were calculated using depth-time plots. The depth and velocities were contoured using Petrel software. LVL thickness varies between 2.5m and 14.8m with an average of 6.7m. The weathered layer velocity varies between 258ms-1 and 554ms-1 with average of 413ms-1. The velocities of the underlying consolidated layer vary between 1015ms-1 and 2450ms-1 with an average of 1764ms-1. Elevations vary between 280m and 290.1m with average of 284.9m. A close study of the results reveals a thinning of the weathered layer, and decreasing of elevations and velocities towards the northeast part of the study area where most parts are swampy towards Lake Chad. The dominant lithologic sequences encountered are sand, clay, and silt. The highly variable low-velocity-layer thickness is an indication of the necessity for static correction, which can be used to eliminate the effect of the low velocity layers at a regional level in the prospect. The results of this work can used for static correction in seismic processing, planning and assessing risk for engineering structures, and for groundwater exploration.

Keywords: Seismic refraction, Near-surface, Uphole, Lithology, Low-velocity-layer, Velocity, Bornu-Chad Basin, Nigeria.

1. INTRODUCTION

Near-surface seismic characteristics have become essential in the search for underground water, oil and gas. It is essential in determining the time delays needed for static corrections during seismic reflection data processing as highlighted by Akpabio and Onwusiri (2004), Eze *et al*. (2003), and in geotechnical engineering for the establishment of bedrock for foundation works in building houses, bridges, dams, and construction of highways as studied by Okwueze *et al*. (1992) and Uko *et al*. (1992). 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 characterize the near-surface in Bornu-Chad Basin Nigeria in terms of soil lithology, elevation, weathered layer and consolidated layers seismic velocities. 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.

2. GEOLOGY OF STUDY AREA

The Chad basin is situated in N-E Nigeria and extends to parts of the Republic of Niger, Chad, Sudan and the northern portions of Cameroon and Nigeria within latitudes 10^{o}N to 14^{o}N and longitudes 12^{o}E to 15^{o}E (Figure 1). The Borno Basin represents the Chad Basin in Nigeria. It is a part of the West Central African Rift System [WCAS] (Genic, 1992; Obaje *et al*., 2011; Adepelumi *et al*., 2011). The basin occupying most of Lake Chad (Fig. 1) is the largest inland basin in Africa occupying an area of approximately 2,500,000 km^2. It represents about one-tenth of the total area of the Chad Basin, and falls between latitudes 11°N and 14°N and longitudes 9°E and 14°E.

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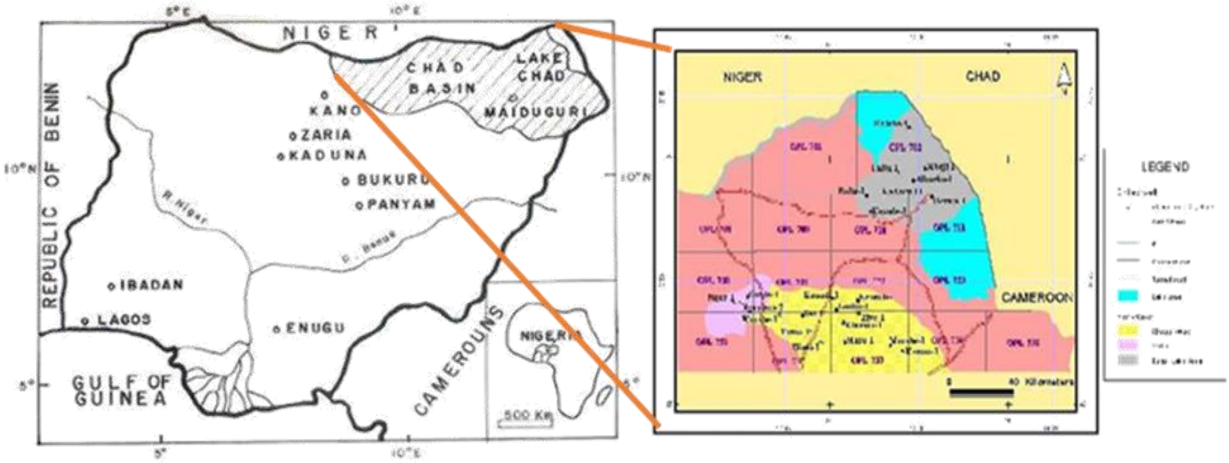

Figure 1: Map of Nigeria showing Bornu-Chad basin (Obaje *et al*., 2004).

The Borno-Chad basin Nigeria is a broad sediment-filled depression spanning north-eastern Nigeria and adjoining parts of the Republic of Chad. The stratigraphy of Borno-Chad basin has been reported by several authors (Avbovbo *et al*., 1986; Obaje, 2009; Nwachukwu and Ekine, 2009). Chad Formation is the uppermost Formation of total thickness ranging between 300 and 1200m. It consists of mudstone with traces of sandstone, muddy sandstone, sandstone, and claystone. The Chad Formation is a sequence which consists of mostly massive and gritty clays, with loosely to uncemented sands and silts. The Kerri-Kerri Formation underlies the Chad formation and consists of shale, mudstone and limestone (Carter *et al*., 1963; Petters and Ekweozor, 1982). The estuarine/deltaic deposition in northeastern Nigeria gives rise to the Gombe Formation sandstone which underlies Kerri-Kerri Formation Carter *et al.* 1963, Adegoke *et al*., 1986).

The Gongila Formation is a transitional sequence between the underlying Bima sandstone and Fika formation. The Formation consists of a sequence of sandstones, shales, clays, and limestone layers. The Fika Formation is a wholly marine sequence, consisting of a sequence of blue-black shales with one or two thin non-persistent limestone horizons, conformably overlies the Gongila. The Bima Formation, considered as the oldest stratigraphic unit consists of thin to thick beds of fine to coarse-grained sandstone of variable colour from white, brown, and reddish brown to grey (Olabode *et al*., 2015). The coarse-grained textures are more common with depth of burial. Thin bands of clay and siltstone occur as intercalations with the sandstone and vary in colour from red to grey or brown. The Bima Formation is the basal unit. The deposition of this sequence consists of sandstones, mudstones and occasional shales of variable lithology, texture, colour and structure (Matheis, 1976; Petters, 1981; Okosun, 1995).

3. THEORY OF UPHOLE SEISMIC REFRACTION METHOD

In Uphole seismic method, a deep hole is drilled, and an uphole tool, a detector cable is placed in the hole. The hole was filled with water. An energy source (hammer) placed on earth surface at an offset of 3m away from the well. A seismograph on the surface measures the arrival times of the generated sound energy to the detectors down the hole. These arrival times already corrected for the slant travel and source paths are then plotted against the detector depths. These interpretation formulas are based on the following assumptions: The model assumes a flat layer, there is no land-surface relief; each layer is homogeneous and isotropic; the seismic velocity of the layers increases with depth; intermediate layers must be of sufficient velocity contrast, thickness and lateral extent to be detected. The formula also assumes straight ray paths for the rays within the LVL. Uko *et al*. (2016) observed that velocities determined using Uphole method with detectors in borehole compares closely with that determined by the surface-detectors by 7-18% difference, which is considered to be within the resolution of the survey.

System	Series	Stage	Formation	Lithology	Average thickness/m	Thickness from seismic data/m	Outcrop Description
Quater-nary			Chad		400	800 (Average)	Variegated clays with sand interbeds
Tertiary			Kerri-Kerri		130		Iron rich sandstone and clay covered by plinth of laterite
Cretaceous	Upper	Maastrichtian	Gombe		315	0–1 000	Sandstone, siltstone and clay with coal beds. Fossils, bivalve impressions and *Cruziana lebana purren*
		Senonian	Fika		430	0–900	Shale, dark gray to black, gypsiferous with limestone beds
		Turonian	Gongila		420	0–800	Alternating sandstone and shale with limestone beds
		Cenomanian	Bima		3 050	2 000	Sandstone, gravelly to medium grained, poorly sorted and highly feldspathic
	Lower	Albian	Unnamed	? ? ?		3 600	Seismically transparent sequence, monolithologic sequence inferred
			Unnamed			0–3 000	Piedmont alluvial fans early rift sediments
Pre-cambrian			Basement				

Sandstone Shale Unconformilty

Figure 2: The Stratigraphy of the Bornu-Chad Basin (Avbovbo *et al*., 1986).

4. MATERIALS AND METHODS

4.1 *Data Collection*

The refraction recording spread consisted of a single SM4, 10Hz hydrophone positioned as shown in the harness diagram (Figure 3). The holes were drilled to a depth 65m, out of which 60m was the maximum depth of recording in most cases. In order to obtain the weathering information and velocity variation with depth of the near-surface layers, fifteen (15) uphole-spread shots in a grid of 5km x 4.8 km was adopted for the entire survey.

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 cable with a rope to prevent lost or damage to the cable in case of hole collapse (Figure 3). Measurement was taken when the cables were carried out by pulling up the cable and maintaining coverage of at a single succeeding position to the former. The energy source used is Hammer. The entire Uphole acquisition (UPH-01 – UPH-40) 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. A hammer was used as the energy source and placed 3m away from the hole to obtain the first breaks. This guarantees that the first breaks are vertical. The recording sample rate is 500μsec.

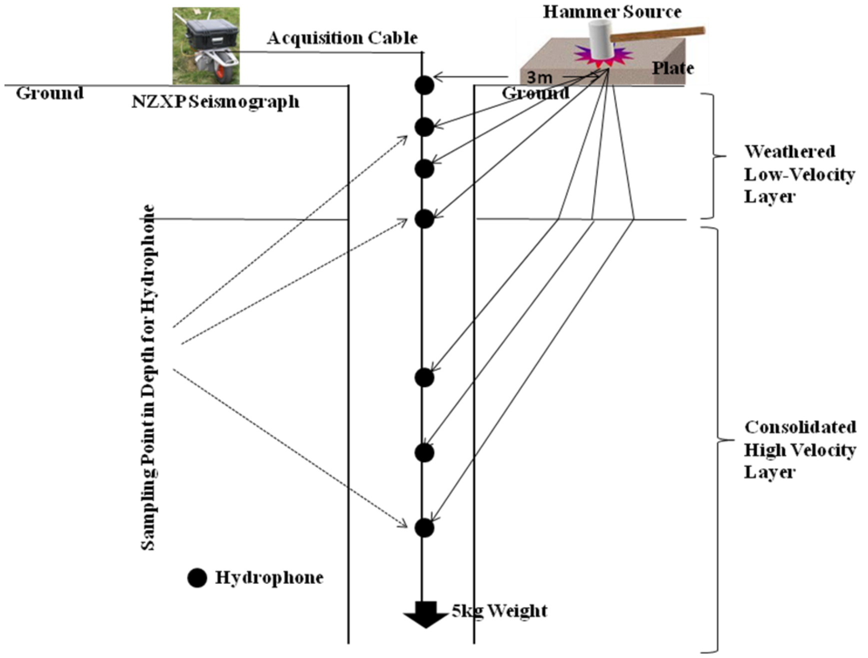

Figure 3: Schematic Diagram for Uphole (UPH) Data Acquisition

An Uphole, surface source, a cable containing one hydrophone is anchored at a given depth. NZXP strata visor refraction seismograph equipment is used to record the arriving energy at each prescribed depth. For each shot a single-trace record was produced. The first break picks were digitized and interpreted using UDISYS Version 1.0.0.0 software.

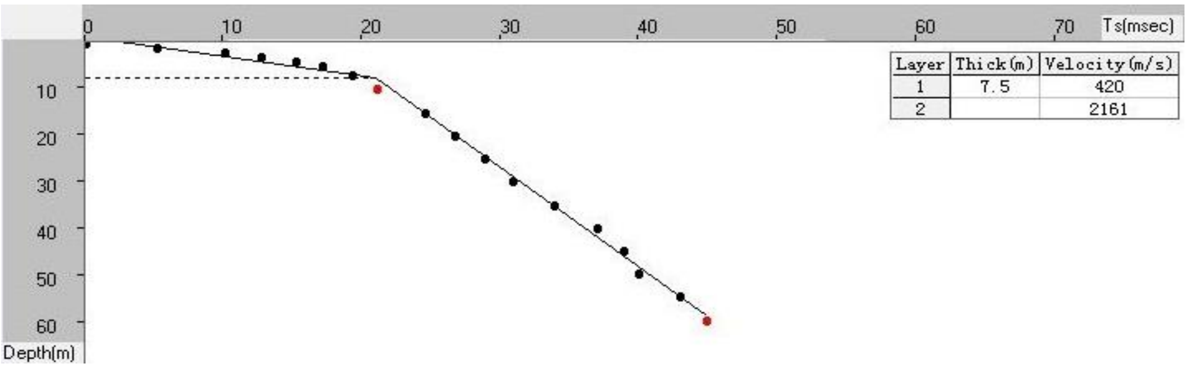

Figure 4: Example of Travel -Time (T) versus Offset (X) Crossplot

Table 1: Uphole Acquisition Parameters

Specific Parameter	Specification
Recording System	Stratavisor NZXP
Source	Iron base plate and Hammer (18pounds)
Detector Model	SM4, 10Hz hydrophone
Record Length	512ms
Sample Rate	0.125ms
Offset	3m away from hole

5. RESULTS AND DISCUSSION

Results presented in Tables 2 and 3 and Figures 5 – 9. The overall refraction and up hole results revealed two/three layer model. Generally the weathering depth ranges from 3.5 to 13.0m, weathering velocity of 235.0 – 550.0 ms^{-1}, the consolidated velocity was from 1500 – 2316ms^{-1}.

In general layer thickness and velocity decreases towards the North East part of the prospect where most area are swampy towards Lake Chad shore. The dominant lithology profile shows Sand, Silt, and Clay (Table 2).

Table 2: Example of Soil-samples Description (from well-bore cuttings)

Depth (m)	Sample Description
0-10	100% Sandstone: Fine quartz grains, colour brownish, poorly sorted.
10-20	100% Sandstone: Fine grained colour brownish, poorly sorted.
20-30	80% Sandstone: With traces of Clay.
	80% Sandstone: fine quartz grains, poorly sorted.
	20% Clay: Soft, sticky, grey colour, and not washable.
30-40	60% Sandstone: with Clay, fine grained brownish colour quartz grains.
	40% Clay: grey, soft, sticky and muddy, not washable.
40-50	100% Clay: Sticky and muddy, soft, milky colour, not washable.
50-60	100% Clay.

The sample monitor records are shown in Figure 5. The elevations, velocities and LVL thickness are presented in Tables 3. Figure 5 shows elevation trend. The velocity of the weathered zone was calculated from the reciprocals of the slopes of the various line segments of the plots.

The interpreted data showed a substantial variation of the weathered layer thickness and elevation in the study area. The thickness varies between 2.5 m and 14.8m with an average of 6.70 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. The weathered layer velocity varies between 258ms^{-1} and 554ms^{-1} with an average of 413ms^{-1}. The velocities of the underlying consolidated layer are 1015ms-1 and 2450ms^{-1} with an average of 1764ms^{-1}. This velocity variation depicts a general increase in the velocity with amount of consolidation of the bedrock in the study area. Analysis of the velocity spectrum suggests that low air-blast velocity, of the order of 337ms^{-1} resulted from direct blast waves could have been drawn in without any sacrifice in resolution.

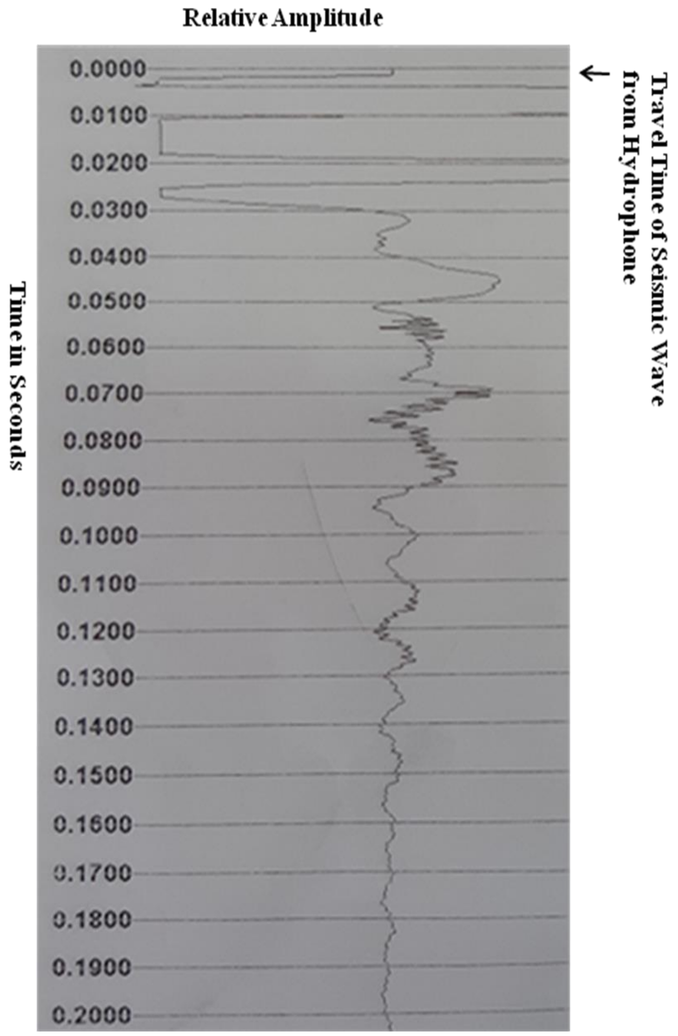

Figure 5: Typical Seismic Monitor Record from the Survey with a single Hydrophone

Table 3: Uphole data

S/N	Eastings	Northings	Elevation (m)	Weathered Layer Thickness, Z (m)	Weathered Layer Velocity, V_o (ms^{-1})	Consolidated Layer Velocity, V_1 (ms^{-1})
UPH-01	326706.1	1432429.0	287.8	7.5	420	2161.0
UPH-02	328001.4	1427600.0	290.1	5.1	297	1749.0
UPH-03	331343.9	1433670.4	289.3	6.2	472	2109.0
UPH 04	332636.5	1428839.3	289.6	8.8	450	2211.0
UPH 05	335979.9	1434911.2	287.4	6.9	457	2257.0
UPH 06	337271.9	1430082.2	288.1	9.8	495	2450.0
UPH 07	340615.3	1436149.8	291.3	10.0	421	1015.0
UPH 08	341909.6	1431325.0	287.9	7.0	389	2053.0
UPH 09	345252.3	1437394.6	284.3	14.8	554	1726.0

 Online ISSN: 2456-883X

UPH 10	346559.3	1432565.2	286.5	14.3	415	2087.0
UPH 11	349888.1	1438638.6	288.1	4.2	448	2130.0
UPH 12	351181.6	1433809.4	288	8.2	443	2242.0
UPH 13	354522.0	1439880.0	285.7	4.3	511	2302.0
UPH 14	355819.5	1435050.5	286.0	5.3	485	2308.0
UPH 15	359159.2	1441124.6	282.0	4.3	374	1922.0
UPH 16	360454.8	1436295.0	284.1	5.5	580	2309.0
UPH 17	363797.7	1442363.8	280.4	5.9	374	2279.0
UPH 18	365091.0	1437536.1	284.3	5.8	402	2090.0
UPH 19	366257.2	1433192.5	282.9	5.4	491	2251.0
UPH 20	368435.0	1443609.0	284.6	6.8	484	2188.0
UPH 21	369730.4	1438780.2	283.0	4.8	372	2004.0
UPH 22	370892.6	1434431.4	279.9	5.4	344	2081.0
UPH 23	374364.6	1440022.0	283.6	5.5	368	2095.0
UPH 24	373071.4	1444850.0	282.0	4.6	529	1909.0
UPH 25	375529.3	1435676.7	281.7	5.0	539	2027.0
UPH-26	346917.0	1440458.0	290.0	13.0	351	1441.5
UPH-27	353152.0	1440369.0	288.8	7.2	445	2316.0
UPH-28	356640.0	1443581.0	283.0	9.0	400	1698.0
UPH-29	363406.4	1443841.6	281.4	9.0	433	1852.0
UPH-30	366942.0	1446859.0	281.1	6.7	448	1889.0
UPH-31	373835.0	1446636.0	283.6	4.5	380	1270.0
UPH-32	349747.0	1443805.0	289.2	10.8	258	1976.5
UPH-33	360050.0	1447082.9	282.5	7.3	463	2121.0
UPH-34	370352.0	1450361.0	280.5	2.6	329	1728.0
UPH-35	346264.0	1447530.0	290.1	5.1	272	1984.0
UPH-36	353157.1	1447306.5	283.2	4.3	280	1478.5
UPH-37	356567.0	1450808.0	281.5	6.7	312	1632.5
UPH-38	363459.0	1450585.0	281.1	6.3	430	1685.0
UPH-39	366882.0	1454038.0	280.1	3.4	357	1750.0
UPH-40	373762.1	1453863.2	280.0	2.5	338	1770.0
		AVERAGE	284.9	6.7	415.3	1764.0

The dominant formations encountered are Sand, Clay, and Silt (Table 2). The dipping direction of the Chad formation is in a NE-SW dipping geometry. This coincided with the dominant NE-SW trending fault system in the Chad Basin.

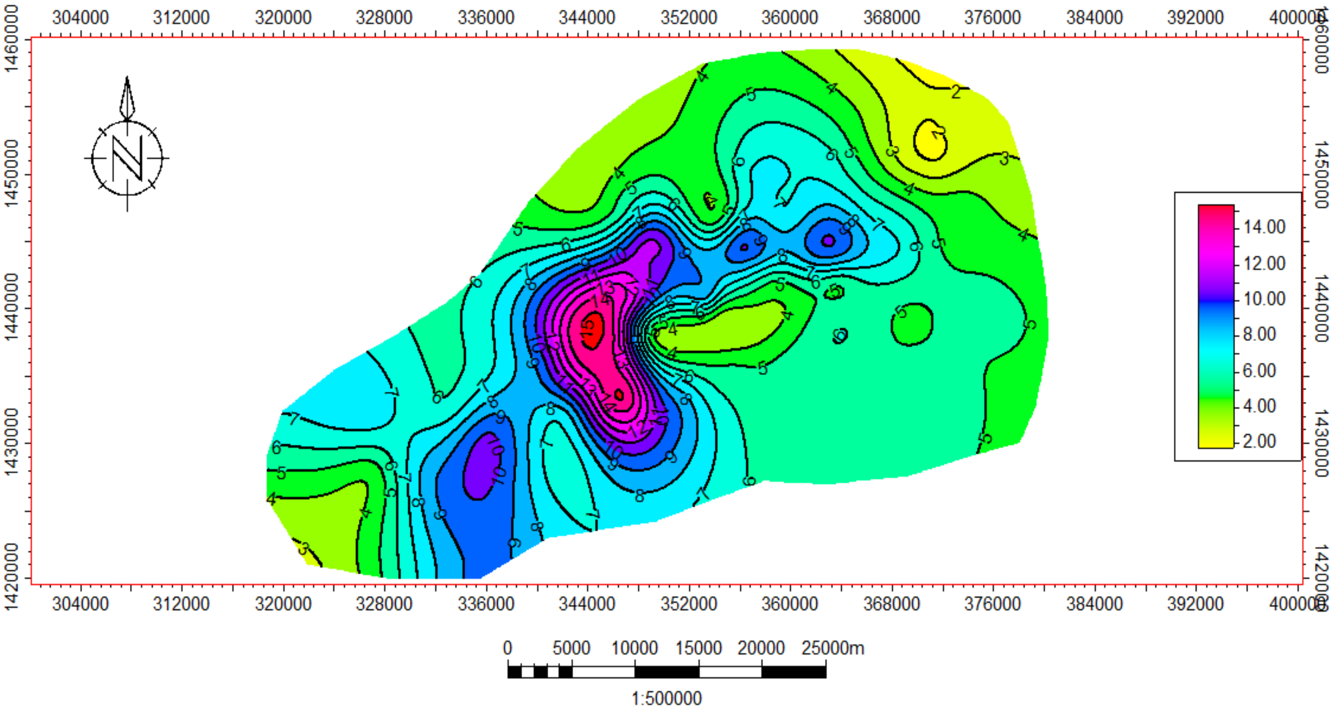

Figure 6: Weathered thickness (Z) contour map

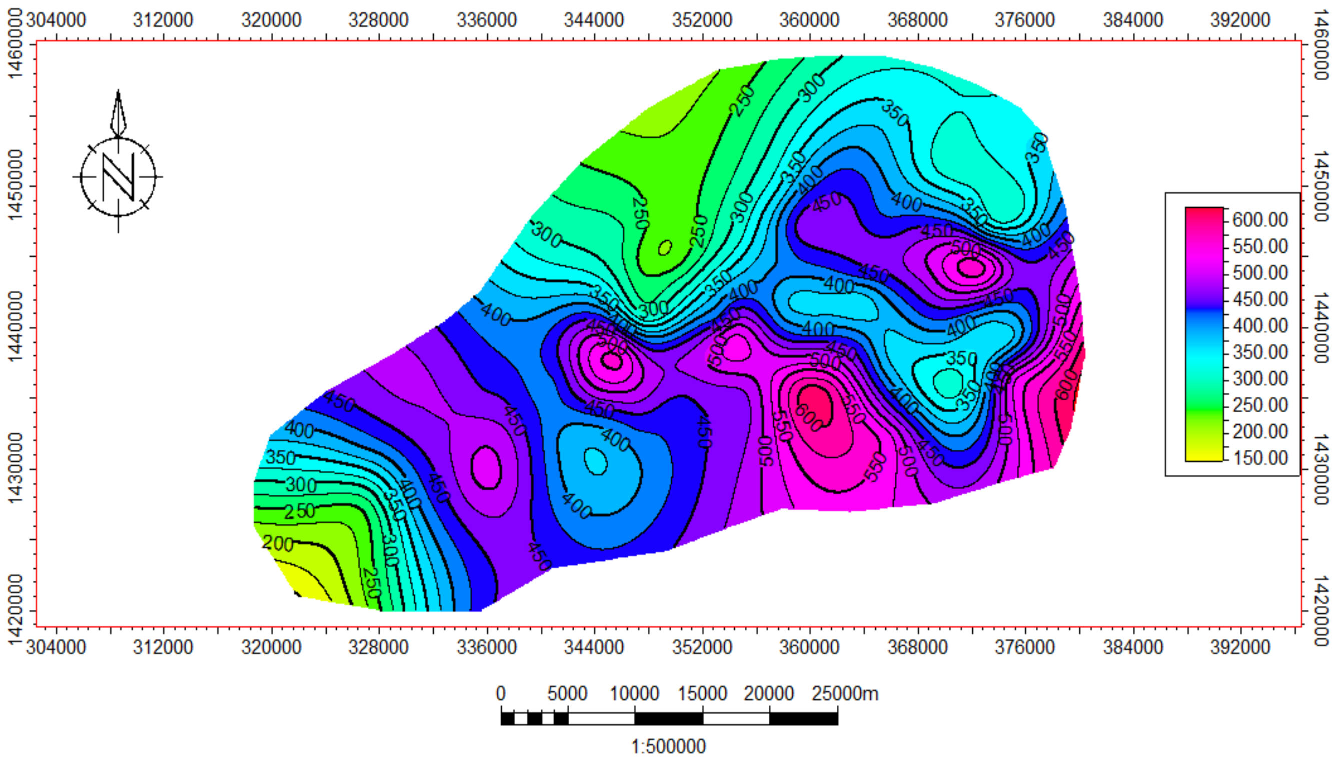

Figure 7: Weathered Layer Velocity Contour Map

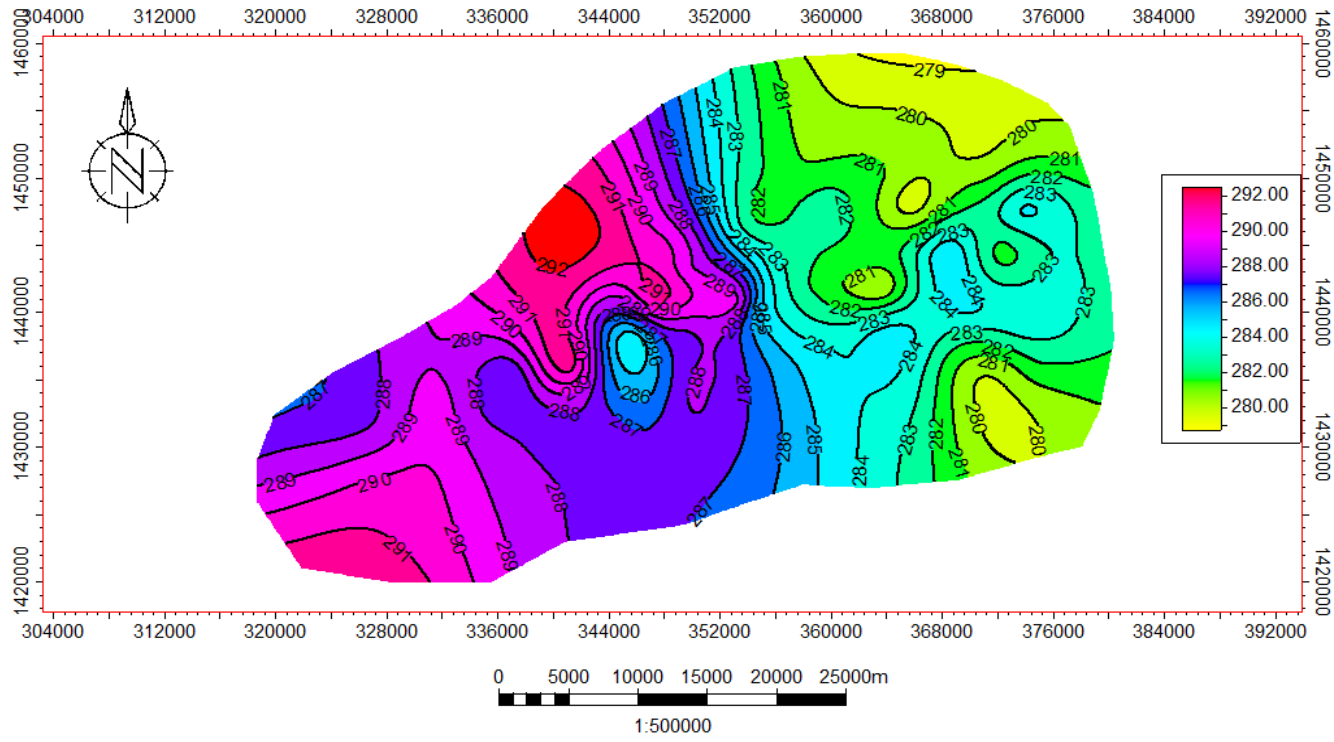

Figure 8: Elevation Contour Map

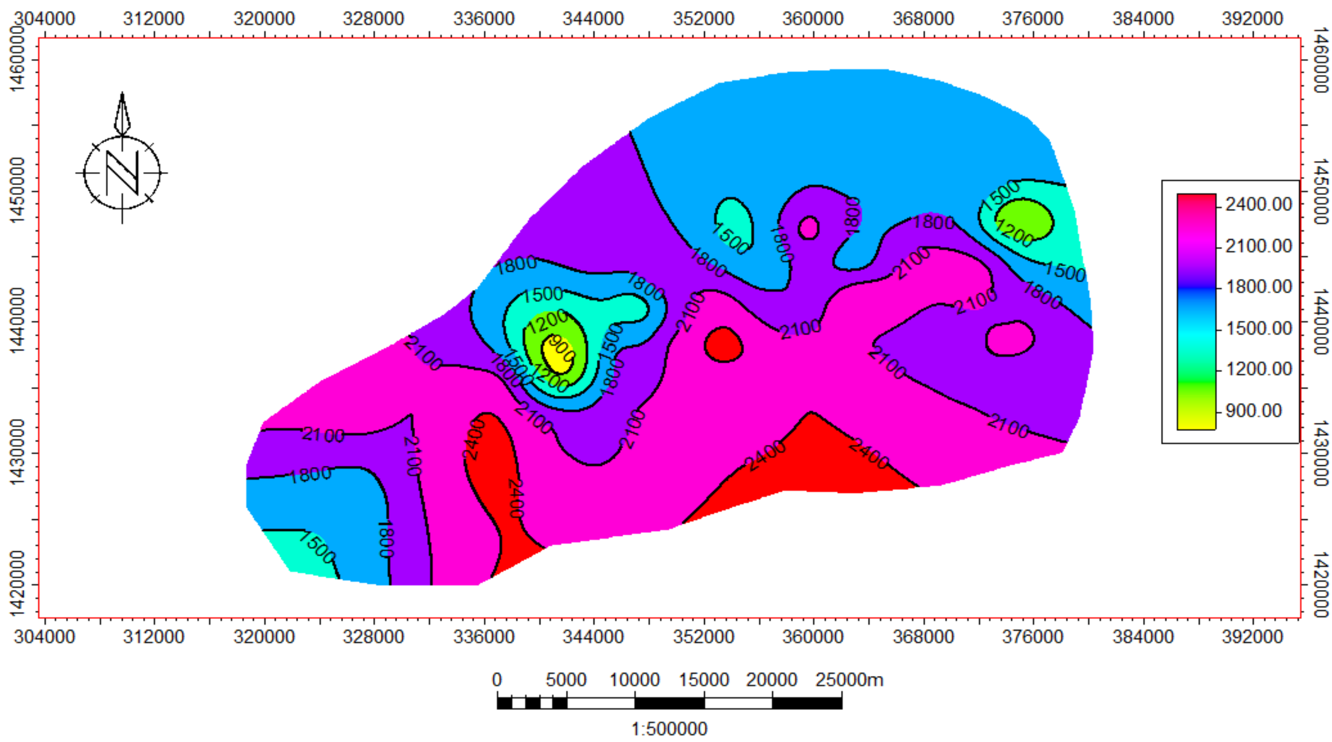

Figure 9: Consolidated Layer Velocity Contour Map

6. CONCLUSION

Based on analyzed results, the following conclusions are deduced for areas. The LVL thickness varies between 2.5m and 14.8 m with an average of 6.7m. This highly variable thickness indicates the necessity of correcting for this layer during seismic reflection exploration. A close study of the results reveals a thinning of the weathered layer, and decreasing of elevations and velocities towards the northeast part of the study area where most parts are swampy towards Lake Chad. This highly variable low-velocity-layer thickness indicates the necessity for static correction, which can be used to eliminate the effect of the low velocity layers at a regional level in a prospect.

(i) Elevations decreases towards the northeast part of the study area where most parts are swampy towards Lake Chad.

(ii) The weathered layer velocity varies between 258.0ms^{-1} and 554.0ms^{-1} with average of 413ms^{-1}. The weathered layer velocity varies between 294.5 ms^{-1} and 863 ms^{-1} with average of 524.10ms^{-1}. The velocities of the underlying consolidate layer are 1015ms^{-1} and 2450ms^{-1}, with an average of 1764ms^{-1}, depicting a general increase in the velocity with amount of consolidation of the bedrock.

(iii) Analysis of the velocity spectra suggests that low air-blast velocity, of the order of 337ms^{-1} resulting from direct blast waves could have been drawn in. The results of this work can be used for static correction in seismic processing, planning and assessing risk for engineering structures, and for groundwater exploration.

ACKNOWLEDGEMENT

The authors of this Paper are grateful to Dr. Lawson-Jack Osaki of the Department of Physics, Rivers State University, Port Harcourt, Nigeria, for plotting contour maps.

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