Asian Journal of Applied Science and Technology (AJAST)
(Peer Reviewed Quarterly International Journal) Volume 2, Issue 4, Pages 10-22, Oct-Dec 2018

Estimation of the Dipping Angles of Refractors in the Middle Benue Trough Nigeria Using Generalized Reciprocal Method

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Article Received: 12 May 2018 *Article Accepted: 04 September 2018* *Article Published: 01 October 2018*

ABSTRACT

Near-surface seismic data were acquired with McSeis-160MX^{TM} equipment in the Middle Benue Trough Nigeria at 38 acquisition stations. Two overlapping reversed profiles were shot into 12 stations of geophones at each measurement position. Each shot hole was 1.5m deep primed with 0.20kg dynamite as source. The data were modelled using Generalized Reciprocal Method (GRM) with the aim of estimating dipping angles, thicknesses and velocities of the refractors. Analysis of the results revealed 2-layers cases. The velocity of the Low-Velocity Layer, V_o, varies between 399 and 944ms^{-1} with average of 659.13 ms^{-1}. The underlying Consolidated Layer has apparent down-dip velocity, V_2, which varies between 1231 and 3901ms^{-1} with average of 2257.66ms^{-1}. The up-dip apparent velocity, V_u, varied between 164 and 4508ms^{-1} with average of 2221.79ms^{-1}. The true velocity of the consolidated layer varies between 1098 and 4147ms^{-1} with average of 2127.11ms^{-1}. Velocity appears greater when shooting down-dip, while velocity is reduced when shooting up-dip which could be attributed to either dipping layers or/and subsurface sediment heterogeneity. Depth of refractor, Z, varies between 2.80 and 6.5m with average of 4.30m. Dipping angle, θ, varies between 7 and 31^o with average of 19^o in N-S direction, while critical angle, i_c, varies between 1 and 7^o with average of 3^o. The angle of dip and critical angle varied from location to location suggestive of a non-planar, non-horizontal and anisotropic localized refractors. Elevation varies between 63 and 228m with average of 144.55m. Weathered thickness and elevation were highly variable resulting from both surface- and subsurface-topographic undulations. The results of this work can be used to decide direction of seismic data acquisition to meet the geophysical objectives.

Key Words: Dipping and critical angles, Generalized Reciprocal Method, interface, refractor, velocity, Middle Benue Trough, Nigeria.

1. INTRODUCTION

Acquisition direction is one of the many decisions to be made prior to shooting a seismic survey. It has a direct impact on survey economics and geophysical integrity. The geologic structural orientation and complexity, survey block size, shape, dimensions, and vicinity to no-access areas or exclusion zones (e.g. mining lease and international boundaries), all influence the direction of acquisition and consequently the ability to meet the geophysical objectives [1]. Agha [2] and Chandola *et al*. [1] observed that shooting data in a predominantly strike direction makes subsurface reflection angles sampled by the surface receiver spread to be reduced; consequently it may impact velocity analysis sensitivity. They further acquired and processed data in dip and strike direction and processed through identical flows. It was observed that there was close similarity in terms of seismic imaging and frequency content. Steep dipping events are not degraded despite the strike direction. Minor differences observed could be attributed to the difference in illumination of the geologic features through two shooting directions, validating the survey design, meets the objective of achieving efficiency, modeling analysis without compromising on geophysical integrity. Osagie [3] also observed that a dipped layer causes a reflected point not to be midway between the source and receiver, a situation which could result in erroneous displacement unless corrected for the dip.

The Generalized Reciprocal Method (GRM) [4, 5] is one of several methods which provide a means of recognizing and accommodating undetected layers, the refractor velocity analysis, dipping refractors and/or the time-depths.

The advantages of GRM over other techniques include but limited to its capability in detecting dips, mapping highly irregular and non-planar refractors, resolution of lateral variations in the refractor velocity [6, 7, 8].

2. THE IMPORTANCE OF RECENT STUDY

This study represents the first systematic effort to compute the dipping angles of near-surface layers beneath the central Middle Benue Trough covering the region between latitudes 07.50° - 08.50°N and Longitudes 08.00 and 09.30°E (Figure 1). As mentioned in geology of the study area, different parts of Middle Benue Trough region have been the focus of geological and geophysical studies aimed at understanding the tectonic evolution [9, 10, 11], morphology [12], mineral deposits [13, 14, 15, 16, 17], imaging the depth to basement [18, 19], structural styles [20, 21], and stratigraphy [18, 22]. The mapping high-angle basement faults in the Middle Benue Trough, Nigeria using gravity inversion was presented by Onyedim *et al.* [23]. Nwosu and Onuba [24] focused only on evaluation of the magnetic basement depth over parts of Middle Benue Trough Nigeria using empirical depth rule based on slope techniques. Maunde and Bassey [25] configured bedrock for geohydrologic and geotechnical studies in Abuja south of the present study area. These authors did not investigate the dipping angles. The mapping of depth to the computation of velocities of bedrock in the Middle Benue Trough Nigeria using seismic refraction method was carried out by Mgbemere *et al*. [26] and did not analyze the dipping angles. The aim of this recent study is to estimate the dip angles and directions of refractors, refractor depths and velocities. The results of this can be used, in the study area, for locating municipal waste disposal site [27], landfill investigations [28], location of a buried doline [7], assessment of rock quality [29, 30, 31, 32, 33, 34], and static and dynamic corrections [35].

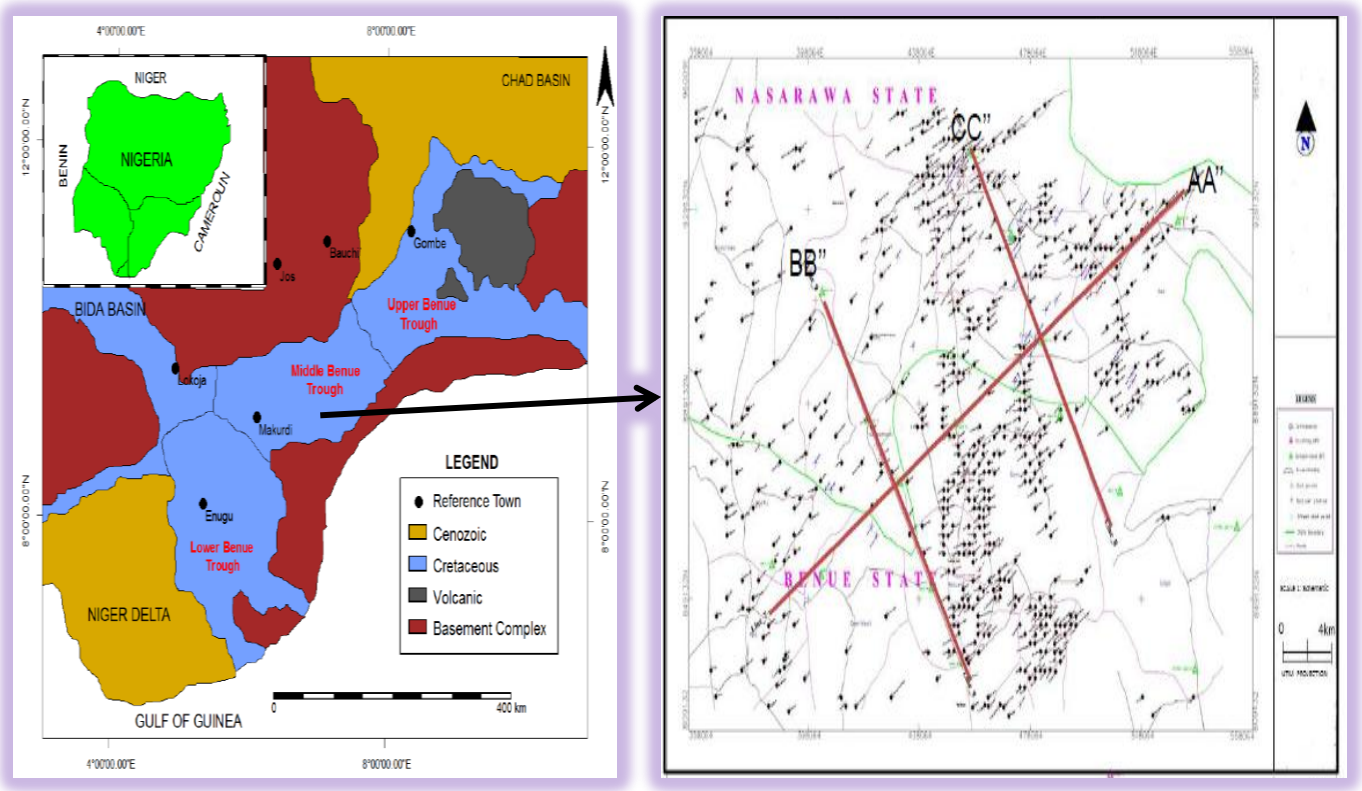

Figure 1: Map of Middle Benue Trough showing Study Area

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3. THEORETICAL BACKGROUND

The GRM calculates refractor depths for each geophone location using overlapping refraction arrival times from both forward and reverse shots (Figure 2), warranting multiple shots along a profile. Multiple shot points along a survey profile permit interpretations of changing interface depths and layer velocities [8]. The GRM assumes a layered model and assumes continuity of refractor surfaces across a profile, and that the velocity structure is relatively simple and refractors are gently dipping at an angle of less than 20^o [6, 7, 8].

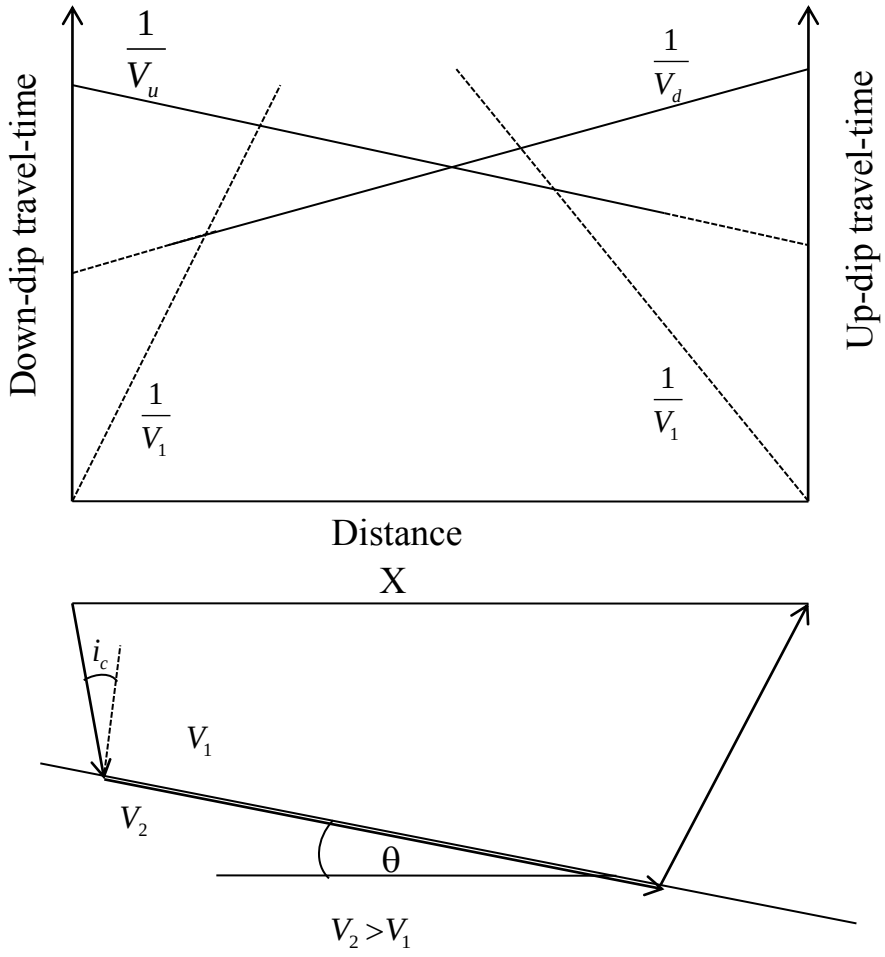

Figure 2: Travel-time versus Offset Curves of Direct and Refracted Rays for Up-Dip and Down-Dip Profiles when the Refractor Dips at Angle θ.

For a dipping two-layer medium in which the energy source is located in the weathered layer, the geometries and velocities of the medium is given by Palmer [4] and Uko [35]:

$$\theta = \frac{1}{2}\left\{\sin^{-1}\left(\frac{V_o}{V_d}\right) - \sin^{-1}\left(\frac{V_o}{V_u}\right)\right\} \qquad (1)$$

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$$i_c = \frac{1}{2}\left\{\sin^{-1}\left(\frac{V_o}{V_d}\right) + \sin^{-1}\left(\frac{V_o}{V_u}\right)\right\} \quad (2)$$

$$V_1 \approx \frac{V_u V_d}{(V_u + V_d)/2} \quad (3)$$

$$D_w = \frac{T_i}{2}\frac{V_o V_1}{\sqrt{V_1 - V_o}}\frac{D_S}{2} \quad (4)$$

where V_o = velocity of the upper weathered layer V_d and V_u are apparent velocities, i_c = critical angle and V_1 = true velocity of the lower consolidated layer, D_w = depth to refractor from earth surface.

4. GEOLOGY OF STUDY AREA

The study area is located in the Middle Benue Trough, North Central Nigeria and it lies within Latitude 07.50° - 08.50°N and Longitudes 08.00 and 09.30°E (Figure 1). The Benue Trough is an intra-cratonic rift structure, which extends from the Northern limit of the Niger Delta to the Southern margins of Chad Basin. The valley which is occupied by up to 600m of marine and fluvio-deltaic sediments, that have been compressionally folded in non-orogenic shield environment has been subdivided geographically into the Lower, Middle and Upper Benue Trough for the ease of mapping.

The Sedimentary Basins in Nigeria comprise the Niger Delta Basin, the Benue Trough, and the Chad Basin, the Sokoto Basin, the Mid-Niger (Bida/Nupe) Basin and the Dahomey Basin. The Middle Benue Trough extends Northeast ward approximately as far as line joining Bashar and Mutum Biyu. This boundary marks the Southern limit of the Gombe and Keri-Keri Formation while the older sediments of the Upper Benue Trough undergo lateral facies change in this area. The Middle Benue Trough is relatively poorly known, especially in its Northeastern part; no detailed geological maps of this portion are available but the area immediately south of Bashar was included in a photogeological map. Maps of the Lafia-Keana-Awe region were presented by Offodile [36] and Offodile and Reyment [37, 38], Ofoegbu and Onuohia [38] and of the area around Makurdi by Kogbe *et al.*[39] and Nwajide [40].

The stratigraphic succession of the Benue Trough is shown below (Figure 2). The six formations include the Asu River Group, Awe Formation, Keana Formation, Ezeaku Formation, Awgu Formation and finally the youngest which is the Lafia Formation, while the two formations exposed in the studied area are the Awe Formation and Keana Formation which are essentially sandstones with intercalations of calcareous shale and claystone which are covered by laterite resulting from the weathering of volcanic rocks which were emplaced during the widespread volcanic activities that took over in the Tertiary Period [41, 13, 38, 42].

5. MATERIALS AND METHODS

The seismic traverse lines (Figure 2) were cut open and pegged as pre-planned. The source and detector set-up is shown in Figure 3. Here a shot was located at each end of the spread of 12 geophones which were planted on the

earth surface as shown in the intervals. At each data recording set-up, 2 overlapping reversed profiles were shot into 12 stations of geophones. Each shot hole was 1.5 metres deep primed with 0.20kg of dynamite. Since we are interested in the layering in the immediate vicinity of the shot point, the source-detector offset (X) was 5 metre minimum and 75 metres maximum. The first 5 geophones were spaced 5 metres apart near the source; the others were spaced 10 metres towards the centre and 5 metres towards the end of the spread for adequate sampling of shallow depths from the surface down to the depth of interest, and to obtain a good resolution. At each data recording set-up, 2 overlapping reversed profiles were shot into the 12 stations of geophones. This procedure enables the computation of apparent velocities, dipping angles and the true consolidated velocities. The cable was connected to the McSeis-160MX Instrument, which recorded the travel times in real time. The ground electronics consist of geophone array connected to take-outs wired into pairs within the cable. The near-surface geometries, and velocities were computes using equations 1 – 4.

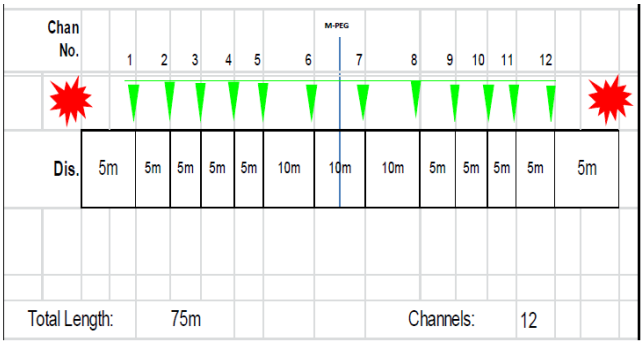
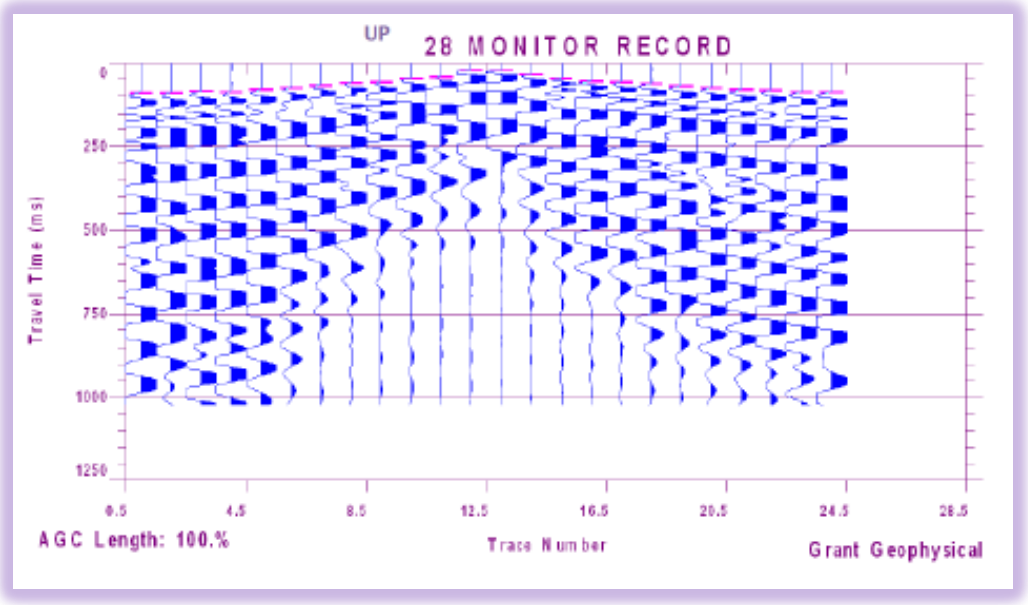


Figure 3: Source-Detector Array Spread

6. RESULTS AND DISCUSSION

6.1 RESULTS

The results of the work are presented in Figs. 4 – 6 and Table 1.



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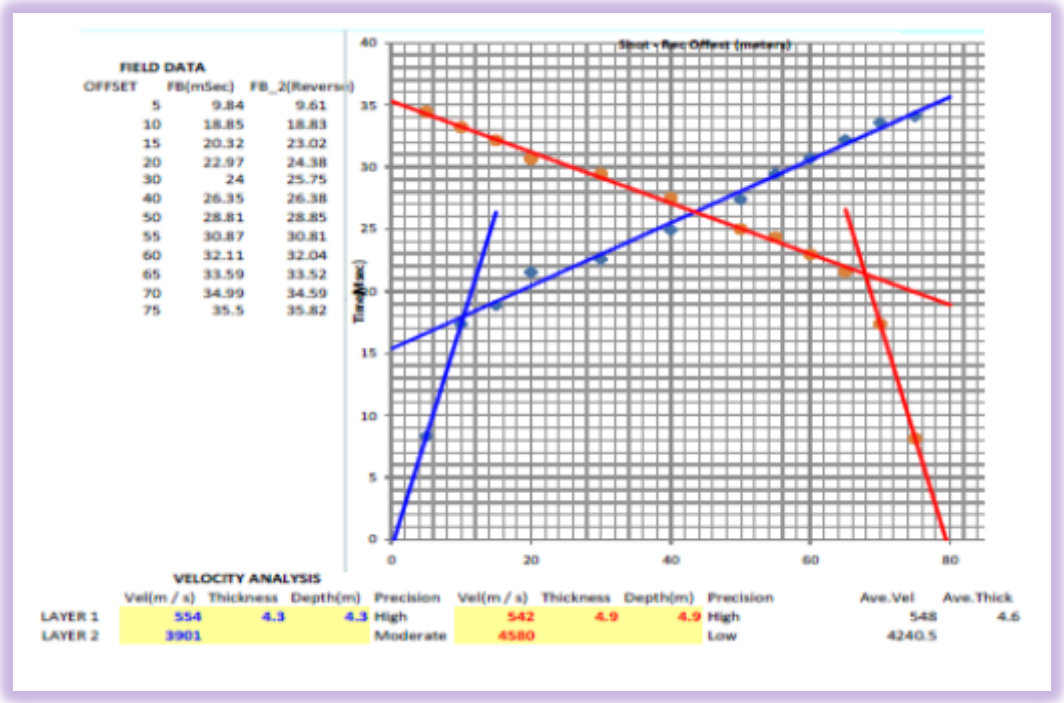


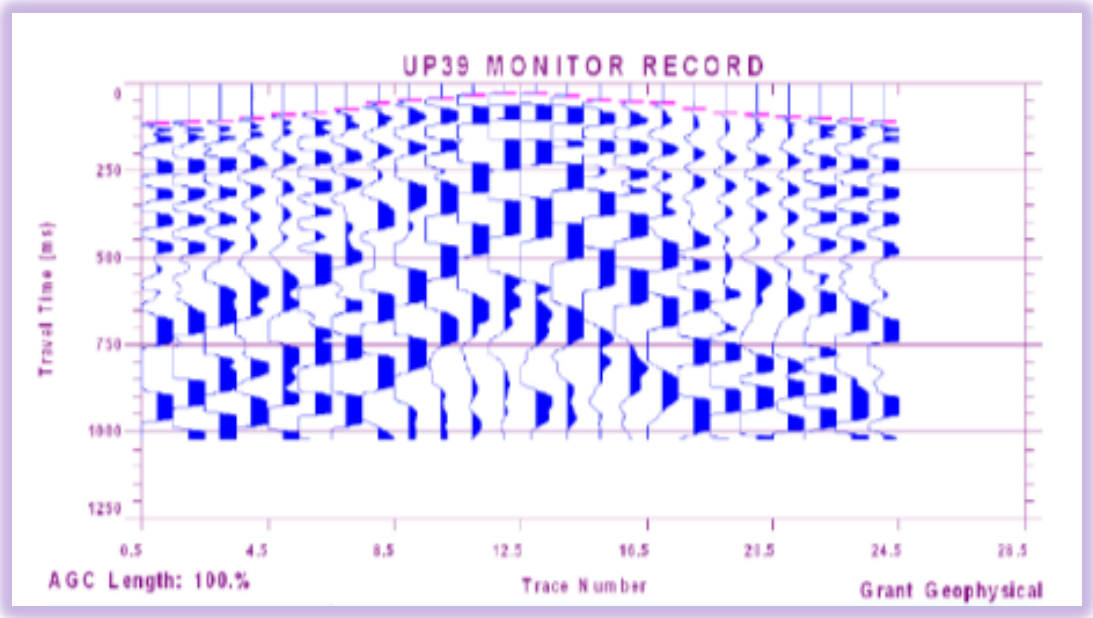
Figure 4: Sample Seismic Monitor Record and T-X Crossplot for Line AA" Station UP28

Table 1: Seismic Refraction Characteristics Data

Line No.	LVL No.	Station No.	Weathered Layer Velocity, V_o (m/s)	V_d	V_u	Consolidated Layer Velocity, V_1 (m/s)	Dipping Angle, θ (Degrees)	Critical Angle i_c (Degrees)	, Weathered Thickness, D_w (m)	Easting	Northing	Elevation (m)
1.	AA"	22	4552	485	2878	2545	2658	10	4	4.9	475708.0	898956.0	110.0
2.	"	23	4719	901	2963	3175	2934	17	1	3.2	475230.0	899100.0	147.0
3.	"	24	4901	871	3224	3121	3052	16	1	3.8	484789.0	904169.0	152.0
4.	"	25	5053	892	2582	2518	2395	20	1	4.5	488789.0	906534.0	184.0
5.	"	26	5220	843	2618	2154	2212	21	2	4.6	493089.0	908931.0	218.0
6.	"	27	5387	815	2634	2509	2422	21	2	6.1	497434.0	911426.0	205.0
7.	"	28	5554	548	3901	4508	4147	21	6	4.6	501820.0	913986.0	180.0
8.	"	29	5721	717	2283	2426	2244	8	1	4.9	506123.0	916416.0	184.0
9.	"	30	5888	861	1862	1840	1653	27	5	3.1	510469.0	918911.0	198.0
10.	"	31	6055	753	2610	2332	2348	18	0.1	3.8	514814.0	921814.0	183.0
11.	"	32	6222	501	3302	3064	3139	9	5	4.6	519028.0	923825.0	172.0
12.	"	33	6389	944	3276	3171	3085	17	1	3.3	523503.0	926393.0	120.0
13.	BB"	34	6556	399	3199	3315	3232	7	6	5.4	527847.0	928888.0	105.0
14.	"	35	1045	756	1410	1403	1207	31	7	2.8	402958.0	910372.0	115.0
15.	"	36	1211	494	1231	1194	1112	23	3	4.6	406753.0	906214.0	106.0
16.	"	37	1379	520	1259	1164	1098	25	4	4.9	408547.0	902056.0	114.0
17.	"	38	1546	592	1618	1585	1493	21	2	4.9	411342.0	897898.0	169.0
18.	"	39	1713	686	1807	1682	1608	23	3	4.2	414137.0	893740.0	124.0
19.	"	40	1880	519	1933	1977	1886	15	2	5.0	416932.0	889582.0	129.0

Online ISSN: 2456-883X

20.	"	41	2041	700	2168	2196	2070	18	0.2	3.4	419625.0885573.0	110.0
21.	"	42	2214	642	1397	1365	1233	27	5	3.4	422520.0881266.0	133.0
22.	"	43	2318	767	1787	1722	1588	25	4	3.1	425316.0877107.0	78.0
23.	"	44	2539	721	1653	1589	1461	26	4	2.9	427960.0873173.0	64.0
24.	"	45	2715	595	1617	1636	1519	21	1	4.4	430905.0878791.0	63.0
25.	"	46	2882	573	1613	1687	1551	20	0.4	4.4	433700.0864633.0	74.0
26.	"	47	3049	500	2022	1992	1945	14	2	3.9	436495.0860475.0	63.0
27.	CC"	53	1042	538	1405	1329	1261	23	2	3.2	455440.0942502.0	228.0
28.	"	55	1379	899	1946	1815	1664	28	5	2.9	461518.0934140.0	210.0
29.	"	56	1546	566	2534	2711	2559	12	3	6.5	464005.0929777.0	200.0
30.	"	57	1713	408	1781	1836	1762	13	3	4.9	466711.0925560.0	194.0
31.	"	58	1880	475	2016	2042	1974	13	3	5.5	468650.0922537.0	168.0
32.	"	59	2040	797	1707	1603	1463	28	5	6.4	422006.0917304.0	135.0
33.	"	60	2114	530	1777	1729	1673	17	1	4.7	473207.0915435.0	195.0
34.	"	61	2381	711	2228	2072	2030	19	1	5.7	477402.0908895.0	176.0
35.	"	62	2548	483	2717	2866	2748	10	5	5.9	480237.0904476.0	113.0
36.	"	63	2615	660	2710	2631	2589	14	2	4.7	481323.0902785.0	146.0
37.	"	64	2782	867	3050	2938	2868	17	1	3.8	48835.0 897312.0	198.0
38.	"	65	2955	704	3073	2986	2947	13	3	4.9	486831.0894199.0	130.0
		AVERAGE		**659.13**	**2257.66**	**2221.79**	**2127.11**	**19**	**3**	**4.30**		**144.55**



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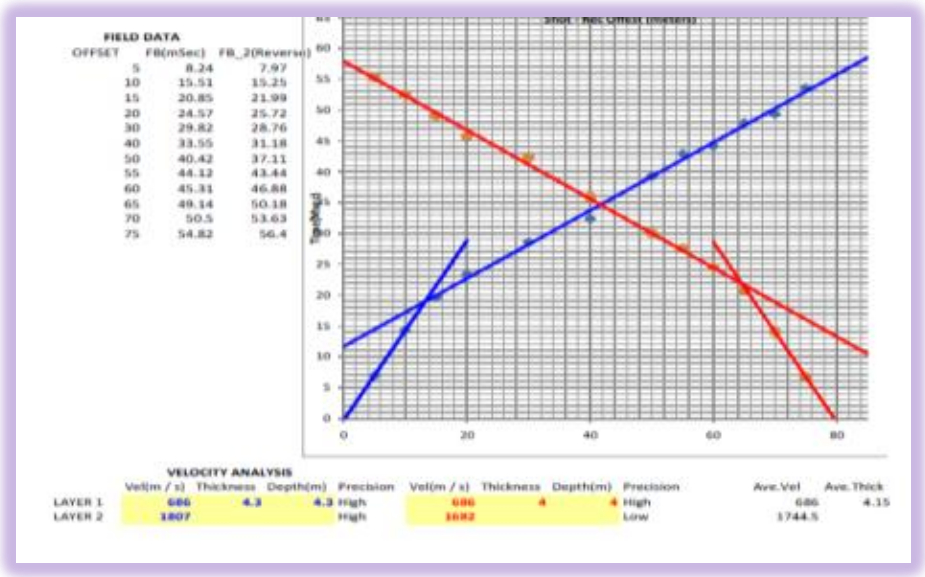
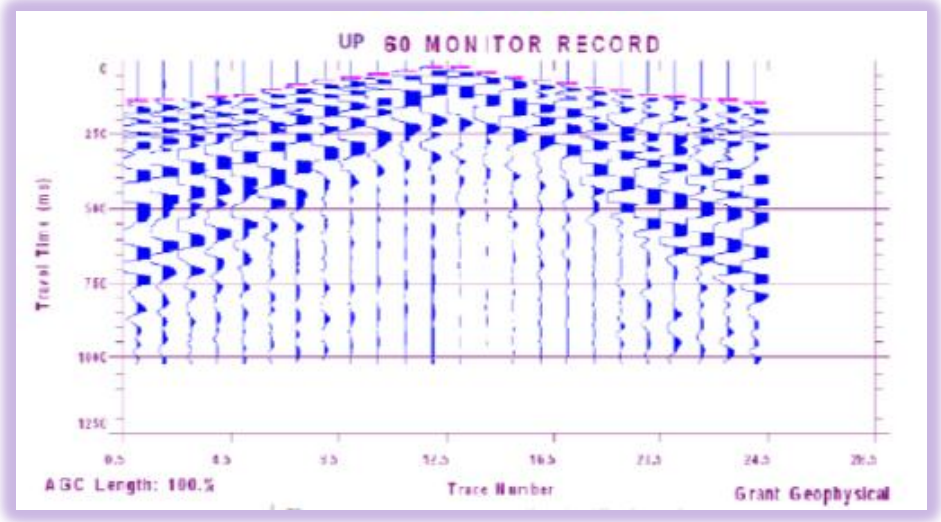


Figure 5: Sample Seismic Monitor Record and T-X Crossplot for Line BB" Station UP39



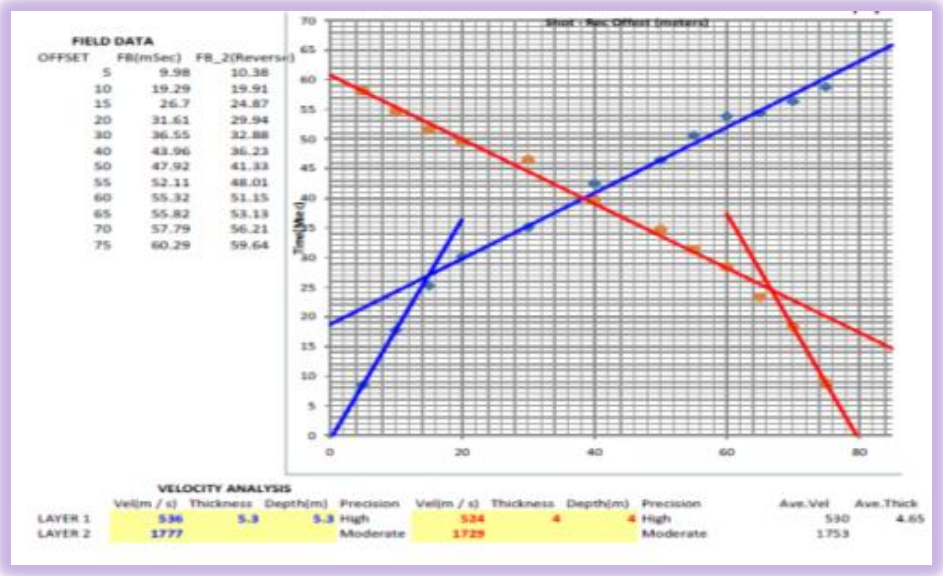


Figure 6: Sample Seismic Monitor Record and T-X Crossplot for Line CC" Station UP60

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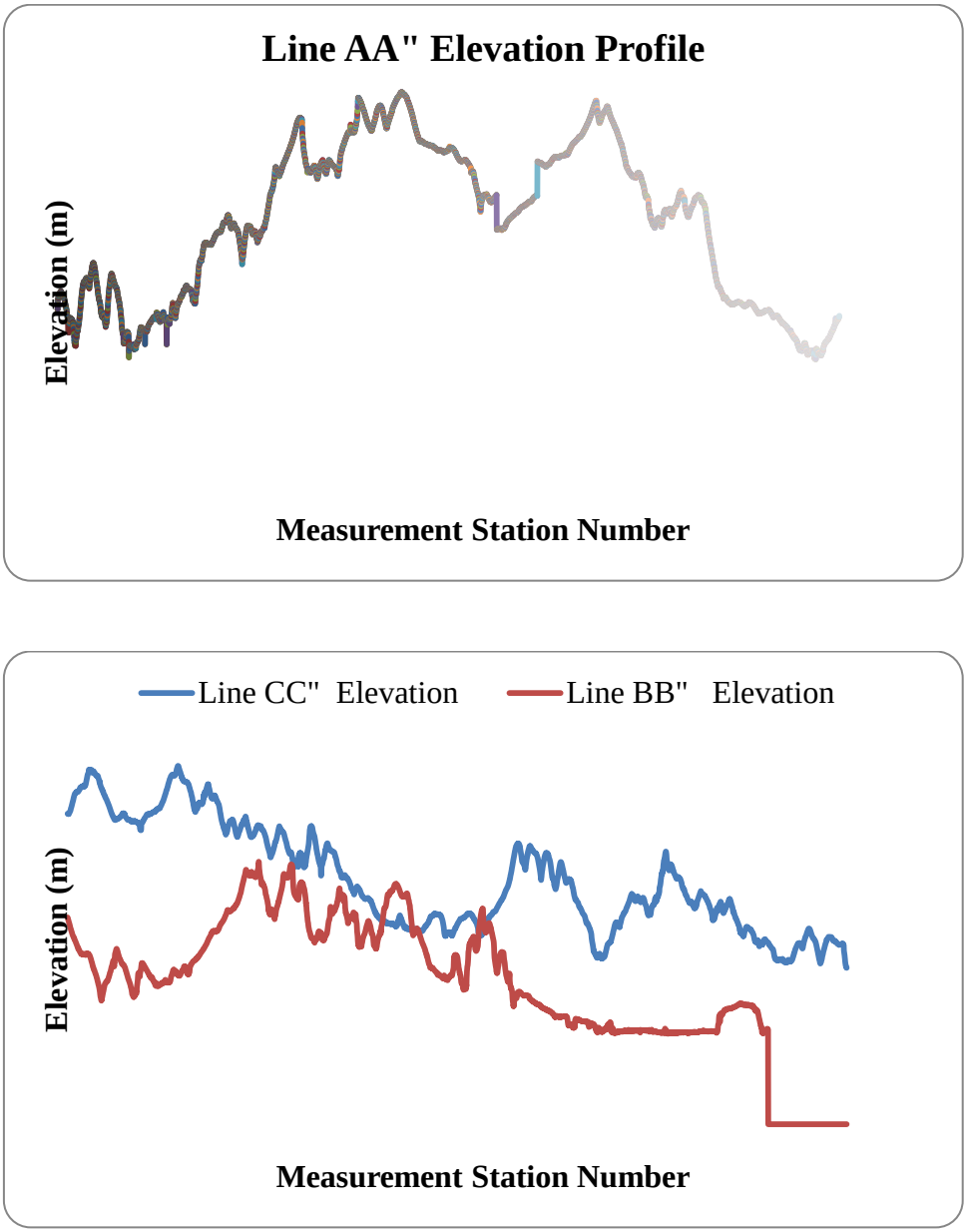

Figure 7: Topographic (Elevation) Profile along Survey Lines

6.2 DISCUSSION

6.2.1 Depth of refractors and Surface Elevation

Depth of refractor is observed to be highly variable with no trend, ranging between 2.80 and 6.5m with average of 4.38m. Elevation is also highly variable, ranging between 63 and 228m with average of 144.55m, showing forth the underlying surface-topographic undulations as seen in Figure 7.

6.2.2 Dipping and Critical Angles

Dipping angle, θ, varies between 7 and 31^o with average of 19^o dipping in the N-S direction, while critical angle, i_c, varies between 1 and 7^o with average of 3^o. The angle of dip and critical angle varied from location to location. The highly variable (Table 1) dips, critical angles, depths, travel times is suggestive of a non-planar, non-horizontal and

 Online ISSN: 2456-883X

anisotropic localized refractors. This assertion is confirmed from the results of the two experiments locations of the parallel Lines BB" (UP39) [427960E, 873173N] and CC" (UP60) [481323E, 902785N] separated by a distance of 60.95km intersecting Line AA" (Figure 1). The travel times, critical and dipping angles, depths, velocities expected to be near-equal, if the refractor were planar, isotropic, homogeneous and horizontal, are different. The principle of reciprocity criteria [4] which states that the time required for seismic energy to travel between two points, that it will require the same time if the source and detector are interchanged. This condition can only work with the assumptions that planar layers are either horizontal or dipping uniformly and with no lateral variation in velocity in the refractor or vertical variation in velocity within the surface layer. These Travel times were not equal in forward and reverse directions for source/receiver positions in our surveys (Figures 4 – 6). We attributed this deviation to anisotropy, dips, variation in refractor elevation and non-planar interfaces of the refractors.

7. CONCLUSION

- Two layers were encountered in the study area.
- The one refractor encountered is non-planar, anisotropic, and inclined.
- The critical and angle of dip varied from location to location; average critical angle is 3^o, while average dipping angle is 19^o in the N-S direction.
- The velocity of the Low-Velocity Layer, V_o, varies between 399 and 944ms^{-1} with average of 659.13 ms^{-1}.
- The velocity of the underlying Consolidated Layer, V_1, varies between 1210 and 4240ms^{-1} with average of 2214.00 ms^{-1}.
- Velocity appears greater when shooting up-dip, while velocity is reduced when shooting down-dip.
- There is highly variable thickness of the refractor, D_w, which varies between 2.80 and 6.5m with average of 4.38m.
- Elevation follows refractor thickness being highly variable, ranging between 63 and 228m with average of 148.51m.

ACKNOWLEDGEMENTS

The authors are grateful to Frontier Exploration Services (FES), a subsidiary of Nigeria National Petroleum Corporation (NNPC) for the data.

REFERENCES

[1]. Chandola, S. K., Foo, L. C., Kady, M. E., Ajewole, T. O., Nayak, S., Idris, F., Supardy, M. I., Tham, M., Bayly, M., Hydal, S., Seymour, N. and Chowdhury, B. (2015). Dip or Strike. SEG New Orleans Annual Meeting. http://dx.doi.org/10.1190/segam2015-5900296.1, Conference Proceedings, 110 – 114.

[2]. Agha, S. O. (2015). Estimation of dipping angles of refracting interfaces. *Journal of Environmental Science, Technology and Food Technology*, 9 (12), 10 – 12.

[3]. Osagie, E. O. (2011). The effect of a dipping layer on a reflected seismic signal. The Pacific Journal of Science and Technology, 12 (2), 523 – 527.

[4]. Palmer, D. (1980). The Generalized Reciprocal Method of Seismic Refraction Interpretation. Society of Exploration Geophysicists, Tulsa.

[5]. Palmer, D. (1981). An introduction to the generalized reciprocal method of seismic refraction interpretation. *Geophysics*, 46 (11), 1508-1518.

[6]. Palmer, D. (1986). Handbook of Geophysical Exploration, Vol. l3: Refraction Seismics. Geophysical Press, London.

[7]. Palmer. D. (1991). The resolution of narrow low-velocity zones with the generalized reciprocal method. *Geophys. Prosp.*, 39, 1031 - 1060.

[8]. Rucker, M. L. (2000). Applying the seismic refraction techniques to exploration for transport facilities, Geophysics 2000 Conference Proceedings, St. Louis, MO, Missouri Department of Transportation.

[9]. Ajayi, C. O., Ikpokonte, A. E. and Ike, E. C. (1991). Structural patterns in the lower Benue Trough, Nigeria: deductions from ground magnetic data. *Journal of Mining and Geology*, 27, 33 – 40.

[10]. Ofoegbu, C. O., Odigi, M. I. and Ebeniro, J. O. (1990). On tectonic evolution of the Benue Trough. *In* Ofoegbu, C. O. (Ed.), *The Benue Trough Structure and Evolution*. Friedr. Vieweg and Sohn, Braunschweig, 203 – 216.

[11]. Onuoha, K. M. (1981b). Problems connected with the origin and evolution of the Benue Trough, Nigeria. *Earth Evol. Sciences*, 2, 171 – 172.

[12]. Jatau, B. S. and Abu, N. (2013). Morphology of Parts of the Middle Benue Trough of Nigeria from Spectral Analysis of Aeromagnetic Data (Akiri Sheet 232 and Lafia Sheet 231. *International Journal of Geological and Environmental Engineering*, 7 (9), 622 – 627.

[13]. Whiteman, A. J. (1982). Nigeria: *Its Petroleum Geology, Resources and Potential*. Graham and Trotman, London, UK.

[14]. Reyment, R. A. and Dingle, R. V. 91987). Paleogeography of Africa during the Cretaceous Period. Paleogeography, Paleoclimate, Paleoecology, 59, 93 – 116.

[15]. Opeloye, S. A. (2006). Characterization of organic matter content of Fika shale in the southwest Chad Basin, Nigeria. NAPE Conference Proceedings, August 2006, 22 – 29.

[16]. Fatoye, F. B. and Gideon, Y. B. (2013). Geology and mineral resources of the Lower Benue Trough, Nigeria. Advances in Applied Science Research, 4 (6), 21 – 28.

[17]. Labe, N. A., Ogunleye, P. O. and Ibrahim, A. A. (2018). Field occurrence and geochemical characteristics of the baryte mineralization in Lessel and Ihugh areas, Lower Benue Trough, Nigeria. *Journal of African Earth Sciences*, 142, 207-217.

[18]. Abbass, A. A. and Mallam, A. (2013). Estimating the Thickness of Sedimentation within Lower Benue Basin and Upper Anambra Basin, Nigeria, Using Both Spectral Depth Determination and Source Parameter Imaging. ISRN Geophysics, 1 – 11.

[19]. Adetona A. Abbass, A. A, and Abu Mallam, A. (2013). Estimating the Thickness of Sedimentation within Lower Benue Basin and Upper Anambra Basin, Nigeria, Using Both Spectral Depth Determination and Source Parameter Imaging. *ISRN Geophysics*, 124706, 1 – 10.

[20]. Carter, J. D., Barber, W., Tait, E. A. and Jones, J. P. (1963). The geology of parts of Adamawa, Bauchi and Bornu provinces in the northwestern Nigeria. Bull. GSN, 30, 109p.

[21]. Genik, G. J. (1993). Petroleum geology of Cretaceous-Tertiary rift basins in Nigeria, Chad and Central African Republic. AAPG Bull., 77, 1405 – 1434.

[22]. Patrick, N. O., Fadele, S. I. and Adegoke, I. (2013). Stratigraphic Report of the Middle Benue Trough, Nigeria: Insights from Petrographic and Structural Evaluation of Abuni and Environs Part of Late Albian-Cenomanian Awe and Keana Formations. *The Pacific Journal of Science and Technology*, 14 (1), 557 – 570.

[23]. Onyedim, G. C., K. D. Alagoa, I. O. Adedokun, A. A. Aderogba and C. Ovuru(2009). Mapping high-angle basement faults in the Middle Benue Trough, Nigeria from gravity inversion surface. *Earth Science Research Journal*, 13 (2), 140 - 147.

[24]. Nwosu, O. B. and Onuba L. N. (2013). Evaluation Of The Magnetic Basement Depth Over Parts Of Middle Benue Trough Nigeria By Empirical Depth Rule Based On Slope Techniques Using The HRAM. International Journal of Scientific & Technology Research, 2 (11), 19 – 29.

[25]. Maunde, A. and Bassey, N. E. (2017). Seismic Refraction Investigation of Fracture Zones and Bedrock Configuration for Geohydrologic and Geotechnical Studies in part of Nigeria's Capital City, Abuja. *Journal of Earth Sciences and Geotechnical Engineering*, 7 (2), 91-102.

[26]. Mgbemere, P. C., Uko, E. D., Mbachi, C. N. C., Tamunobereton-ari, I., Ofoegbu, C. O. and Ngeri, A. P. (2018). Mapping of depth to bedrock in the Middle Lower Benue Trough Nigeria, using Seismic Refraction Method. *Journal of Applied Geology and* Geophysics, *in press*.

[27]. Lankston, R. W. (1990). High-resolution refraction data acquisition and interpretation. In: Ward, S.H. (ed.), *Geotechnical and Environmental Geophysics.* Vol. I: Review and Tutorial. Tulsa: Society of Exploration Geophysicists, 45 - 73.

[28]. Reynolds, 1. M. and McCann, D. M. (1992). Geophysical methods for the assessment of landfill and waste disposal sites. *In*: Forde, M. E. (ed.), *Proceedings of 2nd International Conference on Construction on Polluted and Marginal Land*, 30 June-2 luly 1992, Brunel University, London, 63 - 71.

[29]. New, B. M. (1985). An example of tomographic and Fourier microcomputer processing of seismic records. *Quarterly Journal of Engineering Geology*, 18 (4), 335 - 344.

[30]. Sjogren, N.A., Ofthus, A. and Sandberg, J. (1979). Seismic classification of rock mass qualities. *Geophysical Prospecting*, 27 (2), 409 - 442.

[31]. Gardener, R. (1992). Seismic refraction as a tool in the evaluation of rock quality for dredging and engineering purposes: case histories. In: Hudson, lA. (ed.), *Eurock* '92, *Chester*. London: British Geotechnical Society, 153 - 158.

[32]. Knight, M. J., Leanard, J. B. and Whiteley, R. J. (1978). Lucas Heights solid waste landfill and downstream leachate transport: a case study in environmental geology. *Bulletin of the International Association of Engineering Geology*, 18, 45 - 64.

[33]. Nunn, K. R. (1978). Geophysical surveys at the landfill sites in the West Midlands. In: *Proceedings ofa Symposium on the Engineering Behaviour of Industrial and Urban Fill, University of Birmingham, April* 1978. Midland Geotechnical Society, C45 - C53.

[34]. Baoshan, Z. and Chopin, L. (1983). Shear wave velocity and geotechnical properties of tailings deposits. *Bulletin of the International Association of Engineering Geology* (26-27): 347 - 353.

[35]. Uko, E. D., Ekine, A. S., Ebeniro, J. O. and Ofoegbu, C. O. (1992). Weathering Structure of the East Central Niger Delta, Nigeria. *Geophysics*, 57 (9), 1228-1233.

[36]. Offodile, M. E. (1976). The Geology of the Middle Benue Nigeria. Cretaceous Research, Paleontological Institute: University of Uppsala. Extra-ordinary Publication, 4, 1 - 166.

[37]. Offodile, M.E. and Reyment, R. A. (1977). Stratigraphy of the Keana-Awe area of the Middle Benue Region of Nigeria. *Bulletin Geological Institutions University Uppsala (N. S.)* 7, 37 - 66.

[38]. Ofoegbu, C. O. and Onuoha, K. M. O. (1989). A review of geophysical investigations in the Benue Trough, Nigeria. *Earth Evolution Sciences*, 171 – 201.

[39]. Kogbe, C. A. (1976). The cretaceous and Palaeocene sediments of southern Nigeria, In Kogbe, C. A. (ed.), Geology of Nigeria. Elizabethan Press, 273 – 282.

[40]. Nwajide, C.S. (1985). A Systematic Liithostratigraphy of the Makurdi Sandstones, Benue Trough. *Journal Mining and Geology*, 22, 9 - 23.

[41]. Avbovbo, A. A. (1980). Basement Geology in the Sedimentary Basins of Nigeria. *Geology*, 8, 323 - 327.

[42]. Idowu, J. O. and Ekweozor, C. M. (1993). *Journal of Petroleum Geology*, 21, 105 – 118.