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Relevant Velocities in Seismic Prospecting and High Resolution Petroleum Exploration in the Niger Delta and Adjoining in-Land Sedimentary Basins, Nigeria

Madu Anthony Joseph Chinenyeze[1], Agbo Christian Chukwudi[2], Amoke, Aniebonam Ignatius[3]

[1, 2, 3]Department of Geology, College of Physical and Applied Sciences, Michael Okpara University of Agriculture Umudike, Abia State, Nigeria

Abstract: ***The algorithm of finding relevant velocities and applying appropriate velocity types to static and dynamic corrections, as well as to data processing culminate into optimum Signal/Noise ratio of data, and subsequent accurate interpretation of subsurface structures. Velocity is an important tool in petroleum exploration, and specifically in seismic prospecting. It is a parameter that measures the total distances travelled per given time (in seconds or milliseconds). In seismic exploration, the velocities are measured as the waves travel from the energy source point through the layers of the subsurface. The wave returns to the surface on encountering a reflector or impedance and is detected by the geophones or hydrophones. Seismic velocities include weathering velocities and refractor velocities which underlie the former. They are associated with the near-surface components of the earth. These velocities are essential in the determination or computation of static and dynamic corrections. They also have indications of changes in lithology, porosity, pore fluids, relative bulk-densities, density contrast across lithologic boundaries, and age of sediment. These velocities among others fall into spectrum of velocities comprising, average velocities, root-mean-square (rms) velocities, interval velocities, stacking velocities and semblance velocities, which are profoundly applicable in seismic data processing and subsequent interpretation. Velocity distribution in the subsurface region is derived from stacking velocities. These are obtained from common-depth point (CDP) stacks. The Root-mean-square (rms) velocities are obtained from stacking velocities. The interval velocity values are derived or computed from the rms velocities. These derivations are contained in the velocity analysis algorithm that evaluates and identifies significant lithologic layers, and also provides the amount of normal move-out which should be removed to maximize the stacking of primary events or reflections. A velocity spectrum is generated that brings out level planes of constant coherency. This reveals the location of peaks on the coherency surface that correspond to primary reflections, characterized by identical velocities. These peaks are then suitably joined to obtain an average rms velocity versus time function display. The most popular statistical measures for coherency attribute are cross-correlation and semblance. The contemporary industry practice of multichannel coherence measurement is carried out using the semblance analysis method. This produces a velocity function that maps out increasing magnitude of velocities with increasing depths, which also defines velocities at given depths. Niger Delta and adjoining sedimentary basins were of age Eocene to Pliocene characterized by sediments that have matured from plenty organic deposits. In the subsurface, the layered deposits have yielded to effect of gravity and external forces which distort and modify the layered strata into faulted substrata with favourable structures for entrapment of hydrocarbons.***

Keywords: Average velocities, root-mean-square (rms) velocities, interval velocities, stacking velocities, semblance velocities, Niger delta sedimentary structures growth faults and roll-over anticlines.

1. Introduction

Early reconnaissance investigations in the Niger Delta were based on gravity method which revealed high thickness of sedimentary overburden, while the magnetic method gave results which revealed that the Basement was sufficiently far from the surface, thus distant magnetic elements from the earth's surface, confirming that distance was filled with sedimentary pile or thickness. Both gravity and magnetic methods did not lend themselves to unique interpretation. But seismic methods of prospecting provided high precision measurements that proffered high resolution of dimensions to petroleum structural features, comprising anticlinal folds, faults, and dome features. The velocity of the waves through various sedimentary layers varies with depths (Onuoha, 1983). Velocity is an important quantity a variable in seismic exploration defined as the rate of total distance travelled per second, or in a given time. In seismic exploration, the waves originate from a source near the surface, and travel through several layers underneath the earth's surface, and at the point of encounter of any impedance, it changes direction and is returned to the surface where their arrivals are detected by geophones or hydrophones in the case of water domain of receivers. Arrival times at the surface can be determined quite accurately, but we can only make assumptions about the paths through which the wave has travelled. Empirically, the waves propagate through the subsurface region in such a manner, that the paths taken observe a minimum travel time between source and detector. This is in accordance with Fermat's principle (Telford, et al 1976).

Prospecting for seismic structural features and traps in oil exploration in the Niger Delta has developed to a high level digital dimension and undergone revolution at different stages of computation of analyses, processing and interpretation. All of these computations aggregate to enhance the resolution of results of data carried out by application of different velocities in relational algorithms.

Basically, velocity is an important tool in the resolution of the earth's behaviour and response to the impacts of seismic energy sources. In order to determine the horizons from which reflections come, and in order to obtain depth sections from seismic times-sections, knowledge of the velocity of propagation of seismic waves is of paramount importance.

Some of the processes and correction computations can only be reliable with accurate velocity determinations. Typical of such velocities are the weathering velocity, Vw, consolidated velocity, Vc, also called refractor or elevation velocity, which are commonly used for accurate determination of static and dynamic time corrections, and also for providing indications of changes in lithology, porosity and pore fluids. Other velocities include, Normal-move-out velocities, interval velocities, semblance velocities, root-mean-square velocity. With the characteristic increase with depths the velocity function also yields to becoming an interpretation tool because of sensitivity to numerous geological factors, such as age of the host rock, composition, porosity, density, and overburden pressure or depth of burial (Onuoha, 1983).

2. Geologic Setting

The Niger Delta oil province covers about 300,000 square kilometers and consists of the geologic Tertiary Niger Delta. The oldest formations (Paleocone-Eocene) in the Niger Delta form an arcuate exposure belt along the delta frame. These are the Paleocene Imo Shale (fossiliferous blue-grey shales with thin sandstones, marls and limestones, and locally thick nearshore sandstones); the Eocene Ameki formation (fossiliferous calcareous clays, coastal sandstones); the late Eocene-Early Oligocene lignitic clays and sandstones of the Ogwashi-Asaba Formation and the Miocene-Recent Benin Formation (coastal plain sands). These formations are highly diachronous and extended into the subsurface where they have been assigned different formation names. The Akata, Agbada and Benin Formations are interfingering facies equivalents representing pro-delta, delta-front and delta-top environments respectively. Unconformities, large clay fills of ancient submarine canyons and deep sea fans occur in the eastern and western delta (Burke, 1972; Orife and Avbovbo, 1982). These formed mainly during Early Oligocene and Tertiary low stands of sea level.

By the middle Eocene the major depocentres initiated in the Paleocene-Eocene (in the Anambra basin, Afikpo syncline, Ikang trough) were the sites of deltaic outbuilding with the Niger – Benue and the Cross River drainage system accounting for the bulk of the sediment supply. Both drainage systems merged at the end of the Oligocene and formed the present Niger Delta. Simple growth faults were initiated in the Oligocene. During the Miocene uplift of the Cameroon mountains provided a new and dominant sediment supply through the Cross River, thus constructing of the Cross River delta. The shorelines progressively migrated seaward during deltaic progradation. This was greatly accelerated in Miocene-Pliocene times with attendant increase in growth faulting and large scale diapiric movement of the Akata shale. This involved deep mass movement of the under compacted and over pressured shale towards the continental slope. Deltaic growth declined in the late Pliocene-Pleistocene during a major drop in sea-level, with sediment by-passing into deep sea fans. A late Pleistocene transgression flooded the Plio-Pleistocene offlap upper and lower deltaic plains and as sea level stabilized, a new regressive offlap sequence developed.

Deltaic front sands account for the bulk of the Niger Delta hydrocarbon production. These interfinger with pro-delta source beds. Turbidite sands are also significant reservoirs. Growth faults are very common in the Niger Delta with primary and secondary synthetic and antithetic faults.

Three main formations have been recognised in the subsurface of the Niger Delta complex (Short and Stauble 1967). These are the Benin, Agbada and Akata Formations. The three formations were laid down under continental, transitional and marine environments respectively (Short and Stauble, 1967). The Benin Formation was deposited in a continental-fluviatile environment and mainly consists of sands, gravels and back swamp deposits which vary in thickness from 0 to 7000ft. The Agbada Formation was laid down in paralic, brackish to marine fluviatile, coastal and fluvio-marine environments and consists of interbedded sands and shales. Many subenvironments have been recognised within these major units. The Agbada Formation becomes much shalier with depth and varies in thickness from 0 to 1000 to 15000 ft. The Akata Formation consists of marine silts, clays and shales with occasional turbidite sands and silts forming sinuous lenses. The Akata Formation varies in thickness from 0 to 20000 ft and like the other two formations, age varies from Paleocene to Recent.

The Benin Formation and its equivalent form extensive outcrops inland from the Agbada Formation and south of the outcrops of the Ameki Formation and Imo Shale. The Akata Formation outcrops subsea on the delta slope and open continental shelf and is not exposed onshore unless we view the deeper water facies of the Imo shale as Akata Formation laid down in the front of the Paleocene Anambra delta complex (Whiteman, 1982).

3. Objective

To highlight the criticality of seismic velocities, which spells out that investigation of specific velocities in seismic prospecting or oil exploration as well as adequate knowledge of the appropriate velocity to be applied at various stages of data corrections, processing and interpretation result in accurate and enhancement of signals. Conversely, misapplication of respective velocities will cause smearing or stretching of seismic data or stack section. Accuracy of appropriate velocities applied in the respective stages or algorithms of seismic computation of corrections, processing and interpretation gives favourable results for obtaining high-resolution of targets.

4. Methodology

Different methods were used for obtaining various velocities comprising Low-Velocity-Layer LVL, for obtaining weathering velocity, and apparent refractor or consolidated velocity. The Uphole survey method provided an effective investigation and assessment of both weathering and refractor or consolidated velocity, used for statics and data

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processing. Upon static correction, the dynamic correction is computed using the normal-move-out displacements and zero-offset velocity. Subsequently, the stacking velocity and interval velocity were deduced with the aid of computer-based semblance velocity analysis. Alternatively, velocities at greater depths for well studies are also obtained from Vertical Seismic Profiling, VSP, which involves planting the receivers downhole, while the energy source is positioned at the surface from zero-offset to gradually increasing lateral offsets (x).

Relevant Velocities In Seismic Exploration

Much of the information about velocity distribution in the earth's subsurface region is derived from stacking velocities, interval velocity values, and RMS velocities. For the purpose of defining the different velocity types, the consideration is that the earth is layered.

Average velocity:

If the transit time for the i-th layer is t_i and the velocity for the layer is Vi, the average velocity V is given by

$$\overline{V} = \frac{\sum V_i \; t_i}{\sum t_i}$$

The total vertical transit time is

$$T = \frac{h_1}{V_1} + \frac{h_2}{V_2} \quad + \; .... + \frac{h_n}{V_n} = \sum_{i=1}^{n} \frac{h_1}{V_1}$$

This is generally the representation of intercept times which are obtained from Low-Velocity-Layer (LVL) investigations to derive the weathering velocities Vw, and refractor or consolidated layer velocities Vc, needed for static and elevation correction in data processing.

Root Mean Square (RMS) Velocity

This is a travel-time weighted quadratic average velocity, which naturally depends on the path taken.

$$V_{rms}^2 = \frac{V_1 \, 2 \, t_1 + V^2_n t_n}{t_1 + t_2 + \; .... + t_n} = \frac{\sum_i^n V_i \, 2 \, t_i}{\sum_i^n t_i}$$

With the conventional velocity layering, actual seismic wave paths are replaced with a series of line segments which are straight within each layer, but undergo abrupt changes in direction at the boundaries between layers. Since the reflection travel-time/distances relationship is

$$t^2 = \frac{x^2}{V^2} + \frac{4h^2}{V^2} = \frac{x^2}{V^2} + \quad t_o^2$$

With the replacement above, then for the layers,

$$t_x^2 = t_0{}^2 + \frac{x^2}{V_{rms}^2}$$

Where v is the velocity, x is the offset-distance, h is layer-thickness, to is the travel time for the geophone with the offset distance zero.

Apparent Velocity

This is the gradient of the tangent at a point to the travel time curve, i.e $V_A = \frac{dx}{dt}$. It differs from the stacking velocity, and from the velocity used to convert arrival times to reflector depths. Apparent velocity generally decreases for dipping reflectors. It gets smaller as the dip increases. This is the reason for taking harmonic mean of two sides of the velocity (V_2^+ and $V2^-$) to obtain the actual refractor or consolidated layer velocity. This is the condition when the LVL survey involves significantly dipping layers.

Stacking Velocity (Vs)

This is a parameter in the Normal-Move-Out (NMO) equation which gives the best stack of a reflection on a gather record.

$$t_x^2 = t_0^2 + \frac{x^2}{V^2}$$

If offset distances are not exceedingly large compared to the reflecting boundary, and if layers are horizontal and parallel, the stacking velocity V_s and the rms-velocity V_{rms} are equal (Everett, 1974). This is a useful tool in the NMO application, which generates the best stack of a reflection. This is an industrial equivalent of the semblance velocity. The use of common reflection point channels is also an added advantage because in the event of the reflecting boundary dipping at an angle, the arrivals are still symmetrical about the reflection point. When the angle of dip of the reflector is large, then all the three velocities will differ in magnitude. In this case the stacking velocity does not agree with the rms velocity, but differs from it, because of the angle of dip. For a dip of D°, the relation modifies to

$$V_{rms} = V_s \cos D$$

Semblance Velocity

The normal-move-out (NMO) scan and the velocity spectrum determination are conventional methods for velocity analysis. The velocity spectrum is a display of velocity verses time signals (Taner and Koehler, 1969). The determination of velocity is converted to the task of computer-aided scanning of various gathers of hyperbolic trajectories for maximum reflection coherency. Velocity spectra domain consists of location of peaks on the coherency surface that correspond to primary reflections. These peaks are then joined to obtain an average RMS velocity verses time function display. This is a computer-based measurement of alignment between traces in a multichannel coherence statistical medium called semblance velocity analysis. Neideil and Taner 1971 called it normalized O/I energy ratio. The semblance coefficient which varies between o and 1 measures the degree of identical signals.

Interval Velocity

This is the average velocity over an interval, and can refer to either a lithologic interval within which the velocities do no vary significantly from each other, or an interval between two seismic events. From analysis of continuous velocity logs and from synthetic seismograms we know that interval velocities are not constant over any significant thickness of rock. The definition for interval velocity V_I is (Dix, 1995).

$$v_r^2 = \frac{v_b^2 t_b - v_t^2 t_t}{t_b - t_t}$$

Where v_t and v_b are the rms velocities at the top and bottom of the interval, and t_t and t_b are the corresponding normal incidence travel times to the top and bottom respectively.

Stacking velocities are frequently used as if they were rms velocities to find interval velocities and depths. We now know that this assumption is valid only for plane horizontal reflectors. Everett (1974) confirmed that if this method is used for dipping sections, then the interval velocities and depths could be over-estimated, and would not tie at intersections. In such a case the errors in the depth values could be as to render migration pointless.

5. Results and Discussion

Refer to Tables 1 and 2. Different velocity types were evaluated from direct investigations such as Low-Velocity-Layer, Uphole survey, and Computer-based method of Semblance velocity analysis for data from parts of Central Niger Delta and adjoining sedimentary basin of the Anambra Basin. With the application of specific and appropriate velocities, enhancement of data and structural signatures are achieved, revealing faults, growth faults, and anticlinal structures.

Illustrations are evident on the stack section showing sharp structural signatures, as identifiable on figure 1. Prestack velocity analysis using CDP or common-mid-point (CMP) gathers results in a high resolution of stack data.

6. Conclusion

With the application of accurate velocities, from the weathering and refractor velocities to the processing of semblance and stacking velocities, a good stack section is produced. The application of appropriate and accurate velocities at various stages of data corrections, processing and interpretation result in accurate and enhancement of signals, clearly showing (high resolution of) structural features of events, such as folds and faults, necessary for oil or petroleum entrapment or accumulation. Computer-based

Table 1: Exploration Velocities (From Statics To Final Stack Section) Inter-Related or Interconnected

S/NO	Velocity Type	Influence Areas	Range of Values(m/sec)	Sensitivity
1	Weathering	LVL / VADOSE	450 – 600	Sediment's composition, Porosity
2	Refractor Or Consolidated	Consolidated Layer	1600/1700 -1890/2000	Density, Overburden pressure
3	Normal Move Out	Variation of arrival time with shot-to-geophone distance.	Vel. Function- gives series of velocity values at varying depths; As velocity increases with depths	Marks out layers or horizons of identical velocity character.
4	Stacking	Provides indications of changes in lithology, porosity and pore fluids.	2200 – 2750m/s May be Single velocity function: 2300m/s: t(1-4.5) sec.	Age, density, overburden pressure, depth of burial.
5	Rms	Quadratic weighted average of layer velocities, varying by time intervals	True refractor velocity, V_2 from gradients of Apparent velocities, up-dip and down-dip.	
6	Interval	Average velocity between the reflectors	2550 – 2750 m/sec 2800 – 3050 m/sec	Within a lithologic interval, from one depth level to next horizon (of certain depth).
7	Semblance	In semblance velocity analysis carried out on cdp gathers at different depth (t) locations at intervals to produce velocity as a function of depth, V:f(z)		

Table 2: Time Variant Velocity Function (Computer-Based Method): Velocity Increases with Depth (Z), which is Here represented by Travel Time (MSEC) Through the Depths at Respective Common-Depth-Point (CDP) Locations

CDP LOC: 2371		CDP: 2459		CDP: 2551		CDP: 2639	
time (msec)	vel (m/sec)	time (msec)	vel (m/sec)	time (msec)	vel (m/sec)	time (msec)	vel (m/sec)
0	1500	0	1500	0	1500	0	1500
312	1745	548	1874	568	1893	344	1822
668	1880	948	2119	1180	2177	964	2145
1020	2164	1308	2229	1428	2280	1304	2222
1540	2203	1844	2338	1820	2512	2012	2416
2096	2403	2468	2500	2212	2693	2320	2512
2404	2493	3256	2764	2544	2706	2660	2609
3004	2712	3676	2893	3104	2854	3244	2796
3576	2841			3608	2938	3740	2996
3924	2964			4128	3100	4168	3093

Velocity Analysis: Semblance velocity analysis performed on 3 CDP gathers at four CDP locations on the seismic line to obtain the velocity functions.
NMO: Velocity functions derived from semblance and applied to data with 50% stretch mute.
CDP= True Source + True Receiver.

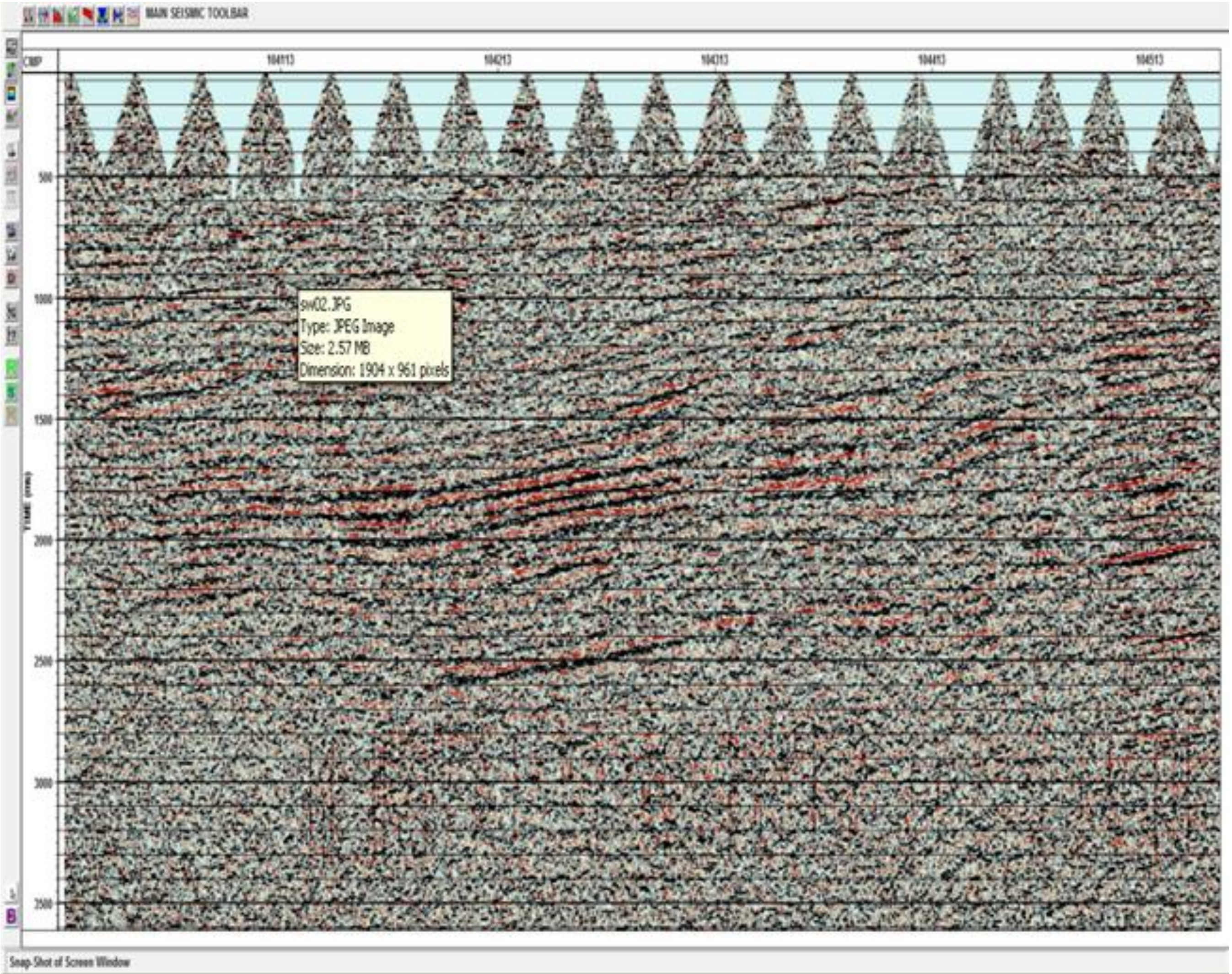

Figure 2: Brute Stack Produced from Seismic Data after velocity functions application from Semblance Velocity, to Normal-move-out (nmo) velocity, to Stacking Velocity which processes and refines the data to Brute Stack. Courtesy of Newcross Petroleum

References

[1] Burke, K, C 1972. Longshore drift submarine canyons and submarine fans. AAPG Bull. 56:1975-1983.
[2] Dix, C. H., (1955). Seismic velocities from surface measurements. Geophysics, Vol. 20, 68 – 86.
[3] Everett, J. E., (1974). Obtaining interval velocities from stacking velocities when dipping horizons are included. Geophysical Prospecting, vol. 22, 122 – 142.
[4] Faust, L. Y., (1951). Seismic velocity as a function of depth and geologic time. Geophysics, Vol. 16, 192 – 206.
[5] Gardner, G. H. F., Gardener, L. W., Gregory, A. R., (1974). Formation velocity and density- the diagnostic basis for stratigraphic traps. Geophysics, vol. 39, 770 – 780.
[6] Neidell, N. S., Taner, M. T., (1971). Semblances and other coherency measures for multichannel data. Geophysics, Vol, 36, 482 – 497.
[7] Onuoha, K. M., (1983). Seismic velocities and the prediction of over-pressured layers in oil fields. Paper delivered at the 19th Annual meeting of the NMGS, Warri. Nig, J. Mining Geol.
[8] Orife, J. M; Avbovbo, A. A, 1982. Stratigraphic and uncomformity traps in the Niger Delta. AAPG, Mem. 32: 251-265.
[9] Scheinder, W. A., (1971). Developments in seismic data prospecting and analysis (1968 – 70). Geophysics vol. 36, 1043– 1073.
[10] Scheinder, W. A., Backus, M. M., (1968). Dynamic correlation analysis. Geophysics Vol. 33, 105 – 126.
[11] Sherrif, R. E., (1976). Inferring stratigraphy from seismic data, Am. Assoc. Petrol. Geol. Bull., Vol. 60 528 – 542.
[12] Short, K. C and Stauble, A. J 1967. Outline Geology of the Niger Delta. AAPG Bull.51:761-779

[13] Taner, M. T., Koehler, F., (1969). Velocity spectra-digital computer derivation and applications of velocity functions. Geophysics vol. 34, 859 – 881.
[14] Whiteman,A. J. 1982. Nigeria: Its petroleum Geology, Resources and Potential. London: Graham and Trotman.