International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

Types of Seismic Energy Sources for Petroleum Exploration in Desert, Dry-Land, Swamp and Marine Environments in Nigeria and Other Sub-Saharan Africa

Madu Anthony Joseph Chinenyeze

Department of Geology, College of Physical And Applied Sciences, Michael Okpara University of Agriculture Umudike, Abia State, Nigeria

Abstract: ***The various seismic energy sources used for petroleum exploration in Nigeria (Niger Delta, Benue Trough, Chad Basin) and sub-Saharan Africa (Niger Republic, Sudan, Ethiopia inclusive) have been undergoing improvement over the years. Explosive source usually Dynamite, Airgun, Thumper/Weight Drop, and Vibrators are remarkable seismic energy sources today with frequencies for primary seismic production, bandwidth 10Hz – 75Hz. These sources contribute to higher S/N ratio and greater bandwidth. The spectral analysis of shot records from the afore-mentioned energy sources confirm their corresponding suitability, effectiveness, and adequacy for wave propagation into the ground, until it encountered an impedance in the subsurface. The latter condition results in reflections and refractions which are picked by the receivers or sensors (geophones or hydrophones). The spectral analyses from these selected sources reveal comparable range of signal frequencies. The Thumpers or vibrator shots at any given shot point location SP, is repeated severally for the purpose of enhancement and then summed or stacked. This is also called vibrator sweep, as it vibrates repeatedly according to specification of program issue. In the repetition of frequency sweep, amplitude increases are optimized to a specific level within the same duration. The sweep technique which increases the low-frequency content of the signal, extends the signal bandwidth to below 3Hz in order to greatly improve imaging results at depth. The frequency of the sweep may vary linearly or nonlinearly with time. A linear sweep is that which the plot of the instantaneous frequency against time, produces a straight line. Thus sweep may start at a low-frequency and end at a high frequency (upsweep). A typical vibrator can create signals with a bandwidth from 8Hz to 105Hz. When it is nonlinear maximum displacement sweep, it helps to generate low-frequencies and illuminate deep reflectors (see figure 10). The explosive sources produce greater signal across the entire bandwidth. Increased low-frequency content with the vibrators contributes to improving imaging of deep targets.***

Keywords: Vibrator, seismic energy source, sweep, spectral analysis, signal frequencies

1. Introduction

Seismic energy sources in Nigerian exploration industry are made up of explosive and non-explosive energy sources and other types not strictly conforming to the above two, but pro electrotypes. Seismic energy sources in the wet lands, swampy terrain, and transition zones are influenced or determined by availability of access of the equipment and personnel to the survey areas and are mostly explosive sources. The energy sources on dry land and swampy terrain are predominantly explosives, specifically dynamite, while airguns harboured in boats as gunboats have been conventional for water bodies such as creeks, rivers and the open sea. The desert terrains provided open land fields with little or no vegetation or obstruction of economic trees which made the sites accessible to fleet of bulky vibroseis machines or vibrator trucks.

A seismic source is a device that generates seismic energy into the earth, used to perform both reflection and refraction seismic surveys. A seismic source can be simple such as dynamite or it can be a more sophisticated and specialised airgun shooting boat. Seismic energy sources can provide single pulses or vibrator's continuous sweeps of energy generating seismic waves which travel through a medium such as water or layers of rocks. Some of the waves then reflect back and also refract and are recorded by receivers such as geophones or hydrophones, and subsequently relayed to the Sercel Recording Instrument which multiplexes the data ready for storage in special a format, SEG or Non-SEG.

Seismic vibrators are non-explosive energy sources which function by use of truck-mounted or buggy-mounted hydraulic device with metal-plate centrally positioned or at the truck's centre of gravity, and capable of injecting low-frequency vibrations into the earth. It is one of the viable and popular seismic sources used in reflection seismology in Nigeria, and other sub-Saharan African petroleum exploration countries, including Niger Republic, Sudan, and Ethiopia.

2. Objectives

Seismic energy sources for petroleum exploration purposes serve for investigating for shallow sub-soil structures for engineering sites and to study deeper structures, either in the search for petroleum and mineral deposits or to map subsurface faults. It is also targeted to find out the best energy source for the common environments of desert and dry-land terrain, followed by swamp and marine offshores. The recorded signals are then subjected to geophysical processing to produce stacking information about the subsurface structures.

3. Geologic Setting of Niger Delta

The southernmost and last of the major deltaic complexes constructed in the Benue Trough, the Niger Delta began to form in the Eocene and now contains over 12km clastics which fill the entrance into the Benue Trough. The Niger Delta complex is a regressive offlap sequence which upgraded across the southern Benue trough and spread out onto cooling and subsiding oceanic crust which had formed as Africa and South America separated.

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 pliestocene 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 and shale diapirs provide the traps. Growth faults are very common in the Niger Delta with primary and secondary synthetic and antithetic faults. In the distal offshore part of the delta, petroleum accumulations are also located at the top and flanks of shale diapirs.

Three main formations have been recognised in the subsurface of the Niger Delta complex (Short and Stauble 1967, Frankl and Cordry, 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. Deposits belonging to these three formations are being laid down today and so thickness estimates should be viewed as arbitrary and are dependent on location.

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, 1980).

The present day late Pleistocene deposits sit on top of a great pile of mainly deltaic sediments which have accumulated since late Cretaceous time within the structural constraints defined basically by a complex triple junction system.

4. Types of Seismic Energy Sources

Explosives: Explosives such as dynamite can be used as raw but effective sources of seismic energy. These are commonly used in swamp and dry land terrain of high sedimentary thickness. Dynamite is a chemical composition which burns extremely fast when detonating. It generates high amount of energy, temperature and pressure. It is made up of combination of explosive glyceroltrinitrate and glycoldinitrate as major constituents.

The integrity of dynamite sources has been evaluated and the signals of shot records were differentiated to comprise range of frequencies fundamentally good for seismic primary events displays. They are prepared as charges which are buried in single deep holes (SDH) Explosive sources were used in experimental stage in early development of the exploration industry. Hexa-nitro-stilbene was used as the main explosive fill in the thumper mortar round canisters used as part of the Apollo Lunar Active seismic Experiments. Generally, the explosive charges are placed between 6 and 76 metres (20 and 250ft) below ground, in a hole that is drilled with dedicated drilling of equipment for this purpose. This type of seismic drilling is often referred to as “Shot Hole Drilling”. A common drill rig used for “Shot

Hole Drilling" is the ARDCO C-1000 drill mounted on an ARDCO K4x4 buggy. These drill rigs often use water or air to assist the drilling.

The use of explosive energy sources was discontinued for marine or water operations in Nigeria after the fatality accident in November 1984 (during water shooting operation that involved dropping a stick of primed dynamite in water). Remarkably, explosive sources are subject to strict security regulations, and permission for use and transportation can be challenging and rigorous to obtain, especially in the Northern Nigerian Upper Benue Trough and Chad Basin.

AIR GUN: Airgun is the seismic energy source used for contemporary water or marine operation or data acquisition. It is used for marine reflection and refraction surveys. This is an option when the zone of interest of the well for drilling is on the deeper perspective. The equipment consists of one or more pneumatic chambers that are pressurised with compressed air at pressures from 14 to 21 MPA (2000 to 3000psi). Air guns are in different sizes and installed with varying capacity of guns with redundancy of (gun-pressure tested) guns for backup should there be breakdown. Gun procedures are followed and they are submerged below the water surface and towed behind a marine vessel (or ship). When an air gun is fired, a solenoid is triggered which releases air into a fire chamber which in turn causes a piston to move, thereby allowing the air to escape the main chamber and producing a pulse of acoustic energy. Air gun arrays may consist of up to 48 individual air guns with different size chambers, fired in concert, the aim being to create the optimum initial shock wave followed by the minimum reverberation of the air bubble(s).

Air guns are made from the highest grades of corrosion resistant stainless steel. Large chambers (ie greater than 1.15L or 70cubic inches) tend to give low frequency signals, and the small chambers (less than 70cubic inches) give higher frequency signals (see Figure 1 for varying frequency).

Plasma Sound Source: A plasma sound source (PSS), otherwise called a spark gap sound or sparker is a means of making a very low frequency sonar pulse underwater. For each firing, electric charge is stored in a large high-voltage bank of capacitors and then released in an arc across electrodes in the water. The underwater spark discharge produces a high-pressure plasma and vapour bubble which expands and collapses, making a loud sound. Most of the sound produced has frequency between 20 and 200Hz, useful for both seismic and sonar application. There are also plans to use PSS as a non-lethal weapon against submerged divers (Sheriff, 1991).

Thumper Truck: At the middle of last century, alternative to explosive sources especially in urban portions of a prospecting area, the weight dropping thumper technique was introduced. A Thumper truck (or weight-drop) truck is a vehicle-mounted ground impact system which can be used to provide a seismic source. A heavy weight is raised by a hoist at the back of the truck and dropped, generally about three meters, to impact (or "Thump") the ground. To augment the signal, the weight may be dropped more than once at the same spot, the signal may also be increased by thumping at several nearby places in an array whose dimensions may be chosen to enhance the seismic signal by spatial filtering. More advanced Thumpers use a technology called "Accelerated Weight Drop" (AWD), where a high pressure gas [min 6.9mpa (1000psi)] is used to accelerate a heavy weight hammer (5000kg) to hit a base plate coupled to the ground from a distance of 2 to 3m. Several thumps are stacked to enhance signal to noise ratio. AWD allows both more energy and more control of the source than gravitational weight-drop, providing better depth penetration, control of signal frequency content.

Thumping may be less damaging to the environment than firing explosives in shot-holes (Sheriff, 2002) though a heavily thumped seismic line with transverse ridges every few metres might create long-lasting disturbance of the soil. An advantage of the thumper (later shared with vibroseis), especially in politically unstable areas, is that no explosives are required.

5. Electromagnetic Pulse Energy Source (Non-Explosive)

EMP sources based on the electrodynamic and electromagnetic principles.

Seismic Vibrator

A seismic vibrator propagates energy signals into the earth over an extended period of time as opposed to the near instantaneous energy provided by explosive sources. The data recorded in this way must be correlated to convert the extended source signal into an impulse. The source signal using this method was originally generated by a servo-controlled hydraulic vibrator or shaker unit mounted on a mobile base unit but electro-mechanical versions have also been developed. Vibrators or vibroseis data from an upsweep or down sweep (increasing or decreasing frequency respectively) are added or stacked together and compared with the source input signals to produce a conventional seismic section. The device is used increasingly in land surveys in place of explosive sources. Vibrators carry the force of upto 60,000lbf (267,000 N) and produce a sweep lasting 2 to 20 seconds. The frequency of the sweep may vary linearly or nonlinearly with time. Linear sweeps start at low frequency and finish at high frequency (upsweep). These vibrators characteristically produce signals with a bandwidth from about 8Hz to 105Hz (See figures 2 to 5). Enhancing low-frequency content favours imaging of deep target, because low frequencies are less attenuated and propagate deeper than high frequencies.

Principle: A seismic vibrator transforms the energy provided by a diesel engine into a vibration. It is performed by a shaker, a movable element that generates the vibration thanks to a piston-reaction mass device driven by an electro-hydraulic servo valve. The shaker is applied to the ground for each vibration, then raised up so that the seismic vibrator can move to another vibrating point. Vibrator capacity is defined by the maximum force it is capable to generate called High Peak Force and measured in pound-force. To transmit a maximum force to the ground and prevent the shaker from bumping, part of the weight of the vibrator is applied to the shaker.

Boomer Sources

Boomer sound sources are used for shallow water seismic surveys, mostly for engineering survey applications. Boomers are towed in a floating sled behind a survey vessel. Similar to the plasma source, a boomer source stores energy in capacitors, but it discharges through a flat spiral coil instead of generating spark. A copper plate adjacent to the coil flexes away from the coil as the capacitors are discharged. This flexing is transmitted into the water as the seismic pulse. Originally the storage capacitors were placed in a steel container (the bangbox) on the survey vessel. The high voltages used, typically 3000v, required heavy cables and strong safety containers. Recently, low voltage boomers have become available. These use capacitors on the towed sled, allowing efficient energy recovery, lower voltage power supplies and lighter cables. The low voltage systems are generally easier to deploy and have fewer safety concerns.

Boomer sources are often used for carrying out shallow seismic surveys for investigating the conditions of oil well platform location sites in the waters, especially in offshore Nigerian waters of the Atlantic Ocean.

NOISE SOURCES: Correlation-based processing techniques also enable seismologists to image the interior of the Earth at multiple scales using natural (eg the oceanic microseism) or artificial (eg urban) background noise as a seismic source. For example, under ideal conditions of uniform seismic illumination, the correlation of the noise signals between two seismographs provides an estimate of the bidirectional seismic impulse response.

6. Data Analyses and Discussion

The frequency content of the signals from various energy sources was analysed by application of spectral analyses of the shots from different energy sources. The signal strength in different energy sources varies with strongest modal signatures showing for the dynamite explosive source as 20Hz – 80Hz (see figure 7), followed by the Thumper Truck/Weight Drop energy source 15Hz – 65Hz, Vibrators/Vibroseis 10Hz – 70Hz, Air Gun energy sources within the range 12Hz – 50Hz.

The Thumpers or vibrator shots at any given shot point location SP, is repeated severally for the purpose of enhancement and then summed or stacked. This is also called vibrator sweep, as it vibrates repeatedly according to specification of program issue. In the repetition of frequency sweep, amplitude increases are optimized to a specific level within the same duration. The sweep technique which increases the low-frequency content of the signal, extends the signal bandwidth to below 3Hz in order to greatly improve imaging results at depth. The frequency of the sweep may vary linearly or nonlinearly with time. A linear sweep is that which the plot of the instantaneous frequency against time, produces a straight line. Thus sweep may start at a low-frequency and end at a high frequency (upsweep). A typical vibrator can create signals with a bandwidth from 8Hz to 105Hz. When it is nonlinear maximum displacement sweep, it helps to generate low-frequencies and illuminate deep reflectors (see figures 1-6, 8). The explosive sources produce greater signal across the entire bandwidth. Increased low-frequency content with the vibrators contributes to improving imaging of deep targets.

The ground roll contained in various energy sources inclusive of vibrators is removed or attenuated in the seismic data processing.

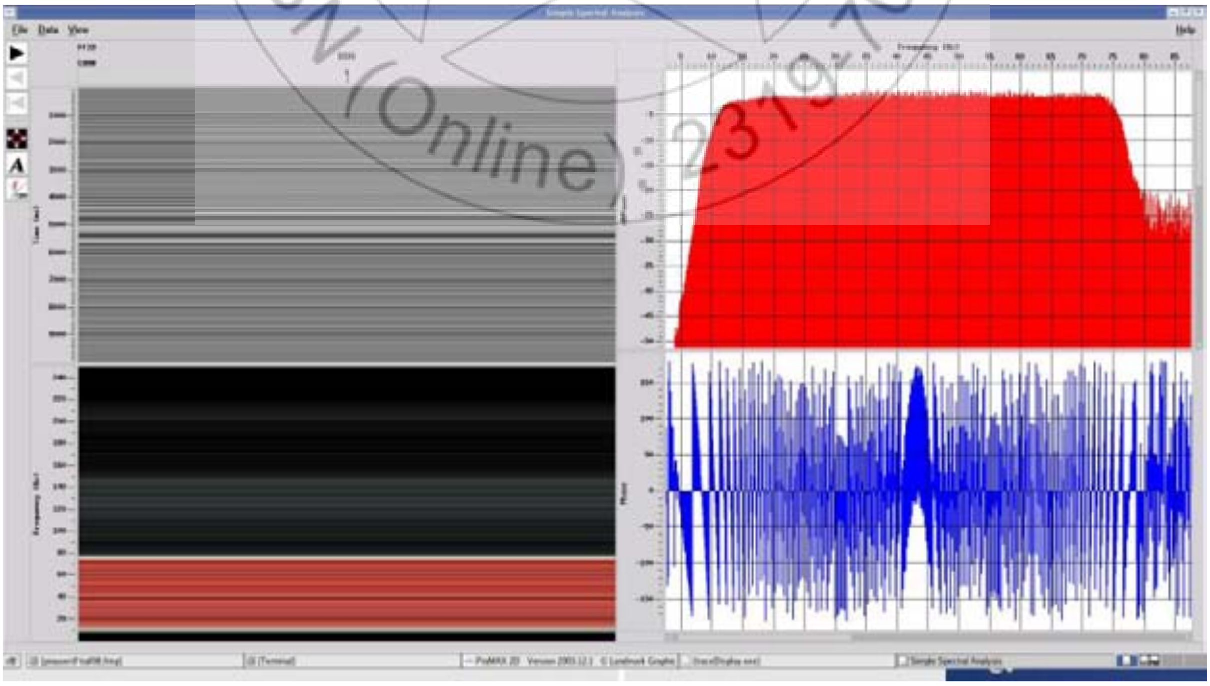

Figure 1: Ground roll contained in the overall frequency content in the various energy sources, but removed or attenuated in data processing

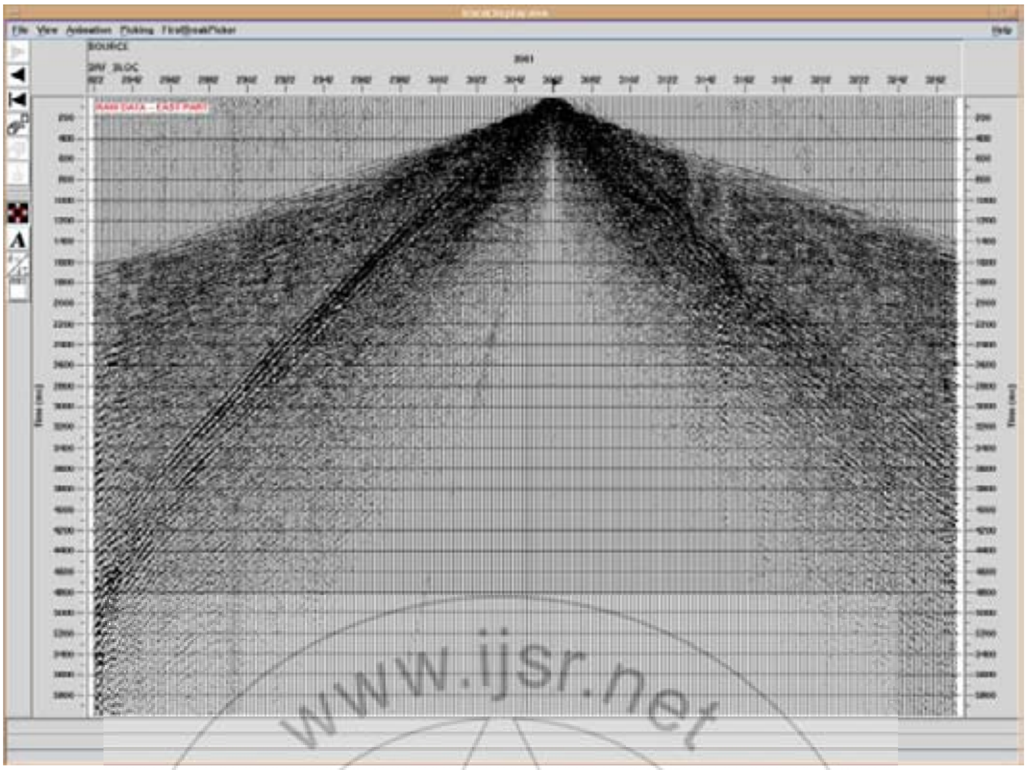

Figure 2: Record of Vibrator shot at full Symmetrical spread of East part of line and accompanying Spectral Analysis below

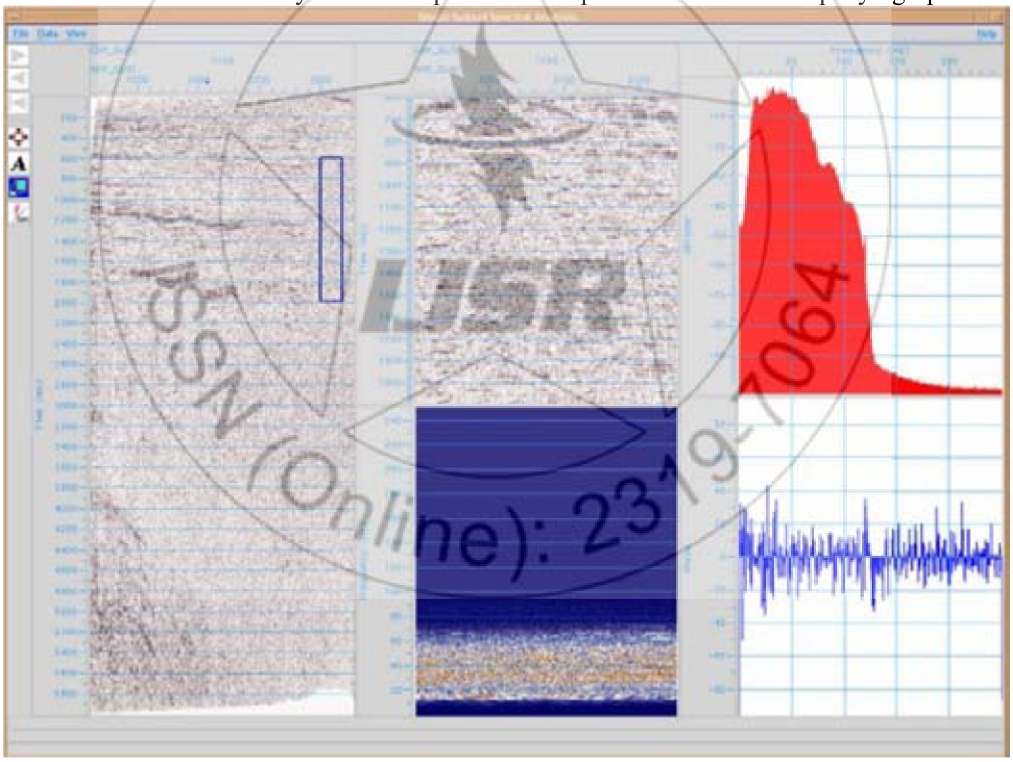

Figure 3: Spectral Analysis of Vibrator record showing frequency content range 20Hz to 115Hz, within the signal's Phase bandwidth -30dB to 50dB

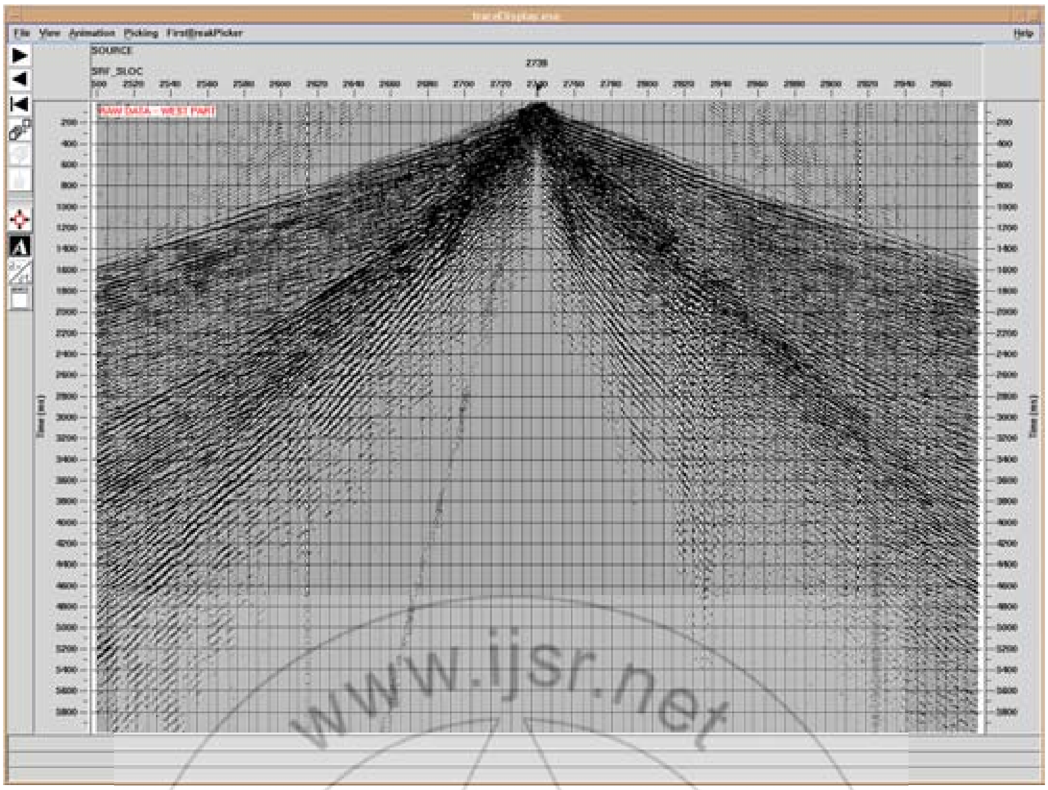

Figure 4: Showing Raw record of Vibrator shot at West part of Seismic line, Symmetrical spread, frequency distribution shown in spectral analysis below.

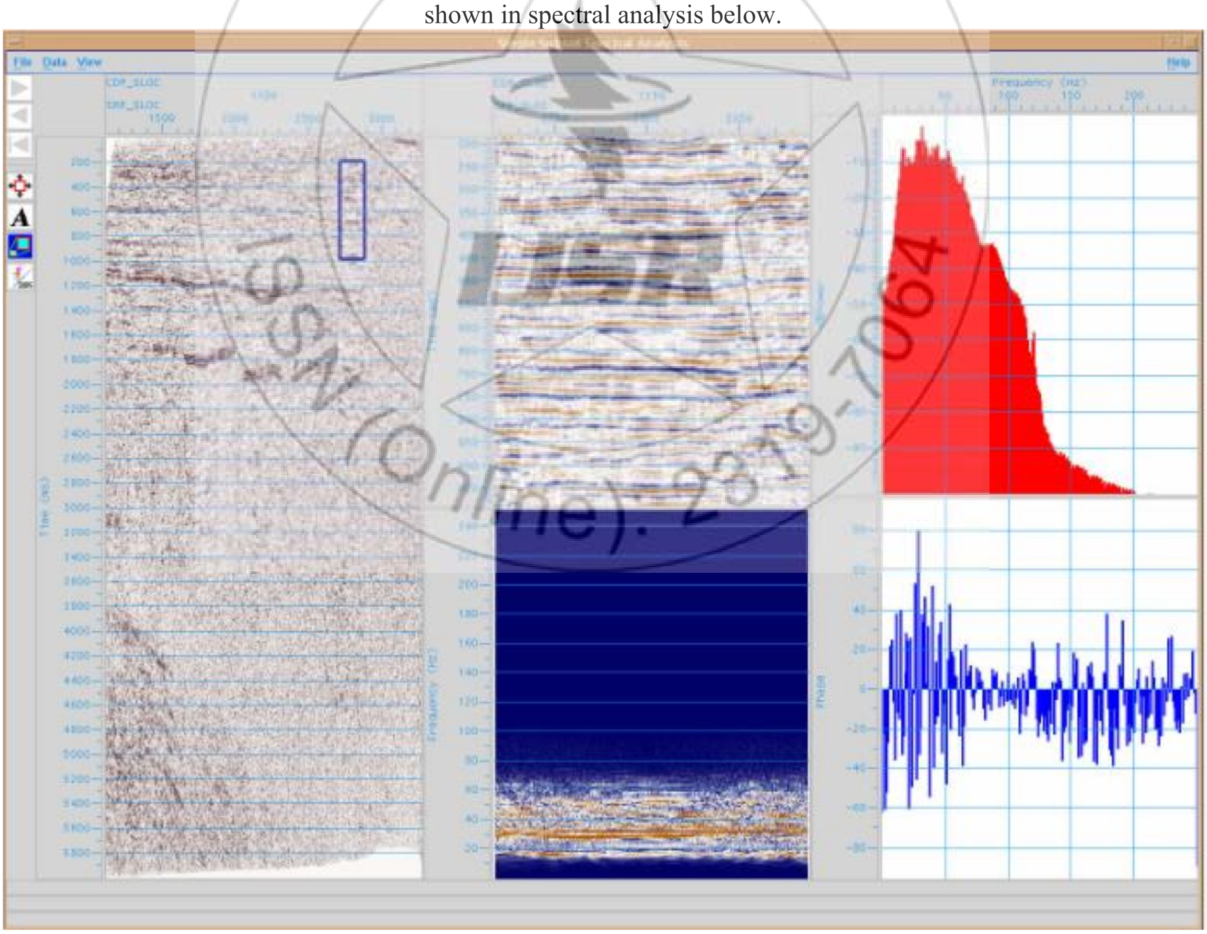

Figure 5: Showing Vibrator maximum frequency content from 18Hz – 110Hz, with accompanying Phase range -40dB to +60dB.

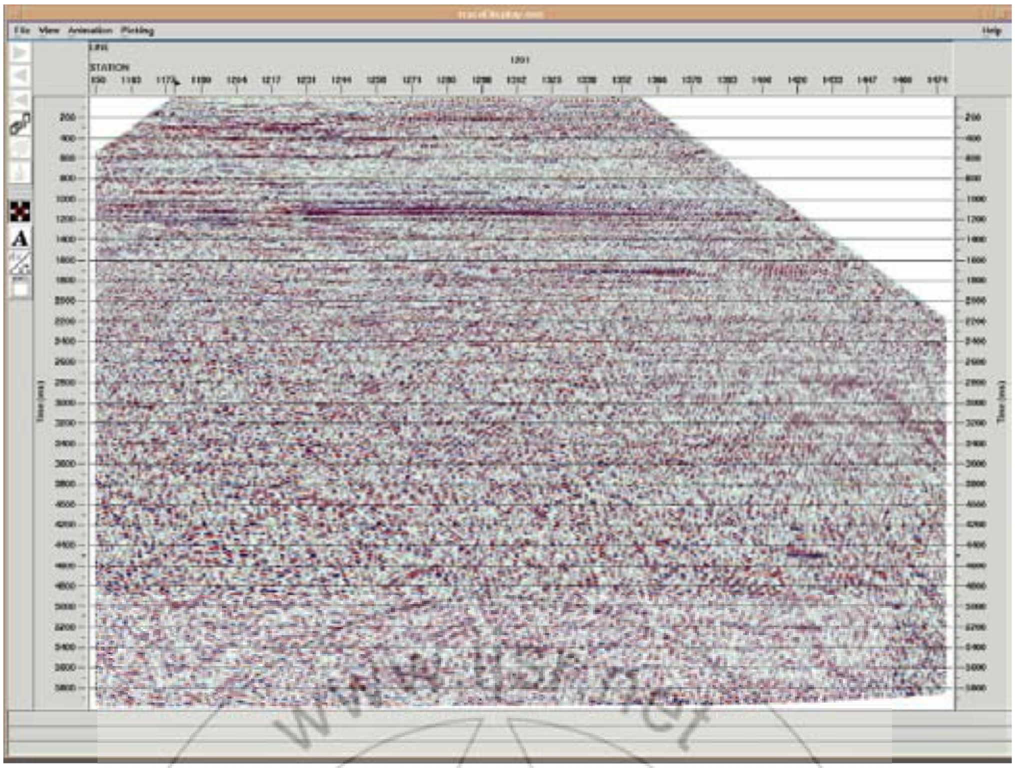

Figure 6: A Brute stack of a Vibrator line, composited the vibe shots of above spectral signatures, showing prominent reflection at time 1000milliseconds where the Phase amplitude was optimum.

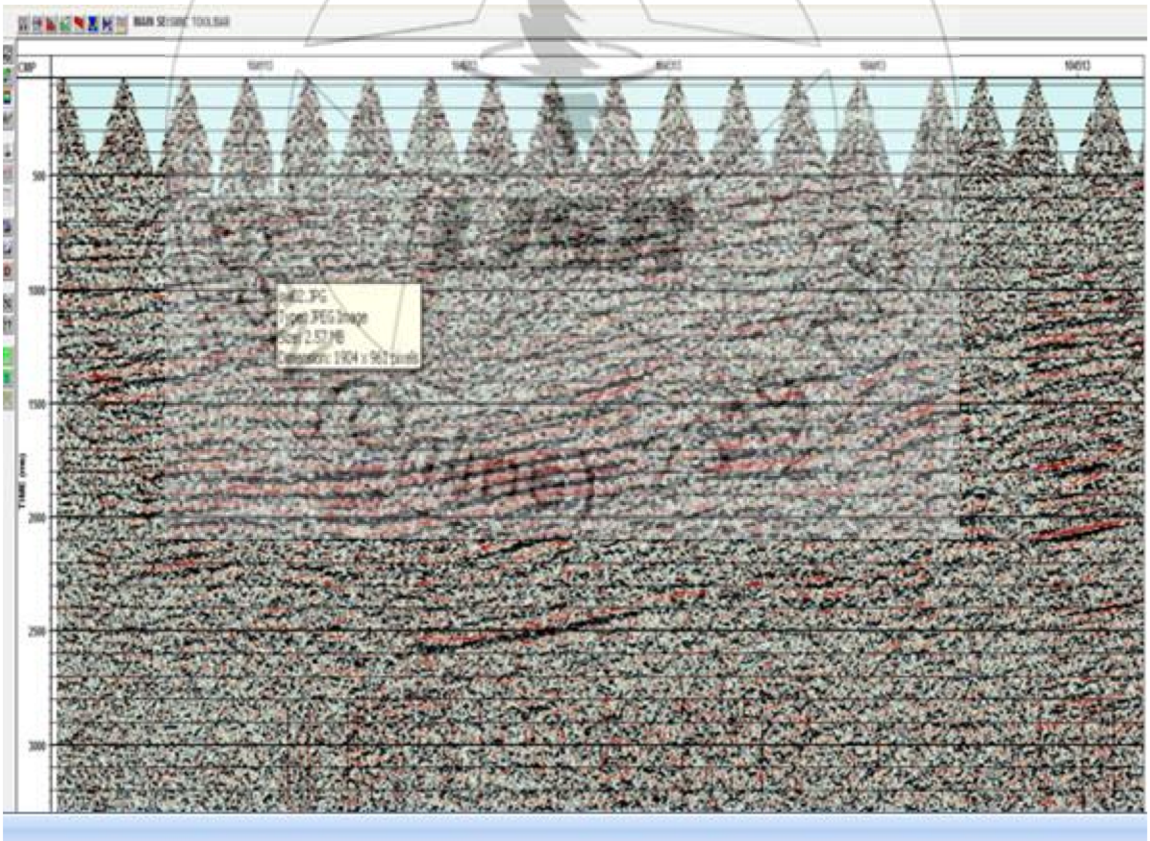

Figure 7: Brute stack of a line acquired with dynamite Explosive energy source, showing structural details, as CDP stacks of different dynamite shots were summed together, or composited.

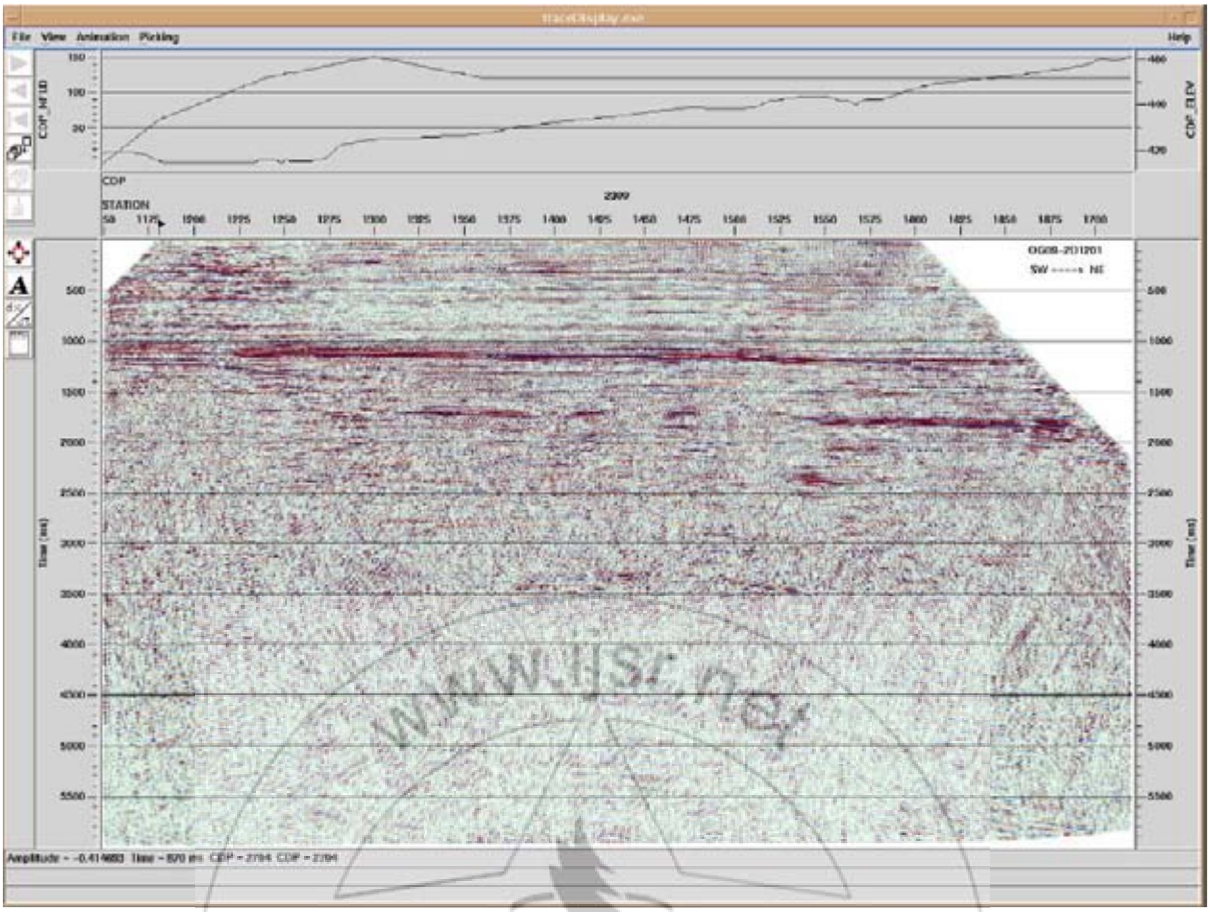

Figure 8: A brute stack showing more detailed structures in the place of explosive energy source, CDP nominal fold of coverage was maintained.

7. Conclusion

The various seismic energy sources used for petroleum exploration in Nigeria and sub-Saharan Africa have been undergoing improvement over the years. Explosive source usually Dynamite, Airgun, Thumper/Weight Drop, and Vibrators are remarkable seismic energy sources today with frequencies for primary seismic production, bandwidth 10Hz – 75Hz. These sources contribute to higher S/N ratio and greater bandwidth. The spectral analysis of shot records from the afore-mentioned energy sources confirm their corresponding suitability, effectiveness, and adequacy for wave propagation into the ground, until it encountered an impedance in the subsurface. The latter condition results in reflections and refractions which are picked by the receivers or sensors (geophones or hydrophones). The spectral analyses from these selected sources reveal comparable range of signal frequencies.

The Thumpers or vibrator shots at any given shot point location SP, is repeated severally for the purpose of enhancement and then summed or stacked. This is also called vibrator sweep, as it vibrates repeatedly according to specification of program issue. In the repetition of frequency sweep, amplitude increases are optimized to a specific level within the same duration. The sweep technique which increases the low-frequency content of the signal, extends the signal bandwidth to below 3Hz in order to greatly improve imaging results at depth. The frequency of the sweep may vary linearly or nonlinearly with time. A linear sweep is that which the plot of the instantaneous frequency against time, produces a straight line. Thus sweep may start at a low-frequency and end at a high frequency (upsweep). A typical vibrator can create signals with a bandwidth from 8Hz to 105Hz. When it is nonlinear maximum displacement sweep, it helps to generate low-frequencies and illuminate deep reflectors (see figure 10). The explosive sources produce greater signal across the entire bandwidth. Increased low-frequency content with the vibrators contributes to improving imaging of deep targets.

References

[1] Bagaini, C., Bunting, T., El-Emam, A., Laake, A., Strobbia, C., 2010. Land Seismic Techniques for High Quality Data. Oilfield Review Summer, 22, no. 2.
[2] Burke, K, C 1972. Longshore drift submarine canyons and submarine fans. AAPG Bull. 56:1975-1983.
[3] Crawford, J. M., Doty, W. E.,N and Lee, M. R. 1960. Continuous signal seismograph: Geophysics, Society of Exploration Geophysicists, 25, 95-105.
[4] Jopling, J. M., Forster, P. D., Holland, D. C.and Hale, R. E. 2004. Low voltage seismic sound source, US patent No 6771565.
[5] Orife, J. M; Avbovbo, A. A, 1982. Stratigraphic and uncomformity traps in the Niger Delta. AAPG, Mem. 32: 251-265.
[6] Robert, E. Sheriff, Encyclopedic Dictionary of Applied Geophysics (Geophysical References No 13) 4th Edition, 2002, 429 pag. ISBN 978-1560801184.

[7] Sheriff, R. E. 1991. Encyclopaedic Dictionary of Exploration Geophysics, Society of Exploration Geophysicists, Tulsa 376p
[8] Short, K. C and Stauble, A. J 1967. Outline Geology of the Niger Delta. AAPG Bull.51:761-779
[9] Whiteman,A. J. 1982. Nigeria: Its petroleum Geology, Resources and Potential. London: Graham and Trotman.