ISSN No:-2456-2165

Theory and Applications of Shallow Seismic Reflection Geophysical Method to Engineering and Groundwater Studies: An Overview

Archibong, G. A., Okeke, O. C., Amadi, C. C., Nwachukwu, H. G. O and Anyanwu, T. C.
Department of Geology, Federal University of Technology, Owerri, Nigeria

Abstract:- Reflection Seismilogy entails the use of generated parcels of elastic strain energy in rocks measuring the travel time through the rock body from a given seismic source to receivers. This parcels of energy travel as P - and S - waves propagated by compressional-dilational uniaxial strain and pure shear strain respectively. Reflections are caused by the propagation of seismic waves from one earth layer to another of significant Acoustic Impedance Contrast with reflection strength increasing with increasing contrast. Recorded Reflection Seismic Data are received and processed to improve the Signal-Noise Ratio (SNR) of the recorded data by attenuating coherent and incoherent noise and provides information about the nature of the sub-surface. Ability to detect shallow faults, bedrock depth mapping, saturated zone mapping and cavity detection makes the shallow seismic reflwction method suitable for groundwater/environmental studies and geotechnical investigation.

Keywords:- *Reflection, Seismic Waves, Acoustic Impedance Contrast, Signal-Noise Ratio and Groundwater Studies.*

I. INTRODUCTION

The reflection seismic geophysical survey method over the course of history has been recognized as an effective form of studying the sub surface with its basic problem being the determination of the respective positions of beds which give rise to reflections on a seismic record (Telford et al, 2001). Seismic survey generally is an extension of the originally understood earthquake seismology (Keary et al, 2002) providing information about the earth layers as the waves propagate through them of which these layers in turn give information about their physical properties and composition. First utilized in the early 1920s, the reflection seismic method, an aspect of the seismic geophysical method has been associated with some of the most profound structural observations (Keary et al., 2002).

Reflection seismic generally entails the use of generated parcels of elastic strain energy in rock measuring the required time for its travel or propagation through the rock from the source to a set of geoohones placed at varying offset distances. From an understanding of the travel time and velocity of the propagated seismic waves, one can reconstruct the path of the seismic waves (Telford et al, 2001). These travelling seismic waves within the rock interact with these rock materials either through refraction, reflection or transmission. The refraction and reflection of this seismic wave provide structural information about the region. In terms of reflection, the incident wave travels downward from the source and at some interfaces back towards the surface with the travel path and total time taken being dependent on the physical properties of the rock through which it is being propagated and this in turn provides desirable information about the region, such as attribute of the beds determined from observed arrival time and from difference in amplitude, frequency, phase and even wave shape.

For subsurface information to be accurately deduced seismic survey have to be conducted and the ground motion caused by unknown source within the given location accurately recorded. Explosion had served as the archetypal seismic source (Keary et al, 2002) but through the course of history more sophisticated sources have been developed such as vibroseis. However for a source to be considered efficient it must be able to generate repeatable but sufficient energy across the broadest possible frequency range which are concentrated in the type of wave energy so required for the specific survey in question and as a rule of thumb ought to be environmentally safe. This ground motion so generated with time constitute a seismogram so detected by a transducer which converts these ground motion to electrical signals being sensitive to these ground motion. These transducers, better known as geo phones and hydro phones depending on their environment, measure the displacement, velocity or acceleration of the ground particles as the waves passes through them causing oscillations. These seismograms are recorded on seismographs by multiple transducers simultaneously at varying offsets so as to ascertain the speed and direction of the waves.

Recorded seismic signal for the reflection method commonly utilizes the "common mid point" gather technology involving roll-along data acquisition. The data is usually large in nature and proves multi fold illumination of points along its reflection line. Its processing, a multi stage process retailing the use of specialised softwares with the resulting time section providing reliable information about the sub surface (Brouwer and Helbig, 1998; Shitvelman 2002).

ISSN No:-2456-2165

The high resolution of the shallow reflection method has so far been the best method of shallow subsurface investigations due to short dominant wavelength, possessing a small Fresno radius which results in high lateral and vertical resolution and as such has found a wide range of applications from environmental, geotechnical, groundwater related investigations to engineering constructions.

II. BASIC THEORY OF SHALLOW SEISMIC REFLECTION METHOD

A. Seismic Waves and Seismic Wave Velocity

When a disturbance to the region within which the seismic survey is to be conducted occurs, say an explosion due to a seismic source, parcels of elastic strain energy in the form of seismic waves are propagated from the seismic source outwards. The external force applied on the rock body due to the explosion sets up internal forces within the rock body which balances the external force, resolved into a component of normal stress perpendicular to the surface and components of shear stress, altogether resulting in a deformation. The internal forces set up refers to the stress and the deformation which occurs is the strain. The ratio between the stress and strain defines the elasticity of the solid rock and the propagation of seismic waves in turn defines the elastic property of the rock (Telford et al, 2001). A body is said to be elastic if its deformation is reversible with the body returning to it's original size and shape when the stress is removed. According to Hooke's law, a body subjected to stress undergoes strain, the strain is reversible being directly proportional to the stress. Beyond the value of yield strength, the strain becomes nonlinear and somewhat irreversible, better known as plastic or futile strain. If the value of the stress in creased beyond this region, the rock body fractures, known as a fracture point. Image 2 below shows the stress-strain curve for a rock body.

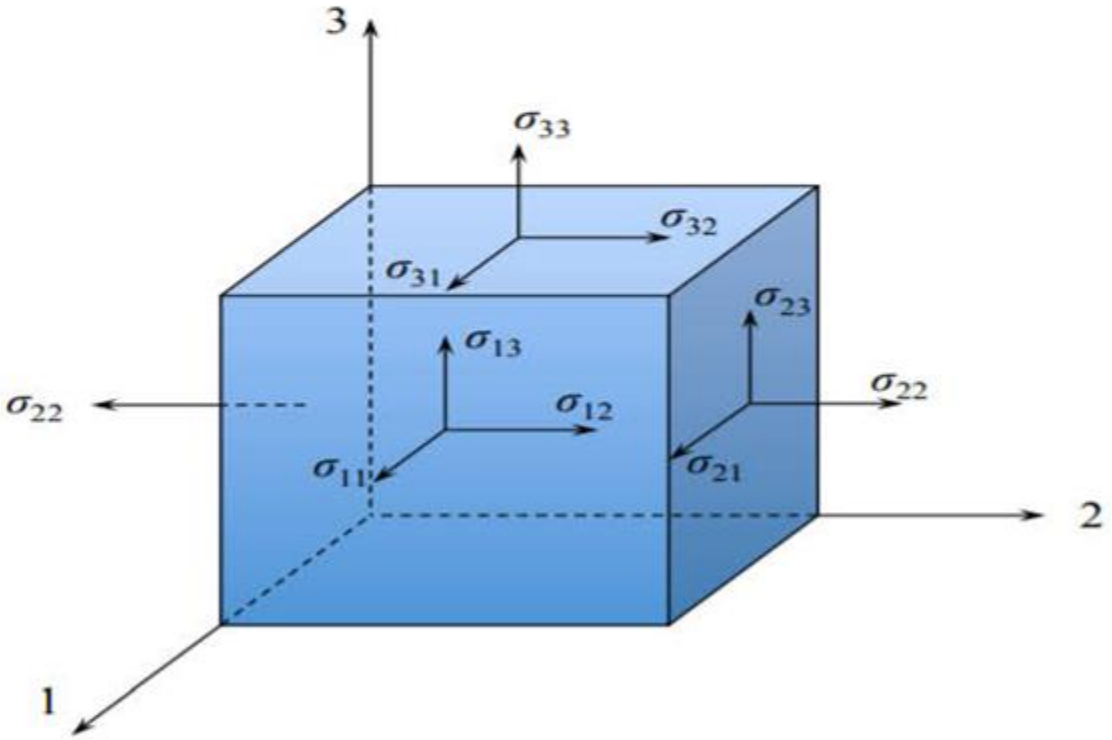

Fig 1:- Components of Stress (Source:www.researchgate.net)

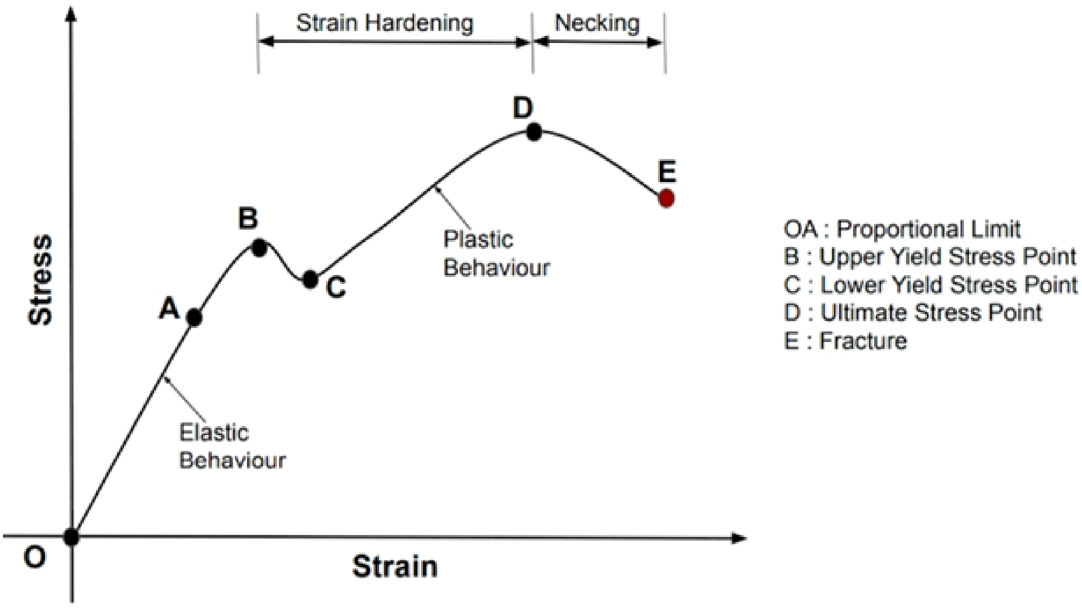

Fig 2:- Stress-Strain Graph (Source:www.researchgate.net)

The stess-strain relationship for any given rock body is specified by its various elastic modulli which describes the ratio of a given type of stress against the resultant strain (See equation 1 through 4). With a minor exception of its immediate point of impact, strain exerted by seismic sources are considered elastic thus facilitating the calculation of the velocity of propagated seismic waves from the elastic modulli and the density of the materials through which it is being propagated (See Keary et al (2002) for more details.)

$$Young's\ Elastic\ Modulus\ (E) = \frac{(Longitudinal\ Stress)}{(Longitudinal\ Strain)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\text{Bulk's Modulus (K)} = \frac{\text{Volume Stress } (\rho)}{\text{Volume Strain } \frac{\Delta v}{v}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\text{Shear Modulus (U)} = \frac{\text{Shear Stress } (\tau)}{\text{Shear strain } (\tan\theta)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$\text{Axial Modulus} = \frac{\text{Longitudinal Stress } (\frac{F}{A})}{\text{Uniaxial Longitudinal Strain } (\frac{\Delta L}{L})} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Two categories of seismic waves exist which are body waves, which travels through the internal volume of an elastic solid, and surface which travels along the boundary of the solid. With respect to the seismic geophysical method, primary interest lies with the body waves, with the surface waves constituting more seismic noise. Based on their form of propagation, body waves are subdivided into congressional/Longitudinal/P-waves and Shear/Transverse/S-Waves which travel by pure shear strain in a direction perpendicular to the direction of wave travel.

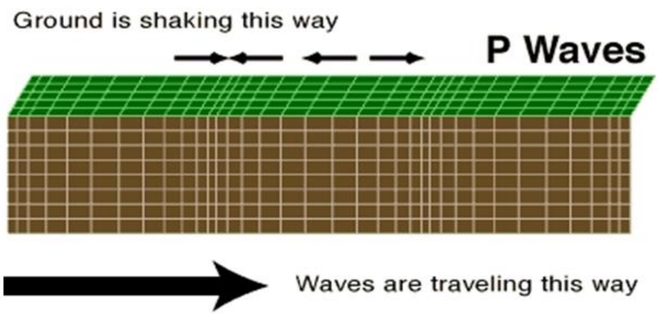

Fig 3:- P-Wave Travel (Source: www.Fandom.com)

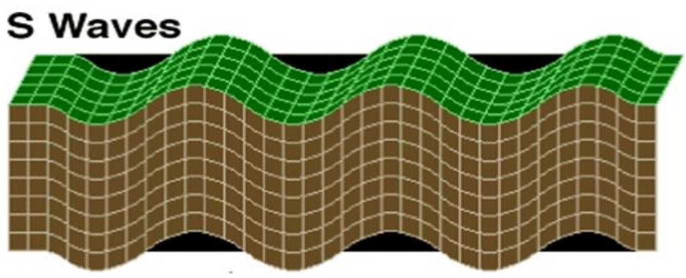

Fig 4: S-Wave Travel (Source: www.Earthquake. Uses.gov)

Equations 5a and 5b below gives the Velocity of the P-waves and S-waves respectively from the elastic modulli.

$$V_p = (\frac{\psi}{\rho})^{\frac{1}{2}} = (\frac{K+\frac{4}{3}\mu}{\rho}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5a)$$

$$V_s = (\frac{\mu}{\rho})^{\frac{1}{2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5b)$$

Where; V_P = Velociry of P-waves
V_s= Velocity of S-waves
ψ= Axial Modulus
K = bulk modulus
μ= Shear Modulus
ρ= Density

ISSN No:-2456-2165

As a generally accepted knowledge, fluids such as liquids and gases possess no shear Modulus thus μ=0, as such, if these seismic waves are propagated through a liquid layer their velocities will be given by equation 6a and 6b.

$V_P = (\frac{k}{\rho})^{\frac{1}{2}}$.. (6a)

V_s = 0... (6b)

If a seismic wave travels through a homogeneous body, it would travel at the same velocity in all directions away from its source or point of origin with this velocity known as its propagation velocity. Rock bodies differ in densities as well as composition, texture porosity, amount and type of fluid contained as a result this, difference in elastic modulli which in turn produces varying seismic velocities. Therefore, these velocities give an indication of the nature of the lithology and fluid but however are extremely useful for depth determination.

According to Keary et al (2002), the following findings hold true for seismic wave velocities:

- The compressional wave velocity increases with confining pressure, rather rapidly within the 100Mpa
- With increased depth of burial and age, progression compaction due to overburden pressure and fermentation results in increased seismic wave velocity for sandstone and shale.
- For most sedimentary rocks the compressional wave velocity is directly related to density (Sherriff and Galdart 1983).
- The presence of gas in sedimentary rocks reduces the elastic modulli.

B. Seismic Reflection

Within the earth's subsurface, rocks are layered with boundaries. For this method, homogeneous layer and definite boundaries are assumed in order to design a working principle albeit this is almost never the case. These layers possess different physical properties and elastic modulli which results in a change of propagation velocities at interfaces of these layers. At these rock interfaces, seismic waves either get reflected, transmitted or refracted.

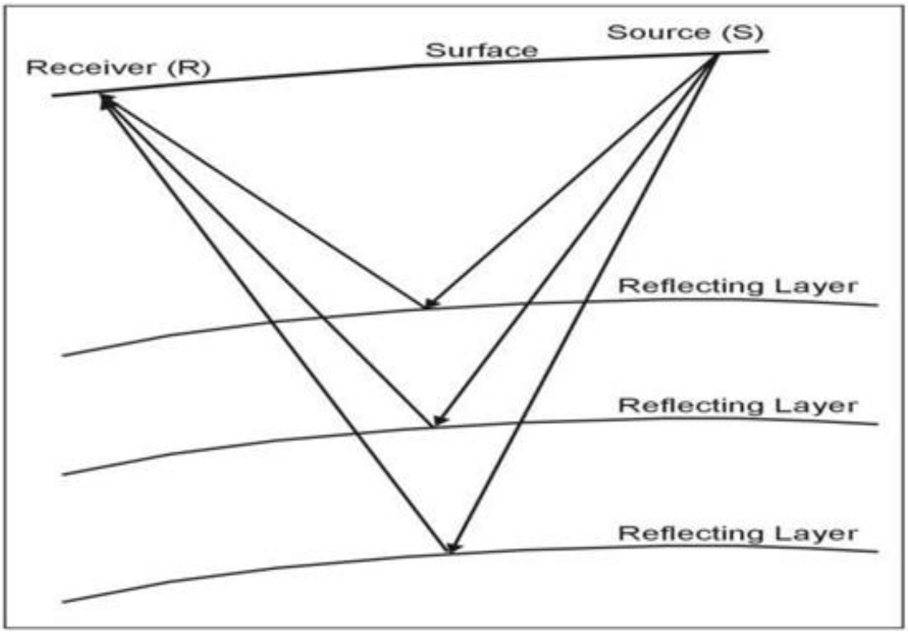

Fig 5:- Reflection Ray Paths (Source: www.archive.epa.gov)

The acoustic impedance of a rock is given by the product of the density of the rock and the seismic wave velocity . The contrast in acoustic impedance of the different layers of the rocks is responsible for the reflection and refraction of seismic waves at these interfaces.

Acoustic impedance (Z) = P×V…………….... (7)

With the intensity of the reflection or refraction increasing with increase in contrast. Given by equation 8, the reflection coefficient R, gives a numerical value of the effect of an interface on wave propagation.

$R = \frac{A_1}{A_0}$…………………………………………..... (8)

Where; R= Reflection coefficient
A_1= Amplitude of reflected wave
A_0= Amplitude of incident wave

Zoepprits (1919) derived the Zoepprits equation (Equation 9) which represents the reflection coefficient in terms of physical properties (Sheriff & Geldart 1982; Keary et al 2002).

ISSN No:-2456-2165

$R = \frac{\rho_2 V_2 - \rho_1 V_1}{\rho_2 V_2 + \rho_1 V_1} = \frac{Z_2 Z_1}{Z_2 Z_1}$... (9)

Where; ρ_1= Density of Layer 1
ρ_2= Density of Layer 2
V_1=Seismic Velocity of Layer 1
V_2=Seismic Velocity of Layer 2
Z_2=Acoustic Impedance of Layer 2
Z_1=Acoustic Impedance of Layer 1

Gardner et al (1974) and Meckel & Nath (1977) both explained the possibility of estimating reflection coefficient from velocity data as shown by equation 10

R = 0.625 on (V_1/VV_1)... (10)

C. Reflection Seismic Ray Paths

Strictly along the vertical axis and ignoring lateral velocity, changes due to heterogeneity, the propagation and reflection of seismic waves at different interfaces as is shown by the image below.

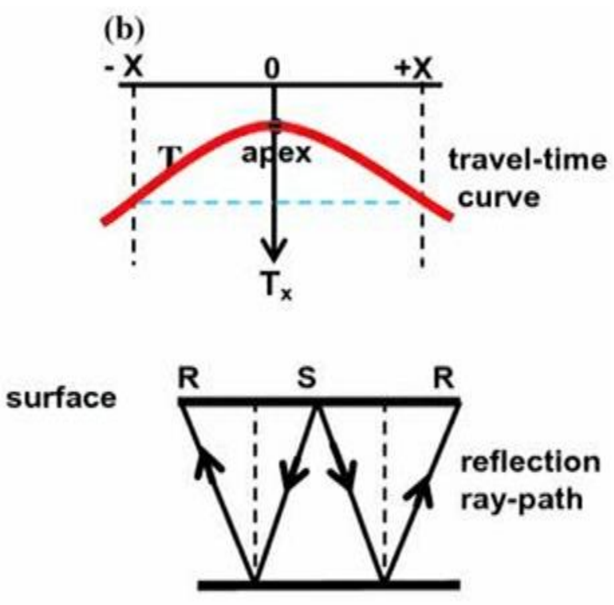

Fig 6:- Seismic Source and Receiveraat Offset Distance (Source:link.springer.com)

If the thickness, velocity and travel time for each layer is given respectively by Zi, Vi and Ti, the velocity for a given layer can be given as:

$V_i = \frac{Z_i}{\tau_i}$.. (11)

Therefore, the average velocity of a given number of layers, say N-layers would be given by;

$V = \frac{\sum_{i=1}^{n} Z_i}{\sum_{i=1}^{n} \tau_i}$....................................... (12)

The time it takes for a seismic wave to travel down through N-given layer to a given reflector and back to the surface is known as a two way time. If it is known and the total thickness of the N-layer is known, the average velocity can be given as:

$V_i = \frac{Z_n}{\tau_n}$.. (13)

Keary et al (2002) gave a detailed explanation of 3 unique reflector scenarios: Single Horizontal reflectors, Sequence of reflector and Dipping reflector. Consider Image 7 below:

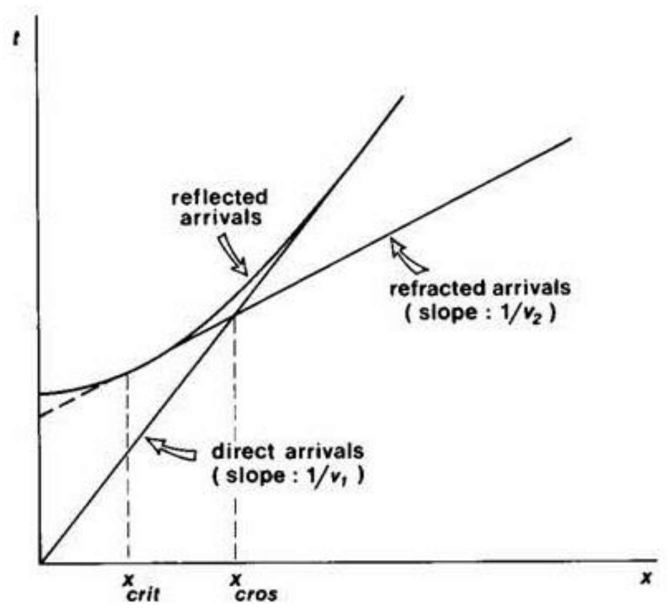

Fig 7:- Seismic Reflection Time-Distance Graph (Source: www.ucl.ac.uk)

If seismic detectors are placed at a horizontal distance from the source, known as offset distance, the equation for the travel time (TWT) through this layer is given by equation 14.

$t = \frac{(x^2+4Z^2)^{\frac{1}{2}}}{V}$....................................... (14)

Such that if the source and detector are placed at the same point, the offset distance x becomes zero making the equation:

$t_2 = \frac{2Z}{V}$.. (15)

From equation 14, it is observed that the travel time "t" measured at varying offset distance will vary. Keary et al defined "Moveout" as the distance between the travel times t_1 and t_2 of reflected ray arrivals recorded at two offset distances x_1 and x_2 respectively. Normal Moveout (NMO) on the other hand implies the difference in travel times of reflected ray arrivals at offset distance; consider the image shown in image 8, the curve is a hyperbolic curve whose axis of symmetry is the time axis. (For further reading see Keary et al (2002) and Telford et al, (2001).

The principle seismic reflection assumes the earth to be homogeneous with only one reflection at the interface between say layer 1 and layer 2. However, within a given layer, say layer 1, there could be multiple reflection before the seismic waves gets to the interface due to the heterogeneous nature of the earth. Such reflections are known as reverberations or multiples and usually possess lower amplitude due to energy loss at each reflection. Two types of multiples with high amplitude are ghost reflection and water layer reverberations. Image 9 below shows different short and long ray path multiples. During processing of reflection seismic data, the correct identification of these multiple is essential to prevent serious errors.

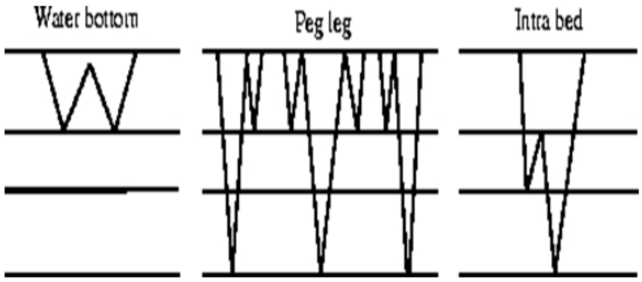

Fig 8:- Seismic Multiples (Source:Sepwww.Stanford.edu)

III. REFLECTION SEISMIC DATA ACQUISITION AND RESOLUTION

The acquisition of seismic data generally entails the generation of seismic pulse from a suitable seismic source, its detection is the ground using a transducer and the display of these recorded signals on a seismograph.

A. Seismic Sources

A seismic source entails the sudden release of energy to the immediate surrounding medium. Keary et al (2002) cited some vital requirements of any seismic source, they include:

1. A suitable source should be able to provide sufficient energy to a large frequency range.
2. The energy of the seismic source should be concentrated in the type of wave energy so desired from the proposed seismic survey, as other wave types would tend to degrade the seismic data.
3. The waveform of the seismic source should be one which is repeatable such that seismograms so generated by these sources at varying locations are comparable with observations variations as a result of heterogeneous nature of the earth and not based on variations of seismic sources
4. Chosen seismic sources should be environmentally friendly and efficient while being cost effective simultaneously.

Various seismic sources exist in modern day, each possessing different frequency band. Most seismic sources possess frequencies ranging from about 1Hz to a few hundred Hz. Some of the most common seismic sources include:

- **Explosive Sources**: This form of seismic source is preferably used on land. Here dynamite and other forms of explosives are detonated within drug shallow holes known as shot holes for improved energy transmisson and reduced surgical damage. The preparation of these shot holes as such makes them somewhat slow to use as thses holes need to first be drilled with their use rapidly declining with time. They provide a wide frequency spectrum, relatively cheap and highly efficient but however usually require special permission for the use, difficulty in its storage and transportation and above all do not provide repeatable seismic waveforms is required for reflection surveys at sea and by modern processing techniques are but a few of its challenges.

- **Vibroseis**: Vibroseis consists of truck mounted vibrators which provide vibrations of continuously varying frequency and low amplitude called sweep signals with frequency ranging from about 10 to 80 Hz, lasting for seconds. The characteristically low amplitude of seismic signal from thses sources reduces the Signal-to-Noise Ratio (SNR). To improve this, while shortening the pulse length these signals are cross correlated with the original sweep signal produced by the vibroseis. The vibroseis provides a quick and convenient source, with repeatable signals, best suitable for hard ground as such can be easily utilized in urban settings with multiple sweep being utilized to increase the SNR. The major set back associated with this Source being that is is not cost effective.

- **Mini-Sosie**: This utilizes a Pneumatic hammer which renders blows to a metal base plate at random, delivering a low amplitude signal to the ground. The source signal is recorded by detectors at the base plate and used to cross correlate as in the case of the vibroseis with its field recording of reflected arrivals of the signals from the subsurface, where peaks within the cross correlation indicate the position of signals that have been reflected.

- **Thumper/Weight Drops**: This was one of the earliest non-explosive seismic sources which was widely accepted where a rectangular steel plate of about 3000kg is dropped from a height of 3m. They have been produced in various forms serving as fast and efficient but relatively low energy sources. On the plate a sensor is typically attached, determing the instant of impact. Variations of these are especially suitable for shallow penetration survey for engineering purposes (McCann et al 1985)

- **Air Gun**: Specifically designed for use within marine environments discharging very high pressure air of about 10 to 15 Mpa into the water (Giles, 1968; Schulzegattermann, 1972; Telford et al 2001; Keary et al, 2002). The air is fed through a hose from a shipboard compressor and discharges through vents as high pressure bubbles when triggered electrically. These bubbles tend to oscillate at a frequency which falls within the seismic frequency range which facilitates in lengthening the source pulse. If detonated at close proximity to these water surface, the effect of these bubbles can be suppressed as gas bubbles resulting in a weakened seismic pulse. Mixture of different gun size, mostly used in parallel, to give a broader spectrum. Several variations of the air gun have been made in an attempt to improve efficiency (Mayne & Quay, 1971).

- **Water Gun**: These are imploded, somewhat a variant of air gun which generates a region of extremely low pressure and the collapsing water generating seismic waves. The water gun generally avoids the bubble pulse problem with the compressed air used to drive a piston that rejects a jet of water into the surrounding water body (Keary et al, 2002). A vacuum cavity is thus created due to hydrostatic pressure existing within the water body generating the seismic shock waves without the nuisance of air bubbles which this gives a potentially higher resolution.

A wide range of several other seismic sources exist from marine vibroseis to sparklers, boomers, pingers, rifles/shot guns, etc. (Baeton et al, 1988; Safar, 1984; Willis,194; Telford et al, 2001; Keary et al, 2002).

B. Seismic Detectors

These are devices which are sensitive to ground motion converting these motion into electrical signals recording the required range of frequency and amplitude with relatively high accuracy. The transport of these seismic energies from their sources outward is basically 3 dimensional, of which vertical velocity component is highly sensitive to P-waves in relation to S-waves and surface waves. Seismic detectors are of two basic types, geophones used on land and hydrophones used on water saturated grounds such as swamps.

- Geophones: Modern day Geophones are made up of moving coil Electromagnets where cylindrical coil is suspended within the magnetic field of a permanent magnet duely attached to the instrument casing, with the magnetic poles of the magnet separated by a slot with a cylindrical pole piece within the coil and its annular pole space surrounding the coil. The suspended coil sets up an oscillator system with a resonant frequency given by the mass of the coil and the stiffness of its suspension such that when the ground moves vertically, the magnet moves with it but the coil remains fixed, so long as the geophone has been duely fixed into the soft ground or firmly mounted on hard, during the propagation seismic waves. The relative motion between the moving magnet and the stable coil results in the generation of a voltage between the terminals of the coil (Sheriff & Geldart, 1982; Telford et al, 2001). Responsive only to the vertical motion, the magnet stays fixed relative to horizontal motion. This geophone motion can be said to be damped as the flow of electric current through the coil generates a separate magnetic field which interact with the magnetic field of the permanent magnet which can be controlled with the setup of shunt resistance across the terminals of the coil controlling the amount of current flowing through the coil.

Its output waveform designed to mirror the ground, insufficient damping of the geophone produces an oscillating waveform at the output and excessive damping generally reduces its sensitivity as such typically arranged to be about 0.7 of the critical value at which oscillation would just fail for an impulsive mechanical input, having a flat frequency response and minimal phase distortion within the frequency range of interest (Keary et al, 2002).

The output voltage of a geophone said to be directly proportional to the strength of the magnetic field of the permanent magnet, the radius of the coil, the number of turns on the coil and velocity of coil relative to magnet.

- Hydrophones: These are made up of piezoelectric elements which utilizes the fact that applying pressure to certain substances produces an electric potential difference proportional to the pressure variation between two surfaces associated with the passage of a compressional seismic wave through water with the synthetic piezoelectric materials like barium zirconia, lead metaniobate or barium titianate commonly used. Arranged in pairs to facilitate the cancellation of translational acceleration and addition for pulse through their output alongside impedance matching transformer to accommodate for this high electric impedance. Hydrophones are usually mounted in a long steamer by distributing them along an oil filled plastic tube arranged to have neutral buoyancy manufactured from materials with an acoustic impedance close to that of water to facilitate good transmission of seismic energy to the hydrophones and towed behind the ship at a depth range of 10m to 20m (Badenbender et al, 1970; Berni 1983; Telford et al, 2001). Dead section are included between hydrophone groups to give the desired spread length with the last group of hydrophones followed by a buoy used to determine the drift of the steamer away from the track of ship due to water currents and to facilitate its recovery should the steamer be accidentally broken.

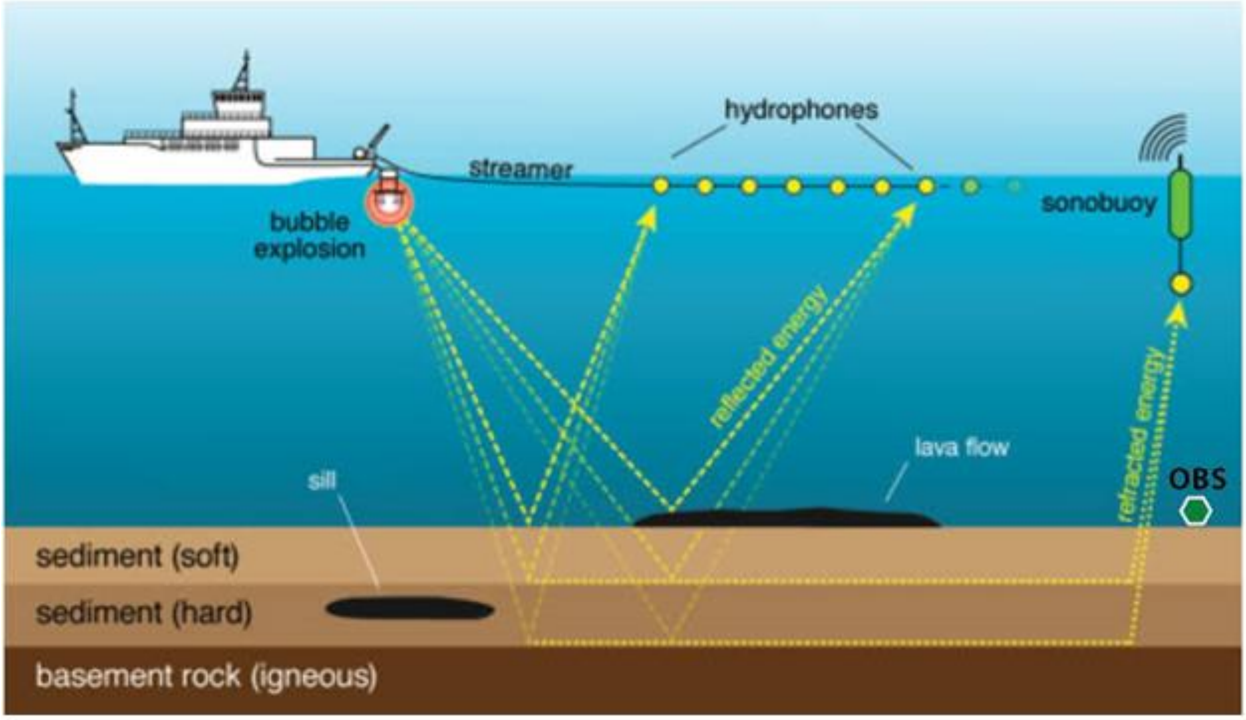

Fig 9:- Hydrophones and Streamers (Source: www.blogs.oregonstate.edu)

Keary et al (2002) stated three technical aspects of recording a seismogram which includes:

- Accurately timed recording relative to the seismic source: During seismic survey, the desired accuracy of the timing generally has to be greater than one millisecond and maybe upto 0.1 millisecond for small scale seismic surveys with its greatest issue being how to determine the exact instant when the seismic source initiated the seismic wave.
- Simultaneous use of multiples transducers for seismogram recording in order to ascertain the subsurface path of the seismic energy by determing the direction from which the seismic wave arrived and measuring small changes in time as the wave moves through them.
- The electrical signal must be amplified, filtered if need be, recorded in real time and stored for future use as described by international standards given by the Soceity of Exploration Geophysicist (SEG).

C. Reflection Seismic Resolution

The resolution of a seismic signal refers to a limit below which a given seismic signal would not pick up certain details within the subsurface reflection seismic surveys have specific depth of penetration and degrees of resolution of subsurface features in terms of both the vertical and horizontal dimensions.

The vertical resolution of reflection seismic survey refers to the degree to which a given seismic signal recognizes individual, closely spaced reflection reflection. The vertical resolution is controlled by the pulse length of the recorded seismic section. For a reflected pulse the vertical resolution would be between the range of one quarter and one eighth of its dominant wavelength. Assuming a wavelength of 80m, its vertical resolution is expected to be around 20m. Vertical resolution generally reduces with increases in depth due to the loss of higher frequencies by absorption and higher velocity by sediment compaction although this can generally be improved by deconvolution seismic data processing.

The horizontal resolution of a given seismic signal is generally determined by two criteria, the reflection process and the offset distance. The seismic reflection ray path consist of an infinite number of back scattered ray which constitute the reflected signal due to interference of energy within half an wavelength of the initial reflected arrival. The section of the reflection interface from which this energy is returned is known as a Fresno zone (See Image 10).

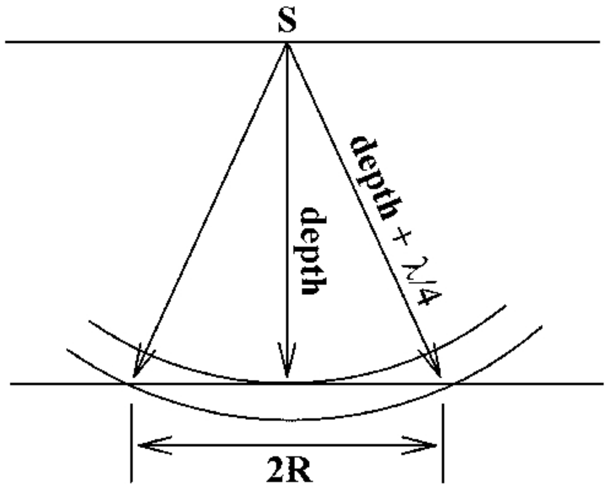

Fig 10:- Fresnel Zone. (Source: www.researchgate.net)

ISSN No:-2456-2165

As earlier stated the horizontal resolution of a reflection survey is affected and partly determined by the spacing of the individual depth estimates from which the reflector geometry is reconstructed and generally understood that the horizontal length of a given reflector within the subsurface is half the offset distance. As such detector spacing are kept small to enable correlation of a given reflection from the same interface.

Although considering the offset distance, the Fresnel zone represents an absolute limit on horizontal resolution since reflector separated by a distance smaller than this cannot be individually distinguished.

D. Design of Reflection Seismic Surveys

Seismic detectors tend to consist of a group of geophone on hydrophone (depending on the environment organized in a given pattern to produce a spread and connected together in series or parallel to produce a single channel of outputs with the effective offset measured from the source to the centre geophone. Some of the basic reflection spread are split dip spread, end-zone spread, split dip spread with end on tap, in line offset spread, broadside T spread and Cross spread (See Telford et al, 2001). In split dips shooting which has the source at the center of a line of regularly spaced geophone, a hotpoint is created as the geophone nearest to the source point are not used. The end on spread has the source at the end, and when offset an appreciable distance of about 680m, it creates an online offset spread.

Whereas the term spread concentrates on the relative position of the source to the center of the geophone group, the term arrays is used to describe the geophone pattern that feeds a single channel. Arrays considers the different location of sources for which the results are combined by vertical stacking. Constructive interference is recorded for a wave approaching a geophone in the vertical direction and destructive interference in the case of a horizontal direction of waves, being linear when the geophones are along a seismic line and a real when distributed over a region.

It is however important that the reflection spread and geophone array used be carefully selected as a means of filtering out coherent noise and improving the SNR.

E. Multichannel Seismic Reflection Survey: Common Mid Point

The common midpoint (or common depth point) is the standard method for multichannel seismic surveying. Here multiple shot detector spreads are used to profile a given region such that no two reflected ray paths sample point within a given shot depth or subsurface reflector. Each shot detector traverse is known as a fold (Keary et al, 2002: Telford et al, 2001; Maybe, 1962; 1967). The number of folds range from 24, 30, 60 or in some special cases 1000 and is usually expressed as a percentage. The folds of a CMP is given by the equation 16 below:

$$\text{Folds} = \frac{N}{2n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

Where;
N=Number of geophone arrays along a spread.
n= Number of geophone array spacing by which the spread is moved forward.

After correction for Normal Movement using a stacking velocity, these seismic traces are stacked in order to improve the SNR, allow a given reflection point F to be sampled multiple times.

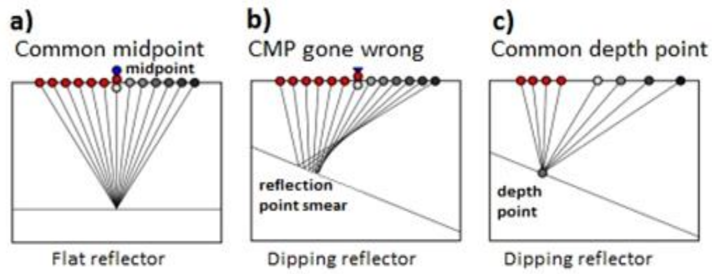

Fig 11:- Common Mid-Point (Source: www.researchgate.com)

F. Reflection Seismic Data Processing

Seismic data processing refers to the act of improving the SNR of a given data set through various activities. The usefulness of seismic data largely depends on the quality of the seismic record. Leaving outside extremes, regions of excellent reflections and regions of no reflection, for most seismic records the quality and quantity of the seismic data has to be improved to yield viable information. A seismic signal refers to an event on a seismic record which we wish to obtain information from while the term noise connotes everything else in the seismic record that is not a signal. The SNR describes the ratio of signal to the ratio of noise within a given portion of a seismic record.

Seismic noise are basically of two types, coherent and incoherent noise. Coherent noise usually consist of noise with pattern that is repeatable through a couple of seismic traces in a given direction, while incoherent depicts the random, unpredictable noise.Coherence, direction and respectability are the basis for data processing which attempts to attenuated the noise contained in a seismic record.

The spread array design utilized in seismic reflection survey is usually the first step towards improving the SNR as the array design can be used to cancel out certain coherent and incoherent noise. For coherent noise, cancellation based on array design, spacing and orientation must be selected on the basis of the noise to be cancelled out. (Schoenberger, 1970; Telford et al, 2001). In Common Mid Point (CMP), stacking all the traces together averages out the noise and increases the SNR. Although this two becomes unreliable when dealing with dipping reflectors.

The removal of coherent noise often begins with a systematic investigation so as to determine the nature of the coherent event, frequencies, apparent velocities and windows where reflection seismic records could not be overridden by these noise by shooting a noise profile or walkaway (Telford et al, 2001). When the nature of the noise present is understood arrays can then be designed to attenuated these noise.

While array designs focuses of improving the signal while recording several data processing technique are employed after recording, to further attenuated the noise. So.e of the most significant ones are discussed below:

- Static Correction: There are variations in the elevation of the earth surface and this tend to constitute errors in the travel time of seismic waves. Static correction aims at correcting the effect of surface irregularities which tend to shift reflection event on adjacent trace out of their true time relationship. In CMP, if the static correction is poorly done, the CMP will fail to stack. According to Cos (2001), one of the most essential problems to overcome is seismic processing is accurate determination is static correction. Static correction takes into consideration not just the surfacial irregularities but the Low-Velocity-Layer (LVL) or weathered layer that exist just beneath the surface and must be designed to include information on the weathered layer. The LVL although barely few meters constitute errors due its abnormally low velocity caused by the presence within surface zone of open joints, micro-fractures and by the unsaturated state of the zone which if not corrected for may lead to false structural relief or underlying reflectors shown on resulting seismic section.

This the major components of static correction are elevation static correction and weathering static correction (Keary et al, 2002; Telford et al, 2001).

- Dynamic Correction: Dynamic correction is design to negate the effect of normal moveout and is a function of offset, velocity or reflector depth, calculated separately for each time occurrence of a seismic traces. Adequate dynamic correction depends on the use of accurate velocities with the appropriate velocity determined by computer analysis as is the case with CMP surveys, carried out after static correction must have been successfully carried out. According to Keary et al (2002), dynamic corrections are calculated for a range of velocity values and the dynamically corrected traces are stacked. The stacking velocity describes the velocity value producing maximum amplitude of the reflection event in the stack of traces given by the equation below:

$$t^2 = t_0^2 + \frac{x^2}{V_{st}^2} \qquad (17)$$

Where: t= Reflection Time
t_0= Reflection time at zero offset
x= Offset Distance
V_{st}= Stacking Velocity

- Frequency Filtering: Frequency filtering is employed when dealing with seismic data containing noise, coherent or incoherent, whose dominant frequency is different from that of the reflected seismic arrivals. Frequency filtering maybe employed severely at various stages of a seismic data processing. Basically, frequency filtering segregates between selected frequency components of an input waveform. However, since the dominate frequency of a reflection waveform tends to decrease with increase in travel time due to selective absorption of the higher frequency by the earth layers, as such filters are designed to vary as a function of travel time. Although the filter may also be varied as a function of distance to compensating for prevailing geological changes in the earth.

- Inverse filtering: One major limitation of frequency filtering lies in the fact that most noise contained in a seismic record have frequency which are within the same range as the reflected seismic arrivals. As such inverse filtering employs other criteria other than frequency. Inverse filtering aims at removing the adverse effects of frequency filtering by deconvolving seismic traces taking out the adverse effects associated with the propagation of the seismic waves through the layers earth. Deverbration and deghosting are inverse filtering carried out to remove multiple reflections in water layers and short path multiple respectively. Inverse filtering generally have the effect of shortening the pulse length on processed seismic section and by so doing improve the resolution of the seismic section (Keary wt al, 2020).

- Velocity Filtering: Some coherent noise can be filtered from a seismic record by exploiting the angle of dip of these coherent noise event, determined using its apparent velocity at which I propagates across a spread of detectors. (Keary et al, 2002 and March & Bailey 1983). In velocity filtering, an "F-K" graph is plotted originating at I where F is the individual frequency of each seismic pulse and K is the apparent wave number which relate to F by the equation given below:

$$f = V_a K_a \qquad (18)$$

$Where$: V_a= Apparent Velocity
K_a= Apparent Wavelength

As each seismic pulse travels with velocity V at a given angle Ө to the vertical which creates an apparent velocity V_a across the detector spread.

$$V_a = \frac{V}{\sin\theta} \qquad (19)$$

Where:
V_a= Apparent Velocity
V= Velocity
Ө=Angle of Propagating Seismic pulse

By utilising the above on plot, depicting each seismic event on a given seismic record with the positive wave number (Ka) depicting event travelling from the source across the spread while events travelling towards the source will depict the negative wave number (-Ka). Since different events fall into different zones, this can be used to filter out distinct coherent event such as coherent noise.

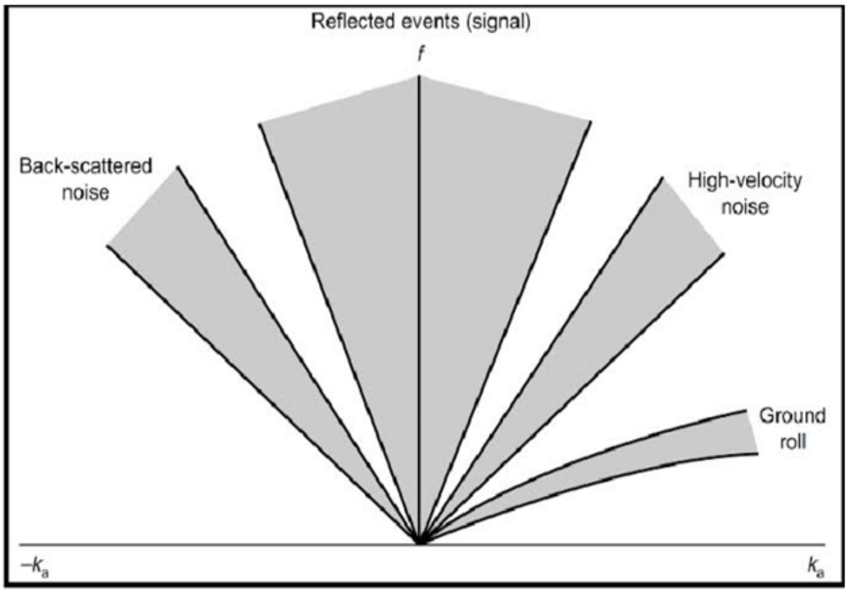

Fig 12:- An F-K Plot (Source: www.researchgate.com)

➢ Migration of reflection Seismic Data: According to Keary et al (2002) migration entails the reconstruction of a seismic section such that reflection events are repositioned under their correct surface location and at corrected vertical time. It simultaneously improve seismic resolution by forcing energy originally spread across a Fresnel zone and collapsing diffraction patterns so produced by point reflection and vaulted beds migration of reflected seismic data can be done either as a function of time or as a function of depth (For detailed study of migration see: Telford at al, (2001); Keary et al, (2002); Robinson & Treitel, (2000); Claerbout (1985); Brower et al, (1985); Laner et al, (1981); Gardner (1985).

It should be noted that the process of seismic data processing is largely fluid in nature and is in no way restricted to the ones discussed above but involve a good number not pointed out here, so as to avoid wandering away from the scope of this work.

IV. CASE HISTORY OF APPLICATIONS OF SHALLOW SEISMIC REFLECTION TO GROUNDWATER STUDIES IN OFFSHORE REGION

The shallow seismic reflection method has found a significant range of application from engineering to groundwater exploration and even geo-technics. Some of the reasons for it's wide range application is as a result of it's ability to record reflection from the top of the saturated zone, detecting shallow faults, mapping of depth to bedrocks, mapping intr-alluvial features and cavity detection amongst others. In the case of shallow faults, these shallow faults can serve as conduits for various migrating fluids, from groundwater to hazardous waste at engineering dumpsites.

Bertoni et al (2020) utilized seismic reflection data directly and indirectly in the identification and mapping of geological features hosting aquifers within the offshore region containing non-saline groundwater where various case histories were analyzed, some of which will be considered below. One Case is that of East Africa, although its seismic data were not originally collected for the purpose of groundwater exploration but rather for hydrocarbon exploration. This data nonetheless were used to define the geometry and aquifer architecture of the aquifer system of the Kaibiji aquifer in Tansazia.

The seismic section of the region shows the extension of the stratigraphuc sequence of paleo-deltaic sediments of mice age, overlying tertiary carbonated extending in the offshore domain where it thickens beneath the Indian Ocean. The aquifer system becomes increasingly confined with increasing depth with various drilling campaigns showing abstraction of portable low salinity water. The seismic reflection data was utilized in defining the scale of magnitude and it's possible connection with deeper geological formation aided by geological and wire line logs.

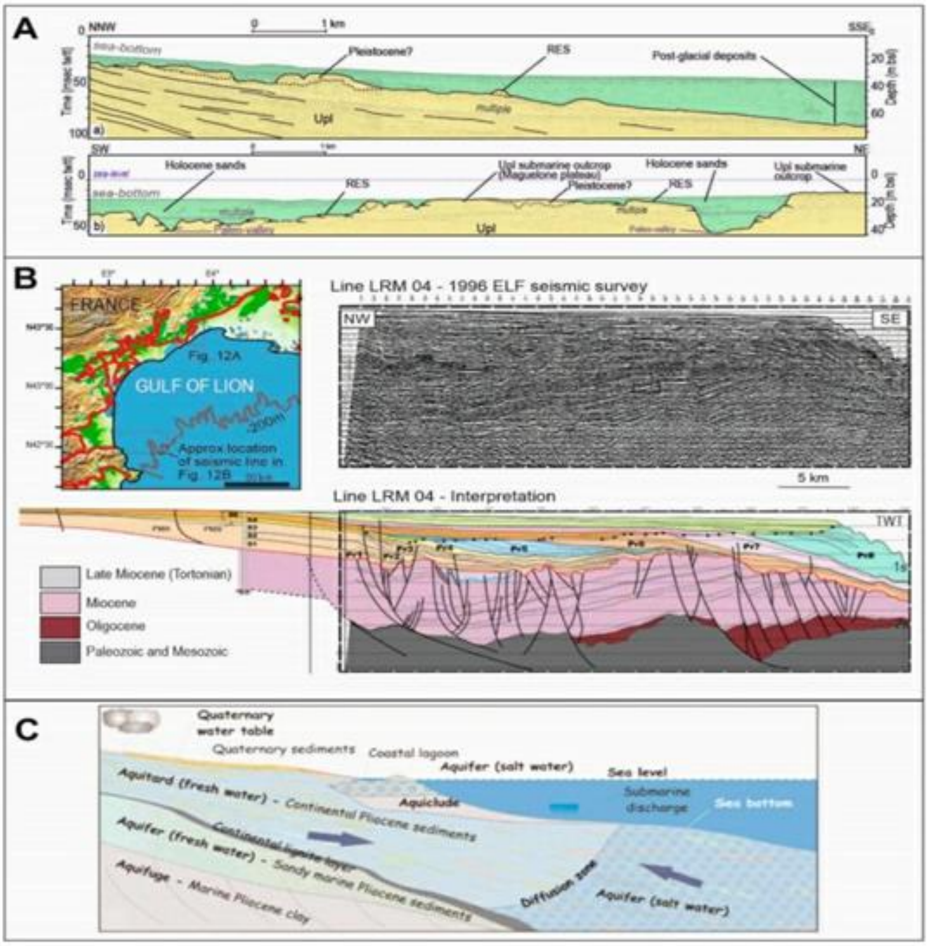

Fig 13:- East African Data Set

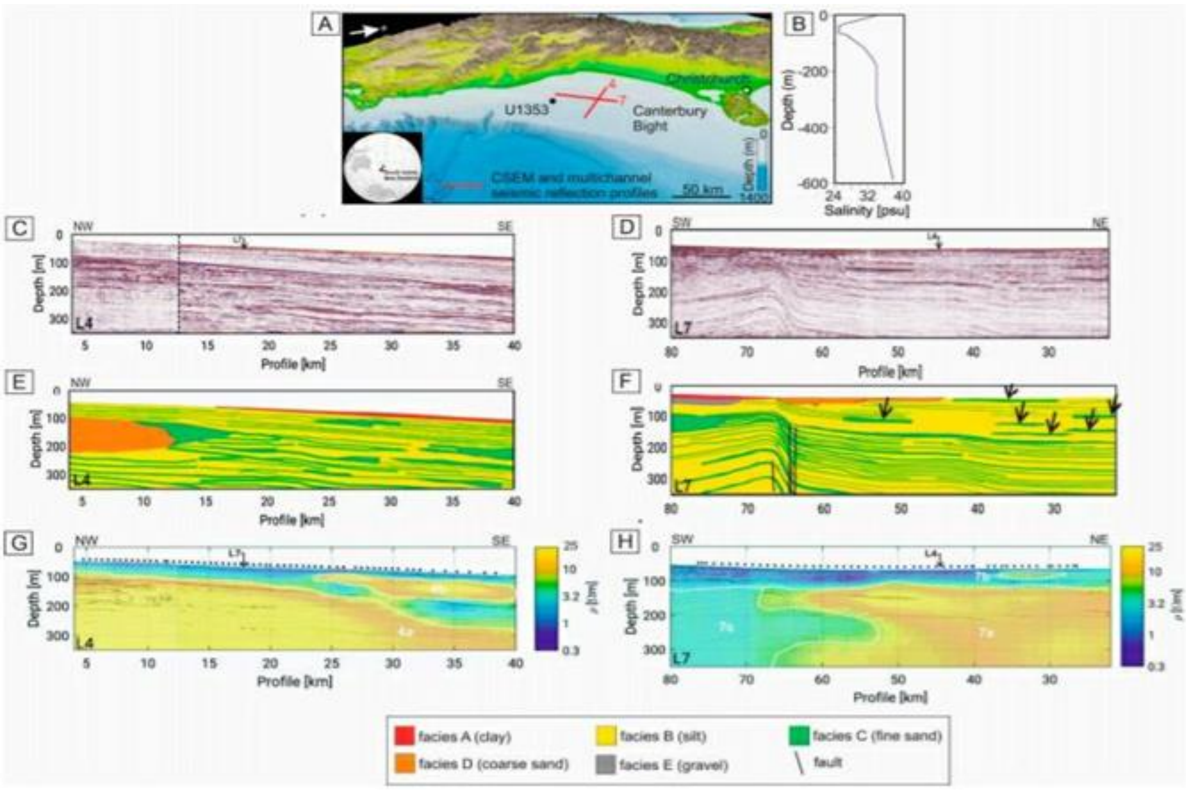

Fig 14:- Canterbury Data Set

ISSN No:-2456-2165

Bertoni et al illustrated the successful utilisation of reflection seismic alongside other geophysical techniques as part of a workflow in to comprehend offshore groundwater quality. This provided the basis for the analysis of aquifer properties and locations. (See Bertoni et al (2020) for a detailed study of this case history)

V. CONCLUSION

While the shallow seismic reflection method may seem relatively easy to comprehend, it is however probe to common 'pitfalls' especially to the untrained, such as interpreting the ground-coupled air waves as a true seismic wave and misinterpreting shallow reactions as shallow reflection in stacked Common Mid-point (CMP) section. While it is very possible to derive seismic reflection data from shallow depths, Birkelo et Al (1987) places the shallow limit at about 2M. Efficient utilization of the shallow seismic reflection method within alluvial and shallow bedrock using the CMP will require detailed velocity analysis. Establishment of coherency of wavelet across several traces on the field seismograms are essential for detecting reflections.

REFERENCES

[1]. Beaten, G., Fokkema, J. and Ziolkowski, A. (1988): "The Marine Vibrator Source". First Break, 6(9), 285-294.
[2]. Bedenbender, J. W., Johnston, R. C. and Neitzel, E. B., (1970): "Electroacoustic Characteristics of Marine Seismic Streamers". Geophysics, 35, 1054-72.
[3]. Berni, A. J., (1981): "Hydrophine Cables For Seiamic Exploration". In: CRC Handbook of Geophysical Exploration at sea, R. A. Heyer, ed., PP. 293-316. Boca Raton: CRC Press.
[4]. Bertoni, C., Kofi, J., Micallef, A., and Moe, H., (2020): "Seismic Reflection Methods in Offshore Groundwater Research.
[5]. Birkelo, B. A., Steeples, D. W., Miller, R. D., and Sophocleous, M. A., (1987): " Seismic-Reflection Study of a shallow aquifer during a pumping test: Groundwater, 25, 703-709.
[6]. Brower, J., Douma, J., and Helbig, K. (1985): "A New Look at Migration". First Break 3, No. 12, 9-15.
[7]. Brower, J. and Helbig, K., (1998): "Shallow High Resolution Reflection Seismics." In: ahelbig K. and Treitel S. (Eds), Handbook of Geophysical exploration, section 1. Seismic exploration, Elsevier, Amsterdam, PP. 1-234.
[8]. Claerbout, J. F. (1985): "Fundamentals of Geophysical Data Processing" McGraw Hill, New York.
[9]. Cox, M. (2001): "Static Correction for Seismic Reflection Surveys Society of Exploration Geophysicists" Tulsa.
[10]. Gardner, G. H. F., ed. (1985): "Migration of Seismic Data". Tulsa: Society of Exploration Geophyscists.
[11]. Gardner, G. H. F., Gardner, L. W. and Gregory, A. R. (1974): "Formation Velocity and density-the diagnostic basics for stratigraphic traps. Geophysics, 39, 770-780.
[12]. Giles, B. F., (1968): "Pneumatic Acoustic Energy Source". Geophys. Prisp. 16, 21-53.
[13]. Keary, P., Brooks, M., and Hill, I., (2002): "An introduction to geophysical exploration", Third edition, Blackwell Science Limited.
[14]. Larner, K. L., Hatton, L., Gibson, B. S. and Hsu, I. (1981): "Depth Migration of Imaged Time Sections, Geophysics 46, 734-50.
[15]. March, D. W. and Bailey, A. D. (1983): "Two Dimensional Transform and Seismic Processing, First Break, 1 (1), 9-21.
[16]. Mayne, W. H. (1962): "Common-Reflection-Point Horizontal Data Stacking Technique. Geophysics 27, 927-38.
[17]. Mayne, W. H. (1967): "Practical Condiderations in the Use of Common Reflection Point Twchniques. Geophysics, 32, 225-9.
[18]. Mayne, W. H. and Quay, R. G. (1971): "Seismic Signature of Large airguns". Geophysics 36, 1162-1173.
[19]. McCann, D. M., Andrew, E. M., and McCann, C. (1985): "Seismic Sources for shallow Reflection Surveying.Geophys. Prospecting. 33, 943-955.
[20]. Merkel, L. D., and Nath, A. K. (1977): "Geologic Considerations for Stratigraphic Modelling & Interpretations. In: Payton, C. E. (ed.), Seismic stratigraphic- Application to hydrocarbon exploration. AAPG Memoir 26, 417-438.
[21]. Robinson, E. A. and Treitel, S. (2000) Geophysical Signal Analysis. Society of Exploration Geophysicists, Tulsa, USA.
[22]. Safari, M. H. (1984): "On the S80 and P400 water guns: A Performance Comparison". First Break 2, No. 2, 20-24.
[23]. S.E.G. (1997) Digital Tape Standards (SEG-A, SEG-B, SEG-C, SEG-Y, SEG-D Formats Plus SEG-D 1&2) Compiled by SEG Technical Standards Committee, Society or Exploration Geophysicists (SEG), Tulsa, USA.
[24]. Schoenberger, M. (1970): "Optimisation and Implementation of Marine Seismic Arrays". Geophysics 35, 1038-53.
[25]. Schulze-gattermann, R. (1972): "PhyPhysical Aspects of the air pulse as a seismic Energy Source.". Geophys. Props. 20. 155-92.
[26]. Sheriff, R. E. and Geldart, L. P. (1982): "Exploration Seismology Vol. 1: History, Theory & Data acquisition. Cambridge University Press. Cambridge.
[27]. Sheriff, R. E., and Geldart, L. P. (1983): " Exploration Seismology, Vol. 2: Data processing and Interpretation, cambridge University Press, Cambridge.

[28]. Shitvelman, V. (2002) "Application of Shallow Seismic Method to Engineering, Environmental and Groundwater Investigations ". Bulletino di Geofisica Teorica Ed Applicata, Vol. 44, PP. 209-222.
[29]. Telford, W. M., Geldart, L. P., and Sheriff, R. E. (2001): "Applied Geophysics", Second Edition. Cambridge University Press.
[30]. Willis, H. F., (1941): "Underwater Explosions- time interval between Successive explosions." British Report. Wa-47-21.
[31]. Zoeppritz, K. (1919): "Uber reflection and durchgang seismischer wellen Durch unstretigkelsflaschen. Berlin l, Uner Erdbebenwellen VII B, Nachrichten Derbyshire Koniglichen Gesellschaff der Wissensschaften zu Gottingen, math-phys. PP. 57-84.