CHAPTER-3

THEORETICAL DEVELOPMENTS IN SEISMIC EXPLORATION

Oil and natural gas play a significant role in the growth and development of a country. In spite of several other energy options viz. hydropower, coal, nuclear etc. oil has been dominating the world market. Unconventional energy resources like bio-gas, wind, tidal, solar, geothermal etc. are yet to make their mark. Due to this there is excessive reliance on hydrocarbon energy resources across the world. Global geo-politics is yet another reason for which these hydrocarbons have acquired strategic importance.

Petroleum geology is the branch of economic geology that deals with occurrence and exploration of oil and gas. Crude oil was formed over millions of years from tiny aquatic plants and animals called planktons that lived in ancient water bodies mainly seas. When the plankton dies they fall into the sea-bed and get trapped under many layers of sand and mud. Over millions of years the sand and mud get stratified to turn into rocks. Also, the pressure and heat of earth turn the dead plankton into 'kerogene' which is a precursor of petroleum hydrocarbons which when gets further heated, with time the chains of hydrocarbons break away forming waxy and viscous crude oil. The rock where oil is formed is called a source rock. When a source rock starts generating oil and gas then it is said to be 'mature'.

At greater depth, the temperature is high and the pressure of overlying sediments and water column is also high. This helps the chains of hydrocarbons to become shorter resulting in lighter oil and gas to separate out.

The transformation of oil and gas from organic matter causes increase in the volume resulting in the fracturing of the source rock. This causes the oil and gas to get expelled out of the source rock and migrate and accumulate into the reservoir rocks. The reservoir rocks are those with enough porosity to be capable of storing economic quantities of petroleum.

Gone are the days when oil fields could be discovered, in gushers that sent crude oil and associated gas spewing out of the ground. More typically, the discovery and draining of fields is a painstakingly slow process involving inferred reconstruction of underground structural geology. The presence of folds (anticlines) and faults several thousand feet underground are important information in locating oil bearing formations. ***[http://www.oilandgas.org.uk/education/storyofoil/index.cfm]***

Seismic exploration has a very predominant role to play in exploration and production of hydrocarbons. Seismic reflection methods involving the use of seismic waves, are particularly very useful, to reconstruct the subsurface geology and provide inferences concerning the presence of oil bearing structures. These provide fairly good resolution even for deep seated structures and serve as a very useful tool to delineate structures suitable for hydrocarbon reserves. Exploratory drilling is very expensive and companies investing in seismic methods of exploration avoid spending on unlikely prospects and unsuccessful wells.

3.1. MAKING OF WAVES

Whenever an acoustic source is detonated on or near the surface of the earth, an acoustic wave is produced that propagates away from the source. Apart from effects very close to the source, this wave moves through the medium without causing a net movement of the material - the medium (more or less) returns to its normal state once the wave has passed through.

Source: http://www.geo.mtu.edu/upseis/waves.htm

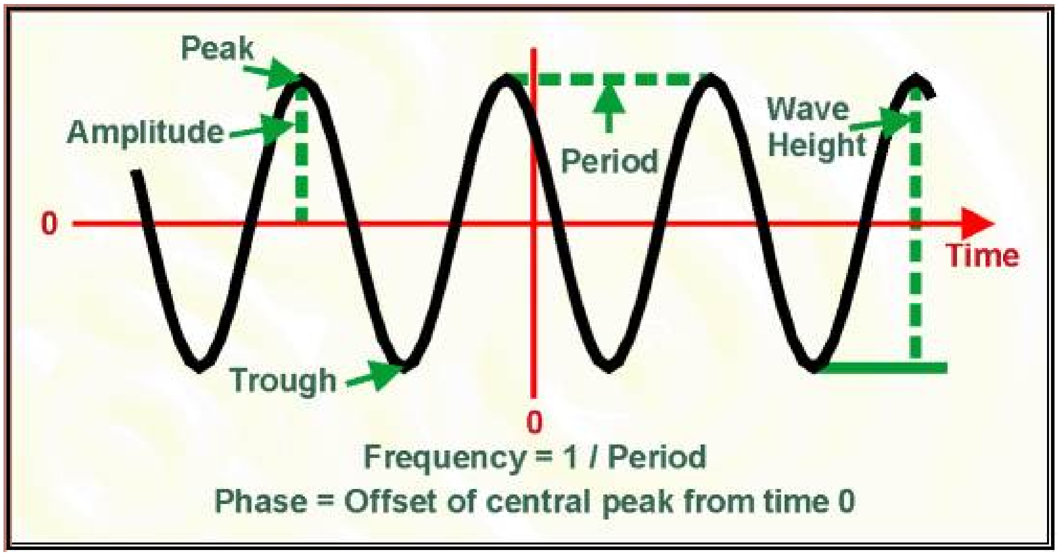


Figure 3.1 Simple sinusoidal waves

A simple sinusoidal wave can be described by three parameters (see Figure 3.1) namely: amplitude, frequency, or the number of "cycles per second" of the wave, and phase - the offset of the maximum value from time 0 measured in degrees along the cycle (1 cycle = 360 degrees). Its wavelength is the distance between successive repetitions of the waveform.

$$\textbf{Velocity} = \textbf{wavelength} \times \textbf{frequency}$$

Waves can travel through a body (**body waves**), or along the surface of a body (**surface or interface waves**), which can be used for shallow investigations (refraction studies) or they can cause problems by masking body waves within seismic data.

3.1.1. Body Waves

These are of two types: P-Waves & S-Waves.

P-Wave/Primary wave/ Compressional wave/ Longitudinal wave: Energy that is applied exactly at right-angles to an elastic body produces an elastic body wave in which the particle motion is in the direction of propagation - a P-wave. The pressure wave pushes the particles of material ahead of it, causing compression and expansion of the material. The P-wave is the type of wave assumed for conventional seismic exploration.

S-wave/Secondary wave/Shear wave/Transverse wave: A wave in which the particle motion is at right-angles to the direction of propagation is known as an S-wave. S-waves have been used for some forms of seismic exploration but they do not propagate through fluids so are not recorded (directly) in conventional marine acquisition.

3.1.2. Surface Waves

These are of two types: Rayleigh waves and Love waves.

Rayleigh wave: This wave is propagated along a free surface of a solid, 'Free surface' means in contact with vacuum. Rayleigh wave is also known as Ground roll.

Love Wave: This is surface wave motion parallel to an interface. They exist only when a semi-infinite medium is overlain by an upper layer of finite thickness terminating at a free surface.

Other surface waves are **Stonely** wave and **Tube** wave which are related to bore-hole seismic. Figure 3.2 shows some of the various wave types and their propagation.

Source: http://www.geo.mtu.edu/upseis/waves.htm

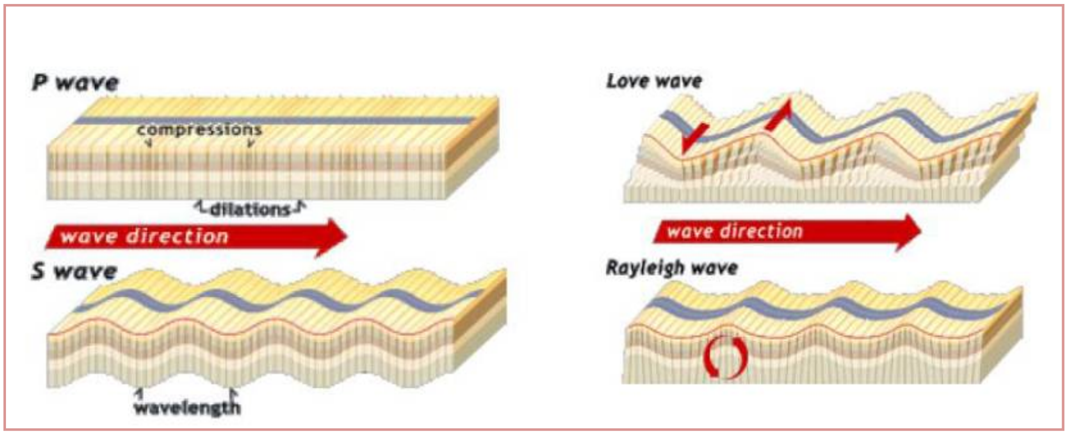


Figure 3.2: Shows types of waves and propagation

3.1.3 Ray Paths

Whenever a wave encounters an abrupt change in the elastic properties, as when it arrives at a surface separating two beds, part of the energy is reflected and remains in the same medium as the original energy; the balance of the energy is refracted into the other medium (Figure 3.3). Huygens's Principle states that every point on a wave-front can be regarded as a new source of waves.

Source: http://www.cyberphysics.co.uk

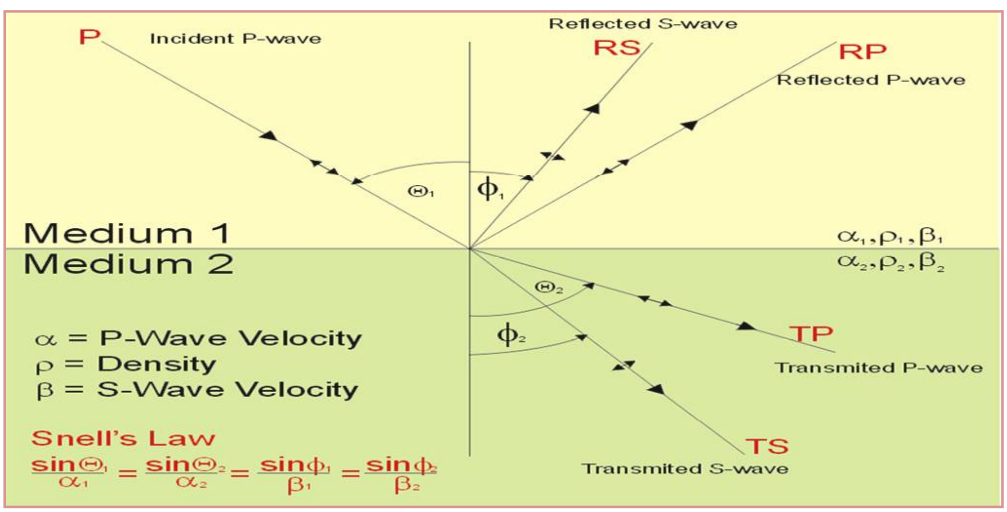


Figure 3.3: Reflection and Refraction of Body waves

Source*: *http://www cyberphysics.co.uk

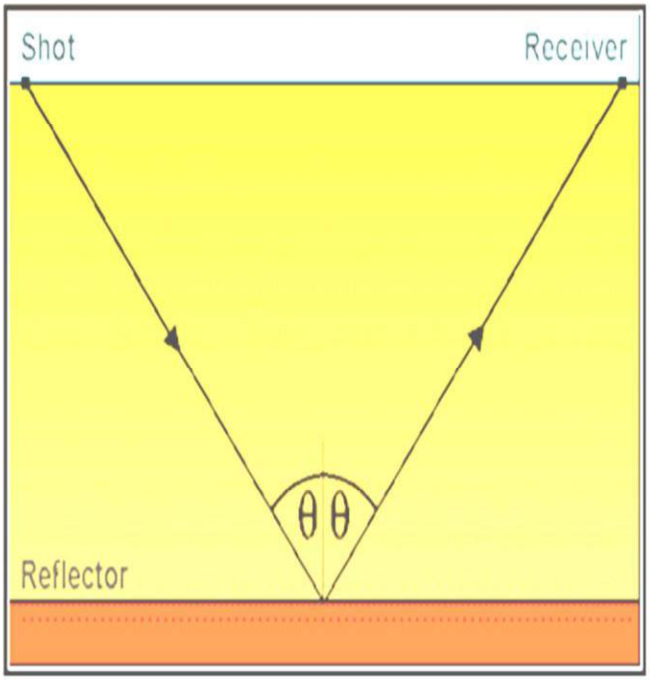


Figure 3.4: Simplest ray diagram

Figure 3.4 shows the simplest form of ray path diagram, showing just one ray from a shot, to a reflecting horizon, and back to the receiver. The reflector in this case is perfectly horizontal, and, as the angle of incidence must equal the angle of reflection, the total travel time from source to receiver can be computed with nothing more complicated than the Pythagorean equation.

Things become a bit more complicated when moving up to more than one reflector as seen in Figure 3.5.

Source*: *http://www.cyberphysics.co.uk

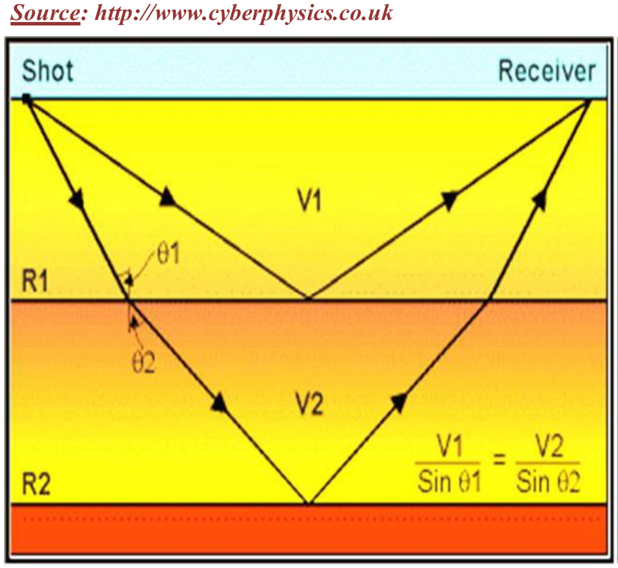


Figure 3.5: Wave propagation through medium

The upper ray path travels through the upper layer (with a velocity of V1), whereas the lower ray refracts at the first interface, and then gets reflected at the lower interface. Its average velocity will be some combination of V1 and V2 (V2 is the velocity of propagation through the lower layer).

Figure 3.6 shows a ray path as it travels through multiple layers of reflectors. Depending on the density contrast, the refracted wave moves towards or away from the normal as it travels through the interface. As shown in Figure 3.10 the travel velocity is progressively increasing since the beds get denser as we go deeper with the except of bed 4 (from top) where travel velocity decreased indicating a decrease in bed density and resulting in the wave moving towards the normal.

Source: http://www.cyberphysics.co.uk

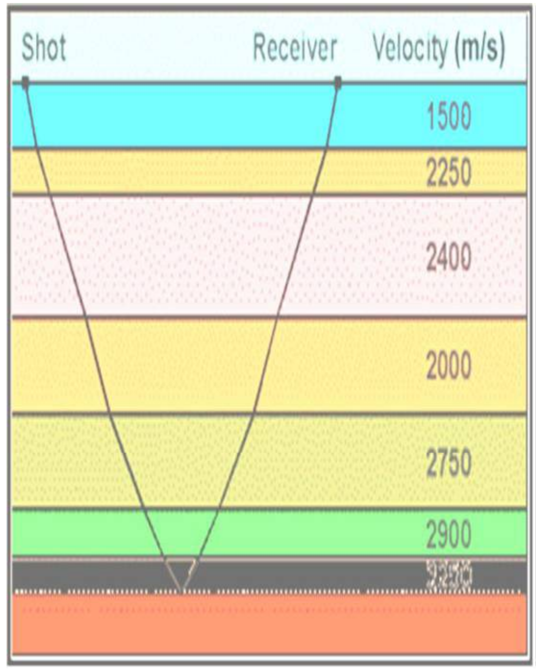


Figure 3.6: A wave path as it travels through multiple layers

Source: http://www.cyberphysics.co.uk

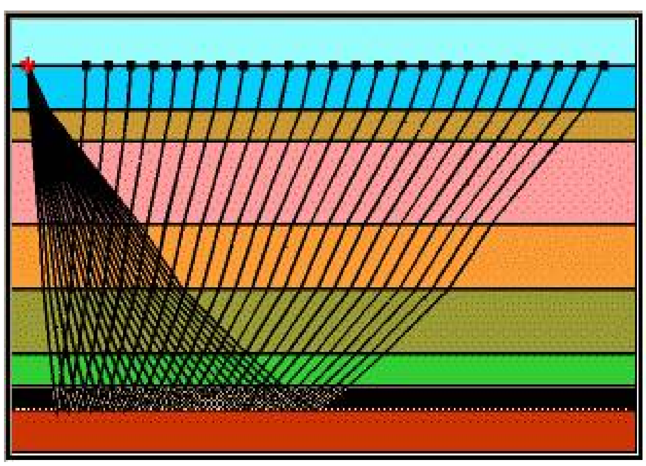


Figure 3.7: One Reflector Interface

Figure 3.7, shows just one reflector, surface with a number of recorders (geophones) and one source.

What we have considered so far is a case where beds as well as reflecting horizons are horizontal. Situation gets more complicated when beds are dipping and reflecting surfaces are curved.

3.1.4 Signal and Noise

Signal is any event on the seismic record from which relevant information can be obtained. Unwanted event in seismic record is called noise.

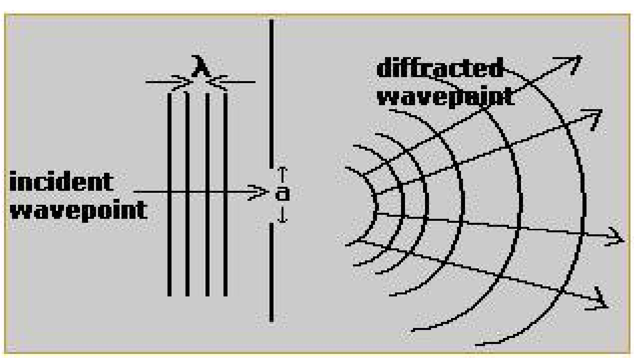
The signal-to-noise ratio, abbreviated $\frac{S}{N}$, is the ratio of the signal strength to noise level in a specified portion. Poor record results when signal to noise ratio is small. Noise can be random or coherent or both and the aim of data processing is to alternate both types of noise without affecting the signal so that $\frac{S}{N}$ improves.

However, the final level of noise may still be sufficient to mask primary reflections on the seismic section. Moreover in some areas it is difficult to find any signal. Sources of noise can be diffraction, multiple reflections, or even moving vehicles etc.

3.1.5 Diffraction

Whenever a wave encounters a feature whose radius of curvature is comparable to or smaller than the wavelength, the ordinary laws of reflection or refraction no longer apply. In such cases energy is diffracted rather than reflected or refracted.

Source: http://www.geo.mtu.edu/upseis/waves.htm



The Figure 3.8 shows how energy is diffracted from a fault plane and how it is recorded on seismic record.

Figure 3.8: Phenomena of Diffraction

3.1.6 Multiple Reflections

***Source*: http://www.geo.mtu.edu/upseis/waves.htm**

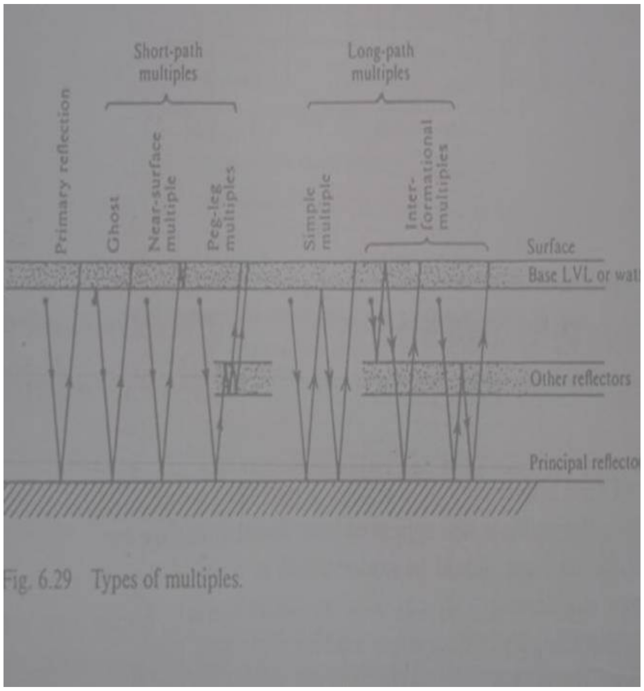


Figure 3.9: Long path and short paths multiples

Multiple reflections or simply multiples are events which have undergone more than one reflection. There are two types of multiples: long path multiples and short path multiples. A long path multiple is one whose travel path is long compared with the primary reflection from the same deep interfaces and hence long path multiples appear as separate events on the seismic record.

A short path multiple, on the other hand, arrives so soon after the associated primary reflection from the same deep interfaces that it interferes with and adds tail to the primary reflection; hence its effect is that of changing wave-shape rather than producing a separate event. Possible ray path of these two classes are shown on Figure 3.9.

3.1.7. Relation between Direct wave, Surface wave, Reflected wave and Refracted wave

The simplest two-dimensional ray paths or lines drawn on a cross-section show the path of the energy from the shot to the receiver. Consider the four types of ray paths that will be recorded on the early part of a particular seismic section. (Figure 3.10)

Source: http://www.geo.mtu.edu/upseis/waves.htm

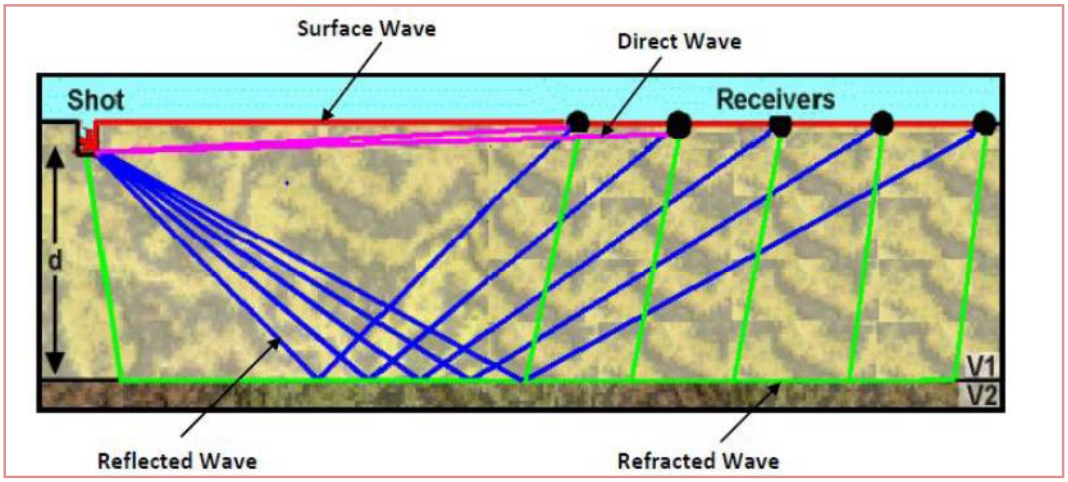


Figure 3.10: Direct, surface, reflected and refracted wave

There will be surface wave that travels through a 'free surface' at very low velocity, and the direct waves that pass through the top of the weathering layer. Then, there will be reflected waves, traveling at velocity V1 and reflecting from the boundary at the base of the top layer, and also refracted waves, reaching critical angles and traveling along the base of the top layer with velocity V2.

3.1.8. Time-Distance Graph

Drawing a time distance graph, (Figure 3.11) the following observations can be made:

At the lowest offset (X1), the first arrival is formed by the direct wave at time T1, the second arrival is the surface wave (T2) and the third is the reflected wave (T3). The refracted wave does not reach the short offsets. At other offsets (X2 & X3) the order of arrivals changes as each wave moves at its own velocity.

***Source*: http://www.geo.mtu.edu/upseis/waves.htm**

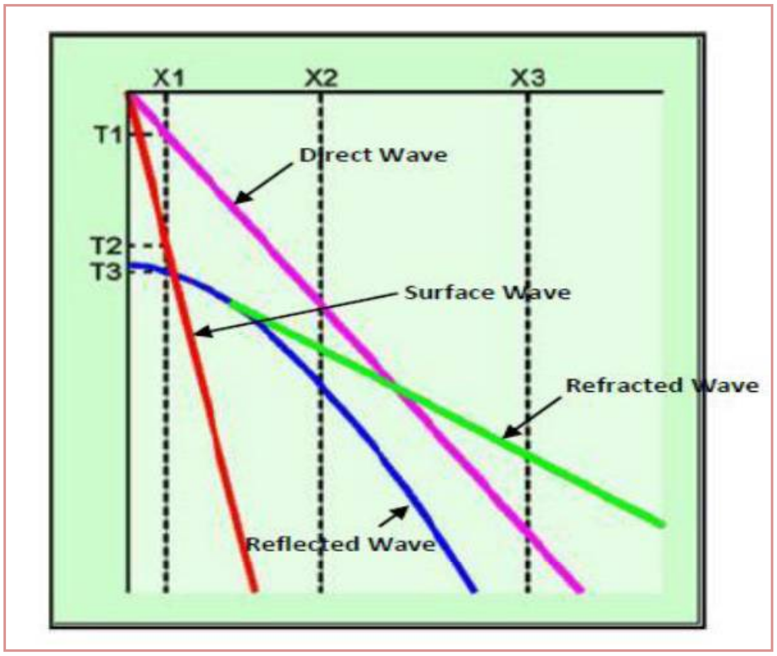


Figure 3.11: Time-distance graph

3.2. SEISMIC SURVEYS

Broadly there are three types of seismic surveys that are generally carried out for oil and gas exploration and production.

3.2.1. 2D Seismic Survey
3.2.2. 3D Seismic Survey
3.2.3. Time Lapsed 3D or 4D Seismic Survey

3.2.1. 2D Seismic Survey

It is generally carried out in virgin/new areas to delineate and map the structures on a regional scale and propose locations for exploratory drilling for the initial discovery of hydrocarbons. An area of operation is covered with seismic profiles at regular intervals both in dip and strike directions depending upon the orientation of the sub-surface structure inferred from the surface geological mapping. The 2D seismic survey provides an image of a geological cross-section only. Figure 3.12 shows a 2D seismic survey field layout.

Source: http://www.geophysics.co.uk/mets3.html

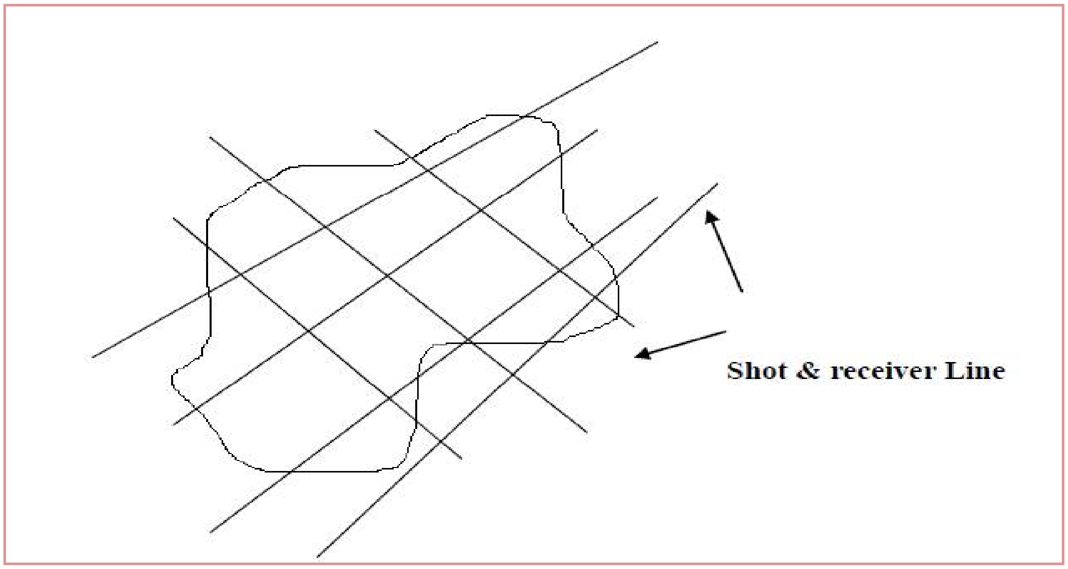


Figure 3.12 2D Seismic Survey field layout

3.2.2. 3D Seismic Survey

These surveys are generally carried out for detailing and field / reservoir development after the initial discovery of hydrocarbons in the area. A 3D seismic survey is a multi-line operation with close receiver line interval and the shot lines placed orthogonal to the receiver lines. 3D seismic is created by shooting a closely spaced grid of 2D lines and interpolating between the lines to create a "seismic cube" or volume. The cube can then be sliced in any vertical dimension to create 2D lines or sliced in horizontal dimensions to create time slices, which represent constant time, or horizon slices.

Difference between 2D and 3D Seismic exploration

The difference between 2-D and 3-D seismic lies in the number of vibrations from which meaningful information can be calibrated. With 2-D, geophones along a line of vibrations provided a picture that was a cross-section - a slice - of the rock formation. With 3-D, the geophones cover a grid, not just a line. With thousands of times more data points, scientists can map a cube, creating a 3-dimensional computer image of the formation.

While 3-D is many times more expensive than 2-D, it allows companies to avoid unlikely prospects, and hence avoids wasting money on unsuccessful wells. While seismic data has typically been collected with the sources and receivers in straight lines, 3-D seismic requires a much denser grid of trails than the 2-D seismic. Figure 3.13 shows the 3D seismic survey field layout.

Source: http://www.geophysics.co.uk/mets3.html

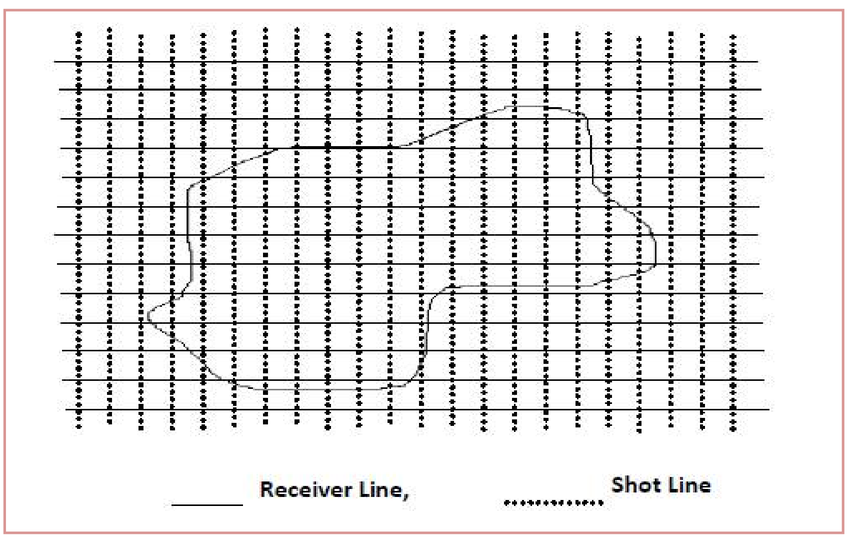


Figure 3.13 3D Seismic field layout

3.2.3. Time-Lapsed 3D or 4D Seismic Survey

This survey is carried out for reservoir monitoring and fluid level movements in a reservoir. These are just repetition of 3D seismic survey over an oil and gas field at regular intervals of time. The data acquisition and processing is more or less same as 3D seismic except the same is acquired at desired time intervals. The interpreted data give information on fluid level fluctuations in the reservoir that in turn helps in production planning and in finding locations for development drilling.

Seismic exploration consists of three main stages. These are: data acquisition, processing and interpretation.

3.3. SEISMIC DATA ACQUISITION

Seismic waves are produced by exploding a charge buried in a shallow hole. These waves travel in all directions on the surface as well as underground. Some of these waves are refracted and others get reflected from the interface between different types of rocks, because of density difference.

Source: ***http://www.ig.uit.no/webgeology/.***

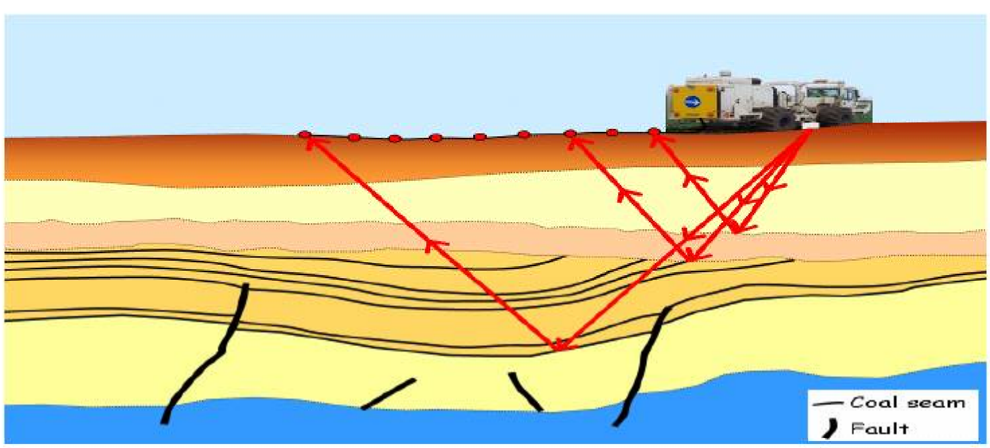


Figure 3.14 the explosion site, geophones, and reflecting horizons

The response to this reflection sequence is received by receivers called geophones located in line with the explosion, on or near the surface. The data are recorded on a magnetic tape for computer processing. Figure 3.14 shows the explosion site, geophones, and reflecting horizons.

Acquisition of seismic data depends on whether the area is land, transition zone or marine and depending on area, equipment varies too.

3.3.1. Land Data Acquisition

Acquisition system comprises sources, detectors, telemetry and recorder. The source creates a seismic disturbance, which propagates into the earth. Reflection generated at the interfaces are detected by geophones and converted to electrical signals. The signals are telemetered to a central location, where they are recorded in a digital format. The traditional seismic source is dynamite or other chemical explosive which is preloaded in a shallow borehole that is drilled for shoot. It is desirable to place the seismic shots below the near-surface highly weathered layers of the earth. This improves the coupling of the source to the ground, and avoids problems with the variable (slow) acoustic velocities in the weathering layer. The optimum shot depth and charge-size are found by trial and error while exploring in a new area. When it is time to acquire data, a shooter ready with the blaster and an electrical signal from the recorder, blast the explosive.

(i). Seismic Source

Most land seismic surveys use either explosives or vibrators as energy source. The principal types of explosive sources have been gelatin and ammonium nitrate. The former is a mixture of nitro-glycerin and gelatin and an inert material which binds the mixture together and which can be used to vary the ‘strength’ of the explosive. Some non-explosive sources like hammers, thumpers are also used in seismic surveys. Another non-explosive source is 'vibro-seis' where specially designed vehicles lift their weight onto a large plate, in contact with the ground, which is then vibrated over a period of time.

(ii). Receiver

This is the recording unit which records the seismic signals. Onshore seismic data are recorded using a simple (normally electro-magnetic) device known as a geophone.

3.3.2. Marine Data Acquisition

Marine operations are conducted in a highly automated fashion, using a boat that tows an array of sources and streamers containing detectors. The boat follows a programmed course using GPS navigation and shots are fired at preprogrammed locations. Figure 3.15 shows marine acquisition system.

***Source**: http://www.oilandgas.org.uk/education/index.cfm*

Figure 3.15: An aerial photograph of a modern Seismic Boat

(i). Seismic Source

The most common offshore (or marine) source in use today is a variety of air-guns. These guns use compressed air typically at 2,000 to 10,000 psi to produce an explosive blast of air into the water surrounding the gun.

(ii). Receiver

For marine acquisition, the recording device used is called a 'hydrophone'. These hydrophones are connected together in groups and may be placed every meter or so along as 6000 meter streamer.

3.4. DATA RECORDING

The data recorded from one "shot" (one detonation of an explosive or implosive energy source) at one receiver position is referred to as a seismic trace, and is recorded as a function of time (the time since the shot was fired). As this time represents the time taken for the energy to travel into the earth, reflect, and then return to the surface, it is more correctly called "two-way time" and the vertical scale is generally measured in milliseconds (one thousandth of a second - 0.001 second).

3.5. SEISMIC DATA PROCESSING

These data are processed using several techniques. Processing transforms field data into information that is useful to an exploration scientist. Data processing in Seismic Surface Prospecting provides sections and maps in both 'time' and 'depth' domains. Information about distribution of selected attributes is being collected in order to help in finding solution of geological problems on interpretation stage. Processing comprises several steps some are performed at a remote processing center, where large computer resides, and some of which are performed in field by smaller but still very powerful computers. The general steps of seismic processing are:

3.5.1. Editing

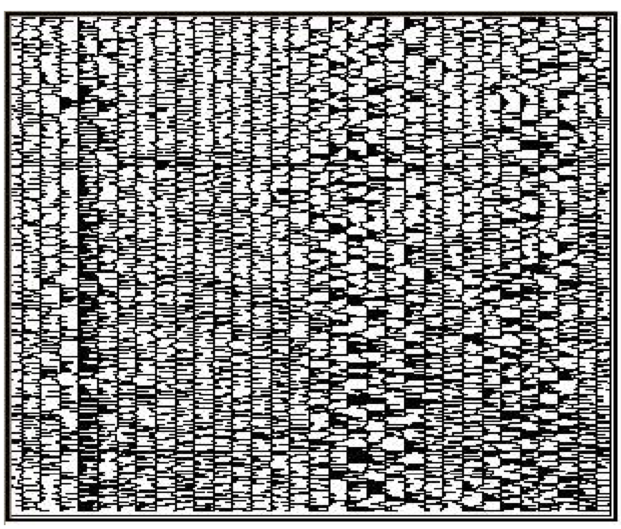
(a) Kill Bad Traces

This process is also referred as sorting and editing traces. At this stage, clearly anomalous traces are edited or removed. The usual convention is not only to "zero" or "kill" the bad trace within records, but also to omit any completely bad records from the following stages.

Another problem is that of *polarity*. By convention most modern seismic data is recorded using the standard specified by the Society of Exploration Geophysicists - SEG polarity. This clearly states that the onset from the compression wave produced by an explosive source is represented by a negative number on tape (and throughout the processing) and displayed as a negative (white) trough. We need to spot those traces within our records that have *reverse polarity* with respect to all other traces and check the above convention.

The recording shows some "*noisy*" traces in the data set, particularly the forth trace from left (seen in Figure 3.16).

Source: http://www.ukogl.org.uk/



This display was scaled so that each trace was displayed with its own "gain" - any trace to trace variations have been lost in the display.

Figure 3.16: Seismic traces with own gains: shows noisy trace (4th from the left)

Figure 3.17 shows same piece of record with the display now set to display the entire screen with one gain - the true trace-to-trace variations are now visible.

It would now appear that the forth trace is "dead", or very weak. We will need to "kill" this trace in the processing to make sure that it is really zero. Figure 3.18 shows polarity reversal.

Source: http://www.ukogl.org.uk/

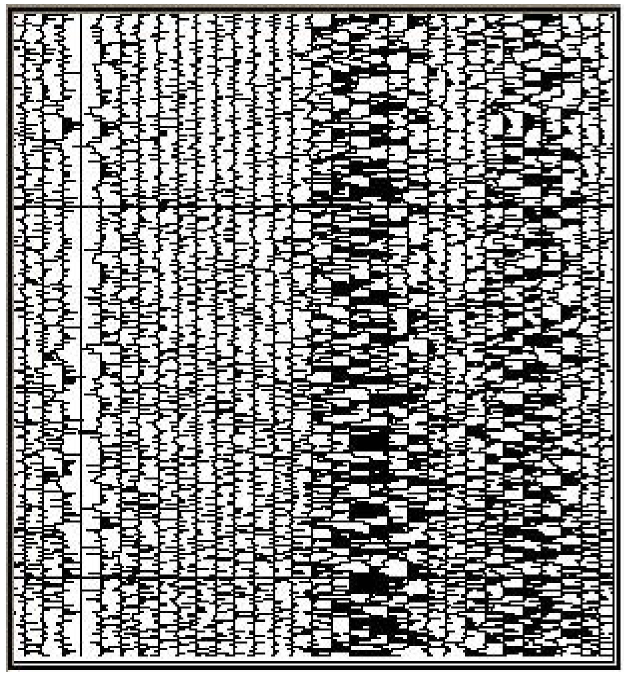


Figure 3.17: Seismic traces with uniform gain

Source: http://www.ukogl.org.uk/

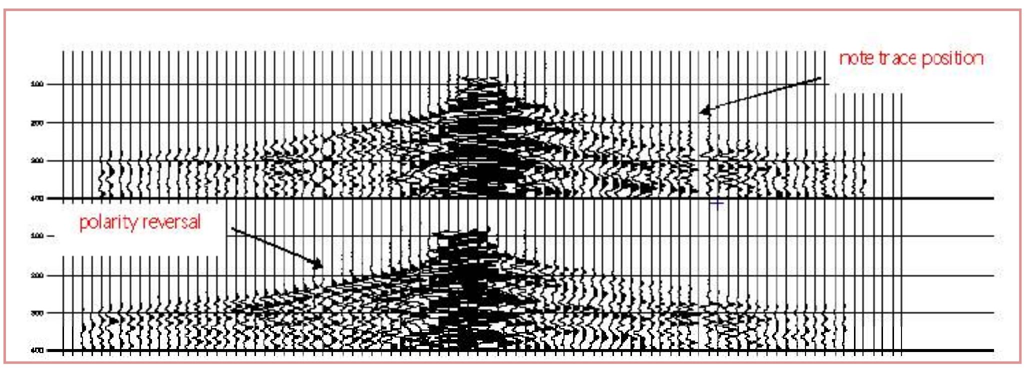


Figure 3.18: Shows Polarity Reversal

(b). Signature De-convolution

Signature de-convolution is normally applied early on in the processing to change the "source wavelet" present on every reflection in the data set into something more desirable. The idea is to find the convolution filter that will accomplish our desired transformation (Figures 3.19 and 3.20).

***Source*: http://www.ukogl.org.uk/**

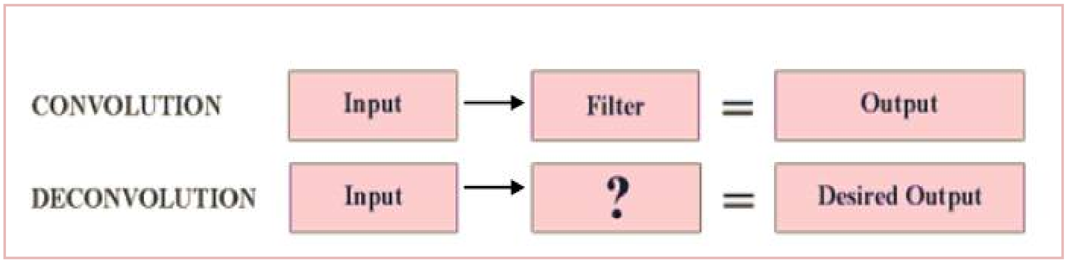


Figure 3.19: Finding convolution filter to accomplish desired output

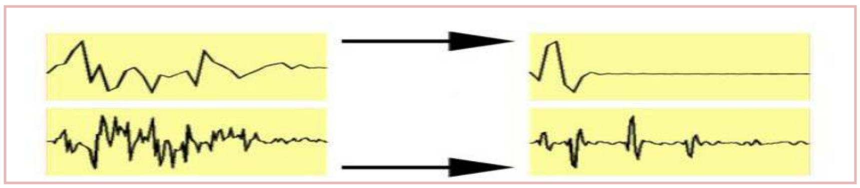


Figure 3.20: Signature De-convolution

(c). Gain Recovery/Adjust

All of the energy initially contained in the shot is spread out over a larger and larger area as time passes. This causes loss of energy on a field record, and is generally referred to as *spherical divergence*. Another cause of energy loss is known as *inelastic attenuation*. This is simply the energy lost due to the particles of earth through which the wave travels not being perfectly elastic - some of the energy is absorbed and thus permanently alters the position of the particles.

Other more complex forms of energy loss (some of which are frequency dependent) include these caused by the friction of particles moving against each other, and losses at each interface through which the wave travels and is refracted. (Some of the energy in the original seismic P-wave is *converted* into an S-wave at each interface and not recorded).

Accurate determination of the inverse of this energy loss, the *gain function* that we need to apply to the data is difficult. But we can use some gain function to adjust the traces so that it can be readable.

3.5.2. Pre-stack Main Processing

(a). Static Corrections

The corrections for elevation and weathering variation are another important processing step. These field statics' are based on the survey, up-hole and first break information, and are subsequently used in processing as the first estimation. Variation in elevation of the subsurface affect travel times and it is necessary to correct for such variation as well as for changes in the low-velocity layer (LVL).

A datum is defined in Sheriff's Encyclopedic Dictionary of Exploration Geophysics as *a reference value to which other measurements are referred, or an arbitrary reference surface, reduction to which minimizes local topographic and near-surface effects*.

For land data our shots and receivers can be at almost any depth. In this case it is common to use a *floating datum* - a smooth line that follows the general elevation trends along our line, but removes any rapid shot-to-shot and receiver-to-receiver variation along the line. The correction to final datum (which can be almost any fixed value for land data) is done at the end.

***Source**: http://www.ukogl.org.uk/*

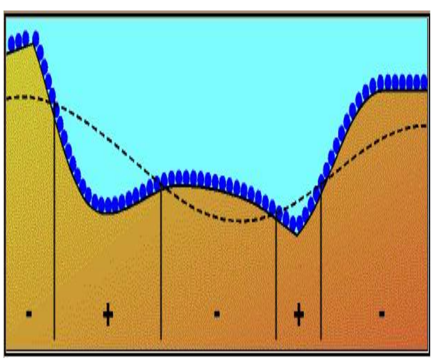


Figure 3.21: Floating datum

The floating datum may be above or below the actual shot or geophone position and the resultant statics may be positive (adding to the time and moving the data downwards) or negative (subtracting from the time and moving the data up towards time zero) (Figure 3.21).

***Source*: http://www.ukogl.org.uk/**

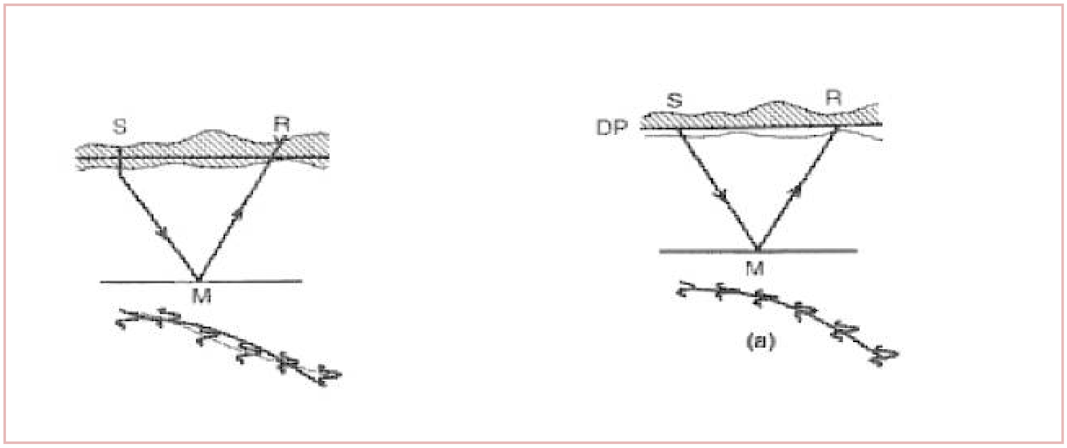


Figure 3.22: Near surface irregularities introduce time shift into the reflection events

(b). Velocity Analysis

Velocity analysis is usually done on common midpoint gathers where the assumption of hyperbolic alignment is often reasonable. A seismic reflections' travel time versus offset curve is a hyperbolic. The relation is exact for a sequence of layers. In analyzing recorded CMP (Common Mid Point) ordered field data, reflections also appear to be hyperbolic, at least approximately. (Figure 3.23) Velocity analysis is one of the first data processing steps, since many procedures strongly depend on velocity.

Source: http://www.ukogl.org.uk/

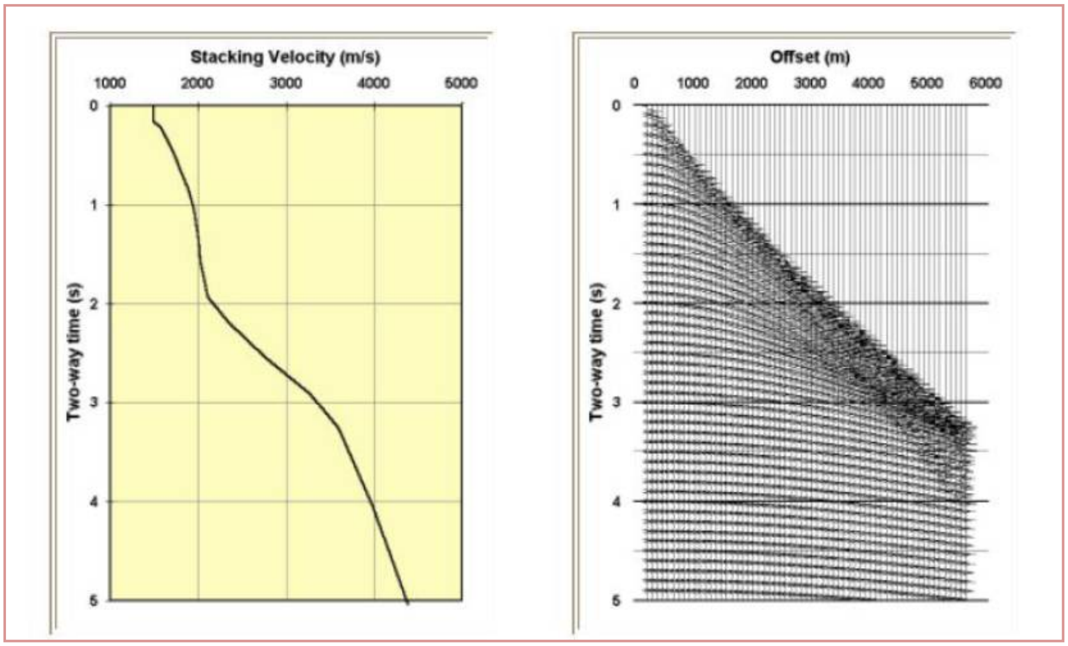
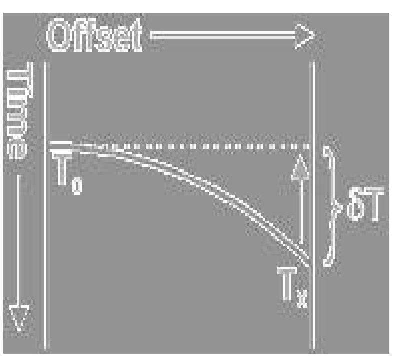


Figure 3.23: Figure showing the velocity curve and the section where from it calculated

(c). NMO Correction

Normal move-out (NMO) correction is a key to the efficacy of CMP stack



If we plot the T_x function shown in reflections travel time versus offset graph as in Figure 3.24, each reflection in our CDP (Common Depth Point) gather appears as a hyperbola. To correct for this distortion we need to move the sample at time T_x up to time T_o so that each reflector is horizontal on our CDP.

Figure 3.24: Normal Move-out Correction

After NMO correction we can see the reflectors are flat not hyperbolic. It is clearly shown in the following figure (Figure 3.25).

Source: http://www.ukogl.org.uk/

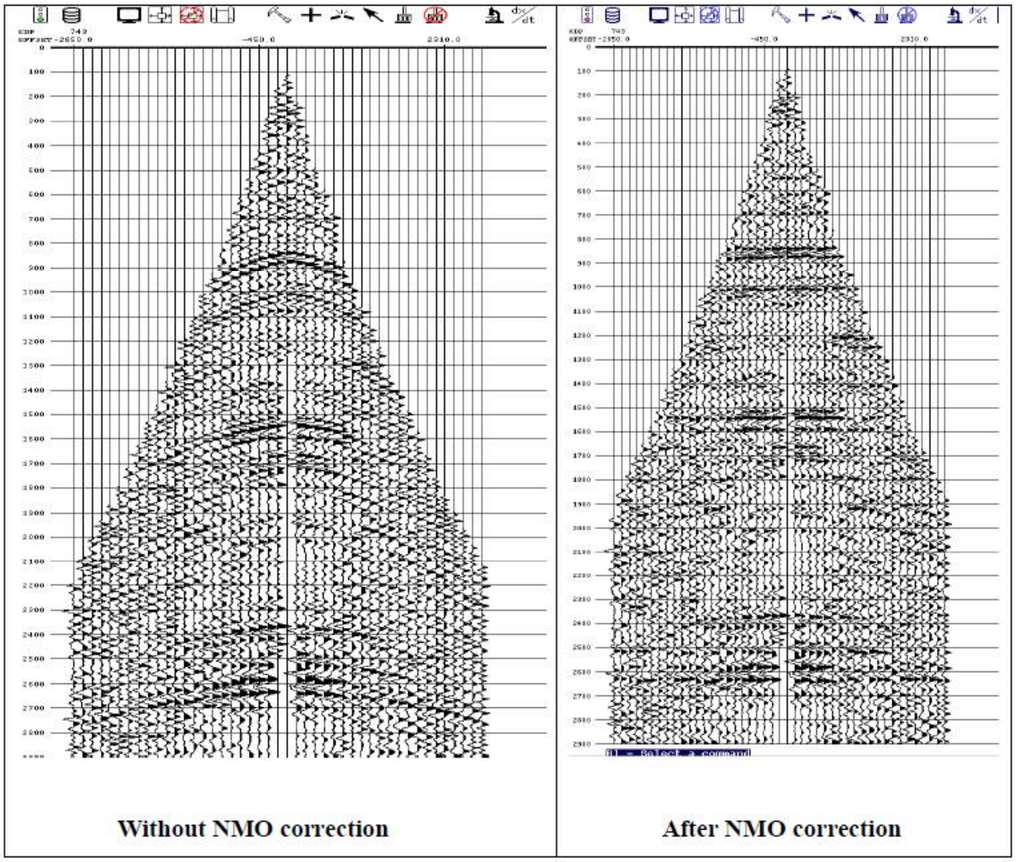


Figure 3.25: Before and after NMO correction

(d). Trace Muting

First-break and the refraction wave trains that follow them are usually so strong that they have to be excluded from the stack to avoid degrading the quality of shallow reflections. This is done by muting. On the right is a CDP gather showing the stretch introduced by the NMO and the "first-break" noise present on all the longer offsets. Before we stack this data we need to remove this early noise by *muting* the data out in this region. The conventional approach to this is to "pick" a mute and apply a ramp to the data starting at the 'picked' time (Figure 3.26).

Source: http://www.ukogl.org.uk/

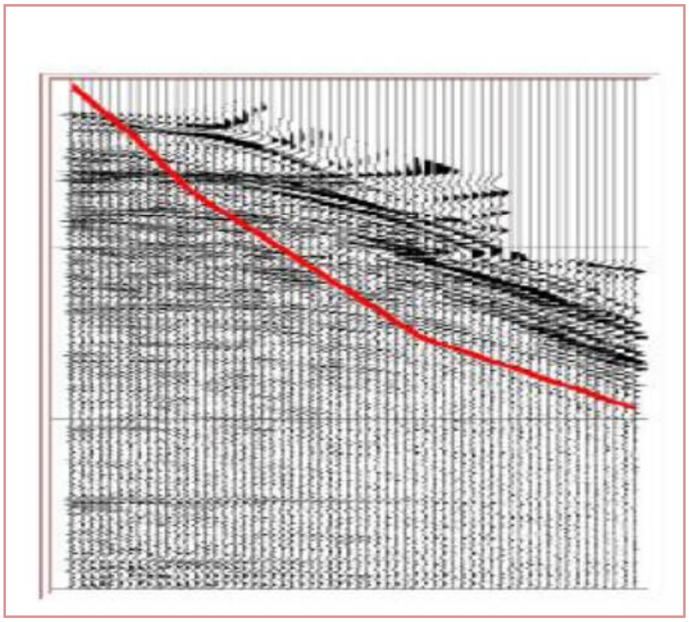
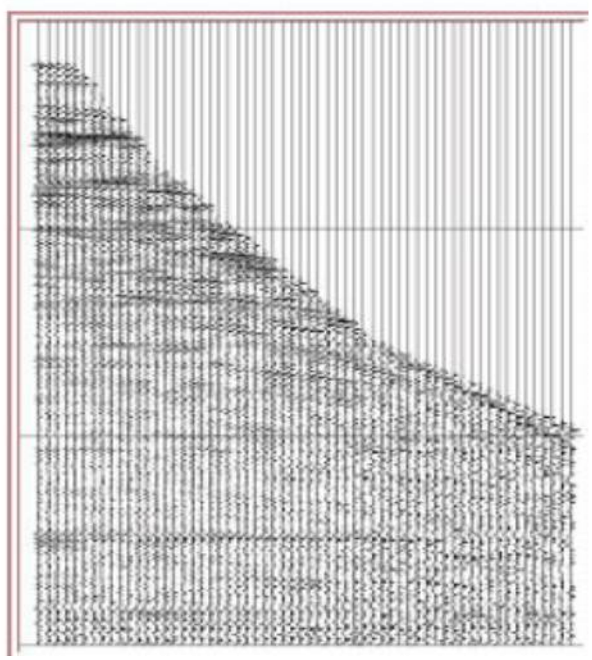


Figure 3.26: Muting the noise



This "top" mute can also be known as *ramping* or *tapering* the data, and typically zeroes everything above the line we pick, and then slowly ramps (over say 30-120 ms) the data to full contribution. (Figure: 3.27).

Figure 3.27: Ramping

(e). Stacking

It is simply summing up together all of the traces from this "CDP" into one final stacked trace (just as the traces on the left have been summed in Figure 3.28).

***Source**: http://www.ukogl.org.uk/*

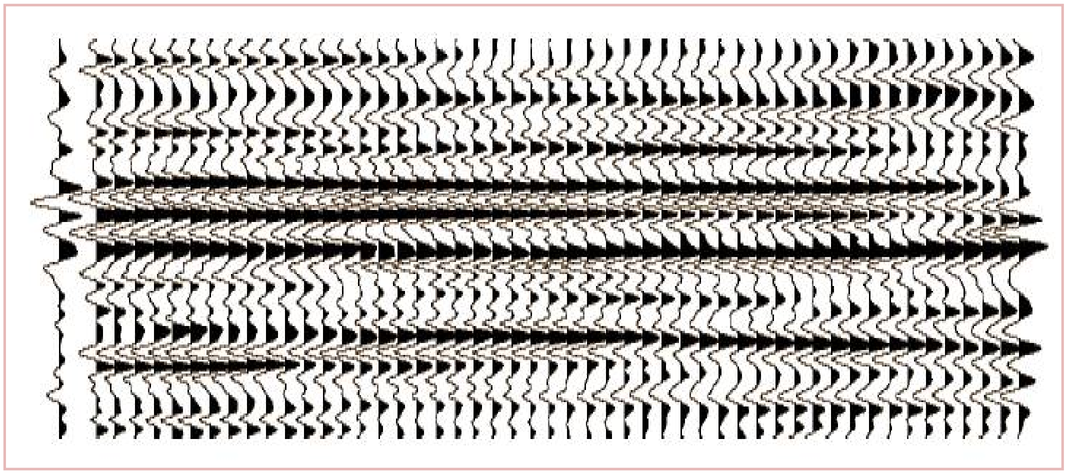


Figure 3.28: Figure represents a CMP stacking (single trace) from 50 traces

3.5.3. Post Stack

(a). Migration

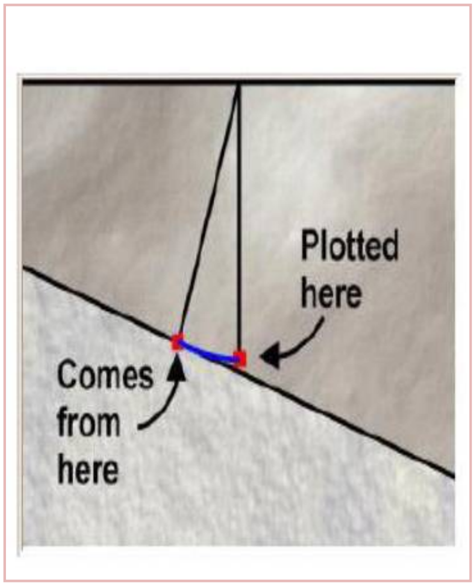


Figure 3.29: Migration

Migration is the process that moves the data on our stacked seismic section into its correct position in both space and time.
Even after the NMO and DMO (Dip Move Out) corrections, reflections from dipping events are plotted on our stack section in the wrong place. They need to be moved "up-dip" along a hyperbolic curve in order to put them in the right place, the shape of this hyperbola depending on the velocity field. (Figure: 3.29).

Source: http://www.ukogl.org.uk/

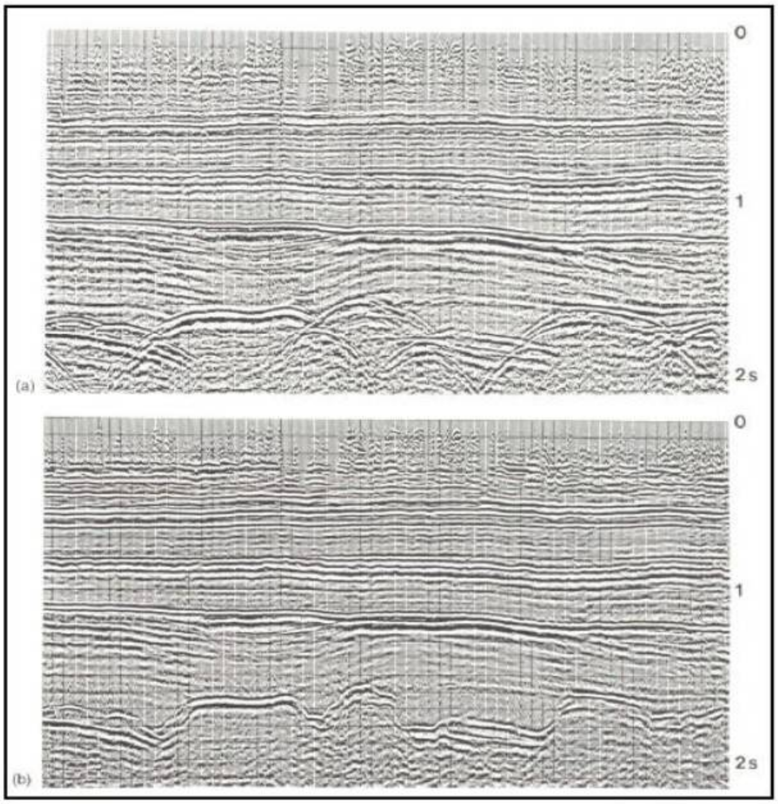


Figure 3.30: Distorted structures before and after 2-D migration

Finally, plotting of the traces is done to give the final output of the seismic processing (Figure 3.30).

The two-way time elapsed vs. amplitude of the seismic wave, after processing is provided in a universally accepted SEG-Y format. This format has been developed by SEG-Society of Exploration Geophysicists.

3.6. STRUCTURE OF SEG-Y FILE

The basic SEG-Y file consists of: Text Tape Header [of 3200 bytes] and Binary Tape Header [of 400 bytes]. The text header of 3200 bytes is used as 40 lines each with 80 columns. The binary header provides information regarding 'number of samples' and 'sampling rate'. It also indicates the format in which the 'amplitudes' are stored (32-bit IBM Floating point format / 16 bit/8 bit) ***[http://www.cwp.mines.edu].***

Each trace has:

Binary Trace Header [of 240 bytes]

Trace data (the size depends on the number of samples and sample format).

In the Trace Header (one per trace) the structure goes as follows:

Trace Header 1 ------ Amplitude Samples for Trace 1
Trace Header 2 ------ Amplitude Samples for Trace 2
....
....
....
Trace Header N ----- Amplitude Samples for Trace N

END OF FILE

Figure 3.31 shows reflecting horizons on which SEG-Y map has been super-imposed.

Source: http://www.oilandgas.org.uk/education/index.cfm

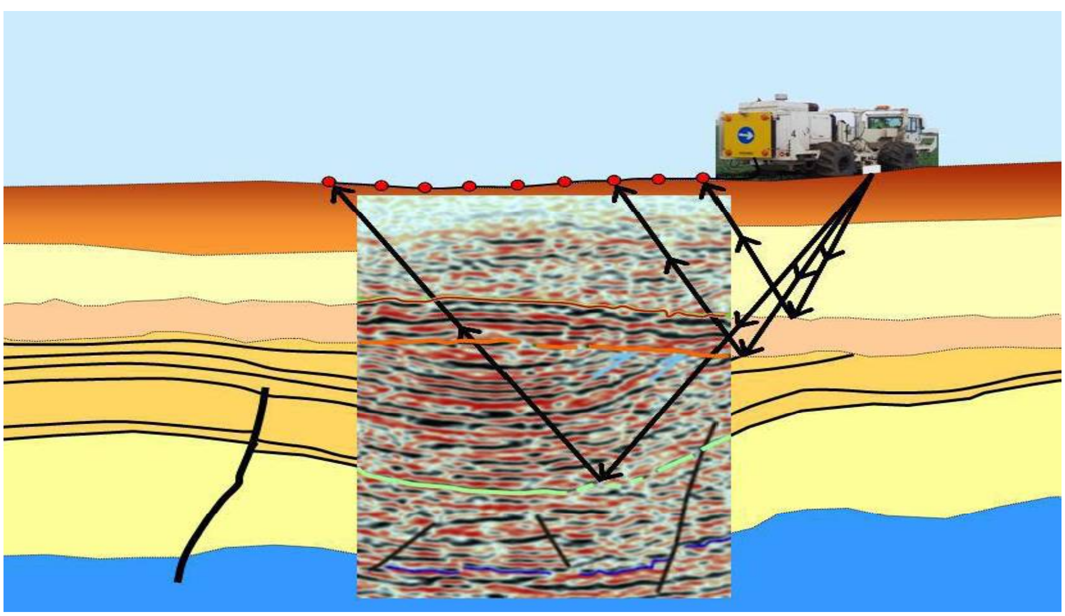


Figure 3.31: Reflecting horizon with SEG-Y map superimposed.

3.7. SEISMIC DATA INTERPRETATION

The basic objective of all seismic data processing is to get the raw data recorded in the field, in a form suitable for geological interpretation of structural features of a particular region. The data due to one shot and at one receiver is recorded as a seismic trace. The seismic snaps are the collection of seismic traces plotted with two way time or depth on y axis and distance (in meters from the shot point presented in form of number of traces), on x-axis.

The seismic maps indicate the seismic traces in the form of wiggles. The traces with the primary attribute 'amplitude of the reflected wave' as a function of 'two way travel time', is available to the seismologists for analysis and interpretation of the geological structures from which the waves were reflected. The geological information of the area being examined is made available to the seismologists, who are experienced people holding background in geology and geophysics. These 'experts' make use of various visual and coloring tools to observe the sections and come up with conclusions regarding the subsurface geology and other information concerning the presence/absence of hydrocarbon bearing structures in the area **[Strernbatch., 2002].**

This information is very useful for oil and gas exploration and production companies that make decisions concerning expensive drilling. There are huge financial commitments and economic risks involved and a wrong prospect can lead to a unsuccessful well.

The experts make use of their several years of experience, their individualistic knowledge-base of thumb rules, heuristics etc in interpreting the seismic sections. Each expert operates within his own environment created with his own beliefs and understanding of the seismic reflections. Due to this reason, there is an adequate chance of two experts coming up with different interpretations for same given seismic snap which might sometimes even deviate from the actual ones. This uncertainty is on one hand due to too much of a complexity of the geological structures and on the other hand, lack of any standard, formal set of rules for interpretation.

3.8. SEISMIC ATTRIBUTES

3.8.1. 'Amplitude' of reflected wave

The traces or wiggles hold within them lot of information about the structural geology of the region and hence require very careful examination. The SEG-Y file when digitized reveals primary attribute 'amplitude' and the 'two way time' as its main contents.

'Amplitude' of the reflected wave serves as the primary attribute for the analysis of the seismic wave signal. It can be used to derive another class of essential attributes, which can be used for further analysis and can generate more meaningful interpretation. There are a few analytical techniques available which use these attributes and help to generate useful information concerning subsurface geology. One of the statistical techniques that make use of 'amplitude' to track reflecting horizons of the subsurface is the 'cross-correlation' technique. This technique has been described in section 3.9.1 on this chapter.

3.8.2 Derived seismic attributes

Amplitude of the reflected wave serves as a base for the computation of certain derived attributes, which are particularly useful in tracking reflecting horizons with discontinuities such as faults. In order to compute these attributes the seismic trace can be considered as a complex quantity with the amplitude of the reflected wave forming the real component. This being, the only measured quantity as a function of time, the imaginary component can be found, by taking *Hilbert transform* of the real part **[Taner et al, 1979].**

Few of the attributes that can be computed through this complex trace analysis are: instantaneous phase, reflection strength (envelope), apparent polarity, instantaneous frequency, weighted average frequency etc **[Chopra and Marfurt, 2005].**

The real seismic trace *f (t)* can be expressed in terms of time dependent amplitude *A (t)* and a time dependant phase $\theta(t)$ as

$$f\ (t) = A\ (t)\ \ Cos\ \ \theta(t) \qquad \textbf{(3.1)}$$

The imaginary part *f * (t)* can be expressed as

$$f\ ^*(t) = A\ (t)\ \ Sin\ \ \theta(t) \qquad \textbf{(3.2)}$$

The complex *F(t)* is represented as:

$$F\ (t) = f\ \ (t)\ \ + f\ ^*(t) = A\ (t)\ e^{\ j\ \theta\ (t)} \qquad \textbf{(3.3)}$$

3.8.2.1. Instantaneous Phase

'Instantaneous phase' is the derived seismic attribute and can be easily computed by the complex trace analysis of the seismic trace. This attribute is characteristic of a reflecting horizon and therefore plays a primary role in tracking reflecting horizons. The fact that, instantaneous phase for a reflecting horizon is constant, makes it the best attribute to be used for tracking reflecting horizons with discontinuities such as faults.

Instantaneous Phase $\theta(t)$ can be calculated as:

$$\theta\,(t) = tan^{-1}\,[f\ ^*(t) \,/\, f\,(t)\,] \qquad (3.4)$$

3.8.2.2. Reflection Strength

The reflection strength, also called the envelope, is another seismic attribute which can be calculated for each time interval in the similar manner like instantaneous phase. Like instantaneous phase, reflection strength is also characteristic of the reflecting horizon, and hence serves as a good choice for tracking reflecting horizons, and also for tracking the discontinuities in the horizon.

Reflection strength *A (t)* can be calculated as:

$$A\,(t) = [\,f^2(t)\ +\ f^{*\,2}(t)] \ =\ |F(t)| \qquad (3.5)$$

3.9 ANALYTICAL TECHNIQUES OF HORIZON TRACKING

3.9.1 Cross-correlation Technique

Cross-correlation is a widely accepted technique to track reflecting horizons. This technique primarily works on the principle of applying statistical method of cross-correlation on the adjacent seismic traces in a pre-defined time window.

The process starts with picking up a user-defined marker, from the first trace of the reflected wave (such as maximum amplitude value in that trace), along with its corresponding time. Then a time window, of user-specified size (e.g. 5, 7, 9 or 11 time instants) is selected, with marker in the center of the window. This is cross correlated with the adjoining trace. These two adjacent traces within the time window represent a matrix with 2 columns and rows as many as the size of the time window. The computations are done and the value of cross-correlation coefficient is calculated. Figure 3.32 shows equations for cross-correlation coefficients for a window of five time instants.

$$a_1 = (x_1y_1+x_2y_2+x_3y_3+x_4y_4+x_5y_5) / n \qquad (1)$$

$$a_2 = (x_2y_1+x_3y_2\text{...........}x_ny_{(n-1)} / (n-1) \qquad (2)$$

$$a_3 = (x_3y_1+x_4y_2+x_5y_3) / (n-2) \qquad (3)$$

$$a_4 = (x_4y_1+x_5y_2) / (n-3) \qquad (4)$$

$$a_5 = (x_5y_1) / (n-4) \qquad (5)$$

Figure 3.32: Cross- Correlation Co-efficient equations

In order to eliminate noise from signal, the cross-correlation coefficients lower than a certain threshold value, are discarded. For example: the threshold value can be taken as 0.2.

The corresponding time interval of maximum amplitude of the adjacent trace in the matrix is taken as the centre for the window for the cross-correlation of the next trace set. Each time after cross-correlation coefficient computation is done and centre for the time window is chosen, the trace from the left of matrix is removed and the adjacent trace is included and the window slides ahead.

This process continues till all the traces within a seismic section have been examined. Typically, a seismic section may contain any number of traces depending upon the length of area for which the recording has been done. The time intervals that formed the centre of the window during cross-correlation process are given as output. These when plotted using a plotting program depict the reflecting horizon. The analysis similar to above is done to track all the reflecting horizons within a given section.

3.9.2. Tracking horizons across discontinuities

The cross-correlation technique is very useful to track continuous horizons, but does not give desired results in identifying discontinuities such as faults in the reflecting horizon. The location and extent of faults is an important geological feature which cannot be overlooked while interpreting the subsurface structures and extents of oil accumulation if any.

3.9.3. Using 'Instantaneous phase' and 'reflection strength' to track discontinuities

The initiation of the process of tracking reflecting horizon takes place, with the user picking up a reasonably large value of instantaneous phase as the starting point. Then the instantaneous phase nearest to this instantaneous phase value is chosen and its corresponding time is considered as centre for the next time window. This process continues till all the traces are examined in the given section.

Instantaneous phase attribute has significant contribution towards tracking the reflecting horizons across discontinuities, clearly outlining even subtle faults.

Following the same procedure as in case of instantaneous phase attribute, a reflection strength value which is reasonably large is used as the starting point and its nearest reflection strength within the pre-defined time window is found. For the chosen reflection strength, the corresponding time interval is taken as the centre for the time window and the same procedure is followed to get the nearest reflection strength from the next trace. This is continued till all the traces of the section have been examined.

Reflection strength too, like instantaneous phase is helpful to track the reflecting horizon across discontinuities very successfully, clearly outlining even subtle faults.