SEISMIC DATA ACQUISITION IN HYDROCARBON EXPLORATION

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ABSTRACT

Seismic data is a true subsurface image of the Earth. Being the most complex and costly geophysical method for hydrocarbon exploration, planning and designing of the acquisition of seismic data plays an important role in cancelling out the risk of inaccurate interpretation. All the major hydrocarbon discoveries have already been made and rest sedimentary basins are still in immature stage. So getting true, detailed and actual data might help us to explore leftover hydrocarbons to its full potential and judiciously. The text discusses all the aspects which can be made to acquire a perfect and flawless seismic data.

Keywords :- Acquisition ,source , receivers , onshore , offshore

INTRODUCTION

Seismic method is a direct method of hydrocarbon exploration and being the most important method it remains to be the most important tool in hydrocarbon E&P activities. It provides the best subsurface structural and lithological image. Generally, there are three components involved in seismic survey namely,

1) Seismic Acquisition(A)
2) Seismic Processing (P)
3) Seismic Interpretation(I)

They are combinedly called the Seismic API. Seismic method is a sequence method that is first and foremost process is to acquire the dataset , once the data is collected it is processed in order to make raw data into interpretable dataset and finally the processed data is sent for interpretation to geoscientists in order to create the perfect result required by company. Accordingly, each seismic project can be quite different in terms of how the data is acquired and processing needs to be applied in order to generate interpretable images. These images are used by the geoscientists to visualize the subsurface geological/structural information and hydrocarbon prospect identification.

Seismic data acquisition is the first and the foremost important step in obtaining interpretable seismic datasets. It is the generation and recording of seismic data and involves different receiver configurations. Seismic data acquisition is carried both on land (onshore) as well as on waterbody (offshore). Based on the objectives of seismic data acquisition, we decide the type of seismic survey i.e. 1D, 2D, 3D or 4D (Time lapse 3D). Exploration stage includes 2D/3D seismic survey whereas in the development stage 3D becomes more important. 4D (Time lapse 3D) is mostly preferred in the exploitation (Production) stage where we have to see the changes in our producing basin in a span of time. Suppose a basin has been exploited for a long time, so to check the amount of hydrocarbon left or to see other nearby areas from where hydrocarbons can be exploited ,survey is carried out at the same location and then the new data is matched with the old acquired data which was collected years ago. The variation in these two data tells the anomaly concluding the required results. Planning of the seismic data acquisition and designing proper acquisition geometry plays an important role in illuminating the subsurface features.

Depending upon whether we are going for seismic acquisition at deeper or shallow area, there are two types of seismic surveys i.e. Reflection and Refraction. Reflection surveys are used for exploration of deeper structures whereas refraction surveys are best for exploration of shallow structures. Therefore, the basic requirements for seismic survey are the source for producing seismic waves, receiver for catching the reflected/refracted wave and recording system to format and store seismic signals. To meet the geological objective, the main geophysical objective is to acquire high quality seismic data. The basic principle is the same for 2D as well as 3D data acquisition.

BASIC PRINCIPLE

The basic principle working behind the Seismic method is generation of acoustic waves by source at the surface of Earth and travelling of these waves in subsurface , getting reflected or refracted depending upon the density variation of different strata and recording these reflected waves at surface in terms of travelling time of the waves . Density variation arises in different strata due to lithology variation, variation in porosity arising due to diagenetic processes, mineralogy, fluid type and saturation (oil , water and gas). This variation in density results in change in velocity of a single wave travelling through different subsurface layers. Subsurface consists of many layers and the interface between layers where drastic change in velocity of waves and density change is observed is termed an acoustic boundary. Seismic reflection and refraction takes place at these acoustic boundaries.

OBJECTIVES OF SEISMIC DATA ACQUISITION

Main objective of seismic data acquisition is to achieve an interpretable seismic dataset . Different stages involved in seismic data acquisition are :-

1)Reconnaissance survey :- When we are allotted a large area for development of a hydrocarbon perspective it is not convenient to directly start acquiring seismic data as the seismic method is a very costly and complex procedure to carry out at the field. So, before going for a seismic survey a reconnaissance survey is done with the help of gravity , magnetic and electromagnetic methods to find out a smaller area of interest.

2)Semi-detailed survey :- Once a reconnaissance survey is completed then based on its result we determine a smaller area of interest over which we go for a semi detailed survey by seismic method in that particular area instead of going for a full large area.

3)Detailed survey :- Based on seismic semi-detailed survey we further delineate our area of interest in terms of high resolution data and this results in detailing subsurface features.

4)Borehole seismic survey :- Once we have detailed data of our area of interest we drill wells in order to calibrate the seismic data acquired in a detailed survey. This is carried out with the help of a process called vertical seismic profiling . *VSP or vertical seismic profiling* helps us to authenticate our seismic data collected. Exact matching of well data with seismic data says that the data collected is purely a true picture of subsurface geology. Any kind of variation in between the seismic data and well data depicts the errors in data collection in seismic data acquisition.

PRE - REQUISITES FOR PLANNING SEISMIC DATA ACQUISITION

There are several factors which needs to be kept in mind before planning a seismic data survey which includes :-

1)Geological objective :-This is defined as subsurfacial study which includes the type of conclusion we need to draw out of seismic survey. Whether we have to go for the subsurface structural studies or we need to study stratigraphy. Clarity in geological objectives is a very important factor because beds may or may not be parallel in subsurface, they may be dipping and there may be a lot of structural differences.

2)Inputs:- Inputs refers to equipements needed, manpower , navigation , support services, communication , budget , time frame. Equipment includes sources(*vibrators, airgun , vibrosis , explosives etc*.), recording system (*geophone and hydrophones*) , cable, etc. Due to complexity of the method a highly skilled manpower is required . Navigation is very important because the area we are choosing will have a latitudinal and longitudinal value on a global scale and this should match with the geoid system we are using in order to provide a global recognition . Time frame generally refers to the issues arised due to climatic and weather conditions of the area, it is hard to carry out seismic surveys in the rainy season or at a very high temperature areas. A pre-sanctioned budget is a mandatory requirement as seismic survey is a highly expensive technique, the budget should include every penny spent before , during and after the seismic survey.

3) Previous Information:- The area over which we are going for the survey should be checked for any previous information available. This previous information can be in terms of geological information or geophysical information. Geophysical information can include any remote sensing data, gravity or magnetic data or even the seismic data whereas geological information means the assumptions about subsurface geology. The presence of this previous information can help us to authenticate our survey or it can provide us with a base to carry out our survey.

4) Expected Response :- This includes the noise conditions of the area and the seismic friendliness . noise condition refers to whether our area is in a tranquil space like forests or it is present nearby very noisy areas like industrial sites and cities. Noise needs to be attenuated in order to get exact data of area. External noise can result in wrong interpretation of seismic dataset .
Seismic friendliness refers to the fragile perspective of an area in terms of geology. carrying out seismic surveys at high altitudes might be risky as it involves use of explosives. Any kind of seismic disturbance in such delicate areas may result in loss of habitat, natural disasters, etc.

5) Logistics :- It refers to transportation, supplying and delivery of equipment, manpower etc. to the target area. This has a direct connection to accessibility of the target area whether the area is well connected with roads or not, and an aerial movement is available in times of emergency or not.

6) Target :- Understanding the target we are mapping is a very important aspect of planning seismic data acquisition. We need to understand the depth of the target horizon based upon the remote sensing data, geology of the area, gravity or magnetic data i.e some information is must to know about depth of target. As we know that beds in the subsurface may be parallel or they may be dipping, so information about the dip of the target horizon is also needed. The dimensions of the target, that is how long it is extending or how much width it is having, is crucial information for planning the seismic data. Structural setting of the target area and the thickness of weathered layers is important to determine the depth of the shot hole drilled.

7) Field layouts :- Field layouts refers to creating the geometry of the target based upon the objective over which the data will be acquired. Field layout has several key elements like group interval , shot interval , line length , line spacing and orientation. Based upon resolution required, we decide bin size , foldage and migration aperture. Field layout is a very precious step in planning a survey. Field analysis is carried out for months in order to get an exact layout of our target area.

8) Quality assurance :- a quality check of data by experts is very necessary because once the data is acquired it is transported to a working station for processing. In case of any glitches in raw data we will have to acquire the whole data again. So, keeping in mind the complexity and cost of methods it is better to get the data checked at the field itself to minimize the risk of data getting wasted.

9)Experimental requirements:- we do not directly start acquiring data in the field . We start with some experiments like shot drillings or use of dynamite to check response, proper functioning of equipements. In case of explosives, amount of explosives required etc.

10) Safety and environment :- This is a very important aspect because fulfilling the safety and environment criteria of the area is required in order to proceed for the acquisition. There are several protocols, monitoring agencies whose permit is required in order to start the survey. Without proper paperwork and required permissions from various related departments may result in halt of the survey.

11) Permits:- permits include public relation jobs, crop compensation, contractual obligations, local socio -political conditions(it is the interference of local political powers in exploration process), legal obligations like labour, industrial, explosives, rules and regulations etc.(explosives like dynamite, RDX are not something which are available in general. They are in government surveillance. They can be used only by several permissions taken from the government and they need a very high security transportation system.)

All the factors mentioned above create a chain like system which needs to be followed before starting acquisition of data. These factors also prove the complexity of seismic methods. These factors and such obligations are not required in gravity, magnetic or electro-magnetic surveys thus making seismic the most important but a complex process in hydrocarbon exploration.

BASIC REQUIREMENTS FOR SEISMIC SURVEY

1) Source : - Source is defined as the equipment whose function is to generate acoustic waves which travel through the subsurface of earth. Depending upon the area where we have to collect data whether it is onshore (land survey) or it is offshore (marine survey) we choose the type of source . Different types of source include explosives, vibrators, vibrosis, air gun, falling weights and mechanical impactors etc. The choice between the source depends on many factors. If we have to carry out acquisition at high altitudes then using explosives might not be a good idea as it might lead to huge natural disasters, loss of life and livelihood. Similarly, using explosives on offshore surveys may result in disturbance in marine habitat and might lead to loss of aquatic habitats. Generally, in offshore surveys airguns are preferred as they are aquatic friendly and they cause minimal disturbance to aquatic life. About 70% of seismic exploration carried out on land are carried by the help of vibrosis. They are less hazardous and environment friendly(Fig.1) .

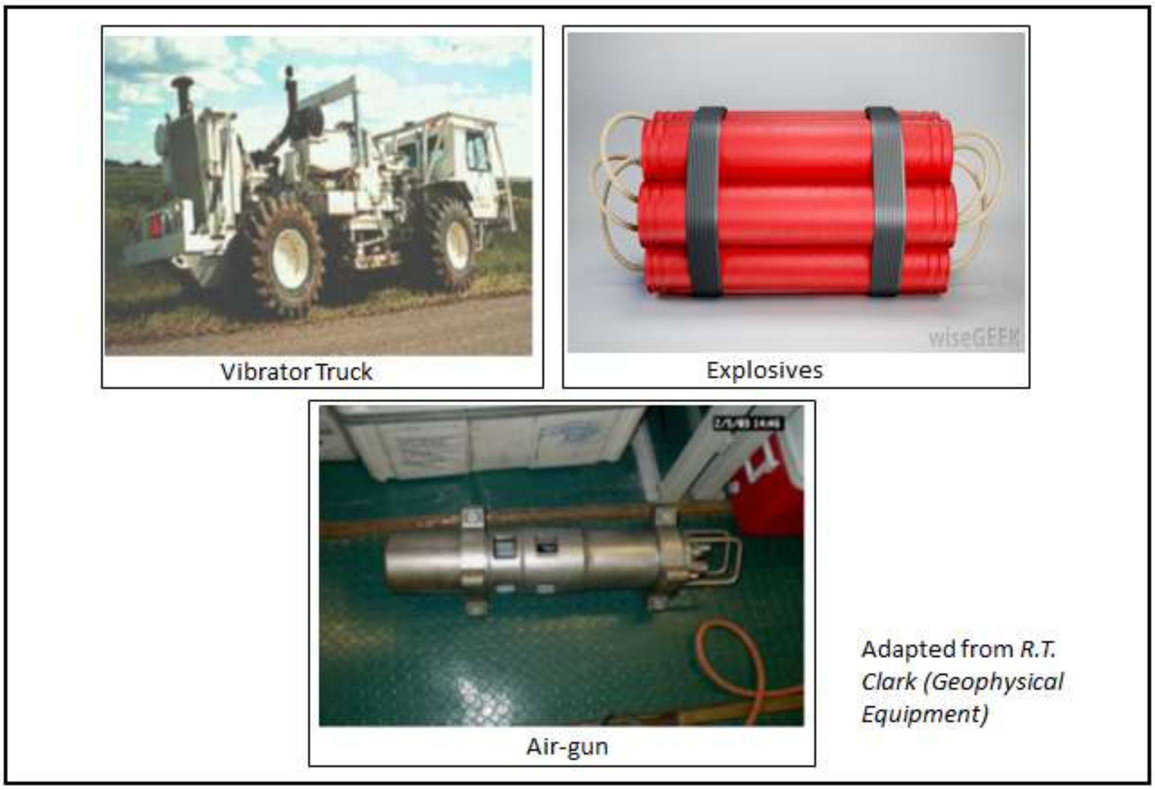

Figure 1:- different types of sources used in seismic data acquisition

2) Receivers :- Receivers are instruments whose function is to catch the reflected /refracted signal .There are two types of receivers: geophones and other one is hydrophones. As the name clearly suggests, geophones are receivers which are used on land surveys while hydrophones are receivers used in marine surveys (Fig.2) .

Geophones are vibration detectors which are velocity sensitive having a spike at the bottom which is planted in the ground .One to dozens of geophones is connected to form a group that records as a single unit called a channel .

Hydrophones are pressure sensitive . Hundreds of hydrophones are trailed behind the ship on steel cables in order to receive the signal.

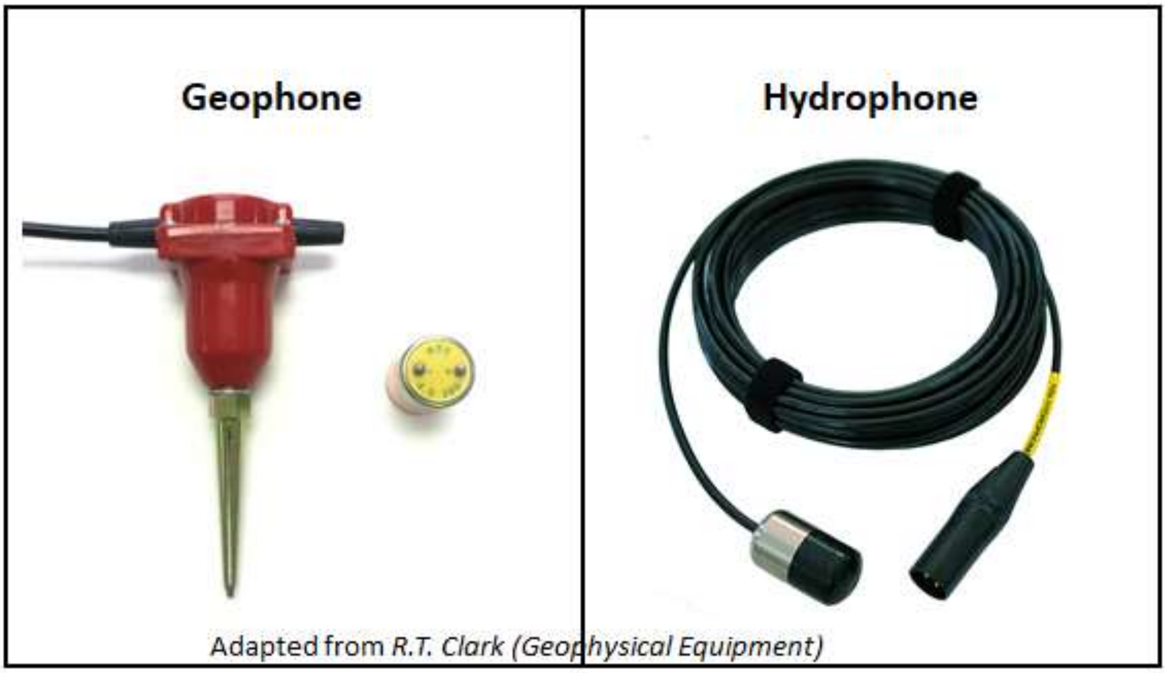

Figure 2: receivers used onshore (geophone) and offshore (hydrophone) in seismic data acquisition

3) Recording system :- Recording systems are used to format and store seismic signals. In land survey recording trucks *(doghouse*) are used whereas in the case of marine surveys seismic vessels are used. Recording systems are necessary because geophones/hydrophones cannot record the signal each and every time the reflection/refraction takes place (Fig.3).

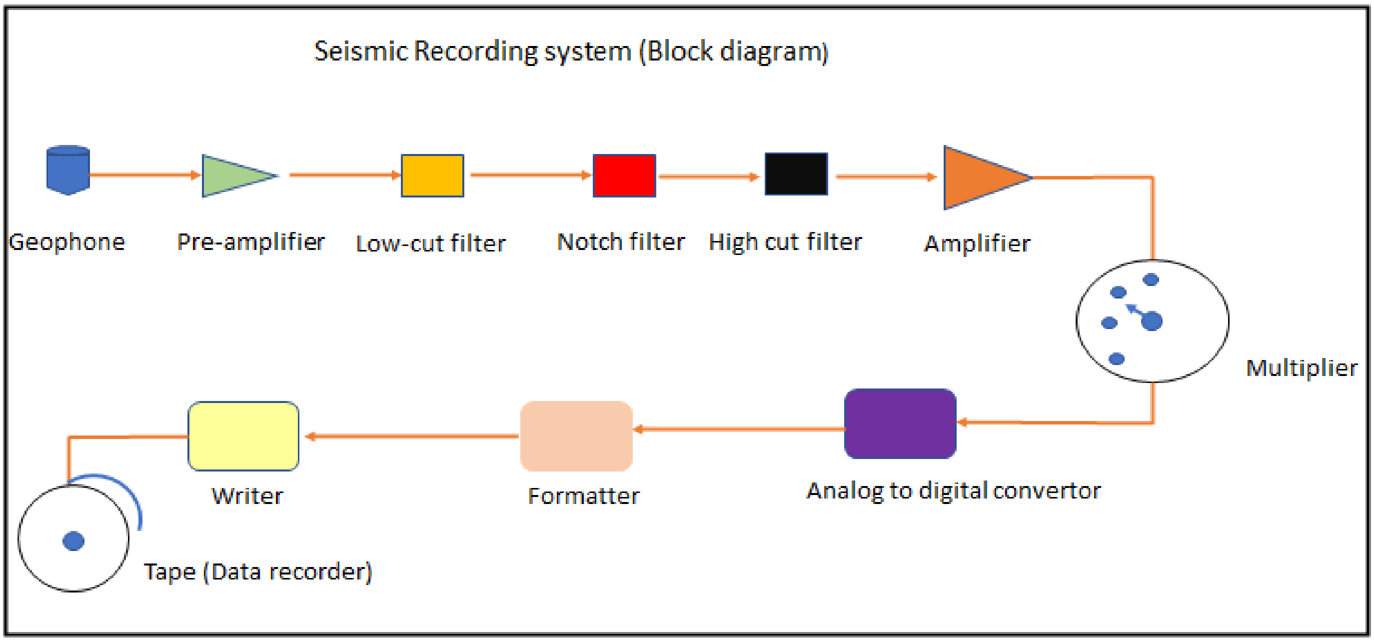

Figure 3: block diagram of recording system showing all the components starting from receiving of signal to recording

METHODOLOGY

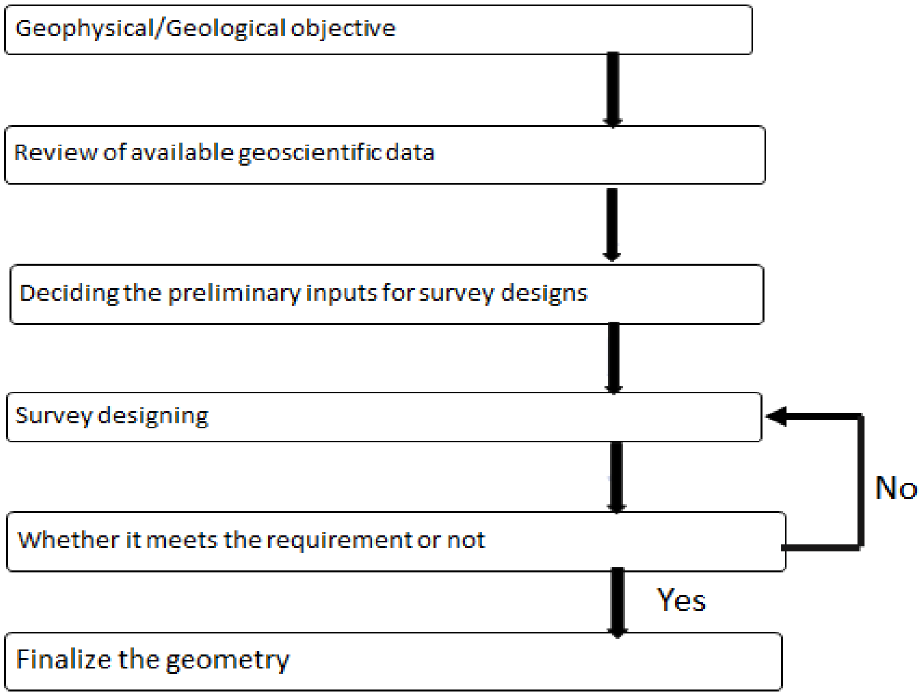

Figure 4:-Approach to select the acquisition parameter

1)Geophysical/Geological objective:- As mentioned above, the primary objective is to figure out the geological/geophysical target. This includes the purpose for which we are going to acquire the dataset. The purpose can be structural interpretation, stratigraphic interpretation, reservoir monitoring, time lapse, or qualitative analysis of the reservoir, etc. So, basically to figure out the requirements for seismic data acquisition.

2)Review of available geoscientific data:- all geoscientific data whether it is geological ,remote sensing data, gravity data, magnetic data, surface topographical features, geological map of area available needs to be analyzed before planning seismic survey. This review of available geoscientific data answers several situations like accuracy of geometry , fulfillment of geological objects, parameters and processing that were able to suppress the noise or not etc. This review gives an idea about our target area and thus helps us in delineation of our target. This data can be seismic data too. It might be possible that someone carried out a seismic survey of that area earlier and then we are acquiring data again.

3) Deciding the preliminary inputs for survey designing:- The preliminary inputs for survey designing is necessary as we need to know about the depth of the zone of interest. Whether we should go for shallow or deep surface because if we go for shallow one, there might be a possibility that deep subsurface features may be missed.
The inputs include the depth of target horizon, velocity of target horizon (Travel time depends on the velocity only), maximum frequency at target horizon, dip of horizon, foldage requirements and area of full fold coverage.

4) Survey designing parameter:- These parameters are instrumental and geophysical parameters.

Instrumental parameters includes:-

a) Recording length - It is defined as the length in terms of two way time which should be selected such that waves travel from the source to the boundary and back to the receivers without getting attenuated. It should be taken into account the two way time of the deepest horizon. Recording time will be high as the two way time will be high. Record length is adjusted to its necessary value to avoid useless increase of duration of survey. Suppose in a field deepest horizon is located at about 5000m so we have to set our record length depending upon two way time(TWT) such that data for more than 5000m depth can be acquired and if we take our recording length less than the two way time then our deepest horizon which is present at 5000m won't be mapped.

b) Sampling Interval -Sampling interval is defined as collection of at least two samples in the time period of highest frequency. This frequency is termed as *Nyquist frequency* (f_n) and mathematically it is calculated as:

Nyquist frequency (f_n) =1/ (2*Sample rate)

Generally, the sampling interval varies from 2ms to 8 ms. Sampling interval is chosen in such a way that the highest frequency data should be recorded. It should not happen that only low frequency data is being recorded. It avoids temporal aliasing of the highest frequency.

c) Low Cut filter :- Low cut filter is a filter applied to a receiving system such that below a particular frequency data will not be recorded. Suppose, in the field source generates some waves. Also, there is a soil cover in the field which gives rise to a lot of low frequency waves which are not useful in seismic data .So in order to avoid the recording of these low frequency waves which were generated by soil cover, a low cut filter is applied. Cut off frequency of the low cut filter must be above the natural frequency to avoid harmonic distortion (Fig.5)

d)High Cut filter:- As the low cut filter is used to attenuate low frequency data, in the same way a high cut filter is used to attenuate high frequency data. So, this can be defined as a filter having a particular frequency above which data cannot be recorded. High cut filter attenuates frequencies above Nyquist frequency which depends upon sampling interval(Fig.5).

e) Notch filter:- This filter is not a general filter it is used in areas having high tension power lines. It is used to attenuate 50Hz -60Hz power line pickup in seismic bands . So , if the frequency of that particular high tension line is known then a notch filter with compatible frequency to the high tension power lines can be applied to such that the particular frequency of the high tension power line is not recorded(Fig.5).

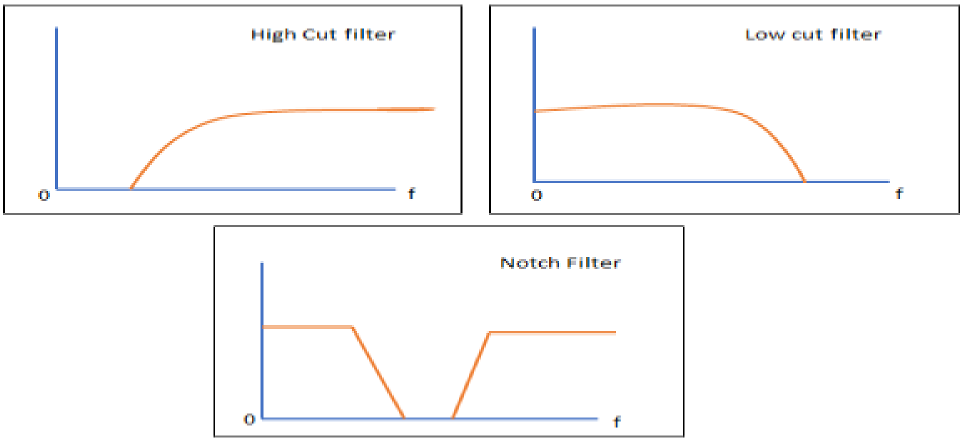

Figure 5:different filters showing frequency range for data acquisition in field

Geophysical Parameters:-

Seismic data can be 1D,2D,3D and 4D (time lapse 3D). So, seismic data can be acquired in 2D and 3D and in order to acquire it the geophysical parameters related to them respectively are(Fig.6) :

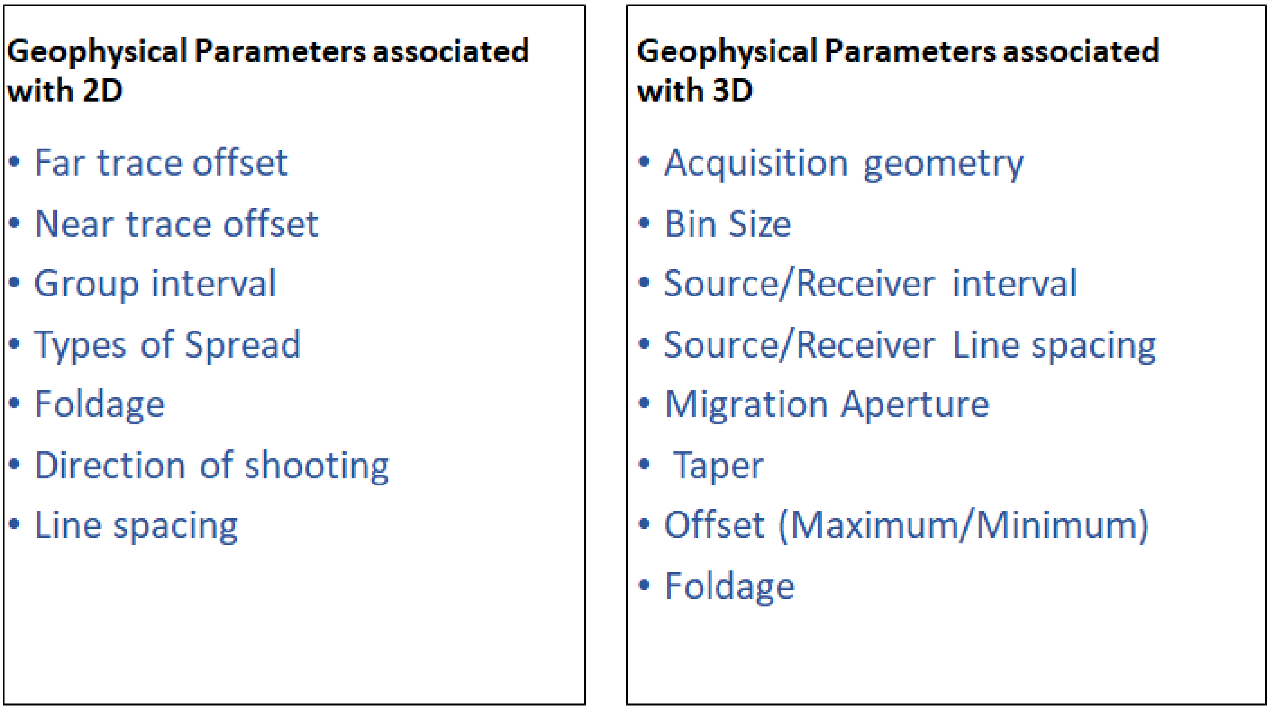

Figure 6: choosing the correct parametre based on the type of data needs to be acquired in field

1)Offset :- It refers to the distance between the source and the receiver. Based on the depth of the target, offset can be far-trace offset (maximum offset , X_{MAX}) or near-trace offset(minimum offset , X_{MIN}).

Far-trace offset :- Maximum offset required in order to image upto depth of deepest target. Far trace offset is chosen after considering suppression of multiples, NMO stretch, velocity analysis, depth of investigation and extension of the dipping reflector.

Near -Trace offset :- Minimum offset required in order to image the shallowest target. It should be small enough to sample the shallowest reflector that might be used for determining or isocroning purposes.

Based on the configuration of the 3D template ,In-line offset and Cross -line offset are defined. In-Line offset is defined as the distance representing half line of the template in line direction whereas cross-line offset is defined as the distance representing the half length of template in cross -line direction(Fig.7) .

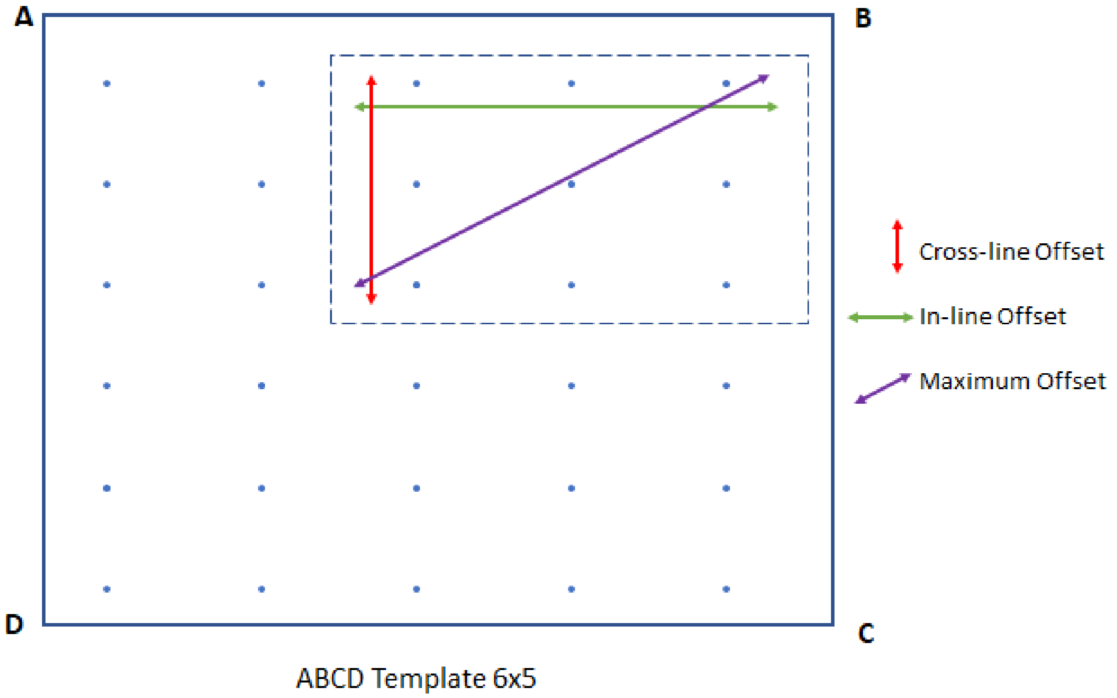

Figure 7: field template showing the offset

2) Bin :-Bin refers to a small grid and bin size corresponds to the length and width of the bin. Smallest bin dimensions are equal to half source point interval and half receiver interval .

Bin size (D_X)= V/4*F_{MAX}*sin□

where , v:- velocity to target depth

□:- steepest dip angle in degree

F_{MAX}:- maximum frequency expected

This steepest dip angle depends on the maximum dip of the area i.e. which is the smallest subsurface feature that can be recorded. If our bin size is very large then features smaller than the bin size won't be recorded. So, optimum bin size is decided on the dimensions of the geological object, depth of target, velocity of target depth and dip of the bed.

3) Group interval :- It is defined as the distance between a geophone or group of geophones. It is calculated from spatial aliasing and fresnel zone criteria .

4) Line spacing:- It is considered particularly when going for a 2D survey. The line spacing is calculated by,

1-R/L=L/4R , occurs when R=L/2

The separation of lines in the grid must be equal to or less than the diameter of the target.

5)Migration aperture :- It is defined as a distance which is added around the subsurface target area in order to correctly migrate dipping events and to correctly focus diffracted energy located at the edge of the target area. Migration aperture has a great significance in case of dipping structure(Fig.8).

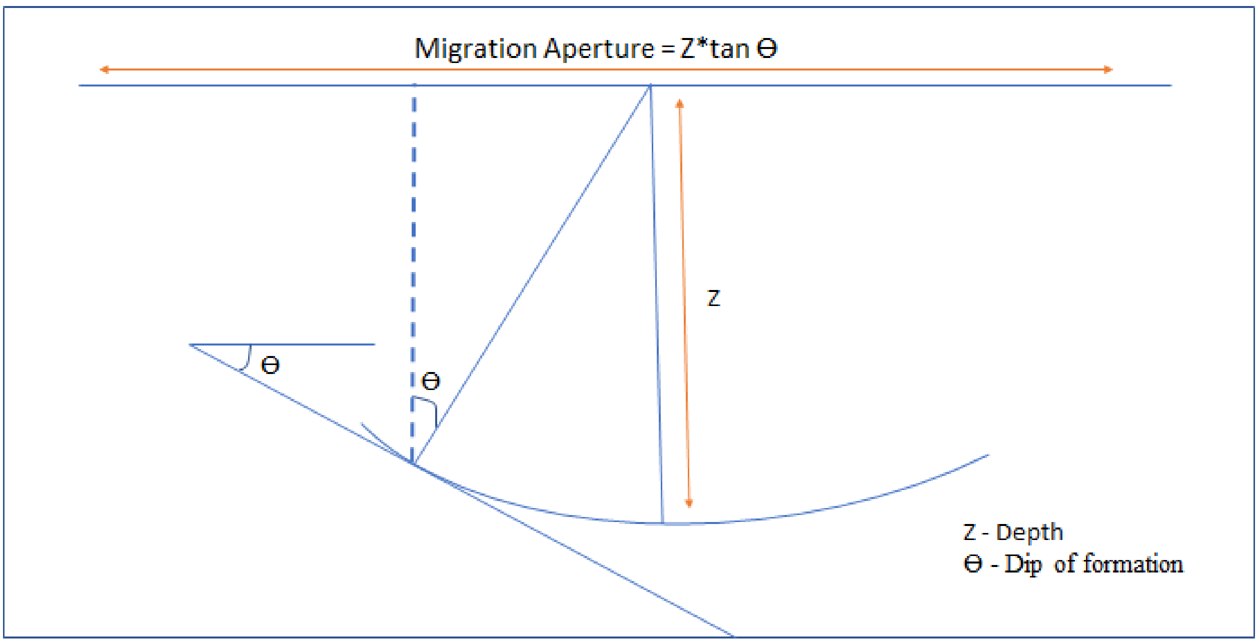

Figure 8: calculation of migration aperture by dip of formation

6) Taper :- It can be defined as the area around the edges of a full fold area where fold turns from minimum to full-fold(Fig.9).

In-Line taper (T_X) = {[(In-line fold /2)-0.5]*[source line interval]}

Cross-Line taper (T_y) = {[(Cross-line fold /2)-0.5]*[Receiver line interval]}

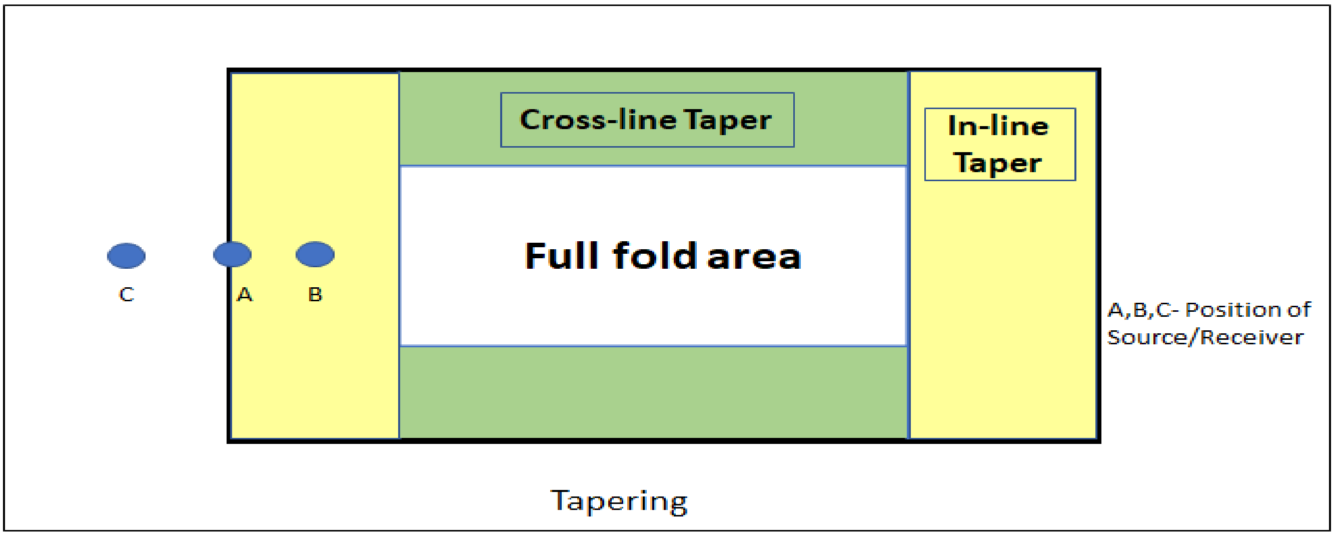

Figure 9: full fold coverage of area and minimizing the tapering effect in field

From fig.9, suppose we want to acquire full foldage data in the tapering area (i.e. to acquire data outside the full fold area) or we need to minimize the tapering. So, in the first case let our source be present at 'A' and receiver at 'B' then due to this arrangement of source and receiver data was not acquired in between them and this resulted in tapering. Now in order to minimize the tapering i.e. case two arises in which we place our source at 'C' and receiver at 'A' then we won't get data between 'C' and 'A' but we can easily acquire data at 'A' thus resulting into acquiring of full foldage data in tapering area .

6)Spread :- Spread refers to grouping of geophones. Whether we need to group the geophones symmetrically at a constant distance towards both sides of shots or shots are moving in one direction and receivers are moving in another. So, depending upon shot position and receiver position the spread will be decided in the field.
The most commonly used spreads are symmetric and asymmetric spreads which are included in split- spread configuration and another one is end-on configuration.

Symmetric spread :- In this equal numbers of channels are kept on either side of the shot. The geometry is such that the distance between two consecutive geophones is similar on both sides(Fig.10).

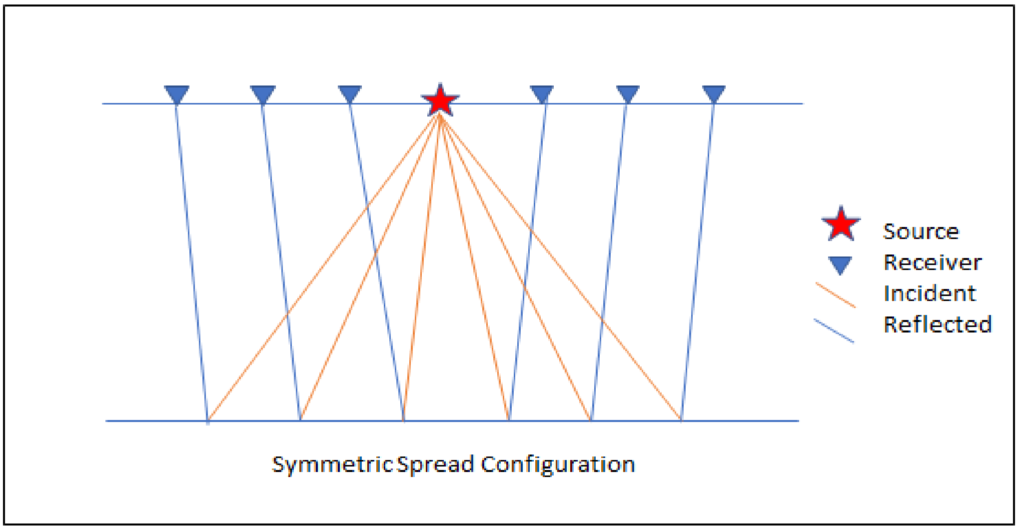

Figure 10 : symmetric spread configuration in field (arrangement of source and geophones **)**

Asymmetric spread :- In this spread, numbers of channels kept on either side of shots are not equal. Suppose we have to cover a large area and some obstacle is there in the line of geophones so we cannot place our geophone there. Thus, there comes the situation where we have to put 'n' numbers of geophones on one side of the shot and other numbers of geophones on another side of the shot(Fig.11).

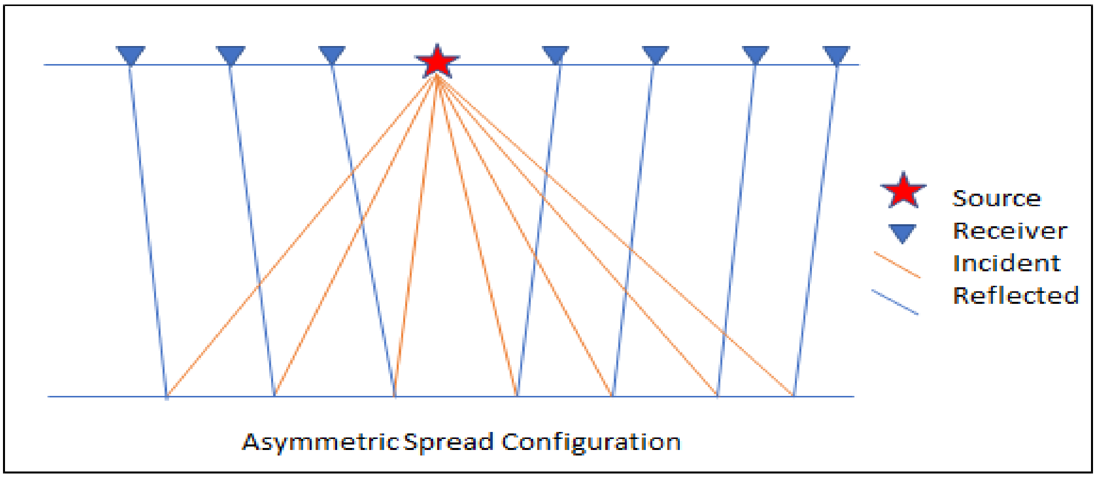

Figure.11: Asymmetric spread configuration in field (arrangement of sources and geophones)

End-on configuration:- In this shot point is kept at one end of the receivers spread and we keep on adding 'n' numbers of receivers in that direction(Fig.12).

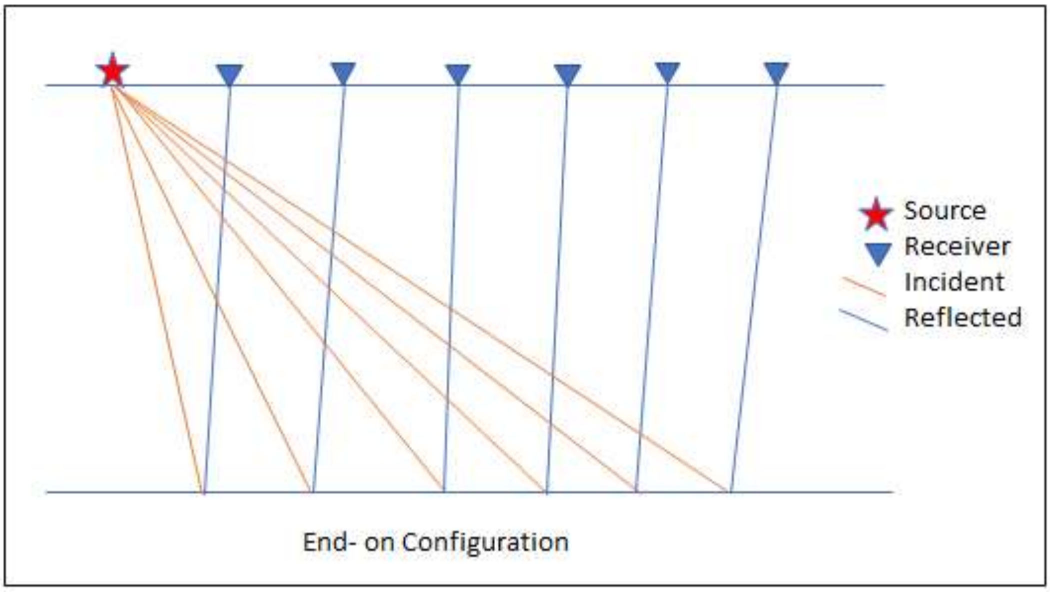

Figure.12: end-on spread configuration in field (arrangement of sources and geophones)

Split- spread configuration is suitable for shallow targets while end-on configuration enables us to look deeper because longer the offset higher will be the number of geophones required. The former is suitable in areas free of multiples while the latter one is suitable for better multiple suppression.

7) Foldage :- It describes how many times a single point is being scanned i.e. from one particular point how many times the wave has been reflected which results in clarity of data thus enhancing the signal/noise ratio. so, for good quality data signals should be increased and noise should be reduced i.e high foldage. Maximum foldage that is possible for a spread is curbed by availability of numbers of geophones.

Fold= N/2*G/S

where N= number of channels , G= receiver interval , S= shot interval

Therefore in order to achieve maximum foldage receiver interval should be equal to shot interval .

The fold of a 3D survey represents the number of traces that are located within a bin(Fig.13). Fold of 3D survey =(In-Line fold* Cross-Line fold)

where, In-line fold = (Numbers of receivers * receiver interval)/ (2* sampling Interval)

And Cross- Line fold= (Numbers of Receivers line) /2

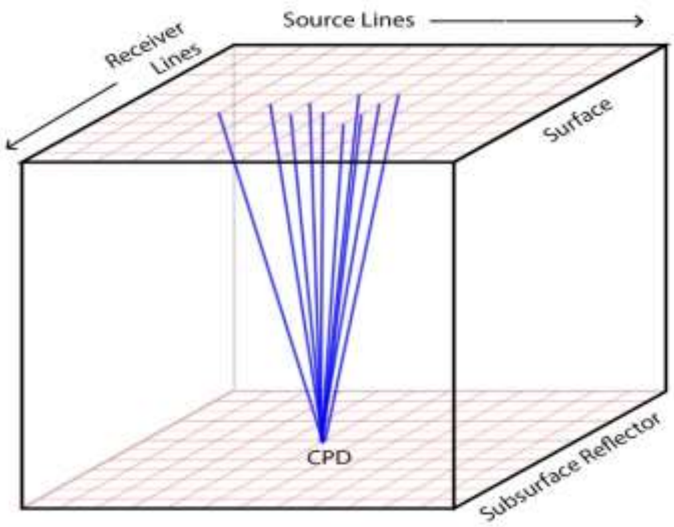

Figure 13: foldage defined by no. traces that we get in a bin

8) Direction of shooting :- Most commonly a shot can happen in up-dip or in down-dip direction. Up- dip direction is one in which we move from source to up dip area i.e. a source is there and we keep on climbing it up while down- dip direction of shooting is one in which we move from source to down dip area like climbing up a mountain and then coming down. Down dip shooting needs a larger spread length than up-dip shooting to map a dipping reflector accurately .Total coverage to map a steeply dipping reflector is less as compared to down-dip shooting(Fig.14).

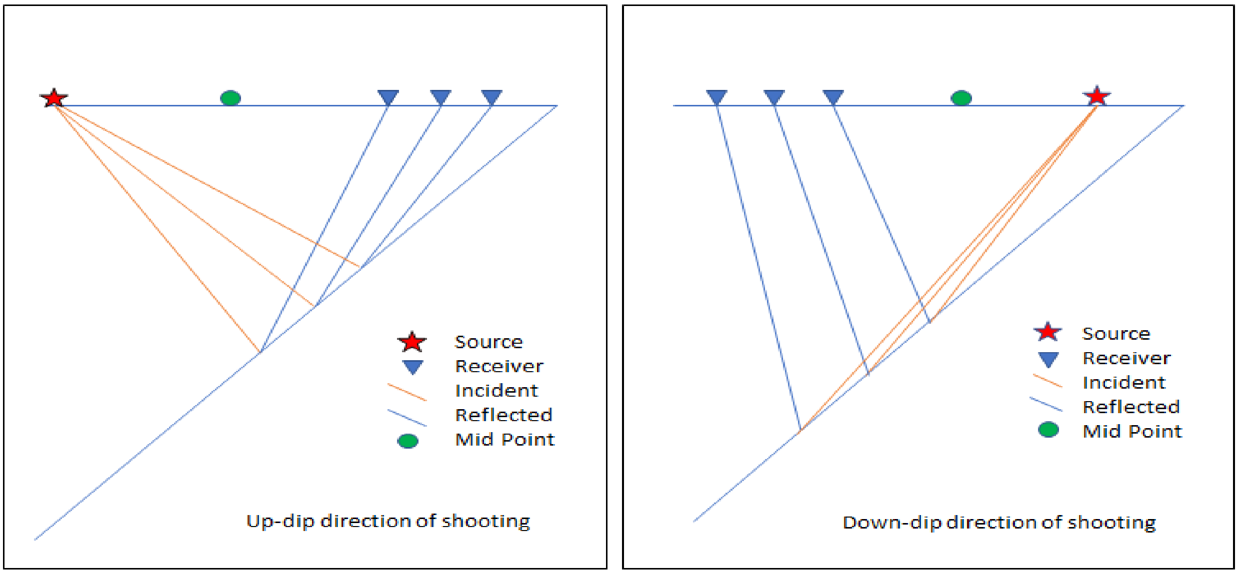

Figure 14:shooting direction used in field for data acquisition

ACQUISITION GEOMETRY

We select the acquisition geometry so that whatever subsurface geological object is there how best it can be covered. Acquisition geometry includes areal geometry, parallel geometry , orthogonal geometry, slant geometry (used when highly dipping folds are there), zig-zag geometry and brick geometry(Fig.15).

Data acquired with respect to the movement of templates is salvo and swath. The former one is the number of fixed shots before the template moves up along the survey and the latter is when the template moves in one direction and reaches the edge of the survey area then it generates swaths.

Once an acquisition geometry has been finalized and all the other factors have been taken into consideration as mentioned above the final field work starts which is termed as shot hole drilling. Shot hole drilling is done in land survey only. This is the first requirement in a seismic survey. Shot hole drills refers to making holes on the surface of earth in order to plant the explosives or to plant the wave generators. The depth of the shot hole is decided on the basis of the depth of the subsurface target. Also, shot hole drilling has significance in terms of environmental aspects too. Directly using explosives on the surface might create a disturbance in ecology and can result in social and economic losses.

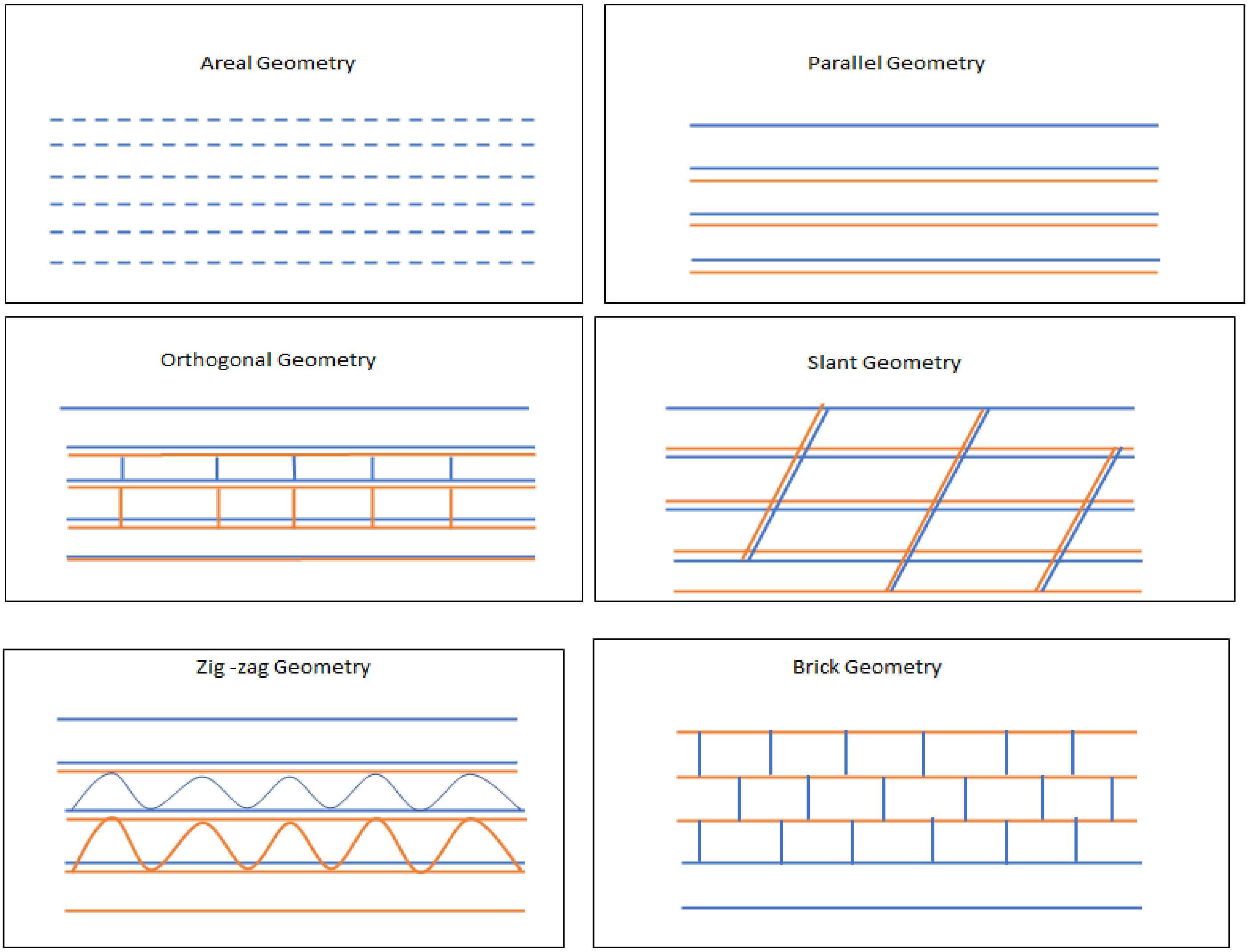

Figure 15: different type of geometries finalized based upon the different parameters considered for acquisition of

CONCLUSION

Planning of seismic data acquisition in a cost and result effective manner requires a deep knowledge of all the requirements and steps mentioned. Seismic data acquisition is the crucial step of all the components of the seismic method of petroleum exploration. If selected factors and parameters are chosen wisely then it can pull off the burden for the processing unit and as the seismic method is an expensive method so deciding appropriate factors also minimizes the risk of money loss. Due to complexity of process data acquisition only does not ensure the success of the survey. So , in order to minimize this risk a planned survey is a must.

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