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Feasibility and design study of a multicomponent seismic survey: Upper Assam Basin

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Summary

Multicomponent seismic analysis, especially using converted waves, has proven useful in the more precise delineation of hydrocarbon reservoirs. However, the surveys and their processing can be more cost intensive than conventional methods (vertical sensors and P-wave processing). The compressional- and converted-wave (P- to-S on reflection) response depend upon the petrophysical properties and geologic setup of the subsurface rock formations. These responses should suggest that there would be a detectable reservoir signature before one engages in a field survey.

Recently, a feasibility & design study has been carried out for a proposed 3D-3C survey to redefine the prospects in the structures/ reservoirs of Miocene- Oligocene groups in an area of Upper Assam Basin. In the study, well-log data are used and existing 3D-seismic data are reviewed. Well-log data shows a distinct difference of petrophysical properties (i.e., Vp, Vs, density, and resistivity etc.) among hydrocarbon-bearing sands and the shales in the entire target horizon level. Modelling of P-P and P-S responses using the given well-log data has produced good P-P & P-S gathers. All these indicate that P-P and P-S responses would be prominent & mappable; and the proposed survey could attain its geological objectives. Subsequently recorded 2D-3C data confirms the feasibility study results.

With this background, the general methodology of a feasibility & design study for clastic sediment regime is presented in this paper. Examples are shown here from the above mentioned study of the proposed 3D-3C survey.

Keywords: Multicomponent seismic feasibility design

Introduction

Converted-wave (P-to-S on reflection) seismology is a fast-developing technology being applied extensively in brown fields as well as in developing fields. It can give valuable information like lithology, type of fluids present, and fracture orientations in the reservoir. All these depend how best the data is interpreted. The interpretation involves:

- Identification of the reservoir and delineation of its boundaries
- Analysis of Vp/Vs values and their pattern within the beds or reservoir
- Studies of Velocity anisotropy and impedances of P-wave & S-wave in the formations

Success in interpretation requires good quality data in which reflections need to be mappable as well as prominent, attributes are distinctive, and the responses capture the subsurface geologic properties. The multi- component seismic survey (three-component recording on land) is generally costlier than the conventional (vertical only sensor) ones in terms of resources and technology. Therefore, before investing the money and resources in such a survey (3C data acquisition, processing & interpretation), one should try to ensure that the acquired P-S data would exhibit prominent events & mappable subsurface geologic properties.



So, interested organizations often undertake a feasibility study before the execution of a proposed survey to investigate whether it would yield desired results or not. In our feasibility study, the petrophysical properties of the target horizons are analyzed and synthetic P-S data are generated to see how they response to subsurface geology. Design of acquisition parameters also plays important role to achieve the geological objective of the survey. In this paper, a general methodology of doing feasibility & design study is discussed with examples from a proposed multicomponent survey project in an area of Upper Assam Basin. The works of feasibility & design study depend upon the geological objectives of survey. Therefore, for better understanding of the process for feasibility & design study, the geological objectives of the survey and a very brief description of geologic background of the study area are also presented here.

Geological objectives of the proposed survey:

- i) Delineation of the broad lithology of the target horizons within the Miocene – Oligocene groups (Girujan, Tipam and Barail)
- ii) Building up of a broad fluid distribution model within the reservoir
- iii) Finding of new prospects associated with stratigraphic traps

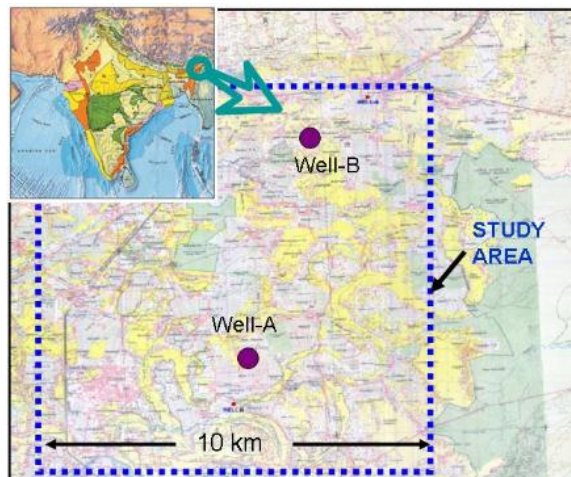


Fig.1: Map of the study area and wells used in the feasibility study.

Geologic set up of the area

The study area in Upper Assam Basin has sediments of thickness around 3.0 to 3.5 km. Sediments are from Recent to Eocene age and are predominantly sand-shale alterations. Reservoirs are mainly within the sands in structural type of traps. However in some cases, the traps are of combination type. Major production is coming from the Barail, Tipam and Eocene groups. Girujan may be a potential producer in future. The target zones (Girujan, Tipam and Barail) are at depths of around 2.00 km to 3.5 km. Major producing sand thickness varies from 10m to 30m.

Methodology for feasibility & survey design study

Feasibility study:

Good reflections/ responses come only if the rock layers (beds) have distinguishing petrophysical characteristics (P-wave velocity, S-wave velocity, density, resistivity, porosity, etc.). In the study area, the formations are predominantly comprised of sands and shales. During interpretation, it is desired to demarcate sands from shales, to distinguish wet sands from oil/gas sands and to find the reservoir's possible extension. With the given geologic background, we investigate in the feasibility study whether shales, sands, gas/oil sands are distinctive from each other in terms of their petrophysical properties or not. Log-data from the 'zone of interest' are studied. The steps for doing feasibility study are as follows:

- 1) Gamma, density, V_p and V_s logs are plotted together. In the plot, we assess whether there is any distinction between shales and sands in terms of velocity and density. This helps to know whether P-S data can delineate sands from the shales (in perspective of lithology) or not. An example is given as Fig.2. Display of various log data plotted together shows that gas sands, wet sands are distinctively separable from overlaying shales. This suggests that good P-P and P-S reflection events would come from shale sand interfaces during converted-wave survey.
- 2) Sands may or may not be hydrocarbon bearing. So, it has to be investigated on whether hydrocarbon bearing sands would be noticeable



among the shales and wet sands etc. in seismic sections. Cross plots of V_p/V_s , resistivity and gamma give information about how hydrocarbon bearing sands are different from wet (water bearing) sands and shales. If the separation of hydrocarbon bearing sands from others is good in the cross plot then it is sure that they would be clearly detectable in seismic.

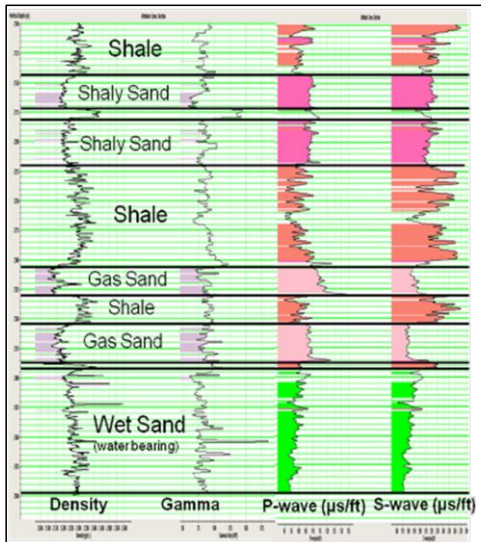


Fig.2: Well logs showing V_p , V_s , Density and Gamma ray data in the target horizon level. Overlaying shales and reservoir sands are indicated. P-wave velocity, S-wave velocity and density of reservoir sands are distinctively different than that of the overlaying shales. Wet sands are also different from shales in terms of V_p , V_s and density.

- 3) Sometimes hydrocarbon bearing sands may be shaly and tight. Clean producing sands are always preferred to shaly & tight sands as hydrocarbon producers. Cross plot of V_p/V_s , Porosity and Gamma gives information about how the clean/porous hydrocarbon sands are different from others and it indicates whether this sand would be delineated easily in seismic or not.

Fig.3 shows cross plot of resistivity and P-impedance. Gas sand, wet sand and shales are demarcated & highlighted based on log data interpretation. Gas sands have separation from wet sands and shales in terms of P-impedance. Note that the clean gas (higher porosity) sands have lower P-impedance in comparison to others.

Fig.4 shows that gas sands ($V_p/V_s \approx 1.7$) clearly separable from shales and wet sands. All these indicate that prominent reflection events will come from clean gas sands in real seismic data.

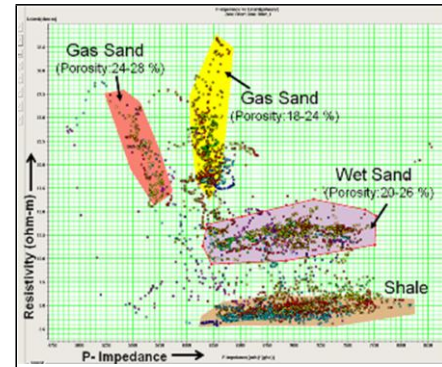


Fig.3: Cross plot of resistivity and P-impedance. Gas sands, wet sands and shales are indicated based on the well data. Porosities of sands are also mentioned.

- 4) Sometimes, there may be some high velocity layer above the target horizons as overburden. This may cause problem (shadow zone) for the target formations to be illuminated. Therefore, synthetic seismic responses are to be generated whether the entire target formations would be illuminated properly or not in the recorded seismic data. Synthetic NMO gathers are to be made based on P-P and P-S responses using density & full-wave sonic for the entire target formations. It would be better to use Zoeppritz equation. If prominent & distinctive P-S responses are generated pertaining to hydrocarbon bearing sands then it is sure that the P-P & P-S sections of proposed survey would provide the subsurface geologic information during interpretation. Fig.5 and Fig.6 are referred as examples.

Multicomponent VSP (vertical seismic profile) using a zero offset source as well as an offset source (500m or more) is also helpful to see generated P-P and P-S values. Detailed analysis & interpretation of the VSP sections give idea how effectively P-S data would illuminate the target formations in the proposed survey. It also gives important information to choose suitable sampling interval and record length for the proposed survey.

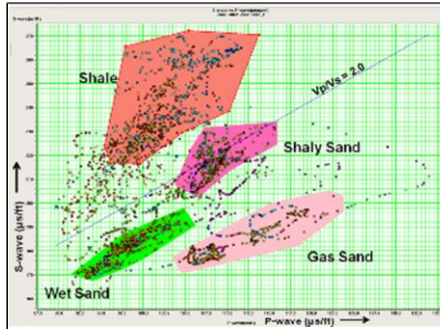


Fig.4: Cross plot of Vp and Vs. Vp/Vs values for gas sands are lower ($Vp/Vs \approx 1.7$) than that of shales and shaly sands in target horizons. Demarcations of shales, wet sands, shaly sands and gas sands are based on the information from log data interpretation.

Survey design

Designing a survey involves considering a number of parameters including sample rate, recording time, coverage length or area, offsets, azimuths, intervals, spacings, and fold. At the outset, one should examine the pre-existing P-wave data. If the data quality is good - reflectors are strong & well defined - then there is a good chances of recording high-quality P-S data (recall that the first part of the P-S event is the P wave). Sometimes, even when the P-wave data are poor, such as through gas-charged sediment, the P-S data can be reasonable.

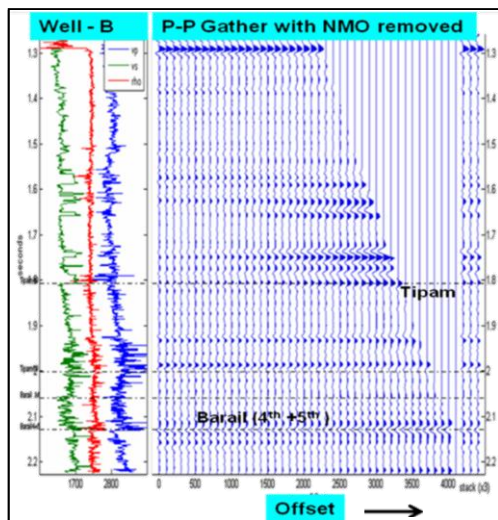


Fig.5: Synthetic NMO removed gather of P-P data using log data of Well-B within the study area. It shows good P-P reflections from target horizons of Tipam and Barail levels.

In the converted wave survey, P-wave and S-wave are recorded at the same receiver station (3C receiver) from same source point. So, the acquisition parameters would be such that it can suite for both P-wave as well as S- wave.

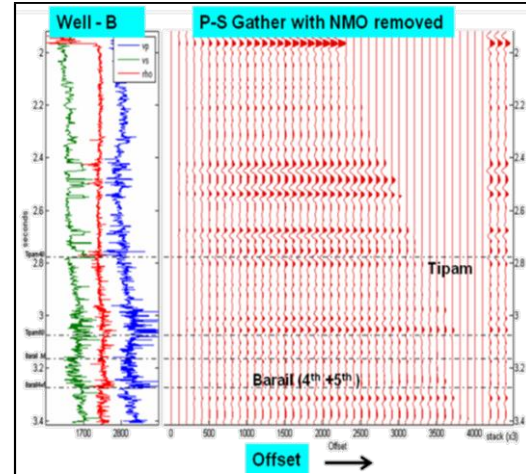


Fig.6: Synthetic NMO removed gather of P-S data using log data of Well-B within the study area. It shows good P-S reflections from target horizons of Tipam and Barail levels.

Although, the P-S reflection points are not spaced exactly as those of the P-P, they will be gathered and processed to the same points. Thus, the bin size for P-S data is kept as half of the receiver (3C) station interval. The receiver interval for the survey design usually must be decided as the optimum receiver interval required to satisfy P-wave objectives of the survey as well as the P-S. Because of statics issues, we try to make the receiver interval small as economically reasonable (perhaps one-half the regular P-wave interval). The source interval and source-line spacings (often the most expensive part of a land survey) may be similar to normal P-wave survey in the area. P-S data is generally weaker than P-P data in terms of amplitude. Therefore, to obtain a good P-S section, it is better to acquire higher fold P-S data. This can be done by choosing smaller receiver and receiver-line intervals.

Since, CCP (Common Conversion Point) bin size is kept the same as CMP (Common Mid Point) bin size for the survey; the CCP fold gets stripped appearance (refer Fig.9), possibly with some holes in it. Ideally, one would like to find a field geometry that produces a smooth midpoint distribution in the compressional data (Fig.8) and also a smooth CCP distribution in the converted wave data while using same bin size for the both. Stripping effect can be reduced by selecting source line intervals to be an odd



integer of the receiver interval rather than an even integer. Parallel geometry can give a smoother P-S fold than orthogonal geometry. If azimuthal anisotropy is to be studied then an orthogonal geometry may be a better option. The far offsets can be chosen as about equal to the depth of investigation as it is normally done in the case of compressional wave survey.

In the converted wave survey total travel time for P-S data from source to receiver is approximately one and half times of that of P-P data. Considering migrations etc. during data processing, record length is usually kept almost double of the P-wave record length.

Type of energy source is chosen as suitable to near - surface logistics and cost. If the area has moisturized soil cover and poor connectivity then dynamite (explosives) may be a better option. Charge size may be larger than that used in the P-wave survey to produce strong and relatively low frequency for generation of good P-S data.

It is always better to have aspect ratio more than 0.5 which generates good cross-line fold that helps to minimize random noises.

Sampling requirements of both P-P wave and P-S wave acquisition have to be harmonized, taking into account differences in maximum frequency between the two wave types. Sampling rate is chosen analysing the previous survey data and the available multicomponent VSP data (using an offset source).

As examples, in the survey area, the quality of available 48 fold 3D compressional data is very good and it gives good image of the target horizons at 2000m to 3500m (refer Fig.7). The bin size is 25m X 50m, receiver interval is 50m, record length is 5.0 Seconds, sampling interval is 2 ms, source interval is 100m, receiver line interval is 400m and source line interval is 450m. From the well-log data it seen that V_p/V_s values are close to 2.0 in most portions of the formations.

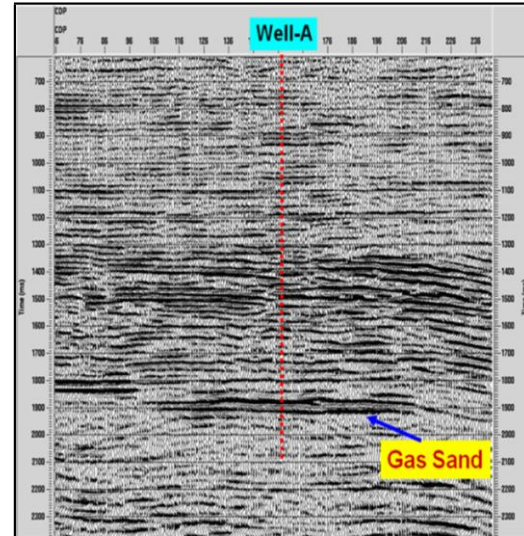


Fig.7: P-wave section of a profile passing through the Well-A. Gas sands are clearly detectable from others. Data quality is good.

Therefore, in line with above concepts & discussion and considering cost factor, the survey design parameters are chosen as the follows:

Bin size	:	20m X 40m
Receiver interval	:	40m
Source interval	:	80m
Receiver line interval	:	300m
Source line interval	:	420m
Maximum offset	:	3600m
Record length	:	10 seconds
Sampling rate	:	2 ms
Energy source	:	Dynamite
Geometry	:	Orthogonal

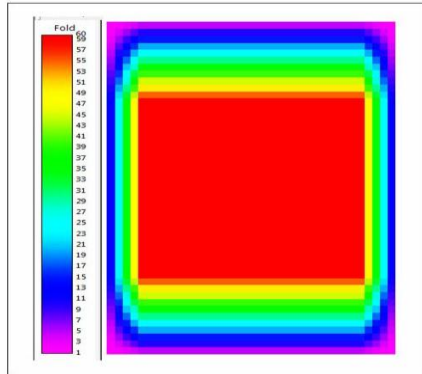


Fig.8: P-P fold diagram of the survey. Note that the fold distribution is smooth.

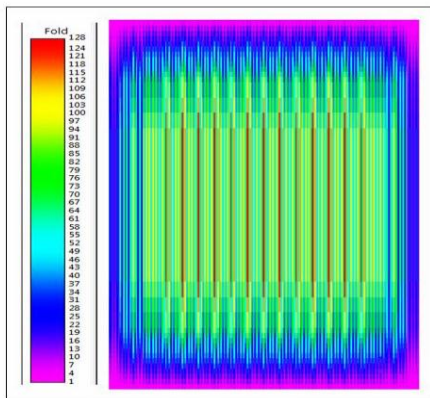


Fig.9: Fold distribution map for P-S data. It is to be noted that fold distribution is not smooth as in P-P data. The fold distribution map is computed by P-S ray path traced from source to receiver (P-S depth specific approach). The V_p/V_s (≈ 2.0) value is kept constant for the entire geological column above the reflector.

Field survey results

Data acquisition of the proposed 3D-3C survey is yet to be started. Meanwhile couple of 2D-3C profiles have been recorded in the study area. Examples from these recorded multicomponent (2D-3C) data (Fig. 10 - 12) data near the Well-A show good P-P and P-S responses from the target formations. This confirms the forecast results of the feasibility study. In the P-P record (common shot gather) the times of reflected events related to target zones (Fig.10) are in range of 1500ms to 2400ms (shown in box).

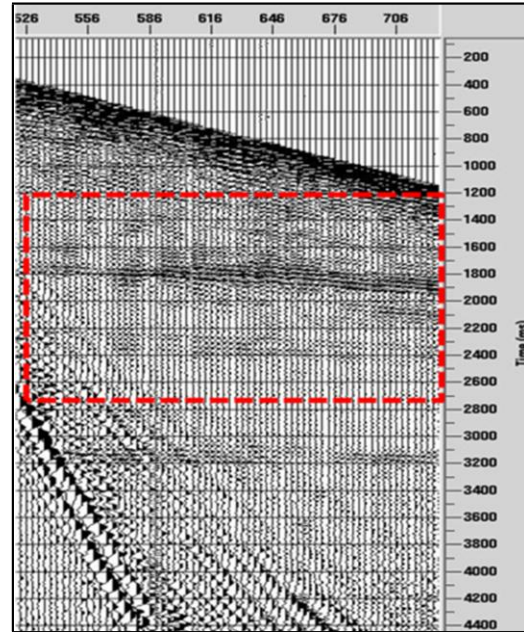


Fig.10: A raw shot of vertical-channel data (largely P waves) near the well. The reflection events pertaining to the target horizons are shown within the box.

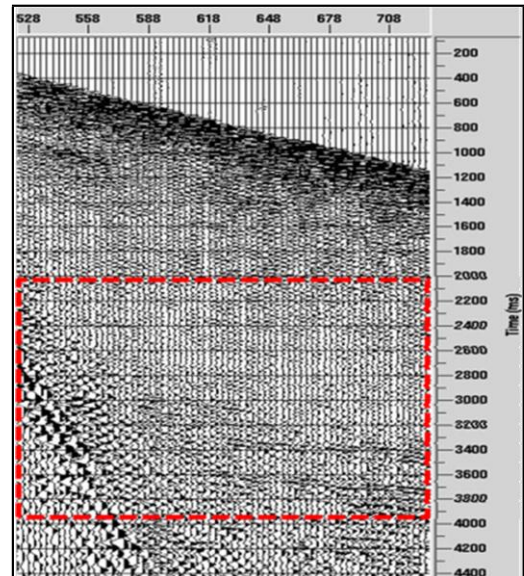


Fig.11: A raw shot of the radial horizontal component data near the well. The reflection events pertaining to the target horizons are shown within the box

The corresponding reflection events in P-S record (Fig.11 & Fig.12) are in range of 2200ms to 3600ms (shown in box). The reason is that the P-S reflection times are 1.5 times of corresponding P-P reflection times in converted



wave survey. It may be noted that the first break times in all three records (Fig.10-12) are more or less same. This happens because the first breaks are related to direct arrivals (no conversion of P to S) which are recorded by all the components of receiver stations.

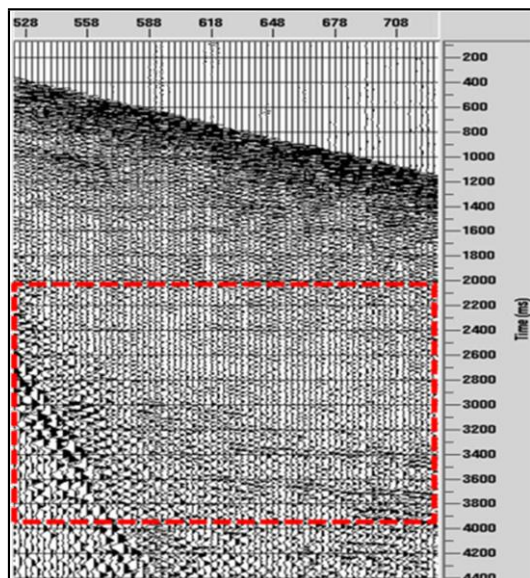


Fig.12: A raw shot of the transverse horizontal component data near the well. The reflection events pertaining to the target horizons are shown within the box.

Conclusions

The methodology for undertaking a feasibility study in a clastic sediment regime is described here with examples from the Upper Assam Basin. The feasibility study involves petrophysical property analysis and modelling of the P-P & P-S responses for the given rock formations. Well log data are extensively used because only they provide the hard information of subsurface rock formations. A so-formulated feasibility study indicates how successful a proposed multi-component survey could be in attaining its geological objectives.

Suitable acquisition parameters are the key to success in the multicomponent (converted wave) survey. Salient points of designing of converted wave survey parameters are also discussed in the paper. Judicious selection of bin size, far-offset, fold and type of geometry are important facets in the survey design. It is desired that fold distributions of P-P & P-S data are to be as smooth as possible. Due to asymmetric

ray path of the converted- wave, stripping occurs in P-S fold distribution. To obtain good image, stripping should be minimized to the extent possible.

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