Multi-Component Seismic (3C) Data Acquisition – A Case Study from Oil India Ltd. Operational Area in Upper Assam Basin*

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Abstract

M/S Oil India Ltd. (OIL) has several old and matured fields in Upper Assam Basin, India, wherein the reservoirs are at various stages of depletion. In these fields, the producing reservoirs are of mainly sand-shale sequences of Late Oligocene Barail group and Miocene Tipam group. The Late Miocene Girujan formation is also prospective in places and has lots of potential hydrocarbon bearing sands. To sustain hydrocarbon production from these fields, it has been decided to arrest the declining production by finding un-swept/by-passed oil as well as new hydrocarbon bearing sands within Girujan, Tipam and Barail formations, which still remain undetected through conventional seismic.

Towards this aim, OIL has decided to carryout Multi-component seismic survey in its fields for having superior subsurface image and improved reservoir model in terms of lithology, types of fluid present and presence of anisotropy and fractures, etc. Multi-component seismic survey is cost intensive. So, before doing a full-fledged multi-component seismic campaign in the fields, a feasibility study has been carried out using well log data and review of available seismic data to understand the suitability of the multi-component survey. The feasibility study found that the multi-component survey can yield good results in indentifying the hydrocarbon bearing potential sands. The whole survey campaign is planned in two phases. In the first phase, a pilot study is planned comprising of acquisition of 2D-3C profiles over the couple of oil fields and a 3D-3C in one of the oil fields. It is also been decided that if the pilot study yields good results then routine 3D-3C will be carried out in other fields in the second phase. The data acquisition is almost complete and that will be processed and interpreted soon.

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As a whole, multi-component seismic survey has three stages viz. Acquisition, processing and interpretation. There is a scope to make the entire survey campaign cost effective if the data acquisition is a low cost one. Quality data can be acquired in a low cost way through proper planning and using 'Fit for Purpose' methodology. This paper covers a case study in this regard in OIL's operation areas of Upper Assam Basin.

Introduction

Multi-component seismic recording (measurement with vertical- and horizontal-component) captures the seismic wave field more completely than conventional P-wave techniques. Multi-component surveying technique development has made it possible, the creation of converted-wave or P-S images. Multicomponent seismic survey is primarily being used world wide for determination of fracture density and orientation, gas identification, estimation of fluid content, investigations into quantitative saturation and pressure changes, providing another/better structural image, determining lithologic information and monitor reservoirs. All these information help immensely to reduce exploration risk further.

In Upper Assam Basin, the historic Digboi oilfield was discovered in 1889 and produced from the Tipam sands. After discovery in Digboi, several big oil pools (fields) namely Nahorkatiya, Moran, Makum-Hapjan, Dikom-Kathaloni had been discovered in south of the Brahmaputra River and north of the Naga Hills. The prospects in Nahorkatiya, Moran, Makum-Hapjan fields are mainly from Barail group. In places, probably due to lithologic conditions, conventional seismic (P-wave) does not provide good image of Tipam and Barail argillaceous (sand- coal shale). Therefore, there may be a number of potential reservoir sands that remain undetected. Until today, the prime producer is Barail Arenaceous in these fields. These fields gradually become matured and presently the production is in declining trend. By-passed /unswept oil have been formed within the reservoirs.

The motivations for acquiring of multi-component seismic (especially converted P-to S) data in these area are several fold, including: improvement of the P-wave section (via multi-component filtering techniques), developing new structural details (faults, compartments, closures) using PS wave images, assisting with new stratigraphic features and providing some large scale lithology (e.g. sand versus shale) information, fractures' orientation and anisotropy in the reservoir and help in providing information about fluid distribution.

All these are expected to help for arresting declining production trend of these fields by:

- Finding new prospects that were unnoticed before (in Tipam and Barail argillaceous),

- Building up improved reservoir model including precise mapping of by-passed/ unswept oil in Barail Arenaceous.

The multi-component seismic campaign under discussion is the first of its kind in the operational area of OIL of Upper Assam Basin (Figure 1).

The implementation program of the multi-component seismic has been decided to be in three stages viz. Feasibility study (to ensure the suitability of the technique in the fields), Pilot study and final adoption. The feasibility study carried out with analysis of well-log data and available seismic data has indicated that the multi-component seismic (converted wave) would yield good results in finding the potential hydrocarbon bearing sands. Acquisition parameters had been decided generating synthetic gathers using full-wave sonic data of the wells.

The 3D-3C survey is recommended to identify the bypassed/un-swept oil in the fields. Since it is a costly one and as it is going to be carried out for the first time in the areas, it has been decided for doing a pilot project recording of a good nos. of 2D-3C Profile in the fields / areas mentioned above and a 3D-3C survey in one of these fields. The results of acquired 2D-3C data will give the feedback on expected benefits of 3D-3C to be carried out in future. Multi-component survey is a costly survey judicious panning and use of ‘fit for Purpose’ methodology during field operation can make substantial cost reduction. In this paper, a case study has been presented covering feasibility study over different producing oil and gas fields in Upper Assam to understand the suitability of the multi-component and field implementation of multicomponent survey in cost effective ways in areas of Upper Assam Basin.

Geological Background

Assam-Arakan basin is a polycyclic basin located in the northeastern part of India. The shelf part of the basin spreads over the Brahmaputra and Dhansiri valley, shelf to basinal slope part lies below the Naga Thrust and the Naga Schuppen belt and the Cachar-Tripura Mizoram-Manipur fold belts occupy the basinal (geosynclinal) part. This is a proven petroliferous basin. About 7 km thick sediments ranging in age from Paleocene to Recent are present in the shelf part and sediments 10 km thick ranging in age from Upper Cretaceous to Recent is present in the fold and thrust belt. Eocene-Pliocene sequences contain potential source, reservoir and cap rocks. Around 115 oil and gas fields have been discovered in the basin. The Upper Assam Shelf part is predominantly a Tertiary Basin. Sediments of Palaeocene/ Eocene age were deposited in shallow marine to marine environment in this basin. Regional tilt/uplift prompted widespread marine regressions with an increase in the supply of sediments to this part of the basin during Oligocene.

Study Area

The study area is located in central part of OIL's operational area in Upper Assam Shelf Basin, at the southern bank of Brahmaputra River, in northeastern part of India (Figure 1).

Feasibility Study

In order to identify and rank the areas suitable for the multicomponent survey, a feasibility study is carried out. In this study, the data of several wells with di-pole sonic have been analyzed. In this study, we present the analysis of wells A, B and C pertaining to three different fields (Figure 1). The prospective Tipam and Barail groups are shallower in Well A. Eocene targets (Narpuh sands) are below 4,000 m depths as encountered in two of the Wells B and C. The Barail sequence defined for Wells B and C includes inter-bedded sands, shales, and coals. In all these fields, the main producing formations are Barail and Tipam sandstones. Their permeabilities range from less than 7 millidarcies to 800 millidarcies, and porosities up to 30%. We note that there are distinct S-wave velocity (Vs) anomalies in the Barail sands. Vs generally increases with sand quality. This is an important observation for the future use of converted (P-to-S) waves as the PS reflection coefficient is a function of the change in Vs across an interface. So, an increase in Vs in the well logs, from overlying sediments to the sands, is an essential property for sand delectability from multicomponent data. Sands are further indicated by a lowered SP, low gamma ray (50 API), 30% porosities, lowered densities, resistivities between 10 and 20 ohms, and high Vs. In the plots (on a Vp versus Vs chart), hydrocarbon bearing sands are found below Vp/Vs=2 and below the mudrock line (Figure 2B). Log analysis of a dry well Well A is shown in Figure 2A. Dipole sonic logs from Well A show little difference between fast and slow shear waves (Figure 2C). This suggests small azimuthal anisotropy at this location. However, the area does have faulting and fracturing, so on a larger scale azimuthal anisotropy may be present. With the vertically layered strata, vertical transverse isotropy or variations of seismic velocity with angle from the vertical is expected.

Synthetic Seismogram

Synthetic seismograms were generated during feasibility study to responses of S-waves from the prospect horizons and to decide the survey design parameters. Three wells, which had P- and S-wave sonic logs available, were used to generate PP and PS synthetic seismograms. None of the synthetic seismograms was deep enough to image the Eocene targets, as sonic logs were not available for that interval. The surface seismic data indicate that there is a signal frequency band from about 10-60 Hz for the P waves. This suggests that PS frequency band may be expected from about 5-30 Hz. Thus, synthetic seismograms with sources wavelets in these ranges were computed.

The PS synthetic seismogram from well A show an amplitude increase with offset at the top of reservoir (Barail) sand (Figure 3B) , however, the same is not appearing on PP section (Figure 3A). It is also evident that up to offsets of about 3,500 m there are little or no changes in polarity, which suggests that an offset to depth ration of about 1.5 is reasonable. Synthetic seismogram results from the well C and well B are shown in Figure 4A and Figure 4B and Figure 5A and Figure 5B respectively. It is noted that there does not appear to be major phase change at 3,000 m offsets at Barail level depths. Furthermore, the PS energy is arriving at about 3.0s.

The feasibility analysis shows that reservoir sands of Barails have anomalous S wave velocity character that may be identified using converted wave methods. Because of the relatively shallow target depths and good S-wave sand responses, it was recommended to take up multi-component seismic surveys in the areas that are ranked in the order Well A, B and C area as priority.

The Jorajan (Well B) and Moran (Well C) regions also have significant S-wave responses, but are relatively deeper and therefore more challenging. However, due to operational constraints for time being, the area pertaining to Well C was taken up for multi-component seismic survey on priority basis.

Multi-Component Seismic Acquisition

Several 2D-3C lines are recorded in the oil fields pertaining to Well A, Well B, Well C and Well D. The 3D-3C acquisition is going on in the oil field of Well A. (Figure 1). The specified 2D lines were proposed to critically observe the P and S wave characteristic, which facilitates to search new oil or gas bearing sand patches rather than the existing reservoir, if possible. Multicomponent Survey is being carried out using latest version of recording instrument and along with Micro-Electro-Mechanical Systems (MEMS) sensors for converted wave recording.

General topography and surface logistics

The areas are the traditional plain lands with thick alluvium cover. There are Tea gardens, thick vegetation, paddy fields, small towns, villages and forests in places. There are a number of small rivers and nallahs that drain out the areas. The soft soil cover condition in places and a number of small river and ‘nallah’ in the area restrict motor vehicles for cross-country movements. Vehicle movements are confined only within highways and village roads. Seismic survey operations are generally put off during Monsoon season and cultivation time i.e. from June to November.

Challenges in quality data acquisition in the area

The study areas have some specific surface and manmade logistics that pose sort of challenging situations for quality data acquisition in a cost effective manner:

- High cost in implementation of 3C sensors
- High cost due to slow production rate
- Cost-effective energy source
- Proper receiver-ground coupling

Methodology adopted

- *Meaningful ground marking for the receiver positions*: Receiver positions on the ground are indicated as a circle with arrow mark pointing the receiver line (In-line) direction. This arrangement allows very ordinary labourers to implant the 3C sensors aligning in the direction of receiver line on the ground very easily by just following the direction of arrow mark. In this way, it does not require skilled manpower, hand held compass and much time for implantation. So, the manpower cost has not been escalated (because of not using skilled labourers for implantation of sensors) and simultaneously production time in a day got increased. Overall, it helped the survey to be cost effective.
- *Low cost drilling strategy*: Experience of tube well drilling by local people for drinking water in the area tempted to choose indigenous manual drilling system over portable mechanized shot-hole drilling rigs to drill shot-hole as cost saving measures. Following the local wisdom, the cow-dung and bentonite are used to stabilize the hole-depth instead using of casing pipe. To get a good shot-hole with full depth and good coupling, the holes are used to be loaded with charge immediately once the drilling is completed.
- *Proper shot-hole depth for good energy penetration*: Based on the earlier seismic data, the shot-holes are drilled down to below of the low velocity weathered layer for good energy penetration. Weathered layer in the area more or less varies from 15 to 20 meter. Near surface velocity model of previous seismic campaign has been used for deciding the optimal hole-depth that varies place to place across the area to ensure that the shot-holes drilled are suitable for good energy penetration.

- *Arrangements for receivers' proper ground coupling*: In case of dry and hard soil, where implantation of 3C sensors is difficult, manual augers /hand held small drilling machines have been used to drill holes matching the diameter to that of spike of the 3C sensors so that sensor's spike can be pushed hard into the ground. It made good ground coupling that enabled the sensors to provide quality signal.

Results

The acquired 3C data sets are currently under analysis. Coherent energy is seen on the PP, PSH and PSV records Figure 6A, Figure 6B and Figure 6C respectively. The dominant energy on P wave records is about 40 HZ, while on PSH and PSV is about 20HZ. We observe strong events around times 2,400 - 3,100 ms in P wave data (Figure 6A) & 4,000 - 5,000 ms (Figure 6B and Figure 6C) on S wave displays, which may be associated with the Barails, the target reservoir sands in the area.

Engagement of mechanized shot-hole drilling rigs and casing pipes has large cost implications in comparison to a local/indigenous manual drilling system. Uses of indigenous manual drilling system in shot-hole drilling followed by adoption suitable work procedures to get good hole-depth has enabled acquire quality data with a substantially low cost.

In the process, savings in drilling cost component and receiver implantation cost component have been obtained as 75% and 25% respectively. The overall cost savings in survey has been achieved as around 50% (Figure 7). The similar work methodology and materials are used in 3D-3C survey in the nearby area, the overall cost saving is found as around 33%.

Conclusions

The above pre-survey feasibility analysis shows that reservoir sands Barails have anomalous S wave velocity character that may be identified using converted wave methods. Petrophysical analysis and synthetic seismogram modeling show the distinctive character of the reservoir sands. Recorded data adds confidence on that. The study also helped to convince the technical merit of applying this new technology in Well C field area. The full benefit of these new data will be realized only after the processing and interpretation of the acquired data. Total cost of the survey is brought down substantially using 'Fit for Purpose' methodology and judicious planning during survey operations. As on date we have already extracted the PP component from raw data and the resulting PP stacks shows exciting results with higher frequency content than conventional single component stack. We look forward to the further analysis of Shear wave components, which will result in further development and more widespread use of the new technology.

Acknowledgements

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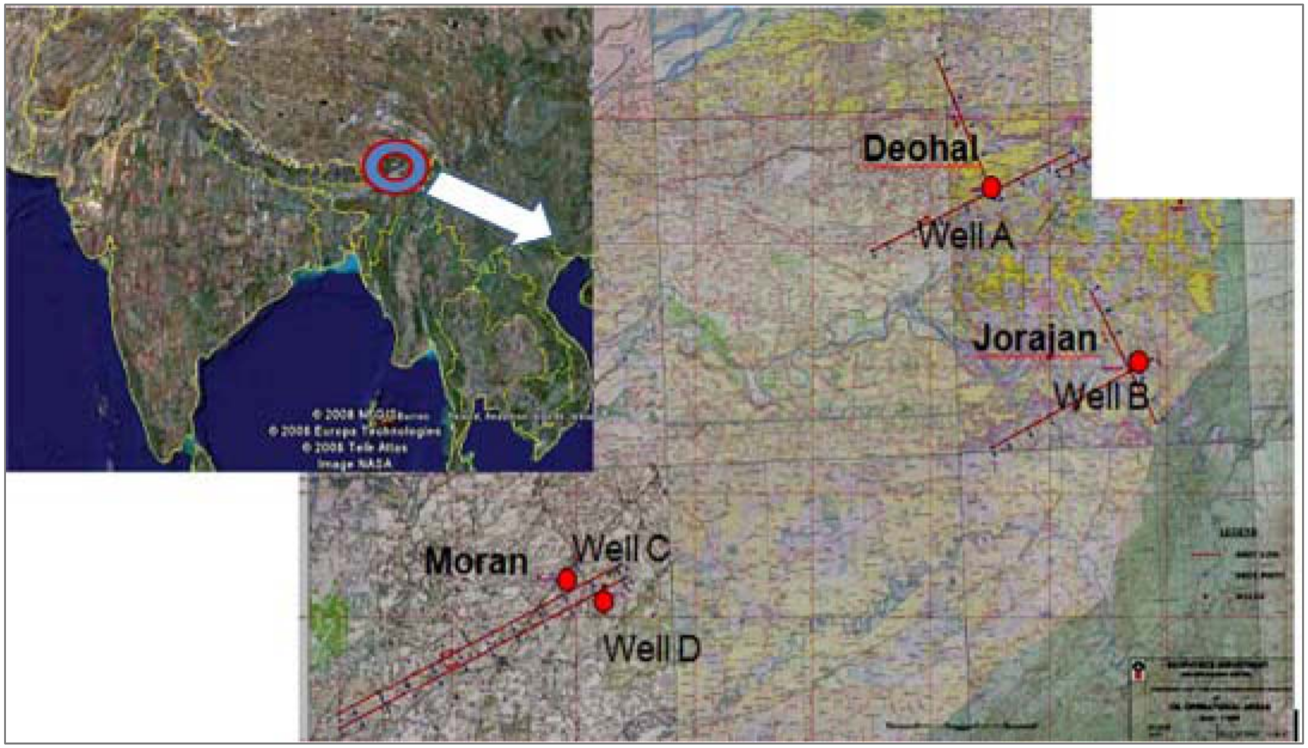

Figure 1. Location map of the study area in Upper Assam Basin.

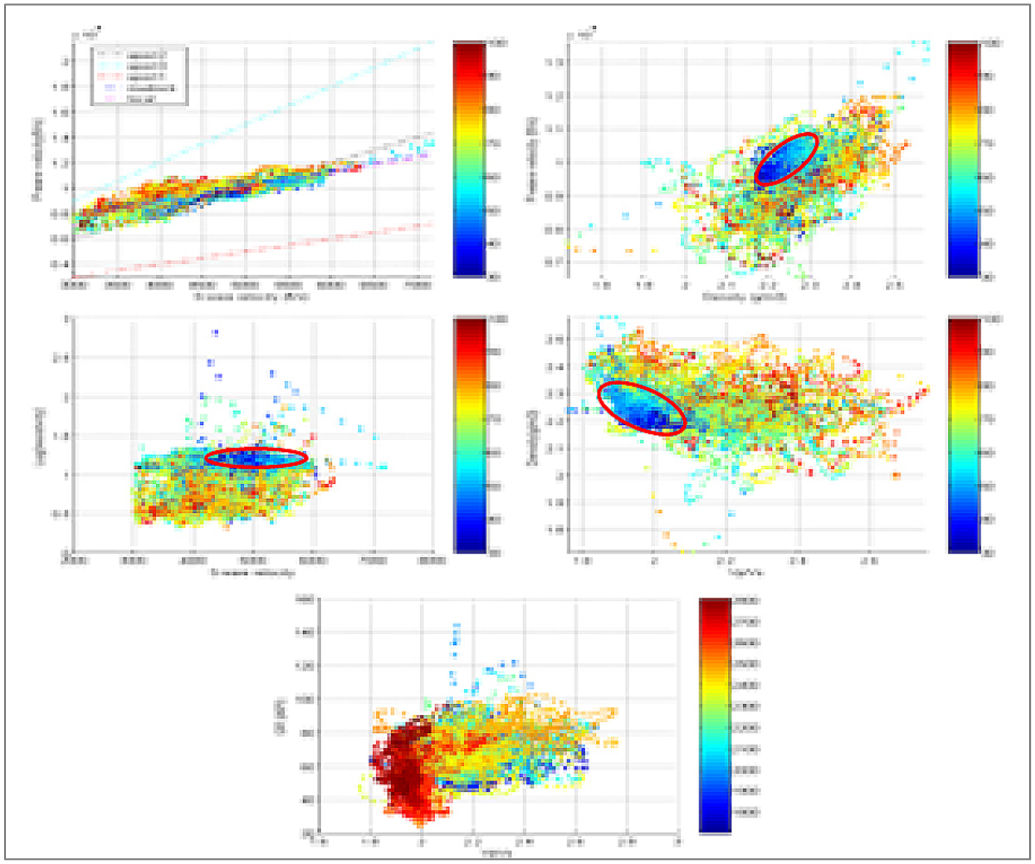

Figure 2A. Crossplots of logs from well A (a) P- vs. S-wave velocity, (b) P-wave vs. density, (c) Resistivity vs. S-wave, (d)Density vs. Vp/Vs and (e) GR vs. Vp/Vs. Color bar indicates GR, except on (e) where it indicates depth.

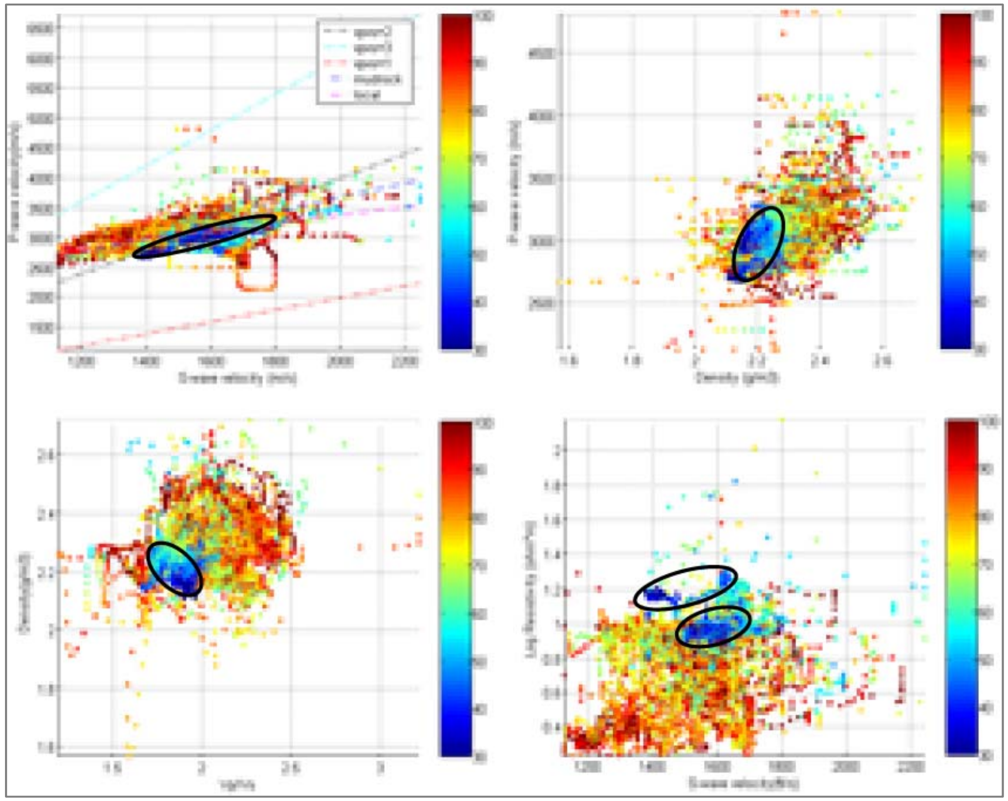

Figure 2B. Crossplots for producing well of nearby area of well A, (a) P- vs. S-wave velocity, (b) P-wave vs. density, (c) Resistivity vs. S-wave, (d) Density vs. Vp/Vs. Color bar indicates GR.

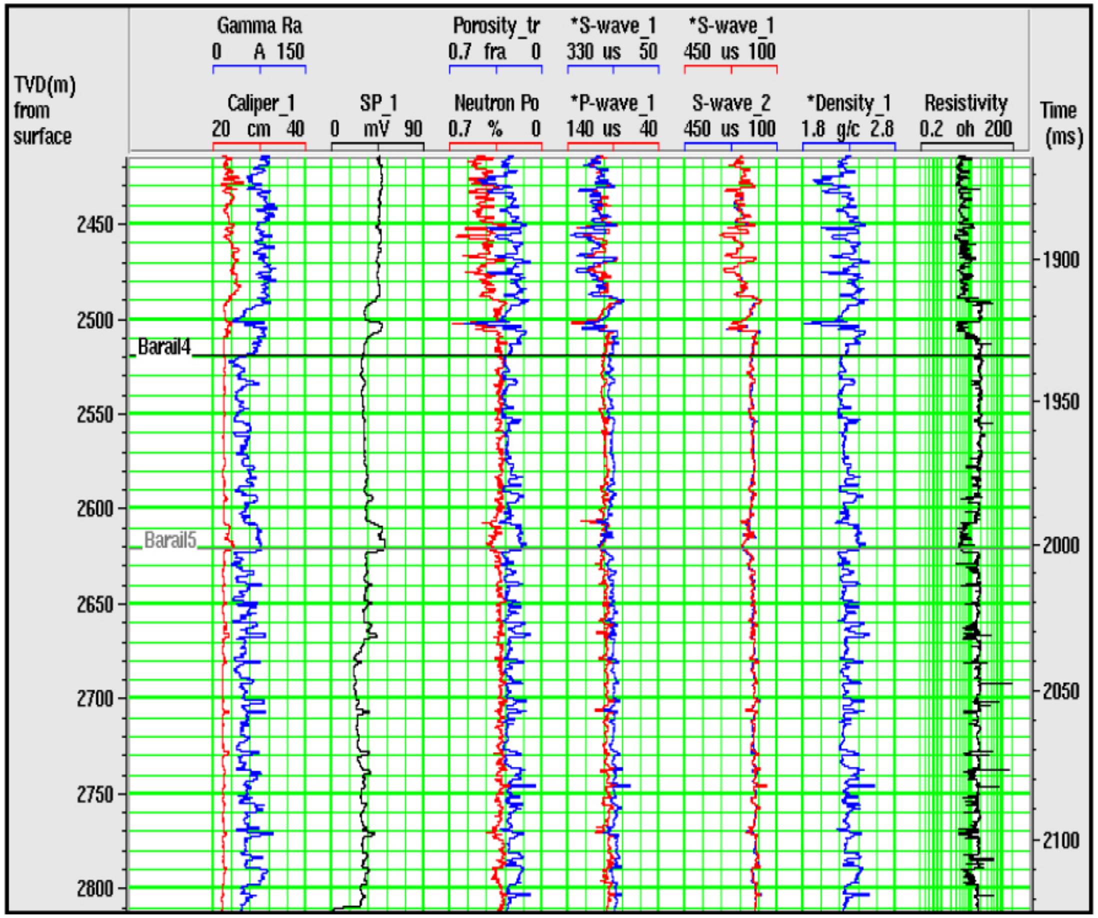

Figure 2C. Details of logs in the Barail 4 and 5 intervals Well A.

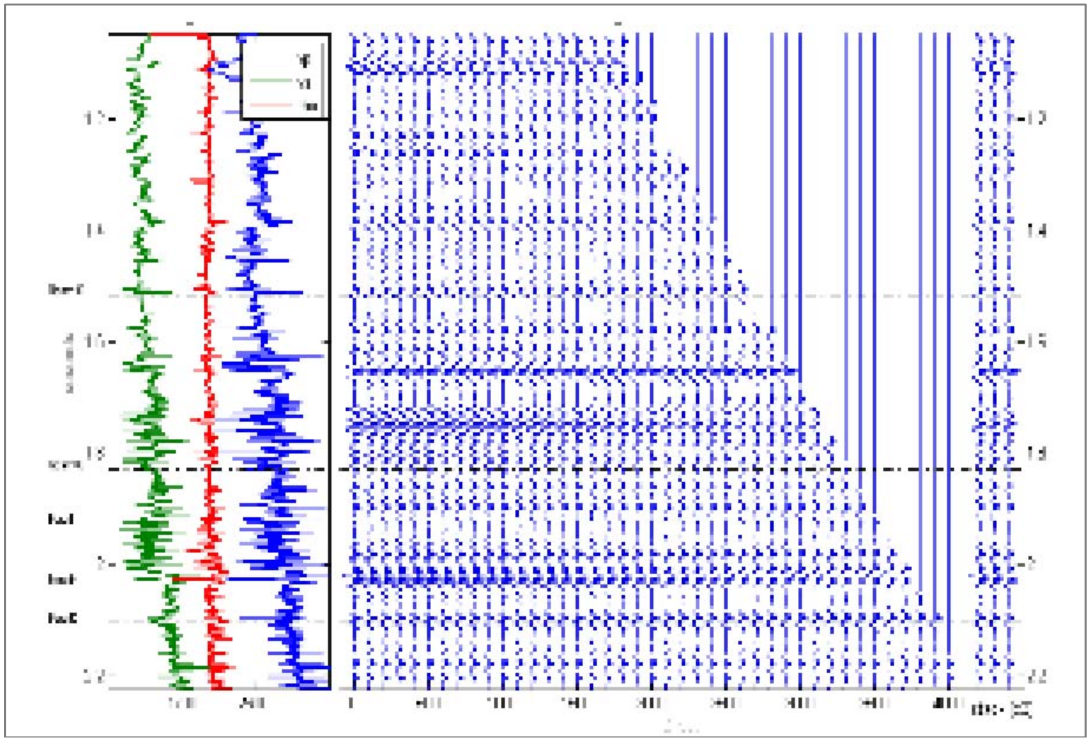

Figure 3A. PP gathers with NMO correction at well A.

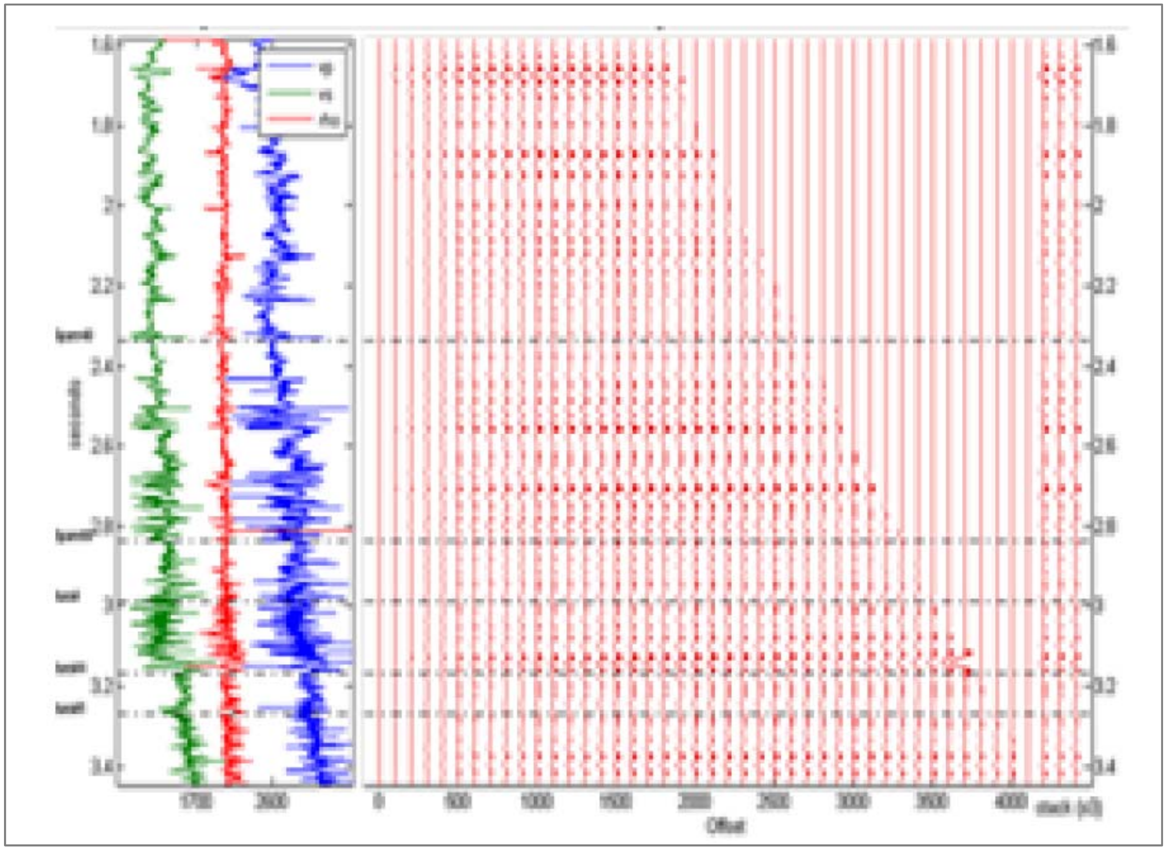

Figure 3B. PS gathers with NMO correction at well A.

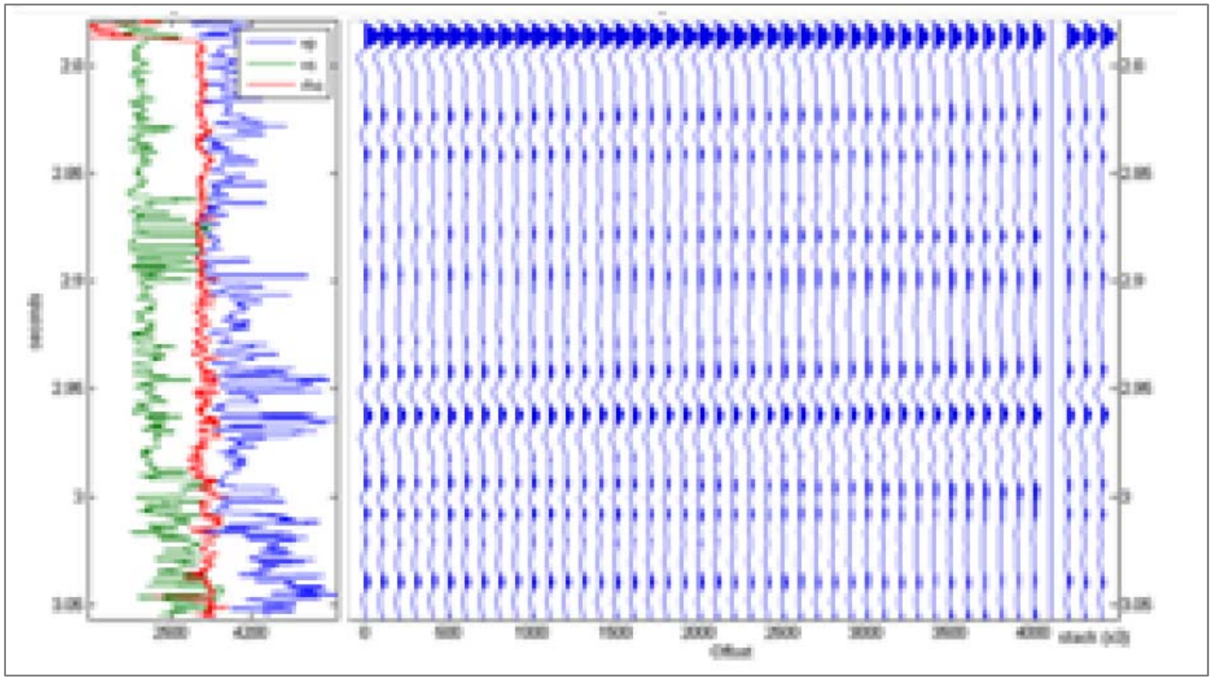

Figure 4A. PP gathers with NMO correction at well C.

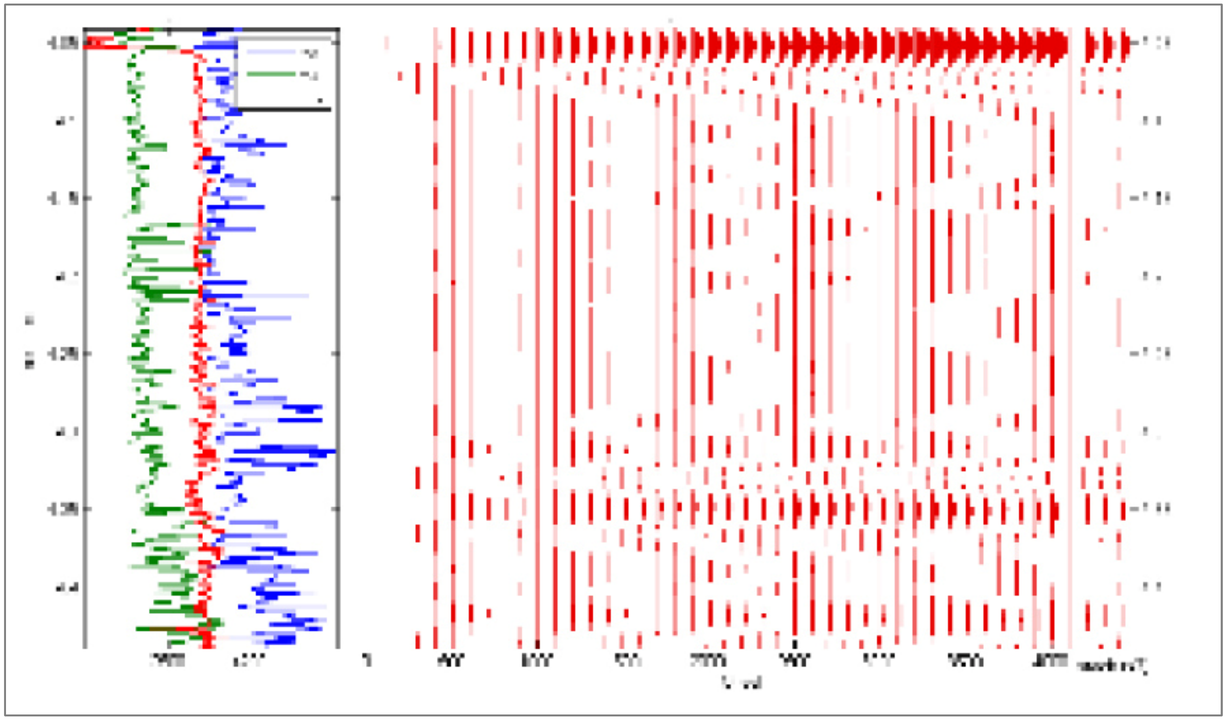

Figure 4B. PS gathers with NMO correction at well C.

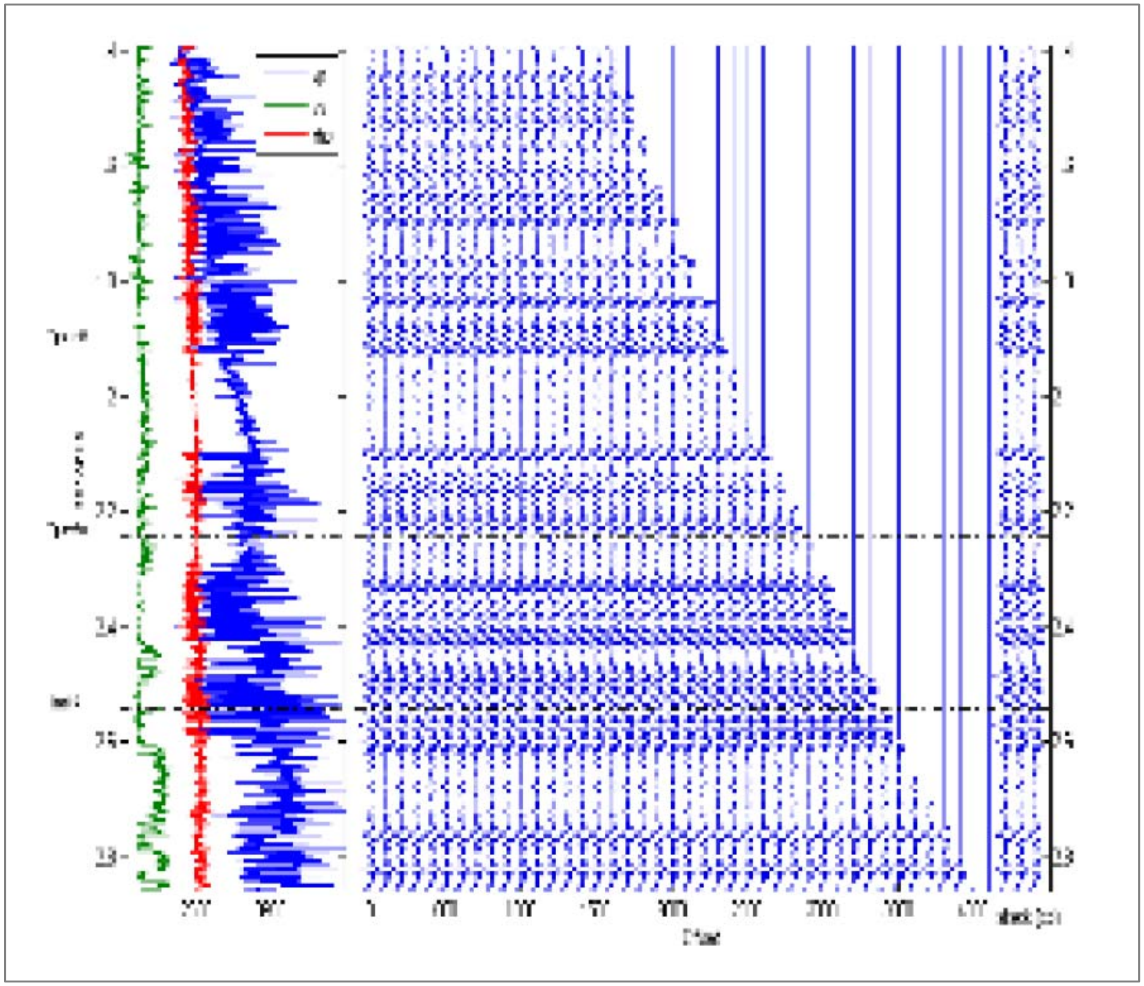

Figure 5A. PP gathers with NMO correction at well B.

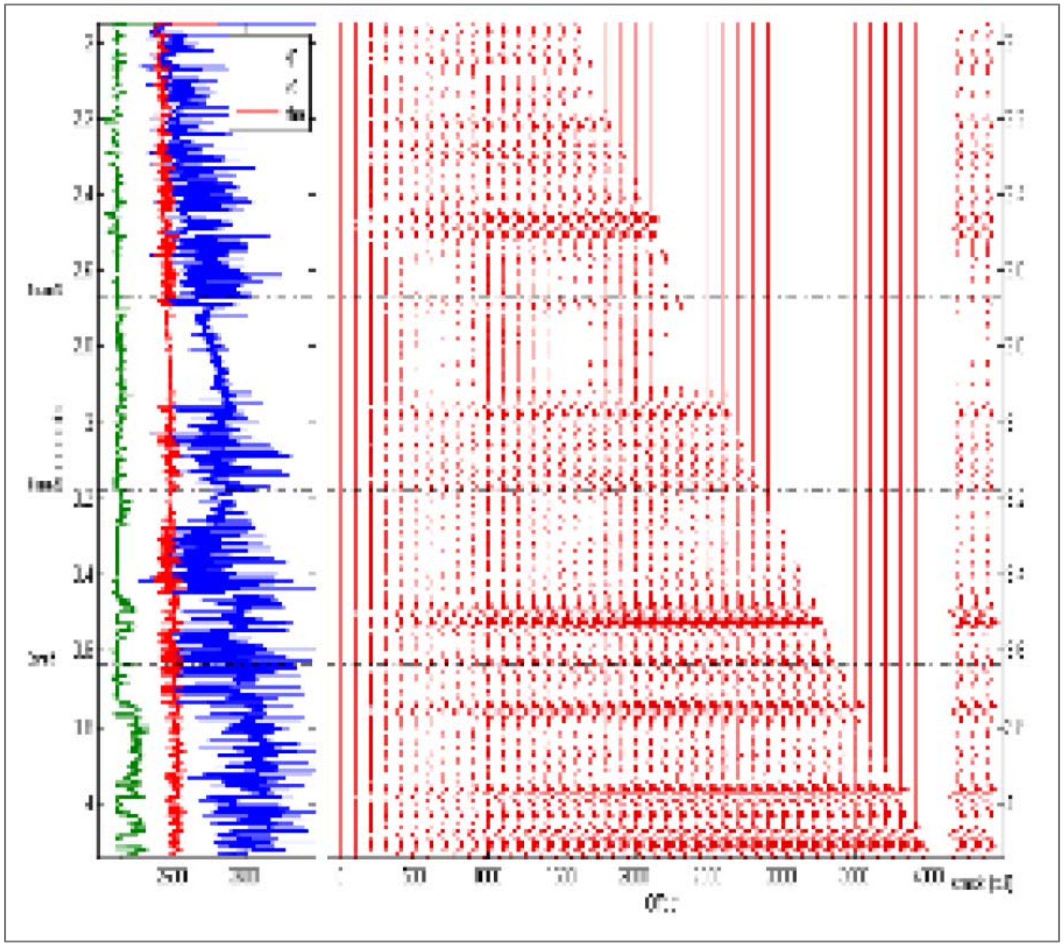

Figure 5B. PS gathers with NMO correction at well B.

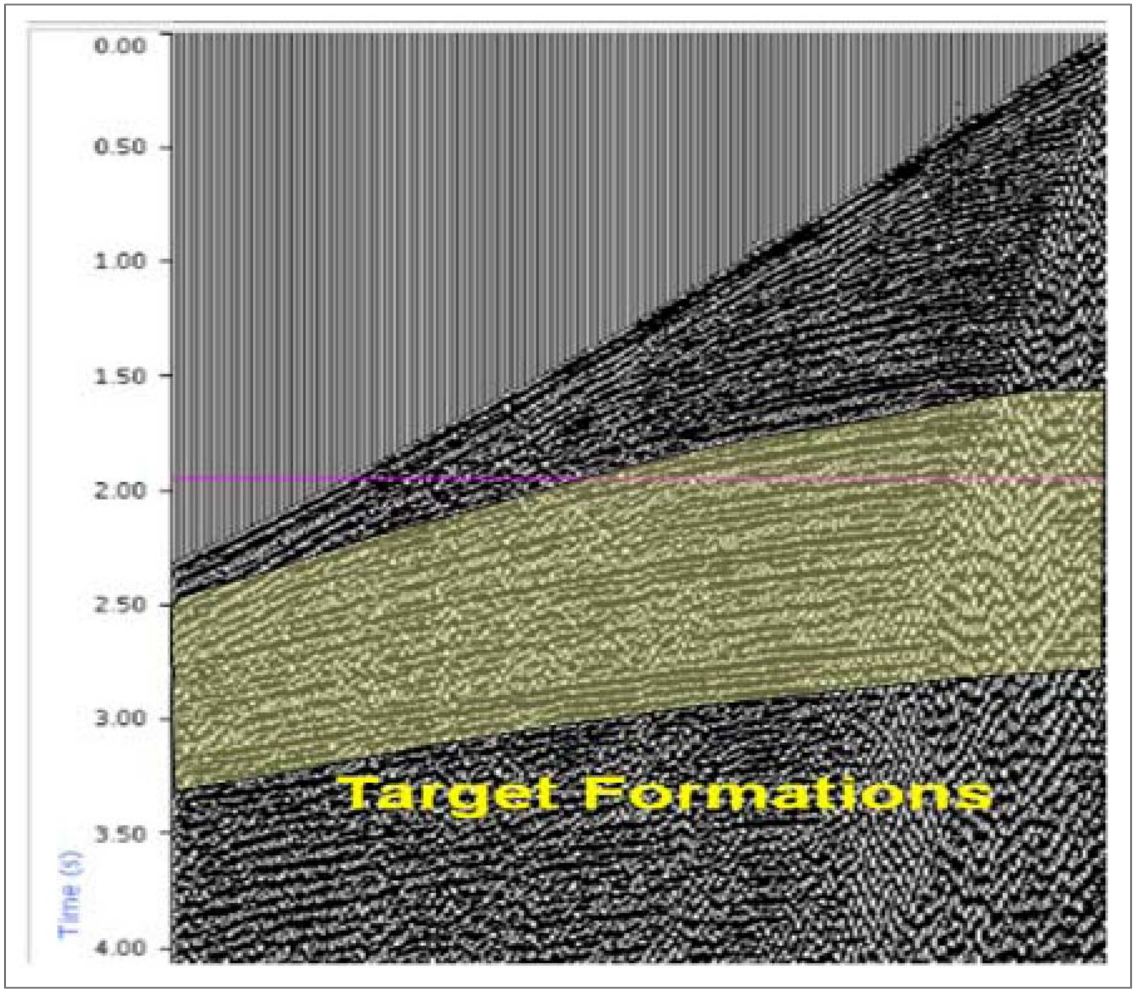

Figure 6A. P wave component.

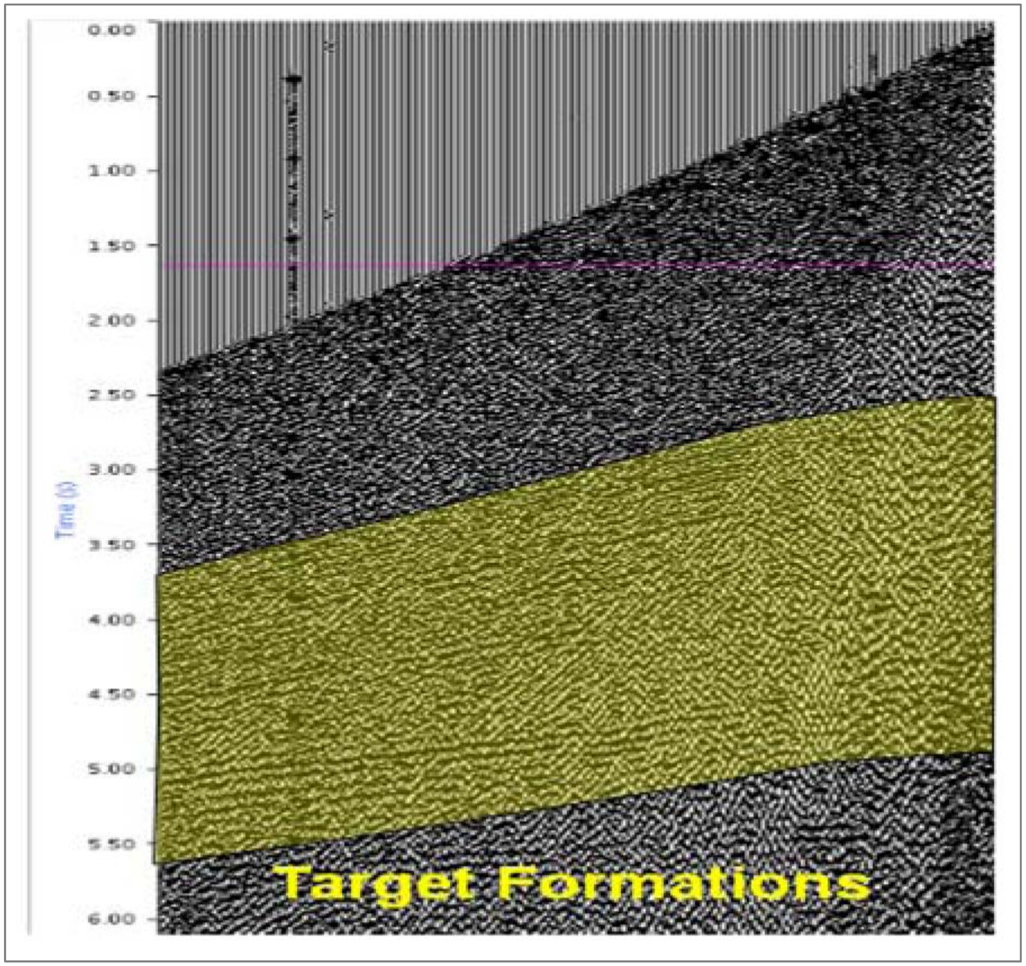

Figure 6B. PSH wave component.

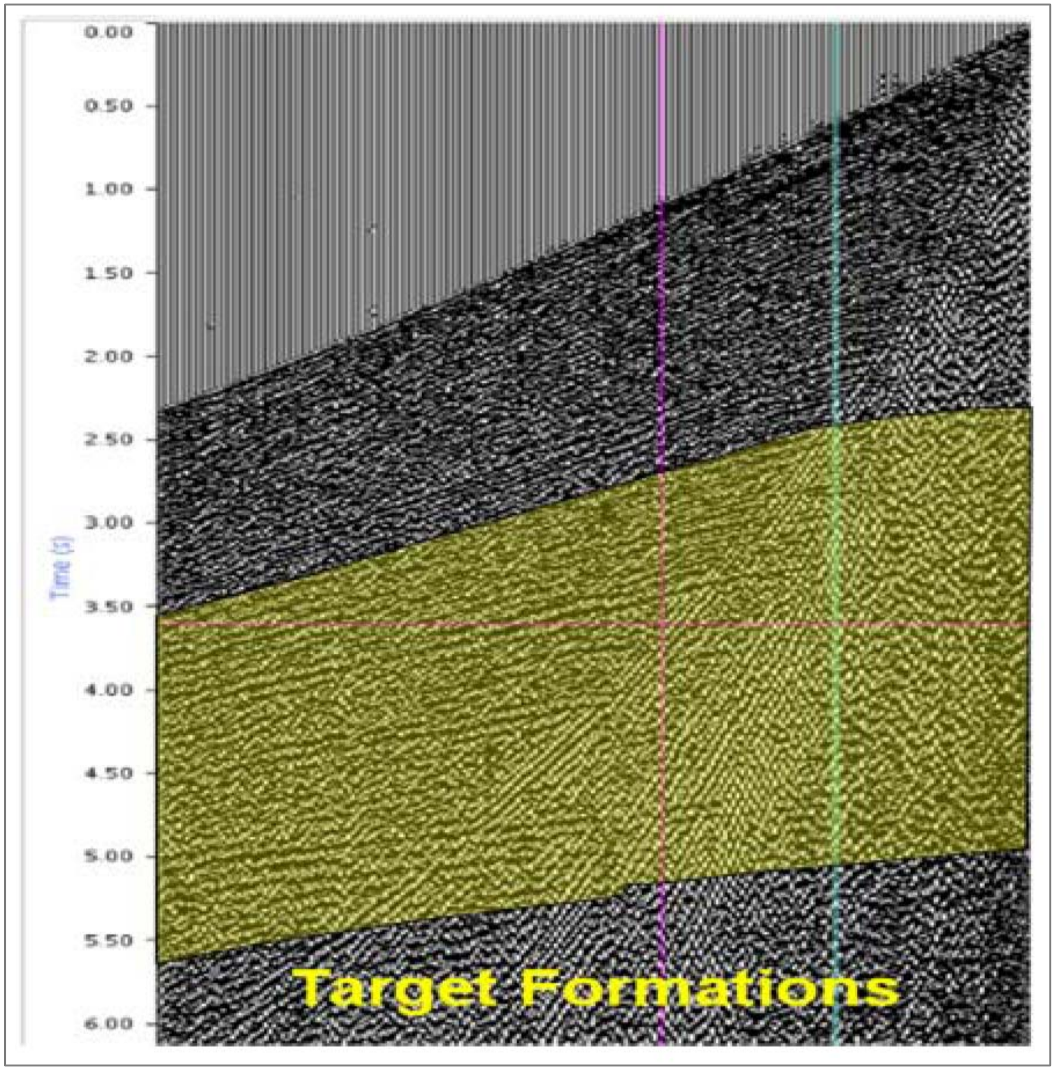

Figure 6C. PSV wave component.

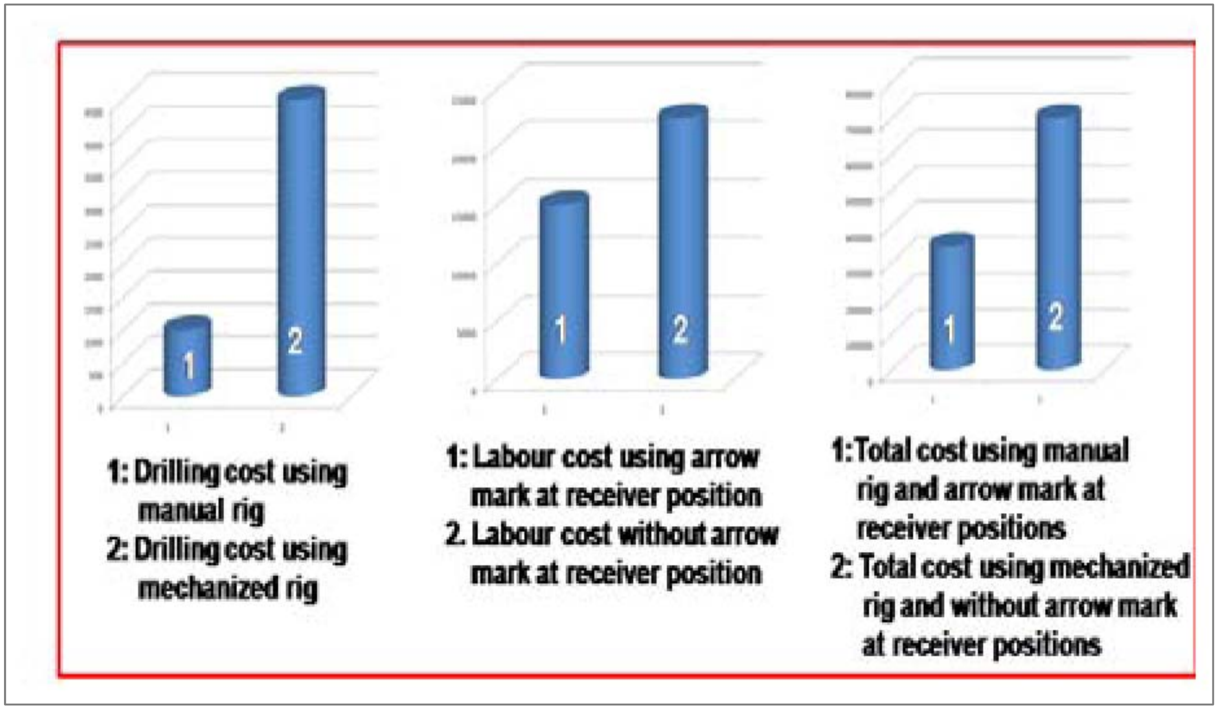

Figure 7. Showing substantial cost saving by applying 'Fit for purpose' techniques.