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3D Converted Wave Data Processing – A case history

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Summary

In recent years, there has been a growing interest in shear- wave exploration for hydrocarbons as it facilitates to extract additional information such as Vp/Vs and other rock characteristics that include lithology, porosity, porefluid etc., In view of the benefits of shear wave data, an attempt is made to assess the utility of converted wave data by processing of converted wave data that was recorded along with vertical component by using 3C receivers. Also, an endeavor is made to understand the intricacies involved in converted wave data processing while paying more attention to some key issues such as rotation of data from (X,Y,Z) domain to (R,T,V) domain, estimation of Shear wave statics, binning and correction to compensate anisotropy. In the present case, anisotropy analysis could not be attempted as the input data contains narrow azimuth distribution. During the processing, PS data was compared to the equivalent PP data and observed that the PS data is corroborating with PP data in revealing the structural aspects of the subsurface. Also, it is observed that the Poisson's ratio estimated using either with the PP & PS velocity field or through horizon matching were found to be nearly same. Hence, it can be concluded that additional information in the form of pre stack time migrated stack volume and Poisson's ratio volume along with PP data thereby facilitating reliable interpretation of the subsurface.

Introduction

In recent years, there has been a growing interest in shear-wave exploration for hydrocarbons. Multicomponent recording provides additional seismic measurements of the subsurface to assist in developing an accurate geological model. Due to the difference in travel path, wavelength and reflectivity, P-SV seismic sections may exhibit geologically significant changes in amplitude or character which are not apparent on conventional P-wave data. Converted-wave 3D (3C-3D) seismic images can accompany a conventional acoustic survey and provide a powerful adjunct toward a more complete interpretation. Proper design schemes are considered here to account for the nature of 3D converted wave recording without compromising either the acoustic or elastic data. Three-dimensional (3D) seismic images have become an essential tool in seismic exploration.

The P-S seismic data can be used in conjunction with the P-P data to determine other rock properties such as Vp/Vs (or similarly, Poisson's ratio). Vp/Vs is sensitive to changes in a number of rock characteristics, including lithology, porosity, pore shape, and porefluid. Rock properties which can be extracted from elastic-wave data, such as Vp/Vs, reduce the uncertainty in predictions about mineralogy,

porosity, and reservoir fluid type. Compressional seismic velocity alone is not a good lithology indicator because of the overlap in Vp for various rock types. Through the analysis of multicomponent seismic data, important rock properties such as Vp/Vs (or similarly, Poisson's ratio) can be extracted. This elastic parameter can improve predictions about mineralogy, porosity, and reservoir fluid type. Coupled P-P and P-S seismic analysis increases confidence in interpretation, provides additional measurements for imaging the subsurface, and gives rock property estimates.

In view of the benefits of shear wave data, an attempt is made to assess the utility of converted wave data by processing of converted wave data that was recorded along with vertical component by using 3C receivers. Also, an endeavor is made to understand the intricacies involved in converted wave data processing while paying more attention to some key issues related to PS data processing.

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Geological setup

The area of investigation falls (fig-1) in Tranquebar sub basin which is bounded in the North and Northwest by Kumbakonam – Madanam ridge, in the south and south-east by karaikal ridge which extends into the offshore Portonova. The sub basin comprises of almost the complete succession of strata from upper Jurassic/Lower Cretaceous to recent. The sub basin is deepening towards north of Karaikal ridge with a thick pile of sedimentary rock and comprises of almost the complete succession of strata from upper Jurassic/Lower Cretaceous to recent. This thick pile of sediments in the sub basin might have acted as source as well as reservoir facies and helped in generation and migration of the hydrocarbons towards the rising flanks and structurally higher areas of the Madanam – Shiyali and Karaikal ridges. The tectonic map of the basin is shown in fig-1 while the generalized stratigraphy is shown in fig-2. The main objective in the study area is to explore strati-structural features of the Albian pay sands situated in the upper cretaceous formation.

Fig-1:- Tectonic setup of the study area.

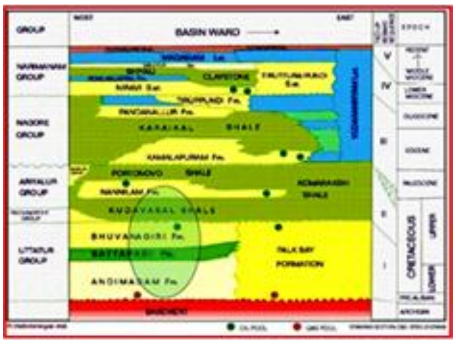

Fig-2:- Generalized stratigraphy of the basin.

Data acquisition

In view of the exploration objective and change in dip of the formations to opposite direction, 3D seismic data was acquired using end-on and asymmetrical split spread geometry by adopting orthogonal swath geometry as depicted in fig-3. It is worth mentioning that the acquisition geometry was tuned for compressional wave data but not for converted wave data, however, data was recorded with 3C geophones as receivers. The source used is an explosive source i.e., not a shear wave source, still facilitates generation of shear waves and hence are recorded in the horizontal components that are designated as X (in line direction) and Y (cross line direction) components.

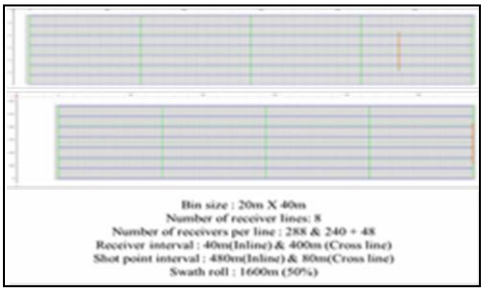

Fig-3:- unit template of survey geometry.

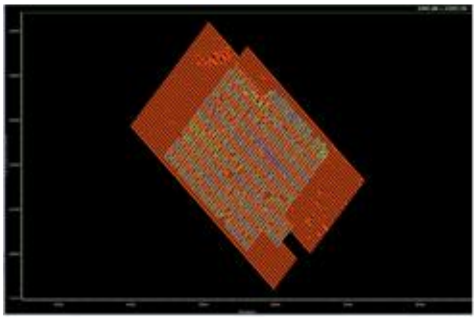

Fig-4:- Source-receiver location map of survey area.

The source-receiver location map over which data is collected is given in fig-4. The fig-5 depicts the most common azimuth and offset distribution. It can be observed that the data contains narrow azimuth which is due to the source-receiver geometry (end-on) used in this case. An inference can be drawn from the azimuth distribution, that the input data is not amenable for anisotropy study and hence could not be done.

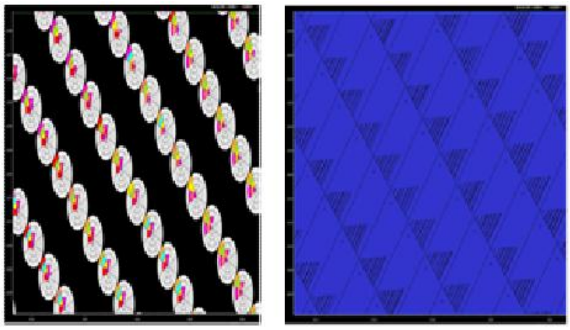

Fig-5:- (a) Rose diagram of azimuth distribution and (b) offset distribution.

The fold map for PP and PS data are shown in the fig-6. It can be observed here, that fold is uniform for PP data whereas the fold for PS data is not only uniform but also reflects cyclic nature in the cross-line direction as expected and the causative is the acquisition geometry. Also, it can be understood that the offset distribution also does not match with that of PP gather data. The fold and offset distribution for PS gathers depend upon the value of Vp/Vs, which usually varies in depth and hence suitable value of Vp/Vs to be used for binning and preparation of ACP gather and precisely for this reason, acquisition geometry is critical and is to be designed in accordance with the exploration objective.

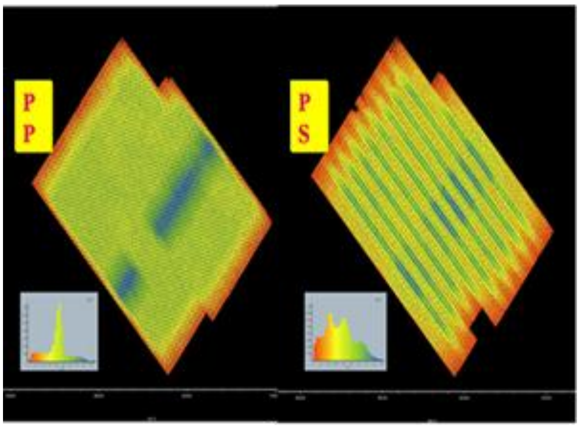

Fig-6:- Fold map for PP and PS data.

Data processing

In general, the key issues involved in converted wave data processing are (1) Rotation of data (2) Receiver statics (3) Gamma estimation for binning and (4) corrections for anisotropy. The 3D converted wave seismic data collected as described earlier, was taken up for processing with the objective (i) to understand the intricacies involved in PS data processing and (ii) to accrue any tangential benefits by way of additional data in the form of pre stack time migrated PS data cube, gamma cube, Poisson's ratio volume etc. Hence, the PS data is subjected to a very simple processing methodology as listed below, while conventional processing is applied to PP data. Also, PS data was compared with PP data at an equivalent stage.

Processing sequence for PS data.

1. Reformat of field data.
2. Geometry insertion and trace header update
3. Spike edit
4. Rotation of data
5. Noise attenuation.
6. Estimation and application of receiver statics
7. Surface consistent deconvolution
8. Binning
9. Velocity analysis
10. ACP stack
11. Surface consistent residual statics application
12. Velocity analysis and generation of velocity volume
13. Gamma analysis and generation of gamma volume
14. Pre stack time migration and stack.

In adapting the above mentioned processing scheme, an endeavor is made to understand the importance of (1) receiver orientation qc and rotation of data from the recorded (X,Y,Z) domain to (R,T,V) domain (2) estimation of shear wave statics to be applied as receiver statics for horizontal component data and (3) derivation of gamma to be used for ACP binning. However, the effect of anisotropy could not be analyzed since the input data contain narrow azimuth distribution. The fig-7 shows a sample field record on the left side and on the right the same record as individual components. .The raw data indicates that S/N ratio of the vertical component is better compared to that of horizontal components.

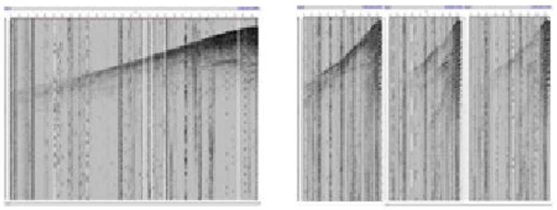

Fig-7:- Sample field data as (a) single record and (b) Z,X,Y components.

The raw data as individual components is considered for insertion of geometry and update of trace header values in accordance with the auxiliary data provided in SPS format. The data was then subjected to despiking and offset limited dataset as receiver gathers was generated for all the three components. The data pertaining to the two horizontal component s was balanced with the scale factor that was derived from vertical component data. Then this balanced datasets as were used for orientation QC through hodogram analysis and the data is rotated from (X,Y,Z) domain to (R,T,V) domain. The fig-8 shows an example of the rotation process.

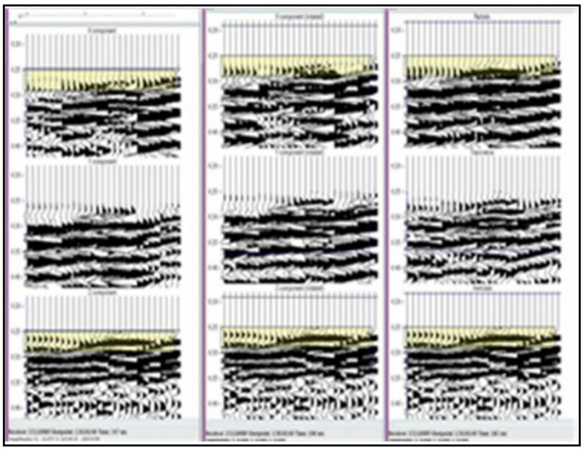

Fig-8:- Rotation of data from (X,Y,Z) domain to (R,T,V) domain

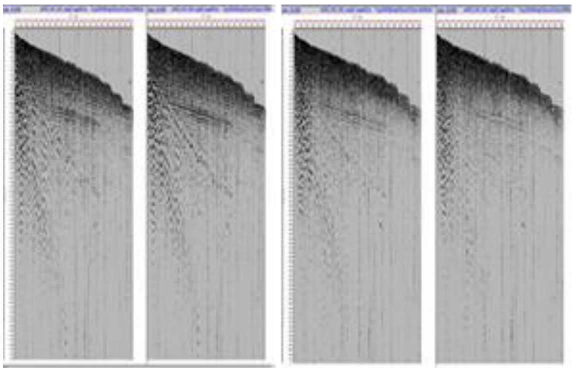

Fig-9:- Receiver gather (a) X to R and (b) Y to T domains.

The fig-9 depicts horizontal component data as receiver gather before and after the rotation of data from X to radial component and Y to transverse component. It can be observed here that, the T component has some residual amplitude suggesting the presence of anisotropy and this aspect was not addressed owing to the limitations present in input data. However, the radial component data is considered for further processing.

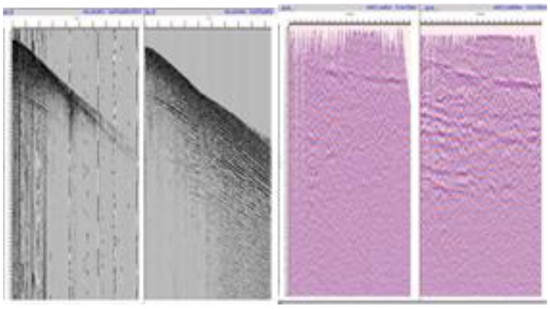

Fig-10:- Example for noise attenuation (a) Shot gather and (b) brute stack.

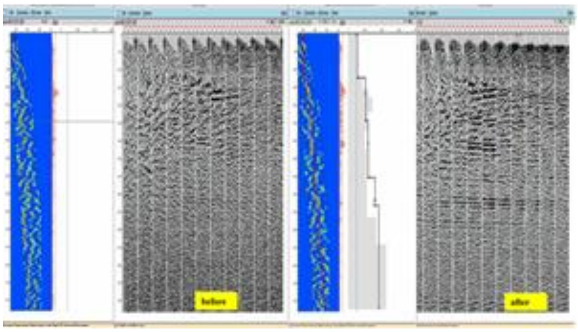

Fig-11:- Effect of noise attenuation on velocity spectra.

The data after rotation was subjected to attenuation of noise in different planes and results of this process are shown in fig10 as source gather and preliminary stack. Also, the effect of noise attenuation process can be clearly on velocity analysis as observed from fig-11.

At this stage of processing, it is worth to remind that for horizontal component data, the source statics will be same as used for vertical component whereas the receiver statics component of P-wave data is not applicable. Also, p-wave receiver statics scaled with some constant may not be valid as the variation in S-wave velocity is severe compared to that of P-wave. Therefore, it is required to estimate receiver statics and the layer picking method was opted using the radial component data. In this method, the shallowest horizon, which could be present in the common receiver stack of radial component data. The horizon is picked first on common receiver data of vertical component, and the same is transposed on to common receiver stack of radial component using a suitable gamma value that was derived from data. In doing so, the structural component of the statics was accounted and then the shear wave statics are derived and this process is an iterative one till satisfactory solution is obtained. In the present data only one iteration is dine and a sample data is shown in fig-12 and observed that the quality of data is enhanced by applying receiver statics.

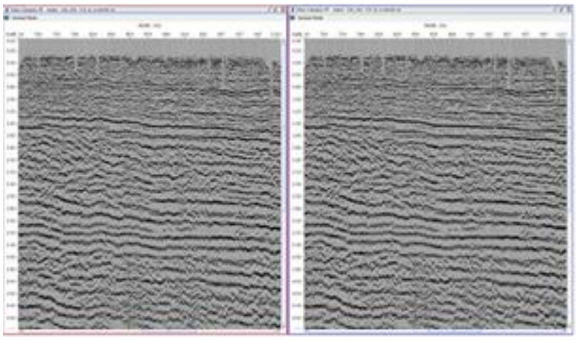

Fig-12:- Common receiver stack without (left) and with (right) receiver statics.

After the application of receiver statics, the radial component data is compared with the corresponding vertical component data for deriving gamma value to be used for binning and consequent generation of ACP stack. As gamma value varies with depth, it is suggested to derive this value by considering the time window corresponding to horizon of interest. Binning of the data was done using an appropriate value of gamma and the ACP gathers were generated .The data at this stage was subjected to surface consistent deconvolution, where in the parameters are different for PP and PS data followed by velocity analysis and residual statics application and the subsequent stack volume. ACP stack section passing through a well with the superposition of velocity log is shown in fig-13. The data shown in reveals that at this stage of processing, both PP and PS data are corroborating each other. And also good match is found with velocity log.

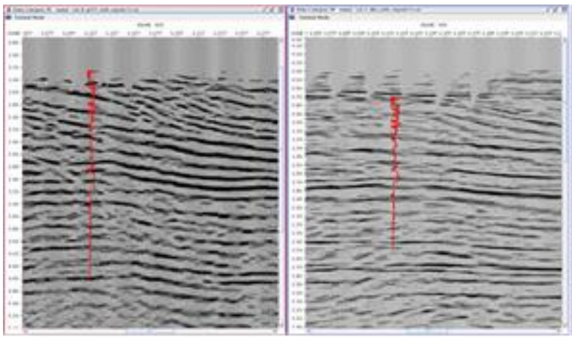

Fig-13:- ACP stack of radial component (left) and CMP stack of Vertical component (right) data.

At this instant, it is proposed to subject the data to pre stack time migration for which in addition to PP and PS velocity field, another requisite is the effective gamma field. This gamma volume is generated using PP and PS stack data by doing a gamma analysis which is similar to that of velocity analysis. A sample of gamma analysis is shown in fig-14.

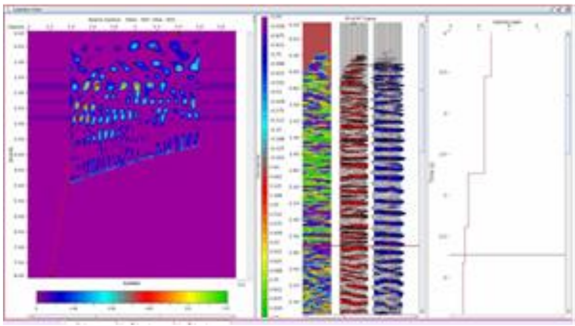

Fig-14:- Typical gamma spectrum.

The gamma field thus generated is used in conjunction with the PP and PS velocity field to do pre stack time migration of radial component data. The result of this process is compared to the corresponding PP data and is depicted in the following fig-15.

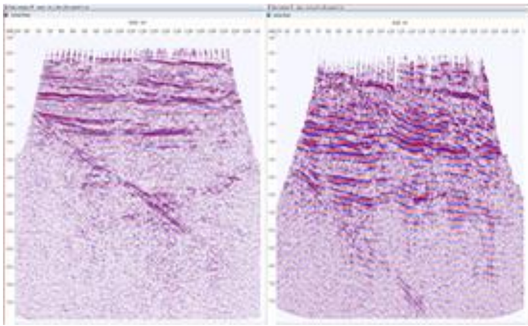

Fig-15:- PSTM stack section of PP (left) and PS (right).

The PSTM stack data of PP and PS components is used for generation of Interval gamma field by picking horizons in PP and their corresponding ones in PS data. The gamma field thus generated is used to create a squeezed PS data so as to compare in PP time. The following fig-16 shows the result of this process.

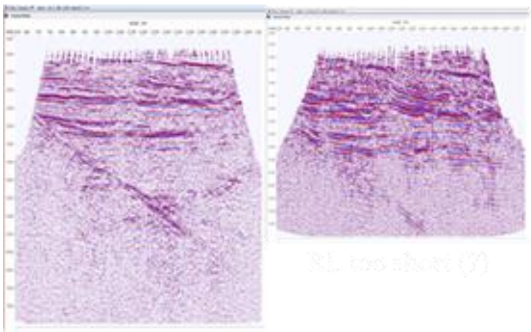

Fig-16:- PSTM stack section of PP (left) and PS (right) scaled to PP time.

Conclusions

The key issues involved in converted wave data processing such as rotation of data from (X,Y,Z) domain to (R,T,V) domain, estimation of Shear wave statics, binning were successfully addressed whereas the anisotropic analysis could not be studied since the input data contains narrow azimuth distribution. During the processing, PS data was compared to the equivalent PP data and observed that the PS data is corroborating with PP data in revealing the structural aspects of the subsurface. It is also observed that top lap features present at shallow level are brought out better in PS data than that of PP data while the record length is insufficient to image deeper horizons. Also, it is observed that the Poisson's ratio estimated using either with the PP & PS velocity field or through horizon matching were found to be nearly same representing the sedimentary rocks. Hence, it can be concluded that additional information in the form of pre stack time migrated stack volume and Poisson's ratio volume along with PP data thereby facilitating reliable interpretation of the subsurface.

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