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3-Component Processing of VSP data

O.P. Singh* & M. Bhanu, *ONGC*

Summary

Vertical seismic profiling also known as borehole seismic has numerous applications in the game of hydrocarbon exploration. Its utility has expanded from simple time- depth information to reservoir characterization. It acts as a vital link between geology and seismic. Typically, three- component receiver is used in VSP data acquisition for recording both compressional energy (P) and mode converted shear waves(S). Converted waves(C-wave) are generated only when source is located a few hundred metres from well. Converted wave data after processing with special algorithm is used for correlation with three component surface seismic and give additional information about geology like fluid content, fracture geometry and orientation. In this paper, the methodology adopted for processing of converted waves has been described with real data examples.

Keywords*: VSP, Shear wave, Data Processing*

Introduction

When the well is vertical and VSP has been recorded as zero offset (rig source), VSP processing can be done using only single vertical component data. In this case only P-wave data will be available as output. There is no need to process the horizontal components because shear wave data is weak as mode conversion has not taken place in this case.

Three component processing is applied to data sets with large source receiver offsets or when the well is deviated and significant amount of shear wave data is generated due to large source receiver offsets caused by well deviation and energy has been recorded in horizontal components. The main aim of the three-component processing is to produce a P-up wave and S-up wave image, by combining all three components. The detailed methodology has been discussed in VSProwess brochures by Avalon sciences Ltd., U.K.

Processing Methodology

VSP data are richer in information but more complex to process than surface seismic data so specially developed software are to be used for its processing. Integration of log data is a desirable step in VSP processing. VSP processed outputs are fine-tuned with the help of synthetic seismograms generated with log data and formation top information. This gives a good confidence in the processing of VSP data.

Normally VSP data is acquired in 3 data channels, one vertical and two horizontal components using orthogonal three-component receivers. The methodology in VSP processing gives PP-up wave and PS-up wave images by combining the data of all the three components recorded.

During the processing, horizontal components are rotated to get radial (H1) and transverse components (H2). The improvement of PS arrivals can be seen after orientation of horizontals. Further improvement in PS arrivals is seen after P-down polarization. Here P- down direct arrivals are used to polarize the P-down energy in to one component (E1) and majority of the Sv-down energy into another component (E2). This simplifies the Down going removal. Polarisation works because the particle motion of P and SV waves are almost perpendicular, as shown in Fig. 1.0.

A bi-product of the down-wave polarization process is that the up-going energy is also partially polarized. In general, the radial component contains down-going P-wave and up-coming SV and, transverse component contains down-going Sv-wave and up-going P-wave.

Once the dataset has been polarized the down-going P-wave in the E1 component and the down-going Sv-wave in

*ONGC, 11E02, CMDA Tower-I, Gandhi-Irwin Road, Egmore, Chennai – 600 008, India;
opsingh57@gmail.com*

the E2 component can be aligned, enhanced and subtracted as in the case of a simple VSP.

Having removed the down-going energy, the E1 and E2 components are returned to their VZ and HX orientation and up-wave multiples are removed using deconvolution techniques.

Finally up-wave polarization gives the desired P-up (PP) and Sv-up (PS) primary arrivals.

In practice, horizontal components are orientated towards the source. After such orientation, the transverse horizontal component may contain both down and up-going SH arrivals that could be used to determine shear-wave splitting. SH up-going arrivals can be processed in a similar way to Sv up-wave arrivals. In areas of complex structures, the transverse horizontal may contain out-of-plane arrivals, useful for interpretation purposes. But in normal case SH components have little energy and they are not processed.

Main steps in three component VSP processing can be summarized as follows:

- Reading SEGY data
- Sorting
- Filter
- First break picking
- Statics
- Preparation of TD curve & Velocity listing
- True amplitude Recovery
    - Horizontal rotation
    - Vertical rotation
    - Separating up-comings (PP/PS)
    - Deconvolution
    - Velocity Modeling
    - NMO
    - VSP-CDP Transformation (Migration)
    - **Final Outputs (PP & PS sections)**

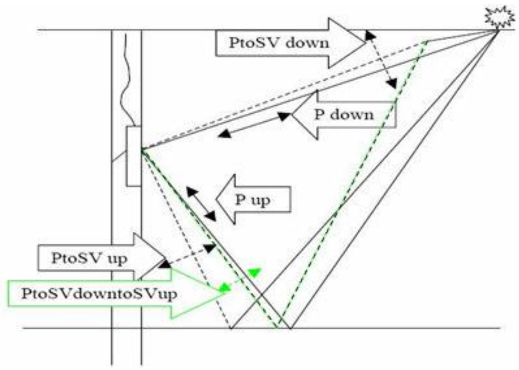

Fig.1.0 Main wave-modes of an offset VSP data

Real data examples

Well A:

This is an offset vertical well VSP data set. Total 102 traces (levels) were recorded. The raw data is shown in Fig. 1.1. Traces 1-80 only have been displayed for all three components for better clarity.

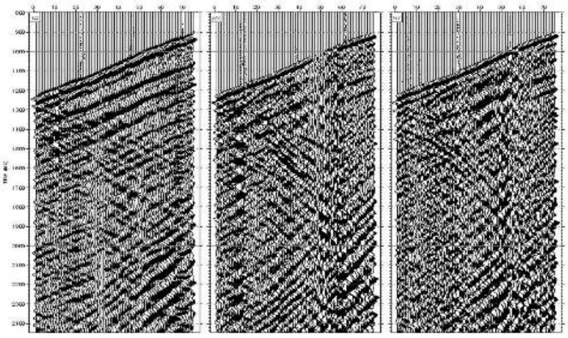

Fig. 1.1 Well A-Raw data after TAR

The zero offset data of the well was also processed for matching with synthetic seismogram and requirement of interval velocities for modeling purpose for the processing of offset data set. Zero offset output along with synthetic seismogram and horizon tops is shown in Fig.1.2.

Data after horizontal rotation is shown in Fig.1.3. A definite improvement in radial component (H1) can be seen. Fig 1.4 shows the data after P-down polarization. Here the vertical component (E1) has P-wave only and radial component (E2) has only the shear wave data. Fig. 1.5 shows the data after P-upcoming polarization and maximization. Here VZ is the upcoming P-wave and H1 is upcoming S-wave data. These data sets were VSP-CDP transformed (migrated) to get the final outputs as shown in Fig. 1.6.

After horizontal rotation the transverse horizontal component (H2) contains both down and upcoming SH arrivals showing presence of anisotropy in the area. SH upcoming arrivals can be processed in the similar way to SV up-wave arrivals. But it has not been done for this well which is the normal practice.

There are 05 offset data sets recorded for the well in different azimuths. Velocities derived from first break picking of these data sets show velocity variation along different azimuths confirming again the presence of anisotropy in the area.

All QC checks were performed to the best satisfaction level. One such QC plot where modeled first break times were matched with the observed first breaks after introduction of Thomson anisotropy parameters in the shallow layers while carrying out the velocity modeling job has been shown in Fig. 1.7.

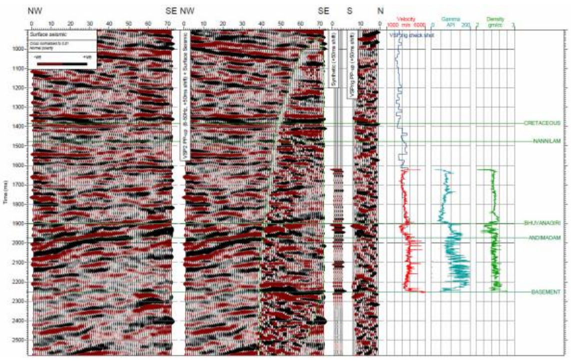

Fig. 1.2 Offset and rig source PP data along with well syn. Seismogram

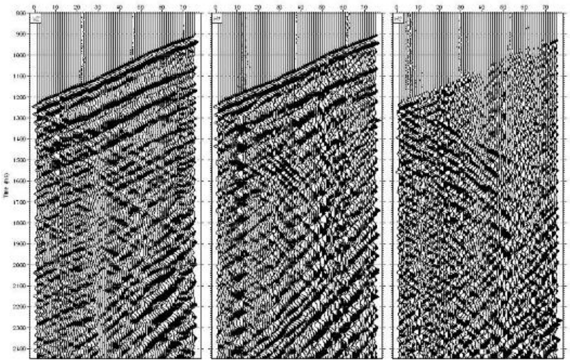

Fig. 1.3 Well A- oriented horizontals

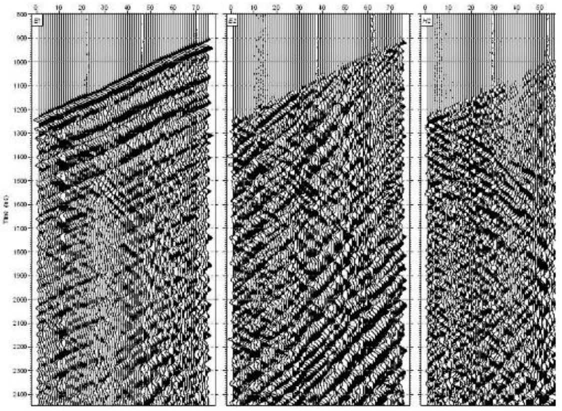

Fig. 1.4 Well A- P down polarized

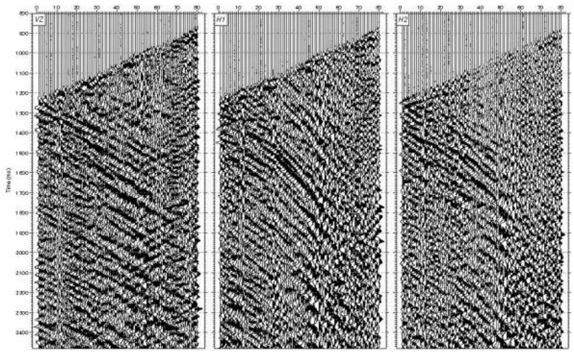

Fig. 1.5 Well A-Upcoming maximized

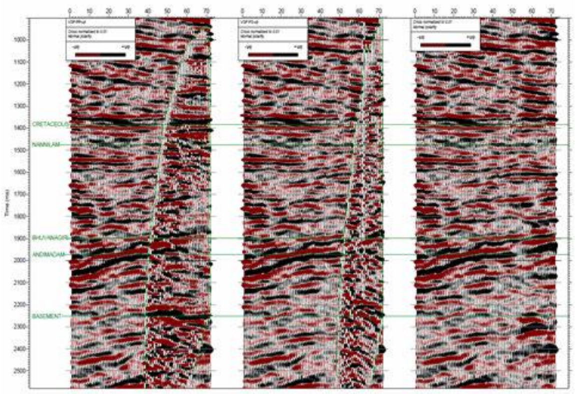

Fig. 1.6 Well A- VSP PP &PS spliced in surface seismic

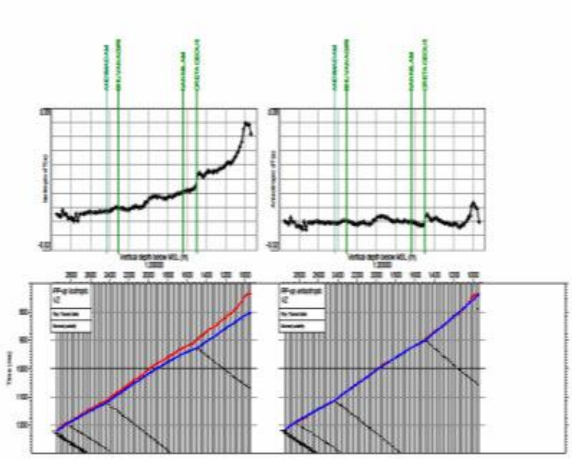

Fig. 1.7 Well A- Comparison of modeled (blue) and picked (red) FB Times

Well B:

This VSP has total 135 traces/levels. The raw data is shown in Fig.2.1. This is zero offset data set but due to deviation of well (≈750m horizontal drift) S-wave data is observed on horizontal components (Fig.2.1). Three component processing sequence was followed to complete the processing of this VSP. Final outputs (PP & PS sections) are shown in Fig.2.2. There is a good match between VSP data and Surface seismic data. VSP data is shown on right side and left side is the surface seismic data. Fig. 2.3 shows the zoomed version of VSP and surface seismic outputs where gas strikes have been recorded at 2110 ms & 2375 ms TWT.

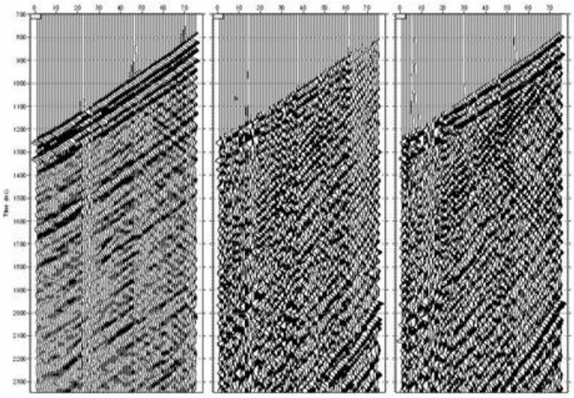

Fig. 2.1 Well B-Raw data after TAR

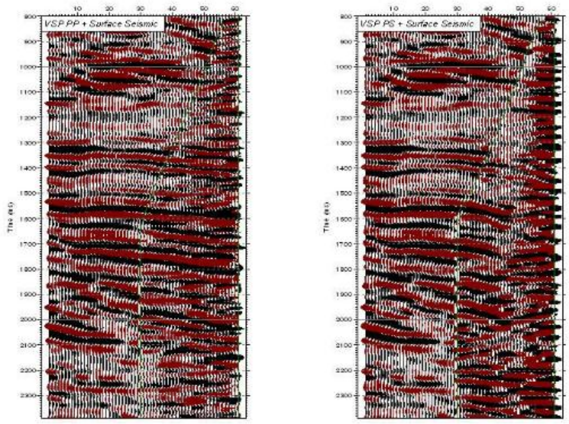

Fig. 2.2 Well B-VSP PP & PS spliced in surface seismic

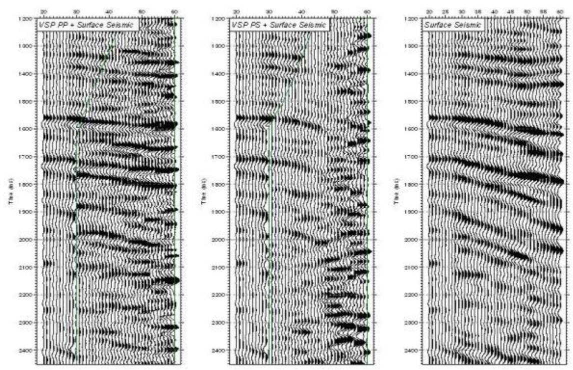

Fig. 2.3 Well B-VSP PP & PS spliced in surface seismic (zoomed version)

Conclusions

Methodology for processing of 3- component VSP data was developed and successfully implemented on different data sets. VSP PP-up and PS-up outputs are in close match with surface data and giving the desired result for interpretation.

The present work will also help to process the 3D-3C bore hole data acquired in future which is the trend in the industry as seen by many recent research articles (Paulsson, B.N.P. et. al. 2004 and Miller K.W. et. al., 2010). Again due to high S/N ratio of VSP data (PP &PS), it can be used for 4D monitoring of target reservoirs (Richard R., 2008).

The views expressed in this paper are that of the author (s) only and may not necessarily be of ONGC.

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