P 200

Reservoir Delineation through multi component VSP data: A Case study from Cambay Basin

Sanjiv Kumar Shrivastava, Rajeev Kumar Jaiswal & U S D Pandey

Summary

Shear-wave seismic data are widely used in hydrocarbon exploration. Although their resolution is similar to P-wave, provide significant information that cannot be extracted from compressional-wave data. However, the surface shear-wave data rarely show any increase in resolution compared to P-wave data due to greater absorption in the weathering layer. VSP data provide a bridge between surface seismic and well data.

An attempt has been made to study, an offset VSP (OVSP) data using multi-component processing technique from Ahmedabad block of Cambay Basin. Good sensor coupling in the borehole enabled three-component (3C) seismic data to be recorded with high vector fidelity. Subsurface imaging by both PP-wave and PS-wave (converted wave) has been analyzed.

***Keywords**: VSP, multi component processing, anisotropy, well log*

Introduction

Vertical Seismic Profiling (VSP) is a very important tool in the exploration and exploitation of hydrocarbons. Zerooffset VSP surveys provide information about the subsurface only around the well. Offsetting the source location away from wellhead moves the reflected zones away from the well thus Offset VSP (OVSP) surveyprovide lateral coverage along the source direction as shown in figure 1. However lateral subsurface coverage is restricted at various levels depending upon some offset are recorded the data at various levels.

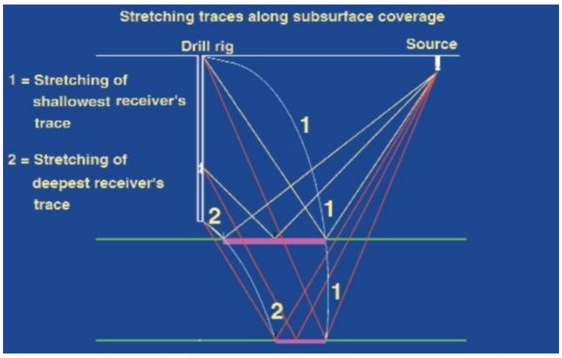

Figure 1: Schematic diagram of offset VSP survey (Prasad, et al., 2012).

As different angle of incidence, Zoeppritz equations describe the partitioning of seismic wave energy at an interface as shown in Figure 2.

Figure 2 shows, for small incident angles, almost all of the energy is in the reflected and transmitted P waves and hence hardly any S waves are generated. As the incident angle increases, P-Sv wave energy increases upto 45° and then decreases. This aspect is very critical while modeling 3 components offset VSP data acquisition.

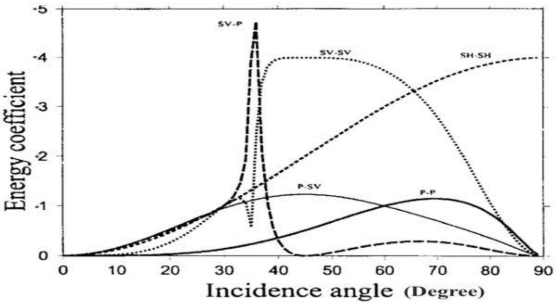

Figure 2: Apparent P-and S-wave energies measured at the surface for an incident plane wave. (Shapiro, et al., 2000)

Offset should be enough to allow mode conversion as well as to illuminate zone of interest (ZOI). Hence In multi

Geophysical Services, ONGC, Vadodara
Email: sanjiv013@gmail.com

component offset VSP, there should be sufficient incident angle to get mode converted wave.

Figure 3 shows Schematic diagram of offset VSP survey. The receivers not only receive mode converted reflected wave but also receive near surface mode converted direct arrivals. This is useful to determine Poisson's ratio and many more attributes derive from Vp and Vs.

Converted-wave VSP data processing is carried out with a view for better subsurface imaging as well as to study anisotropy. Multi component processing includes analysis of vertical as well as both radial and transverse components data. There is no system to measure downhole tool orientation. As the geophone moves, it rotates and randomly orients two horizontal components. So the effective alignment or re-orientation of two horizontal components is very critical before actual processing steps.

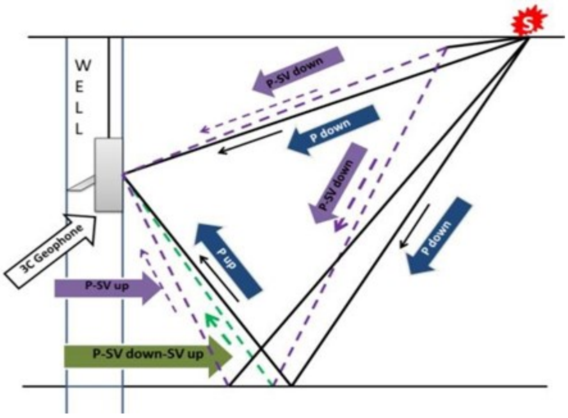

Figure 3: Schematic diagram showing ray paths, of an offset VSP data. (Singh & Bhanu, 2012)

Geology of the Area

Cambay Basin has been characterized as a narrow elongated intra-cratonic rift-graben extending from Sanchor in the north to Gulf of Cambay in the south and further opening up into Arabian Sea. It is surrounded by Saurashtra Uplift in the west, Aravalli-Delhi Fold Belt in northeast, and Deccan Craton in the southeast. The basin is about 425 km long and having width varying between 40 and 80 km. About 5 to 7 km of sedimentary thickness is envisaged in the basin (Pandey et al., 1992). The major trend of the lineament in North Cambay Basin is NNWSSE and NE-SW. In the southern part, however, the main trend is ENE-WSW (Chandra et al., 1969). The basin is divided into discrete tectonic blocks based on major lineament trends.

The Well considered for the current study fall in Ahmedabad Block of the Cambay basin. General stratigraphy is shown in Table 1.

Table 1: Stratigraphy of well

Formation / Member	Depth (m)
Post Kand + Kand	0 – 738
Babaguru (Top)	738
Tarapur (Top)	1040
Kalol (Top)	1259
Cambay Shale (Top)	1635

(Unpublished Well Completion Report of ONGC)

Processing methodology

The processing sequences of three component data are somewhat similar to P-wave processing. In three component VSP, total wave-field as a function of depth (within the borehole) is recorded using three component Geophone (Horizontal X, Horizontal Y and Vertical Z). Under such situations, different kinds of body waves e.g. P waves, SH waves and SV waves are excitation. The processing of three components VSP data is carried first with processing of PP-wave and then PS-Wave. PP-up and PS-up going wave images by combining the data of all the three component records are obtained.

Main steps in 3-C VSP processing are summarized as below:

- Input SEGY data
- Sorting
- Band pass Filter
- Statics
- First break picking for P-wave
- Preparation of TD curve & velocity analysis
- Amplitude recovery
- Horizontal rotation
- Vertical rotation
- First break picking for S or PS-waves
- Computation of velocity for S or PS-wave
- Separating up-coming (PP/PS)
- Spherical divergence correction on P- and S-wave
- Deconvolution
- NMO
- VSP-CDP transformation
- Final Outputs (PP & PS sections)

Different approaches are necessary at several phases, inherent with the shear wave properties, which are discussed below.

Hodogram Method

Hodogram display is the terminus of a moving vector as a function X, Y and time. They allow simultaneous analysis of amplitude, polarization and relative orientation. 3-C geophone records different types of waves longitudinal, shear and converted (upgoing and downgoing), separated or superimposed in time from a geological setup. Identification and enhancement of desired wave modes and suppression of undesired wave modes is very important. Figure 4 shows a typical record where all major three components, Z contain maximum energy but at the same time X and Y has also significant energy.

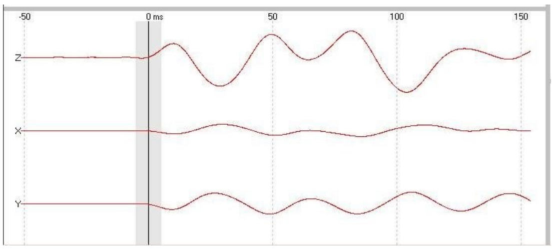

Figure 4: A typical raw data (Z, X and Y components).

Horizontal Rotation

After rotation of (X, Y) components, showing energy for derived components namely Radial & Transverse components are obtained. SV component is expected to be enhanced along with the compressional waves in the Radial component. If strong source generated shear waves are present, then SH energy is captured in Transverse component with small enhancement. Figure 5 shows that the energy of X component has been boosted and Y has not as much of energy.

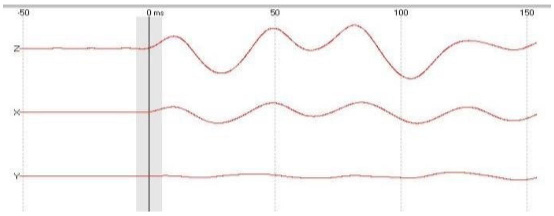

Figure 5: After horizontal rotation, energy enhanced in X component.

Vertical Rotation

Radial and vertical components are rotated in vertical plane to get rotated vertical and horizontal components using same principle of energy maximization technique of hologram method. These are the two inputs for further processing. The "Rotated Vertical component" should be used for P waves (from total vector) and "Rotated Horizontal" component for normal SV waves.

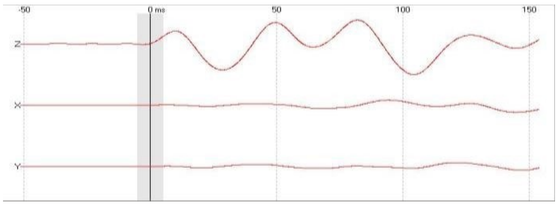

Figure 6: After Vertical rotation, energy enhanced in Z component.

Like Horizontal rotation, Vertical rotation has enhanced Z component energy and at the same time X component energy has been reduced which is shown in Figure 6.

Objective of survey

3 component offset VSP operation in Well-A were conducted in 2010. One ZVSP and 3 offset VSP have conducted. Schematic of Offset VSP geometry survey in Well-A, shown in figure 7. Objective of acquisition was to explore Chhatral (in between K-XI and K-XII), K-IX and K-VIII and to know the extension of Pay Sands within pays.

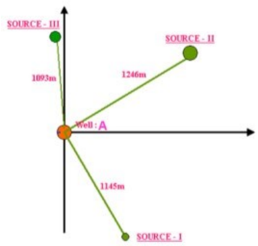

Figure 7: Geometry of acquisition of Offset VSP survey.
(Unpublished offset VSP data processing report of ONGC)

Sand Silt Isolith map of pay zone K-XI and K-XII is shown in figure 8, provide information (before processing) of lateral extension of both pays was envisaged in all offset directions.

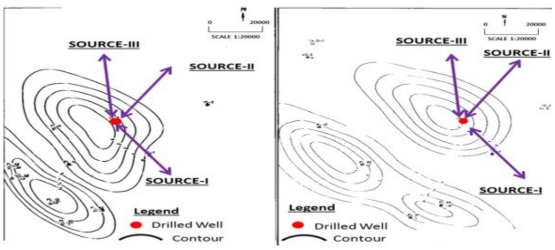

Figure 8: Sand Silt Isolith map of K-XI (left) and K-XII (right)
(unpublished Well interpretation reoprt of ONGC)

Acquisition Parameters

The following Acquisition parameters were used for Offset VSP.

Source Type: Vibrator (one Vibrator); *Sweep Period:* 12s *Type of Sweep:* Linear; *Sampling Interval:* 1ms; *Record Length:* 4s; *Taper:* 250 ms; *Depth interval:* 20m; *Frequency:* 12 Hz-108 Hz; *Depth Logged:* 1700m-100m (ZVSP), 1700m- 340m (offset-I), 1700m-520m (offset-II), 1700m-340m (offset-III); *Offset Distance:* 1144.90m (offset-I), 1246.49m (offset-II), 1092.82m (offset-III)

Based on ZVSP data, Depth and TWT of K-VII, K-IX and Chhatral are in Table 2.

Table 2: TD table for Well-A (depth values w.r.t. MSL)

Pay Zone	Depth (m)	TWT (ms) (ZVSP)
K-VIII	1393-1414	1305 – 1323
K-IX	1414-1441	1323 – 1356
Chhatral	1542-1583	1447 – 1480

(Unpublished Well completion report of ONGC)

There are 03 offset data sets recorded for the well in different azimuths. An offset-I has been taken for showing processing steps. 69 depth levels were recorded for offset-I. Raw data for all three components (One Vertical and Two Horizontals), before and after TAR is shown in Figure 8 and 9 respectively.

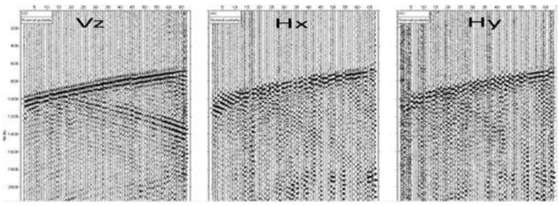

Figure 8: Raw data of OVSP, for all three components in well-A

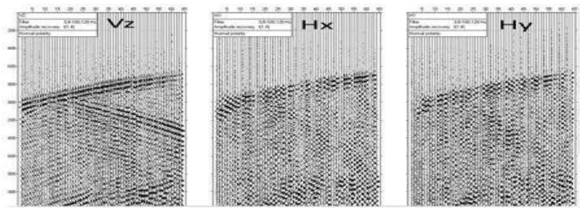

Figure 9: Data after TAR

Figure 10 shows, results of horizontal rotation, enhancement of PS arrivals in H1 and reduction of energy for H2 component is observed.

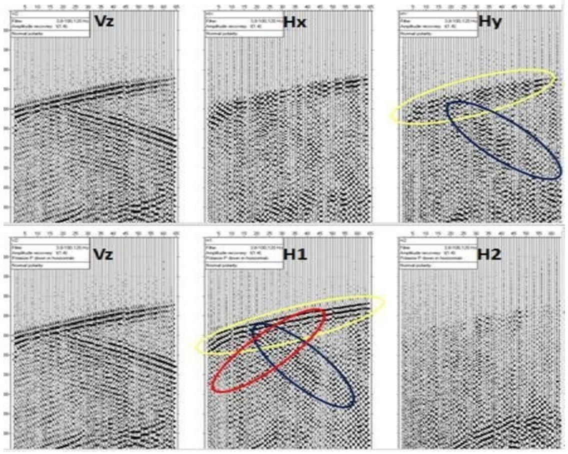

Figure 10: After Horizontal rotation, improvement of P-Sv wave, Downgoing P-and S-wave.

After horizontal rotation the transverse horizontal component (H1) contains downgoing P-wave, downgoing mode converted S-wave and upcoming SV arrivals showing presence of anisotropy in the area. Velocities derived from first break picking of these data sets show velocity variation along different azimuths indicating anisotropy in the area.

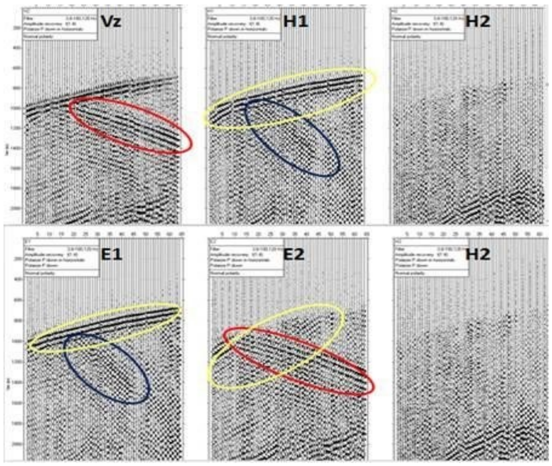

Figure 11: Improvement of PP-wave, PS-wave, downgoing P-and S-wave, after vertical rotation

Again enhancement of P-Sv wave arrivals achieved by Vertical rotation technique. Here P- down direct arrivals is used to polarize the P-down energy into one component (E1) and majority of the P-Sv down energy into another component (E2). Figure 11 is showing not only the P-Sv up as well as P-down, P-up and P-Sv down wave have also been enhanced.

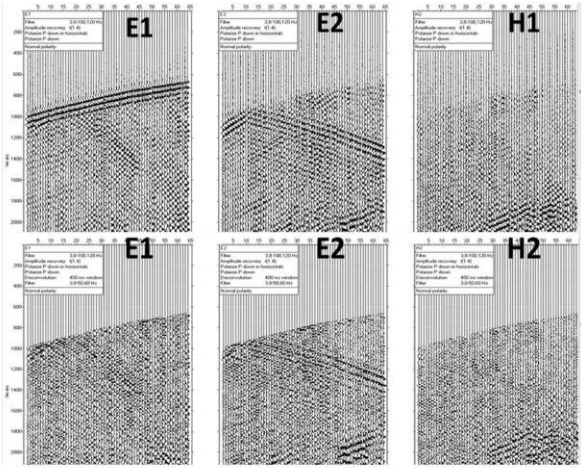

Figure 12: Before and After Deconvolution, Removal of multiples.

Now the dataset has been polarized the down-going P-wave in the E1 component and the down-going mode converted P-Sv wave in the E2 component has been aligned, enhanced and subtracted like normal VSP processing. Multiples were removed using Deconvolution techniques, as shown in Figure 12.

Lithology of the Well-A is given in table 3, Kalol formation lies between 1259m – 1635m.

Table 3: Lithology in zone of interest in well A

Depth (m)	Lithology
1354-1386	Shale with coal layer
1387-1420	Coal with development of shale layer in between
1422-1449	Shale with coal and silty layer
1486-1507	Coal with silty shale in between
1507-1534	Thick coal and thin silt shale laminae
1534-1553	Coal and shale
1563-1578	Shale with sand layer in between

(Unpublished well completion report of ONGC)

Figure 13 shows upgoing PP data from ZVSP (after applying AGC & filter) along with, major horizons at depth levels 1540m and 1400m.

Important horizons are marked after correlation of nearby wells in time and depth domain, Interpreted well logs data with Synthetic Seismogram shown in Figure 14.

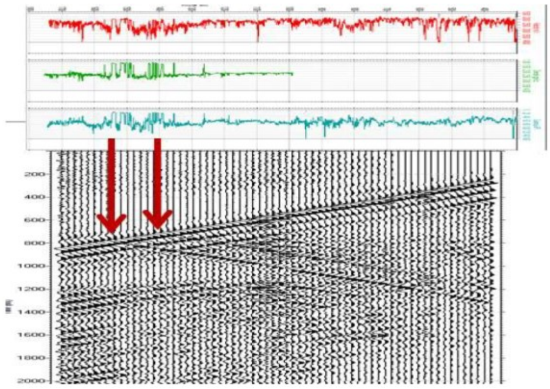
Figure 13: upgoing PP data from ZVSP (after AGC) and well log of Well-A

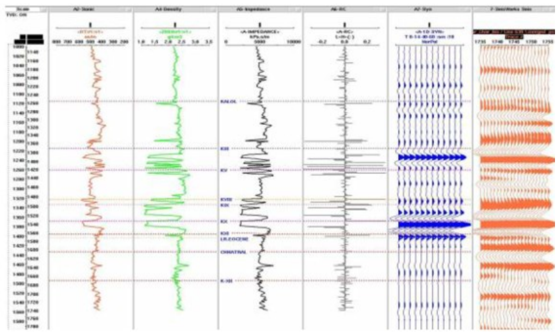
Figure 14: Synthetic Seismogram for Well-A (unpublished Well interpretation reoprt of ONGC).

Figure 15 shows matching of two prominent horizons within zone of interest at around 1230ms & 1375ms in surface seismic is inserted with VSP-CDP transform of PS and PP-wave for offset-I.

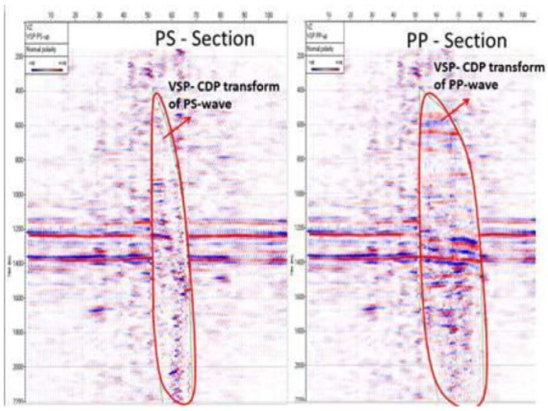

Figure 15: Overlay of Surface Seismic with VSP-CDP transform of PS- and PP-wave for SOURCE-I.

The final output of offset VSP processing required validation with Well data.

Overlay of VSP-CDP transfrom of PP-wave of offset-I, major horizons matching very well with a section which contains well logs, reflection coefficent and synthetic sysmogram, shown in figure 16. Sand Silt isolith map also confirm lateral extension of horizons in offset-I direction.

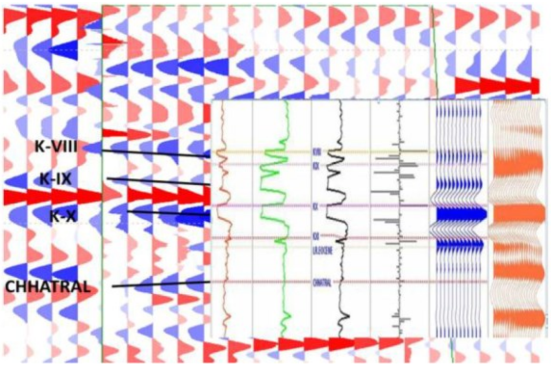

Figure 16: Matching of well logs, synthetic sysmogram with major horizons in offset-I.

Observations

1. By energy maximization of horizontal and Vertical components, multi component offset VSP shows better match in the target zone as compared to conventional offset VSP data as shown in figure 17.

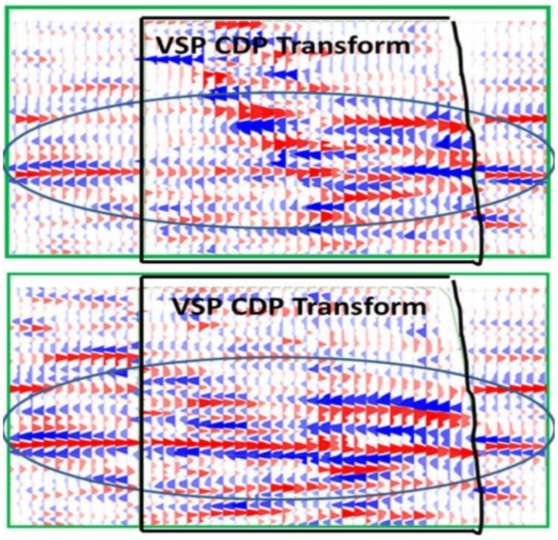

Figure 17: Conventional offset VSP data processing (above) and 3-C offset VSP data processing (below) of PP wave.

2. Figure 18 and 19 shows, VSP-CDP transform of PS and PP-wave with surface seismic along offset-II and offset-III respectively. Prominent horizons were not found in offsetII while offset-III shows major horizons within zone of interest.

Sand Silt Isolith map of K-XI and K-XII shows in figure 8 refers that lateral extension of these horizons were well developed in the direction of offset-II and offset-III. However result of VSP-CDP transform showing lateral extension of sand bodies seems to be lesser than anticipated in offset-II and offset-III. This may lead for further integrated interpretation.

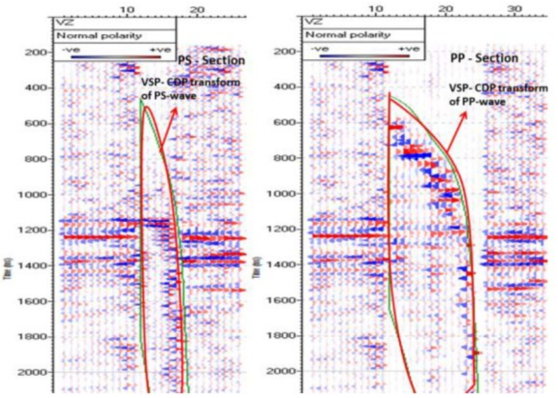

Figure 18: Overlay of VSP-CDP transform of PS- and PPwave for offset-II on surface seismic

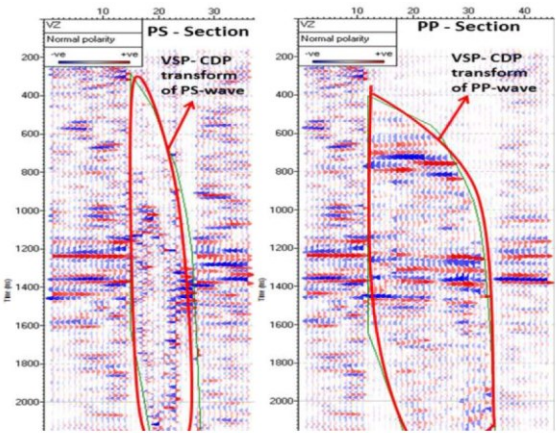

Figure 19: Overlay of VSP-CDP transform of PS- and PPwave for offset-III on surface seismic.

3. VSP-CDP transform of PS-wave were not well developed in offset-II and offset-III. However there is some significant information in offset-I. This indicates anisotropic behaviour of subsurface. Resolution at around 1230ms is better than deeper because of less absorption of PS-wave in shallow region, shown in figure 20.

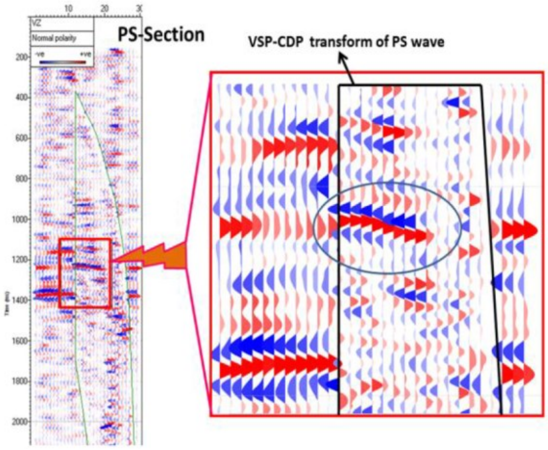

Figure 20: Overlay of VSP-CDP transform of PS-wave for offset-I on surface seismic

Conclusions

Reservoir delineation through processing of 3- component VSP data was developed and successfully implemented on different data sets. VSP-CDP transform of PS- and PPwave outputs are in close match with surface data and giving the valuable result for interpretation. 3-C VSP processing also shows anisotropy behavior by shear wave splitting analysis.

The present work will also help to process the 3D-3C bore hole data acquired in future.

The view expressed here are solely of authors and do not necessarily reflect the view of ONGC.

Acknowledgments

Authors are deeply indebted to Shri S. K. Das, Executive Director-Basin Manager, WON Basin, ONGC, Vadodara for his kind inspiration and permission to publish the paper.

Authors are very much grateful to Party Chief GP-61 and party personal for acquiring good quality data. Sincere thanks to RCC and Interpretation team of WON basin Vadodara for their support.

References

Hardage, BOB A, 1985, Vertical Seismic Profilling, Geophysical Press, Part A: Principle Sencond Enlarged Edition.

Shapiro, N. M., M. Campillo, L. Margerin, S. K. Singh, V. Kostoglodov, and J. Pacheco, 2000, The energy partitioning and the diffusive character of the seismic coda, Bulletin of the Seismological Society of America, 90(3), pp. 655–665.

Prasad T.K., Srivastva S.K. & Sinha D.K., 2012, Modelling Studies as a Tool for Offset VSP surveys – Case Studies, SPG, P-243, 1-5.

Singh, O.P. & Bhanu, M., 2012, 3-Component Processing of VSP data, SPG, P-232, 1-5

Report on VSP data processing of well-A, Unpublished report of ONGC, 2010.

Report on Formation Evaluation of well-A, Unpublished report of ONGC, 2010.

Report on well completion of well-A, Unpublished report of ONGC, 2010.

Report on well interpretation of well-A, Unpublished report of ONGC, 2010.

Wikipedia, An encyclopedia