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Processing of Mode Converted Shear Waves from 3C Offset VSP in Western Onshore Basin, India - A Case Study

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Summary

Mode converted waves are observed with sufficient amplitudes in many offset VSP data sets. Proper extraction of these waves and processing them with suitable processing flow generates a P- SV section which correlates well with the P- wave VSP section. Joint interpretation of P-wave VSP section along with P- SV section is preferred to studying the P- wave section in isolation.

Introduction

Two dimensional VSP surveys are designed to give illumination of subsurface around the borehole in the zone of interest. Different configurations are in practice in the industry like walk away VSP, far-offset VSP and deviated VSP.

In these surveys, the source is placed at a distance from the well head. As a result, wave fronts are incident on the formation boundaries at non-normal angles of incidence and generate converted waves. Converted wave surveys use conventional P-wave sources and three component geophones. In VSP, the most common mode conversion in the source-receiver vertical plane is, from compressional P-wave to shear wave or SV-wave.
Processing of converted shear waves can provide additional and independent seismic image near the borehole which may give greater confidence and adds value to the seismic interpretation.

In case of VSP, converted S-waves, which do not travel through near surface, have similar frequency content as P- waves and thus have shorter wavelengths (Dillon et. al, 1988) and therefore has greater resolution.

In many offset VSP data sets, mode converted waves are noticed. If the up-going S-wave energy can be separated from up-going P- wave energy, converted S-wave image

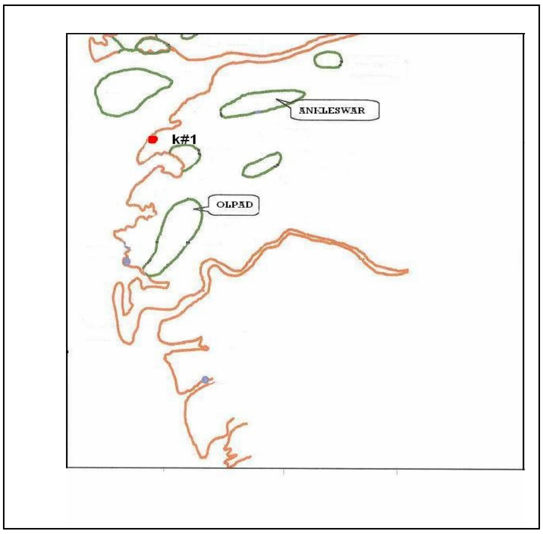


Fig.1 Map of study area

near the borehole can be generated using VSP CCP (Vertical seismic profile common conversion point) (Dillon et. al,1984) transform.

In this paper, a case study of an offset VSP survey conducted in well K#1 of Western Onshore basin, in Western India is presented where an attempt has been made to process the mode converted dataset with its possible interpretation. A SV wave image is generated near the well.

Geology

The study area (Fig.1) is located in south west of Ankleswar oil field and north of Olpad gas field. The main hydrocarbon bearing sands are S3+4 sands of Hazad member of middle Eocene age , lower sands of Ardol member of upper Eocene and Ts1 and Ts2 sands of

AGE	FORMATION	MEMBER	DEPTH(M)	LITHOLOGY
Recent to Miocene	Post Dadhar	-	Surface to 1100 m	Sandstone,claystone,shale
Oligocene to up. Eocene	Dadhar	-	1100-1200	Sand with shale intercalations
Up. Eocene to M. Miocene	Ankleswar	Telwa Ardol Kanwa Hazad	1200 –1270 1270-1400 1400-1440 1440-1470	Shale Mainly sand with alternations of shale Shale Mainly sand
M. Eocene to L. Eocene	Cambay shale	-	1470 onwards	Predominantly shale

Fig.2 Generalised Stratigraphy of the area

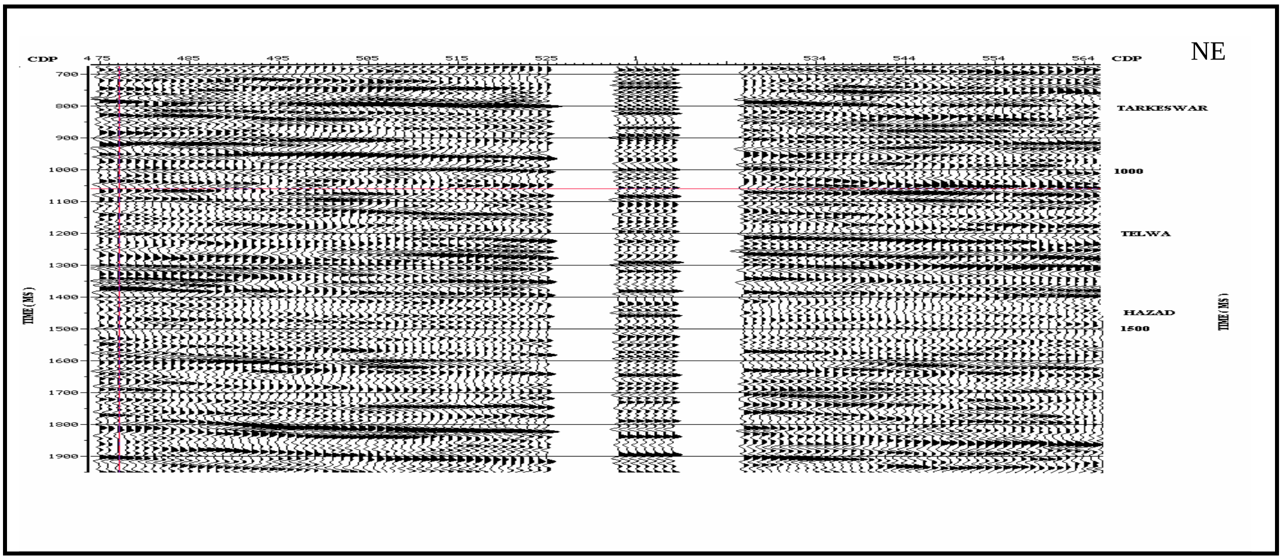


Fig.3 Migrated surface seismic section near the well. A corridor stack is inserted at the projected location. Major boundaries are marked.

Tarkeswar formation of Miocene age. The sands are envisaged to have been deposited in deltaic environment. Generalised stratigraphy of the area is given in Fig.2. The hydrocarbon entrapment is mainly strati structural. The traps formed by shale out zones of sands, associated with structural play are considered to be best locales for hydrocarbon entrapment in this area .

Fig.3 shows the time migrated P-wave surface seismic section in the area (the source was dynamite and data was processed with standard processing flow).

A zero offset VSP corridor stack is inserted at the well location and various formation boundaries are marked.

Data Acquisition

A three component VSP survey was conducted with source offset 1470 m and Azimuth 193 Deg . Two P-wave vibrators were used with sweep frequency of 12-108 Hz. The tool used was three component Geolock-H. The survey was conducted for 61 levels between depths of 580 m and 1700m with 20m and 10m receiver intervals.

Data Analysis

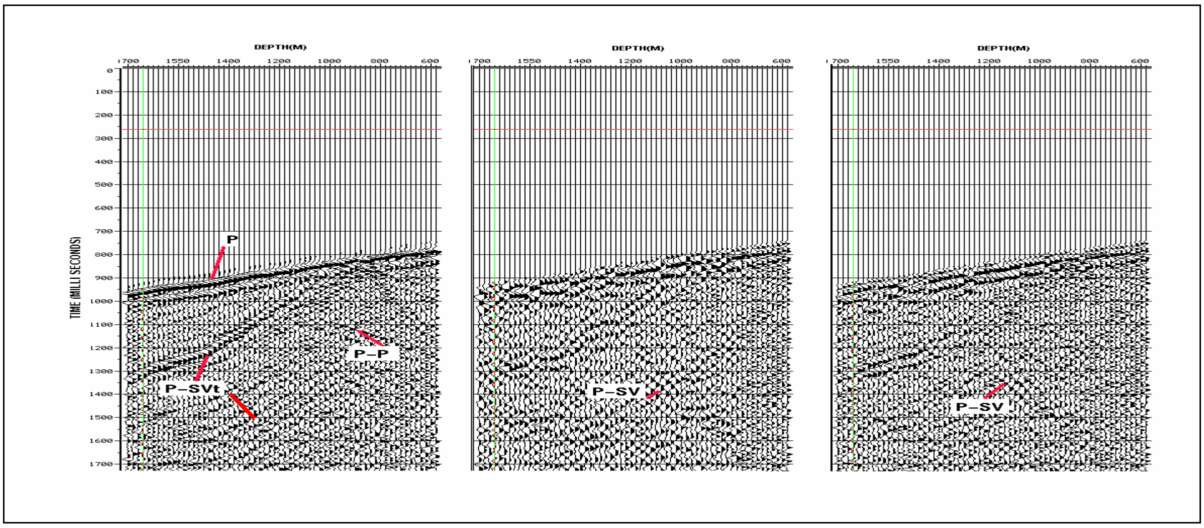


Fig.4 Raw vertical (V), horizontal (H1) and horizontal (H2) components. Various events are annotated; P (direct P wave), P-P (reflected P wave), P-SVt (mode converted transmitted S wave and P-SV (mode converted reflected S wave)

Fig.4 shows the all the three components of raw data recorded. Z is the vertical component of the wave field and H1 and H2 are two horizontal components. Strong down going P-wave direct arrival (event P) and up going P-wave reflections (event P-P) and converted P- S down going (event P-SVt) are seen in the raw records. From the analysis of raw records, it is observed that one of the modes converted down going event (event P-SVt) generated from the seismic boundary at depth 980 m is very strong in amplitude and easy to identify. And also some of the S- down going events which originate from shallow depths are observed in raw data but have less amplitude. Such events are only used for computation of S- velocity .The mode converted up going events (event P–SV) can be extracted after suitable processing and can be subjected to a further processing flow to generate a P –SV image around the well.

Data Processing

Following processing flow is used to process the data. Input for the processing is raw gathers (V, H1 & H2 components.)

- Pre processing (geometry merging, pre filter, editing, spherical divergence correction, first break picking)
- Correction of H1 & H2 components of wave fields for tool rotation using hodogram method.(Fig.5).
- Wave field polarisation (using V and horizontal radial component) which produces two wave fields one in the direction of P-wave down going field (ZS) and the other transverse to it (ZT).
- Extraction of mode converted up going wave field (by parametric separation technique, Fig.6) .The up going event corresponding to SV- wave (labelled P-SV in Fig. 6d) terminates against the down going P- wave travel time curve thereby indicating the interface where the incident energy is P – down going and travelling as SV-up going after mode conversion.
- Model based VSP CCP transform has been performed on the data. A flat layered model has been created from P- velocities estimated from zero offset VSP data. As no full waveform sonic is recorded in the well S - velocities are derived from down going P-SV wave of offset VSP data after proper slant path correction. Then the S - velocities are incorporated in the model. Stratigraphic boundaries are taken from well logs and zero offset VSP data.

- NMO correction and VSP CCP transform with respect to the generated model.

- Bin stack: A bin size of 25m is defined for summing the data. Due to nature of P-SV ray path the maximum lateral coverage obtained is 425 m against coverage of 650 m for P wave image.

- Post processing : (Predictive deconvolution with op. length of 240ms, gap 8 ms and white noise 1%,median filtering to enhance coherency of events followed by Band Pass Filter; Datum : MSL).

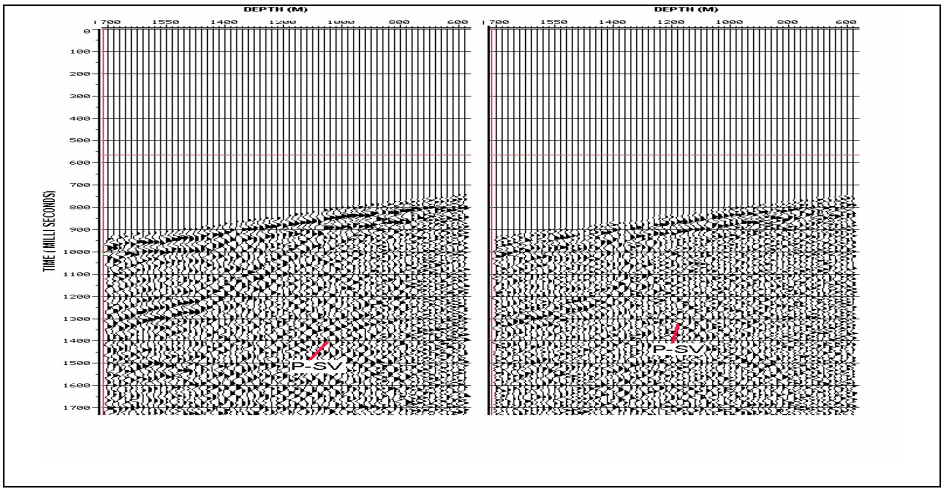
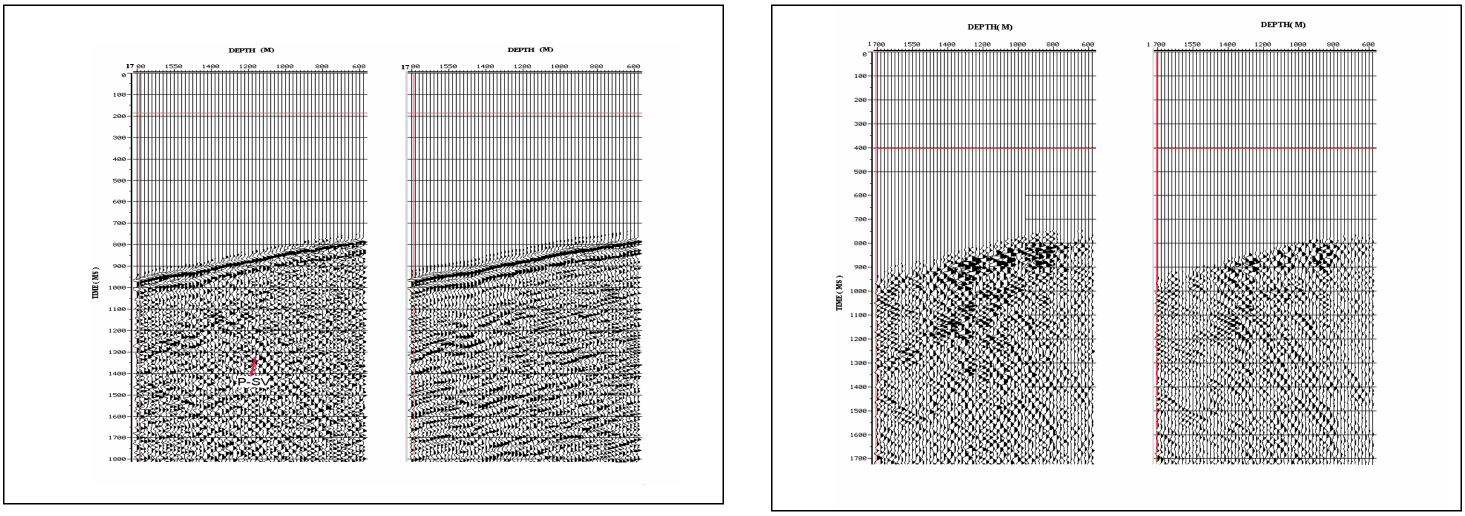


Fig.5 Horizontal radial component (Left) & Horizontal transverse component (Right) . The first arrivals are much enhanced in this field (left) as compared to raw H1 component.It (right) is showing a lot of shear wave activity but its energy level is low.



a) **b)** **c)** **d)**

Fig.6 a) VSP data after rotation of vertical and radial horizontal components (ZS component) **,** it is polarised towards P down going energy .Hence P direct arrivals and P-SV reflected energy are much pronounced. **b)** Down going P wave after separation from ZS component **c)** Residual field from a. after subtracting P down going energy **d)** extracted P-SV reflected wave field from c separated by parametric separation method.

Interpretation

A composite plot (Fig.7) consisting of sonic log, P up going field in two way time, corridor stack, synthetic seismogram , and both P & P-SV VSP CCP transforms is studied to interpret VSP data. Formation tops of various prominent horizons have been interpreted from logs and converted from depth to two way time in seismic data. Both the P and S sections correlate well at the well head. Shallow section in S image is better resolved than P image (fig.8).It is observed that there is no strict one to one correspondence between all events of P and S-wave sections. It could be due to the response of the two wave fields being different to the elastic properties of the sub surface (P.B. Dillon et al). However, the gas bearing zone at Hazad level is seen resolved in SV-section better than the P-wave section. The fault at Hazad level is clearly depicted in P-SV section.

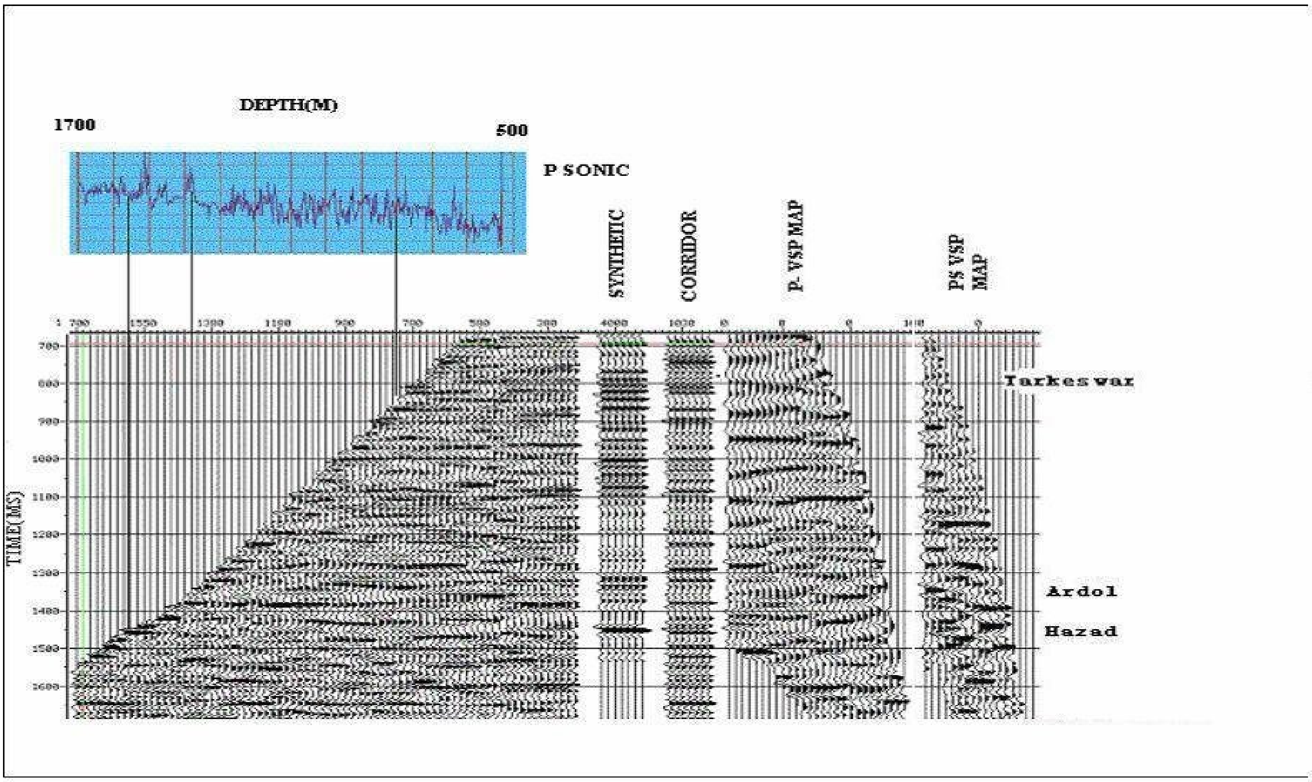


Fig.7 L-plot display consisting of various P-wave and P-SV wave sections .Prominent horizons are correlated between data types in both depth and time.

Conclusion

Studying VSP data (P and SV section), well logs and P wave surface seismic data together can help in understanding shear wave properties in the area. The quality of processing of the three components VSP data depends mainly on the efficient extraction of mode converted waves and data quality. Processing of converted shear waves can provide additional and independent seismic image near the borehole which may give greater confidence and adds value to the seismic interpretation.

With the help of S-wave velocities elastic properties of different formations can be studied. Last but not the least; the raw data quality should be good so as to generate an interpretable and reliable P-SV image near the borehole.

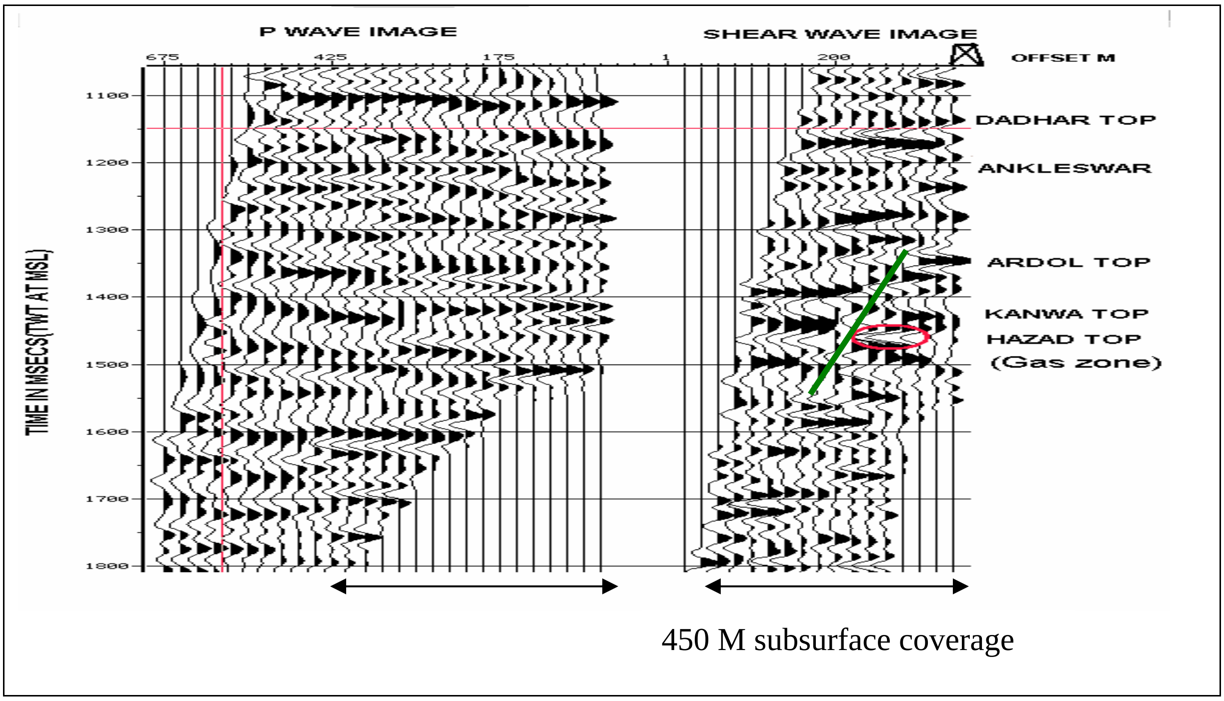


Fig.8 Enlarged P and P-SV maps showing similarities/differences in reflectivity between them. Various formation tops have been identified in Well logs and correlated with the section.

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