Synrift imaging using Converted wave seismic data in Gandhar area of Cambay Basin, India

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Keyword:
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Summary:
Hazad member of Ankleshwar formation is the main producer of hydrocarbon in the Gandhar area of Cambay basin and it has been explored reasonably seismically as well as exploratory drilling. But synrift sediments below Cambay shale in deeper part needs to be explored which has also been developed as good reservoir and producing hydrocarbon in nearby areas in the basin. Imaging of these sediments is poor in this area. Dramatic lateral and temporal lithological variations in the fluvial sediments at deeper part have posed potential challenges and difficulties to distinguish between amplitude variation due to fluids or lithology. A high resolution multi-component seismic survey conducted recently in the area has provided a good opportunity to solve the problem of poor imaging. Due to different reflection response of shear waves to lithology and fluid content, additional information is obtained for delineating the characteristic of subsurface successfully. Surface consistent amplitude preserving and high resolution processing has produced high quality pre-stack PP and PS migrated gathers and stacks. Some special processes for P-S analysis include rotations, shear receiver statics, asymmetric and anisotropic binning, shifted hyperbolic velocity analysis and NMO correction, P-S to P-P time transformation, subsurface Vp/Vs values and pre-stack migration with two velocity volumes of Vp and Vps. In currently processed volumes, the quality of both the volumes are good and correlatable events are visible corresponding to the synrift sediments in PP as well as PS sections. This multicomponent seismic dataset has provided an additional tool for imaging the synrift sediments below Cambay shale and help in identifying lithological & fluid information for further hydrocarbon entrapment studies and extraction.

Introduction:
Among all the elastic waves, compressional waves has high velocity so arrive first, usually have high signal to noise ratios, having close to rectilinear particle motion, can be easily generated by a variety of sources and propagate in fluid environment. When P-wave surveying fails, can we use other seismic techniques? Answer is yes. There was considerable expectation in using multicomponent recording to get S-wave section however source for generating of shear wave is difficult task. Shear waves converted from compressional wave source at an interface and recorded by 3C digital geophones provided opportunity to get PS wave section. This phenomenon of conversion of waves at interface or partitioning of energy can be understood well by Zoepritz equation of reflectivity for elastic waves.

We see that (Fig.1) there is an asymmetry in the P-S ray path. Snell’s law gives the basic geometry of the ray paths, where as Zoepritz equations give the amplitude of the reflection. In general, a P-wave incident on an interface between two elastic media will generate a shear wave reflection and the reflectivity of the converted shear wave varies with offset. (Fig.2). Recording of good quality of converted wave data of offset VSP conducted in a well in Gandhar with explosive as energy source has been reported (Harilal, 1998). Modelling studies has shown that good S-wave impedance contrasts exist at Sand-shale in Older Cambay shale (Harilal 2002). The multicomponent data was acquired with primary objective of exploring Hazads sands, this dataset is re-processed for synrift imaging.

Fig. 1: Asymmetric ray path for converted wave (Left) & amplitude variation with offsets and incidence angle for PP & PSv waves (Right).

Fig. 2: Relative energy conversion at an interface for P and converted shear waves

Geology:
The area under study lies in Jambusar – Broach tectonic block of Cambay basin. The evolution of the basin began following the extensive outpour of Deccan trap Basalts during the late Cretaceous and development of tensional faults along its margins. The basin is characterized by thick sedimentary section of Tertiary – Quaternary age, which is underlain by Deccan trap Basalts. During Paleocene, the Basin continued to remain as a shallow depression, receiving deposition of Trap wash/conglomerate/clay-stone exclusively derived from basaltic trap showing digenetic alterations under the fluvial environment named as Olpad formation. The oldest sequence,
Olpad formation, overlies the Deccan trap basalts with an erosional unconformity. After this, there was a conspicuous and wide spread marine transgression, and a thick, fissile, pyritiferous shale sequence known as Cambay shale was deposited during upper paleocene to early Eocene unconformably overlies the Olpad formation. This was followed by a number of regressive and transgressive cycle. The sandy facies of Hazad, Ardol (Ankleshwar formation), Dadhar, Tarkeshwar, Babaguru (Mid Eocene to Miocene) were deposited in various regressive phases interspersed with minor transgressive cycles of deposition of the shaly facies of Kanwa, Telwa and intervening shales of Tarkeshwar and Babaguru formations. Hazad member of Ankleshwar formation, of the Jambusar–Broach tectonic block, comprises of alternating shale and sand sequences formed during high-stand and low-stand sea level respectively is the main producer of hydrocarbon in the area. The petroleum system in the study area consists of Cambay shale as source rock, Hazad member as reservoir rocks and Kanwa shale as cap rock. The generalized stratigraphy of the area is given in Fig. 3.

3D-3C Seismic data acquisition:

The multi-component data was acquired with the objective for to decipher pinch out / shale out of lower and upper pack of Hazad reservoirs and to image synrift sediments. The acquisition survey geometry for multi-component seismic exploration in the current area was symmetrical split-spread with 4536 active channels which provided 162 fold data with maximum far offset of 5055m in a bin size 17.5 m X 17.5m. The data is recorded with 3 component digital sensor and explosive was used as energy source. Logistically area was highly populated, full of salt pan, metal roads, under ground oil pipe lines and many small and large scale industries causing cultural noise and scattered coherent noise. Fig. 4 shows the bandwidth of raw data.

Data processing:

The processing of PP volume was done following standard practices with utmost care for signal conditioning on the basis of amplitude, frequency, velocity in different domain to enhance signal to noise ratio. The linear coherent noise, ground-roll and scattered noise was removed transforming the data in X-spread domain. Surface consistent amplitude correction and deconvolution was run with proper parameters in slant time windows. Velocity analysis was carried out in a 500m X 500m grid. 3D Regularization of data done in offset mode before migration. The final migration was run using RMS velocity volume, anisotropic parameter volume. The post processing on migrated data was done for suppression of random and linear noise, foot print removal and spectral balancing for good resolution. Processing of this converted wave data is more challenging due to deeper target and nature of shear wave attenuating faster with time and depth due to shorter wavelength. Although the receivers were taken out on daily basis during data acquisition but proper orientation was ensured in the fields. Initially, the recorded data was in coordinate system related to field geometry system. Then it was transformed from field based coordinates to the source coordinates of radial and transverse S-wave motion. Only the radial component, oriented in the source-receiver azimuth, is used to get processing parameters and velocity model. The transverse data was also processed in the same way as radial component using all the processing steps and parameters as used for radial component. The processing steps are given in table 1.

Table-1: PS processing steps

- Separation of the X & Y components and data merging
- ACP binning using gamma value 3.0
- Removal of the high amplitude burst noise and spikes.
- Rotation of X, Y component to R & T component.
- Application of source and receiver statics (with Gamma (Vp/Vs) value 3.0)
- Receiver statics computation using receiver stacks and application.
- Spherical spreading correction.
- Signal conditioning in different domain
- Surface consistent amplitude correction
- Velocity estimation in ACP mode
- Surface consistent deconvolution.
- Velocity estimation
- Residual statics computation and application.
- Migration of data on selected line for RMS velocity computation
- Velocity volume generation and running of migration on selected lines.
- Variable gamma picking using PP and PS stack & volume generation for final migration.
- PP velocity vol. PS vel. Vol., Gamma vol. and PS gathers as input for PS data migration.
- Conditioning of migrated PS gathers, stacking of volume.
- Post processing. (Random noise attenuation, scattered and remaining linear noise attenuation, foot print removal, spectral balancing).

Though the range of elevation variation in the area was not more even then the computation of receiver statics for shear data was a challenging job. The data was sorted in receiver offset mode and stack was generated for picking of dominant horizon window for computation of receiver statics based on cross correlation techniques and output was created. Any
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abnormal value of the statics had been edited before application.

Multichannel Trace Editing to attenuate high-amplitude traces and spikes and Multichannel Spectrum Editing in Surface Wave attenuation mode to attenuate the most of ground roll were applied. To attenuate residual high amplitude noise, Multichannel Spectrum Editing in Sliding mode were also applied. For adaptive ground roll attenuation in cross spread domain, data split into f-k domain & modelling of ground roll in f-x domain using least squares iterative approach. Optimised parameter for ground roll attenuation resulted in effective suppression of ground rolls. The resulting output after removal of all type of noises is shown in figure 5 for PS radial data.

![Input, output, difference](image)

![Fig.5: PS- shot gather after final data conditioning.](image)

Surface consistent amplitude corrections (SCAC) were applied after testing of different combinations of time horizons in order to choose an optimum time window for amplitudes estimation. The results after SCAC are compared with input as shown in figure 6 & 7 for PP and PS-radial stack respectively. Single window surface consistent deconvolution with operator length 240 ms, Gap 12 ms, noise 0.5%, for PS data was applied.

![Fig.6: PP stack application of SCAC.](image)

![Fig.7: PS-radial stack application of SCAC.](image)

Velocity estimation for both PP and PS data was carried out in the grid of 500 mX500 m in inline direction. For PS data the Vp/Vs value of 3.0 was taken for binning. Variable Vp/Vs volume was created by picking of Vp/Vs along inline at the similar interval of 500mX500m. Four prominent horizons on PP section and similar corresponding horizon on PS time section were taken for event registration to pick Vp/V value. A fifth phantom horizon below basement was taken on both the section for control of gamma function stability in temporal and spatial volume in 3D space (Fig.8). Once the gamma function volume is created and end product volume is obtained, the volume is smoothened and scanned by certain percentage to check for the best possible output of the PS image section. This process of gamma volume generation was done for many iterations until the satisfactory result was achieved. PP data migrated with migration aperture 5000X5000m, SI-2msec, Variable dip 10-50D while for PS data aperture used is 4000mX4000m, SI-4 ms and variable dip 10-50 D.

![Fig.8: Event registration for Variable Vp/Vs on PP & PS migrated stack.](image)

Post Stack Processing:
Post stack processing was done to improve the image quality by suppressing random noise, remnants linear noise and geometry foot-print but maintaining over all true relative amplitude. For linear noise dip-dependent Median mean filtering was performed. The footprint was removed using FK filter in 3D mode (FKF3D). The input data is converted from the time-space domain to the frequency-space domain. Acquisition footprint is treated as an additive noise with spatial periodicity. In the process, the Kx-Ky points to be filtered are located on an orthogonal grid defined by inline and crossline periods. For widening of spectra, spectral balancing program was run which applies time-variant amplitude deconvolution, equalization, and filtering. The result is shown in figure 9 for improved resolution after spectral balancing.
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**Discussion:**
The processing and imaging of synrift sediments below 4000m in the Gandhar area was really challenging job because previously processed data was not showing any events below 3000 m. During processing the main attention was given to conditioning of data, velocity analysis and overall maximum care for Vp/Vs estimation which is the backbone of the converted wave processing. It can be seen from the figure 10 &11, how the processing result is changes in subsequent stage of processing using correct velocity and Vp/Vs volume. Figure12 shows the time slices at 4000 msec. and 7500 msec. PS time. The PS data technically should have better resolution at shallow level which can be seen from Fig13.

**Conclusion:**
Multi-component high resolution amplitude preserving processing on Gandhar data has resolved a false bright spot at a well as shown in fig15. Since at the time of drilling the well PS data was not available and this was the only well drilled for deeper target in Olpad formation, below main reservoir member Hazad sands based on high amplitude contrast seen in PP section. The PS section shows different amplitude character from the PP section and lack of a fluid anomaly.
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Figure 15 Absent of characteristics in PS section, seen in PP section.

Figure 16 indicates that imaging of subsurface feature in PS section is highly matching with PP section even at depth below 4000m. Even at some places PS section is better than PP section and it will help in many ways to understand the sedimentation process and environment of sedimentation if both data are used for studies together.

Figure 16: Comparing synrift imaging in PP & PS sections.

Figure 17: Imaging synrift features in Gandhar area

Figure 18 clearly shows the difference of mapping and imaging subsurface in PP and PS section. It means both the wave-field behaving differently to subsurface rock fabric and PS section has provided additional information to understand the reservoir. In PP section at shallow depth the data gap is there, but PS section has no data gap because for same offset PS image is closer to SP as shown in fig 17. Due to shorter wavelength PS data has better resolution upto depth of 1000m and better fault mapping because of low velocity. The currently processed PS section is compared with the earlier processed (Fig.18). The marked improvement is obtained in imaging of synrift sediments.

Figure 18: Comparison earlier and currently processed PS section

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References:

It is concluded that reflection seismic method has used P waves for many years and with great success. However, there is more to be done in exploration seismology by using the other elastic modes, basically the PS converted wave. Recent example of successful PS imaging indicate a meaning of the technology.