Realizing the benefits of WAZ processing: A case study from Cambay Basin, India

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Keywords

NAZ, WAZ, OVT, Cross-spread, Regularization, VVAz, Anisotropy, Snail plot.

Summary

Wide Azimuth (WAZ) data acquisition offers better sampling of wavefield compared to narrow azimuth acquisition. Improvements in the spatial sampling helps in better attenuation of the ground roll and other coherent noise and improved data regularization. Azimuth dependent velocity estimation provides insight for the study of anisotropy in the subsurface formations. The difficulty often faced while processing the WAZ data is the inadequacies in the processing using 2D based approaches. Signal and various noise is registered in the 3D sense and hence needs the methods based on 3D. Offset Vector Tile (OVT) based approaches are better suited for the wide azimuth acquisition (Vermeer, Gijs J.O, 1994). 3D Seismic data of Padra area of WON basin was acquired with orthogonal geometry is processed to assess the value addition. Coherent noise attenuation was carried out in a real 3D sense by making cross-spreads. 5D regularization was performed to improve the azimuthal coverage and reduce migration artifacts. An effect of both was realized in gather as well as in stack. Offset Vector Tiles (OVTs) were formed with offset & azimuth dimensions of 60m and 45° respectively. Each OVT was migrated and the migrated gathers when sorted as “snail gather”, seismic events exhibited a wavy behaviour as a consequence of azimuthal variations. Significant improvement was observed in the stack section after incorporating azimuthal velocity variations.

Introduction

Wide Azimuth (WAZ) acquisition and processing is used where the conventional Narrow-Azimuth (NAZ) data is unable to address azimuth-dependent velocity effects, either because of lateral velocity gradients or because of azimuthal anisotropic effects. During the course of WAZ processing, first order of improvement in data quality will arise because of noise attenuation done in cross-spread domain. Second order of improvement can be realized by incorporating azimuthal velocity variations present in the area. In addition, data is regularized in five dimensions (Inline, crossline, offset, azimuth and time), better target illumination is obtained after migration.

Tectonically, Padra area falls in the North-eastern part of the Jambusar-Broach tectonic block of South Cambay Basin and lies on the northeastern rising flank of Broach syncline. Fig-1 shows the area of study in the tectonic map of Cambay basin. Area of study falls in the eastern part of the section. The main geological targets in the area are Dadhar & Hazad sands above basalt and also identifiable features below basalt. 3D seismic data was acquired in Padra area using orthogonal geometry and with fair distribution of offset and azimuth distribution. WAZ processing workflow including 5D regularization and azimuth based velocity analysis or Offset Vector Tile (OVT) processing was carried out to assess the value addition.

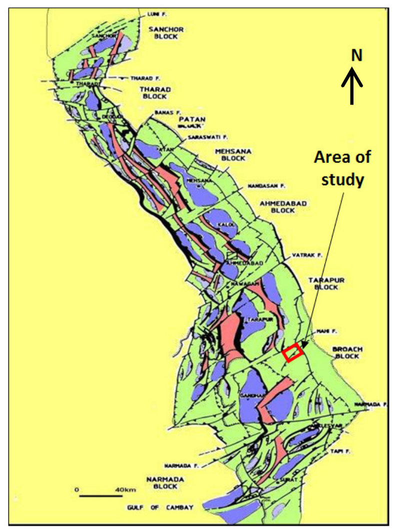

Fig-1 Tectonic map of Cambay Basin showing area of study in red rectangular boundary.

Input Data

Seismic data was acquired under three different seismic investigations with same geophone, recording instrument and a common bin size of 10x10 m in the area. The three seismic investigations were having a fold of 110, 110 and 80. Before 5D regularization, data was re-gridded into a bin size of 20x20 to increase the foldage up to 400. Combined fold map of the data is shown in Fig-2. One swath was extended to connect the well location.

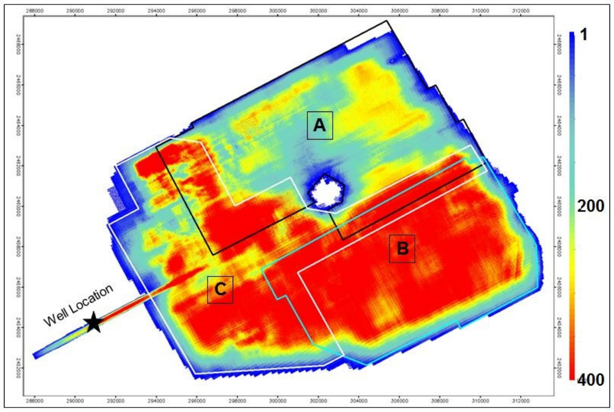

Fig-2 Combined fold map of the area.

General Processing Flow

Broadly, the processing steps included signal conditioning process especially in Cross-spread domain, deconvolution, multiple passes of residual statics estimation & application, 5D regularization, RMS velocity analysis, OVT domain pre stack migration, azimuthal velocity corrections and finally Random Noise Attenuation over PSTM stack. The general processing flow adopted is shown in Fig-3. The crucial steps for Wide Azimuth flow are shown in yellow color.
Noise analysis & attenuation was judiciously done with the combination of different approaches. Noise strips, spikes, random and frequency dependent noise were suppressed using single and multichannel based methods. Ground Roll attenuation was done in Cross-Spread domain. The data acquired with orthogonal geometry can be considered as a collection of cross-spreads (Vermeer, 2002). Each intersection of a source line and a receiver line forms the center of a cross-spread. The dense sampling of the sources along the source line and of the receivers along the receiver line creates a dense single-fold areal coverage. A sample cross-spread along with its coverage is displayed in Fig-4.

The midpoints of traces with the same absolute offset are located on a circle with diameter equal to that offset. Therefore, the first arrivals of the ground roll are lying on the surface of a circular cone. Hence, the ground roll in a cross-spread behaves as a truly three-dimensional event and can best be attenuated in 3D sense. Fig-5 & Fig-6 shows Ground Roll attenuation in cross-spread domain. A representative stack section before and after noise attenuation processes is shown in Fig-7 and Fig-8.

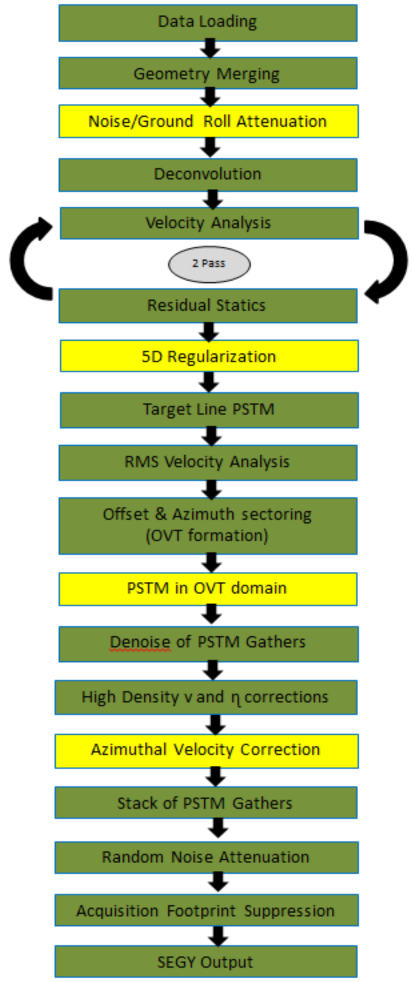

Fig-3 General processing workflow; yellow shaded boxes showing crucial steps for WAZ processing.

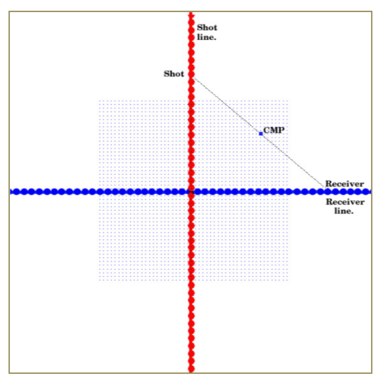

Fig-4 Cross-spread contains one shot line and one receiver line orthogonal to each other & corresponding CMP coverage in square / rectangular form.

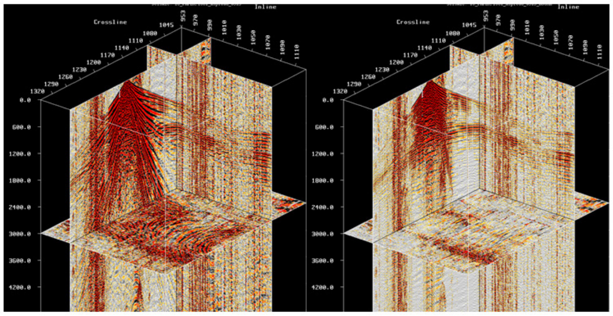

Fig-5 3D view: Before and after Ground Roll attenuation

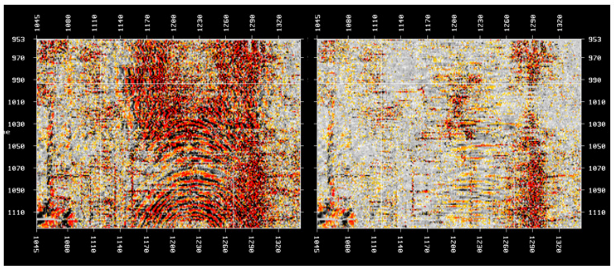

Fig-6 Time Slice: Before and after Ground Roll attenuation

Based on the test results related to improved frequency and event continuity paricularly below basalt, a two window de-convolution was applied on the data. Two passes of residual statics application were also performed. After deconvolution and residual statics application, 5D regularization was performed on the data.

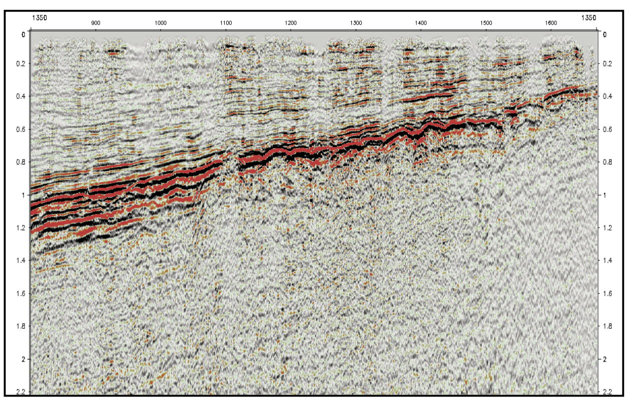

Fig-7 Stack section before noise removal.

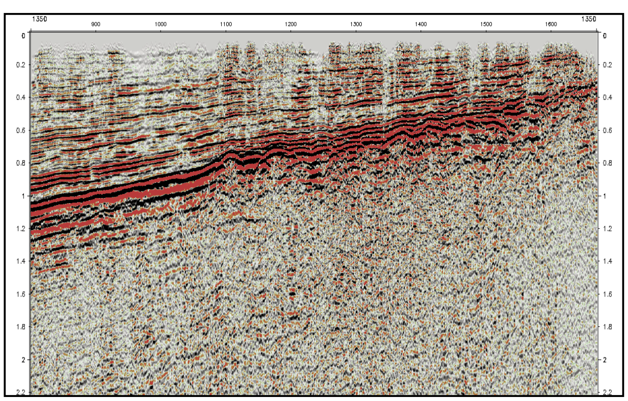

Fig-8 Stack section after noise removal.

5D Regularization

Various obstacles at surface will alter the regularly sampled acquisition survey geometry (orthogonal) and introduce some randomness in source and receiver spacing and source line and receiver line spacing. These perturbations will clearly affect the uniformity of the coverage. Midpoint, Offset, and Azimuth variations in the recorded data result in non-optimal interference of seismic energy during migration. The need for regularizing inadequately sampled seismic data is to minimize migration artifacts. 5D interpolation offered a potential way of improving the spatial sampling so that pre-stack time migration (PSTM) could be used to provide a higher resolution image.

5D regularization can perform simultaneous regularization of several pre-stack dimensions through a forward-reverse Fourier transform (FT). Forward irregular Fourier transform is done in all five data dimensions simultaneously to build a representation of the data in the frequency domain. Reverse transform is to output the data on a regular grid (e.g. regular midpoint, offset, and azimuth).

It is known that FT of regularly sampled data too may exhibit aliasing depending on sampling rate. Likewise, FT of irregularly sampled data in any domain also leads to aliasing popularly termed as “Leakage”. 5D interpolation uses an Anti-Leakage Fourier Transform. (Xu and al. 2004). This has resulted into a clearer image. Residual statics applied gather was taken as input for data regularization. Data regularization for azimuths was carried out for 8 azimuth classes of 45° aperture (Fig-18). As the data was acquired with a nominal foldage of 100, which after re-gridding into 20x20m bin size have become 400. To maintain a sufficient foldage in each offset-azimuth sector (i.e. OVT), the offset sectors as well as azimuth sectors were taken as 60m and 45° respectively. By making azimuth sector as 45°, the nominal OVT foldage has become 50 which were sufficient for azimuthal velocity analysis and further processing. As a result of this, the size of OVT was not a conventional (RLI x SLI in Cartesian coordinates) but rather defined in polar coordinates with Offset class increment of 60 m and azimuth class increment of 45 degree. Representation of OVT in Cartesian as well as in polar coordinates is shown in Fig-9.

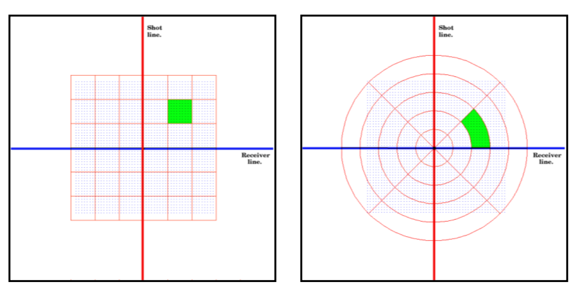

Fig-9 OVT formation – Cartesian (left) & Polar (right) coordinates.

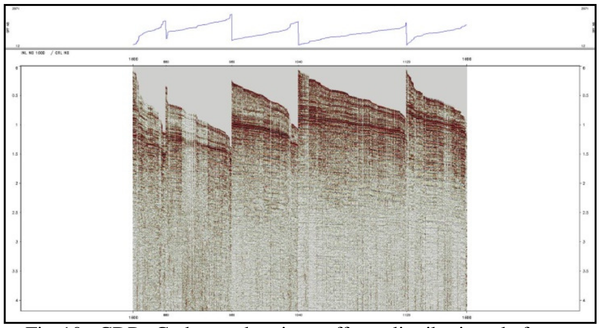

Fig-10 CDP Gathers showing offset distribution before regularization (Offset values plotted above).

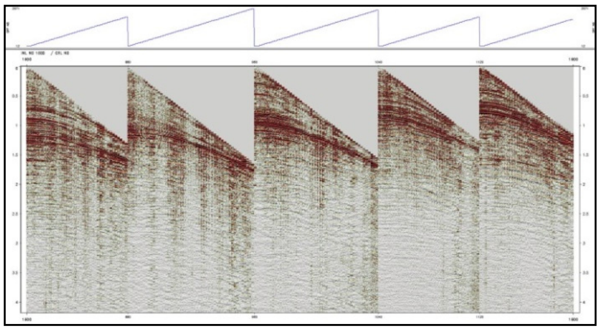

Fig-11 CDP Gathers showing offset distribution after regularization (Offset values plotted above).

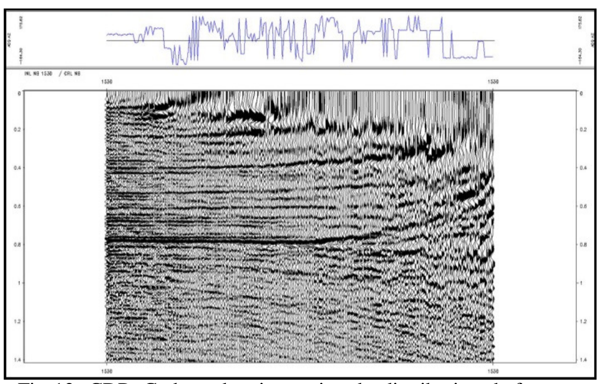

Fig-12 CDP Gather showing azimuth distribution before regularization (Azimuth values plotted above).

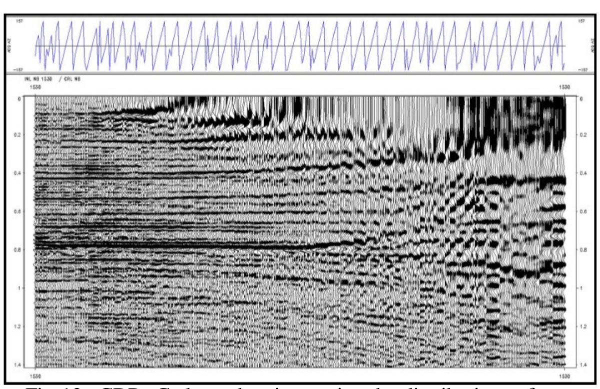

Fig-13 CDP Gather showing azimuth distribution after regularization (Azimuth values plotted above).

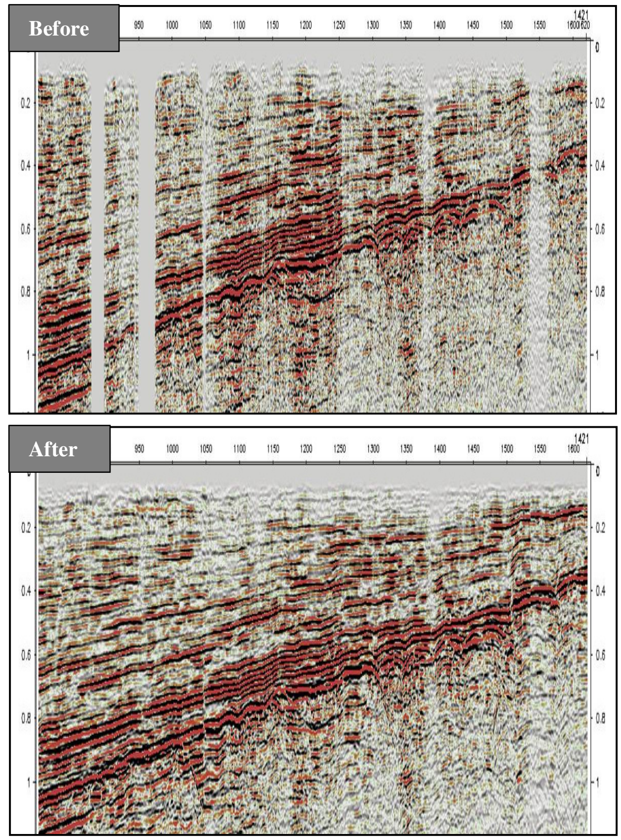

Fig-14 Near offset stack before (top) and after (bottom) 5D regularization.

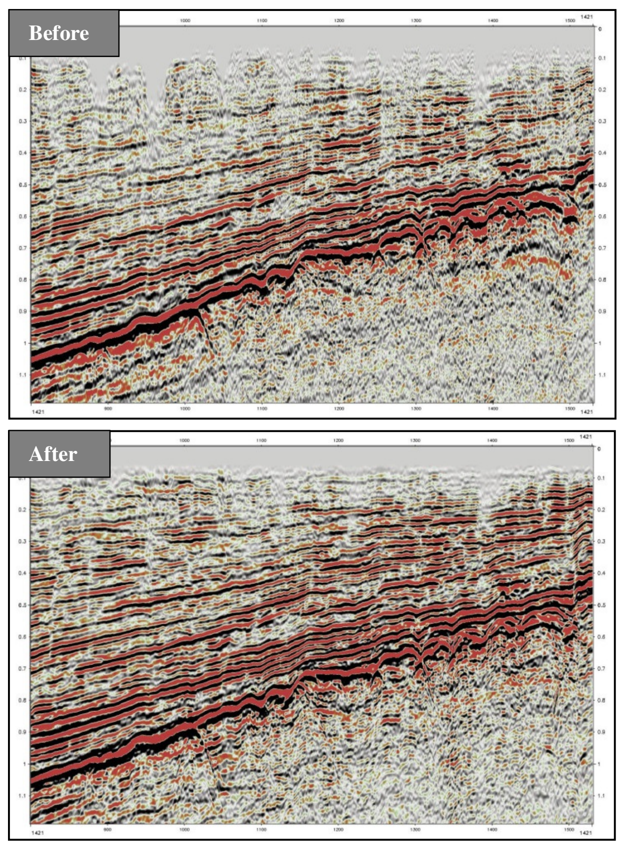

Fig-15 Full offset stack before (top) and after (bottom) 5D regularization.

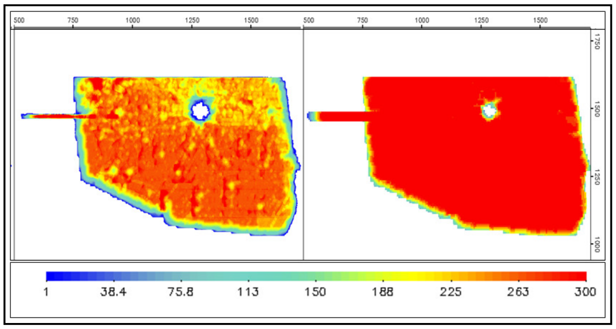

Fig-16 Combined fold map before and after 5D regularization.

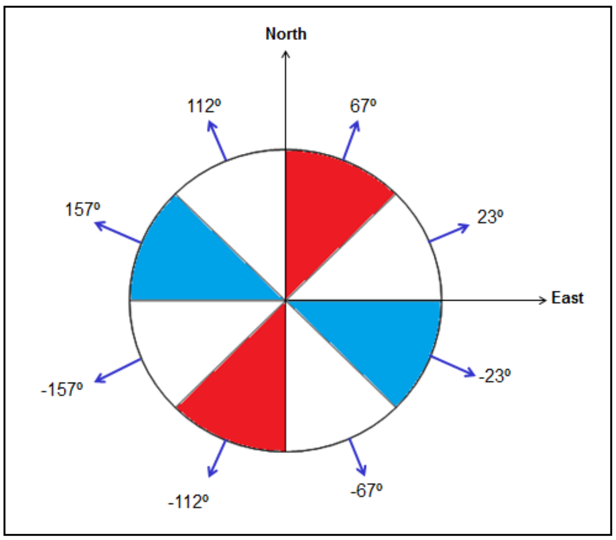

Fig-17 Azimuth classes after 5D regularization. Angle displayed on arrows represents central angle of each class

Further processing was carried out with this dimension (60m X 45°) of OVT. After 5D regularization, Quality control QC) was necessary to select interpolated data based on the minimum distance (between a trace and its original neighbours). Several other QC parameters can be estimated and saved into headers. Effects of 5D regularization on offsets and azimuths is shown in Fig-10, 11 and Fig-12, 13 respectively. Near offset stacks before and after 5D regularization is shown in Fig-14. Fig-15, 16 shows full stacks and fold map before and after 5D regularization respectively.

OVT Domain Migration

Wide azimuth seismic data sets offer the benefit of better illumination of the subsurface. The data was divided into 400 OVTs (50 offset classes x 8 azimuth classes). Fig-17 shows azimuthal sectoring as a result of 5D regularization which was used for migration. Considering the Source-Receiver reciprocity, diagonally opposite azimuths (e.g. 23° & -157°, 67° & -112° etc) are exactly same; however for demonstration purpose they are handled and displayed separately. Kirchhoff's pre stack time migration was run for each OVT using RMS velocity. 400 OVTs were migrated rather than 200 OVTs to understand their uniqueness for study purpose.

Azimuthal Velocity Correction

Variation of Travel Time with Azimuth (VVAz), also known as Azimuthal NMO, examines variation in travel time (velocity) with azimuth to characterize the anisotropy. With the introduction of aligned fractures, the rock structure can no longer transmit P waves equally in all directions. Azimuthal NMO methods try to describe how P-wave velocity varies with direction of travel. For short recording offsets – less than or equal to the reflector depth – the variation in NMO velocity with azimuth can be described by an ellipse. This velocity ellipse is a simplified model, characterized by the major axis, V_{fast}; the minor axis, V_{slow}; and the azimuthal orientation of V_{fast}. For most rocks, the fast velocity corresponds to the rock matrix, and so the orientation of V_{fast} is parallel to the fracture strike. The ratio of the two velocities provides an estimate of the magnitude of the anisotropy. The anisotropy magnitude delivered by VVAz is directly related to Thomsen's parameter $\delta(v)$. The analysis of effective anisotropy gives V_{fast} and V_{slow} averaged down to the target and is typically used to correct for azimuthal moveout in the data and to improve the imaging. The stack can be improved by azimuthal moveout correction; therefore, it was important to correctly model the azimuthal variation in wave propagation velocity. When traces are sorted in "snail gather", that is increasing azimuth within each offset range, any seismic event may exhibit a wavy behaviour as a consequence of azimuthal kinematic variations (Fig-18).

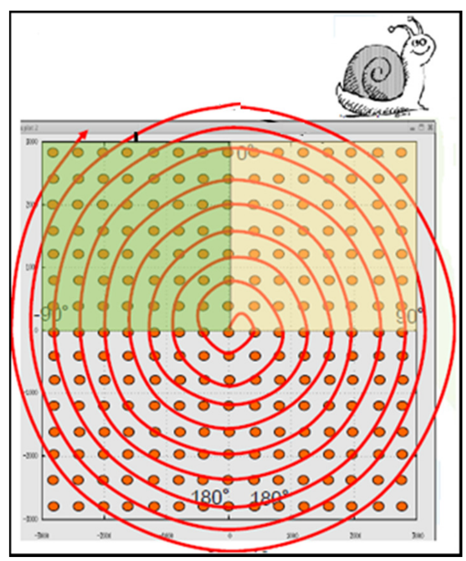

Fig-18 Snail plot representation (Source: CGG University training material).

After the azimuthal residual move-out application, the event is flattened and can be stacked successfully. The CMP illustrated in Fig-19 is one where azimuthal anisotropy is present. The traces in the gathers have been ordered as snail gather. The effect of azimuthal velocity variation is not noticeable at near offsets but it is very pronounced at larger offsets. This prevents us from obtaining a constructive stack image from different azimuths.

For azimuthal velocity corrections, CDP gathers were divided into separate 8 azimuth sectors. High Density Velocity and Anisotropy Picking were carried out on these common azimuth sectors.

Moveouts due to velocity (v) & anisotropy (η) fields were picked for each azimuth sector of a bin & corrections were applied. Fig-20 shows azimuth sectors corresponding to a single CDP.

Fig-21 shows the representation of a seismic event in snail gather earlier shown in Fig-19, after azimuthal residual move-out correction. Zoomed version of selected portion of snail gather before and after azimuthal moveout correction is shown in Fig-22.

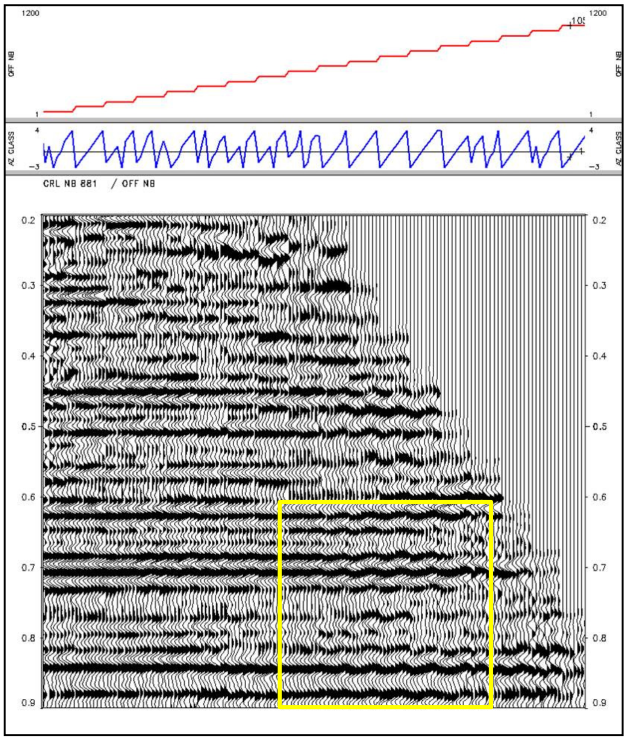

Fig-19 Snail gather with offset and azimuth headers overlaid above: obvious azimuthal residual moveout can be observed.

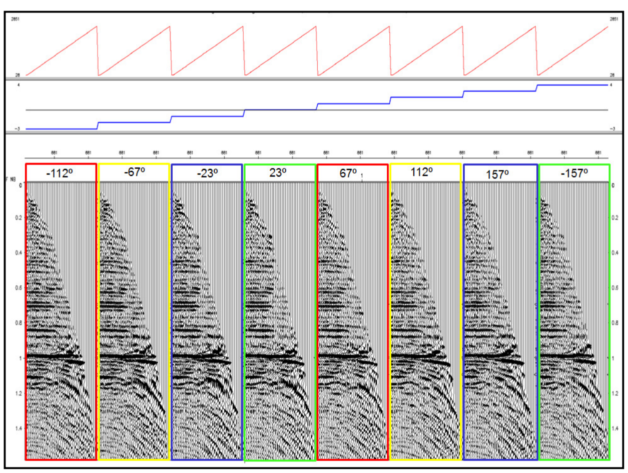

Fig-20 Single CDP divided into 8 common azimuth sectors with increasing offsets. Complimentary azimuths are shown with same color boxes.

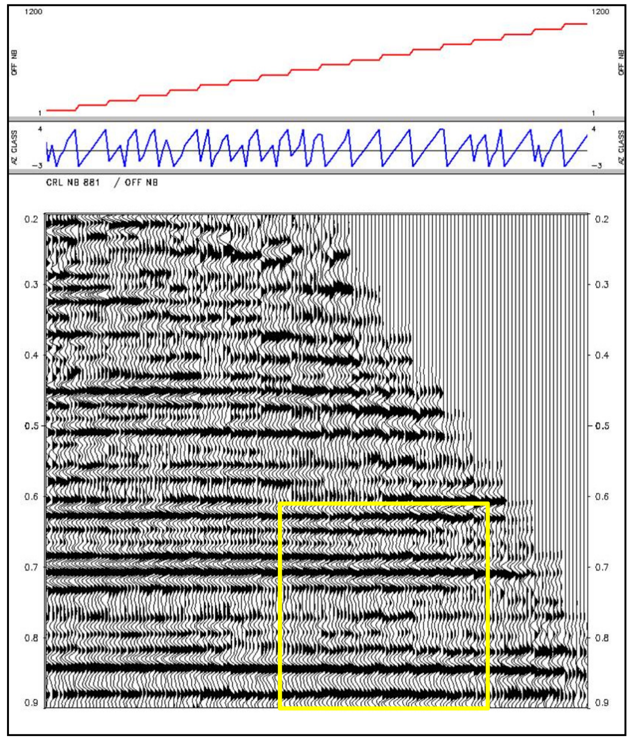

Fig-21 Snail gather after azimuthal residual moveout correction corresponding to Fig-19.

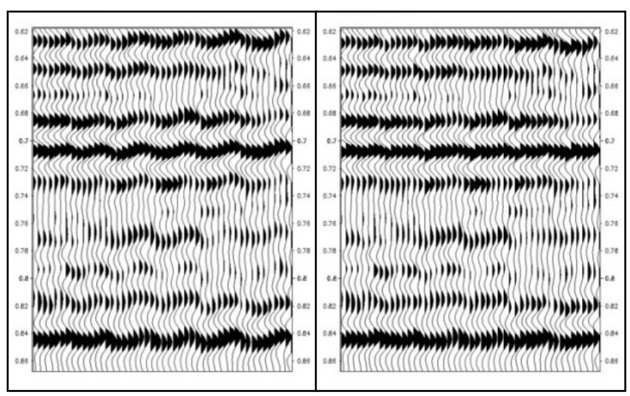

Fig-22 Zoomed version showing portion of snail gather before and after azimuthal moveout correction.

Results and Analysis

Gathers at several locations were analyzed for V_{fast} and V_{slow}. It was found that the direction for V_{fast} is 145° while for the V_{slow} is 235° which is perpendicular to the V_{fast} direction (Fig-23 and Fig-24). Improvements in the event continuity were noticed after azimuthal velocity corrections which are displayed in stack section (Fig-25 and 26). Zoomed portions corresponding to boxes A and B are shown in Fig-27 and 28 respectively.

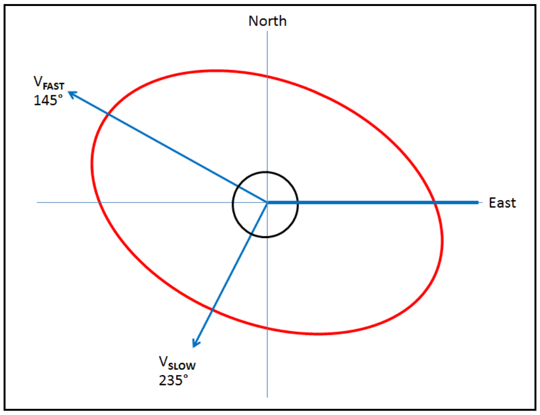

Fig-23 Observed Fast and Slow velocity directions.

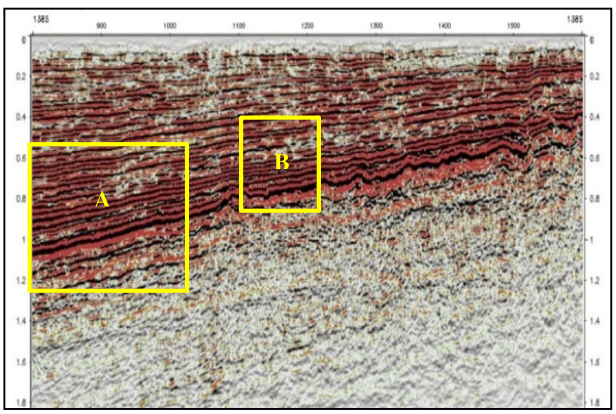

Fig-24 PSTM stack before azimuthal moveout corrections.

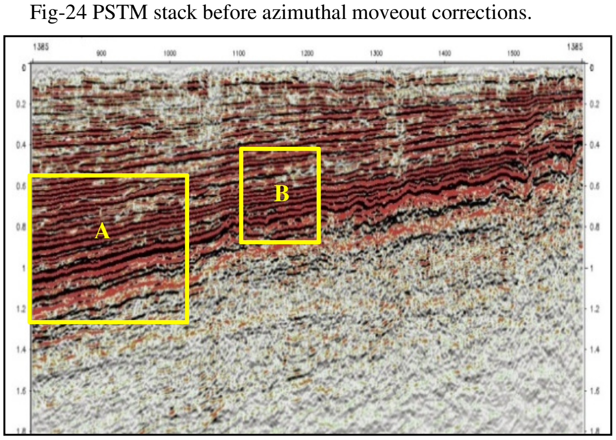

Fig-25 PSTM stack after azimuthal moveout corrections.

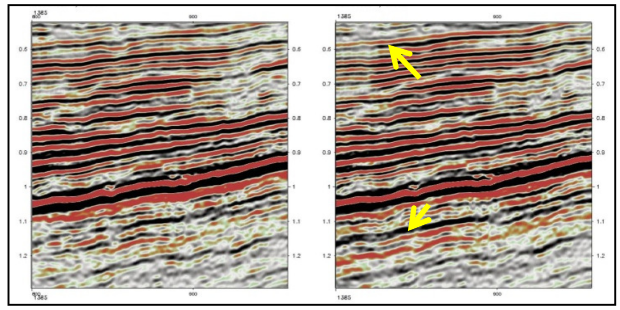

Fig-26 Zoomed version of portion A (in yellow box) shows improvements in event continuity.

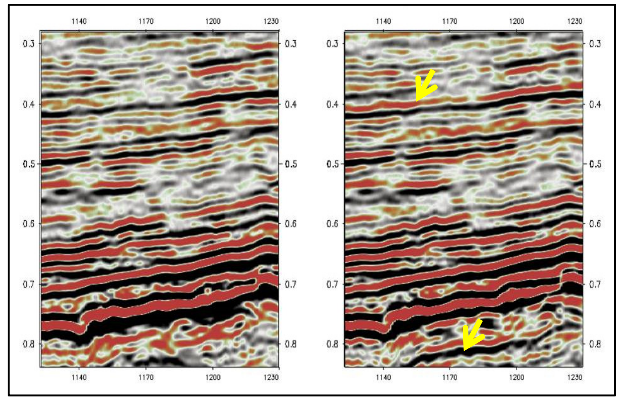

Fig-27 Zoomed version of portion B (in yellow box) shows improvements in event continuity.

Conclusions

Wide azimuth processing workflow includes standard signal conditioning in Cross-spread domain, 5D regularization followed by data segregation into OVTs, Migration in OVT domain and Azimuthal velocity corrections. Improvement in event continuity particularly, at shallower levels was observed as a result of 5D regularization. Due to regularized offsets and azimuths Improvements after migration were observed. After Migration, azimuthal velocity corrections also showed improvements in event continuity as well as sharpening of events. Overall, significant improvement in the output is observed by adopting wide azimuth data processing flow over conventional processing work flow.

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Acknowledgements

Authors convey sincere thanks to Director (E), ONGC, for permitting the publication of this study. Authors express sincere thanks to Shri Anil Sood, Ex-ED-HOI-GEOPIC & respected Shri Ashutosh Bhardwaj, ED-HOI, GEOPIC for his support and providing infra structural facilities to carry out this work and Shri T R Murlimohan, GGM (GP), for technical guidance & encouragement and support.

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