Creation of PSTM 3D volume from 2D seismic lines, A case study from Western Offshore Basin, India

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Abstract

This paper presents a pioneering attempt to generate a seismic three-dimensional(3D) volume by performing pre-stack processing on a close grid two-dimensional (2D) seismic data of the Ratna Area, Western Offshore Basin, India. The technique offers a more comprehensive understanding of the subsurface compared to earlier conventional 2D, enabling improved characterization and interpretation of geological features. The findings underscore the significance of converting close grid 2D to 3D by conducting pre-stack processing as an effective tool to enhance imaging capabilities for detailed subsurface analysis, with the potential to provide valuable insights for hydrocarbon exploration and geological mapping.

Introduction

In this study, re-processing was conducted on a 4400 line kilometer (LKM) 2D lines of the Ratna area of the Western Offshore Basin near Mumbai, India. On the northern side of the current study, a 3D volume is available which was acquired in a Broadband sense. (Fig.1) Ultimately, the current processed 3D volume generated from 2D lines was merged with the mentioned 3D volume in the north.

The objective of the current study was to create a 3D volume for structural mapping at different stratigraphic levels.

The dataset comprised 136 2D lines, with 98 lines having an azimuth of 65° and a line spacing of 500m, and 38 orthogonal lines with an azimuth of 155° and a line spacing of 1000m. The processing grid (25mx50m) was designed to align the former lines in the In-line direction and the latter lines in the Cross-line direction.

The pre-stack re-processing involved complex steps such as data conditioning, noise reduction, 4D regularization, velocity analysis, migration, post-migration conditioning, post-stack conditioning, and merging the newly processed data (in the south) with earlier processed 3D volume (in the north).

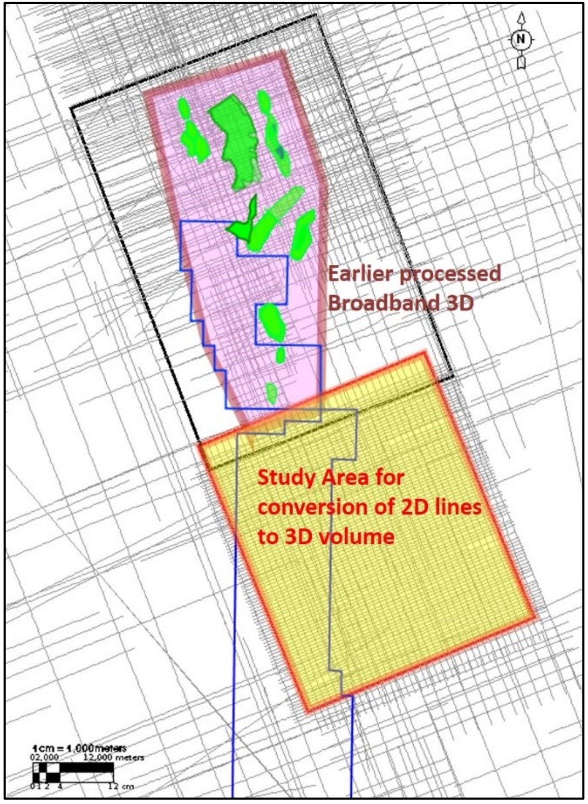

Fig. 1 Map illustrating the study region for the transformation of 2D lines into a 3D volume, along with previously processed broadband 3D data in the north of the study area.

Overall, reprocessing 2D seismic data to generate a 3D volume represents a significant advancement, providing a better understanding of the area's geological structures and potential hydrocarbon reservoirs. This valuable information enhances the value of the acquired data, benefiting oil and gas exploration and production efforts.

Data Acquisition

The acquired 2D seismic data had a streamer length of 5 km and was equipped with 200 channels, spaced at 25 m intervals. It was towed at a depth of 8 m below the sea surface.

The source configuration consisted of two sub-arrays, totaling a volume of 2000 psi, and was towed at a depth of 5m below the sea surface. The shot interval was set at 25m.

Each shot had a 6-second record length and a 2 ms sampling rate. A P1/90 file was created for each shot, containing source and receiver coordinates, cable compasses, underwater distance measurements, and tail buoy positions. Details of the acquisition parameters are summarized in Table 1.

General Parameters	
Area	Ratna
Nominal fold	100
Length	4400 LKM
Source Parameters	
Source volume	2000 psi
Shot point interval	25 m
Source depth	5 ± 1m
Source separation	25 m
Receiver parameters	
Streamer length	5000m
Streamer depth	8 ± 1m
Group interval	25 m
Record length	6000ms
Sampling interval	2 ms
Streamer Channels	200

Table 1 Seismic data acquisition parameters of the 2D survey

Methodology

The processing strategy was tailored to align with the objectives of the project. The major processing steps included loading the raw seismic SEG-D data, merging the geometries, attenuating random and linear noise, applying zero-phase filters, de-ghosting, removing multiples (such as water layer and surface-related multiples), performing 4D regularization, conducting PSTM velocity analysis, pre-stack time migration, post-migration conditioning, post-stack processing and merging the newly processed data with earlier processed 3D volume.

Throughout the process, all parameters of various processing modules were carefully examined and tested to determine the optimal values for the entire dataset. Quality checks (QCs) were conducted after each processing step to ensure the reliability and quality of the results.

Fig. 2 illustrates the steps involved in the processing:

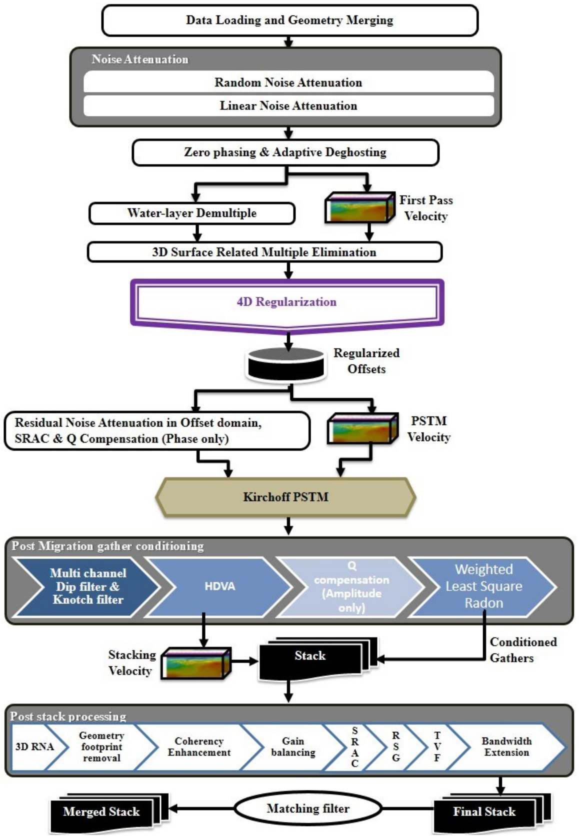

Fig. 2 Flowchart showing the sequence of seismic data processing steps carried out as part of the project.

A detailed description of individual processing steps is provided below:

1. *Data Loading and Geometry Merging*

The raw seismic data from 136 2D lines was integrated with their respective geometry files, yielding merged navigation data for the lines.

2. *Denoise(Random and Linear Noise Attenuation)*

- Random Noise Attenuation

Noise characterized by anomalous amplitude such as marine swell, rig, or ship noise was removed from pre-stack seismic data. Amplitudes were attenuated or boosted effectively to improve data quality by mitigating unwanted noise sources.

- Linear Noise Attenuation

Linear noise trends, such as direct arrivals, guided waves, side-scattered energy, and other linear noise components in shot gathers were reduced using linear Radon transformation. This changed the data from the t-x domain to the tau-p domain, creating a linear noise model based on minimum and maximum move-outs. This model was subtracted from the data to eliminate linear noise.

3. *Zero phasing and Adaptive Deghosting*

The conventional acquisition of marine seismic data is susceptible to the presence of ghosts, which are generated at both the source and receiver sides, thereby limiting the bandwidth of the recorded data.[1] To overcome this limitation, an Adaptive Deghosting technique was employed to remove the ghost events simultaneously from both the source and receiver sides.

4. *Water-Layer Demultiple*

The Water-layer demultiple technique is employed to mitigate water-layer multiples, particularly suitable for shallow water regions with high water bottom reflectivity.[2] The water bottom in this area varies between 40 and 90 meters which necessitated the application of this technique. It consisted of three steps. First, near offset extrapolation was performed to predict multiples at the nearest recorded offsets. Subsequently, a water layer multiple model was prepared. Finally, the generated multiple model was adaptively subtracted from the input seismic data.

5. *First Pass Velocity Analysis*

Velocity picking was conducted on regularly spaced gathers, with a 1km x 1km interval along the direction of 2D lines. The process maintained the structural trends observed in the data and a velocity volume was generated from the picks.

6. *3D Surface Related Multiple Elimination (SRME)*

Surface-related multiples include all multiples except those generated by totally internal reflections. They are typically the strongest multiple events present in the seismic data and therefore need to be removed from pre-stack gathers before any further imaging process.[3] This elimination was achieved through a 3-step process: initial pre-conditioning, involving the integration of velocity functions into seismic trace headers; followed by the generation of a surface multiple model; and ultimately, the successful removal of undesired surface multiples via adaptive subtraction from the input seismic data using an adaptive filter.

7. *4D Regularization*

The Common Mid-Point (CMP) gathers were divided into 100 offset classes ranging from 150 m to 5100 m, with a 50 m interval. 4D Regularization was applied, which encompassed In-line, Cross-line, Time, and Offset as the four dimensions. It is an interpolation method that aims to interpolate and regularize spatially irregularly sampled data while supporting anti-aliasing or beyond-aliasing interpolation.[4] Applying this technique facilitated the conversion of 2D lines into a comprehensive 3D seismic volume, resulting in an output grid with dimensions of 25 meters by 50 meters.

8. *Residual Noise Attenuation in Offset domain, SRAC & Q Compensation (Phase only*)

- Residual anomalous noise was encountered and attenuated in the offset domain.
- Spatial Relative Amplitude Conditioning (SRAC) addressed variable amplitudes by applying an automatic gain function and calculating a scalar relative to the original amplitudes, which was then adjusted in both in-line and cross-line directions before application to the data.
- Furthermore, to account for the earth's Q-filter, phase-only constant Q-value compensation was performed before migration.

9. *PSTM Velocity on Target Lines(1km X 1 km)*

Regularized data in 3D mode for each offset range was migrated, taking output at velocity lines that were 1 km apart. The outputs for all offsets were sorted to the CMP domain. These PSTM gathers were used as input for migration velocity analysis is at 1km x 1km intervals.

10. *Pre-Stack Time Migration (Kirchhoff)*

This process played a crucial role in accurately depicting subsurface structures in time. Kirchhoff's integral imaging technique was employed for the pre-stack time migration, utilizing a smoothed RMS velocity volume derived from velocities picked on the target line.

11. *Post-migration gather conditioning*

Several techniques were employed: The Multichannel Dip Filter separated dipping events in seismic data, allowing unwanted dips to be attenuated while preserving desired ones. The F-k filtering method effectively removed linear noise with low velocity. The K-notch filter targeted spectral peak locations to reduce specific frequency components' influence. High-Density Velocity Analysis (HDVA) determined the stacking velocity model at each CMP location(Fig. 3). Q Compensation applied time-variant amplitude compensation using a frequency-constant Q model. Weighted Least-Square Radon Technique utilized high-resolution radon transformation to model and eliminate residual multiples from the data.(Fig. 4)

12. *Post-stack processing*

Various Post-stack techniques were employed to improve the seismic data quality. 3D Random Noise Attenuation (RNA) reduced random noise, enhancing coherent event continuity and suppressing non-linear noise. Geometry footprints were effectively eliminated using 3D F-K filtering. Coherency Enhancement with 3D F-K filtering removed incoherent seismic signals while preserving coherent ones. Automatic Gain Control (AGC) achieved gain balancing, and Spatially Related Amplitude Conditioning (SRAC) addressed amplitude variability within the stack. The Reflection Strength AGC function balanced seismic trace amplitudes. Time-variant filtering (TVF) applied zero-phase convolution filter operators to account for signal characteristic variations over different reflection times. Lastly, Bandwidth Extension used spectrally-constrained zero-phase deconvolution to restore attenuated higher frequencies from the de-ghosting process.

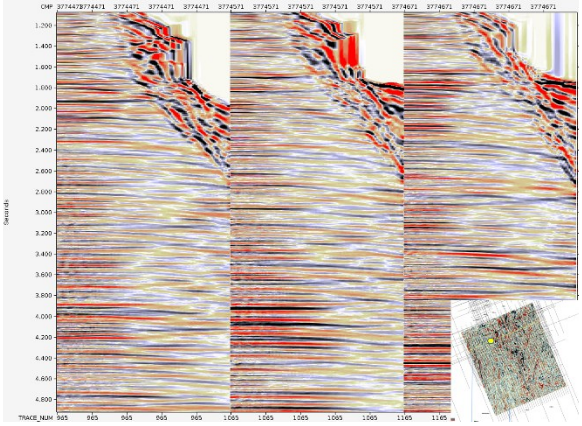

Fig. 4 Image showing pre-stack gathers subsequent to the implementation of post-migration gather conditioning techniques.

13. *Merging of the current stack with earlier processed Ratna 3D stack*

The current 2D to 3D converted seismic stack was merged with earlier processed broadband 3D stack in the north of the current volume. The current data was re-grid to the grid of the 3D stack and a common area was identified where the matching filter was designed for merging the 2 volumes seamlessly. A quality control process was conducted to assess the reliability and coherence of the merged dataset. This involved visually inspecting the merged seismic volume and time slices at different stratigraphic levels.
(Fig. 5 and Fig. 6).

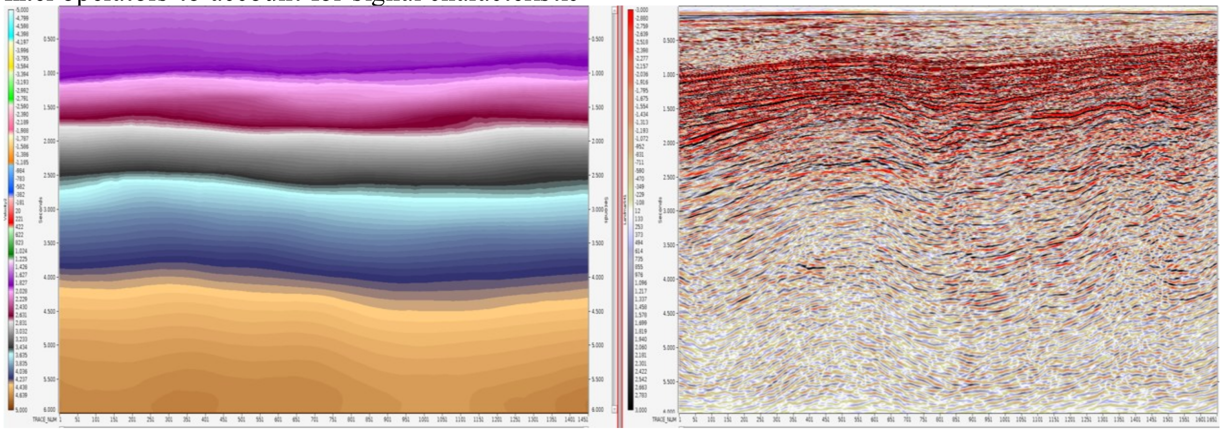

Fig. 3 Image validating the final stacking velocity with a cross-section of 3D seismic volume at the same geographical location

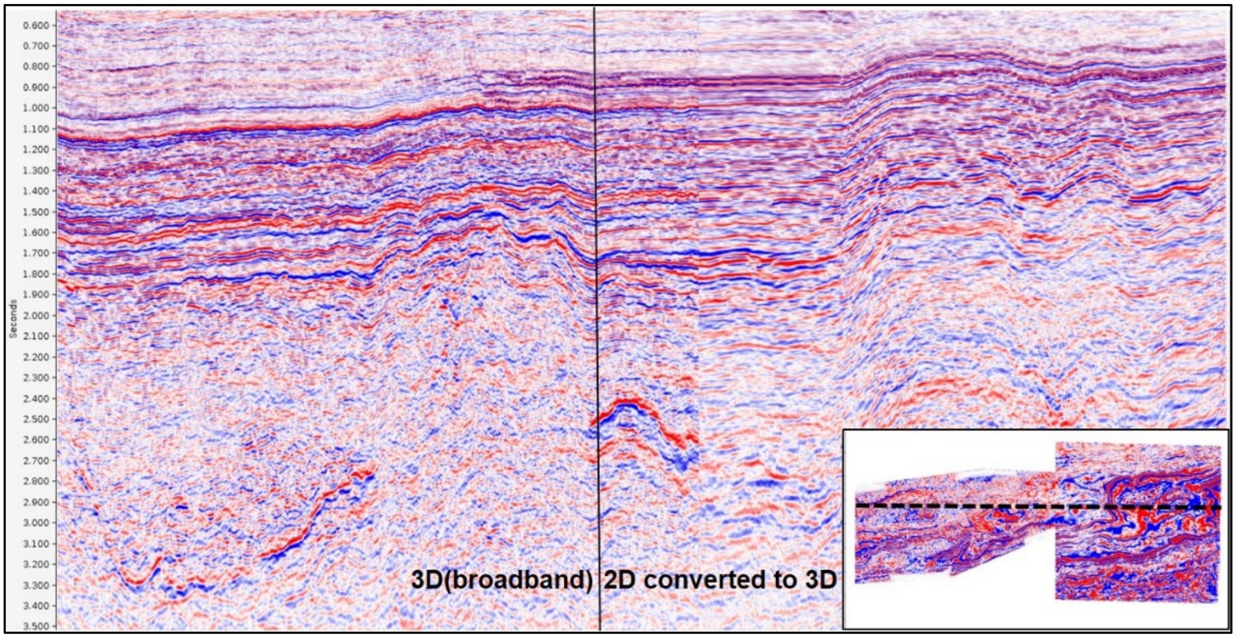

Fig. 5 A seismic cross-sectional view depicting an arbitrary line as it cuts through the unified volume containing both previously processed broadband 3D data and recently converted 2D lines transformed into a 3D volume.

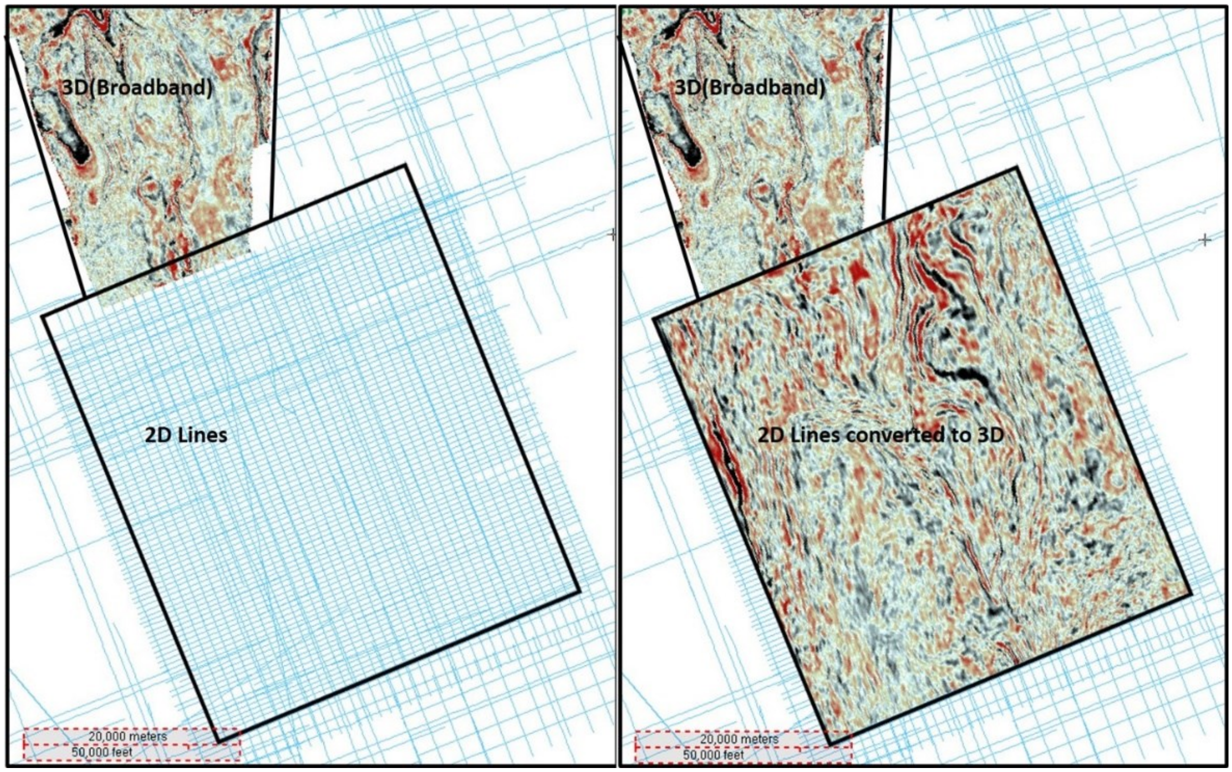

Fig. 6 Map showing 3D(broadband) data in the north and, before and after images of 2D lines and Time slice after converting 2D to 3D.

Conclusions

The project imposed several challenges during its execution. Strong water and surface-related multiple energies were masking primary events. To overcome these, advanced demultiple techniques were employed, effectively attenuating the water layer and surface-related multiples while preserving the primary reflections. Additionally, advanced processing techniques such as Adaptive Deghosting and Bandwidth extension were employed to enhance the quality of the data.

The utilization of 4D Regularization played a crucial role in filling major data gaps, interpolating the data, and converting 2D seismic lines into a coherent 3D seismic volume. In the processing workflow, regularization and 3D velocity analysis posed notable challenges, demanding expertise and meticulous attention to detail.

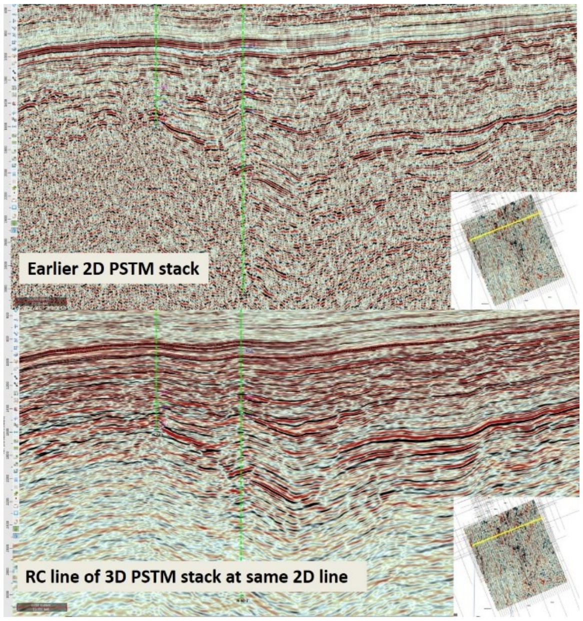

Fig. 7 Image comparing a 2D line and RC line of 2D converted to 3D PSTM stack, both at the same geographic location.

Furthermore, the reprocessed South Ratna 2D data was successfully merged with the Ratna 3D volume in the north, resulting in extension observations at different stratigraphic levels. The optimization of conventional intermediate processes, along with post-migration gather conditioning and post-stack processing, significantly improved the resolution and continuity of different stratigraphic sequences.

The generation of a 3D seismic volume from a close grid 2D data provided a more detailed understanding of the structural framework, benefiting from the higher spatial sampling and improved imaging and interpretation of subsurface features, faults, and horizons (Fig. 7). The final volume met the desired requirements and delivered a remarkable quality output, thus enhancing the understanding of the subsurface and supporting decision-making processes in hydrocarbon exploration, reservoir characterization, geological mapping, and regional studies.

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