8th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2010"

P-119

Prestack Depth Migration - An ultimate aspiration for subsurface imaging in geologically complex area.

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Summary

Over the last decade, it is predominantly perceived that there have been significant evolutions in Prestack depth imaging — consisting of both velocity/depth model building and prestack depth migration (PSDM). This evolution initially began in structurally complex areas and the problems with incorrect geologic models and associated velocity fields in precise sub-surface imaging. Growth in the application of depth imaging has been most welldefined in the recent years and the advances in velocity model building and migration have produced significant gains in image quality.

Prestack depth migration (PSDM) is the most theoretically accurate seismic processing technique for representing the subsurface today. PSDM naturally handles multi-arrivals and can, therefore, produce higher quality images in areas of complex geology. Building of the geologic model and the associated velocity fields is the most critical step in PSDM processing. In addition, the effect of anisotropy, commonly encountered in petroleum exploration, affects image focusing and positioning. Therefore incorporating anisotropy in PSDM will produce more accurate subsurface images.

This present study deals with t he advantages of PSDM over time migration are better focusing and positioning of reflectors to resolve complex structures, fault shadows, pull-ups, and sags caused by variations in lateral and/or vertical velocities. The success of PSDM processing, assuming reasonable data quality, considering the enhancements of the accuracy and value of the processed output have encouraged oil companies to expand their use of depth imaging both geographically and geologically.

Introduction

Depth imaging is now being applied around the world to remove obscuring effects produced by a diverse range of geologic and geophysical conditions both in onshore and offshore. Recent case studies illustrate that thrusts, normal faults, salt, reefs, low signal-to-noise ratio, gas clouds, slump zones, shale, and basalt can all result in velocity complexity and imaging challenges that only prestack depth imaging can address effectively.

In recent times, prestack depth migration is increasingly becoming the rule rather than the exception when the goal is to more clearly reveal a subsurface complicacy by structure or velocity and to provide superior subsurface imaging. Due to the subsurface intricacy, interpretation remains ambiguous, even when using the recent time data. The geologic and geophysical complexities of this area present many challenges to develop an accurate image and understanding of the region.

In this present study, t he 3D prospect pertaining to Kuthalam Phase- V area of Cauvery Basin was taken up for prestack depth migration to enhance the accuracy in structural imaging for identification of accurate fault descriptions and to bring out meticulously the wedge out prospects against raising flanks of basement. This PSDM project was carried out in particular in need of further precise delineation of meticulous strati-structural prospects to assess the hydrocarbon potential in Kuthalam area.

This paper deals with how the PSDM data can be effective for further precise delineation of wedge-out and pinch-out features and can be used to improve the critical subsurface

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imaging to meet the exploration objectives which were much more difficult to decipher using time data.

Geological Background of the study area

The envisaged area under study falls to the south west of Kuthalam field of the PEL Block of L-1 area in Tranquebar sub basin, bounded by Kumbakonam ridge in the north and TD-SPUR to the south. The area had been dissected by a number of NE- SW & ENW-WSW trending basement controlled normal faults (first order) which are affected by a few NW-SE & NNW-SSE trending transverse faults (second order) which are acting as conduits for migration. The basement tectonics played a major role in bringing out and shaping the present structural configuration especially in Andimadam formation.

The sedimentological studies have shown that sandstone layers within Andimadam formation were deposited as slumps/debris flows in a fairly deep water regime. These sediments were deposited due to slumping along the meta-stable slope which might have been induced by the basement tectonics. Shales within Andimadam formation are the effective source rocks and have the proclivity to generate both liquid and gaseous hydrocarbon. Basement controlled faults are thought to be the main conduits for migration of hydrocarbon. The Index map of the area under study i.e., Kuthalam – Phase V area alongwith other 3D campaigns is shown in Figure-1.

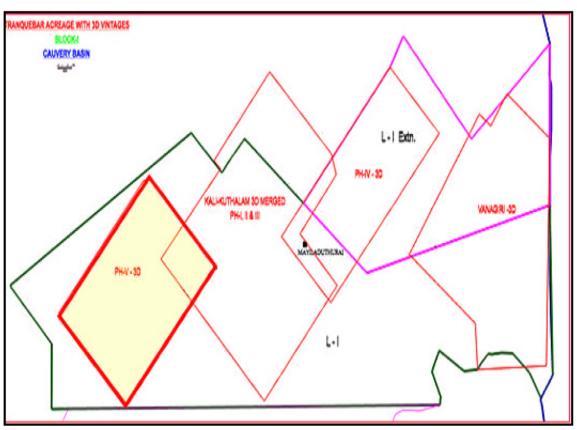


Figure-1: Index map showing Kuthalam – Phase V area (in yellow portion) with other 3D campaigns.

The shales within Andimadam Formation in the basinal part over the Kuthalam area are the main source facies with sufficient thermal maturity to generate gaseous and liquid hydrocarbon. Basement controlled faults are thought to be the main conduits for migration of hydrocarbon.

The area is crisscrossed by faults originating from basement. Structural, Strati-structural prospects against the Basement are the main entrapments. Shales within upper Andimadam formation as well as the overlaying Sattapadi shales in Lower Cretaceous also may act as Cap rock. A sand body pinching-out within the shales has been mapped in the Upper Nannilam sands within the Nannilam formation where the shales will act as cap in this present study area.

Sandstones within Andimadam and Bhubanagiri formation are the well established reservoirs. Nannilam sands are thick and posses very good reservoir characteristics which is indicative of good petrophysical bearings but not yielded results.

Sandstone reservoirs within Andimadam formation are the hydrocarbon producers in Kuthalam area, therefore the Andimadam formation becomes the primary exploration target and the Bhuvanagiri formation is the secondary target. Nannilam formation in Upper Cretaceous is also a target which has emerged as a new play for exploration but no encouraging results except some indications. Hence to know the hydrocarbon potential of Andimadam, Bhuvanagiri and Nannilam formations and to identify the areas of better entrapment conditions to the south west of Kuthalam Field, the processed PSDM data and the available well data alongwith the geological model are the quest of the detailed interpretation.

Details of the wells drilled in the area

There are several wells drilled within the proposed 3D survey area. Wells # W-1, W-2, W-3, W-4, W-5, W-6 & W-7 fall within the projected surface area for the survey. The study area falls to the south west of Kuthalam field in the Tranquebar in the PEL block of L-1. Initially all wells were drilled on structural closures. The structural map close to top of Andimadam formation showing all the wells in the Kuthalam Phase-V area is shown in Figure-2 below.

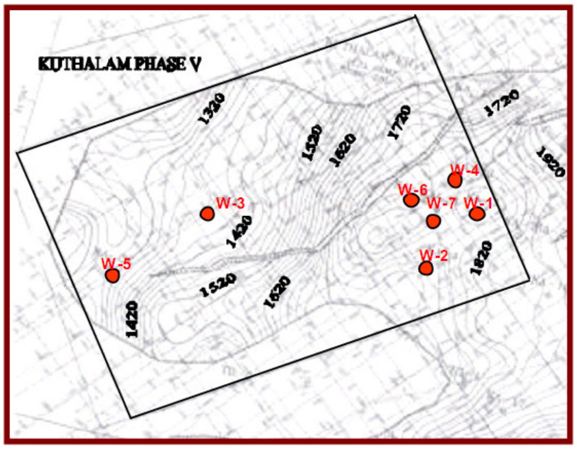


Figure-2: Structural map close to top of Andimadam showing all the wells in the area.

The well W-4 was released to test a structural prospect which was turned out as wedge-out prospect after drilling/interpretation of processed seismic data and found to be hydrocarbon bearing for the first time. The well W-6 was also drilled as wedge-out prospect and was hydrocarbon bearing.

With the same analogy the study was carried out to locate stratigraphic features on the flanks of the basinal highs all along the Kumbakonam-Madanam Ridge. In this area to the south-west of W-6 in particular only two wells i.e., W-3 & W-5 were drilled as structural prospects on the basis of 2D-seismic data coupled with drilled well data were proved to be dry. Keeping in view the above perspective, pre-stack depth migrated 3D data is to be utilized to assess the hydrocarbon potential of the wedge-out and pinch-out features all along the flanks of the Kumbakonam, Ridge and TD spur.

Theory and Methodology

The PSDM method is more demanding of the data requirements than conventional time techniques to deliver the degree of velocity model accuracy required for optimal spatial positioning of target reflectors. However, the ability to define a precise interval velocity model and economically perform pre-stack imaging in depth domain provides the opportunity to more fully exploit the critical subsurface imaging.

For accurate Velocity Estimation & refinement of Subsurface Imaging, an economic & feasible Kirchhoff pre-stack depth migration and velocity model-building solution was selected. It was endeavored to obtain the true interval velocity model in depth under given data and time constraints.

Initially, RMS velocities were obtained using horizon velocity analyses on PSTM gathers. These RMS velocities were good enough to build initial interval velocity model extracted along the horizon maps picked up in the time migrated domain (shown in Figure-3) and a total of ten horizons were used for initial velocity modeling. The various horizons used for interval velocity modeling and the corresponding initial interval velocity model is shown in Figure-4.

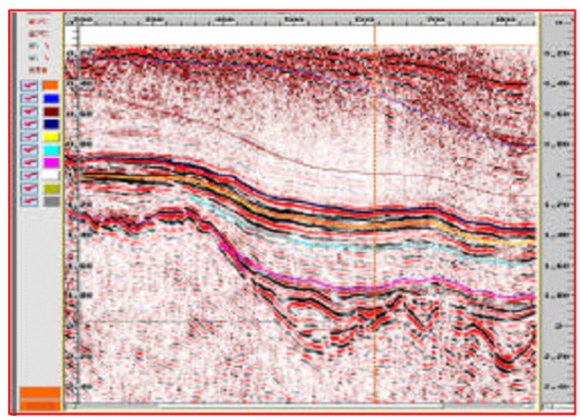


Figure-3: Various horizons used for interval velocity modeling.

An iterative process was adopted to progressively establish the upper layer velocities and horizon positions before moving deeper to define the next series of formations. The initial velocity model would be high- graded using Kirchhoff PSDM image gather and residual curvature (velocity) estimates from semblance analysis for subsequent and deeper iterations.

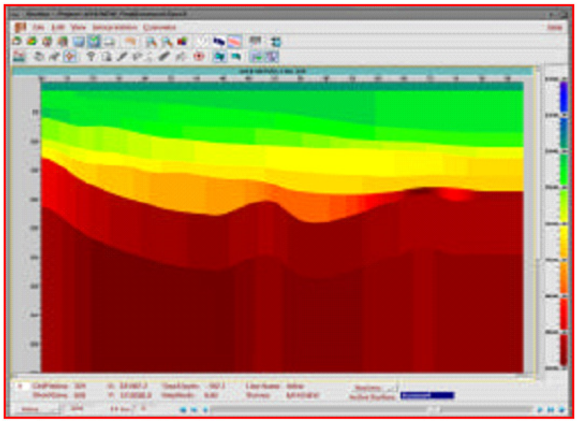


Figure-4: Initial Interval Velocity Model using the horizons.

The corresponding T-Surface volume of depth model and the corresponding solid model comprising various horizons alongwith the wells used to carry out the interval velocity model building and depth migration are also shown in Figure-5 and 6.

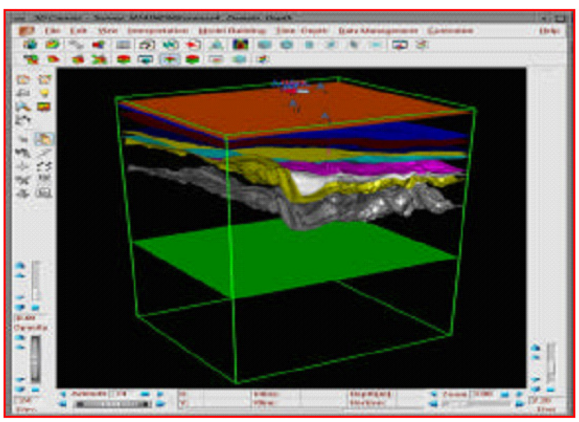


Figure-5: T-Surface Depth volume comprising various horizons and wells.

For refinement of interval velocity model through successive iterations, Target oriented depth migrations were performed at every 5th inline with all crossline range. An aperture of 8 km was selected after testing a number of different values ranging from 4 km to 10 km. The offset weights calculated earlier for Pre Stack Time Migration were used during Target oriented depth migration.

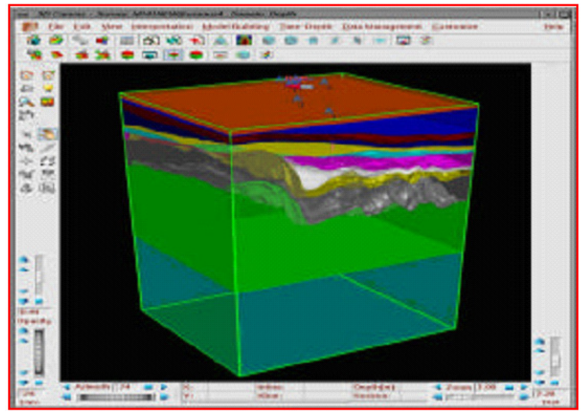


Figure-6: Solid Depth Model comprising various horizons and wells.

Tomography is an imaging technique that attempts to correct errors in the velocity depth model by analyzing the residual delays after PSDM. An important feature of tomography is that it is a global approach as compared to layer stripping. Global Tomography can attribute an error in time at one location to an error in velocity and depth at another location. These errors are solved simultaneously by making changes to the velocity and depth model across the entire volume.

Horizon based tomography was adopted here as the topology of the subsurface is well defined and the first and very important step of the velocity and structure determination has been truthfully performed. In such a situation the subsurface velocities will be geologically plausible, and hence, horizon based tomography precedes any other approach.

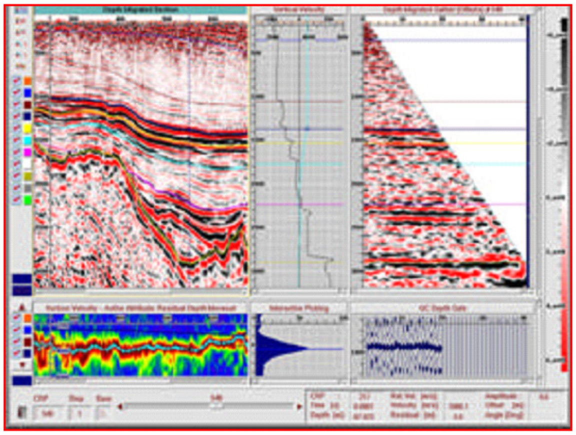


Figure-7: Residual Depth Moveout Picking along the horizons for Model Refinement.

Velocity variation in inline direction being larger, every 5th inline was used for initial PSDM and residual picking on image gathers. These residuals were used for tomographic updation of velocity model. This led to improvement in velocity estimates and resultant reduction of residuals as shown in Figure-7.

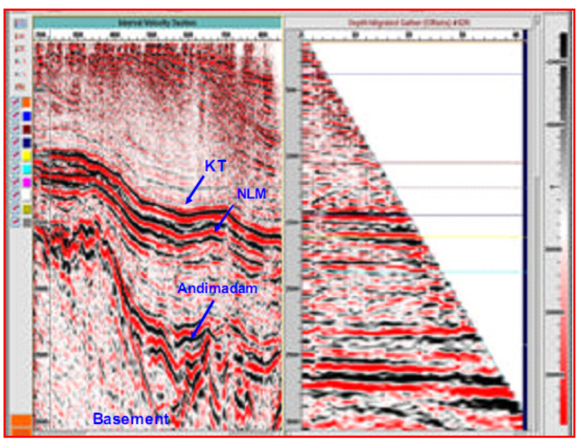


Figure-8: PSDM Section alongwith the flat PSDM Gather after Global tomography.

Subsequently 3D Global Tomography with Residual Depth Moveouts was run for updating the Depth/interval Velocity Model. After updation of the interval velocity iteratively through Global Tomography the PSDM Section alongwith the corresponding flat PSDM Gather is shown in Figure-8 and consequently the PSDM section overlaid with interval velocity after iterative updation is shown in Figure-9.

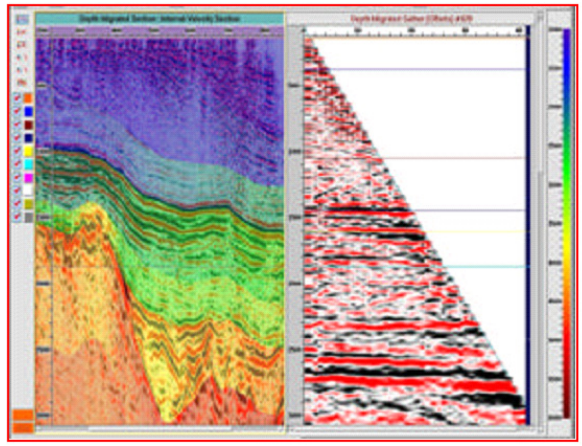


Figure-9: PSDM Section with interval velocity overlay alongwith the flat PSDM Gather after Global tomography.

Final Pre Stack Depth Migration was carried out using time processed gathers and global tomography updated final interval velocity model. The output (shown in Figure-10) was found to be optimum with the interaction with the interpreters to meet the geological objectives for accurate identification and meticulous delineation of strati-structural prospects and critical subsurface imaging.

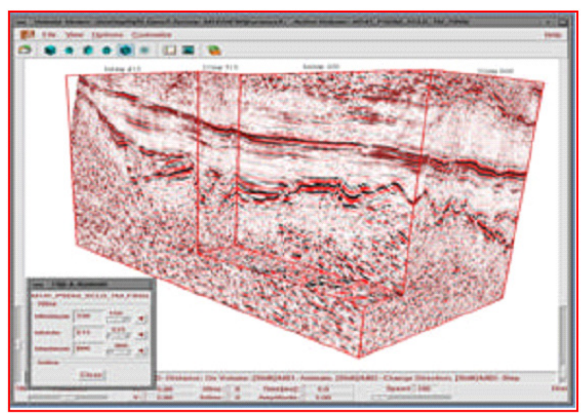


Figure-10: 3Dcube of the TM scaled Final PSDM Section.

Comparison of PSDM with PSTM Outputs

A depth imaging projects in particular starts with some sound justification of subsurface complexity that cannot be revealed adequately with time domain processing. Successful execution of PSDM projects with accurate determination of interval velocity in subsurface gives a critical and striking concept of subsurface understandings. In this present study, the processed PSDM 3D outputs of Kuthalam area Phase- V is definitely presumed to give a lot of crucial and decisive information to the interpreter's desk for better subsurface imaging.

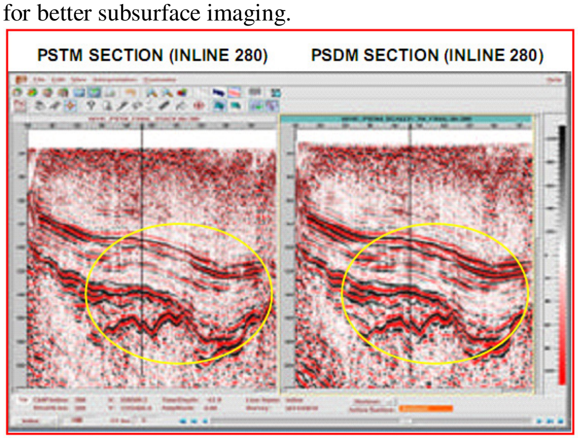


Figure-11: Comparison of PSTM section with TM scaled PSDM Section (Inline 280).

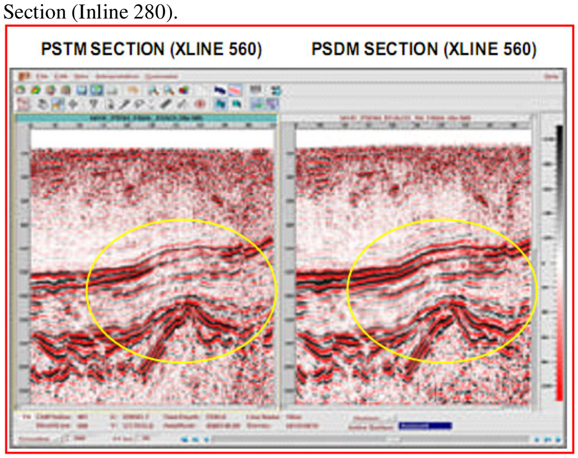


Figure-12: Comparison of PSTM section with TM scaled PSDM Section (Crossline 560).

Few follow-up comparisons of PSDM with PSTM outputs (shown in Figure-11 to 13) clearly reveal that subsurface imaging on PSDM (scaled to time) Stack Volume as compared to PSTM Stack Volume shows improvement in fault definitions, further precise delineation of wedge-out and pinch-out features and for the generation of meticulous strati-structural prospects to assess the hydrocarbon potential in the envisaged Kuthalam Phase- V area.

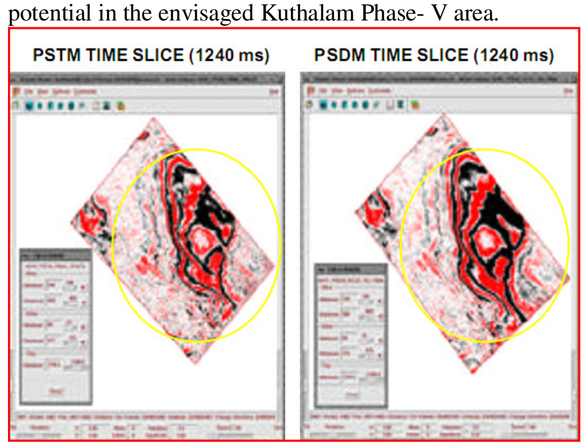


Figure-13: Comparison of Time Slice 1240ms of PSTM with TM scaled PSDM volumes.

A representative RC line passing through wells is shown in Figure-14 showing the meticulous imaging of the stratistructural prospects with clear-cut fault descriptions. And the plausible structural maps close to Bhuvanagiri formation top (G-1) & close to Andimadam formation top (G-2) are shown in Figure-15(a) & 15(b) in interpreted PSDM volume.

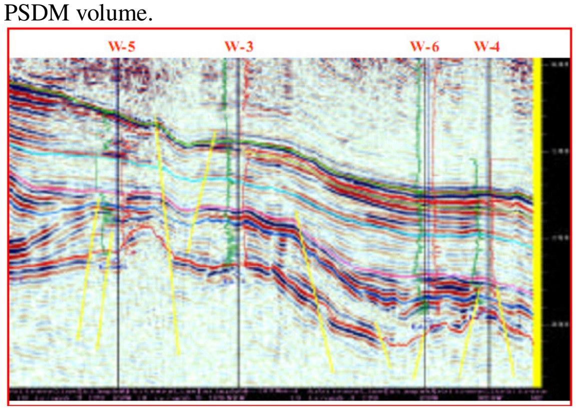
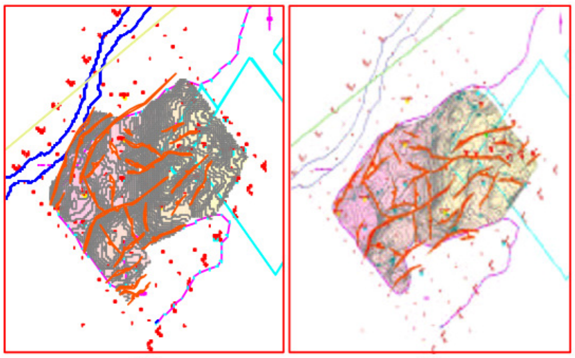


Figure-14: RC line passing through W-5, W-3, W-6 and W-4 wells in PSDM volume.



(a) (b)

Figure-15: (a) Structure map close to Bhuvanagiri formation top (G-1); (b) Structure map close to Andimadam formation top (G-2).

Conclusions

To begin with, Pre-Stack Time migration was done in Kuthalam Phase-V area of Cauvery Basin to explore the wedge / pinch out prospects of Andimadam & Bhuvanagiri formation. Later as per the interpreter's further requirement, Pre Stack Depth Migration was carried out to enhaunce the delineation in structural imaging for detailed study in subsurface imaging and also to help in precise delineation of subsurface complexity for identification of accurate fault descriptions.

Significant improvement in depth imaging for this project in particular as per the interpreter's literal need for the critical subsurface delineation. Pre-stacked Depth Migrated (PSDM) seismic data has meticulously imaged the the wedge out / pinch out prospects in Nanilam formation and the strati-structural prosp ects in Andimadam formation against the raising flanks of basement and also brought out the explicit fault descriptions in the PSDM domain comparing the time migrated data.

The Pre-Stack Depth Migration (PSDM) method is the most reliable method for subsurface imaging in geologically complex area and also providing a significant exploration advantage rather than time migrated outputs in areas with lateral velocity variations. Even though there are large computational costs but this will be undeniably counterbalanced by the minimizing the exploration risk. Prestack depth migration should be the ultimate goal of seismic processing and in the near future it is believed that, essentially all seismic data will be on depth, with time sections merely a preliminary output of the entire process of prestack depth migration.

Acknowledgements

The authors express their deep sense of gratitude to Oil & Natural Gas Corporation Limited to provide technical & infrastructural facilities to carry out the above work.

The authors sincerely thank to Shri J. S. Sekhon, GGMBM, Cauvery Basin and Shri G. Sarvesam, GGM -HGS for their motivated guidance, expertise interaction and constant encouragement to carry out this work and permitting to publish the same.

The authors also express their gratitude to Shri Chaman Singh, GM (GP) and Shri B. S. N. Murthy , GM (GP) & Head RCC for their active guidance, proficient interaction and valuable suggestions during this work.

Last but not the least, the authors are immensely thankful to Shri T. N. Rao, DGM(S) and Shri K. Jutshi, SG(S) for providing necessary petrophysical and geological information for the entire work.

Views expressed in this paper are that of author(s) only and may not necessarily be of ONGC.

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