

PSDM through Tomography driven Interval Velocity Model building for Precise Delineation of Miocene to lower Paleocene and Synrift sequences in Cambay Basin

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Keywords

3D Global Tomography; Structural Attributes; RMO Picks; Depth Map; Mistie Map; Well Tie Tomography.

Summary

In the modern epoch, it is pragmatically conceived that Prestack depth migration (PSDM) is the paramount technique for precise subsurface imaging in the recent years and the proficiency to define a truthful interval velocity model and consequently accurate subsurface imaging of the target reflectors is a major challenge in pre-stack depth imaging.

The Cambay basin is an intra-cratonic basin, which came into existence at the close of Mesozoic period by the development of tensional faults along its margins. The area under study is in Dabka – Jambusar – Matar Phase – I area lies in "Jambusar - Broach" tectonic block of Cambay basin and is characterized by thick sedimentary section of Tertiary – Quarternary age, which is underlain by Deccan Trap. This area is surrounded by number of oil and gas fields, viz. Gandhar, Dahej, Jambusar, Pakhajan, Palej etc.

The main thrust of this work is to improve the imaging quality by PSDM through Tomography driven Interval Velocity Model building for Precise Delineation of Miocene to lower Paleocene and Synrift sequences in Dabka – Jambusar – Matar Phase – I area of Cambay Basin and hence to meet the exploration objectives which were not so evident to decipher using time migrated output.

Introduction

Exploration for Oil & Gas in the study area was started in the year 1970. Exploratory drilling has proven hydrocarbon accumulations in the Dabka field & about 60 wells (Exploratory & Development) have been drilled yet and out of these, 29 wells were found to be Hydrocarbon bearing. Since then, exploratory efforts in the area has led to the discovery of Kural, N. Kural, N. Sarbhan, Matar & Gajera fields.

The objective of the study is to bring out strati-structural prospects from Miocene to Lower Paleocene for prospectivity of Shallow horizons of Babaguru & Tarakeshwar and for synrift sequences and deeper reflectors at Olpad level. The study area (Figure-1) is adjacent to the highly prolific Gandhar oil field. The area is an extremely sand rich delta.

The PSTM output of the recent data in the study area could not delimit the desired objectives to its fullest extent as per interpreter’s requirement. That is why a great effort was taken to accomplish PSDM through tomographic refinements/updates of the interval velocity model and subsequently much better resolved seismic depth migrated volume to give the utmost accurate sub-surface definitions with greatest confidence to the exploration geoscientists.

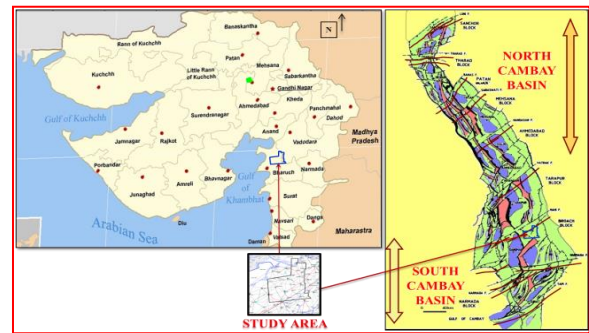


Figure-1: Tectonic map of Cambay Basin with study area.

General geology of the area

The Cambay Basin is in north western part of Indian Peninsula in the state of Gujarat and part of Rajasthan covering an area of about 59000 sq.km. The entire Cambay basin is divided in to five major tectonic blocks based on major basement faults which have been named from south to north are as Narmada-Tapti Block; Jambusar-Broach Block; Tarapur-Cambay Block; Mehsana-Ahmedabad Block and Sanchor Patan Block (Figure-2).

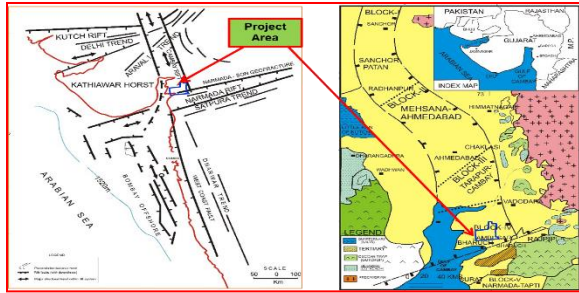


Figure-2: Structural and Tectonic Framework of project area.

The subsurface stratigraphy of the study area is shown in Figure-3. The oldest sequence, the Olpad formation, overlies the Deccan trap with an erosional unconformity. The study area lies in “Jambusar-Broach” tectonic block. Fields like Gandhar, dahej, Jambusar Nada, Pakhajan, Palej lie in this Block and are the major oil producing fields. General dip in the operational area is observed in E-W direction and NE-SW direction. Major Thickness from Hazad to Y-marker is changing from 30-170m in NE-SW trend.

Geological age	Formation	Environment	Lithology
Pliocene 5M	Broach Formation		Shale with Sand Stone, Minor silt stone
	Unconformity		
Miocene (5-25 MY)	Jhagadia	Shallow Marine	Mainly Sand with Shale
	Kand	Marine	Shale
	Babaguru	Fluvial	Mainly Sand with Shale
	Tarkeswar	Marine	Shale
Unconformity			
Oligocene to Upper Eocene (25 – 39 MY)	Dadhar	Lower Delta Plain to Delta Front	Mainly Sand with Shale
	Unconformity		
Eocene (39 – 49 MY)	Ankeshwar		
	Telva	Marine	Shale
	Ardol	Lower Delta Plain	Mainly Shale with Sand
	Kanwa		Shale
	Hazad		Mainly Sand
Unconformity			
Lower Eocene (49 – 54 MY)	Cambay Shale	Marine	Shale
Unconformity			
Paleocene (54 to 66 MY)	Olpad		Trap derivatives and Conglomerates
Unconformity			
Upper Cretaceous	Trap		Basalt

Figure-3: Subsurface Stratigraphy of the Study Area.

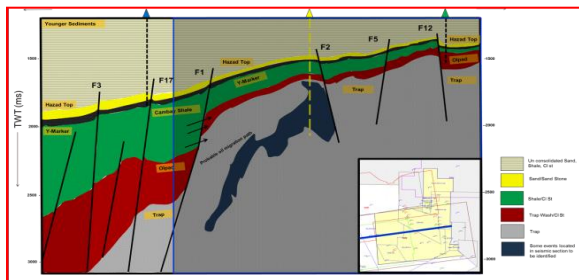


Figure-4: E-W Seismo-Geological section showing juxtaposition of OCS against Olpad & Trap.

Gandhar sands of the Hazad member are main reservoir sands in the area. These pay sands cannot be resolved seismically due to their small thickness (3-15m) at depth range of 3000m to 3600m (Figure-4).

Analysis of Processed data of earlier 3D vintages

Several 3D seismic data of earlier vintages were available in Jambusar-Broach area and the merged PSTM data of these earlier volumes (Figure-5) could not meticulously delineate the synrift sequences and the deeper reflectors in particular. The allied TWT Maps of different formations are simulated in Figure-6 congruently from the erstwhile merged volume.

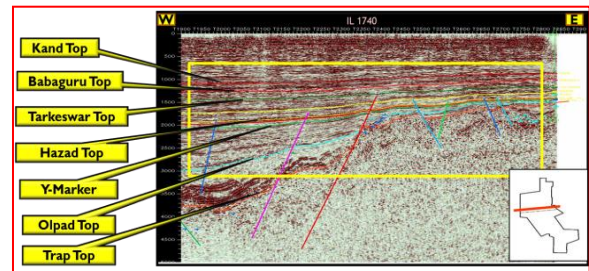


Figure-5: PSTM Stack of earlier merged data (representative Inline).

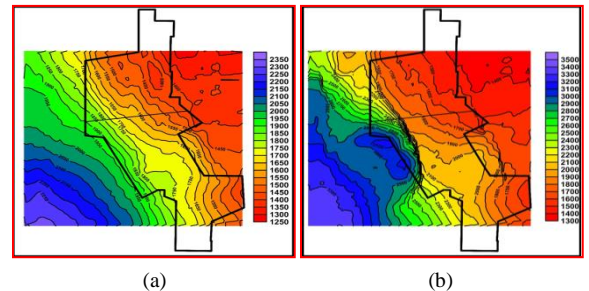


Figure-6: TWT Maps of (a) Top of Hazad; and (b) Top of Olpad.

Later, in the recent past, again 3D close-grid high-resolution seismic data was acquired in the same Dabka–Jambusar–Matar Phase–I area with enhanced high-resolution 3D acquisition geometry and modern state-of-art seismic instrument and digital sensors.

The time migrated output of this recent acquired data could fulfill the geological objective in limited extent and as per the requisite of the interpreter’s desk to improve the imaging quality further, this PSDM project was taken up through Tomography driven Interval Velocity Model building for Precise Delineation of Miocene to lower Paleocene and Synrift sequences explicitly in the study area.

Theory and Methodology adopted

In recent time, the Pre-stack Depth Migration is more widely accepted in resolving the accurate delineation of the sub-surface imaging mostly in geological critical area than conventional time migration and also to deliver the velocity model precisely required for finest spatial imaging excellence. However, the proficiency to delineate an explicit interval velocity model in depth domain bids the opportunity to achieve more enhanced subsurface imaging.

Tomography is an imaging technique for updating non-accurate interval velocity models. An important feature of tomography is that it is a global approach to correct errors in the velocity depth model by analyzing the residual delays after PSDM. The error in the velocity model is extracted from the moveouts (non-flatness) of the depth migrated gathers. The extraction of depth moveout error, which are performed prior to building the tomography matrix can be either created using a Relative Residual Velocity Volume or by Running RMO Automatic Picking. These extracted depth moveout errors are incorporated into tomography and can be utilized in Build Matrix mode and QC RMO Auto-pick mode.

Depth Interval Velocity Model Building and Refinement Using Tomography

Primarily, the initial interval velocity in depth was obtained from the RMS velocity through Constrained Velocity Inversion (CVI) technique using the horizon maps picked up in time migrated domain. For refinement of interval velocity model through successive iterations, 3D Global Tomography technique was adopted for updating the Depth/interval Velocity Model.

3D Global Tomography uses this measurement of non – flatness (residual move out) as input and attempts to find an alternative model, which will minimize the errors. Tomography can be either Model (Horizon) based tomography or Grid based tomography or a combination of both which is called Hybrid Tomography. In the model (horizon) based approach, the grid nodes are at discrete points along the horizons. In the grid based approach, all the points (samples) are grid nodes. Horizon based approaches update both the reflector geometry and the velocity simultaneously but the Grid based

approaches update velocity only. In this project, for refinement of Depth/interval Velocity Model through Tomography, the combination of both Horizon Model and Grids were adopted.

Structural Attributes are used in 3D Grid Based Tomography and this application uses a seismic stack volume as input to compute the structural attributes: Dip, Azimuth and Continuity. Structural Attributes is a new application for estimating the local orientation vector at each depth point in the form of structural dip and azimuth volumes. In addition with these volumes, a continuity volume was also produced, measuring the quality of the estimate (Figure-7).

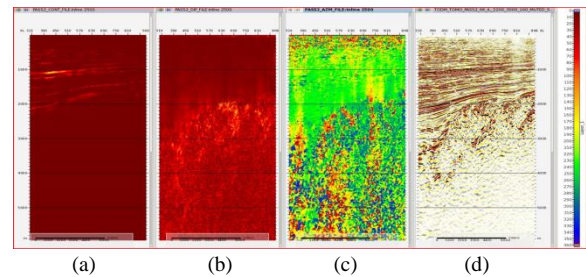


Figure-7: (a) Continuity Attributes; (b) Dip Attributes; (c) Azimuth Attributes; and (d) PSDM Section of a representative inline.

Grid Tomography requires any additional input horizon-based depth information to be transformed into discrete points that are arranged in vertical databases called Pencils. In grid tomography, the Pencils have a two-fold functionality: (i) Pencils serve as seed points for autopicking the gathers and shooting rays during tomographic matrix computation. (ii) Pencils also serve as update grid points that eventually store the tomography results.

Pencil data is a type of vertical function that carries discrete information about the structural subsurface model and its geological and geophysical attributes. Information is sampled by intersecting points of interpreted surfaces along a predefined spatial grid, and includes structural attributes such as dip, azimuth and continuity (DAC) of reflecting surfaces. The pencil data repository is a neutral and simplified format for structure and attributes data. It is the main data repository as it provides access to diverse data types in a consistent manner by simplifying the depiction of structural models and related attributes. Figure-8 replicates that Pencils extracted along the horizons overlaid with 3D seismic & available wells.

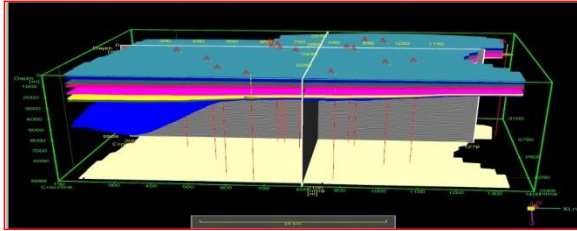


Figure-8: Pencils extracted along the Depth horizons are overlaid with seismic volume and available wells.

Consecutively for updating non-accurate interval velocity models, the error in the velocity model was extracted from the residual moveouts causing non-flatness of the depth migrated gathers. RMO automatic picking outputs were created from the non-flat depth migrated gather and written to the pencil database. Threshold masking of RMO autopicks were done to remove the erroneous RMO values prior to building and then solving the tomography matrix for continual velocity refinements.

Successive iterative processes were adopted progressively by running target line isotropic depth migrations and tomography driven Interval Velocity Model refinement unless the adequately flatness of the depth gather are achieved.

After achieving the precise interval velocity model through successive four iterations for the velocity depth refinement through tomography, final isotropic Pre Stack Depth Migration was carried out using time processed conditioned gathers and global tomography updated final interval velocity model. Figure-9 replicates the isotropic PSDM gather and PSDM Section is overlaid with Interval Velocity Volume. Figure-10 shows the comparison of Initial Interval Velocity for 1st iteration PSDM and Final Interval Velocity after welltie tomography used for PSDM.

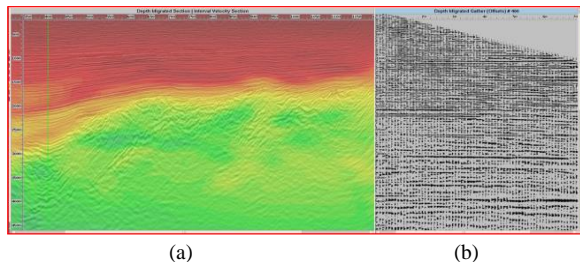


Figure-9: (a) PSDM Section of a representative line is overlaid with Interval Velocity Volume; (b) PSDM Gather (for the location shown by green vertical line in the PSDM section).

Then to remove the anisotropic effect from the isotropic PSDM gather, fourth order anisotropic Eta corrections were applied to incorporate the anisotropic effect in the far offset region on the PSDM gather. Figure-11 shows the application of Eta correction to make the PSDM Gather more flat particularly in the far offset region in depth migrated gather. The resulting PSDM gather were found to be faithfully flat and the corresponding depth section showed clear-cut, understandable and highly resolved structural intricacy with better subsurface imaging.

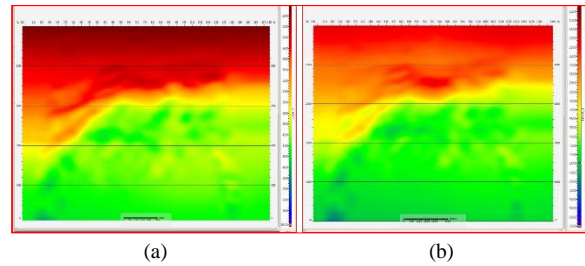


Figure-10: (a) Initial Interval Velocity for 1st iteration PSDM; (b) Final Interval Velocity after welltie tomography used for PSDM.

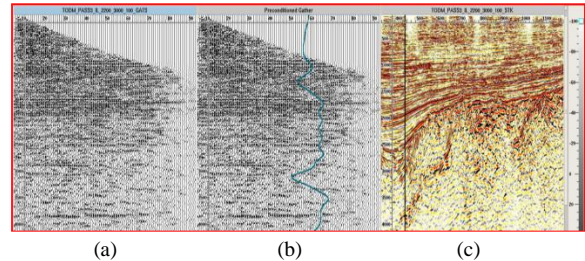


Figure-11: (a) PSDM Gather before 4th order Eta Correction; (b) PSDM Gather after 4th order Eta Correction and showing Eta curve (green); (c) PSDM Section (Vertical Black line is showing the corresponding location of PSDM Gather).

Consecutively, the welltie tomography was proficiently used to correct the miss-ties between seismic and available well markers. In this project, welltie tomography has been successfully adopted to incorporate further anisotropy in the updated interval velocity model to minimize miss-ties and also to produce very good match with the interpreted major seismic horizons and well markers. Through well tie tomography, the misties were significantly minimized (< 0.5%) at their respective depths and finally in the range of -2.9m to +3.1m in the Hazad top level (Depth Range is 1.0 to 2.3 km); -3.6m to +4.1m in the Y-marker level (Depth Range is 1.05 to 2.5 km); and -0.4m to +0.4m in the deepest Olpad top level (Depth Range is 1.2 to 5 km) as shown in Figure-12 to 14.

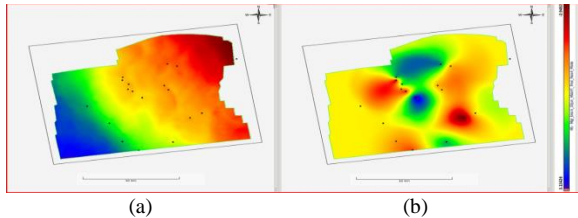


Figure-12: (a) Hazad Depth Map; and (b) Hazad Mistie Map.

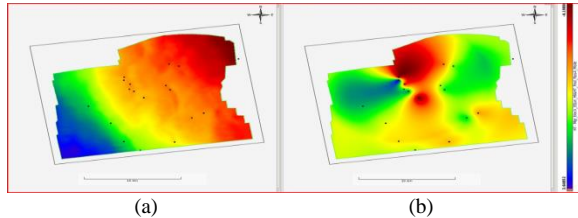


Figure-13: (a) Y-Marker Depth Map; and (b) Y-Marker Mistie Map.

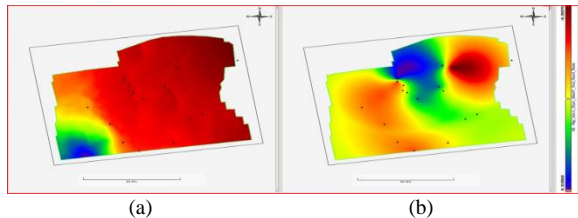


Figure-14: (a) Olpad Depth Map; and (b) Olpad Mistie Map.

The welltie tomography updated final PSDM outputs (representative lines are shown in Figure-15 & 16) were found to be optimum with the interaction with the interpreters to meet the geological objectives for precise delineation of Miocene to lower Paleocene and Synrift sequences.

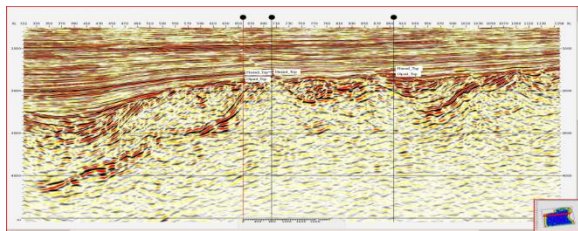


Figure-15: PSDM Section with adjoining Wells (Inline 2700).

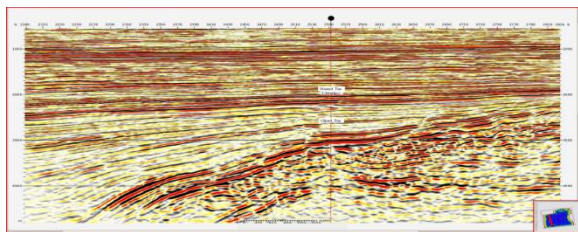


Figure-16: PSDM Section with adjoining Wells (Crossline 400).

Comparison of PSDM with PSTM Outputs

Explicitly, a depth imaging project in particular necessitates with some comprehensive elucidation of subsurface complexity that cannot be revealed satisfactorily with time migrated output. Prolific accomplishment of PSDM projects with perfect determination of interval velocity in subsurface gives a truthful insight in subsurface imaging.

In this present study area in Dabka – Jambusar – Matar Phase – I of Cambay Basin, the processed PSDM 3D volume is definitely well-accepted to provide a lot of vital and decisive indications to the interpreters for improved subsurface understandings to fulfill the desired objective for precise delineation of miocene to lower paleocene and synrift sequences.

Few follow-up comparisons of PSDM with PSTM outputs are shown in Figure-17 to 21. It is evidently depicted that subsurface imaging on PSDM (scaled to time) volume as compared to PSTM volume shows significant improvement in structural imaging with better subsurface definition.

It is clearly observed that the final PSDM sections show the meticulous delineation and highly resolved Miocene to lower Paleocene and Synrift sequences to assess the hydrocarbon potential in the study area.

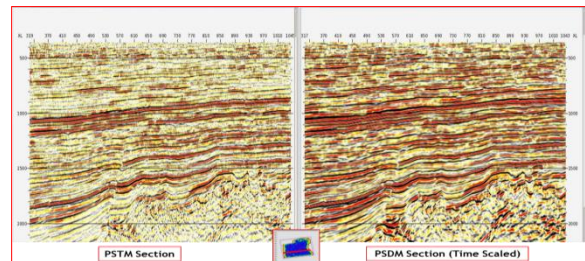


Figure-17: PSTM – PSDM Comparison showing improvements in shallow level in Inline 2400.

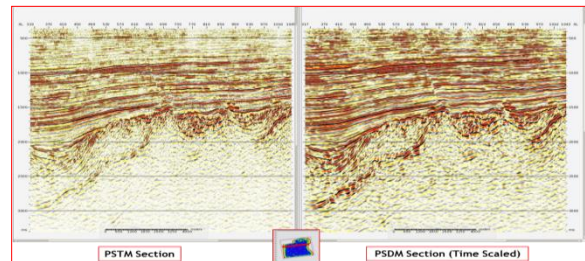


Figure-18: PSTM – PSDM Comparison showing improvements in deeper level in Inline 2700.

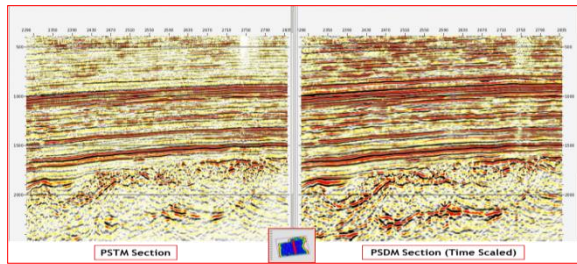


Figure-19: PSTM – PSDM Comparison showing improvements in shallow level in Crossline 600.

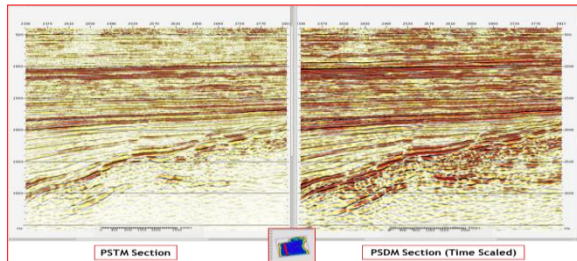


Figure-20: PSTM – PSDM Comparison showing improvements in deeper level in Crossline 400.

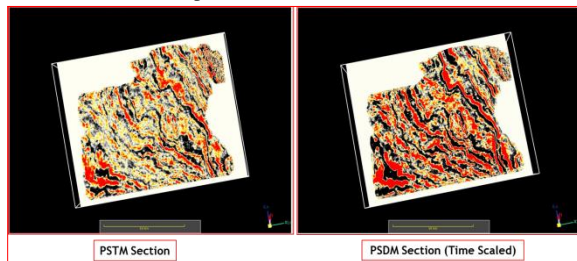


Figure-21: PSTM – PSDM Comparison (Time Slice at 1200 ms).

Discussion and Conclusions

Primarily, Pre-Stack Time migration was done in the recently acquired seismic data of Dabka– Jambusar– Matar Phase–I area of Cambay Basin for meticulous delineation of Miocene to lower Paleocene and follow-up Synrift sequences. Subsequently, as per the interpreter’s further necessity, Pre Stack Depth Migration was carried out to enhance the precision in detailed subsurface imaging and also to aid in truthful depiction of subsurface complexity for identification of accurate Synrift metaphors.

Remarkable enhancement in depth imaging for this project is observed as per the interpreter’s literal need for the critical subsurface delineation. Pre-stacked Depth Migrated (PSDM) seismic data has meticulously imaged and brought out noticeable improvement in Miocene to lower Paleocene

progressions and also augmented the explicit Synrift sequences in the PSDM domain compare to the time migrated data entrusting value-added interpretation in finding more hydrocarbon prospects in the area. However, there are large computational costs involved in PSDM but this will be certainly recompensed by the reducing the exploration risk.

Depth processing based on iterative 3D global tomographic updated velocity model can produce reliable results in complex geologic locales. It is firmly believed that Prestack depth migration should be the ultimate bull's eye of seismic processing in ensuing decades and also to provide a significant exploration advantage rather than time migrated outputs. Progressively, all seismic outputs will be on depth, with time sections merely a maiden output for the petrophysical and geological understanding.

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N.B: Views expressed in this paper are solely of the authors and may not necessarily be of ONGC.

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