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Improved 3D seismic imaging through anisotropic pre-stack depth migration: a case study from upper Assam basin

Abstract

In areas characterized by complex geology, time domain imaging more often than not falters in resolving structural geometries and their true disposition in the subsurface. Depth domain imaging and more so the incorporation of anisotropy driven solutions is the answer to suitably address the underlying challenges. The area of study poses similar challenges and lies within the Upper Assam Basin. The Structural framework is defined majorly by faults which are trending E-W to NE-SW and heading towards south and southeast direction.

Incorporation of Thomsen's anisotropic parameters [epsilon (ε) and delta (δ)] allowed us to model earth as Vertically Transverse Isotropic (VTI) medium. In this area, derived δ & ε lie in the range of 0.03-0.06 and 0.05-0.15 respectively. The earth velocity model generated from the imaging workflow was subjected to rigorous QC measures and is found to exhibit lateral variation and inversion of seismic velocities.

Vis-à-vis the classical Pre-STM image, anisotropic PreSDM imaging has resulted in better definition of the structural geometries, while improving upon the coherence and spatial disposition of the target formations. Overlay of well markers exhibits a good correlation of subsurface depths at key stratigraphic horizons within the ambit of seismic resolution.

Introduction

Depth imaging honours lateral velocity variations present in the subsurface and thus reduces velocity sags or pull ups arising out of simple time to depth conversion (which is essentially a vertical axis stretch or squeeze exercise). Incorporation of anisotropy (which in seismic prospecting refers to dependence of seismic velocity upon angle) in the imaging process depurates the structural disposition, and allows us to approach their true geological depth.

Earth velocity model is vital to depth imaging as structural uncertainty is sensitive to uncertainties in estimation of velocities. Hence, it requires that the velocity updates are geologically consistent and converge towards the true subsurface velocity. Diagnosis of the velocity updates using CIP tomography was done through qualitative and quantitative QC's. This included a measure of the flatness of CIP gathers through visual inspection and gamma maps. Departures from flatness, termed "residual moveout" and geological insight of expected velocities were used as the fundamental basis for estimating and applying the requisite velocity updates. PreSTM image of the dataset was used for final comparison with regards to the improvements obtained in both lateral and vertical sense.

Dataset Used

The 3D seismic dataset used for this study lies within the hydrocarbon bearing upper Assam basin. The target reservoirs in the area are of Miocene-Oligocene and Lower Eocene age. The auxiliary dataset used included checkshots (available in the depth range of around 1800-3600 m) for determination of anisotropy parameters and information derived from sonic log, well markers etc.

Methodology Adopted & Results Obtained

Initial Model Building:

Earth velocity model building is central to entire depth domain imaging exercise and therefore has been carried out with prudence and sound geological reasoning in the background. In our case, the smoothed version of the final PreSTM velocities was used as the Initial Velocity Model. The smoothening parameters were selected judiciously and applied in a manner so that the regional trend of the velocities matched fairly with up-scaled velocity logs at key well locations (see figure 1).

KPreSDM Workflow:

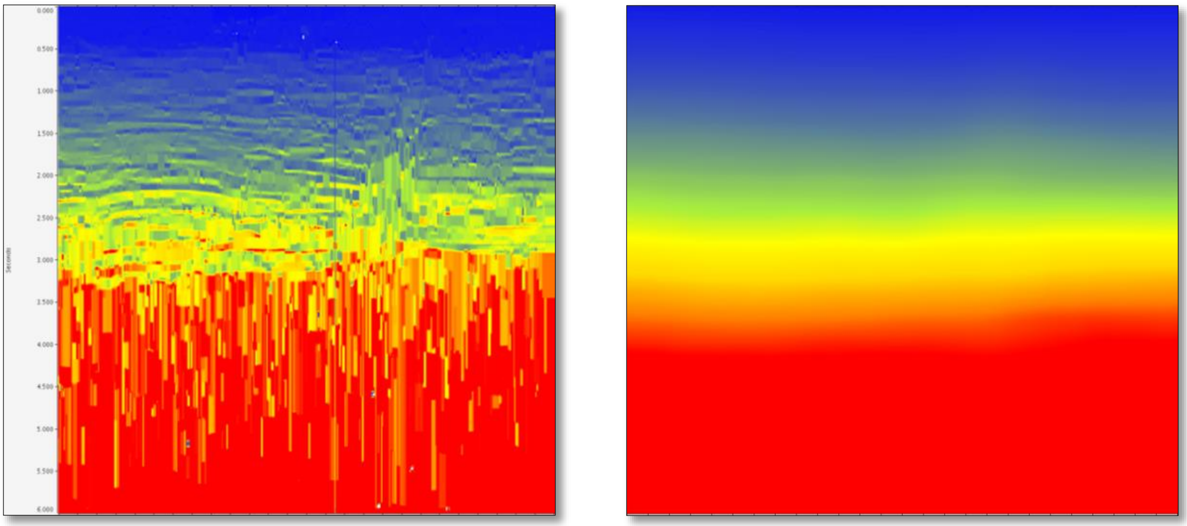
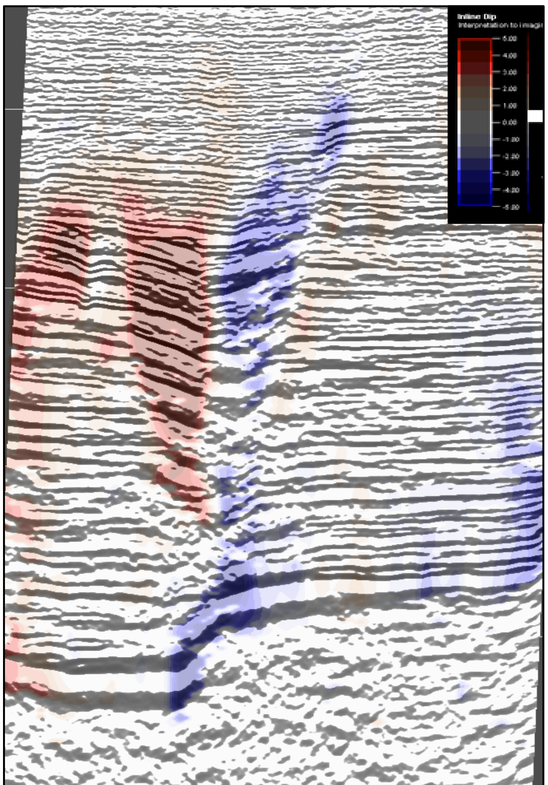


Figure 1: PSTM velocity (Interval, time) before smoothing (left) and after smoothing (right).

The PreSDM algorithm works in two steps: (a) On the basis of the initial velocity model, it performs travel time computation at all source and receiver positions, (b) The CMP gathers were migrated with this initial velocity model.

The CIP gathers obtained after PreSDM were pre-conditioned while preserving Residual Moveout (RMO) trend. The RMO trend in the gathers was picked on the basis of attributes like coherence and semblance. As the area under study contains subtle structural dip elements with positive and negative curvatures, thereof, it was imperative to perform dip estimation for defining take-off angles during ray tracing to have an accurate update of velocities.



Thus, along with the RMO trend, dip field information was also fed to form a set of linear equations which were then input to the tomography algorithm for determining the perturbations necessary in velocity model. The tomographic update was run for various damping factors (here, damping factor is inversely proportional to the change in velocity model) and scale lengths (here, scale corresponds to spatial axes, i.e. x, y and z) as shown in Table 1.

The results obtained were QCed keeping in mind geological conformance of the velocity update and the

Table 1: Tomography parameters for depth imaging

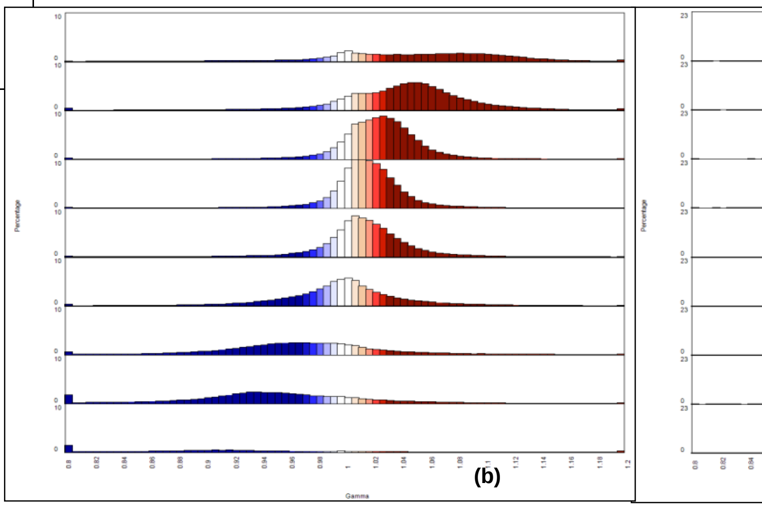
Figure 2: Overlay of Dip field over stack section for tomography update.

most plausible update was chosen for running PreSDM at target lines. Gamma maps were used to statistically (quantitatively) determine the improvement in terms of gather flatness (as shown in figures 3 & 4).

After Qcing viz. gathers, velocity model, gamma maps, PreSDM was run on the complete dataset. Each complete loop of tomography, model update and QC, and validation migration, is referred to as "iteration". The velocity model obtained from the above step was isotropic in nature (the angle mute on gathers was limited to 35 degrees).

	Iteration 1	Iteration 2	Iteration 3
XY Scale (m)	5800	3500	2000
Z scale (m)	420	300	218
Damping factor	0.1	0.1	0.1
Velocity model type	Isotropic	VTI	VTI

(a)



(b)

Figure 3: (a) Initial and (b) Final RMO statistics QC Map at gamma value 1) signifies perfect flatness of gathers whereas

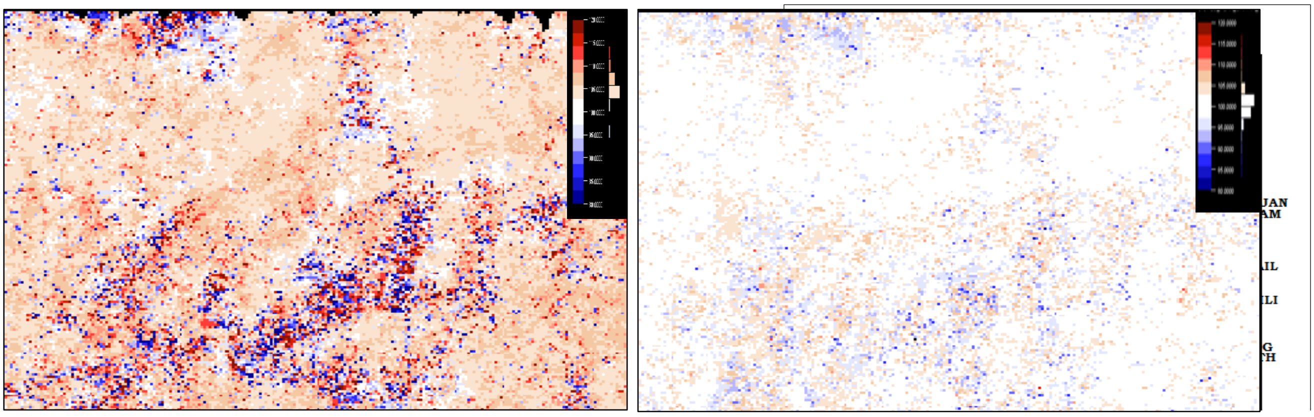
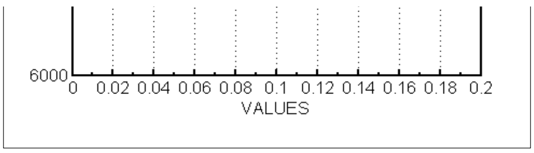
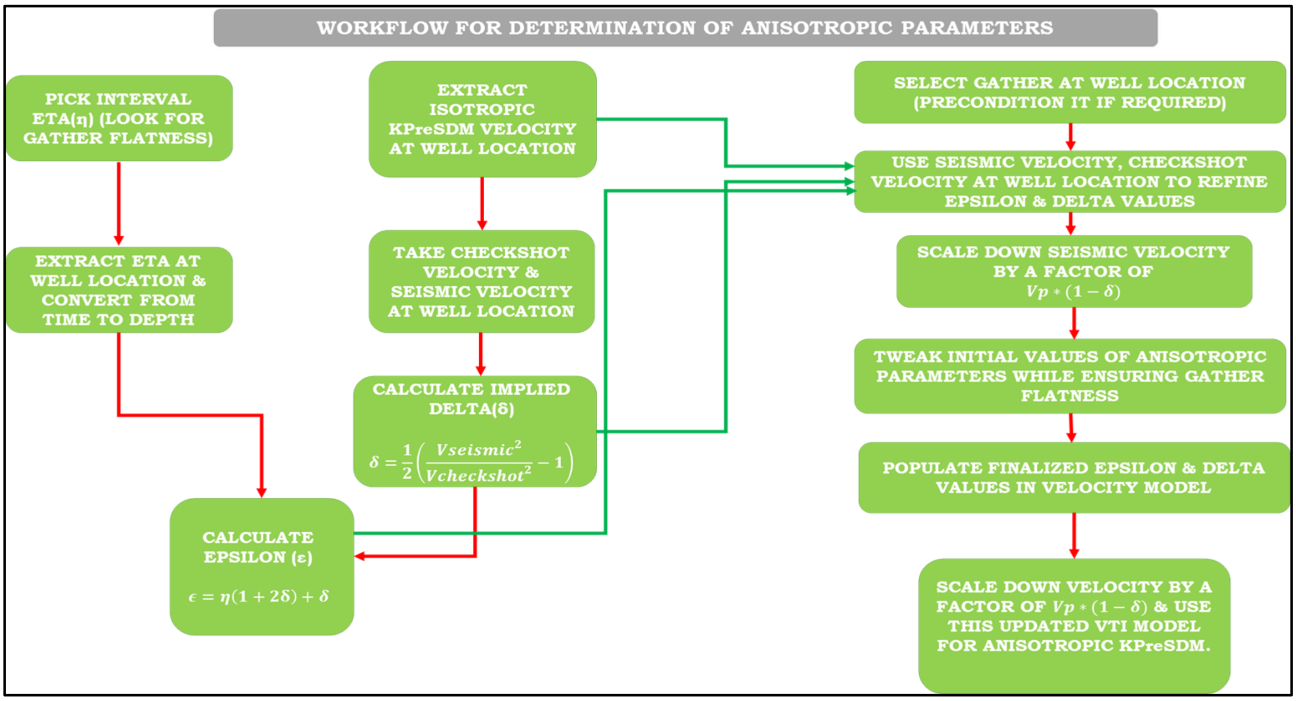


Figure 4: Initial (left) and final (right) Surface overview of Gamma values map at zones 1000-1500m. White colour (equal to gamma value 1) signifies flatness of gathers whereas red and blue depict deviation from flatness.

Incorporation of Anisotropy:



In this study area, VTI (Vertically Transverse Isotropic) subsurface has been considered due to the fact that the reflectors are dipping at small angles or are more or less horizontal. The VTI model is characterized by three properties, i.e. compressional Velocity, epsilon (ε) and delta (δ). Determination of these parameters requires estimation of eta (η) in time domain and implied delta in depth domain using checkshot velocity (also called



as vertical velocity). These parameters were then used to give an initial estimate of epsilon. The anisotropic parameters obtained were refined and then populated in the isotropic velocity model. The value of derived anisotropic parameters (δ) is found to be in the range of 0.03-0.06 and epsilon (ε) in the range of 0.05-0.15.

Anisotropic parameters populated in the earth velocity model along with well markers at well location are illustrated in figure 5. The workflow for their determination is shown in figure 6. CIP gathers before & after incorporation of anisotropic parameters are shown in figure 7.

Figure 5. Illustration of Thomsen's Anisotropy parameters along with well markers at well location.

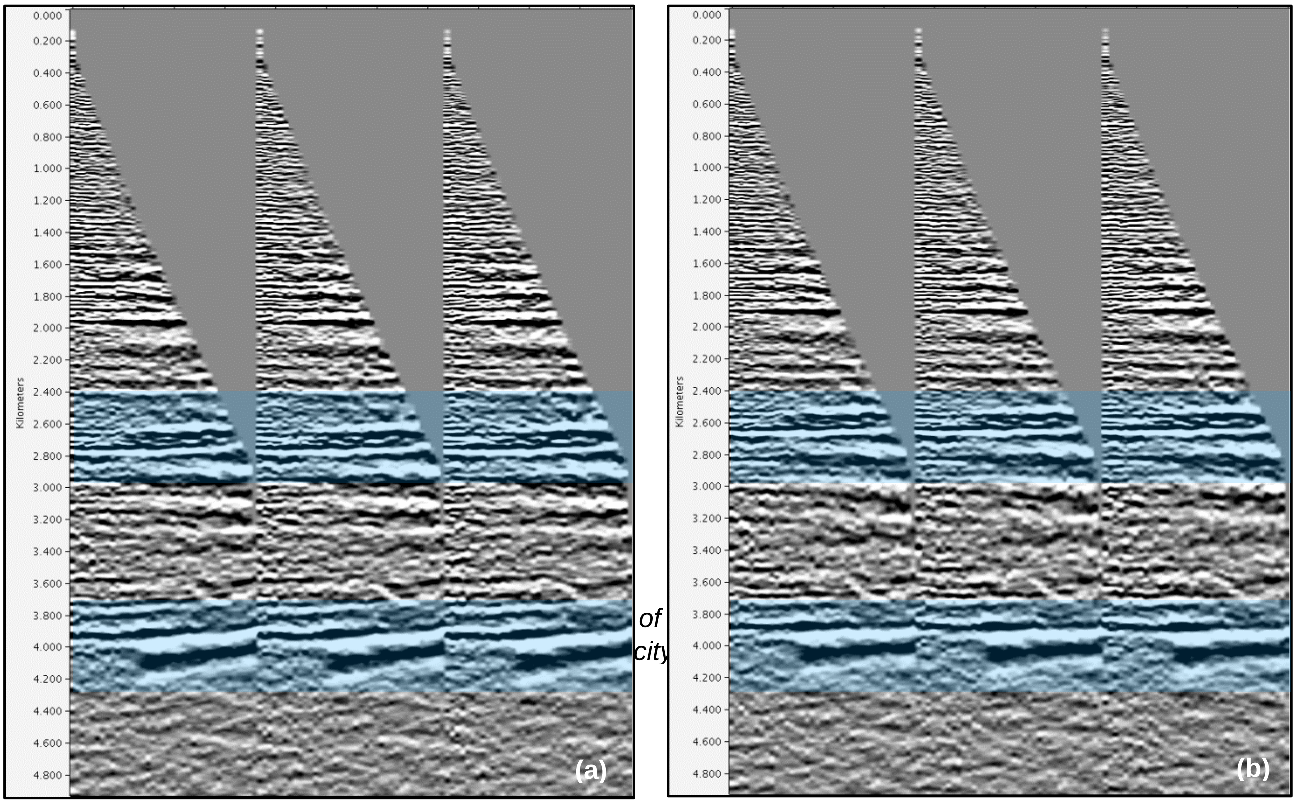
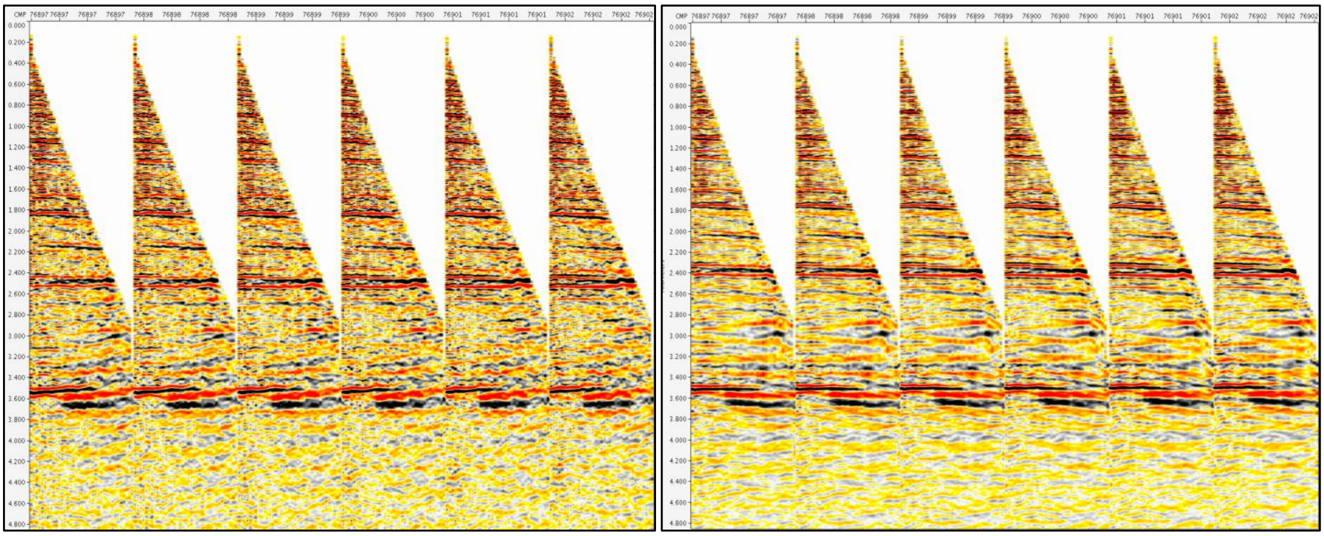


Figure 7: PSDM gathers (a) before and (b) after incorporation of anisotropic parameters in velocity model. Hockey stick effect can be seen in (a) at far offsets in highlighted portion.

Re-Iterations for final results:

This VTI model was then used to re-perform the “iterations” mentioned above. The velocity updates were continued till we obtained reliable results in terms of improvement in our image and gather flatness (see figure 8). Some pre-conditioning was applied in order to improve the image. The final anisotropic PreSDM stack section was then QCed in conjunction with the PSTM image (see figure 9) in terms of the structural



disposition and image improvement. Also, well markers were used to validate the VTI model by ensuing in minimal misfit with seismic horizons.

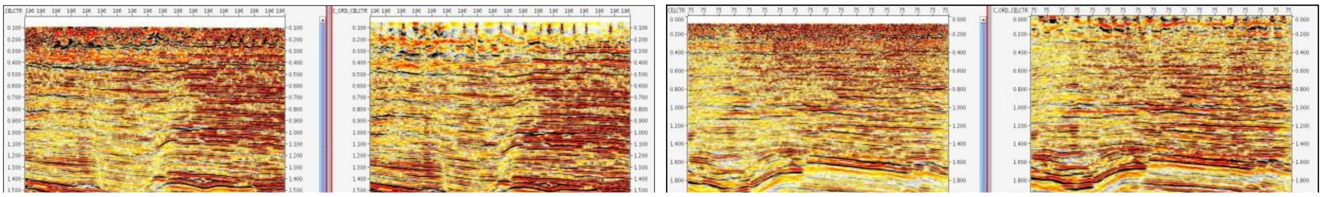


Figure 9: (a) and (b) show comparison between PSTM (in time) (left) and PSDM (in depth) (right) stacks.

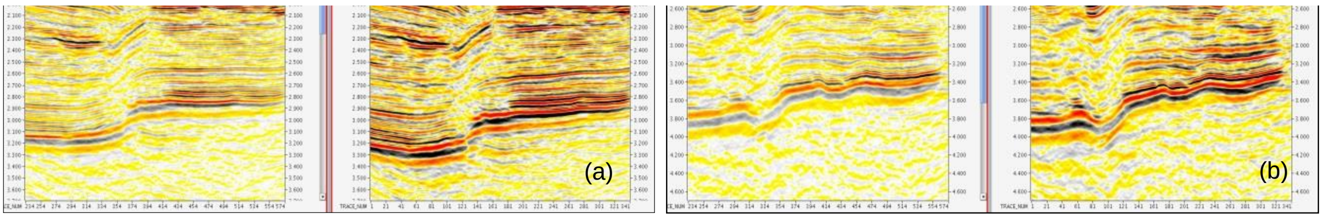
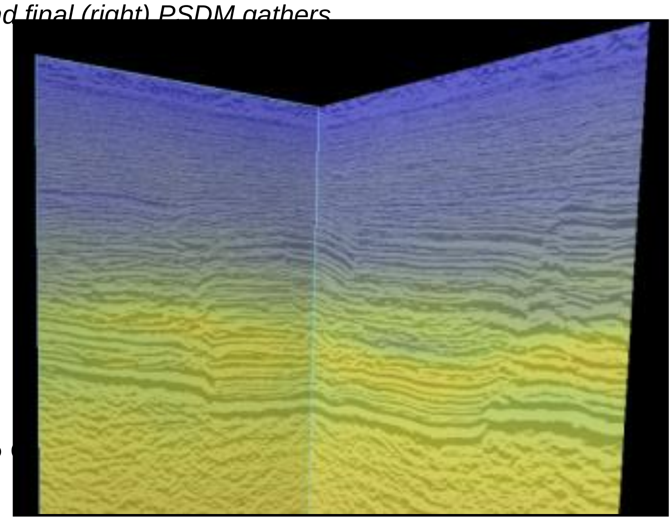


Figure 8: Initial (left) and final (right) PSDM gathers



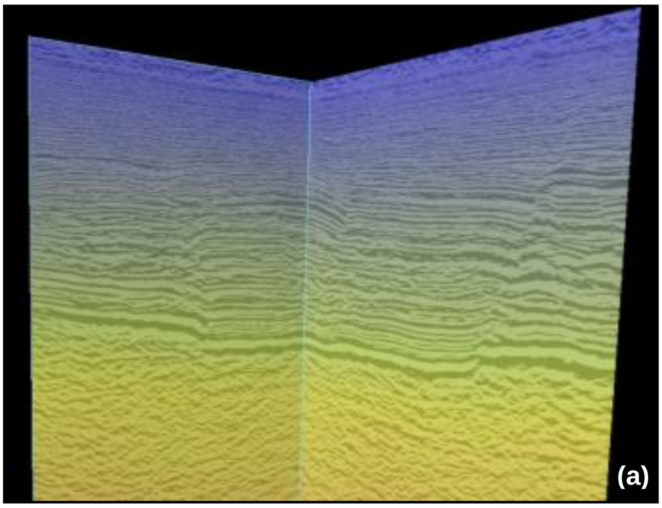


Figure 10: (a) Initial PSDM velocity model overlay the initial PSDM stac
Final PSDM velocity model overlay the final PSDM stack vol

Conclusions

The anisotropic PreSDM image has improved in terms of continuity of the reflectors and in definition of the subtle structure geometries of subsurface vis-à-vis PSTM image. Earth velocity model derived from the imaging presen consist with structural geometries and relative disposition of formations along faults (see figure 10(b)) and has reasonable match with well velocities (see figure 11). Overall, enhanced imaging of the structural details in terms of geometry and lateral resolution along with better delineation of faults has necessarily resulted in a subsurface image and earth velocity model which shall aid in reduction of geological uncertainties like prospect definition & it's volumetric along with increased understanding of the static/dynamic behaviour of the field. Incorporation of anisotropic parameters in imaging workflow demonstrate a good match between well markers and seismic (as shown in figure 12) within the seismic resolution which shall assist in better placement of wells and targeting prospective spots which are economically viable. Advanced analysis of data in terms of seismic inversion studies & geomechanics for well bore stability are bound to benefit from this study.

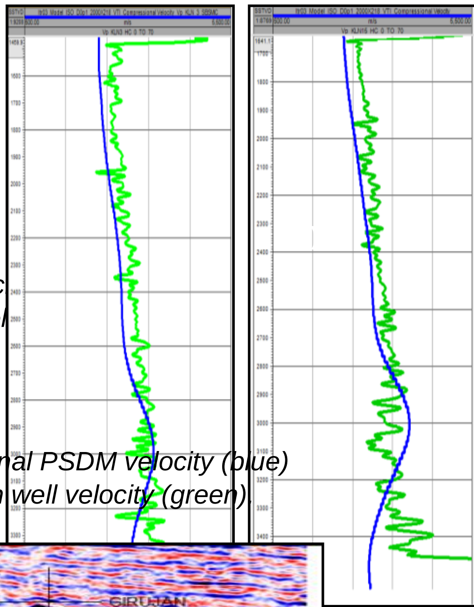


Figure 11: Final PSDM velocity (blue) overlain on well velocity (green)

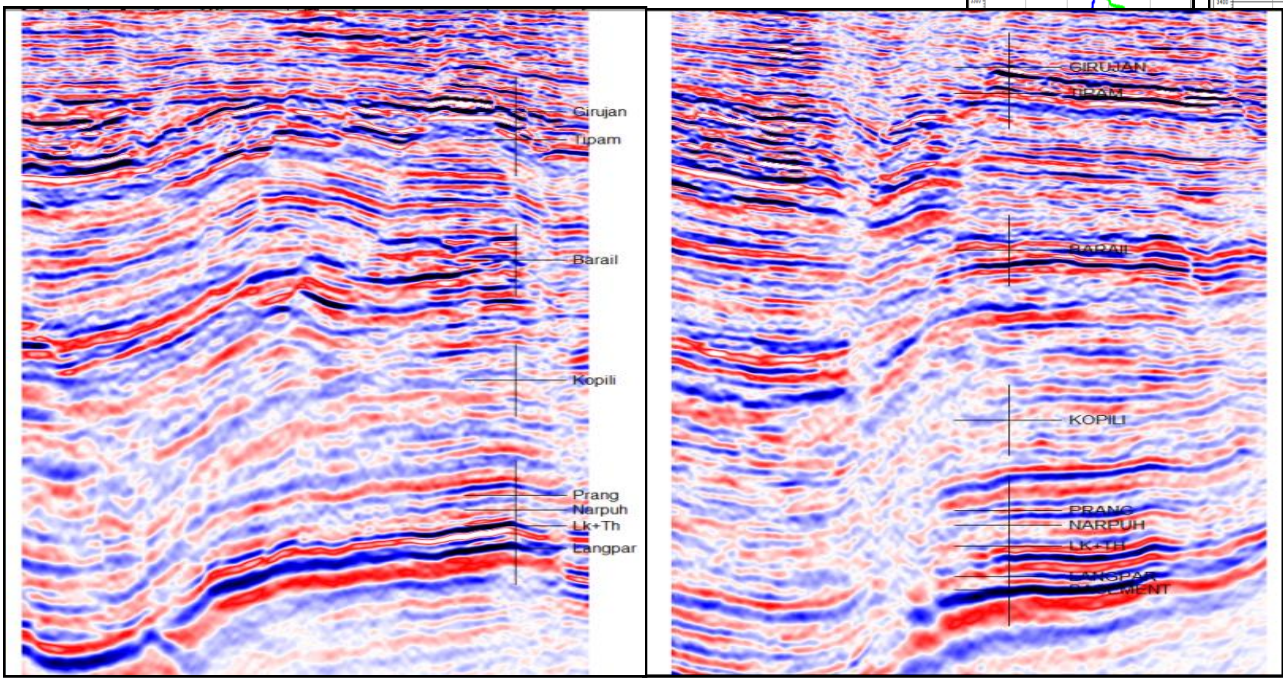


Figure 12: Overlay of well markers on PSDM stack sections.

Acknowledgement

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