



P 324

## Use of Traveltime Tomographic velocity model beyond imaging: “Estimating 3D pore pressure & effective stress volumes”

*Kanharol K Hari\*, Subrata Chakraborty, Ajay Pundir and Samit Mondal*

### Summary

Pre-stack depth migration (PSDM) is widely used in the industry to improve subsurface imaging in complex geological settings. The major step in a PSDM workflow is iterative construction of an accurate velocity model using traveltime tomography. This is a case study in deep water seismic data from the East Coast of India, where PSDM analysis has improved imaging beneath a thrust belt. The velocity volume has further been used to do quantitative predictions of pore pressure and effective stress. These pore pressure and effective stress volumes have been used in prospect evaluation to evaluate seal capacity and hence maximum hydrocarbon column height. The results of the study has enhanced our understanding regarding the geological uncertainty in this area to avoid any drilling surprises and related cost effectiveness and further been incorporated in well planning.

**Keywords:** PSDM, RMO velocity, Pore pressure, Effective stress, MTC, Tomographic velocity

### Introduction

Pre-stack time migration (PSTM) is still of great importance in the industry, thanks to its simplicity, efficiency and robustness and its ability to focus seismic reflectors in many smoothly varying geological settings. The limitations of PSTM appear in the presence of complex water bottom and other strong lateral velocity variations, in which case the more rigorous imaging and accurate velocity models offered by Pre-Stack Depth Migration (PSDM) are required (Schneider, W. A., 1978, Sun, Y. H, *et. al.*, 2000, Santosh *et. al.*, 2008.). Apart from better imaging, the other useful byproduct we get from PSDM is an interval velocity model in depth which can be interpreted, adding a lot of value.

The correctness of PSDM imaging is mainly dependent on the accuracy of the velocity model. That is why a great effort is being taken in a PSDM workflow to build a velocity model much more accurately. Generally this accurate and geologically meaningful velocity model is used only for routine work like imaging and depth conversion.

Predrill pore pressure estimation can be done using the seismic velocity and offset well information (Bell, David

W., 2002, Bowers, G.L., 2002, Chopra, S., Huffman, A.R., 2006.). The normal compaction trend analysis is performed to the velocity dataset to derive the pore pressure values.

The uncertainty in pore pressure prediction depends upon the uncertainty in velocity model. The velocity model which is geologically consistent and can explain the complex geological structure with reasonable depth control can suitably be used for the pore pressure prediction workflow.

In this paper, a case study is presented to show the effectiveness of traveltime tomographic velocity model in depth imaging. Added to this, further conversion of this velocity model to pore pressure and effective stress volumes adds extra dimension to the interpretation in terms of seal effectiveness and well planning.

### Geology of the Study Area

Our study area is located in deep water slope setting in the Southern part of Krishna-Godavari basin, east coast of India (Figure1).

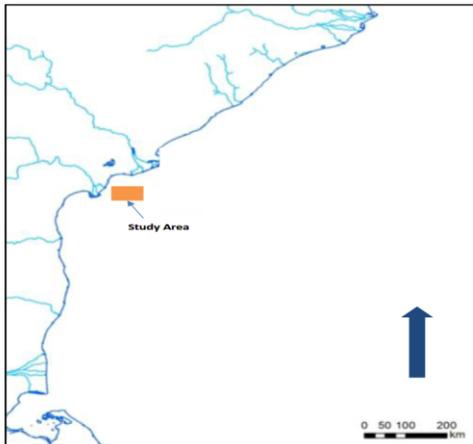


Figure 1: Location map of the study area.

Sediment distribution in the basin is controlled by Krishna and Godavari river systems, along with numerous tributaries and represents a depositional setting of a well-defined shelf, slope and deep water system. The basin contains thick sequences of sediments with several cycles of older sequence ranging in age from Late Carboniferous to Holocene (G N Rao, 2001). The offshore portion of the Tertiary sequence includes depositional systems ranging from shore-face through to deep-water submarine channels, levee and overbank facies. The primary targets in this area are Miocene to Pleistocene submarine meandering river channels and submarine fan complexes.

In offshore Krishna-Godavari basin, during Miocene period, the sediments were deposited rapidly with relatively lower expulsion of fluid which resulted moderate to high pore pressure generation in these sequences.

The study area is inundated with toe-thrusts in the shallower Pliocene-Pleistocene sections. Beneath the detachment surface of these thrusts lies the Miocene subthrust wedge-out which are the target prospects in this area. The thrusting zone above the detachment surface has added extra dimension (related to tectonic stress) to the pore pressure in this area.

### Case study

As discussed earlier, the shallow stratigraphic units are affected by the thrusts and then a huge thick mass transport complex sequence above the detachment surface, the imaging below the thrusts is a challenge for this area. The processing objective is to obtain a better and sharper image

beneath the mass transport complex and intra-thrust zone. Additionally, an accurate analysis of velocities within the overburden and target level is required for pore pressure and seal capacity estimation for prospect and drilling of wells successfully.

A PSDM project was carried out with these objectives. Figure 2a & 2b compares PSTM and PSDM stack sections (in time) for a line passing through the area processed; the PSDM image reveals much more detailed features through the slump zone. This improvement is attributed mainly to the accurate velocity model, built in the iterative manner outlined in the next section, as well as the ability of PSDM to handle migration through the velocity model correctly.

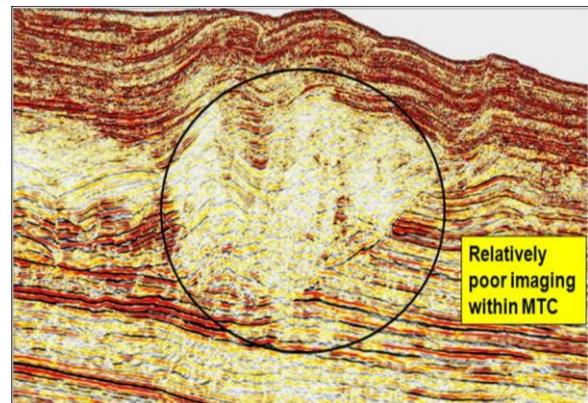


Figure 2a: PSTM stack section (in time), showing the zones where improvement in imaging is necessary.

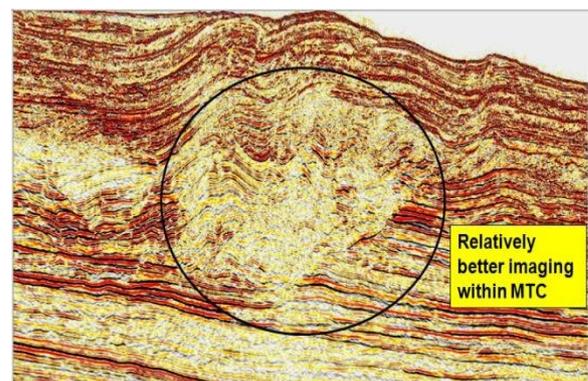


Figure 2b: PSDM stack section (in time), showing better imaging in depth processing over time within slump zone.

### Velocity model building

Estimating an accurate 3D depth velocity model is one of the major challenges in seismic imaging. The velocity

model building starts with a smooth initial velocity field, usually derived from PSTM stacking velocity.

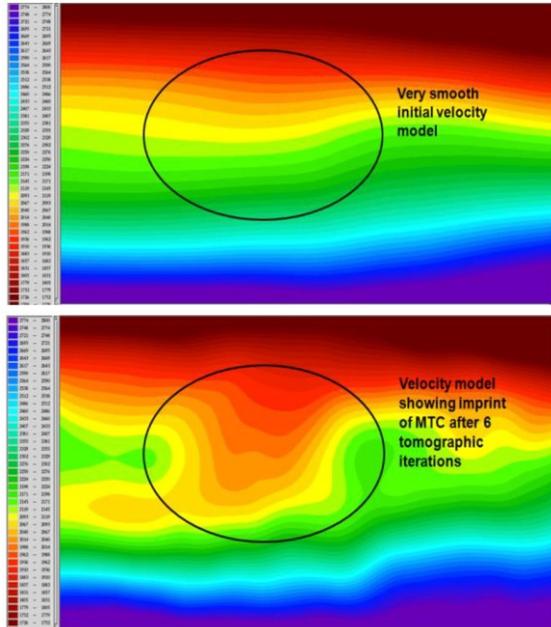


Figure 3a: Comparison of interval velocity models in depth – PSTM (Top) and PSDM (bottom).

An initial PSDM is performed to build Common Image Point (CIP) gathers for the picking of residual moveout (RMO) and structural dip in the migrated depth domain.

To image the slump zone (MTC) properly, a dense (50m x 50m) RMO picking was used. The depth velocity model is then updated iteratively by ray-based gridded tomographic inversion to minimize this RMO.

Figure 3a compares the initial (top) and final (bottom) interval velocity models after six iterations of tomography (Guillaume *et. al.*, 2008) at the same subsurface location shown in Figure 2a. In the first three iterations RMO was picked restricting the mute to near angle ( $\approx 30^\circ$ ) and the next three iterations the mute was extended to far angle ( $\approx 40^\circ$ ). The PSDM velocity model, in this case, is geologically consistent and defines the subsurface geological features more accurately.

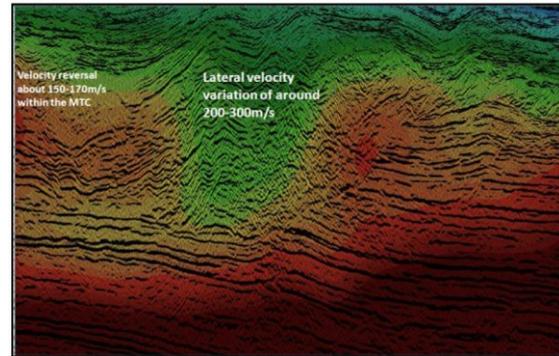


Figure 3b: Interval velocity overlaid on PSDM stack section, showing the lateral velocity variation.

Thus when we overlay the velocity model on the stack section (Figure 3b) we see that the PSDM velocity at the Mass Transport Complex (MTC) shows velocity changes inside the MTC which follow thrust sheets and major fault boundaries. This is not a „forced“ result: no model boundaries are imposed, the detail emerges from the data.

The 1D PSTM, PSDM and Handpick (HP) interval velocity fields are compared as shown in Fig 3c. The pore pressure estimated from PSDM velocity field has further been validated with an offset well pore pressure in the same geological setting.

Once this velocity model is validated to be consistent with the interpretation, it is then used for estimation of 3D pore pressure and effective stress volumes as described in the next section.

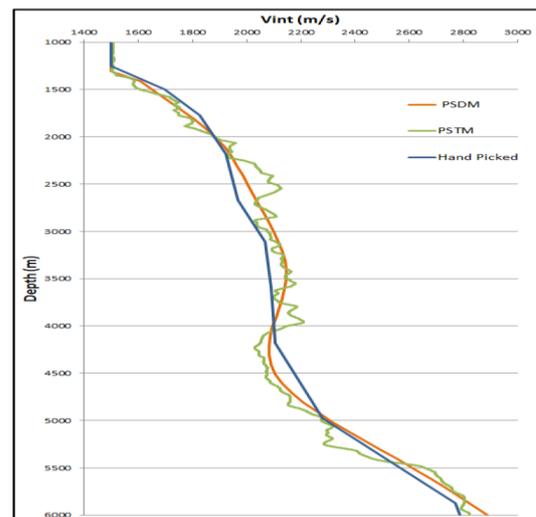


Figure 3c: 1D plot of PSTM, PSDM & HP interval velocity

### Pore pressure analysis

The traveltome tomographic velocities were used to predict 3D pore pressure distribution in the area. The target objectives lies below the Mass Transport Complex (MTC) and due to relatively high pressure and narrow margin of pore pressure and fracture pressure, uncertain effectiveness of the top seal and the lack of offset well data in an analogous geological set up, drillability is a major issue for these prospects.

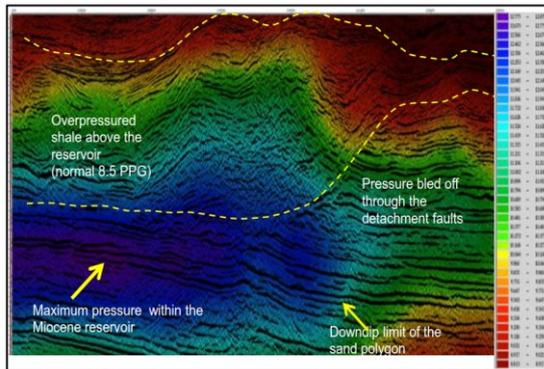


Figure 4a: Pore Pressure overlay on the PSDM stack section, showing the pressure distribution in the area.

The velocity data were used to calculate the lithostatic pressure gradient based on Gardner's (Gardner, *et. al.*, 1974) velocity-to-density transform and calibrated against the regional density trend. Miller's (Miller *et. al.*, 2002) compaction trend analysis was used to calculate the pore pressure gradient in ppg (Figure 4a).

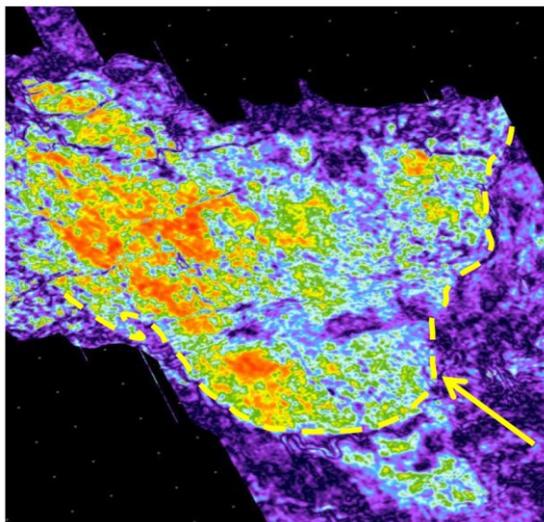


Figure 4b: Reservoir polygon in RMS amplitude map

The pore pressure values remain close to the normal hydrostatic (8.5ppg) till the top of MTC and then increases rapidly within the MTC zone. The reservoir pressure shows relatively high pore pressures (~13ppg) compared to the top seal claystone sequences. The downdip limit of the reservoir polygon (as shown in figure 4b) shows a lower pressure (~11.8 ppg). Beyond the reservoir zone, the nonreservoir sequence reveals a lateral pressure difference, clearly indicating the boundary of the reservoir. This pore pressure volume has further been used to evaluate the seal effectiveness for these prospects as discussed below.

Offset well was drilled few kilometers away from the present study area within same geological setup. The well had shown the pore pressure magnitude which is similar in order with the outcome of our study within the toe thrust and mass transport complex area.

### Seal failure analysis

An effective stress volume was also derived to test the top seal for the prospect. As shown in Figure 5, the thick shale sequence above the detachment surface has higher effective stress compared to top reservoir (~1200psi at prospect top). There are lateral variations in effective stress within the MTC sequence. The effective stress increases towards the downdip of the prospect polygon. This magnitude of effective stress can hold sufficient hydrocarbon column to make exploration worthwhile.

Pore pressure and seal failure estimation provides overall pressure scenario of the prospects. They add additional dimensions to the interpretation and enable us to visualize the prospect from different angles like the risk analysis of the prospect and arriving to a best geological chance factor.

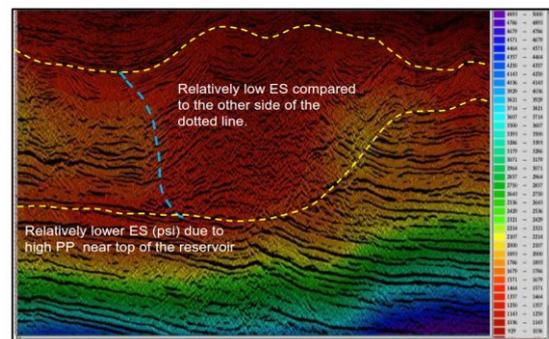


Figure 5: Effective stress (psi) overlay on the PSDM stack section, showing the effective stress distribution in the area.



## Conclusions

The main objective of a PSDM process is to obtain a more geologically reliable subsurface image starting from a PSTM RMS velocity field. Our example shows that the PSDM 3D depth velocity model is superior to that of PSTM leading to significant improvements in imaging of MTC in the intra thrust zone. This PSDM velocity model emerges a good subsurface geologically consistent image and provides estimates of the pore pressure and effective stress distribution in the area. Calibration of these pore pressure and effective stress volumes minimizes drilling risks.

Hence the PSDM approach is very effective in interpretation in a complex geological setting. The 3D pore pressure and effective stress volume, integrated with the better imaging enhanced our interpretation related to the seal integrity and would lead to safe completion of well with proper well placing and casing/mud weight designs.

## Acknowledgement

The authors are thankful to Reliance Industries Ltd. For giving them the necessary permissions to present this research paper in the SPG-2013 conference, at Kochi.

Authors are also grateful to Mr. A. K. Biswal, Mr. M. K. Balasubramaniam, Mr. B.K. Patel, Dr. G. Srikanth and Mr. Brian Barley for critical review of this paper. The authors appreciate the concerned asset and wellsite team members of RIL for their support for this study.

## References

Bell, David W., 2002, Velocity Estimation for PorePressure Prediction; in A.R. Huffman and G.L.Bowers, eds., Pressure regimes in sedimentary basins and their prediction: AAPG Memoir 76, 177-215.

Bowers, G.L., 2002, Detecting high overpressure; The Leading Edge, 21, 2, 174-177.

Chopra, S. and Huffman, A.R., 2006, Velocity determination for pore pressure prediction; CSEG RECORDER, April 2006, 28-46.

Gardner, G.F, Gardner, L.W and Gregory, A. R., 1974, Formation Velocity and Density –The Diagnostic basics for stratigraphic Traps; Geophysics, 39. 770-780.

Guillaume, P., Lambaré, G., Leblanc, O., Mitouard, P., Moigne, J. L., Montel, J. P., Prescott, T., Siliqi, R., Vidal, N., Zhang, X. and Zimine, S., 2008, Kinematic invariants: an efficient and flexible approach for velocity model building; presented 78th annual SEG meeting “Advanced velocity model building techniques for depth imaging” SEG workshop.

Rao, G.N, 2001, Sedimentation, stratigraphy and petroleum potential of Krishna-Godavari basin, East Coast of India; AAPG Bulletin, 85, 9, 1623-1643.

Miller. T. W., Luk. C. H. and Olgaard. D. L., 2002, The Interrelationships between Overpressure Mechanisms and In-Situ Stresses, A.R. Huffman and G.L. Bower, eds, Pressure regimes in sedimentary basins and their prediction; AAPG Memoir 76, 13-20.

Santosh, N., Chakraborty, S., Hari, K. K., Bawra, A. and Balasubramaniam, M. K., 2008, Objective based depth imaging and its application to data from East coast of India; presented in SPG-2008 at Hyderabad.

Schneider, W. A., 1978, Integral formulation for migration in two and three dimensions; Geophysics, 43, 49–76.

Sun, Y. H, Qin, F. H., Checkles, S. and Leveille, J. P., 2000, 3-D prestack Kirchhoff beam migration for depth imaging; Geophysics, 65, 1592–1603.