An innovative way of 3D velocity model building for PSDM Processing: a case study from Andaman deep water basin, India

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Keywords

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Summary

Seismic data processing is one of the three key stages of 3D seismic surveys for oil & gas exploration i.e. data acquisition, data processing and data interpretation. Without good data processing, it is impossible to get good subsurface image for data interpretation. Pre-stack depth migration (PSDM) is one of the tools to get subsurface image in depth for geologic interpretation. For PSDM processing, interval velocity model building scheme is key to arrive at optimum velocity model and to arrive at global optima, the starting interval velocity model is critical. The paper illustrates an innovative way of obtaining optimum interval velocity model used for PSDM. The velocity model building scheme comprises two steps. Firstly, RMS velocity refinement is attempted by running PSTM twice. Secondly, after a few tomographic iterations, average interval velocity is fixed for all the horizons and new velocity model is created. One more tomographic iteration after target line PSDM and residual moveout analysis provided the best interval velocity model. This velocity model building scheme for PSDM processing has resulted in very good subsurface imaging. The velocity model obtained showed higher confidence. The velocity variation observed within the layer (between Hz-5 and Hz -6) seems to be genuine and caused due fluid influx from below or some localized lithologic changes or it might be a mud volcano. Velocity maps depicting structural features including fault systems are unique outcome of this study.

The velocity maps mimicking the structural maps, and flat migrated CRP gathers are the testimony of very good velocity model resulted from this scheme. The accuracy of the interval velocity model is ascertained by flat migrated gathers and semblance residual moveout coinciding with zero residual axis. The subsurface image obtained depicts seismic anomalies corroborating very well with velocity anomalies. Other geologic features such as channel-levee complex at Neogene level, basement high corresponding to the Ninetyeast Ridge and associated faults are the significant outcomes of the innovative velocity modeling used for PSDM processing.

Introduction

Seismic data processing is one of the three main stages of seismic surveys for hydrocarbon exploration: 1. Data acquisition, 2. Data processing, and 3. Data interpretation. The goal of seismic data processing is to get improved subsurface image which facilitates in building up the geologic knowledge about the basin. Prestack time migration (PSTM) and Pre-stack depth migration (PSDM) are the two standard techniques to get subsurface image in time and in depth domain respectively. In relatively homogeneous structure having less lateral velocity contrast, PSTM is able to produce good subsurface image that very closely corresponds to the actual geological conditions. However, in complex structure such as when there is a salt dome or carbonate reef structures that have high heterogeneity horizontally, PSTM technique generally fails (Yilmaz O. ,2001). Here comes the PSDM technique to rescue us which takes care of lateral velocity contrast in the complex geologic area for better subsurface imaging. However, an optimum interval velocity model in depth is very much required for PSDM process. To obtain an optimum velocity model is processor's skill and the right choice of the optimizing algorithms (seismic tomography). Chang et al. (1998) developed tomography method to refine the interval velocity model for Pre-Stack Depth Migration (PSDM). Seismic tomography is used to refine the interval velocity, as the initial velocity model is less accurate. Tomography algorithms generally are of two types- Horizon based and Grid based. The horizon based tomography fixes the error in seismic waves travel time along the horizon while grid based tomography fixes the error along segments (Chang et al., 1998). Several iterations are generally required to arrive at a satisfactory velocity model ultimately used for PSDM.

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The interval velocity model building is the most crucial step for PDSM data processing and the quality of subsurface image is very much dependant on the velocity model (Yilmaz O., 2001). If the initial velocity model is not closer to the optimum model, seismic tomography may land up in a loop of suboptimal velocity model which is detrimental to the subsurface imaging and jeopardize the very purpose of depth migration. Therefore, it is very much important to start with a very good starting velocity model. The best way would be to do few iterations of horizon RMS velocity refinement by repeating Pre-stack time migration (PSTM). After getting the best RMS velocity map for all the interpreted horizons, the initial interval velocity model is obtained using Dix conversion (Dix C.H., 1952). However, it is to be kept in mind that the time gap between two consecutive horizons should not be less than 200 ms, since the error increases exponentially as the layer thickness decreases (Dix C.H., 1952). The RMS velocity model and resulting initial interval velocity model should be smooth and do not contain bull's eye of low or high velocity.

In the present study, 3D velocity modeling is done using all the best quality control practices to do pre-stack depth migration (PSDM) of 3D seismic survey in Andaman deep water Basin. Figure-1 shows the location of the study area which falls in the west Andaman basin over the Ninetyeast Ridge. The area covers the northern part of the Ninetyeast Ridge which is probably the longest aseismic linear geologic feature (> 5000 km) of the World Oceans along 90° E meridian. This part of the Ridge is covered under thick sediments of Bengal fans (Schlich, 1982).

After several tomographic iterations for interval velocity refinement, low velocity pockets within high interval velocity layer are observed. Theses bull's eyes are corresponding to seismic anomalies observed within that geologic intervals. A new interval velocity model is created using average interval velocity maps which are obtained after final tomographic iteration. Target line PSDM is carried out using the new interval velocity and subsequently residual moveout analysis is carried out. The tomographic iteration results final interval velocity volume. The isotropic Kirchhoff's PSDM is carried out using this interval velocity volume. The subsurface images thus obtained are of superior quality and the final velocity volume shows anomalously low interval velocity pockets within high velocity layer corresponding to the seismic anomalies. These geologic features may be very interesting from hydrocarbon exploration point of view in the area.

Seismic data processing

3D seismic survey was carried out in deep water area of west Andaman basin to map Palaeogene structures and wedge out geologic features against Cretaceous structural highs (?). Eighty fold data with 2 ms sample interval and record length of 10 s is recorded using 4 streamers. De-multiple offset regularized bin data with sample interval of 4 ms is used as input to PSDM processing. Nine interpreted horizons are picked on PSTM processed 3D data volume. RMS velocity maps are extracted along the interpreted horizons from RMS velocity volume used for pre-stack time migration. Smoothed RMS velocity maps are used to create a new RMS velocity volume which is used to run target line PSTM in a grid of 500X500 m in order to refine the velocity maps.

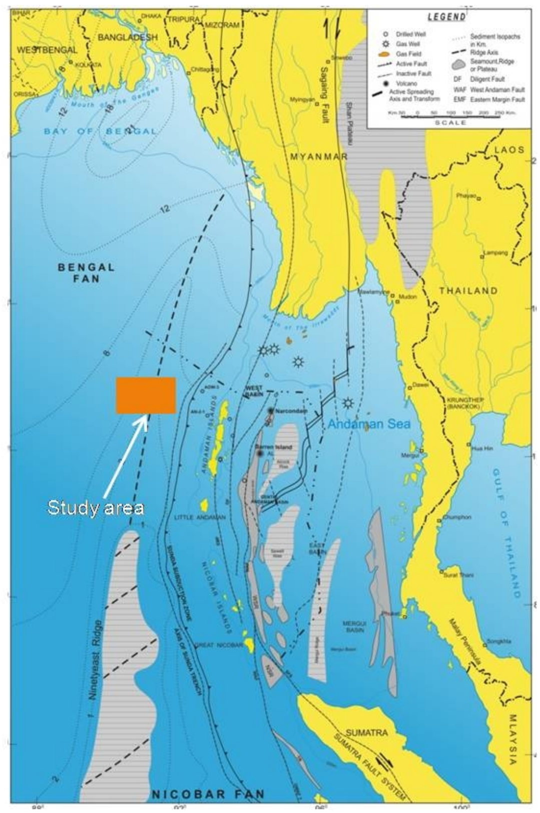

Figure 1. Location map of the study area

The updated RMS velocity maps are used to derive an interval velocity maps by Dix (Dix C. H., 1952) conversion. The initial interval velocity volume is obtained by map migration of the time migrated horizon maps.

Three iterations of horizon based tomography are carried out to refine the interval velocity maps/model. Horizon based tomography is preferred to grid based tomography, since the horizons are well developed and are picked unambiguously in the area. Further, horizon based tomography is supposed to provide a better solution than grid based tomography in such a geologic situation (Geodepth Training Manual, 2007). After that an average interval velocity is derived from the optimized interval velocity map for each horizon and an interval velocity volume is created subsequently. This interval velocity model is used to run PSDM in a grid of 500X500 m. After carrying out residual moveout analysis, horizon based tomography is run to refine the velocity maps. The updated final velocity model is used to run isotropic Kirchhoff's PSDM with an aperture of 8.0 km. Figure 2 shows the processing sequence and the parameters.

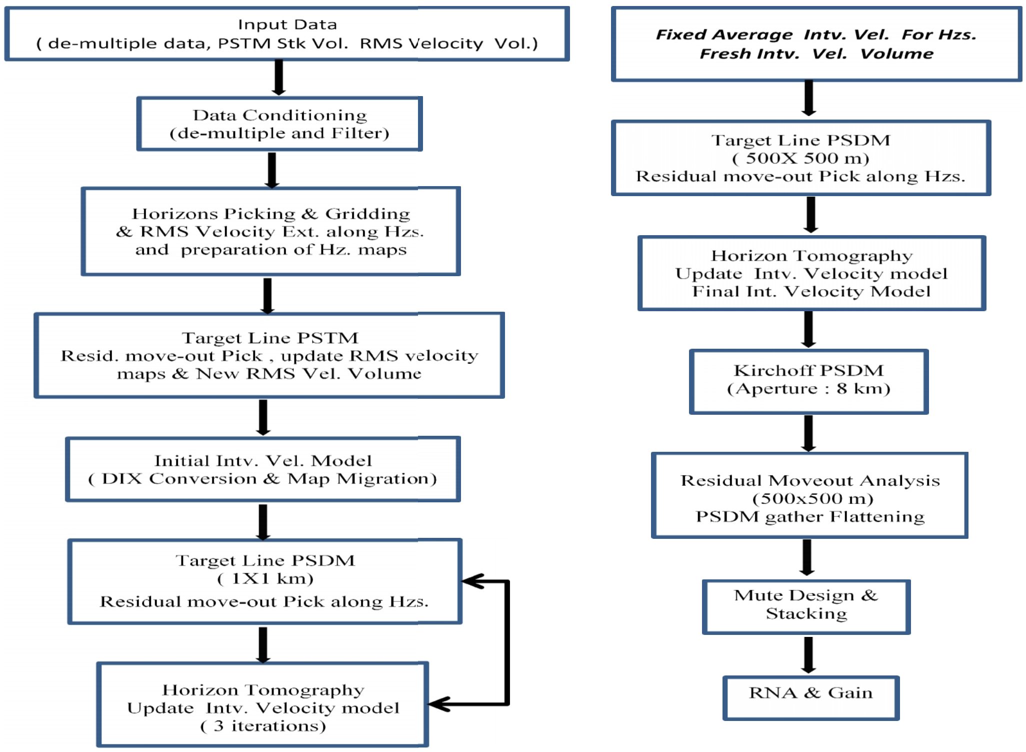

Figure 2. PSDM processing scheme

Results and discussion

The RMS velocity maps derived from initial RMS velocity volume depict high and low velocity bands as seen in figure 3A & 3B, however, time structure maps depict NW-SE trending major fault systems (Figure-4) having throw of 30-50 ms . These bands did not impose serious imaging problems in time domain; however, it would be detrimental to the imaging in depth domain, since small change in RMS velocity result in large variation in interval velocity. Therefore, it is decided to run PSTM once again to refine RMS velocity volume. The updated RMS maps now depict two major fault trends and very well corroborate with the time structure maps (Figure 3A &3B). The fault trends are seen on RMS velocity maps for the horizons 3, 4 , and 5 very radically. However, RMS velocity map for the horizon 6 shows some low velocity patches corroborating with the seismic anomalies.

It is deduced from the study that RMS velocity volume must be very accurate to start model building; otherwise it will be difficult to arrive optimum interval velocity model for PSDM processing.

The initial interval velocity maps corresponding to horizons 3, 4 and 5 derived from Dix (Dix C. H., 1952) conversion depict the fault trends nicely. An anomalous low interval velocity patch is observed on horizon-6 which corroborates very well with the seismic anomaly (Figure-5).

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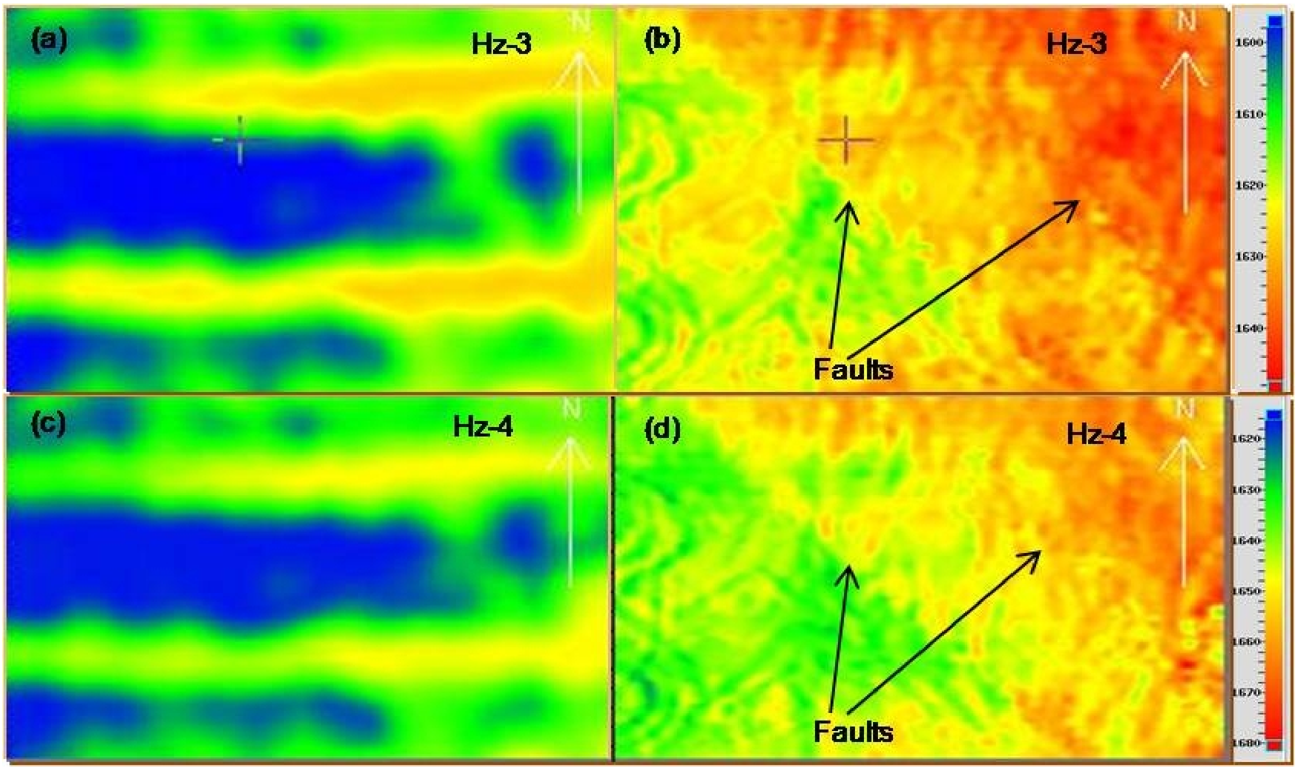

Figure 3A. (a) and (c) are RMS velocity maps for horizon 3 and 4 extracted from the initial RMS velocity volume and (b) & (d) show velocity maps extracted from the refined RMS velocity volume depicting two NW-SE trending faults in the area

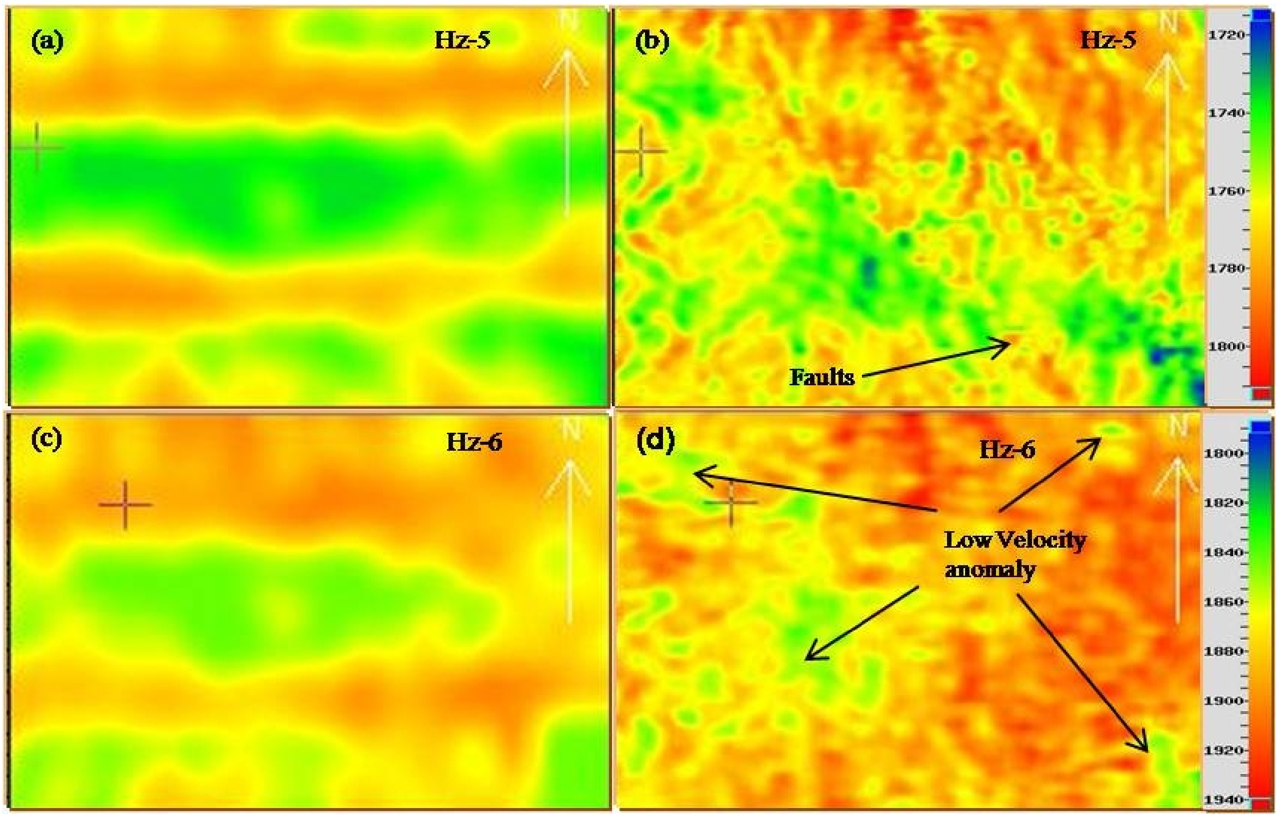

Figure 3B. (a) and (c) depict RMS velocity maps for horizon 5 and 6 extracted from the initial RMS velocity volume. (b) & (d) are velocity maps extracted from the refined RMS velocity volume. Two major NW-SE trending faults in the area are clearly seen on velocity map of Hz-5.However, low velocity pockets corresponding to seismic anomalies are seen in velocity map of Hz-6.

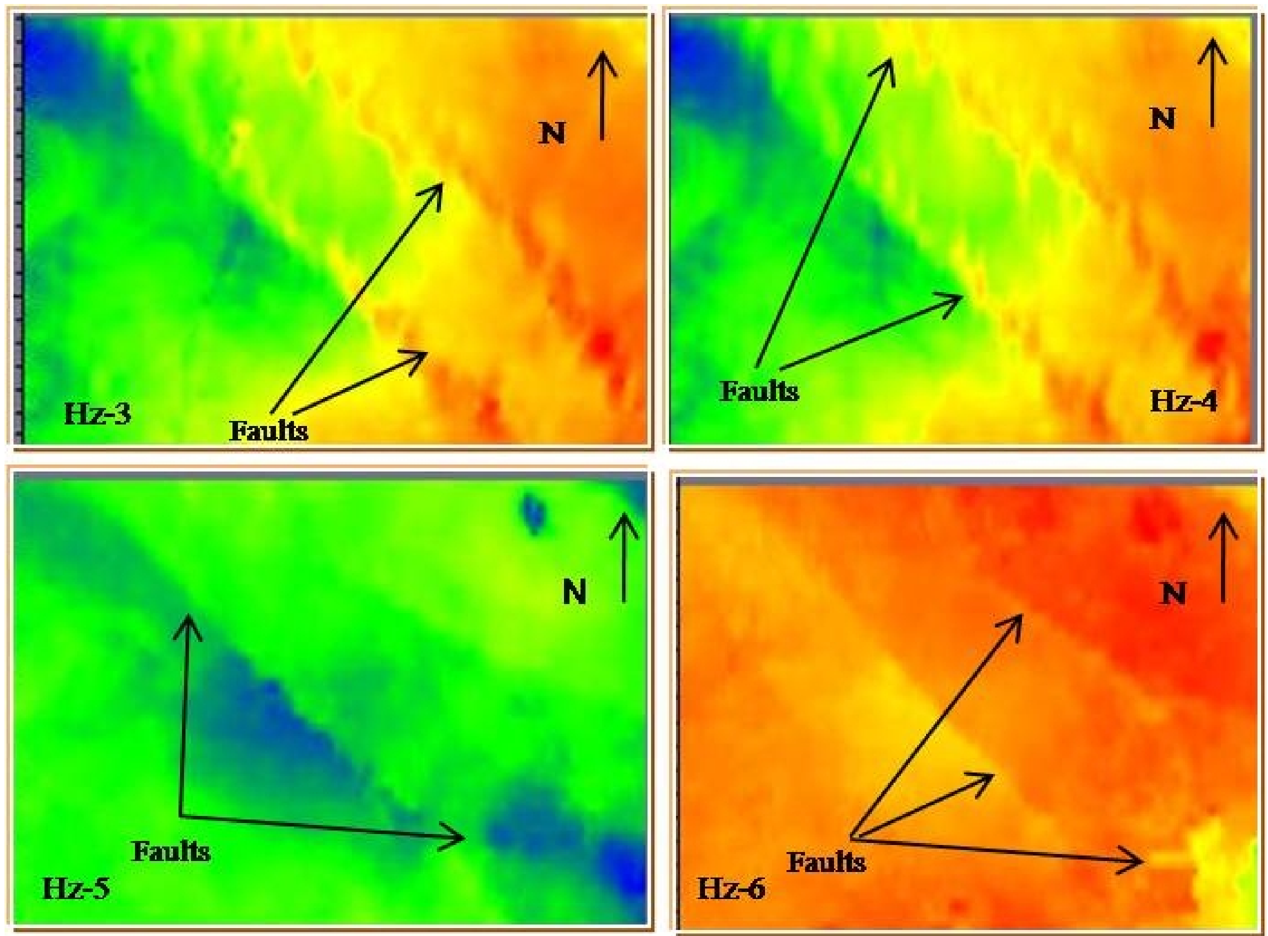

Figure 4. Time structure maps for the horizons 3, 4, 5, and 6 depict NW-SE trending major faults in the area. Blue colour depicts relatively shallower and red colour depicts deeper time values in each horizon maps.

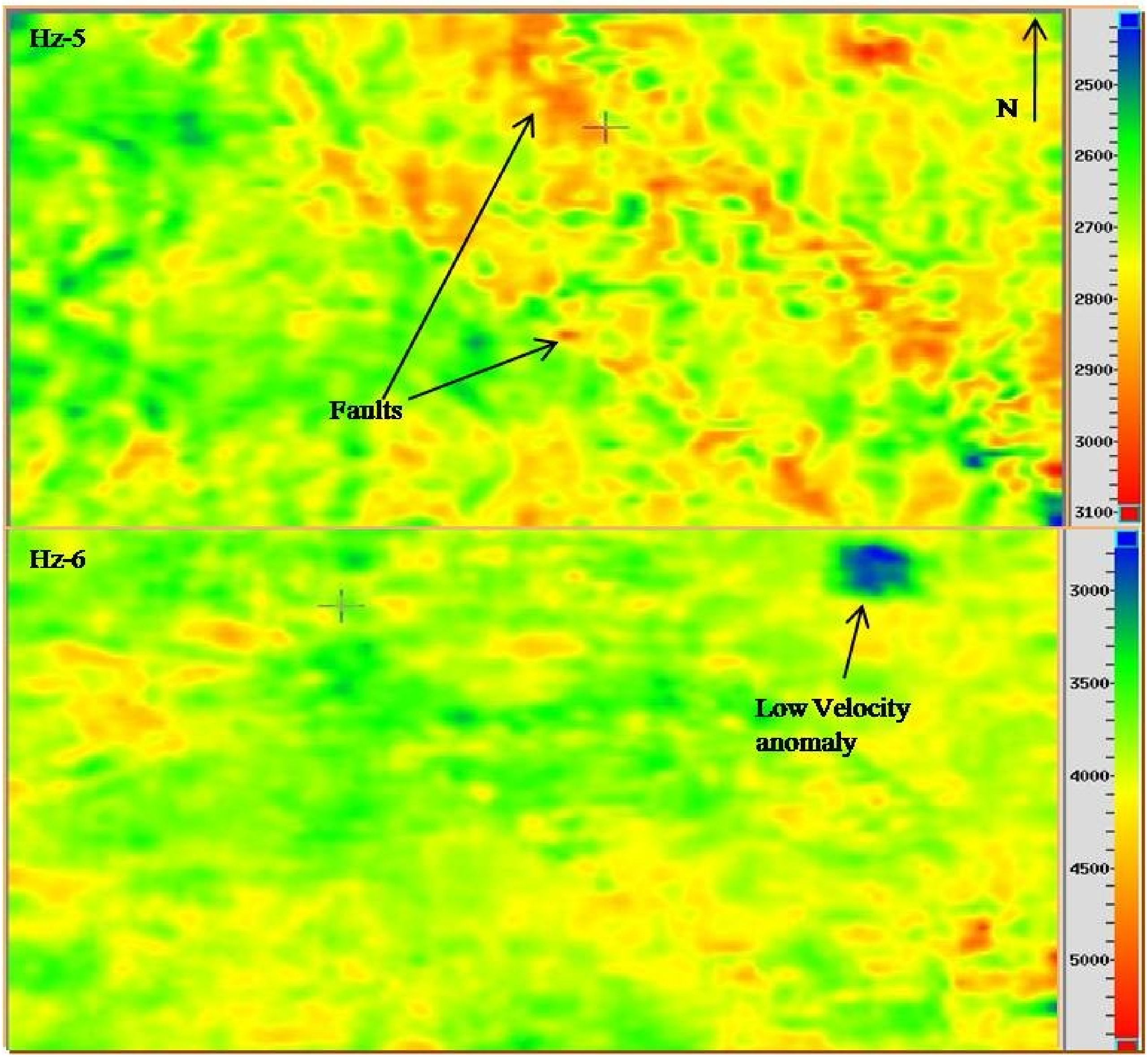

Figure 5. Interval velocity maps for horizon 5 and 6 derived from DIX conversion. Two major fault trends are seen very clearly on velocity map of Hz-5. However, Velocity map of Hz-6 depicts a low interval velocity patch in the NE corner of the area and it corresponds to a seismic anomaly.

Three iterations of horizon based tomography have been carried out to update and optimize the interval velocity maps. The low interval velocity patches on Horizon-6 observed in the initial interval velocity model survived the tomography processes and the PSDM gathers show more or less flattened reflection events. The optimization processes for interval velocity could have been terminated since the residual moveout in the PSDM gathers are neglegible. But low velocity patches observed on velocity map of Hz-6 created some doubt about the velocity model. It is therefore, an innovative approach is adopted to further optimize and gain faith in the velocity model. In the process, an average interval velocity is derived from the final interval velocity map for each horizon and a new interval velocity volume is created having each layer a constant interval velocity. Once again target line PSDM is run and residual moveout analysis in a grid 500X500 m is carried out. The horizon based tomography resulted final interval velocity maps for each horizons. Figure-6 depicts the interval velocity maps for horizon 5 and 6 before and after final tomography. The NW-SE faults seen on velocity maps corresponding horizon 3, 4 & 5 and the low velocity patches on velocity map of horizon-6 are significant outcome of this experimentation.

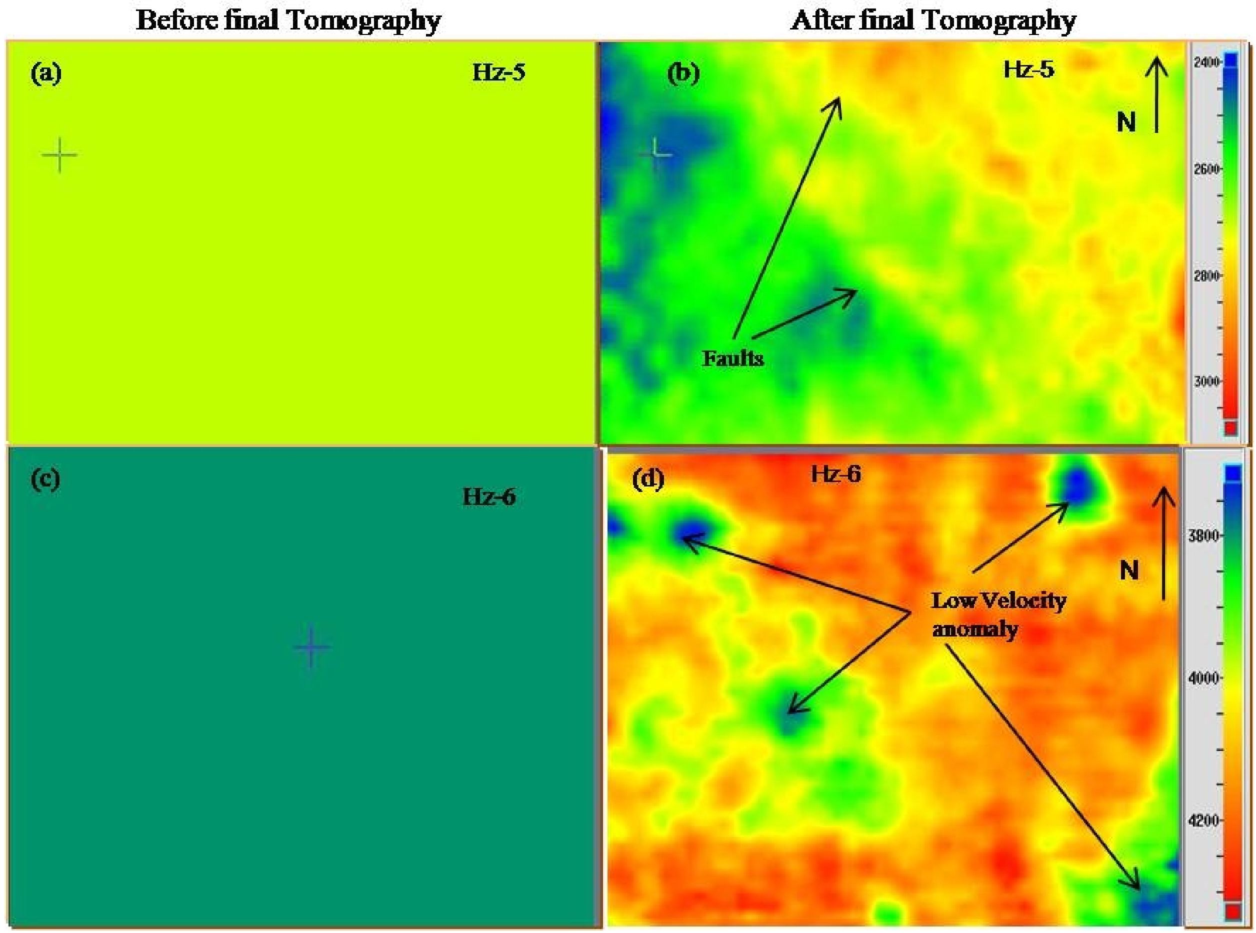

Figure 6. Interval velocity maps for horizon 5 and 6 before and after final tomography. Two major fault trends are seen very clearly on velocity map of Hz-5 after final tomography (b). However, Velocity map of Hz-6 depicts several low interval velocity patches in the area and they correspond to the seismic anomalies (d).

Velocity maps depicting structural features including fault systems are unique outcome of this study which is a copy book example of velocity model building for PSDM processing. The velocity volume thus derived is used for isotropic Kirchhoff's PSDM using 8.0 km migration aperture. The PSDM gathers are flat and stacked after applying inner and outer mute function. Figure-7 shows PSDM stack section overlain by interval velocity.

The seismic anomaly at depth interval 4500-5400 m shows significantly lower interval velocity (~ 3200 m/s) than on either side (~ 4200 m/s). The seismic character and the interval velocity of the layer suggest a limestone sequence of Eocene age (??) and the seismic anomaly may be due to lithology change (dolomitization/secondary mineralization). This kind of seismic morphology in Mahanadi and KG Basins, India turned out to be mud volcanoes after drilling (Subir Das et al., 2013). Therefore, these kind of seismic anomalies present in the area might be mud volcanoes. These seismic anomalies might be caused by fluid movement from below. Deep sited fault running from basement to the top of the section is very much evident. Just below that seismic anomaly, very high velocity (6000 m /s) chaotic reflection events are seen which might be interpreted as magmatic flow from the Ninetyeast Ridge. The Ridge ends in this part of West Andaman basin and buried under the Bengal fan sediments (Schlich R. ,1982) .The Ridge seems to be the major cause of basement related NW-SE faults running up to the Pliocene sediments.

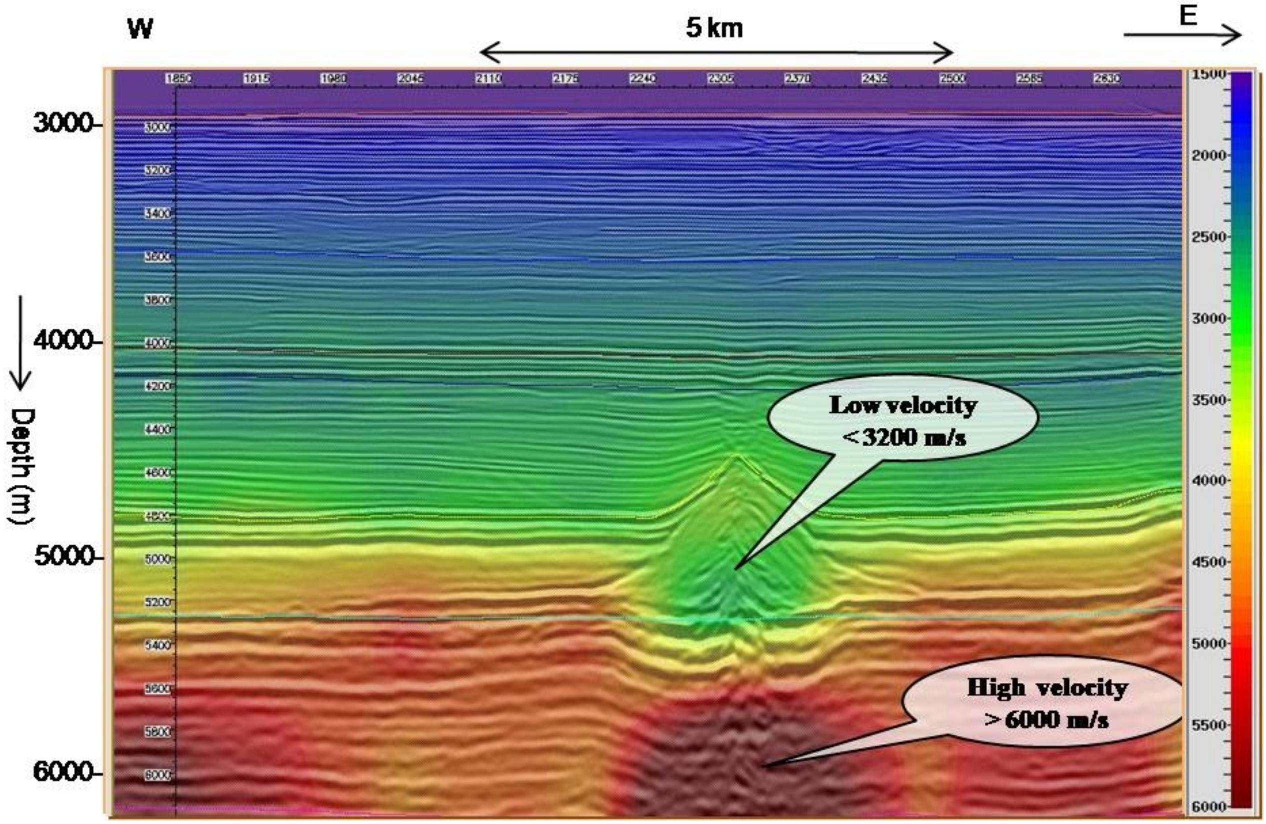

Figure 7. The PSDM stack section overlain by final interval velocity depicts low velocity corresponding to the seismic anomaly. Very high velocity below this anomaly may indicate possible magmatic body.

Conclusion

The study is an attempt to demonstrate an innovative interval velocity model building approach comprising two steps. Firstly, RMS velocity refinement is done by running PSTM twice, secondly, after a few tomographic iterations, average interval velocity is fixed for all the horizons and new velocity model is created. One more tomographic iteration after target line PSDM and residual moveout analysis provided the best interval velocity model. This velocity model building scheme for PSDM processing has resulted in very good subsurface imaging. The velocity model obtained showed higher confidence. The velocity variation observed within the layer (between Hz-5 and Hz - 6) seems to be genuine and caused by fluid influx from below or some localized lithologic changes or it might be a mud volcano. The present study very clearly demonstrated that the seismic anomaly shows significantly lower interval velocity than on either side. The velocity maps mimicking the structural maps and flat CRP gathers are the testimony of very good velocity model resulted from this scheme.

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