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Structural Modeling and Seismic Attributes Analysis of Synrift Sequences in East Andaman Basin: A Qualitative Approach towards Fault Seal Analysis in a Frontier Exploration Area

Mahendra Kishore*, Pritam Jha, Dino Ros; *Eni India Ltd., New Delhi, India.*

Summary

East Andaman Basin (EAB) is a north-south oriented elongated basin located in the Andaman Sea. This basin is bounded by the Mount Sewell Rise at its East and the Mergui Ridge at the West. Recent studies by Eni operated consortium reveal that the basin originated during Paleogene in response to the back-arc related extension (rifting) and is time & genesis-equivalent to the other rift basins present on the western margin of Sundaland (namely North Sumatra, Mergui, Moattama Basins). East Andaman basin has undergone series of complex events and is currently in ultra-deepwater setting (avg. water depth 2000m and more).

Recent 2D and 3D seismic surveys results indicate that the basin has accommodated a thick pile of sediments through Cenozoic. Interpretation of these high-quality data points out that the area has undergone intense structural deformation manifested in innumerable faults. To de-risk the fault related hydrocarbon entrapment issue, fault seal analysis is an absolute necessity which needs to be taken care of. A streamlined method of integrating seismic interpretation volume and complex attribute volume was used as a time geological model, which was then converted into depth geological volume using stacking velocity in the absence of well data. The resultant volume indicates relative shaleness parameter of the rocks, which was analyzed for qualitative fault seal analysis.

Introduction

During the Cenozoic, a number of active subduction zones bordered the Sundaland due to the closure of Tethys and opening of Pacific Ocean. Rapid advancement, collision and subduction of Indian Plate with the relatively stationary Eurasian Plate coupled with eastward movement of China away from India created significant changes in the stress regime of the area. These tectonic events forced Sundaland to take a clockwise rotation, which eventually was expressed by series of regional strike-slip faults along its western margin. As a consequence of these geodynamic processes, subduction of the Indian Plate beneath Sundaland became increasingly oblique and eventually led to the development of associated transtensional basins across the region (Polachan & Racy 1994, Hall 2002, Curray 2005, Doust & Sumner 2007, Jha et al. 2008).

The Early Eocene onwards subduction of Indian Plate below Sundaland subsequently gave rise to typical destructive plate margin features; the western Sundaland therefore was in a back-arc setting since then. As the subduction was oblique in nature with principal stress in roughly N-S direction, the area was under enormous transtensional stress. This stress stretched the continental mass of Sunda through extensive rifting (presently oriented in a gross north-south direction). The continuing subduction and relative plate movement also put additional rotational component into the system, which are manifested by the roughly N-S trending regional right lateral strike slip movements in the form of typical pull-apart features (e.g. West Andaman Fault, Sagaing Fault, East Andaman Fault, Samalaga Fault, Mergui Fault and Ranong-Khlong Marui Fault Zone etc.). The latest and most prominent manifestation of this pull-apart tectonics can be envisaged at the Central Andaman Basin, which is a nascent NE-SW oriented spreading center (Raju, 2005).

As the East Andaman Basin is located almost at the centre of Andaman Sea under, it has experienced a very strong and complex tectonic history, with initial extensional phase (rifting) followed by the strike slip movements. As a result, intense deformation of the rocks can be clearly envisaged in the high quality seismic data. A fault seal analysis is

Eni India Ltd., Eros Corporate Tower, 14th Floor, Nehru Place, New Delhi-19; email: mahendra.kishore@eni-india.com

therefore essentially required to risk the entrapment parameters.

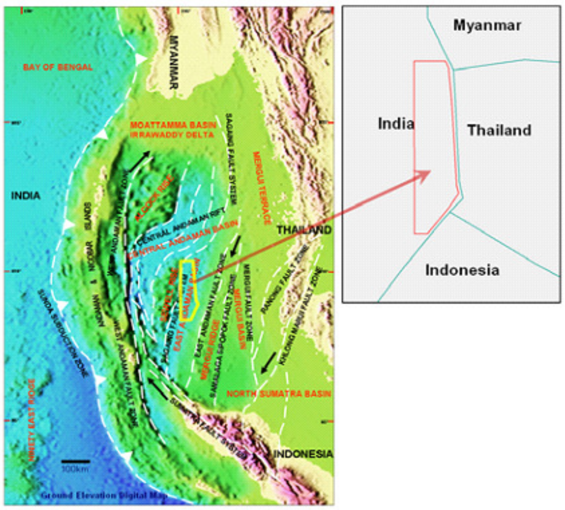

Fig. 1: Simplified tectonic map of Andaman Sea region with basins, major tectonic features and regional faults (white stripes). (Inset) The Eni operated deepwater block.

Structural Model

The purpose of the creating structural a model is to understand, describe, or predict how things work in the real world by exploring a simplified representation of a particular object or setting. The study area is situated at the southern part of the East Andaman Basin, where detail mapping reveals very complicated fault system. A structural model in time-seismic was created with regional faults only. Seismic interpretation of the study area shows the presence of two major fault trends (Fig. 2) and characters. 1) The N-S trending strike slip fault (Fig. 3A) which runs parallel to the regional strike slip fault direction trends. 2) The NE-SW trending domino style extensional faults (Fig. 3B).

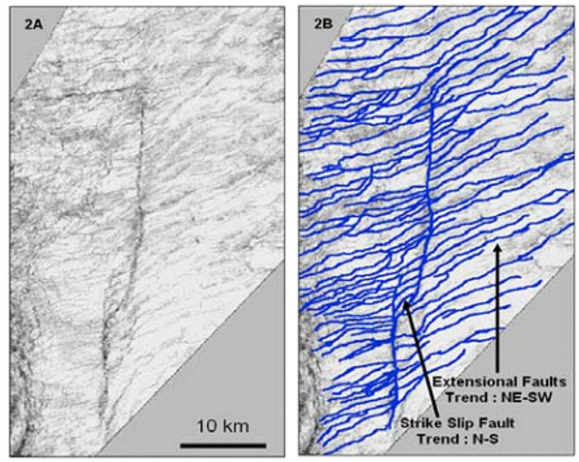

Fig. 2: Continuity map of a horizon within synrift level showing two major fault trends (2A) with interpreted faults (2B).

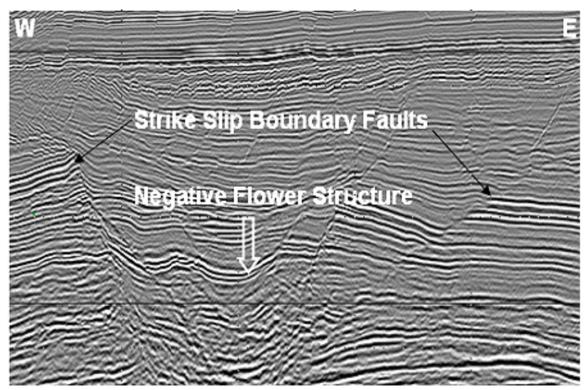

Fig. 3A: Seismic section showing the pull-apart feature (negative flower structure).

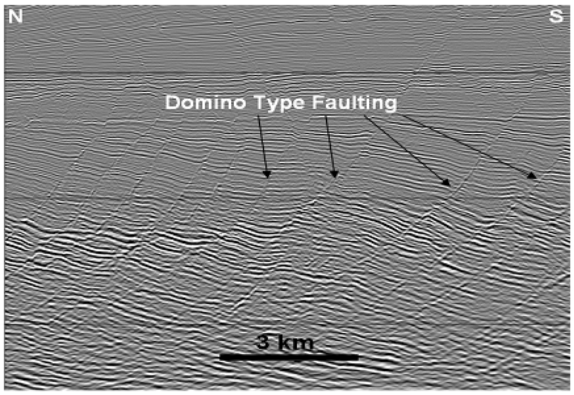

Fig. 3B: Seismic section showing the domino type faulting in the extensional regime.

The faults were interpreted in time migration volume and the fault sticks (seismic fault interpretation) were analyzed in the 3D view for QC purpose. It was observed that the NE-SW faults truncated against the N-S faults and subsequently the fault model was generated. The fault model creation is the major step for generating a structural model as it honors the proper orientation and height of fault planes. The skeleton grids of 50mX50m cell were then generated. One of the advantages of this process is that the grid is created based on the faults and not based on the surfaces themselves (only the fault information from the surfaces). Vertical layering or the creation of stratigraphic horizons and subdivisions is the final step in structural modeling. To put stratigraphic horizons in model, the first step is to make horizons that honor the grid increment and the faults defined in previous steps. The positions of the projected horizons will then show fault displacements across individual faults.

The process mentioned above produced the structural model for synrift sequence of East Andaman basin study area. The grids of each and every level of synrift sequence were then posted on time migration volume along with the faults (Fig 4A). Afterwards a detail QC was performed to refine the structural model. Since the layering within the zones is the key to make the final structural model, in the absence of borehole defined discrete geological facies log, 50ms vertical thickness were taken to generate the proportional layering with in the zones (Fig. 4B). The 3D structural model is the one of best ways to understand the tectonic setting of the prospect area/reservoir. However it does not describe the seismic facies variation within the zones. The zones are empty in the structural model and there is a need to generate the seismic facies volume to fill the zones of structural model.

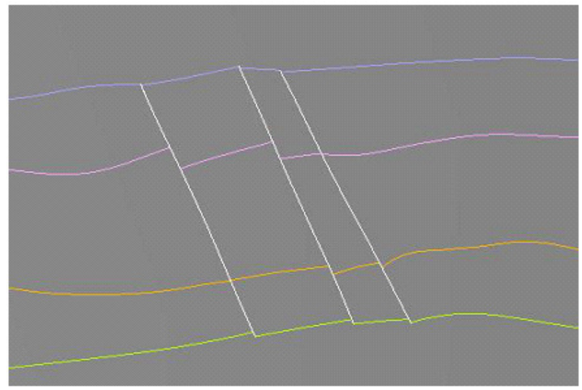

Fig. 4A: Structural model without layering with in the zones.

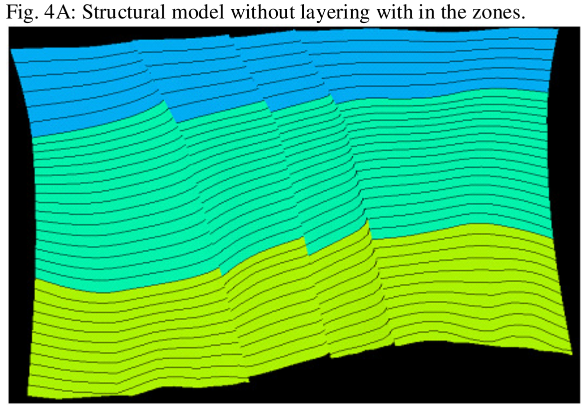

Fig. 4B: Structural model with 50ms of defined layering.

Seismic Facies Volume

There are number of ways to drive the seismic facies volume that depends upon the area considered for the study. The area considered here for the study is in the exploration stage and no well has been drilled so far. The well data is always an advantage in computing the seismic facies volume as facies log of the well can be used as an absolute input data.

In exploration area with no well control, the only or the best way to derive seismic facies is through the study of complex seismic attributes analysis. The seismic attributes can be analyzed by cross plots and correlation matrices. For the purpose of seismic facies volume computations, the thumb rule is that the seismic attributes considered as an input data must have the negative correlations among each other, in addition to the positive correlations. Once the seismic attributes are finalized, the seismic facies distribution can be generated with the help of neural network.

Following the principles, various seismic volume based attributes were generated in the area of interest and their relationships were then identified with the cross plots, correlation matrices and principle component analyses. Finally the Relative Acoustic Impedance (Fig. 5A), Sweetness (Fig. 5B), Envelope and Continuity volumes were identified for the generation of Seismic Facies volume.

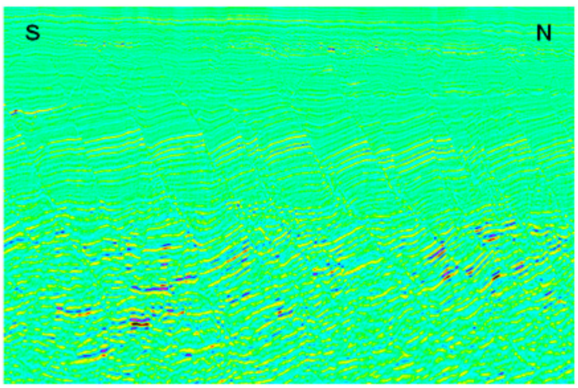

Fig 5A: Time seismic profile on Relative Acoustic Impedance volume.

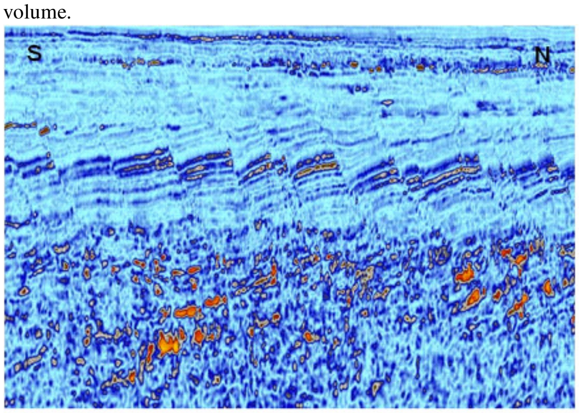

Fig 5B: Time seismic profile displayed on Sweetness volume.

The Back propagation neural network was used to compute the seismic facies volume. A Neural Network is an interconnected assembly of simple processing elements, units or nodes, whose functionality is loosely based on the animal neuron. The processing ability of the network is stored in the inter-unit connection strengths, or weights, obtained by a process of adaptation to, or learning from, a set of training patterns. This method goes backward with defined number of iterations to optimize the error and drive the desired results. There are two very commonly used neural networks:

1) Supervised Neural Network, & 2) Unsupervised Neural Network.

The training data set (like well data in the form of well tops or discrete facies log) is required to follow the supervised neural network and there is no training data set required to run the unsupervised neural network. Unsupervised seismic facies analysis provides an effective way to estimate reservoir properties by combining different seismic attributes through pattern recognition algorithms. However, without consistent geological information, parameters such as the number of facies and even the input seismic attributes are usually chosen in an empirical way.

Since there was no training data set available the network in area of interest, unsupervised neural network was used to generate the time seismic facies volume (Fig 6). The three colors (red, yellow and green) were chosen to compute the seismic facies volume. It was assumed that red color class could represent better reservoir facies (coarser clastics) sequences in comparison to the green and yellow (finer clastic sequences).

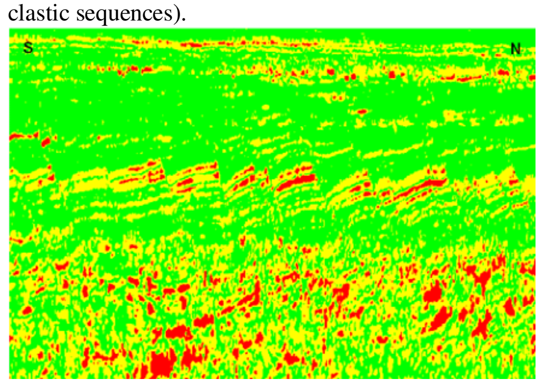

Fig. 6: Seismic Facies Distribution in time (red representing the best reservoir facies and green the poor reservoir facies).

Velocity Modeling & Depth Conversion

The layer cake velocity model approach was used in making of velocity model. The advantage was that structural model was already created for the area of interest. Between the zones of structural model, stacking velocity data was also re-sampled to create the velocity property. The re-sampling of velocity yields a velocity property, which provides better control of velocity variation in the structural setting. The velocity property was then used to define the layer cake velocity model (Fig 7A).

This velocity model is very robust and it reduces the vertical stretching problem during the domain conversion process (as usually observed for simple layer cake models using stacking velocity and grids of the area).

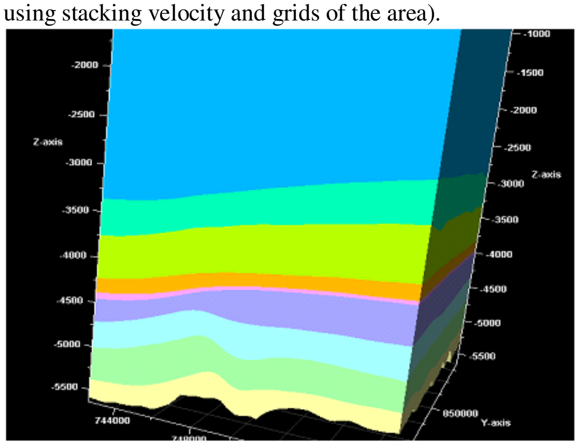

Fig 7A: Layer cake velocity model prepared with velocity property.

Once the velocity model was ready for the study area, time migration volume and seismic facies volume were converted from time to depth domain. The same velocity model was then used for converting time structural model to depth structural model. The 50m vertical thickness was taken to perform the proportional layering within the zones (Fig 7B).

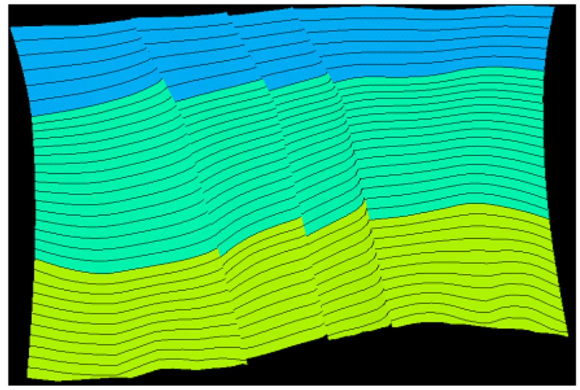

Fig 7B: Depth Structural Model with 50m layering

Depth Geological Model

The depth structural model gives better understanding of tectonic setting of sub surface. It becomes a challenge to understand the lithology / facies variation within the zone defined in structural model and therefore geological model creation is required to address the facies variation in time and space.

The first step of deriving the geological model is to define layering between the zones as described above. Depth shaleness indicator volume was then re-sampled honoring the depth structural model as the second step to come up with the depth geological model.

The "most of the method" of geometrical modeling was subsequently used to derive the geological model property. Geometrical properties are the 3D properties created by using the pre-defined system variables such as cell height, bulk volume and depth. Each cell then gets a numerical value corresponding to the selected system variable. A linear correlation was performed in depth seismic facies volume to convert into shaleness volume that represents the shale percentage within the sequences. The shaleness distribution without structural setting (Fig 8A) and with structural setting (Fig 8B) was used as a qualitative approach for fault seal.

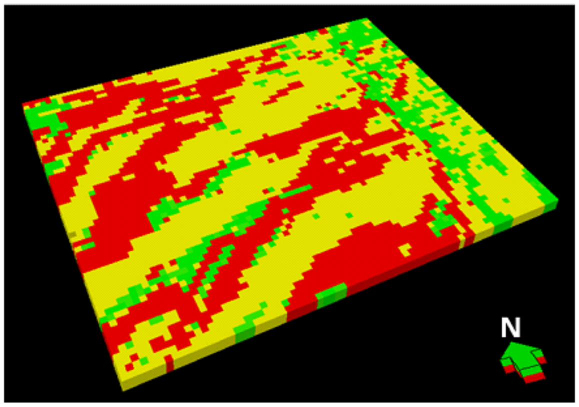

Fig 8A: Shaleness Distribution along a seismic horizon without structural setting.

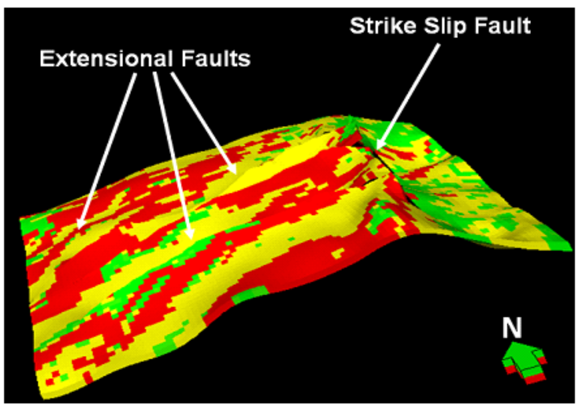

Fig 8B: Shaleness distribution along a seismic horizon collaborated with structural setting.

Conclusions

Seismic data interpretation of the study area of East Andaman basin concludes that the area under consideration is heavily faulted and affected by two major fault trends, NS trending strike slip movement and NE-SW trending extensional fault system. Integration of the structural model with seismic attributes yielded a time volume of seismic facies (Fig. 9A), which displayed the shaleness volume in time in assigned color classes (red as best, yellow as moderate and green as poor). Depth conversion of this time geological model through a velocity model (created from the stacking velocity of seismic volume in absence of borehole data) and re-sampling of the product generated the final depth geological model with shaleness distribution (Fig. 9B), which can be used as fault seal indicator.

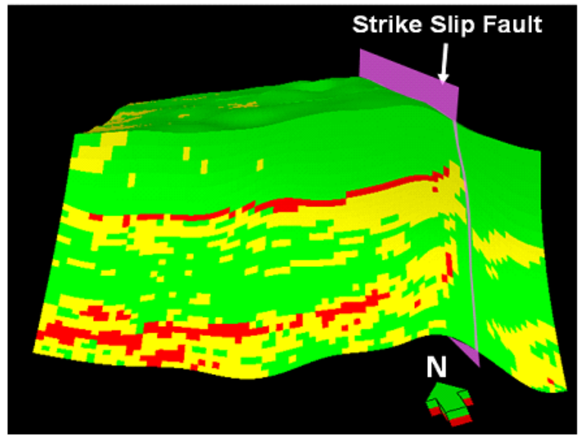

Fig 9A: Shaleness distribution in time seismic volume with structural model along the strike slip fault.

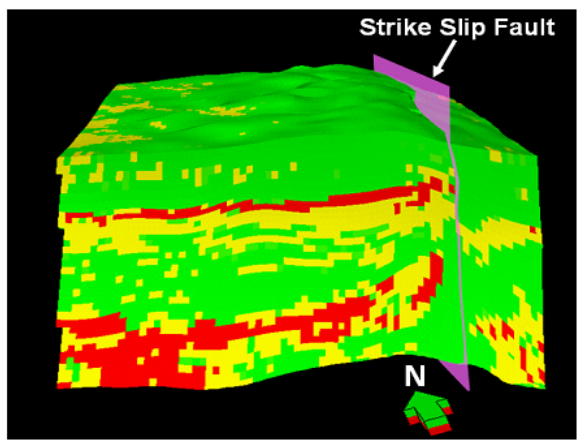

Fig 9B: Shaleness distribution in depth seismic volume with structural model along the strike slip fault.

It was observed that best possible reservoir facies (red color facies) is juxtaposed against the poor reservoir facies (green colored facies with highest shaleness component) along NS strike slip fault. This qualitative study therefore brings an estimate towards the fault seal analysis, where a possible entrapment scenario can be envisaged. However, the realization of this model with quantitative approach for fault seal analysis can also be further worked out.

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