P 077

# Seismic Mapping of Inversion and Shear zones, generation of oblique shears and associated structures and implications on hydrocarbon entrapment: A case study from a Miocene oilfield of Upper Assam, India

*Dr.Gupta S.R*., Singh, Chiranjit, Mishra Ashish*

***Summary***

*Post Miocene tectonics is believed to have caused final structurization that has resulted in entrapment of hydrocarbons across major fields of North Assam shelf. Two major fault trends are identified in the region; the earlier Permian age rifting associated down to basement sub-longitudinal faults and the later cross trends associated with the main Himalayan orogeny. During the later phases of deformation the earlier faults were reactivated and oblique movement along them often resulted in renewed movement and modification of earlier fault geometry (commonly referred to as inversion), formation of en-echelon oblique shears and associated folds. These features associated with both the major fault trends have been mapped in a small sized oil field of Upper Assam. It was also remarkable that such features are best developed in incompetent lithologies, such as interbedded sand/shale of Oligocene sequences. The variation in intensity of deformation from older to younger sequences has also been brought out. The study also identifies new prospective structures, associated with shear faults, in the deeper Palaeozoic sequences, on the rising flanks of the regional low*

**Keywords:** *Longitudinal and Cross faults, oblique shears and associated structures, fault inversion, hydrocarbon entrapment*

## Introduction

The study has been carried out on a small sized oil field of upper Assam that has sequences ranging in age from Eocene (directly underlain by the Basement) to recent sediments. The field is producing oil from structural traps in Miocene sequences on either side of a deep seated NNE-SSW trending major fault which is the earliest tectonic trend and is cut by the younger ENE-WSW trend. The last stage of deformation caused inversion of the earlier deep seated faults, closure and plunge of earlier folds, generation of fresh oblique shears and small scale en-echelon folds. These later deformations had a great bearing on hydrocarbon accumulation as they are believed to have opened up the earlier faults as well as created new ones that facilitated charge migration and accumulation.

The area has been earlier studied by various G&G groups of ONGC as well by a number of Task Forces, but a satisfactory working and tectonic model is still elusive. A channel based sedimentological model for hydrocarbon entrapment was also proposed earlier by Gupta et al,2012.

## Methodology and Observations

Seismic logs, correlated and tied to seismic horizons. Horizons corresponding to Basement, Eocene (Sylhet), Oligocene (Barail), Miocene (Tipam sandstone TS5, LCM, TS1 and Girujan Clay), were mapped. The volume was studied both in Landmark and petrel software and involved identification of the major tectonic trends of the area, the nature and mapping was carried out in PSDM seismic volume covering an area of approx. 80 sq-km. The main formations were picked from well sequence of deformation, generation of later oblique shears and effect on deformation on incompetent beds (such as interbedded sandstone, shale and coal sequences of Oligocene). An attempt was also made to study the inversion tectonics and its role in generation of structures.

*KDMIPE,ONGC*
*raj42802@yahoo.co.in*

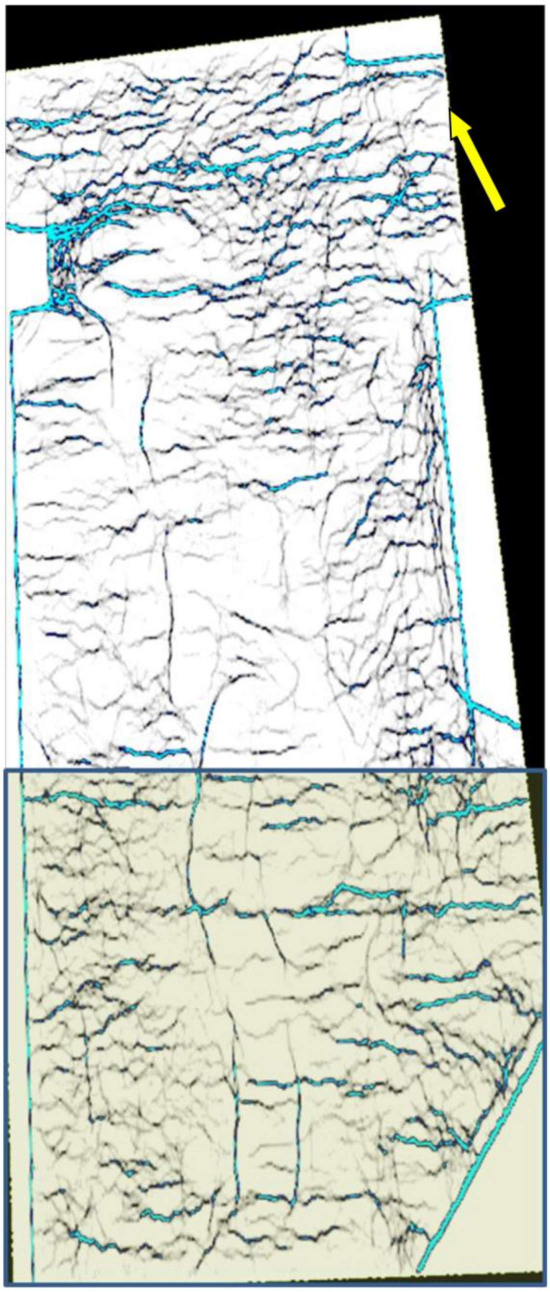

Fig1. Lineament Patterns seen in Regional Volume (study area shaded)

Fault and fracture patterns were extracted both in Petrel and Landmark software. A fracture identification tool- Ant tracking was applied at various depths to extract the main fracture patterns and deformation sequence. . The flowmap used to extract the fault was seismic data realization – smoothening - variance cube generation – ant tracking on this variance cube. The result was very strong N-S and E-W fault traces. On further using stereo filter in N-S direction for getting longitudinal fault and E-W filter to get cross fault the result was very clear and it brought out the relationship between both the fault trend. Structure maps were generated at main formation surfaces- Sylhet, BCS, Lower Clay Marker (LCM) and Pliocene. New Prospect analysis was also carried out in respect of Lower Eocene formations (Tura and Sylhet).

Following were the main observations-

1. The main tectonic trends are the earlier NNE-SSW and the later WNW-ESE.

2. The later cross trend caused swings and displacement in the earlier longitudinal trend. Fig1 shows the main NNE-SSW fault that has been deformed by later transverse movements. (A larger volume has been taken to see the regional trends; the studied area is restricted to the lower half)

3. During late stage of deformation rotation of stress axis took place and it reactivated the earlier faults as well as caused strong shearing movement in the earlier structures. New oblique shears and smaller folds were also produced. The complex of fractures at different levels is shown in Fig2. The pattern of deformation corresponds to a typical pure shear with intermittent sigmoidal fracture zones and small scale folds. Fig 3 depicts the theoretical development of a typical shear zone deformation pattern and associated structures which are seen to be replicated in a seismic line of the studied area.

4. The oblique shears developed at acute angles to the first generation longitudinal fractures. Figs 4&5 bring out the two main trends of associated oblique shears extracted by ant tracking on Petrel.

5. The Shearing also affected different formations variably. The maximum deformation is seen in the interbedded Barail coal -shale and sandstone –shales sequences due to prevalence of incompetent argillaceous facies that provide easy planes for slippage. Numerous small scale folds and faults are seen in this formation (Fig7&8). The overlying Tipam comprising thick sandstones and shales/clays are also highly deformed while the underlying Eocene formations are well folded but not as extensively fractured due to more ductile deformation at lower depths (Fig 2).

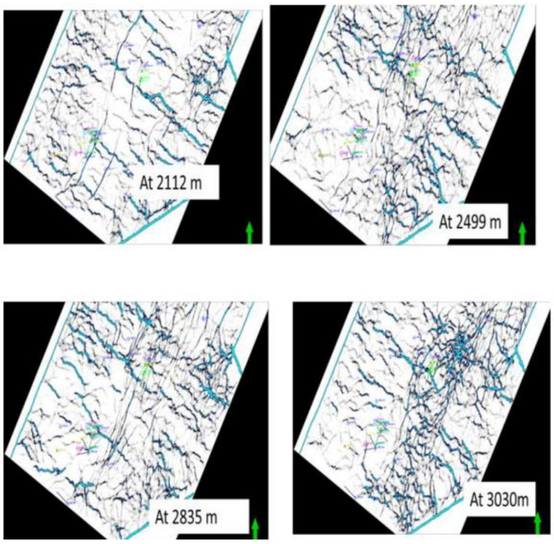


Fig2. Lineament Patterns seen in at different depths Intensity of Fracturing increasing in BCS Layers (2835m)

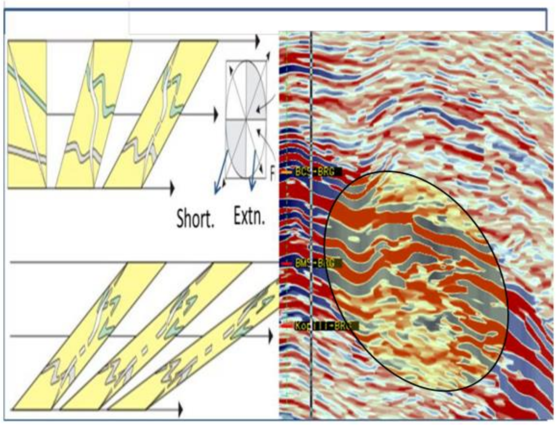


Fig3. Schematic development of structures in Shear Zones and Analogous structures seen in Study area

6. Numerous fold/closures in Tura, Sylhet, Kopili and Barail formations with amplitude of around 100m are observed to be associated with the shear faults developed in the SE part of the area (Fig6).

7. Presence of oil on the downthrown side of the fault in South-Eastern part of the field on the downthrown side of the fault in South-Eastern part of the field has been proved in this area by conventional testing of well #11 which flowed oil for a few minutes in Lower Tipam (TS6).The well is located and located on the rising flank of the regional low to its East.

8. Oil migration in the area appears to be along major faults that have acted as conduits. Fig 9 shows 3-D view of the major faults along with their deformation by shearing and development of closures.

9. As most of the oil wells in the field are in the vicinity of major faults, oil migration and entrapment is also likely along similar structures of the rising flanks of the regional low to the Southeast. The RMS amplitude extracted in the window from 0m to 50 m from Barail top shows the development of favorable facies in the vicinity of the major faults (Fig10).

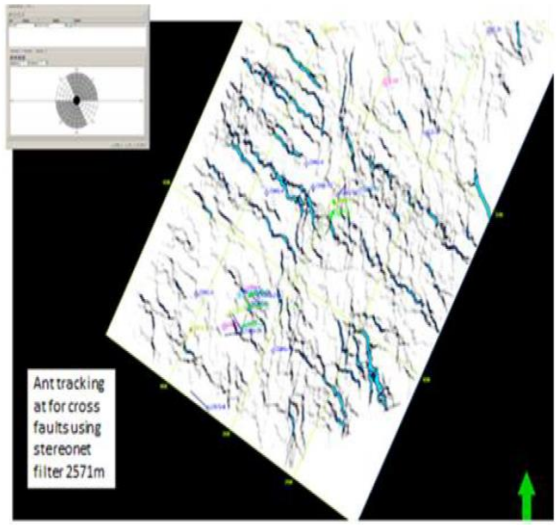


Fig4. Latitudinal and sub- Latitudinal Lineament Patterns Extracted by applying Filter through Ant-Tracking

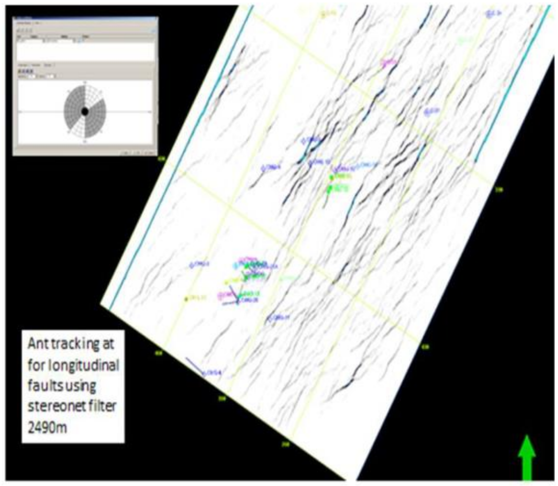


Fig5. Longitudinal and sub- Longitudinal Lineament Patterns Extracted by applying Filter through Ant-Tracking

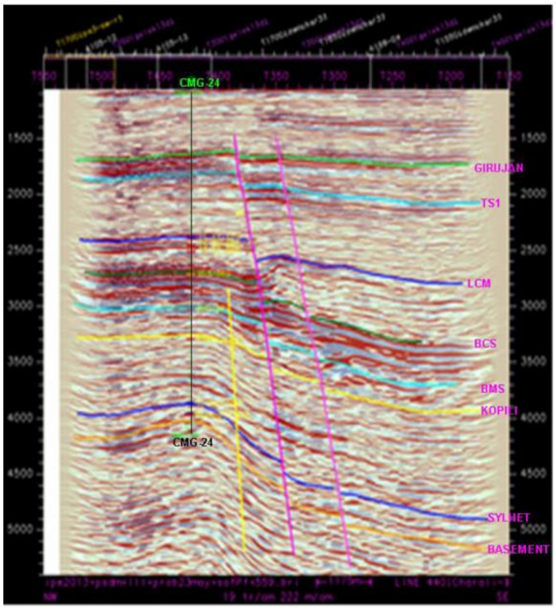


Fig6. NW-SE Line with deepest well #24 (upto Basement) showing Regional Faults and associated structures showing folds in deeper formations in downthrown block

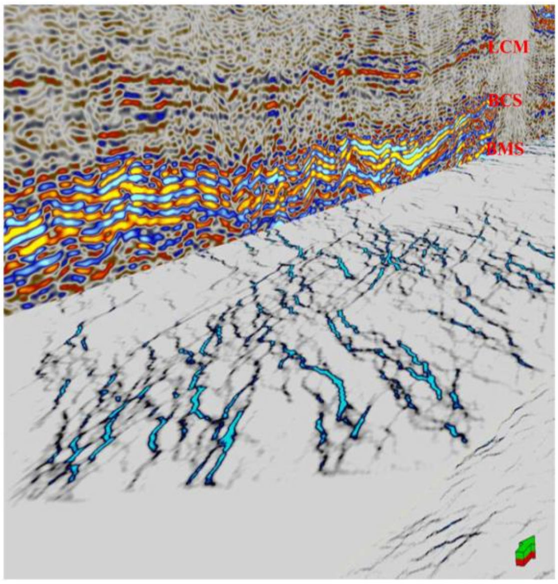


Fig7. N-S line and intersection plane at BMS level showing Lineament Patterns & smaller folds developed by movement along oblique and cross- faults

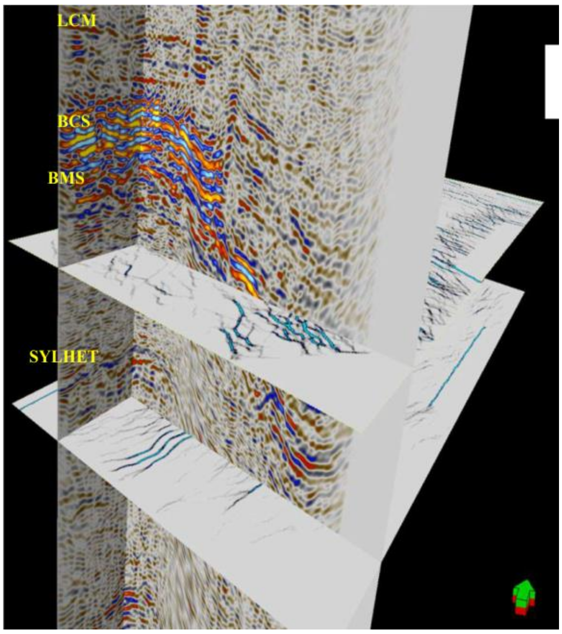


Fig8. Lineament (fault) Patterns and associated folds at BCS, BMS and Sylhet level

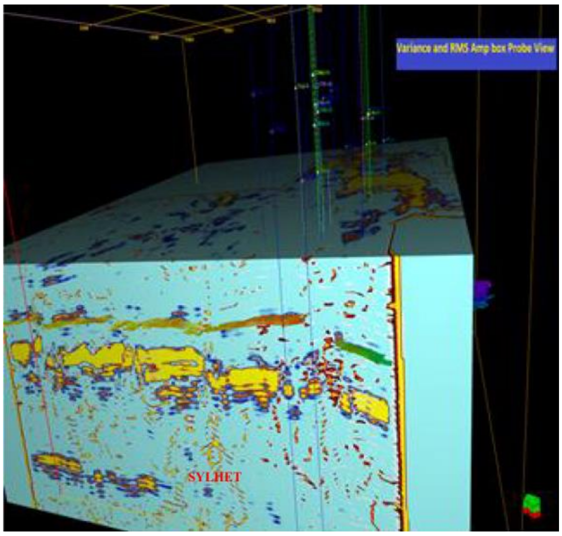


Fig9. Major Faults showing shear distortion, curvature of fault planes and Horizons in Variance and RMS amplitude Box- Probe

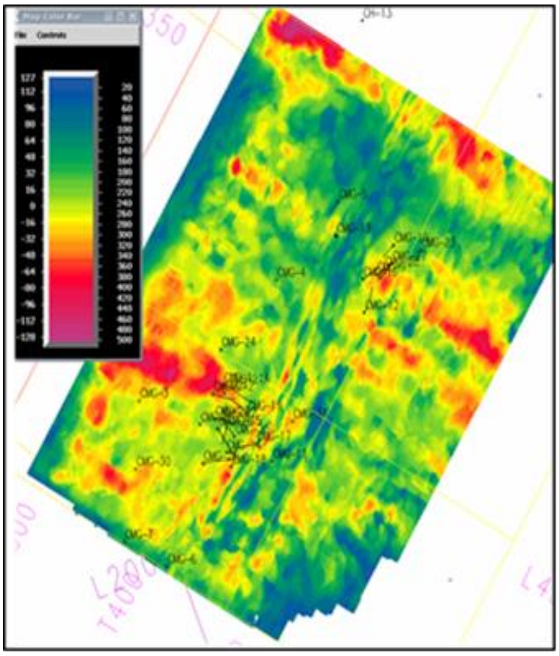

Fig10. RMS amplitude in the window 0-50m from BCS top showing Well locations and swings in the Major Lineament

## Conclusions

1. The earlier tectonic grains have been modified by the last phase of deformation at the close of Upper Miocene, which produced the present day structures.

2. Directive stresses (Shearing) is identified as the process for this late stage deformation, evidenced by development of a network of oblique faults. They also produced a number of small-medium scale en-echelon folds.

3. Incompetent formations were more affected by late stage deformation resulting in generation of a number of faults and small scale folds.
4. A number of fault associated fold closures in the Eocene and Oligocene formations have been identified in the downthrown eastern block of the field that appear favorable for hydrocarbon entrapment.

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