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Prediction of fracture porosity of Eocene limestone near the hinge zone area of Bengal onland Basin

Abstract

As on date, fracture porosity prediction remains one of the most challenging tasks. It is mainly because of the paucity in data availability on fracture intensity, fracture length and fracture aperture. These three properties have major role in the fracture porosity generation. Core and FMI log data provides information of the well point, regarding these parameters; however prediction of its variation in the 3D is a difficult task. In present study, an attempt was made to combine the two methods of fracture modeling, viz. Predictive and Deterministic. Predictive method is based primarily on kinematic and geomechanical restoration and has robustness in capturing the strain regime. Deterministic method focuses on seismic anomalies and provides information about fracture intensity and fracture length in 3D space. The current study characterizes the fracture trends of the Eocene Hinge-Zone of Bengal Basin. Either of these methods suggests two sets of fracture NE-SW and NW-SE within Eocene limestone, within the study area. The results of these two approaches have been used to generate a better Discrete Fracture Network model. Stress modelling results demonstrate Bengal Basin is in strike slip regime.

Introduction

Bengal Basin is a divergent margin sedimentary basin rests over intracratonic Damodar graben and is occupied by the Permo-Triassic sediments of Gondwana super group and then overlain by Rajmahal traps. Thick successions of Late Cretaceous, Paleogene and Neogene sediments are deposited in the basin over Rajmahal Trap.

For the present work merge 3D volume of 900 Sq. Km of subsurface coverage near the Eocene Hinge zone of Bengal onland Basin has been used (Fig.1). Nine wells have been drilled in the study area.Two wells Well-1 and Well-4 have penetrated Paleocene. Well-2 and Well-3 wells were terminated in Eocene limestone. Log data including FMI of these wells were used in this study.

Methodology

The two methods which are widely used to predict the fracture porosity are Predictive Method and Deterministic Method. Predictive method is mainly based on kinematic and geomechanichal restoration and has robustness in capturing the strain. Whereas Deterministic Method is mainly based on seismic anomalies e.g. Ant track, curvature etc. it provides some knowledge about the variation of fracture intensity and fracture length in the 3D space.

In this present study, an attempt was made to combine these two methods so that merits of each method can be used to build a better Discrete Fracture Network (DFN). Strain was captured from geomechanical and kinematic restoration and possible fracture sets were determined. Based on the leads on fracture sets, guided Ant track and other seismic attributes (Variance, Amplitde contrast and Curvature) were generated. All these properties were used to prepare a DFN and it was further validated by well data (Porosity, Cores, and FMI etc.) (Fig.2).

Predictive Fracture Modelling Method

3D structural restoration of deformed surfaces is performed by kinematic and geomechanical techniques. Kinematic restoration removes fault displacement and unfolds deformed surfaces by set geometric rules (area and volume preservation) whereas geomechanical restoration uses the mechanical properties of rocks. In the present study both kinematic and geomechanical restoration of Eocene surface was carried out for capturing the strain required for rock deformation.

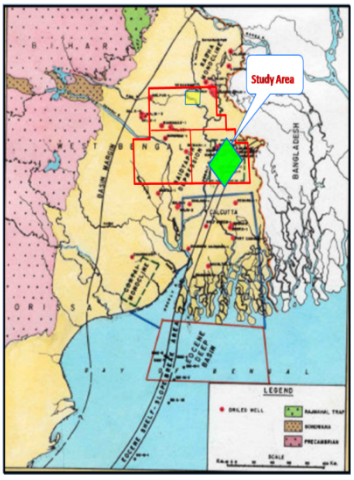

Fig.1 Location Map showing the study area

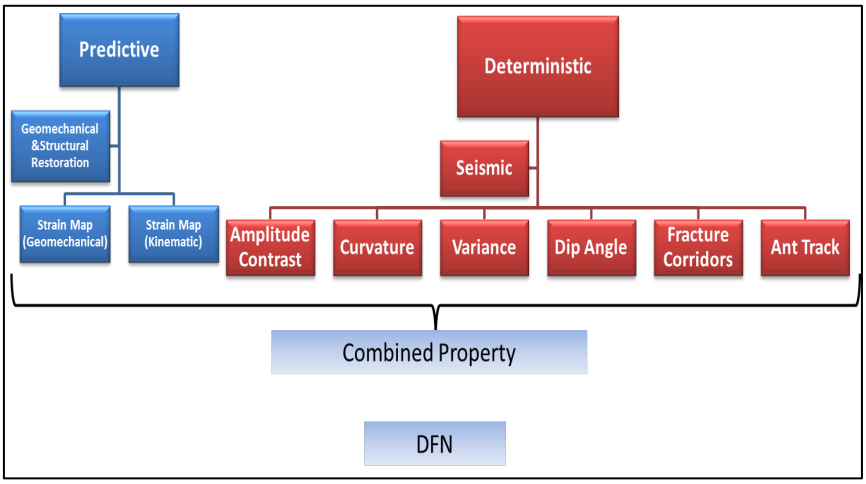

Fig. 2: Workflow for generation of Discrete Fracture Network

Geomechanical restoration was carried out to capture the strain on Eocene surface due to Hinge zone flexure. Based on the well logs lithologies were assigned for each formation and depending on the lithology ratios Young's modulus and Poisson's ratio were calculated and assigned. Constraint in the form of fault gap closure was not performed in the view of few faults with minor throw.

3D Kinematic restoration was carried out to capture strain and surfaces were unfolded to 0m datum. However, it was observed that captured strain was similar from these two different processes (Fig. 3). It showed that deformation is mainly related to flexure at the hinge zone.

Strain Analysis

Geomechanical restoration captured the strains on the Eocene surface. Principal strain values and their orientations (viz. e1, e2 and e3) (Fig. 4) were determined from the captured strain data on Eocene surface. e1 represents maximum principal strain axis whereas e2 and e3 represent intermediate and minimum principal axes respectively. This corresponds to maximum principal stress ($\sigma 1$) for e3, minimum principal stress ($\sigma 3$) for e1 and intermediate principal stress ($\sigma 2$) for e2. e1 strain values represent high strain areas of the deformed surface . There were two dominant NE-SW and NW-SE distribution of e1 and it was used as input for fracture intensity in the DFN model.

Deterministic Fracture Modelling Method

A number of relevant volume attributes were calculated to find out fracture prone areas. Some of the calculated attributes are Amplitude Contrast, Variance and Consistent Curvature. Ant track algorithm was run on various attribute volumes e.g. edge enhanced volume, variance, Curvature (K2) etc (Fig.5). It was found that Ant track on curvature (K2) volume attribute without any dip and azimuthal guidance showed very well match with the predictive fracture sets (Fig.6.). Based on this observation it was decided to carry on 12 sets of dip and azimuthal ant track on curvature attribute volume. Each of the 12 Ant tracked fracture sets were thoroughly analyzed for their likelihood and results were optimized through iterative process (Fig. 7).

Discrete Fracture Network (DFN)

Seismic derived fracture sets were used to establish a logical discrete fracture network model for Eocene carbonate. Discrete fracture network (DFN) was prepared utilizing strain captured during structural kinematic (Sanders et al., 2004) or geomechanical restoration (Maerten and Maerten, 2006) as an input to predict high fracture intensity areas and fracture length and aperture were derived from the seismic derived attributes (Deterministic Method). Further it was constrained by the FMI and core data Fig. 8.

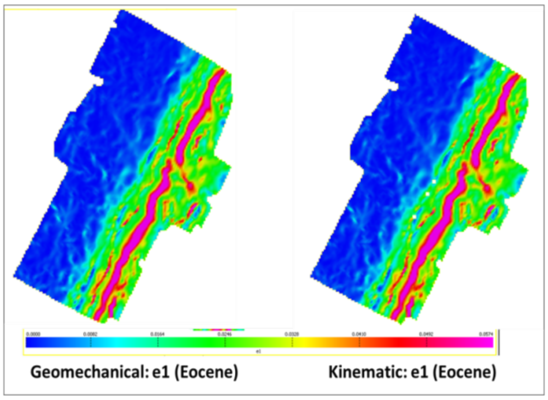

Fig. 3: Maximum principal strain e1 captured from Geomechanical as well as Kinematic restoration

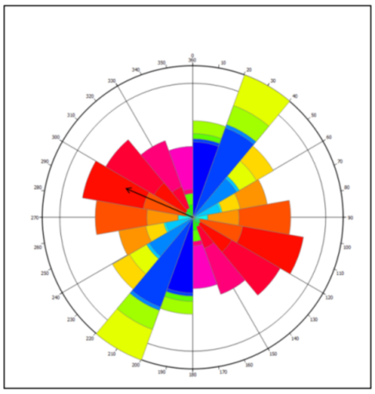

Fig. 4: Maximum principal strain (e1)

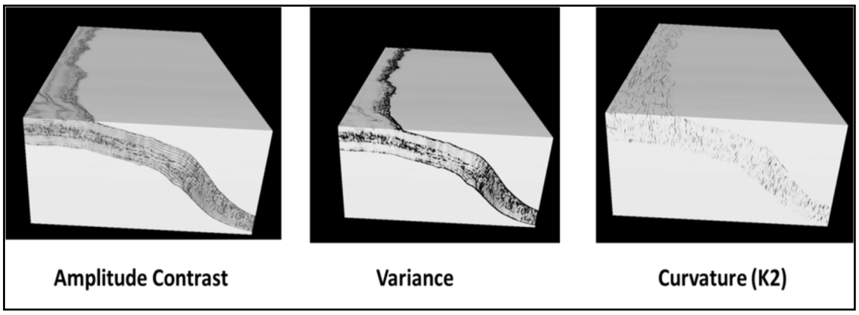

Fig.5: Box Probe showing Amplitude contrast, Variance and Curvature attributes for Eocene sequence

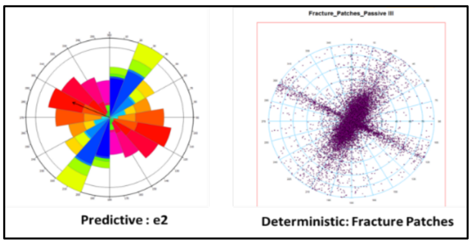

Fig.6: Fracture sets from predictive deterministic methods showing very good match

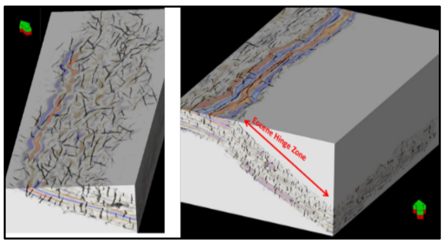

Fig. 7: Fracture sets in seismic volume

Present Day Stress Modelling

Maximum Horizontal Stress Orientation Determination

Analysis of borehole breakouts and drilling induced tensile fractures (Fig. 9) Maximum horizontal stress (S_{Hmax}) and minimum horizontal stress (S_{Hmin}) directions can be established. FMI log of well Well-1 (Fig. 8) were carefully studied and based on borehole breakouts it was established that S_{Hmin} direction is NW-SE and thus S_{Hmax} would be perpendicular to it in NE-SW direction.

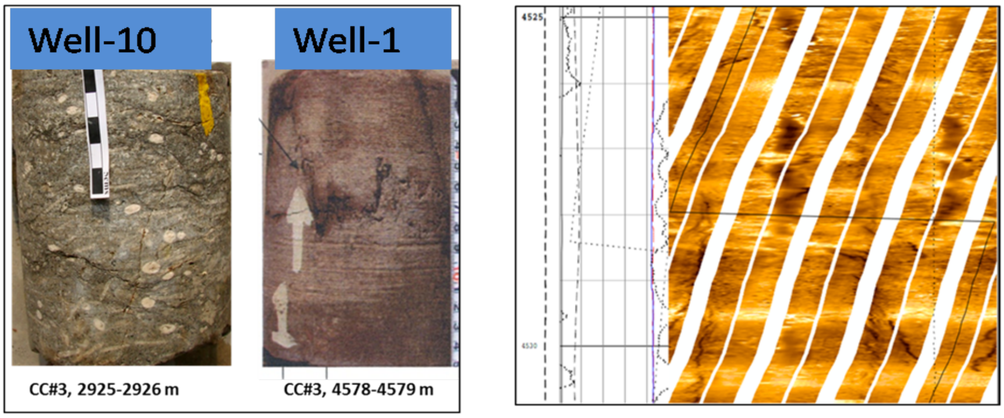

Fig. 8: Presence of fractures in cores and FMI data of wells, Well-10, Well-1and Well-3

Estimation of principal stress Values

Vertical stress (S_v) is calculated by integrating the bulk density of the rocks. The bulk density is measured from the density logs recorded in the wells. The minimum horizontal stress (S_{Hmin}) is generally obtained from Leak off Test (LOT), Hydro Fracturing and Pressure Integrity Test (PIT) data from drilled wells. In the present study LOT values collected from 4 wells of study area were analyzed and EMW was converted to pressure values which represent the minimum horizontal stress.

Maximum horizontal stress (S_{Hmax}) was calculated by assuming that the ratio of the maximum to minimum horizontal effective stress cannot exceed that required to cause faulting on an optimally oriented fault. The frictional limit to stress is expressed as below (Jaeger and Cook, 1979, Zoback and Healy, 1984)

$$S1'/S3' \leq \{(\mu 2+1)^{1/2}+\mu\}^2$$

Where μ is the coefficient of friction that is the crust can support until an optimally oriented pre-existing fault slips to regulate the stress magnitude, S1' is effective maximum principal stress and S3' is effective minimum principal stress.

For a typical value of $\mu = 0.6$, $S1'/S3' \leq 3.12$

This relationship is used to estimate the magnitude of effective maximum principal stress in seismically active regions (Zoback and Healy, 1984).

The principal stress calculated and their graphical representation for study area shows that the minimum horizontal stress ($S_{Hmin=}$) is less than Vertical stress at Eocene sequence level (Fig. 10) and vertical stress is less than horizontal maximum stress (S_{Hmax}). This orientation of the stress axes suggests the likelihood of a strike slip stress regime in Bengal Basin.

In this case the maximum compressive stress becomes greater than the determined minimum horizontal stress and vertical stress and hence the present day Geomechanical model suggests a strike slip regime i.e. $S_{Hmax}>S_v>S_{Hmin}$.

Slip and Dilation Tendencies and Porosity Estimation

Slip and dilation tendencies were estimated for the four modelled fracture sets in the prevailing Geomechanical model at Eocene limestone depth using the relations

$$\text{Slip Tendency} = (\tau/\sigma_n) \quad \& \quad \text{Dilation Tendency} = (\sigma 1 - \sigma_n)/(\sigma 1 - \sigma 3)$$

Where τ is shear, σ_n the normal stress on the fault plane and σ1 and σ3 the maximum and minimum stresses respectively. A cut off of 0.6 is taken for slip and Dilation tendencies.

Values of the principal stress were derived from the graph shown in the Fig. 10. The compressive principal stresses σ1, σ2 and σ3 at 4500m depth were calculated as 84.4, 62.9 and 24.8 MPa respectively. Orientation of maximum horizontal stress derived from drilling induced fractures within Eocene limestone in the direction NE-SW was incorporated in the model. Average pore pressure within Eocene limestone has been considered to be 46.4 MPa. To test the slip and dilation tendencies, cohesion value of 0 MPa and angle of internal friction of 30^0 was considered for carbonates.

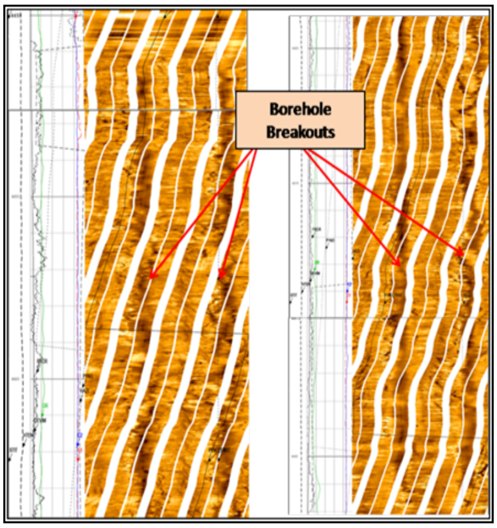

Figure 9. Presence of borehole breakouts in FMI log data of Well-3

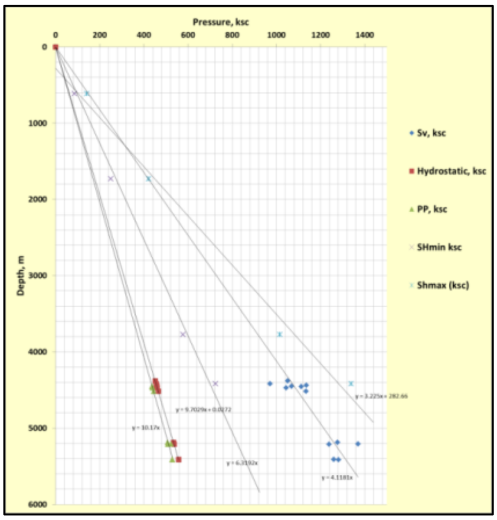

Figure 10. Graph showing the trend of Vertical Stress (S_V), Maximum Horizontal Stress (S_{Hmax}), and Minimum Horizontal Stress (S_{Hmin}). The present Geomechanical model suggests strike

Each modeled fracture set was analyzed for these attributes to assess criticality to slip in the defined Geomechanical model. It is observed the fracture sets oriented in NW-SE direction have very high slip and dilation tendency (>0.6) Shown in Fig.11&12. So, it can be inferred that the fracture set oriented in NW-SE direction are critically oriented and are much prone to remain opened (Fig.13). As a result, this fracture set remained optimal for fluid storage and mobility and it should be considered for potential reservoirs.

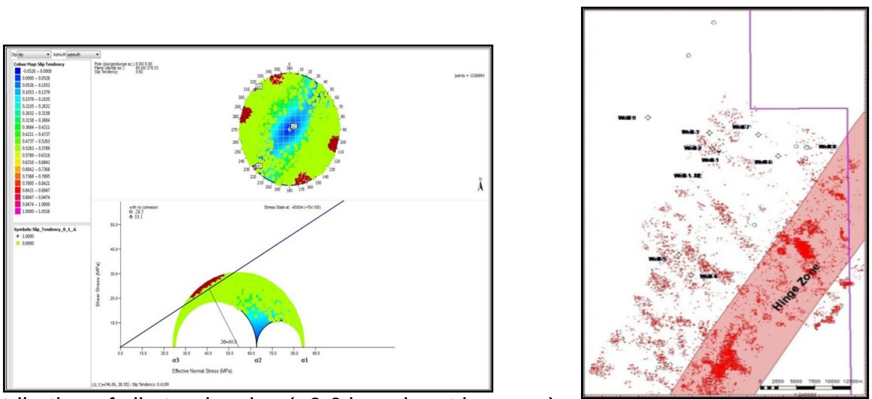

Fig. 11: Distribution of slip tendencies (>0.6 in red rest in green) on Stereonet, Mohr circle and map view

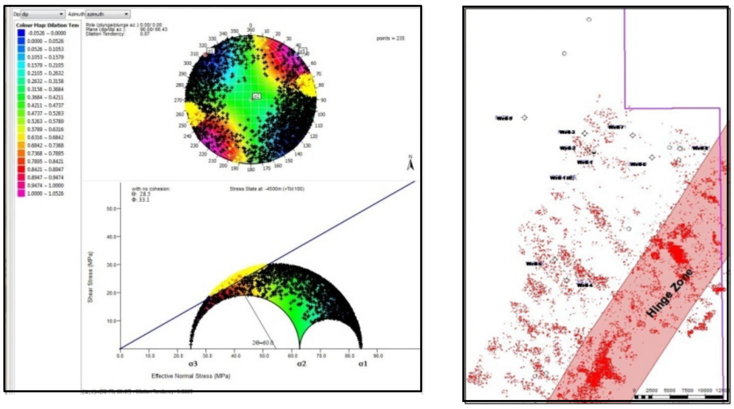

Fig. 12: Distribution of dilation tendencies (>0.6 in red rest in green) on stereonet and Mohr circle and Map view

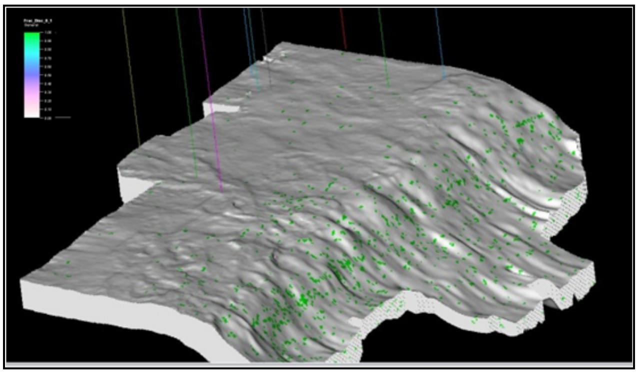

Fig. 13: Distribution Porosity in Eocene Carbonate

Conclusion

In present study mainly two sets of fractures NE-SW and NW-SE were identified through predictive as well as deterministic methods. Estimated principal stress values suggests that presently Bengal basin is in strike slip stress regime Analysis of slip and dilation tendencies (>0.6) indicates that fracture oriented in NE-SW are critically stressed and remain main contributors towards fracture porosity and permeability. Therefore, NE–SW fracture prone areas may be interesting for hydrocarbon exploration within the Eocene Hinge Zone.

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References

1. M. D. Zoback and J. H. Healy, “Friction, Faulting and In-Situ Stress,” Annals of Geophysics, Vol. 2, 1984, pp. 689-698
2. Maerten, L. and Maerten, F. [2006], “Chronologic modelling of faulted and fractured reservoirs using geomechanically based restoration: Technique and industry applications”, AAPG Bulletin, 90, 1201-1226
3. Sanders, et. al, “Kinematic structural restorations and discrete fracture modeling of a thrust trap: A case study from the Tarija Basin, Argentina”, Marine and Petroleum Geology 21(7):845-855, August 2004