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Geomechanical Modelling based on Elastic dislocation (ED) for prediction of Fractures Network characteristics, density & orientation in complex compressional regime of Upper Indus Basin of Pakistan and comparison with FMI logs

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Summary

The problem of identifying and quantifying the brittle deformation of carbonate reservoirs in compressional, extensional and transpressional tectonic regime is a challenging subject and addressed in different ways in exploration. Naturally occurring fractures may substantially increase or decrease the porosity and permeability of reservoirs, and therefore, knowledge of location, orientation, density and connectivity of fractures is required to locate hydrocarbon accumulation and optimize production. One of the approaches applied in recent days is the application of elastic dislocation (ED) theory. It has also been applied on some practically observed slips on the surface due to earthquake, which modelled accurately small faults & fractures generated by coseismic slip on large faults. These small faults/joints and fractures prediction can increase chance of success in case of carbonate reservoirs. The effects of small-scale faults and fractures on reservoir behavior requires a definition of their spatial distribution, orientation and mode.

The application of Elastic dislocation (ED) theory can predict the distribution of displacement, strain and stress in the rock volume surrounding major faults, from mapping of fault geometry and slip distribution in 2D/3D seismic-reflection datasets. The intensity of large & small-scale faulting can be related to the predicted local strain, or the degree to which the shear stresses exceeded the rock failure envelope.

In this research work we have applied this methodology with the case study of field situated in Potwar Fold Belt (Fig. 1) Upper Indus Basin (**UIB**), which occupies NW corner of the Indian Plate. Initially the prospect was developed on the basis of 3D (PSTM version). The prospect is an axially faulted anticlinal structure which is developed as hanging wall anticline along a south verging major thrust fault oriented in the E-W direction.

Key requirements for the development of a robust predictive model of the large and small-scale faults and fracture network are a geometrically consistent structural framework model, judicious choice of mechanical properties, and a reasonable estimate of regional background strain.

Geomechanical models based on linear elasticity have been used to predict the mode and distribution of sub-seismic small faults/fractures around larger faults. These models can be tested against well's FMI results of wellbore (fractures). This paper presents forward modeling based on elastic dislocation theory of the deformation. Using fault parameters to define a set of larger and associated smaller faults, our model calculates the deformation field in the surrounding rock volume. We have compared predicted strain and stress fields in the prospect in the form of fractures and their characteristics with wellbore FMI results. Using a combination of the redistributed elastic dislocation stress due to slip on the major faults and a mall component of overburden stress, the models successfully predict fractures in the hanging wall of the reverse thrust fault system. Orientations of the predicted fractures vary along strike of the fault system, being parallel to the main reverse fault directions but oblique faults system also possible to it along the central segments, agreeing with observed structures dip variations. The results of forward modeling are not sensitive to the magnitude or direction of a regional tectonic stress. The predicted fractures are controlled by redistributed stresses due to coseismic slip. The agreement between modeled and wellbore FMI results adds confidence in the use of elastic dislocation theory to accurately small faults & fractures generated by coseismic slip on large faults.

Theory / Method / Workflow

The objective Chorgali horizon (Eocene) was interpreted fully and developed as a "Standard Trimesh Surface", interpreted gaps assumed to be faults in the horizon surface. Remedial worked done on fault interpretation and generated horizon-fault intersection polygons and initial framework developed. Hand-edit fault polygons, where required to ensure sensible lateral terminations. Added fault segments to planes to extend lateral fault plane terminations, examined throw distribution on surfaces. Constructed faulted horizon surface for Chorgali horizon and finally developed a 3D realistic model on the basis of 3D seismic.

Converted the model from time domain to depth domain for which process velocity data to produce a time-depth curve appropriate for wells. Created a time-to-depth scenario from well data and generated a velocity cube and depth converted all time data (interpretation, surfaces, seismic etc.). After that design a geomechanical model and run fracture prediction scenarios for calculations at the level of the Chorgali, in which used computed strain boundary conditions and used strains to compute an equilibrium solution for fault displacement (DDM) for reservoir faults and basal thrust (Major Fault) of prospect. The shear planes generated and created fractures sets from these shear planes. The Maximum Coulomb Shear Stress (MCSS) attribute applied on model, which shows the fractures density along with orientation. The results were compared with wells FMI logs.

Results, Observations, Conclusions

1. The prospect data was evaluated and re-visited interpretation, made changes in fault planes generation and build a proper model.
2. The Chorgali Horizon interpretation shows that it is a faulted rollover type geometry (Hanging wall anticline) which becomes deeper towards north.

3. On the basis of available seismic data and interpretation we developed a geomechanical model and applied Elastic Dislocation theory for fracture predication, the result of which depend on the seismic data quality and interpretation.
4. Applied different conditions on boundary elements to get the reasonable results.
5. The model looks reasonable which include intra-reservoir faults & Basal Thrust, but applied static constrained condition observed DDM (displacements discontinuity method), means the basal thrust must be having role on horizon development along with above intra-reservoir faults may be or may be not involve.
6. The model show that well-1 has more fractures than well-2.
7. The well-2 fractures are striking almost NW-SE, while well-1 fractures strike in West-Northwest (WNW)-East-Southeast (ESE) to East-West (E-W) directions (Zoomed view of model-07).
8. The FMI logs for both wells correlate with developed geomechanical modeled fracture analysis on the basis of ED theory.

Acknowledgements

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References

All references will be incorporated in full length paper and presentation.

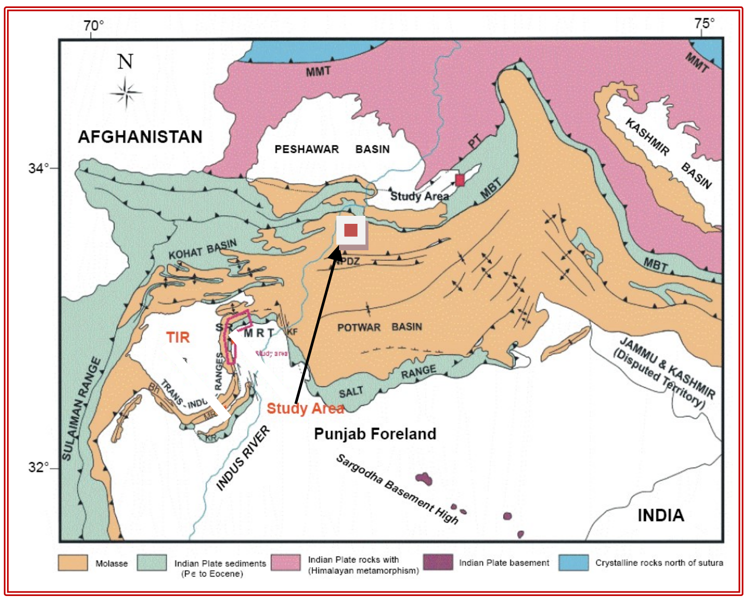


Fig. 1 - Map showing the location of Model area

Depth Model on Chorgali Horizon (Eocene) & Fault Planes

After complete interpretation the Chorgali Horizon (Eocene) Trimesh generated and faults planes were developed on the basis of interpreted sticks on sections.

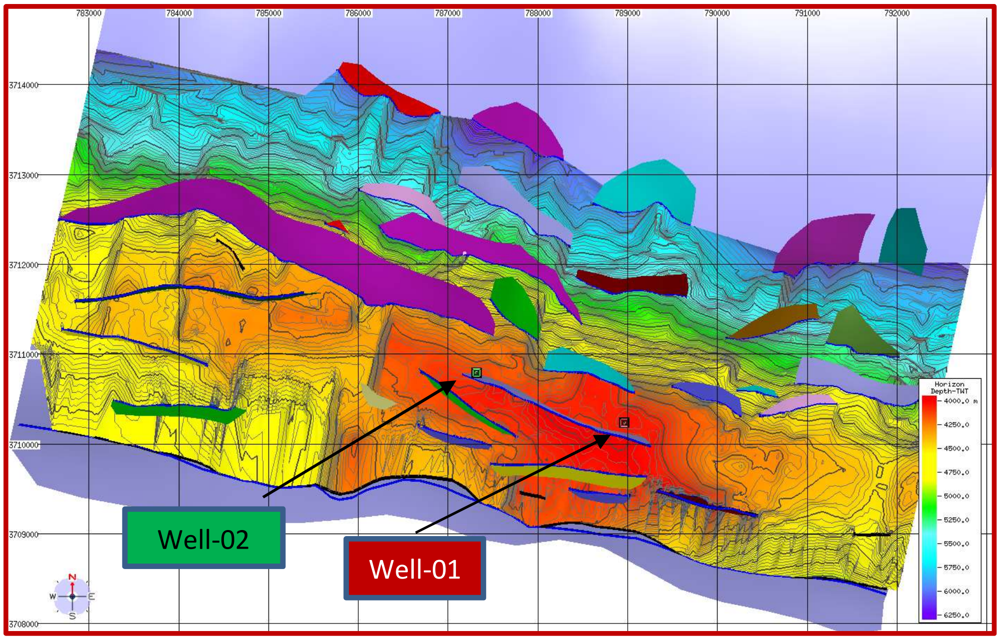
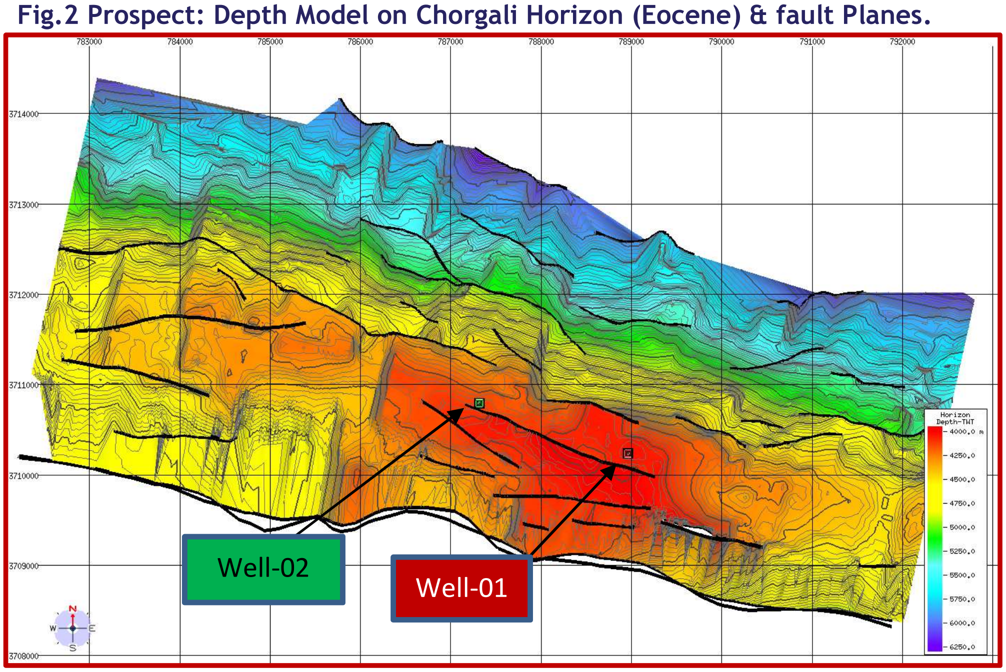
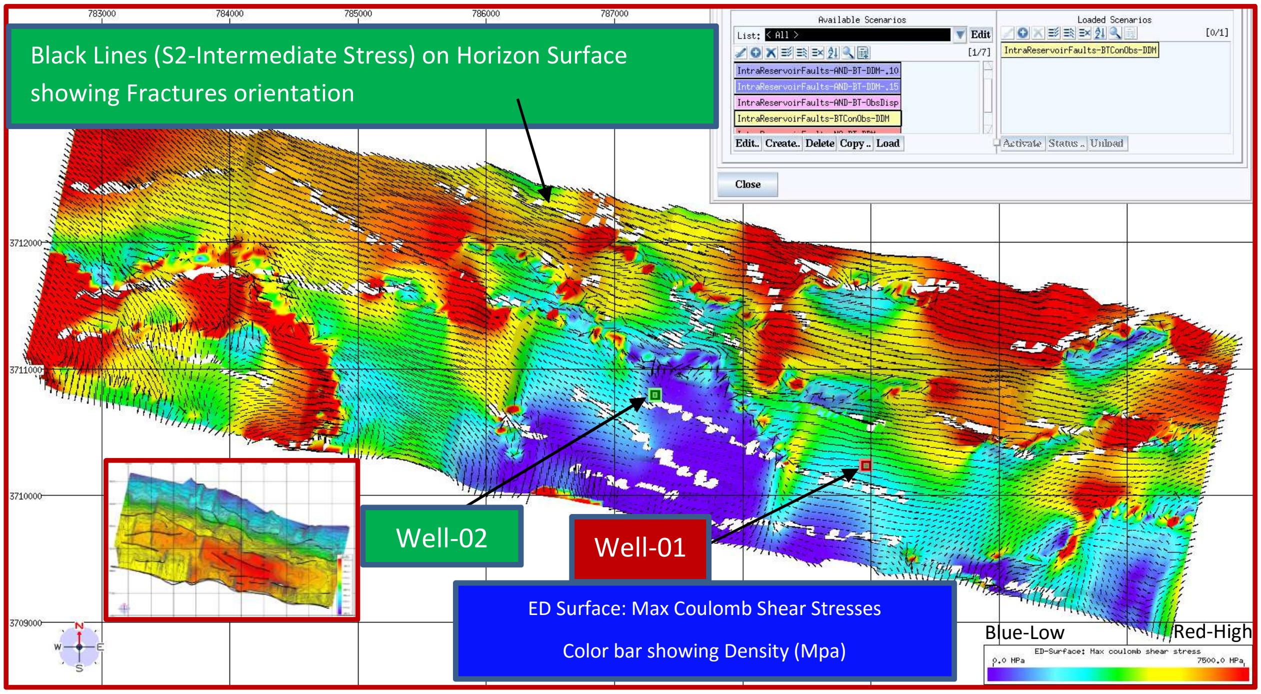


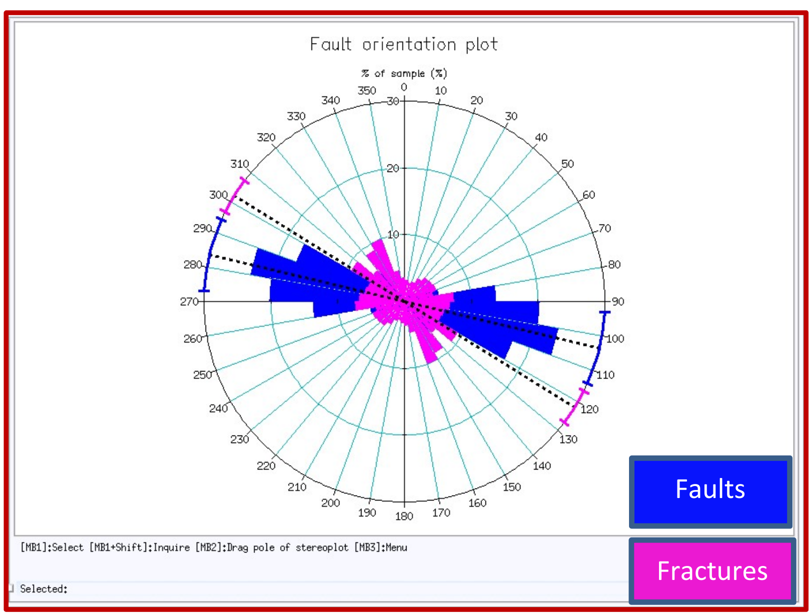
Fig.2 Prospect: Depth Model on Chorgali Horizon (Eocene) & fault Planes.



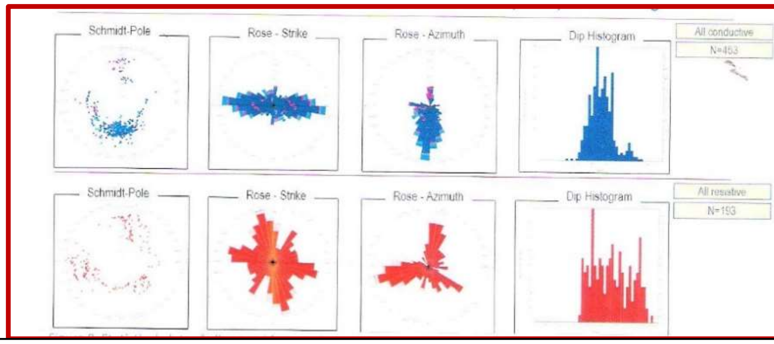
3- Prospect: Model Chorgali Horizon (Eocene) & faults polygon.



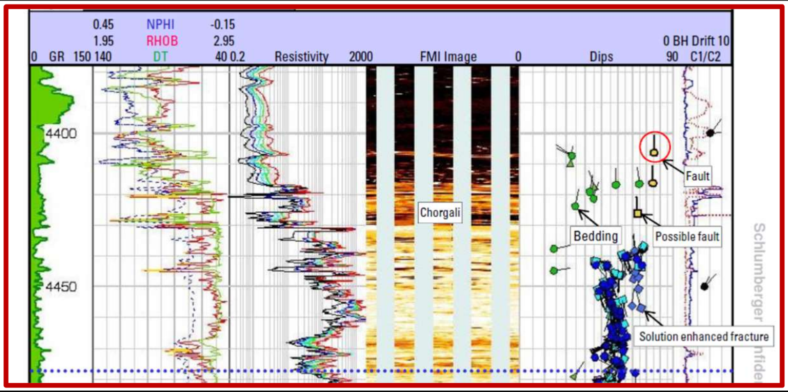
4-Geomechanical Model for Chorgali Horizon showing Fracture Density and Orientation.



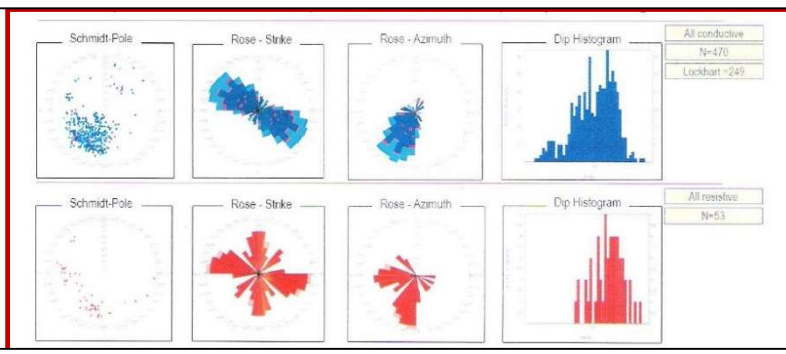
5-Chorgali horizon: Faults and Fractures Orientation Plot (Rose Diagram)



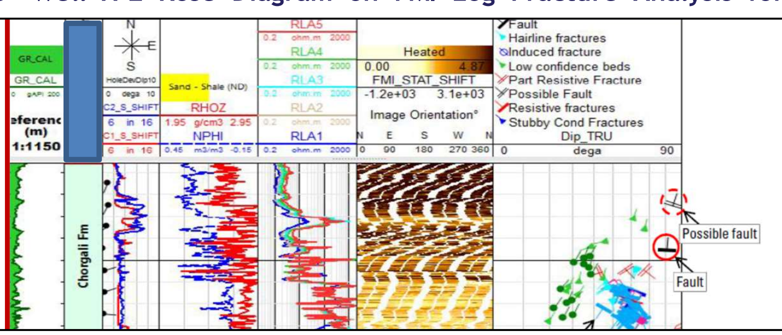
06- Well X-1 Rose Diagram on FMI Log Fracture Analysis for Chorgali Horizon



07- Well X-1 FMI Log Fracture Analysis on Chorgali Horizon (Eocene)



08- Well X-2 Rose Diagram on FMI Log Fracture Analysis for Chorgali



09- Well X-2 FMI Log Fracture Analysis on Chorgali Horizon (Eocene)