Modelling of fractures developed due to structural deformation in the Karjan prospect of Cambay basin in India.

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ABSTRACT

The unconventional fractured basalt reservoir of the Karjan prospect in Cambay basin has proven to be promising oil plays in the area. Recent oil find in trap basalt in Karjan prospect, Cambay basin India, is an immediate motivation to understand the occurrence of oil and role of fracture distribution. Paper describes the method adopted to characterize the discrete fracture systems within the basalt for hydrocarbon accumulation as unconventional trap.

The seismic data used to map the top of trap surface and a reflector below the surface guided by the events with varying continuity to generate a volume of trap strata in Karjan prospect. This volume is utilized for forward modelling to analyze deformation attribute, using geo-metric and geo-mechanical restoration work flow of structural modelling software.

From the mapping of faults it is found that area has undergone tectonic stress in two directions. This has defined number of fracture sets.

The restoration process calculates stress and strain attributes. These attributes are used for fracture modelling to define two sets; This has worked as a dip and azimuth constraint for 3D Discrete Fracture Network (DFN) of defined fracture sets. The paper analyses and presents the result of fracture modelling. The workflow used for fracture modelling can be used by petroleum industry to define spacing, density and orientation of the various fracture systems. The optimal modelling results will depend upon appropriateness of geometries adopted for restoration and constraining parameter of fracture system. The discreet fracture network model generated is a direct input for Simulation Model for further study and to generate the field development model.

INTRODUCTION

The natural fractures play an important role especially in low-permeability tight rocks having virtually no primary porosity. As fracture do provide the required secondary porosity and permeability for oil entrapment within tight rocks. Precisely for this reason, many workers have attempted to determine the characteristics of fractures. These workers have adopted mainly geophysical methods in form of P-wave and shear wave analysis[1] or cross-hole tomography as reliable indicators of fracture orientation and distribution[2]. Gerard Bloch[3] expressed seismic facies analysis as a powerful tool for fracture detection. Chang and Gardner(1993)[4] suggested that the fracture orientation of a subsurface fracture zone may be determined by analyzing P-wave interval velocities. Fractured zone can be indirectly predicted by means of seismic inversion detecting lithology distribution, Jun Chen et al, 1999 [5].

The P-wave can also be used for fracture detection by characterising presence of low stacking velocities, anisotropy and seismic wave attenuation. Beside these geophysical methods, Mai Thanh Tan[6] suggested that the highly fractured nature of basement reservoirs is created during the process of tectonic deformation, cooling, hydrothermal and weathering. Role of Structural deformation in development of natural fracture is demonstrated by C. Sanders and T.A. Murray[7] using structural modelling to characterised fractured basement reservoir and concluded that any deformation process can potentially be modelled and analysed in 3DMove. 3D move is structural modelling software from midland Valley Exploration Ltd.(MVE) primarily uses geometric restoration as modelling process.

However MVE has developed advanced 3D Structural modelling software known as 4DMove. The 4DMove software has a 4DMove Restoration module. This module has an exclusive algorithm – The Mass spring Restoration. This is a Geo-mechanical restoring of volume and surfaces in comparison to Geometric restoration by 3D move restoration techniques (fault and fold restoration). 4D Restore creates the geo-cellular grids with strain outputs that can be directly export to Fracture modelling module 4D Frac of 4DMove.

The present study demonstrates the modelling of fractures developed due to structural deformation in the Karjan prospect of Cambay basin by using 4DMove software. The paper discusses the workflow used in fracture modelling and analyse the results obtained thereof.

AREA OF STUDY

The Padra- Karjan area is located on the eastern rising flank of Broach block in Cambay Basin (Figure-1- Area of study) is distinctive as unconventional fractured basalt reservoir has proven to be promising oil plays besides Tertiary sediments. The area of Karjan Prospect selected for fracture modelling based on seismic attribute of Karjan 3D volume (Figure.2) that suggest presence of extensional fractures due to structure deformation in the area.

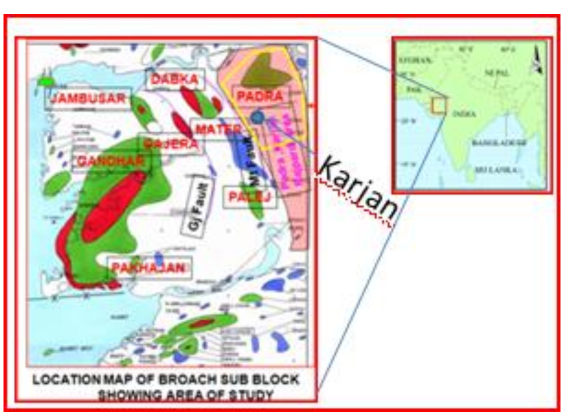

FIGURE.1 Location Map showing area of study

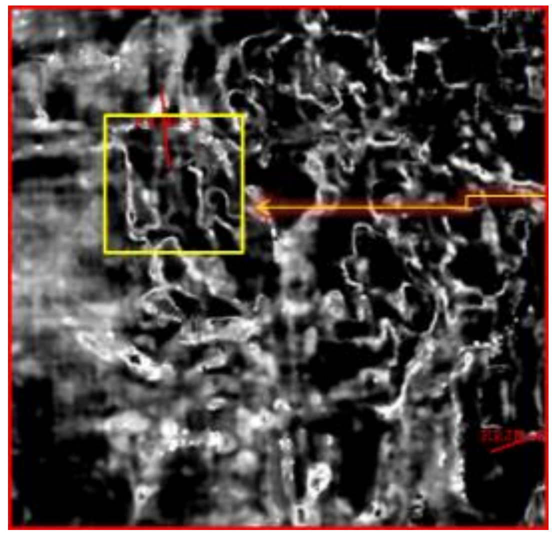

FIGURE:2 seismic attribute indicating presence of possible extensional fracture in Karjan Propsect. Area in bounded by Yellow square is taken up for Fracture modeling.

OBJECTIVES

The objectives of the present study are:

- To generate Discrete Fracture Network:
- To evaluate Capability and utility in predicting the discrete fracture network for reservoir simulation.
- To understand the limitations and constraints

WORKFLOW

Methodology includes creation of geo-cellular volume by mapping the present day top and bottom surface of geological strata for which DFN to be generated using 3D seismic data. As, identifying seismic reflector within low permeability rocks like trap basalt and granite is difficult on seismic data, alternative is to generate mathematical geo-cellular volume by using surface top and adding layers of constant thickness to it. However in the present study it is attempted to map bottom of geo-cellular volume following a seismic event (may be corresponding to the bottom of fractured /weathered basalt layer) of varying continuity below trap top surface on seismic data (Figure.3) to create real geological dataset.

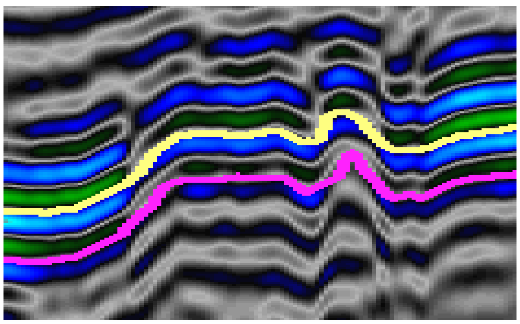

FIGURE.3 Showing the seismic reflection near the trap top. Yellow is mapped as top of trap surface and event below (pink colour) mapped as sub-layer base.

This volume is utilized as present day geological structure to generate Discrete **Fracture Network** as follows:

- Step 1: Present day model is restored using geometric/Geo-mechanical Restoration. The results represent the geological situation before deformation took place. At this stage the fracture growth is simulated using constant spacing and orientation.
- Step 2: The restored geological situation is forward modelled to simulate the present day structure. Strain estimates are calculated during the simulation.
- Step 3: stress and strain in the above process is represented by colour mapping of surface.
- Step4: Shear fracture growth is simulated in fracture modelling module 4DFrac of 4DMove using the strain parameters obtained during restoration process.
- Step5: From the mapping of faults it is found that area has undergone tectonic stress in two directions. This has defined number of fracture sets. Therefore defined two fracture sets with orientation constrained by dip and azimuth parameters of faults mapped.
- Step 6: Generate Discrete Fracture Network (DFN), perform connectivity analysis and output the volumetric (porosity, sigma etc.) and directional (permeability) properties.
- Step7: Modelled output saved to export for simulation studies.

PROCEDURE AND RESULT

A seismic horizon mapped near to the top of Trap basalt surface and a seismic event below as shown in ***Figure.3*** and exported to 4DMove software. 3DMove software used to create two grid surfaces one for Trap-Top and another one for a surface within trap basalt to generate a Geo-volume (***Figure.4***) using Volume creation tool. This Geo-volume is used as input to create geo-cellular grid volume in 4DMove required for fracture modelling in 4Dfrac module.

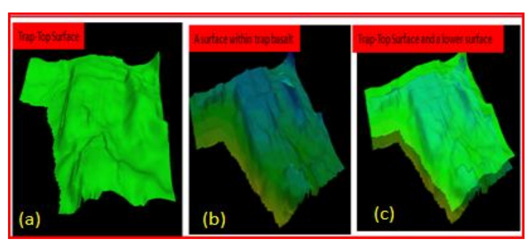

FIGURE.4 Input for creation of Geo-cellular volume.(a) Top of trap surface(b)surface of sub-layer base and (c)bounding surface of 3D volume taken for creation of Geo-volum.e

Present day structure can be restored to the initial surface by using either geometric restoration in3DMove or Geo-mechanical

(Mass-spring) restoration in 4DRestoration module of 4DMove. Both restores the present day structure to the initial modelled surface i.e, flat (Figure5). Here, it is assumed that initially surface was flat and subsequently due to tectonic stress it is deformed to the present day structure.

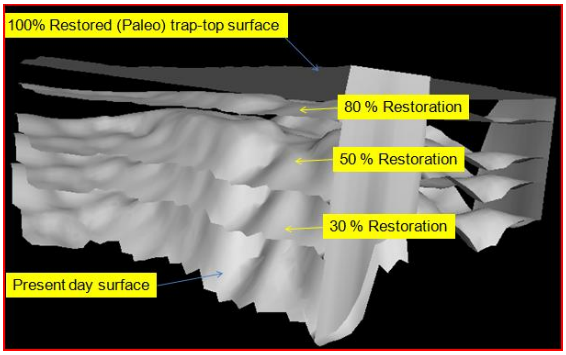

FIGURE.5. shows the reverse restoration of present day surface to the initial state of surface. 100% restoration has flattened the surface (assumed as initial surface).

This flattened surface is the input for forward modelling to deform it to the present day structure using the geometric (folding) or Geo-mechanical (virtual mass spring) kinematic algorithm. Both of these method stores the change in stress/strain attribute due to restoration mechanism. In the present study Geo-mechanical restoration process preferred and ***figure-6*** shows the major stress/strain distribution as colour coded surface.

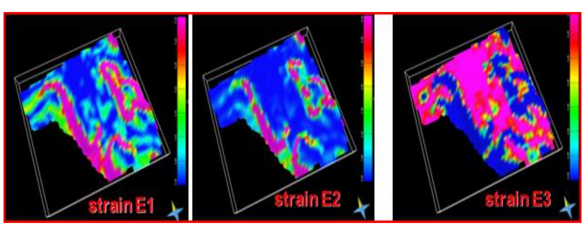

FIGURE -6 Strain distribution pattern, pink colour representing high strain value, pink .

The surface grid stores the strain and stress parameters, therefore restoration can be done for intermediate stages also and resultant attributes can be analyzed. Analysis does provide the valuable insights to the geologists about deformation process involved.

Volume restoration may be preferred than surface restoration, however in this study surface restoration is used as mapping of event below trap basalt surface is not reliable due to seismic resolution. The volume is used only to create the geo-cellular volume grid for 3D discrete fracture network distribution in fracture modelling process.

In the 4D move you can create as many DFN as you like. But the choice normally restricted through analysis of fracture data from well. If well data has fracture parameters it can be analysed in 4DMove to provide the two important parameters, one is mean principal direction(Dip/Azimuth) and another is Fisher Dispersion, (k). These two parameters used to constrain the DFN's. In case where fracture data is not available from the well, same information can be obtained from field analogues or through forward modelling.

In the present study two fracture sets (4DFrac_0 and 4DFrac_1) are defined, as orientation analysis of faults mapped in the area suggests that area is undergone tectonic stress in two directions viz., Dip/Azimuth of 63/267 and 71/203. Input parameters for these two fracture set is given in ***Table***-1. These parameters used to generate two discrete fracture network shown in figure-7. These two DFN's are analyzed for component connectivity are shown in figure.8 with and without Geo-volume. For better visualization and analysis they are also superimposed on surface topography and grid (***figure.9***). The connectivity analysis of the DFN's is given in ***Table-2***.

The connected DFN component is used to drive the reservoir parameters like degree of connectivity, permeability and porosity. The spatial distribution of these parameters is shown in ***figure-10***.

Table-1. Summary of Fracture set generation parameter

4DFrac_0	4DFrac_1
Input Parameters:	Input Parameters:
Input Grid:	Input Grid:
GeoCellular_from_KM_Trap_volume	GeoCellular_from_KM_Trap_volume
Intensity From Grid:	Intensity From Grid:
Frac_Session1_kms_P32	Frac_Session1_kms_P32
P32: true	P32: true
Length Defintion is Normal:	Length Defintion is Normal:
Length Param1: 200	Length Param1: 200
Length Param2: 30	Length Param2: 30
Length Param3: -2	Length Param3: -2
Orientation is Defined:	Orientation is Defined:
Distribution Is Fisher:	Distribution Is Fisher:
Fisher K Param: 0.0110569	Fisher K Param: 4.61
Orientation Param1: 63	Orientation Param1: 77
Orientation Param2: 267	Orientation Param2: 203
Aspect Ratio: 0.5	Aspect Ratio: 0.5
Aperture: 0.205669	Aperture: 0.105669
Number of Fractures: 6429	Number of Fractures: 6429

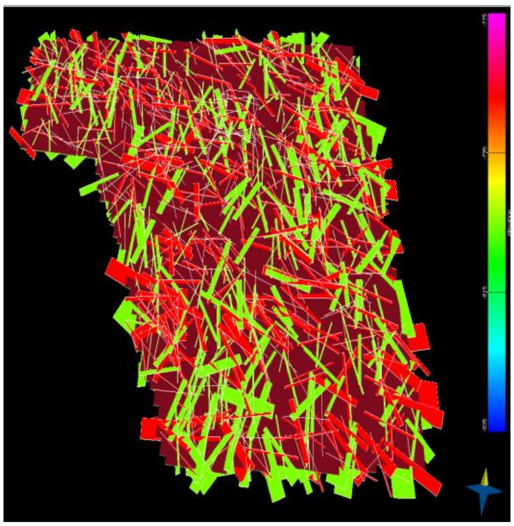

FIGURE -7. Two set of 3D DFN generated is shown in green and red color as probable fracture networks plane.

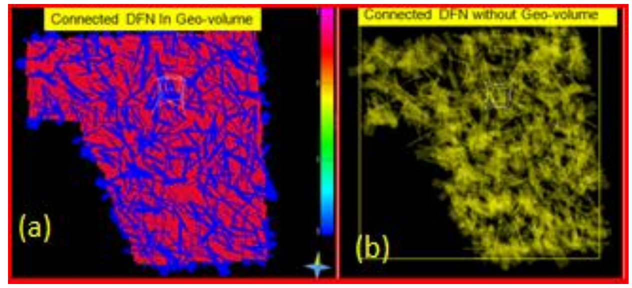

FIGURE -8. Connected DFN is shown with and without Geo-volume. The intensity, orientation and spacing distribution can be seen.connectivity analysis of DFN with geo-volume(a) and without geovolume.

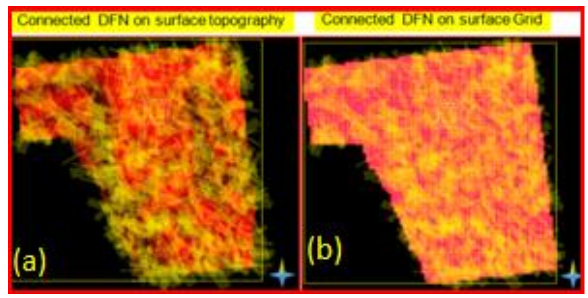

FIGURE -9. Connected DFN is shown on surface topography(a) and grid (b). The intensity of DFN's along faults can be seen clearly.

Table-2. Connectivity Analysis report of of Fracture sets

Output Grid: GeoCellular_from_KM_Trap_volume

Generated Properties:	Min Value	Max Value
Frac_Km_050510_Rel_Conn	0	3030.74
Frac_Km_050510_Conn_Degree	0	0.0833652

Total Fracture Area: 1.29277e+08 (meter-squared)
Total Fracture Volume: 289771 (meter-cubed)
Total Model Volume: 2.84334e+08 (meter-cubed)
Average Fracture Porosity: 0.00101912
Average Aperture: 0.00224147 (meter)
Average DFN P32: 0.454666 (1/meter)
Run Time : 573.297 (sec)

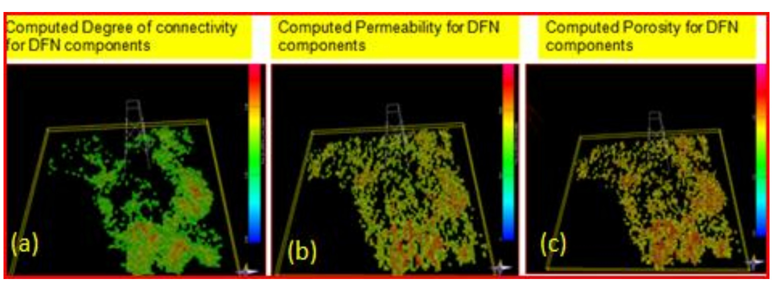

FIGURE -10. Parameters computed for *connected DFN's. Parameters are showing the spatial variability of reservoir parameters.*

CONCLUSION

The forward modelling recreates the historical deformation and consequently the changes in stress and strain attributes. These attributes are attached with restored surface grid and can be analyzed for different stages of restoration and compared. These attribute changes can be used in fracture modelling process as constraints for fracture distribution and computation of reservoir parameters. Distribution of reservoir parameters of 3D DFN can be analyzed to identify the fracture/secondary reservoir porosity areas for placement of location for exploratory drilling. The output can be directly used for reservoir simulation process. However its geological validity depends upon the appropriateness of restoration mechanism and constraining parameters of fracture sets. Moreover, use of volume restoration instead of surface restoration may lead to more geological plausible results.

REFERENCES

1. Mueller, M. C., 1992, Using shear waves to predict lateral variability in vertical fracture intensity: The Leading Edge, v. 1, p. 29-35.
2. Satio, H., and H.Ohtomo, 1989, Identification of fracture zones through curved ray seismic tomography: Scientific Drilling, v. 1, p. 42-46
3. Gerard Bloch, 2003, Seismic Facies Analysis for Fracture Detection : a Powerful Technique, Middle East Oil Show, 9-12 June 2003, Bahrain Society of Petroleum Engineers
4. Chang,C. H., and Gardner,G.H. F., 1992, Determination of subsurface fracture orientation by analysis of the interval velocity: 62nd Ann. Internat. Mtg., Soc. Expl. Geophys., Expanded Abstracts, 1069–1072.
5. Jun Chen et al, 1999, Application of Seismic Inversion and Special Processing Techniques to Fracture Distribution Prediction: SPE Asia Pacific Oil and Gas Conference and Exhibition, 20-22 April 1999, Jakarta, Indonesia
6. Mai Thanh Tan, 2001, The Possibility of Applying Geophysical Methods to Study Fractured Basement Reservoir in the Continental Shelf of Vietnam, Offshore Technology Conference, 30 April-3 May 2001, Houston, Texas
7. C. Sanders and T.A. Murray, AAPG Annual Meeting, Denver, CO, June, 2001