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Modelling and Fracture Characterisation of Basement Highs in Krishna Godavari Basin, India

Abstract:

Basement highs in KG basin form enechelon pattern of horsts and grabens filled with Permian to Recent sediments. Success in basement exploration in similar tectonic set up in Cauvery basin has warranted a focussed exploration effort in this basin. In this context, structural modelling was carried out using interpreted depth converted seismic and well data to obtain insights into the evolution of basement highs and associated fractures. Discrete Fracture Network (DFN) was generated using 3D surface data, FMI log and outcrop data to model basement fractures.

The present study indicates high fracture intensity to be concentrated along fault intersections of the horst block associated with fault movement. 3D geomechanical restoration analysis has enabled identification of areas of higher strain. Discrete Fracture Network (DFN) was generated with two fracture sets trending NNW-SSE and ENE-WSW. Stress analysis indicates the NE-SW trending faults and NNW-SSE trending fracture sets to be related to high shearing and also having dilation potential for fluid flow.

The above studies have quantified the fracture porosity in the range of 0.0 to 0.265%, permeability of 0.0 to 50darcy and intensity (P32) 0.0 to 0.7. Areas of high porosity, permeability and P32 have been identified in the vicinity of fault damage zones, fault tips and fault intersections in Kaikalur, Kaza, Tanaku, Bantumili, Endamaru, Draksarama, Yanam highs and can be prospective from hydrocarbon exploration point of view.

The study also suggests an exploration strategy to target prolific zones of NNW-SSE conductive fractures along different basement highs.

Introduction:

Precambrian igneous and metamorphic complex of Eastern Ghats form basement of horsts and grabens which are filled with thick pile of Permian to Recent sediments (Figure1). The Basin is divided into Krishna, West Godavari and East Godavari sub-basins separated by Baptala and Tanuku basement highs. Of the 56 wells which have penetrated in the basement in different highs, only 15 wells were tested. One well, SL-1, showed HC indication and rest 14 were dry. Majority of the wells penetrating into basement have been drilled on the Kaza, Kaikalur, Bantumilli and Endamuru highs. In most of the wells, penetrations in the basement are 20-200m and are not in proximity of fault damage zones. Hence basement plays of KG Basin remain a frontier area and needs focussed exploration strategy.

Methodology:

2D Structural Restoration and backstripping of horizons was carried out to analyse the subsidence history through progressive removal of sediment loads, incorporating the isostatic and sediment decompaction responses to unloading and quantifying the relative amount of extension and contraction. Flexural isostatic response to sediment loading was adopted to determine basement-driven subsidence.
Geomechanical Restoration Technique was utilised for capturing the strain attributes between deformed to undeformed stages. It uses the principle of mass spring algorithm, which is an iterative numerical technique, designed to minimize the strain within a solid body while attempting to retain its original shape. The process involves restoration of deformation.
Discrete Fracture Network (DFN) Model generated using Fe1 (principal strain axis) strain map obtained from geomechanical restoration was used as the attribute to model fracture intensity. The fracture attributes namely shear fracture dip and joint dip were derived from strain tensors. Fracture model was calibrated with well data and characterisation was carried out using fracture properties computed through DFN modelling and fracture distribution. Fracture geometry and orientation were calibrated with well data. The DFN was then up-scaled to porosity and permeability distribution at well MS-A.

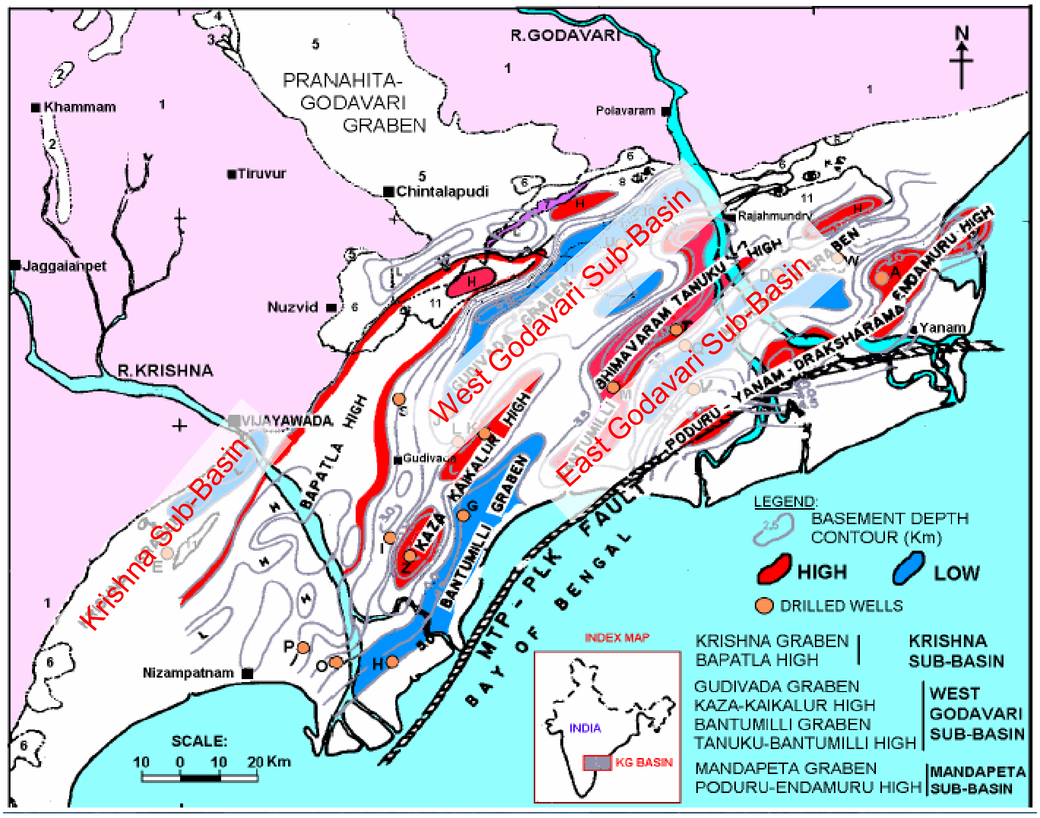
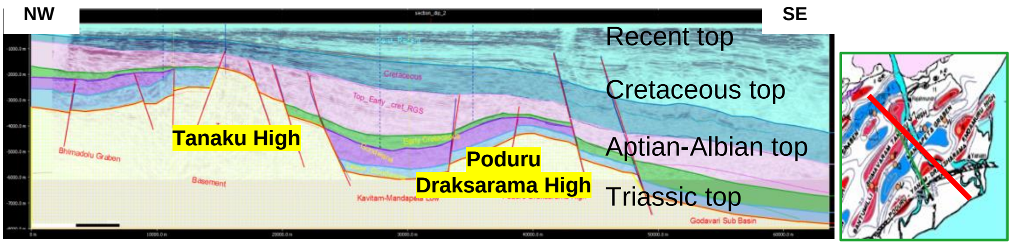


Figure1: Basin Fill Map with Tectonic elements of Krishna Godavari Basin

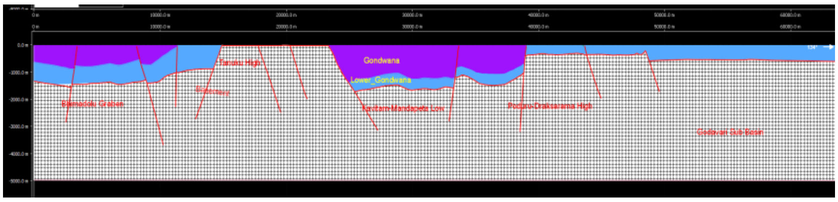
Structural Evolution of Basement highs and Associated Fractures

Structural modelling was carried out along three NW-SE dip lines and one NE-SW strike line, to model the deformation history of basement highs. The modelling result shows, Tanaku high evolved as a horst since Permian and Endamaru high developed in Triassic, whereas Kaikalur, Kaza, Bantumili, Draksarama and Yanam highs developed in Early Cretaceous rifting. Development of Tanaku-Poduru-Draksarama Highs through restoration of NW-SE interpreted seismic lines comprising Pre-rift sequence (Kommugudem and Mandapeta) Gondwana (Permo-Triassic) sequence, Synrift sequence (Barremian to Albian-Aptian) to top most alluvium horizon is shown in Figure 2.



NW-SE seismic line through Tanaku-Poduru-Draksarama High

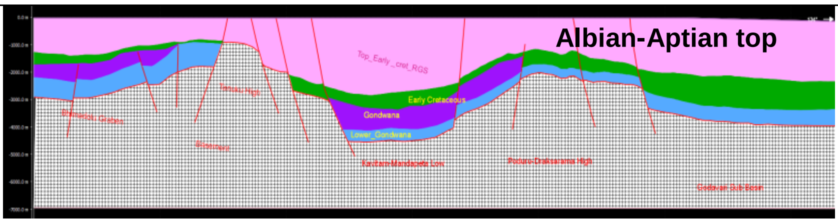
Permo-Triassic (Intracratonic Grabens)



Poor fracture density expected at highs due to erosion

Gondwana deposited in Bhimadolu and Mandapeta low. Tanaku high eroded and source of sediments for adjacent grabens

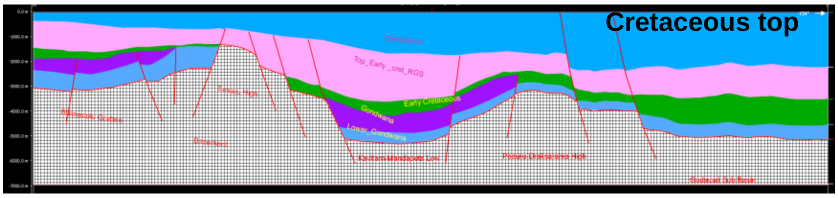
Albian-Aptian (Pericratonic Rifting)



Fault parallel fractures localised at fault intersections in highs

Lower part of Raghavpuram Shale deposited on rift fill sequence and upper part blanketing the existing highs. Onset of passive margin sequence. Significant thickness variations in grabens.

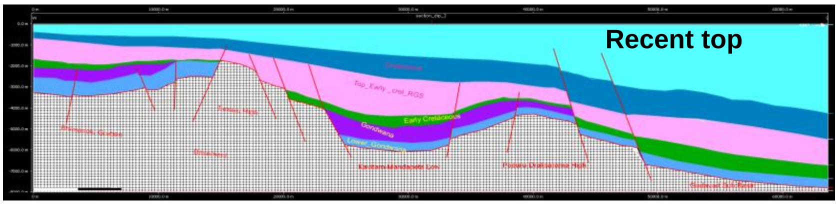
Cretaceous (Passive Margin)



Fracturing expected on footwall due to differential deformation

Sediments thickening towards South East. Reactivation of pre-existing syn rift faults causing foot wall uplift and hanging wall subsidence

Post Cretaceous-Recent (Flexural subsidence & Upliftment)



Fault block rotation and deformation along fault zone leading to fracturing

Flexural uplitment along Tanaku high. Subsidence in adjacent Bhimadolu graben. Poduru -Yanam high experienced flexural bending due to more post Cretaceous sediments in adjacent lows.

Figure 2: Structural Evolution of Tanaku-Poduru-Draksarama High

Strain Modelling through Geomechanical Restoration

The average geomechanical properties for Basement were assigned from the global average value for Granite-Gneiss complex. Distortion and volume change in rock are the main deformation styles responsible for fracturing. These deformations were restored and the amount was quantified in the form of finite strain captured on the surface and was colour coded with high values in red and low values in blue (Figure 3). Fe1 strain azimuth plotted in rose diagram indicates NW-SE direction of principal strain axis (Figure 4)

Discrete Fracture Network Model

Fe1 strain map obtained from geomechanical restoration was used as the attribute to model fracture intensity. Fracture attributes with fracture length of 750m, aperture value of 2mm and aspect ratio (height: length) of 1:2 were used for generating fracture model and displayed in geocellular volume of 100x100x120 cell size (Figure 5). Two major fracture sets oriented ENE-WSW and NNW-SSE have been observed from outcrop and FMI log in study area and used for fracture modelling. Several of the key observations made by analysing the DFN model are as follows.

- Porosity, permeability and intensity of fractures increased along fault intersection, fault damage zone and at fault tip (Figure 5).
- High fractures intensity have been observed in areas of high Fe1 value and along fault zone which affect permeability in the vicinity of faults
- Fractures dipping at an acute angle to the fault surface, are related to block-uplift, whereas fault parallel fractures are formed due to block-rotation.
- ENE-WSW trending set-2 fractures appear to be developed by fault block rotation and NNW-SSE trending set-1 fractures by block uplift.
- Modelled fracture set-1 matched with fractures observed in the well MS-A.

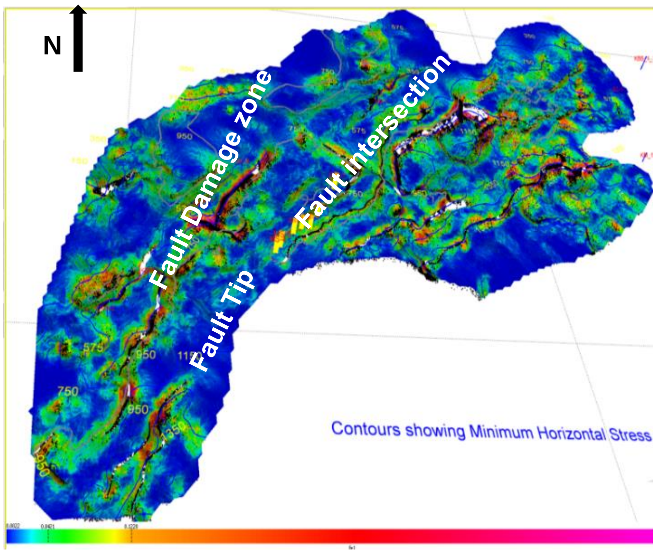


Figure 3: Map showing finite strain Fe1, high values represented as red and low values as blue

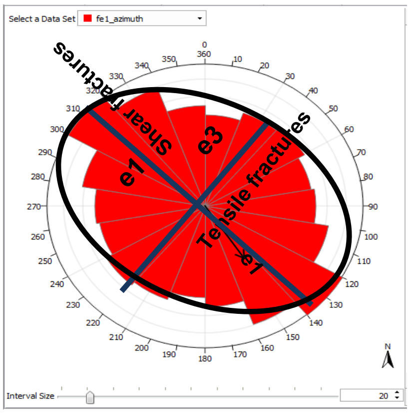


Figure 4: Predicted fracture orientation from Strain Azimuth on strain ellipsoid with three strain axes (e1 > e2 > e3) with possible developed fractures

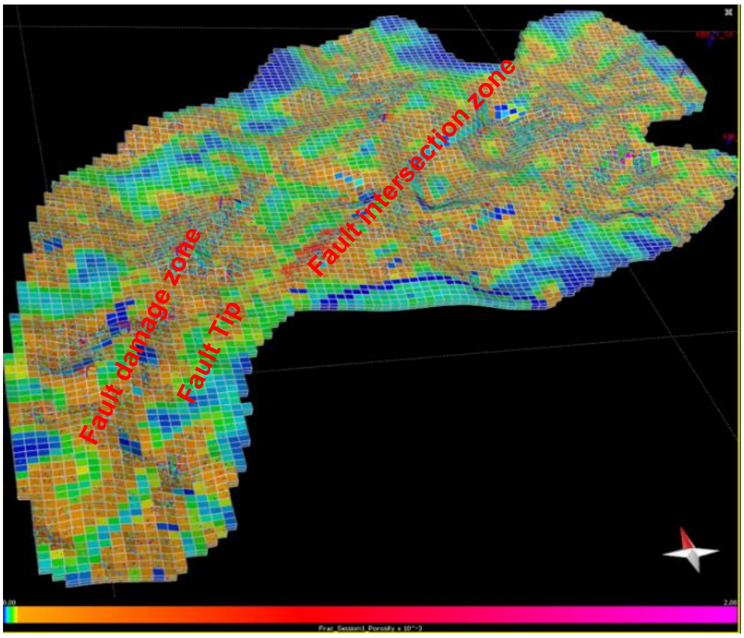


Figure 5: DFN showing Fracture Porosity 0.0- 0.265% in geocellular model 100x100x120 cell size

Fracture Characterisation

Fracture characterisation was carried out through connectivity analysis by calculating Porosity, Permeability, and fracture intensity P32 (m^2/m^3) properties.

- **Fracture porosity** is generally a small number compared to "normal" matrix Porosity. Most good fractured reservoirs possess less than 1 percent porosity (Aguilera, 1995). Fracture porosity in well MS-6 ranging from 0.0002 to 0.02% was upscaled by generating iterative models varying the aspect ratio and aperture value. It has been observed that the aperture value 0.1mm and aspect ratio of 1 is optimum for attaining the porosity value of 0.01% (Figure

6) The model shows fracture porosity in the range 0.000 to 0.265% with warm colours as higher value and blue colours as lower value (Figure 5)

- **Fracture permeability** is usually several orders greater than fracture porosity and overshadows the volume in the fractures. The modelled permeability value ranges from 0.00 to 50 darcy. Higher values are concentrated at fault damage zones (Figure 5 & 6).
- **Fracture intensity** P32 (m2/m3) is surface area per volume. Fracture intensity with structural position varies with the radius-of-curvature or rate-of-change-of-dip. Increase in strain gives an increase in fracture intensity. Modelled fracture intensity P32 is in the range of 0.0 to 0.7. High fracture intensity areas show higher porosity and permeability concentrated at high strain areas (Figure 7 & 8).
- **Stress analysis** indicates the NE-SW trending faults and NNW-SSE trending fracture sets to be related to high shearing and having dilation potential for fluid flow.
- **External stress** increases (below the yield point) due to either increase in depth of burial or confining pressure. Fractures compress or reduce in porosity and permeability much more readily than the matrix. The model shows low permeability at basement high and at grabens. This is due to erosion at basement highs and high confining pressure at grabens (Figure 9).

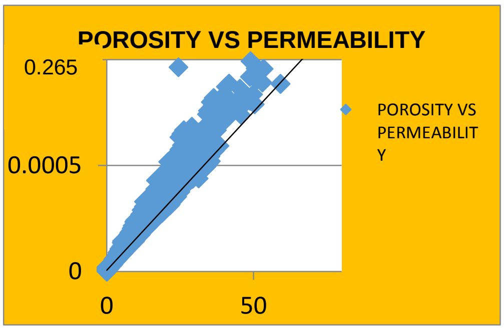


Figure 6: Relationship of porosity and permeability

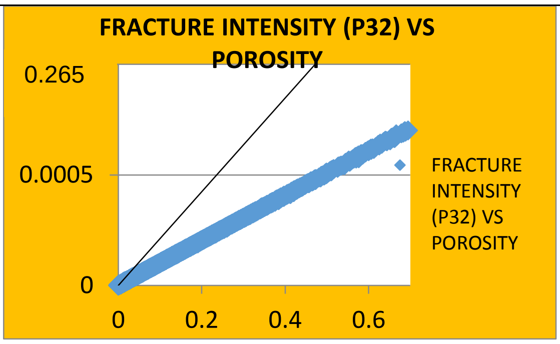


Figure 7: Linear relationship of porosity with P32

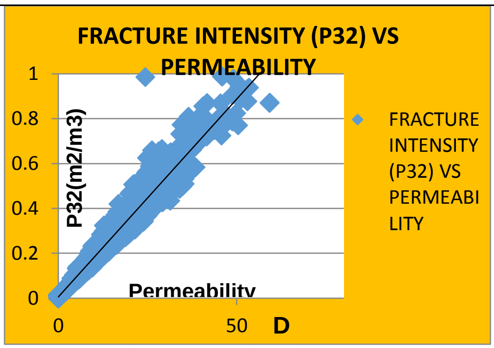


Figure 8: Linear relationship of permeability with fracture intensity

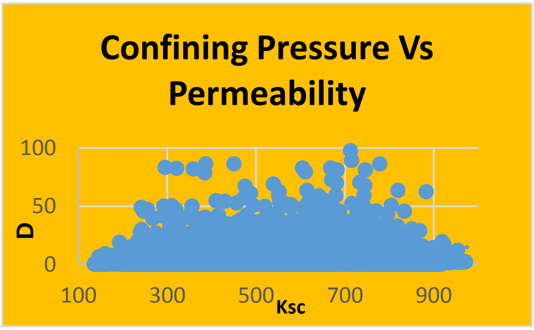


Figure 9: Permeability decreases at high confining pressure at high burial depth

Prospectivity Analysis

Petroleum system modelling carried out along NW-SE line A-B in Tanaku and Yanam highs indicate mature source rock with >50% transformation ratio juxtaposed with fractured basement highs (Figure 10). NNW-SSE oriented fractures and NE-SW trending fault damage zones are in open mode for fluid migration in present day stress regime. Areas of high fracture porosity, permeability and fracture intensity concentrated at fault damage zones, fault intersection and fault tips are to be targeted. On this basis prospective areas have been identified in Kaikalur, Kaza, Tanaku, Bantumili, Endamaru, Draksarama and Yanam highs (Figure 10)

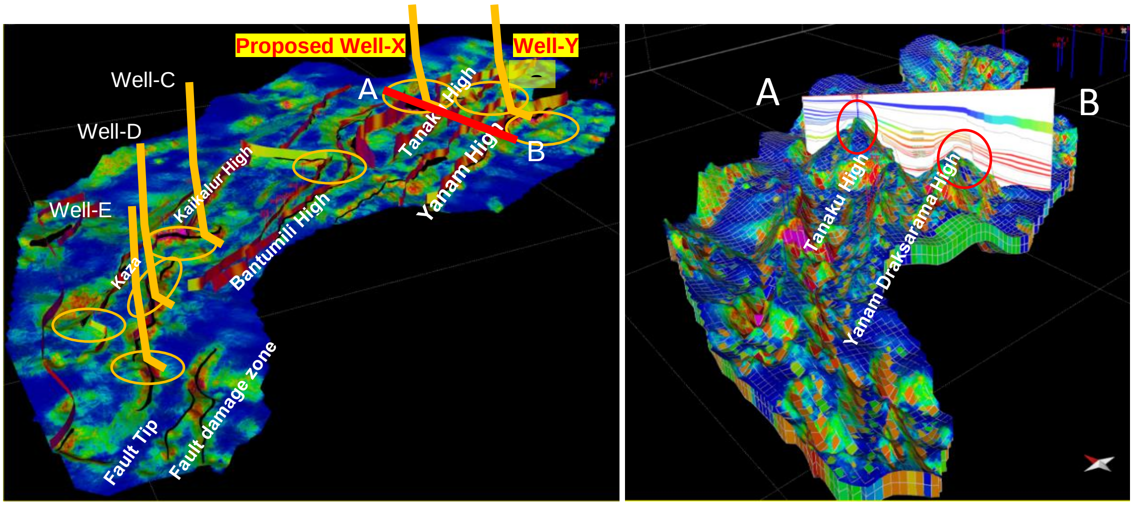


Figure 10: Prospective areas with proposed wells and source rock transformation ratio in section A-B

Optimum Design and Placement of Well

The study suggests the exploration strategy for basement exploration by designing well path to target critically stressed NNW-SSE fractures and NE-SW trending fault damage zones. Hence horizontal or high inclined wells in ENE-WSW direction may be preferred to intersect maximum number of conductive fractures in the highs for fluid flow (Figure 11).

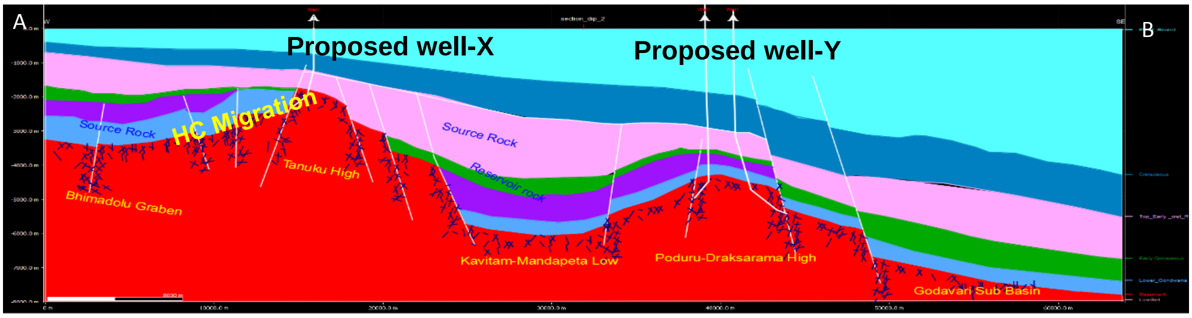


Figure 11: Optimum design and placement of proposed inclined well in Tanuku and Draskarama high

Conclusions

Main conclusions drawn from the study are given below:

- 2D palinspastic section analysis shows high fracture density concentrated in fault intersection of the horst blocks
- Strain map analysis shows high strain values around the fault damage zone, fault intersection and at fault tips.
- High porosity and permeability zones are concentrated along fault damage zones with lateral extent of 500 to 1000m.
- Low permeability and porosity values are observed at top of horsts due to erosion and grabens due to high confining pressure at high burial depths.
- Stress analysis indicated NE-SW trending faults and NNW-SSE trending fractures sets to be having high shearing and dilation potential and are in open mode for fluid flow.

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References

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