

**Reservoir Characterization in Deccan Trap GK-28 Area, Kutch Offshore: an Integrated Analysis**

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**Keywords**

FMI™, Sonic scanner, Tectonic trends, Seismic attributes, Fracture model, PLT

**Summary**

GK-28 area, in the shallower waters of Kutch offshore on the Western passive margin of India, has been in focus for Trap exploration after discovery of hydrocarbon in Trap in a recently drilled well. The tectonic architecture defined by three Precambrian trends, the NNW-SSE normal faults and the NE-SW & ENE-WSW trending transfer faults, play a key role in migration and accumulation of hydrocarbon in trap. Detailed study of well logs was carried out in wells drilled considerably within Trap. Analyses brought out that the secondary porosity in Trap is limited to joints and moderately weathered vesicular basalt and permeability is entirely fracture driven. Fracture modeling workflow was adapted for the GK-28 area along with integration of petrophysical analysis and laboratory inputs. The integrated fracture model best explains the heterogeneity of the trap reservoirs in this area and helped identify future potential areas for Trap exploration.

**Introduction**

Kutch basin, a pericratonic rift basin, has evolved as a promising area for Deccan trap exploration. In the GK-28 area, so far eleven wells have been drilled to trap, out of which seven wells have required data for carrying out fracture characterization. Of these, two wells have penetrated entire thickness of Basalt, though these were not hydrocarbon bearing. Other two wells which have penetrated only a few meters in Basalt have produced hydrocarbon from weathered trap during initial production testing.

Three distinct fault trends i.e., NNW-SSE (Dharwarian trend), NE-SW (Aravalli trend) and E-W (Satpura trend) are the regional fault trends in the area. An analysis of the satellite lineaments in Peninsular India and Kutch offshore show distinct parallelism to the major Precambrian trends suggesting their tectonic origin (Misra

et al., 2013) (Figure 1). The reactivated NW-SE fault trends act as conduits for hydrocarbon migration from the underlying Mesozoic sediments to the overlying volcanics (Payal Kataruka et al; ONGC Internal report, 2016). These lineaments extend from Archaean basement right up to Trap volcanics.

The present-day maximum horizontal stress is ~N-S to NNE-SSW direction as deduced from earthquake focal mechanism solutions and well data.

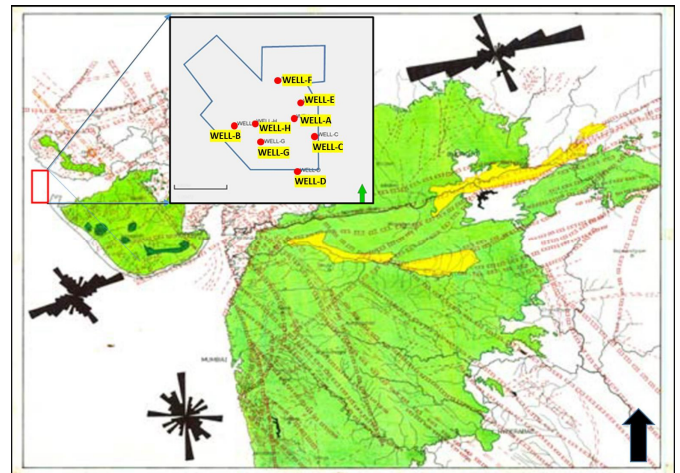


Figure 1: Map of peninsular India depicting the distribution of satellite lineaments along with Fracture dip plot of WELL-G (Misra et al.2013)

Volcanic reservoirs are primarily secondary porosity reservoirs where hydrocarbon migration and fluid flow mechanism is directly influenced by fracture permeability. The best way to characterize such reservoirs is by integrating petrophysical analysis, well test and reservoir data with geostatistical fracture model based on seismic. The conceptual integrated fracture characterization model generated on seismic data and constrained by well data have been able to explain to a large extent, the role of

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fracture distribution pattern vis a vis the anomalous hydrocarbon accumulation patterns in the area.

This model has been successfully used in generating new prospect for trap exploration in the area and resulted in hydrocarbon discovery in a well drilled subsequently based on the fracture model.

### Methodology

FMI™ (Formation Micro Imager) log records the fracture dips encountered in a well and determines the major fracture orientation and attributes/ properties. Micro image resistivity logs of four wells have been used for calibrating the fracture trends observed in the well logs with the seismic attributes. Sonic scanner log from two wells have been used to characterize fracture openness in the trap section.

Gross characterization of Trap lithofacies variation using ECS (Elemental Capture Spectroscopy) and XMAC-GR (Cross-Multipole Array Acoustic- Gamma ray) log available in one well (WELL-F) was carried out to analyze the nature of Trap reservoir. Conventional logs viz; density logs and Micro Spherically Focused Log (MSFL) and resistivity logs were used to identify fracture zones in wells where image log has not been acquired.

In order to understand the orientation of fractures, the nature of Deccan trap, their relation to source areas, as also for identifying possible accumulation locales within trap, integrated fracture analysis using seismic and well log data has been carried out.

Fracture intensity model was generated to analyze the fracture trends in the area on a regional scale. Fault trends brought out in the seismic attributes and well log data were used for this purpose. In the fracture modeling workflow, seismic attributes viz; similarity, variance, semblance, etc. were generated. Antrack attribute generated from variance as an input was used in fracture model for integrating the seismic data with the FMI™ log data. The fracture data from well logs and seismic data from Antrack constrains the fracture model considering the fracture trends from the FMI™ log. Point data calibration using Side wall core data and real time master log data have been used to validate the fracture model.

### Case study

Formation Micro Resistivity image logs have been used to identify the fracture traces and trends in the wells. Analysis of the logs bring out 2 major trends, the major NE-SW trend and a conjugate NW-SE trend. The conjugate trend is parallel to the  $SH_{max}$  and is favorable for hydrocarbon migration.

In WELL-G, which yielded hydrocarbon gas in commercial quantities; the top most part of Deccan trap is weathered, as evidenced from a side wall core cut in this section. Similar observation can be made from the image log also. Gas shows observed in the trap is from the top part which is weathered (weathered trap evident from image logs as well as lithoscanner log indicating high Fe/Si ratios). These intervals interpreted from well logs have been calibrated with the fracture intensity and show a good match (Figure 2a and 2b). Analysis of FMI™ and Stonely slowness in WELL-G indicates porosity as high as 11-12%.

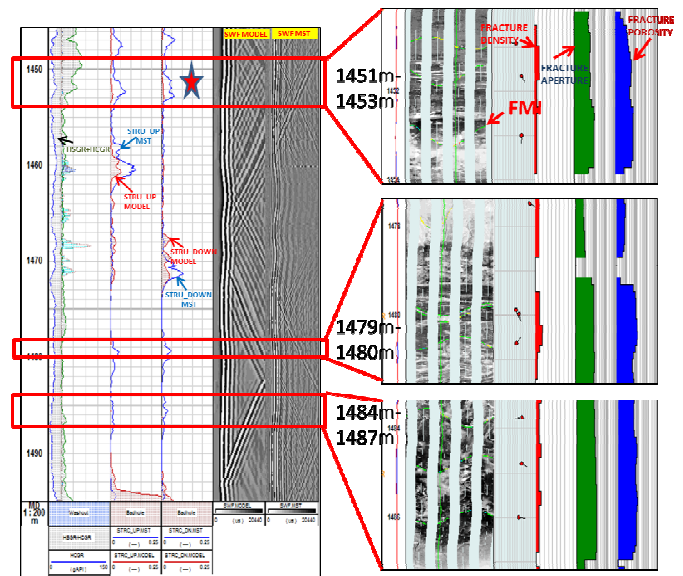


Figure 2a: Fracture intervals seen in both FMI Frac View and Stoneley Fracture Analysis logs in WELL-G

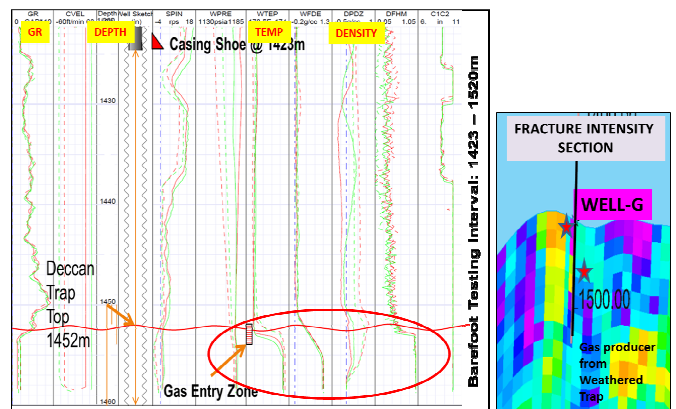


Figure 2b: PLT log calibrated with Fracture intensity section through WELL-G

## Fracture Characterization of Deccan Trap- a Case Study

From the micro resistivity image logs the nature of trap in wells WELL-D, WELL-E and WELL-F have been interpreted as altered trap (Figure 3-5). XMAC-GR in WELL-F with low  $V_p/V_s$  ratio indicates secondary porosity development in trap. Correlation of FMI and Sonic Scanner Stonely fracture analysis shows presence of open fractures in the weathered and fresh Trap sections. ECS log in WELL-F (with 49m penetration in Trap) indicates basalt with very high Fe/Si ratio in top 15-20m of Trap which represents heavily jointed / weathered part of trap. All the available logs data in WELL-F show good calibration with Ant track attribute (Figure 5).

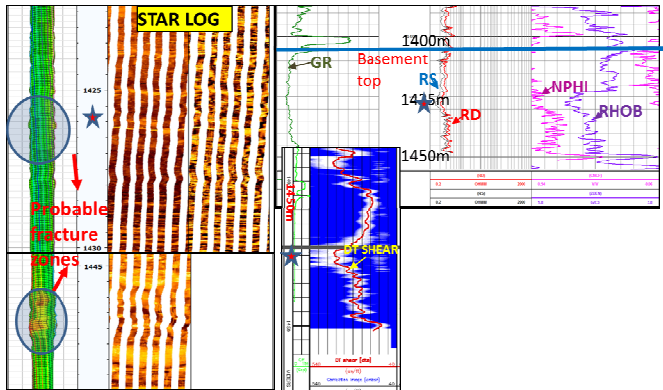


Figure 4: Star log analysis and DT Shear along with conventional logs of WELL-D indicating probable fracture zones (Star mark indicates zones with probable fractures)

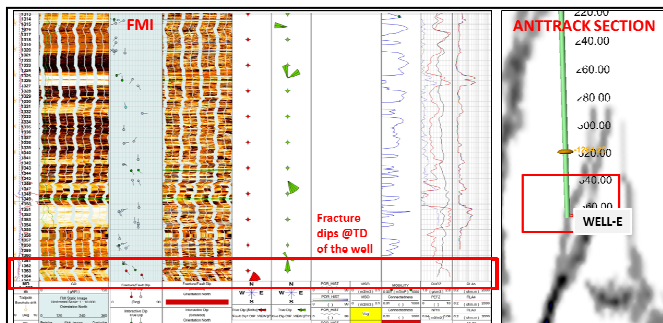


Figure 3: Log analysis and Antrack section of WELL-D

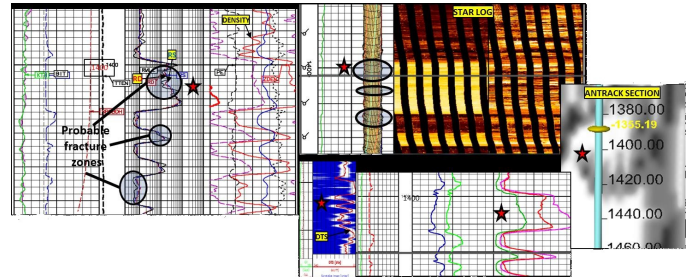


Figure 5: Log analysis and Antrack section of WELL-F (Star mark indicates probable fracture intervals)

Well data in the form of ditch cutting samples, caliper log, resistivity log, density log and MSFL log have been used in wells WELL-A, WELL-B and WELL-C to characterize fracture zones.

Cuttings data of WELL-C which yielded total gas of 0.09% within Trap section has corresponding low density values. These lowering of densities are indicative of good reservoir porosity. WELL-B has suffered from partial mud loss while drilling the trap section. These intervals show a good match with Caliper log at intervals prevailing to bad hole conditions (Figure 6). Similarly, WELL-A also has several possible fracture intervals analyzed from the resistivity logs. All the three wells show a good calibration with the antrack and fracture intensity.

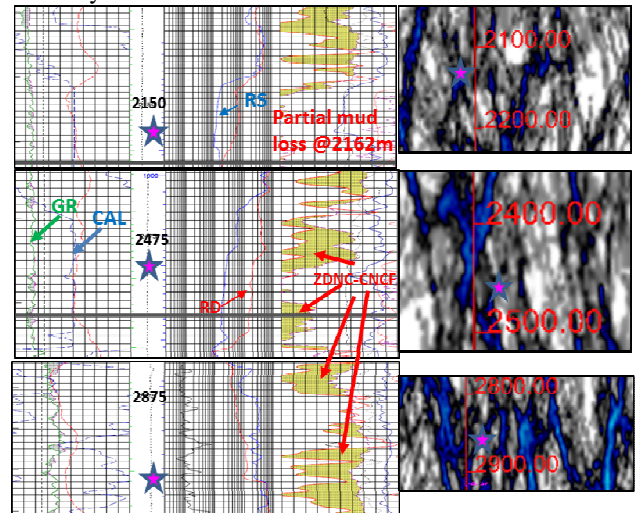


Figure 6: Log analysis and Antrack section of WELL-B (Star indicating probable fracture intervals)

The attributes generated from Seismic depth volume bring out the major fault trend along NNW-SSE and minor ENE-WSW trending cross faults. From the seismic

attributes it is observed that the major fault trend continues down to 400m within Deccan trap. Antrack volume and FMI™ data are the seismic input and well input respectively, to generate the Fracture network model.

The dip pole plot of WELL-G has been divided into four fracture codes considering the orientations from the regional tectonic trends. These fracture codes have been used with the Antrack volume to generate a meaningful fracture intensity model.

On comparing the fracture intensity model with the well data, the validation of the model was ascertained. The fractures encountered in the wells show good correlation with the fracture intensity in the model. The Fracture network enhances both trends in the area (Figure 7).

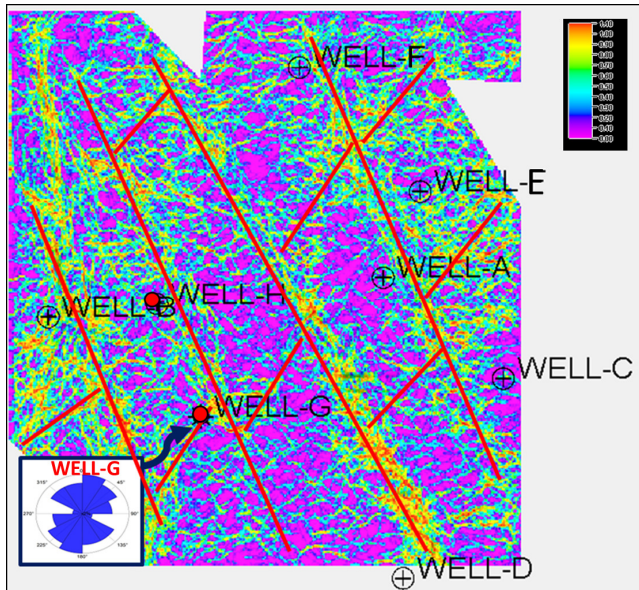


Figure 7: Fracture intensity section near Trap top with fracture trends (Red filled circles being gas wells)

PLT (Production Logging Tool) record is a very important tool for identifying producing interval in a well. In WELL-G, it shows good calibration with the fracture model where weathered trap is the major gas producing interval (Figure 2b). The well has been drilled at intersection of NNW-SSE and ENE-WSW cross trends. These are the junctions of maximum fracture density.

With the same analogy, WELL-H was proposed to access prospectivity of Deccan trap. The well was drilled close to maximum fracture intensity at the intersection of fault trends. It has encountered weathered Trap in the top part

and has emerged as a gas producer from Trap. Hydrocarbon indications in the top weathered part were recorded. Master log data calibrated with Antrack and Fracture intensity shows a good match (Figure 8).

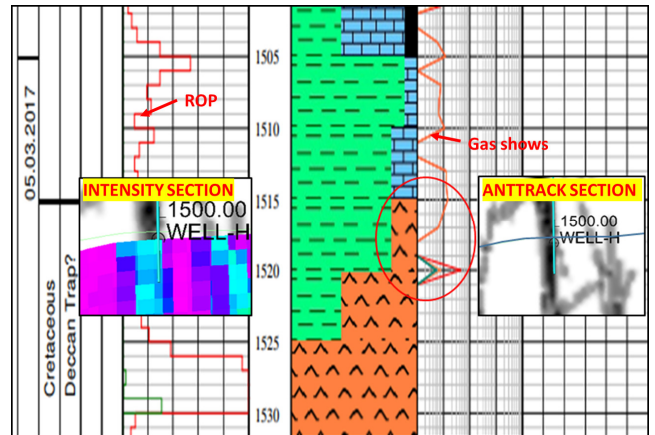


Figure 8: Master log showing hydrocarbon indications in weathered trap calibrated with Antrack and intensity sections through WELL-H

### Conclusion

-Areas with defined intersection of fractures trending NNE-SSW and NW-SE direction are the best areas for Trap exploration. Trends sub parallel to the  $SH_{max}$  direction define the well paths to be designed for Trap exploitation.

-Reservoir has secondary porosity defined by joints and vesicles with fracture aided permeability. Fault parallel permeability is more relative to host rock compared to fault normal permeability.

-Lateral extent of the reservoir is deemed vast as all well logs exhibit the top part of Trap to have necessary properties to qualify as reservoir provided the top seal in Nakhtarana Formation exists.

- Fracture model integrated with image logs, sonic logs, well and lab data is the best way of characterizing Trap reservoirs in this area.

-PLT log is proved useful and should be made a practice in all the future wells.

## References

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