



P 058

Multi-Disciplinary Approach to Fault Seal Integrity Analysis: A Case Study from Jambusar Field Cambay Basin, India

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Summary

Identification of the sealing characteristics of faults is crucial in making decisions at hydrocarbon exploration, appraisal and development stages. Keeping in view the importance of fault seal and seal integrity, two main faults of Jambusar field, Cambay basin, compartmentalising the field in different blocks, were evaluated by conventional fault seal and geomechanical analyses. The faults analysed show sealing behaviour based on observable high average shale gouge ratio values (>25%). Fault reactivation study by geomechanical modelling method suggests that fault membrane seal and top seal are stable under the present stress regime and an additional pore pressure of >100ksc may be required to reactivate the faults. The information about seal integrity of the faults could be very helpful in devising exploration and development strategy in Jambusar field.

Keywords: Fault seal integrity, Shale gouge ratio, Hydrocarbon column height, Geomechanical modelling, Slip tendency, Dilation tendency, Fracture Stability.

Introduction

Fault seal integrity significantly impacts exploration success and production strategy particularly in areas with fault-bounded reservoirs. So, there has been renewed interest in the behaviour of faults as lateral seals and their seal integrity. A multidisciplinary approach to fault seal integrity, involving situations of juxtaposition of lithologies, fault membrane seal and fault reactivation studies in changed stress regimes are employed globally in exploration and appraisal stages. In this study, fault seal and seal integrity analysis is carried for Jambusar field, Cambay Basin by juxtaposition seal, shale gouge ratio (SGR) and geomechanical methods. Two main faults of the field, compartmentalising the field in different blocks, are evaluated.

Geology of Study Area

Jambusar field is located in NE of Gandhar field in Cambay basin and has very vital position from hydrocarbon production point of view (Figs.1&2.). It has been a prolific oil producing field and till now about 50 exploratory and development wells are drilled and production is from three sand units JS-1, JS-2 and JS-3 of

Hazard Member of Ankleshwar Formation of Middle Eocene age.

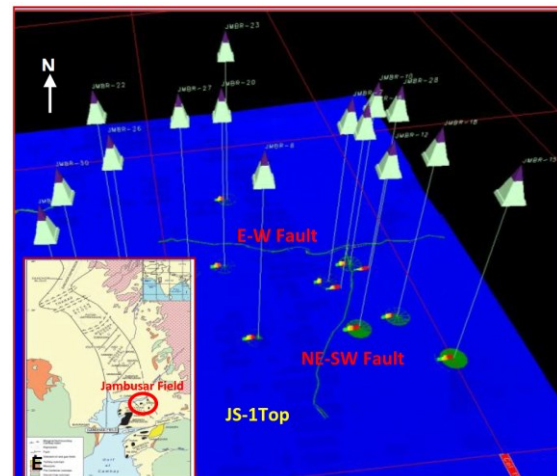


Fig.1. Depth map on the JS-1 Top of Jambusar field. The map shows the wells of the field and E-W and NE-SW faults. These two faults are analysed for fault seal.

These sands have overall gentle dip towards SW and SE. The pay sand JS-1 (GS-6) is selected for present study as it is the main producing sand and most uniformly



developed with thickness range of 12-15m in the field. (Fig.3.)

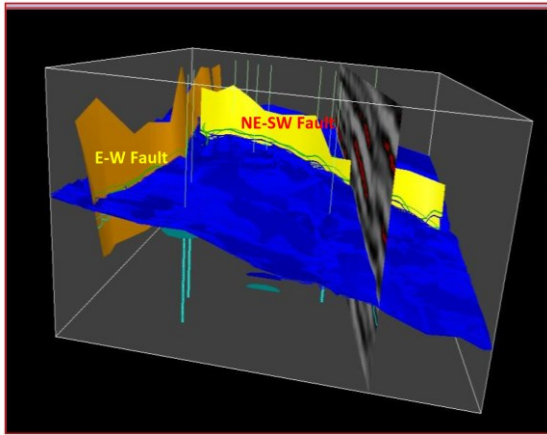


Fig.2. 3D view of Jambusar field showing JS-1 Top, E-W and NESW faults.

Hydrocarbon reserves occur in four blocks, each separated by E-W and NE-SW trending normal faults. The E-W fault has throw in range of 2-5m towards south. The NE-SW fault has throw towards west in range 5-8m. These two normal faults and their respective hanging and footwall blocks are analysed for fault seal analysis (Figs.1&2).

(Allan,1989). Second order fault seals are formed due to sealing potential of the faults themselves. Membrane seals and hydraulic membranes come under the second order fault seal category. Membrane seals can form due to clay smearing, cataclasis or diagenesis.

Juxtaposition Fault Seal

The most common type of fault seal is created in nature by the geometric juxtaposition of impermeable lithological units against reservoir by fault throw. Triangular diagram for lithological juxtapositions as a function of variable throw of faults are prepared to get idea of juxtaposition seals expected in the study area. These diagrams have been generated for two fault blocks of Jambusar filed (Figs.4&5), where representative lithostratigraphy was selected from wells on hanging (J-10) and footwall (J-23) sides respectively. It is observed that for all the throw values at JS-1 pay sand, sand/sand and sand/shale juxtaposition exists. Hence, for these two faults to be sealing, role of SGR values become very significant.

Shale Gouge Ratio (SGR)

Shale Gouge ratio is very robust algorithm to predict the sealing capacity at reservoir-reservoir juxtaposition on a

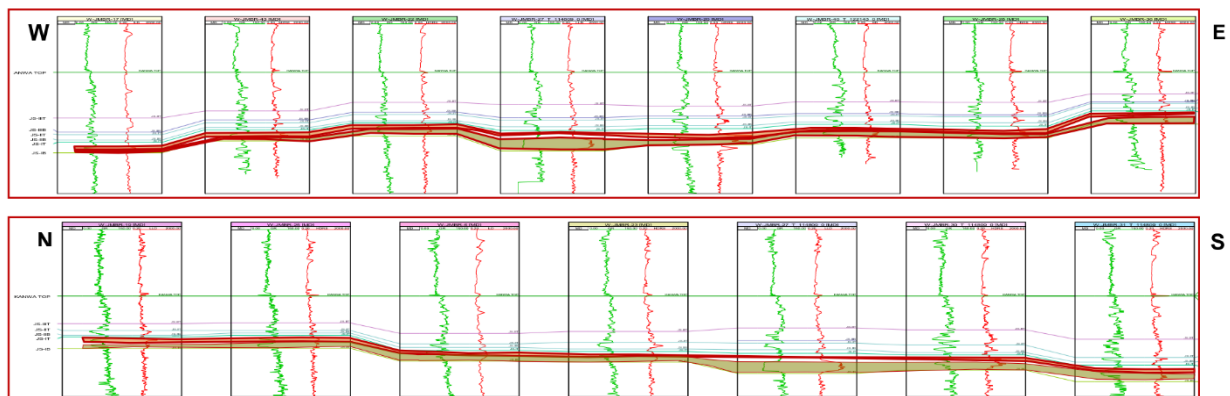


Fig.3. Electrolog correlation of pay sands of Jambusar field along E -W and N-S profiles.

Fault Seal Analysis

Fault can act as good seal to the migration of hydrocarbon, and in process results in formation of traps and hydrocarbon accumulations. First order seals can be created by geometric juxtaposition of reservoir against nonreservoir lithology by the throw across the fault

fault plane (Yielding et al.,1997;Yielding,2002). This algorithm basically predicts the shaly material in the fault zone (VShale) by calculating the net content of shale/clay in the volume of rock that has slipped past on the fault plane (Fig.6). It has also been observed that a strong relationship between SGR and sealing/leaking nature of faults exist. Globally, SGR values of 15-20% are considered to be the threshold between sealing and leaking



behavior of faults (Yielding, 2004). The SGR values calculated are generally higher than 25% for zones of sand on sand juxtaposition and are displayed as attribute map on

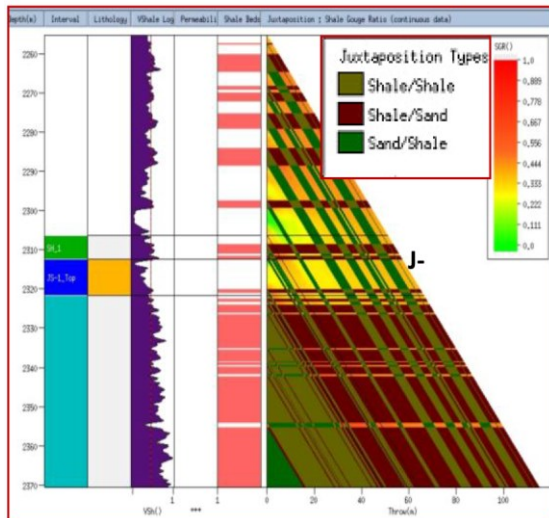


Fig.4. Fault seal triangle diagram showing variation in lithological juxtaposition as a function of fault throw for E-W fault.

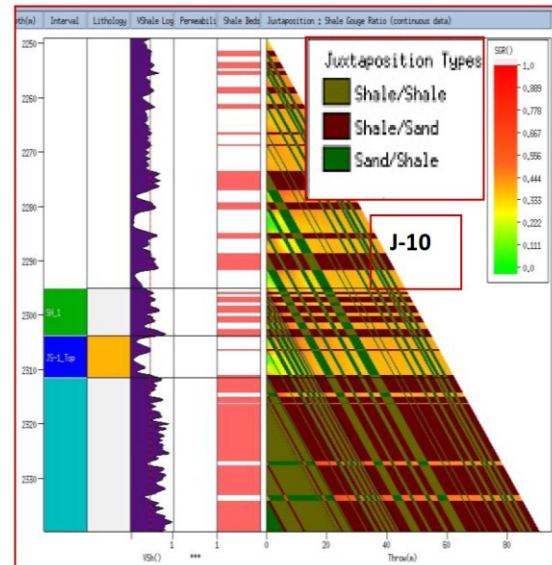


Fig.5. Fault seal triangle diagram showing variation in lithological juxtaposition as a function of fault throw for NE-SW fault cutting a generalised stratigraphic sequence of fault blocks variation.

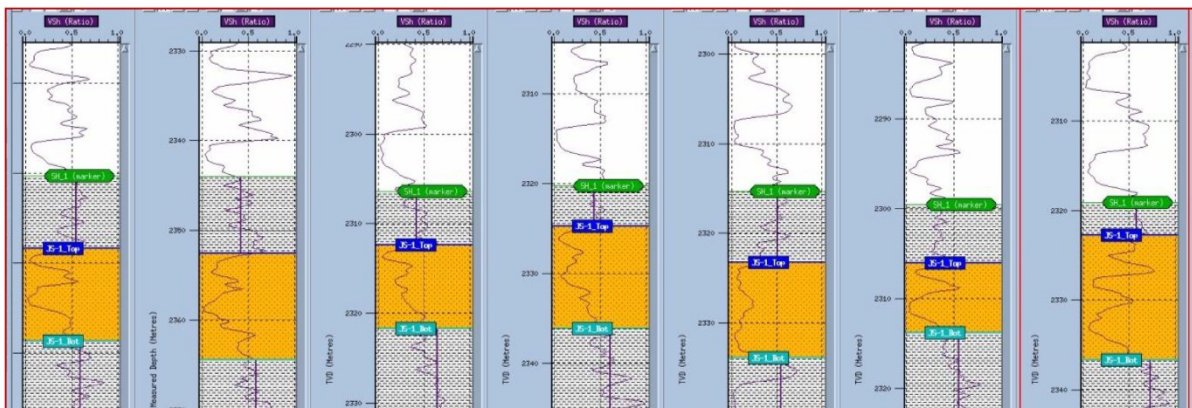


Fig.6. V shale Curves (Ratio) for Reservoir for Hazad member of wells of Jambusar field. Lithology type is shown for JS-1 sand. Vshale curve show low values in the range 0.1-0.3. These curves are utilized for calculating SGR.

fault surface (Figs.8&9). Based on the SGR values, therefore it is predicted that the sand on sand juxtaposition zones on the fault surface are sealing in nature.

4.1.5 Hydrocarbon Column Height

The empirical relationship between the fault-zone composition (SGR) and the capillary entry pressure of the fault zone (AFPD) are used to derive the potential hydrocarbon column heights that each part of the fault may be able to support (Childs et al., 2002).

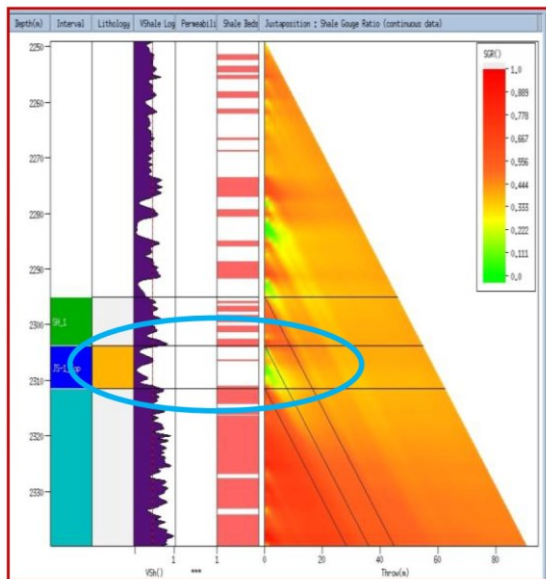


Fig.7. SGR values for sand on sand juxtaposition zones on NE-SW fault surface. Values are generally more than 30%. So, SGR suggests overall sealing behavior of the fault.

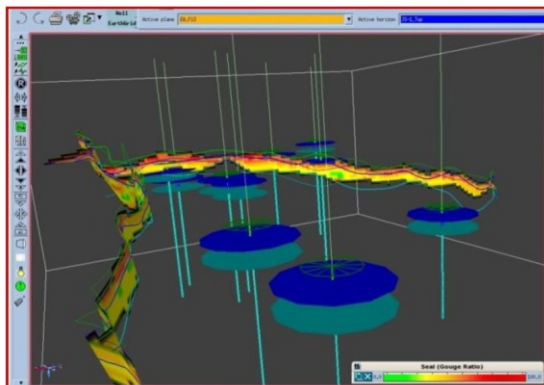


Fig.8.SGR values for sand on sand juxtaposition zones on E-W fault surface. Values are generally more than 30%. So, SGR suggests overall sealing behavior of the fault.

First, SGR values are calibrated in order to derive the maximum supportable pressure (taken to be equivalent to capillary entry pressure) along the fault plane. The maximum potential hydrocarbon column height can be derived using the equation:

$H = dP/g(\rho_w - \rho_h)$, where H is the hydrocarbon column height.; dP is the AFPD or buoyancy pressure.

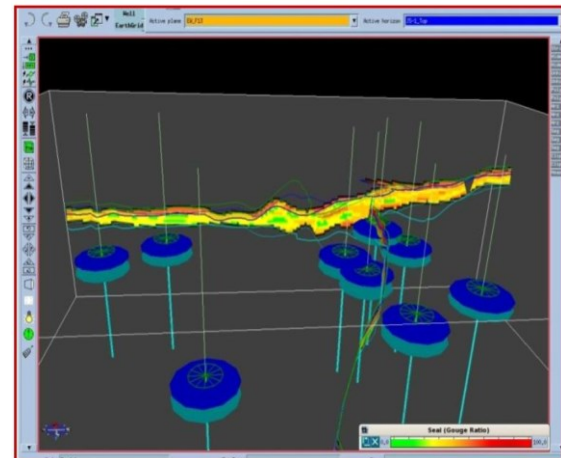


Fig.9.SGR values for sand on sand juxtaposition zones on E-W fault surface. Values are generally more than 30%. So, SGR suggests overall sealing behavior of the fault.

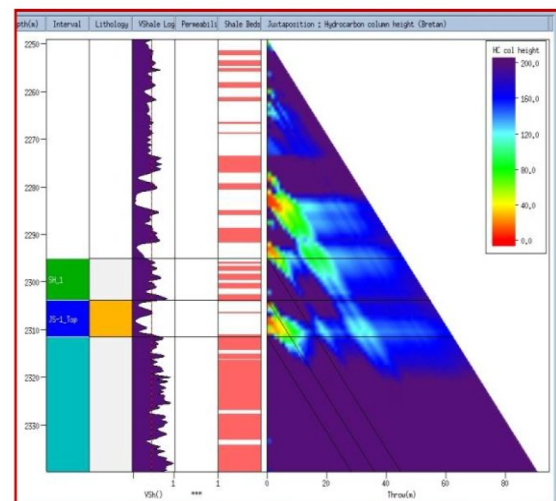


Fig.10.Triangular diagram showing expected HC height. A hydrocarbon column height of 40-80m can be maintained for throws less than 20m.

Hydrocarbon column height prediction is based on method adopted by Bretan et al., 2003, i.e. based on the empirical relationship between across the fault capillary pressure and SGR (Figs. 10, 11 & 12). Hydrocarbon column predicted is in the range of 80-120m.The predicted HC column height is similar to the field observation.

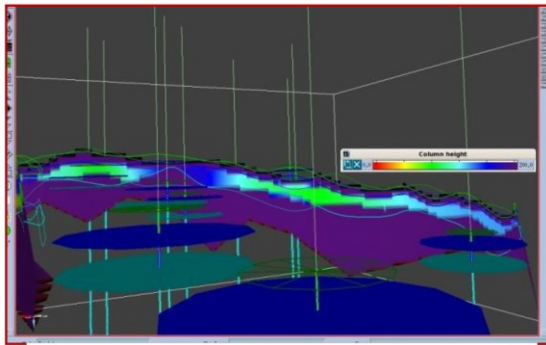


Fig.11. HC height along NE-SW fault surface. HC predicted is in the range of 80-120m..

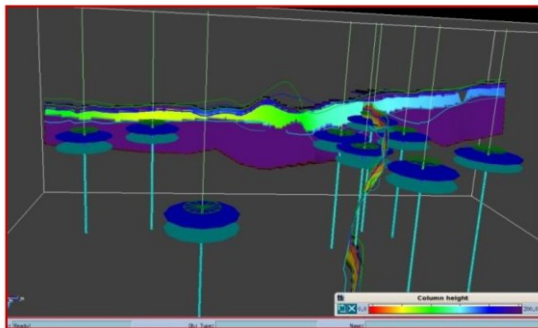


Fig.12. HC height along E-W fault surface. HC predicted is in the range of 80-120m..

Geomechanical Fault Reactivation Analysis

Several geomechanics based risk analysis are now applied to hydrocarbon reservoirs to assess the likelihood of reactivation of faults (Bailey et al., 2006). The reactivation of faults is caused due to its critical orientation and stresses in situ stress regime prevailing in the region. In this study, fault reactivation is analyzed by computing four geomechanical parameters viz. fracture stability, slip stability, slip tendency and dilation tendency.

Determination of regional stress field is the first stage in geomechanical modeling. The orientation of maximum horizontal stress S_{Hmax} for this study is taken as $N45^0$ from world stress map, 2008 (Fig.13). The gradients for effective Vertical stress (S_v), Horizontal maximum stress (S_{Hmax}) and horizontal minimum stress (H_{min}) are determined as 0.101ksc/m, 0.241 ksc/m and 0.077 ksc/m respectively. The principal stress calculated and their graphical representation for Jambusar area shows that S_{Hmin} is less than Vertical stress beyond reservoir depth. So, a strike slip stress regime (Fig.14) is considered and

the reactivation probability of faults of Jambusar field is assessed.

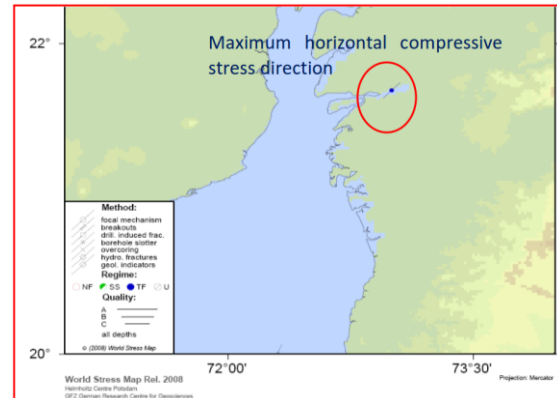


Fig.13 World stress map showing regional maximum horizontal stress direction for Cambay basin.

The stress field defined for average reservoir depth i.e. 2350m was displayed as semi-Mohr circles with fracture envelope for fault rock for the average reservoir depth. The coefficient of friction (μ) was taken as 0.75 and the cohesiveness value as 40 considering the deformation at depths $> 1000m$ take place by cataclasis. The poles of the E-W and NE-SW faults were plotted on Mohr's diagram.

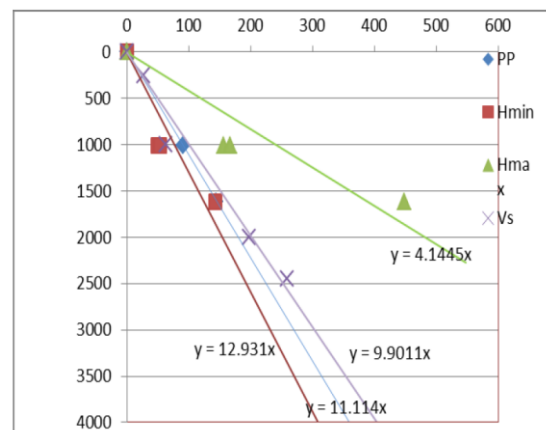


Fig. 14. In situ effective stress regime for Jambusar field showing effective stress gradients. Strike slip stress regime is inferred for Jambusar field

Stereoplots displaying zones of high or low values for Slip tendency, Slip Stability, Fracture stability and Dilation tendency were generated. The poles of fault were plotted on the stereograms of all the geomechanical attributes for seal integrity. The faults E-W and NE-SW have slip

tendency values in range 0.3-0.4 suggesting that the tendency of the slip along this fault is less in the prevailing stress regime (Fig.15). The value for dilation tendency for the faults was in range 0.5-0.6 (Fig.16) and it exhibits that faults are more critically oriented for a greater tendency of dilation than slip. But in both the analyses the faults at reservoir depth are stable and reactivation chances are remote. The fracture stability model suggests that an additional pore pressure more than 100 ksc would be required for reactivation of the fault at the reservoir depth (Fig 17). The results of the geomechanical modelling of the Jambusar field can be utilized in framing a production plan.

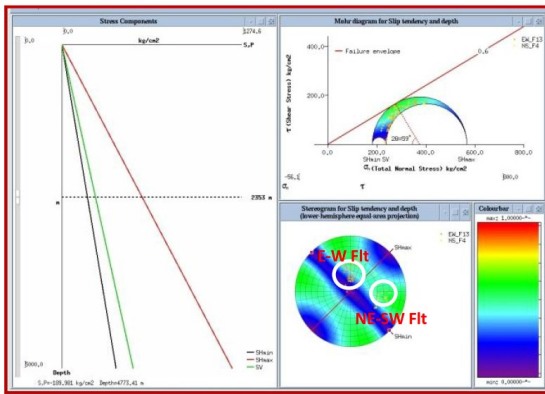


Fig.15. Slip tendency for faults E-W and NE-SW Faults. The faults have low slip tendency in the range 0.4-0.5.

In the later part of the production from field, at the stage of fluid injection for improved oil recovery, the geomechanical data will help in determining maximum allowable increase in pore pressure without causing the reactivation of the faults.

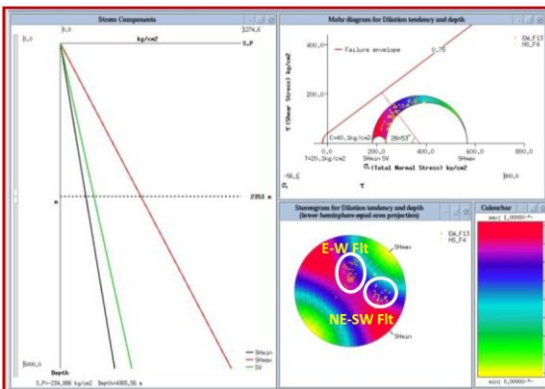


Fig .16. Dilation tendency for faults E-W and NESW Faults. The faults have dilation slip tendency in the range 0.7 -0.8. These faults are critically stressed for dilation

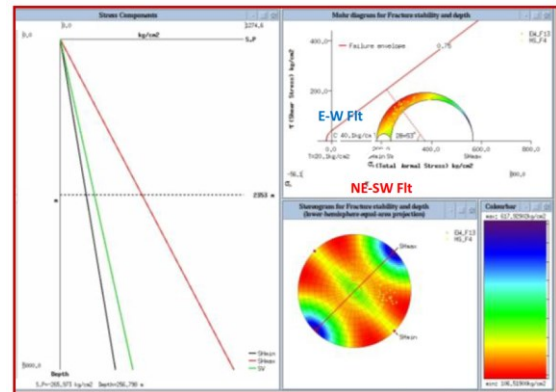


Fig.17 . Fracture stability for E-W and NE-SW faults. The faults will require >100 ksc increase in pore pressure for reactivation.

Conclusions

Two major faults analysed for seal analysis show a sealing behavior, based on high average SGR values observed (>25%). Hydrocarbon column heights predicted by empirical relationship between SGR and across fault differential pressure difference are in the range of 80120m. Fault reactivation study of E-W and NE-SW fault by geomechanical modelling suggests that fault membrane seals are stable under present stress regime. Both of the faults have higher dilation tendency than slip tendency. Fracture stability analysis predicts that an additional pore pressure >100ksc may be required to reactivate the faults at reservoir depth under present stress regime. The information about seal integrity of the faults could be very helpful in devising exploration and development strategy in Jambusar field.

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References

Allan, U.S., 1989. Model for hydrocarbon migration and entrapment within faulted structures. AAPG Bulletin 73 (7), pp. 803–811.

Badleys, 2005: Reference manual, Trap Tester.



Bailey Wayne R., Jim Underschultz, David N. Dewhurst, Gillian Kovack, Scott Mildren Mark Raven (2006). Multi-disciplinary approach to fault and top seal appraisal; Pyrenees–Macedon oil and gas fields, Exmouth Sub-basin, Australian Northwest Shelf Marine and Petroleum Geology 23, pp. 241–259.

Bretan, P., Yielding, G., Jones, H., 2003. Using calibrated shale gouge ratio to estimate column heights. American Association of Petroleum Geologists Bulletin 87, pp. 397–413.

Childs, C., Sylta, O., Moriya, S., Walsh, J.J., Manzocchi, T., 2002. A method for including the capillary properties of faults in hydrocarbon migration models. In: Koestler, A.G., Hunsdale, R. (Eds.), Hydrocarbon Seal Quantification. Elsevier, Amsterdam. Norwegian Petroleum Society (NPF), Special Publication vol. 11, pp.127–139.

Jennings, J.B., 1987. Capillary pressure techniques: application to exploration and development geology. American Association of Petroleum Geologists Bulletin 71, pp. 1196–1209.

Knipe R.J., Q.J. Fisher, G. Jones, M.R. Clennell, A.B. Farmer, A. Harrison, B. Kidd, World stress map, (2008).

Yielding, G., 2002. Shale gouge ratio-Calibration by geohistory. In: Koestler, A.G., Hunsdale, R. (Eds.), Hydrocarbon Seal Quantification.

Elsevier, Amsterdam. Norwegian Petroleum Society (NPF) Special Publication, 11, vol 67, pp. 1–15.

Yielding, G., Freeman, B., Needham, D.T., 1997. Quantitative fault seal prediction. American Association of Petroleum Geologists Bulletin 81, pp. 897–917.