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Full Length Research Paper

Fault seal analysis: a regional calibration Nile delta, Egypt

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Abstract

Faults in the subsurface generally have compartmentalization and sealing properties, the sealing properties of the faults were determined using Shale Gouge Ratio, Shale Smear Factor and the changes in pressure across the faults. Two fields (A and B Fields) in the Nile Delta were analysed, the fields were mostly dominated by structural traps where faults play an important role in trapping of hydrocarbons. A threshold of > 20% SGR and < 7 SSF was used as threshold for faults to seal. Five faults in A field and two faults in B field were analysed, faults in both fields were characterised by Sand-Shale juxtaposition in the footwall while the hanging wall is characterised by Sand-Sand juxtaposition and Shale–Sand juxtaposition. Five traps were identified in A field and 2 traps were identified in B Field, traps analysis shows that 4 of the traps in A field are structural spill point controlled traps (Spill point >Leak point). The faults in these traps are sealing with potential of over 200m hydrocarbon column height, the last trap in the field is a fault leak trap (Spill point <Leak point) and would not trap hydrocarbons. In B field, trap analysis for the main trap of the field shows a structural spill controlled trap (Spill point >Leak point), however the leak point of this trap is in the oil leg. The second trap in this field is a fault leak controlled trap and would not trap hydrocarbons.

Keywords: Faults, shale, hydrocarbons, trap and juxtaposition.

INTRODUCTION

Faults in the subsurface generally have compartmentalization and sealing properties. These properties are usually delineated by algorithms using the amount of shale on the fault surface, performance of flow monitoring and performance in reservoirs, identifying variations in oil and gas contacts across a fault plane or from measurement of difference in pressure across a fault.

Fault sealing properties are controlled by the juxtaposition of reservoir against sealing lithologies, deformation during fault displacement and subsequent evolution and the current state of stress of the fault /proximity to failure (Yielding, 2001). Whilst the stress state of fault relates to the in situ stress state of fault and the critical stress state at which a fault may leak (Barton et al., 1995), juxtaposition relates to detailed mapping of an area to identify reservoir-reservoir juxtaposition and possibilities of a non-permeable lithology forming a side seal to reservoirs across a fault plane. Although in reservoir –reservoir juxtaposition, the possibility of seal still exist if the fault zones have capillary pressure higher than reservoirs on either side of it.

Fault seal analysis has been done by several methods. These methods include using distribution of pore pressure, clay smearing to predict seal strength of faults (Berg et al., 1995), using Shale Smear Factor (SSF) to predict the possibility of continuous shale smear on the fault surface (Lindsay, 1991), using geochemical studies of fluid types and pressure to identify fluid composition in juxtaposed sands (Alexander 1998), using Allen Diagrams to determined juxtaposed reservoirs (Allan, 1989) and traps in closure and using Shale Gouge

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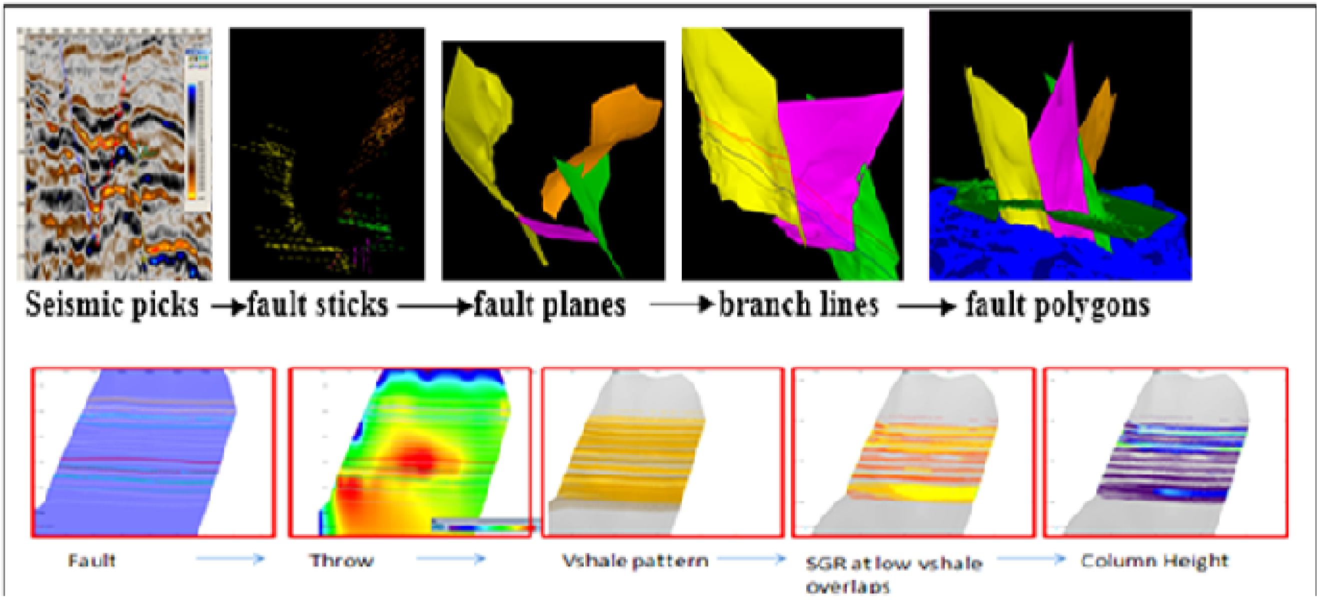

Figure1. Workload for trap analysis

Ratio(SGR) to predicate the sealing capacity of faults (Yielding, 1997).

Two fields (A and B Fields) in the Nile Delta Basin were analysed for this study. The fields are mostly dominated by structural traps where faults play an important role in trapping of hydrocarbons. Thus it is imperative that to reduce risks and uncertainties associated with exploration and better quantification of hydrocarbon volumes, fault seal calibration of prospects need to be carried out. The sealing properties of the faults were determined using SGR, SSF and the changes in pressure across the faults. A threshold of > 20% SGR and < 7 SSF was used as threshold for faults to seal (Yielding, 1997). The traps formed by these faults were also analysed to test the integrity of the sealing properties. Trap Tester Software ™ was used for analysis of this study.

METHOD AND THEORY

Faults were identified and picked from the field seismic data. Picked faults segments (sticks) were converted to fault surfaces. Branch lines representing intersection of faults were created to show the fault model. Wells (Vshale) data was mapped on the fault plane to show the distribution of the sand and shale layers at the fault. Pseudo wells were created where no wells exists on the hanging wall of faults. Primary seismic horizons and well marker horizons are used to constrain the mapping of well attribute data such as Vshale curves, onto fault plane surfaces (Figure 1). This process is automated within the Trap Tester Software and is achieved by scaling the well attribute data between where marker horizons occur on fault surfaces.

Pressure analysis was carried out by mapping Modular Tester (MDT) pressure data from wells on to the fault surface. From the mapped pressure data; buoyancy pressure, capillary pressure, across fault pressure difference (∆Pressure) for each faults was computed to help determine the sealing properties of the faults. Structural model was for the fields were constructed by synchronising the well tops and well data with the fault. Various attributes of fault such as Vshale, SGR, SSF, hydrocarbon column height, buoyancy pressure are then displayed for analysis. The theory of this work is based on SGR, SFF algorithms proposed by Yielding 1997 and Lindsay 1991. The pressure data was used to further confirmed if faults are sealing.

RESULT

Five faults in a field and two faults in B field were analysed for this work. Faults in both fields are characterised by Sand-Shale juxtaposition in the footwall while the hanging wall is characterised by Sand-Sand juxtaposition and Shale–Sand juxtaposition; this is because the throw of faults was sufficient to allow juxtaposition of overlying sealing shale formation with

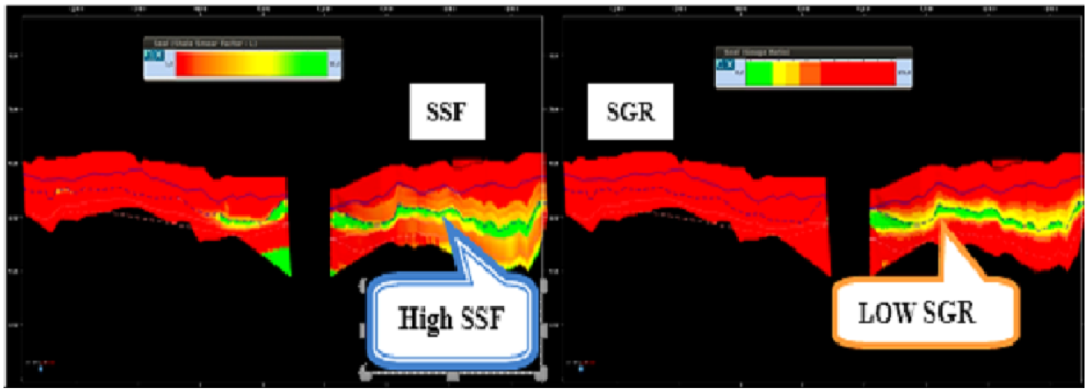

Figure 2. SSF (left) and SGR (right) attributes of some faults in the A Field .Leak zones are seen with low SGR and high SSF

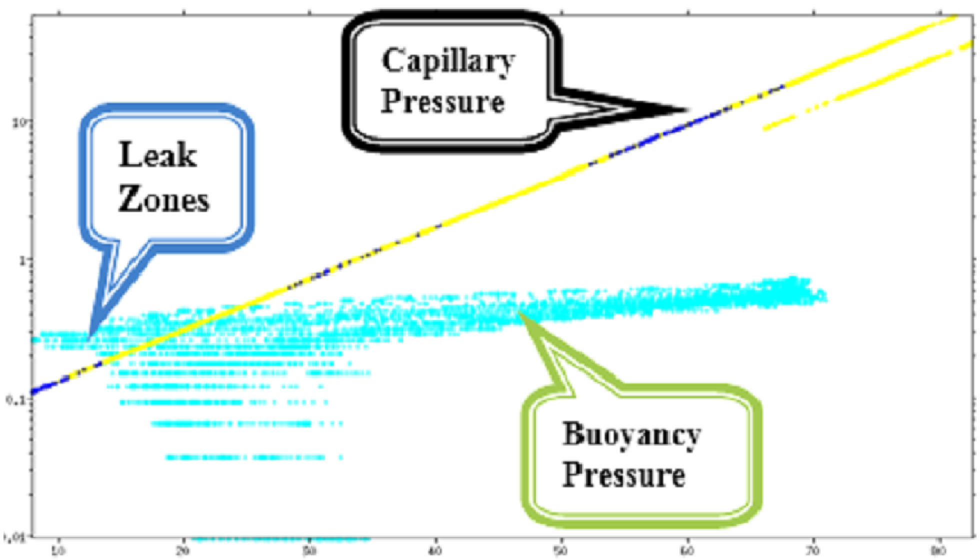

Figure 3. SGR -Capillary and Buoyancy Pressure Crossplot. Leak zones have Buoyancy pressure > Capillary pressure. Sealing zones are vice versa

sands in the footwall. The hanging walls of fault, where sealing are sealed by intra-formational shale within the reservoir. Faults in both fields are sealing as indicated by low average SSF (<7) and high SGR (average > 40 %). However leak zones exist in the hanging wall of the faults in both fields. Average SGR for A Field is 45% for all the faults in this field while the SSF values are very low and averages between3-5. The leak zones exist only in the hanging wall of faults in northern part of the field. The leak zones are characterised by discontinuous shale smear (high SSF values>7) on the fault surface, sand–sand juxtapositions and low SGR (0-19%).Leak zones were also observed in the hanging wall of faults in the B Field. These zones like A field have low SGR values between 10-20 % while an average SGR of 50% in the footwall of the faults (Figure 2).

Pressure analysis shows that the faults have high capillary pressure (>20MPa) and low buoyancy pressure (average of 0.10MPa). Across fault pressure difference for all the faults are negative (higher pressure in the hanging walls than the foot wall) and shows no communication of fluids across faults. The only exceptions to these are the leak zones which are seen to have higher buoyancy pressure than the capillary pressure (Figure 3) and 0 MPa across faults pressure (which shows communication of fluids to cause

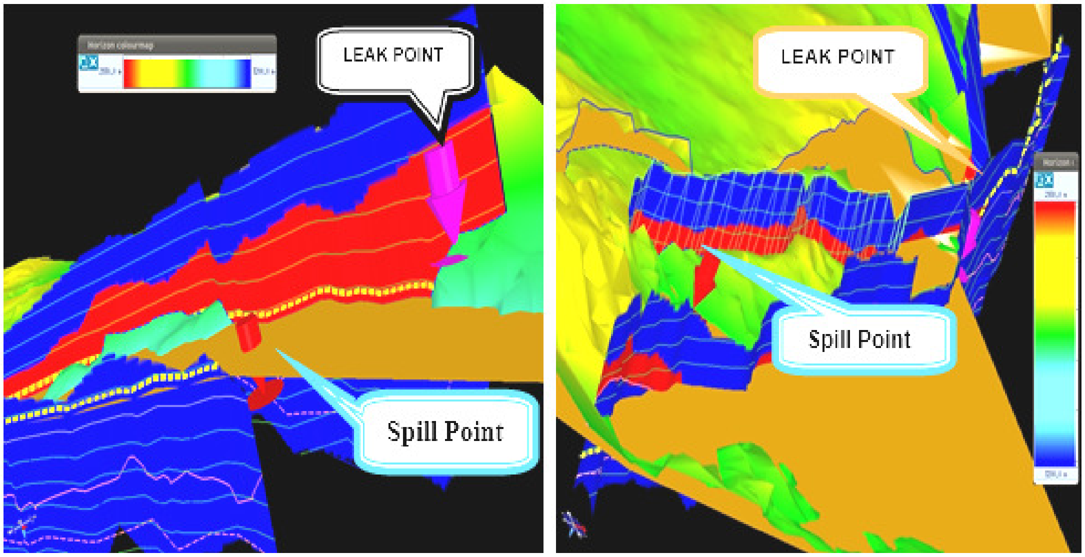

Figure 4. Fault leaked (Left) and Structural Spill Control (right) traps in A Field showing leak and spill points

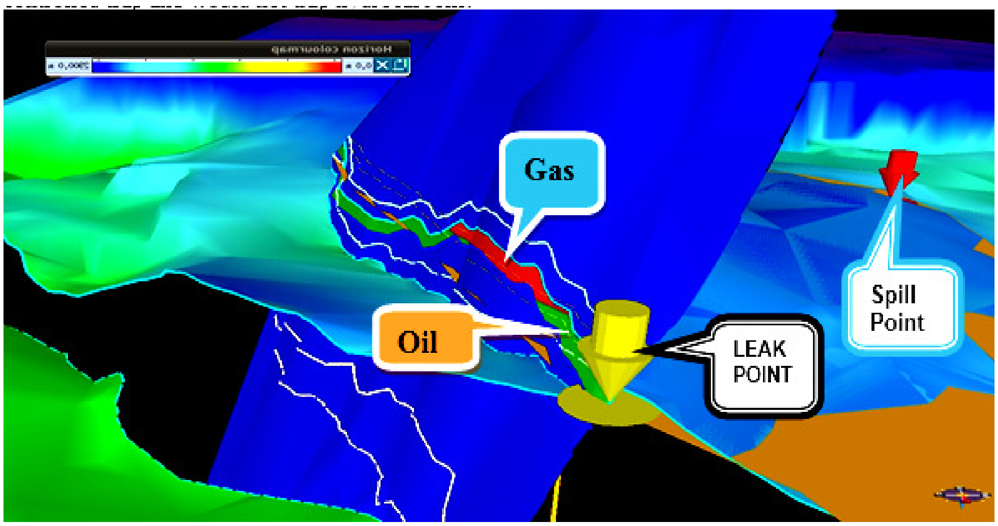

Figure 5. Structural Spill Control trap in B Field showing leak point in the oil leg

Equilibrium of pressure across the faults) and corresponds to low SGR and high SSF zones.

Five traps were identified in A field while 2 traps were identified in B Field. The traps were delineated based on the bounding faults and structural analysis of the fields. Traps analysis shows that 4 of the traps in A field are structural spill point controlled traps (Spill point >Leak point). The faults in these traps are sealing with potential of over 200m hydrocarbon column height. The last trap in the field is a fault leak trap (Spill point <Leak point) and would not trap hydrocarbon (Figure 4).

In B field, trap analysis for the main trap of the field shows a structural spill controlled trap (Spill point >Leak point), however the leak point of this trap is in the oil leg (Figure 5). The leak point controls the amount of oil that would be accumulated in the trap and it explains why a higher gas column with low oil column was observed in the field production data. The second trap in this field is a fault leak controlled trap and would not trap hydrocarbons.

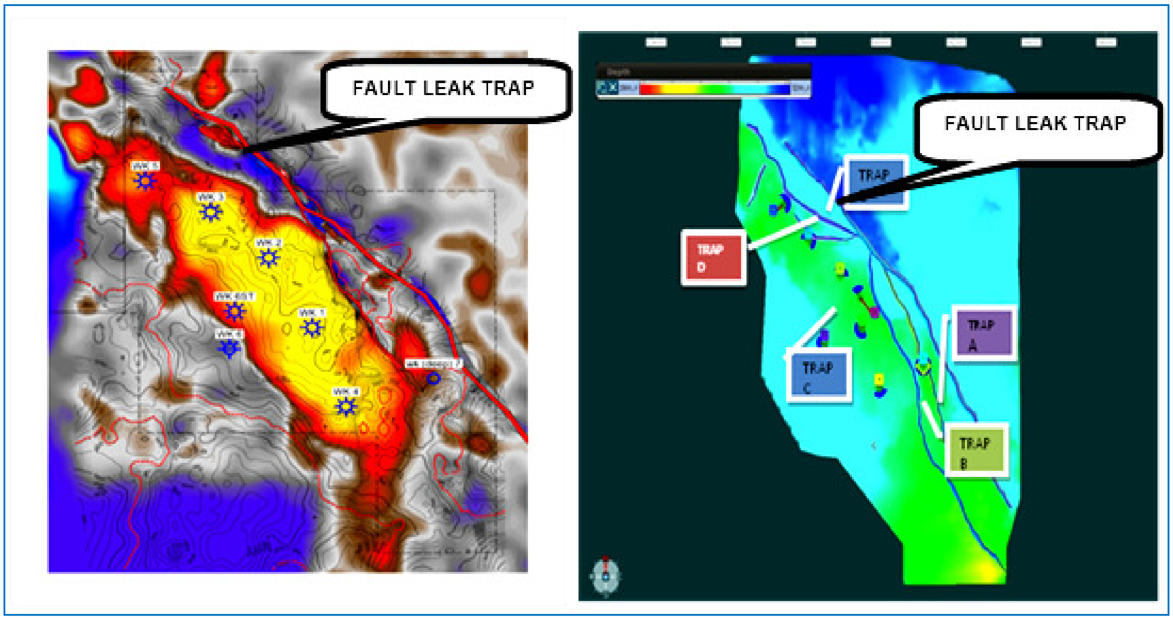

Figure 6. Comparison between amplitude map and Trap Analysis of Field A. Fault leak trap

DISCUSSION AND CONCLUSIONS

All faults in the two fields have good sealing properties in their footwall while their hanging wall is characterized by leak zones. Except for these leak zones, the faults are considered to be sealing as deduced from average SGR (higher than threshold SGR of 20%), low SSF, high capillary pressures and negative ∆Pressure. The sealing mechanisms are mostly dominated by continuous shale smears on the fault surface. The leak zones are characterised by sand-sand juxtaposition areas of the fault. These zones are considered not be sealing because of their low SGR, zero ∆Pressure values, low capillary pressures and high SSF values.

Trap analysis results were compared to the field data, and they show remarkable collaboration with what is observed on the fields. In A Field, the amplitude map shows no hydrocarbons in the identified fault leaked trap while other structural spill controlled traps shows hydrocarbons potentials (Figure 6). This result was buttressed by a well drilled in one of the structural spill controlled traps and was a significant gas discovery with commercial reserves.

Based on this analysis, hydrocarbon reserves for A was recommended to be recalculated to include prospects in the structural spill control traps while fault leaked trap prospect should be ignored. In B Field, understanding of the field was enhanced based on this study and production plan re-evaluation was recommended.

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