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Control of fault seal in hydrocarbon accumulation- an example from Jaisalmer Sub Basin

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Abstract

Jaisalmer basin hosts few gas fields of smaller size associated with the major/ minor faults system. However, one of the major concerns in the area is that traps are under-filled at most of the reservoir levels and the traps constituting the fields are filled with hydrocarbon to Spill/leak point. This indicates that the seal capacity is not constant in the different stratigraphic level. The column-heights in the reportedly under-filled reservoirs are suggested to be controlled by trap leakage. 1D fault seal analysis was carried out in Petrel Workflow tool application in the present study with the help of available G&G data. Simplified juxtaposition triangle diagram was used along with Shale Gauge Ratio method to enable a quick initial examination and prediction of fault seal capacity and its role in hydrocarbon entrapment in the structure.

Case studies have indicated that Manhera Tibba structure is under-filled due to the presence of dip leak fault system. Wherever dip leaking and cross leaking fault system co-exist, this leads to a larger accumulation. In a monocline like entrapment situation as in Chinnewala Tibba, cross seal and dip seal nature of fault system exist, which has helped in entrapment in the hanging wall structure and larger hydrocarbon column.

Introduction

Richard Bishop, in his presentation "Percent Trap Fill and Its Implications", stated: "Observations of hundreds fields in many different types of basins and source rocks shows that traps are full to either a leak point or spill point". He also emphasized on the fact that the field size is limited by a leak or spill point and not source rock yield. A trap capacity is thus defined by the spill or leak point in the trap and is dependent on the structural closure, seal capacity and/or fault juxtaposition. A basin can have a combination of fill-leak and fill-spill scenarios.

In basins where a large number of traps are associated with faults, predicting fault behaviour and property can be useful in identifying fault-dependent leak points which controls the volume of trapped hydrocarbon.

In the present paper, an assessment of sealing efficiency or flow capability of the fault with the help of analysis of fault behaviour and property has been carried out to ascertain the role of juxtaposition and fault leak point in explaining the hydrocarbon accumulations in Jaisalmer Sub Basin.

Geological Background

The Jaisalmer sub basin has evolved as the integral part of Indus basin and represents the eastern shelf part of the Indus Basin having an areal extent of 42000 sq km. It is a pericratonic sedimentary basin situated on north-western slope of the Indian peninsular shield. The basin slopes towards northwest. It has 10 km sedimentary succession ranging from Permo-Carboniferous to Quaternary. Deposition in both non-marine to shallow marine conditions has been established with the sediments ranging from terrestrial siliciclastic to marine carbonates. Mesozoic exposures are seen in the eastern part of Jaisalmer sub basin.

The main development of Jaisalmer sub basin took place in Mesozoic time in response to rifting of India-Madagascar and East Africa. The north-western part of the Indian plate entered a foreland phase in Oligo-Miocene times as a sequel to the Early Tertiary (main) continent-continent collisional event. Owing to the interplay of the Indian and Eurasian plates, the dominant stresses in the study area became transpressional leading to inversion and reactivation of the earlier faults in the

Jaisalmer-Mari Fault Zone during Plio-Pleistocene. This resulted into thrusting/strike-slip faulting, as evident in broad axial uplifts in the Jaisalmer-Mari Fault Zone. The area is dominated by near vertical fault system cutting across all stratigraphic horizons in different part of the sub basin. This fault system has been brought out by mapping of the area. Hydrocarbons are largely found in the structural highs associated with the broad axial uplifts created by the strike slip tectonics. The hydrocarbon fields are located on a prominent sub surface high element known as Mari High and are found in Cretaceous traps in Pariwar and Goru reservoirs and Paleocene-Eocene traps in Sanu, Khuiala and Bandah reservoirs.

Background Theory

Faults can act as a transmitter of or barrier to fluid flow and an assessment of sealing efficiency or flow capability of the fault can be understood with the help of analysis of fault behaviour and property.

It has been previously discussed that a trap is filled to either a spill point or a leak point. The point of maximum accumulation of a trap is referred to as the spill point (Figure 1). This can be controlled by a structural spill point or a fault spill point. The structural spill point is the deepest point of an anticline structure. The fault spill point is the point at which the hydrocarbon column can extend down to where juxtaposed reservoir layers are in communication. When the structures have a fault spill point, then the structure remains under-filled. The offset created by a fault influences the fault sealing and properties of the fault rock within the fault zone. A juxtaposition seal occurs when a permeable layer is placed across an impermeable one. A fault seal can also exist in absence of juxtaposition seal if the rock within the fault zone acts as an impermeable layer. This depends on the conditions of deformation and lithological factors such as clay content. Thus, depending on the above factors, a fault can act as dip seal or dip-leak and cross-seal or cross-leak respectively

For determining the nature of the faults in above light, 1D fault seal analysis was carried out in Petrel Workflow tool application. Simplified juxtaposition triangle diagram was used along with Shale Gauge Ratio calculation to enable a quick initial examination and prediction of fault seal capacity. Triangle diagram show the juxtaposition of the stratigraphy across the fault and SGR method estimates the percentage of clay from the host lithology mixed within the fault zone. Triangle diagram is prepared from well logs and SGR is calculated from Vshale curve. The sealing along the fault increases with increasing percentage of SGR.

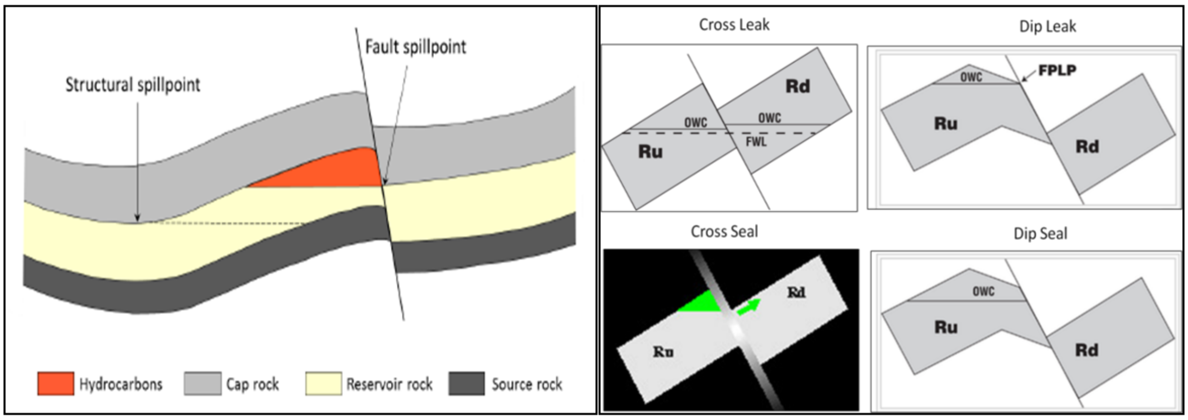

Figure1: Spill points in a trap and leak & seal point in a fault

Fault Seal Analysis

Most of the major traps in the Jaisalmer sub basin is under filled in nature, i.e. hydrocarbon pool size is smaller than the trap size at most of the reservoir levels. The structure is under-filled at all reservoir levels like B2 (Bandah), B4 (Khuiala), D4 (Sanu) and G2 (Lower Goru) except at C2-C4 (Khuiala) which is having maximum fill. The pool touches the fault at one side which indicates that the fault is leaking either as cross leak or as dip leak or as both resulting in under-filled nature of trap (Figure 2).

MT-A and MT-Bare two wells drilled in Manhera Tibba structure and is separated by a fault passing in between the two wells with MT-A being on the downthrown side (Figure 3). The average throw of the fault is 10 m. The hydrocarbon pools at Tertiary and Lower Goru level except for Khuiala are restricted to hanging wall of this fault. MT-A produces gas from B2 Limestone in Bandah (Pay top- 74 m), B4 (Pay Top- 111m) and C2-C4 (Pay Top- 167m) Limestone in Khuiala and D4 Limestone in Sanu (Pay Top- 240m) while gas is present in only C2-C4 (Pay Top-184m) reservoir of MT-B (Figure 2). Thus, the fault is limiting the presence of hydrocarbon in all the levels except that in C2-C4, Khuiala, creating a bigger pool. Also the presence of GWC of C2-C4 reservoir at 207m (the pay top in well MT-A is 167m and in well MT- B is 184m) across fault proves that both Cross seal and Dip Seal of the fault is leaking making the seal capacity poor at C2-C4 reservoir level.

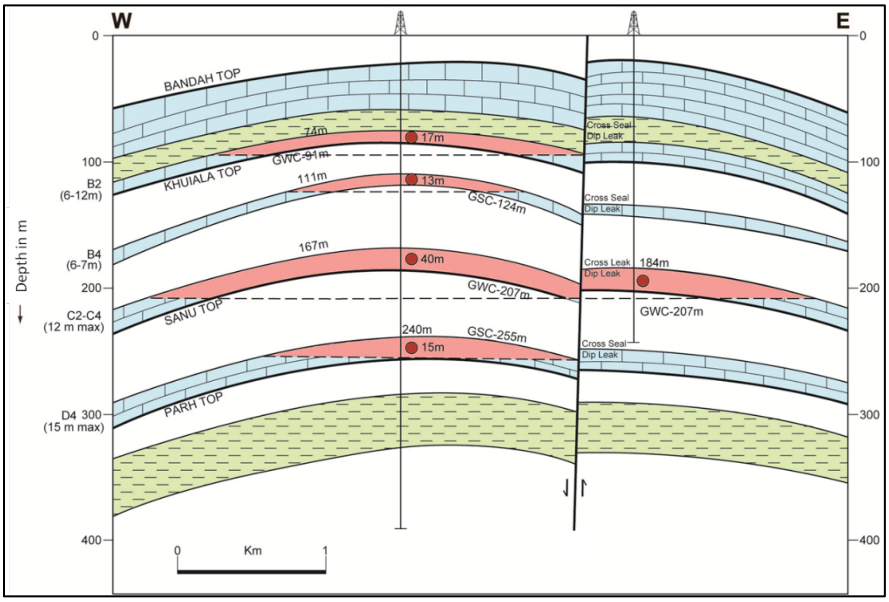

Fig. 2: Geological cross-section along the Manhera Tibba field (covering Tertiary Section) showing under-filled nature of the trap

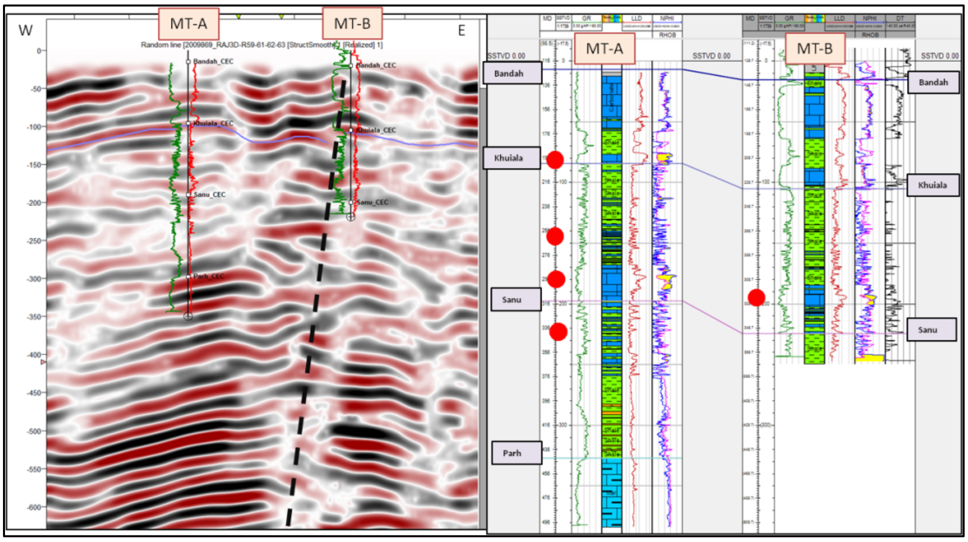

Fig. 3: Seismic and well section passing through well MT-A and MT-B

Triangle juxtaposition is prepared in the depth interval 0-400m (TVDSS) in the well MT-A taking well information and VShale curve of the well. Reservoirs (limestone and sandstone) and non-reservoirs are identified giving a cut-off as 40% to VShale curve (Figure 4). The juxtaposition diagram of MT-A and MT-B shows that considering a throw of 10 m, the B2 limestone reservoir is juxtaposed against the B2 reservoir in the footwall side and the C2-C4 Limestone reservoir is juxtaposed with C2-C4 reservoir (Figure 4). The B4 Limestone reservoir shows tip point juxtaposition. Although all the three reservoirs are in contact across the fault, the presence of gas at one level and absence of it in others points to the fact that the fault acts as a cross-sealing fault at two levels and cross leaking in the other. The same can be seen from the SGR diagram (Figure 4) which was prepared in the depth interval 0-400m (TVDSS). The value of SGR in B2 (Bandah) reservoir is coming to approximately 80 %, in B4 (Khuiala) reservoir to approx 50 % and in D4 (Sanu) reservoir it is coming to approx 60 % while in C2-C4 it is coming less than 20 %. These values of SGR proves that the cross seal is more effective in the all the other level than in C2-C4, thus creating a pool bigger than the others.

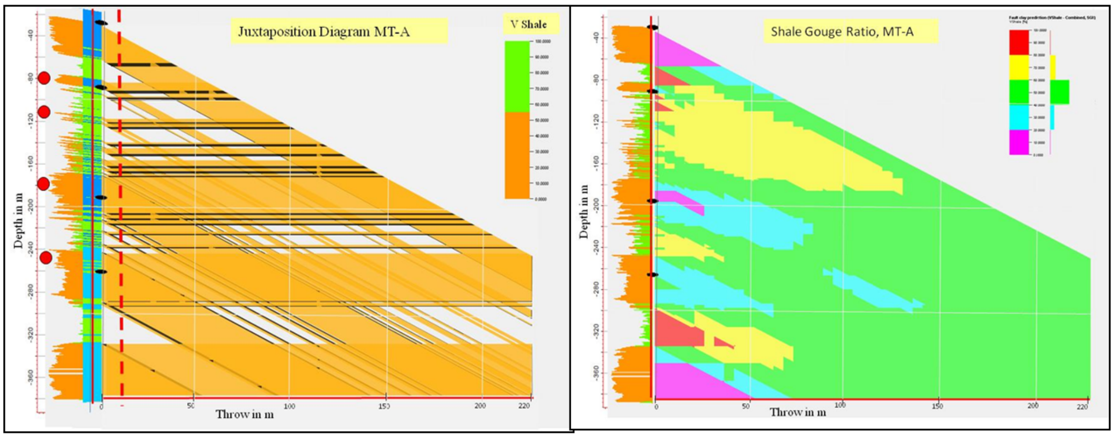

Fig. 4: 1D Juxtaposition Diagram and Shale Gouge Ratio of MT-A

Similarly in Chinnewala Tibba structure, hydrocarbon accumulation in one fault block and its absence in another can also be explained with the help of juxtaposition diagram. The section containing wells CT-A, CT-B and CT-C (Figure 5) shows that the wells falls in three separate fault blocks with two faults separating them. In well CT-B, gas is produced from G2-3 and G2-4 reservoir in Lower Goru and H2 reservoir in Pariwar. In well CT-C, hydrocarbon was found in the G4 reservoir. Though the well CT-C is structurally higher then CT-B, still both G2 and H2 reservoir in the well was devoid of hydrocarbon.

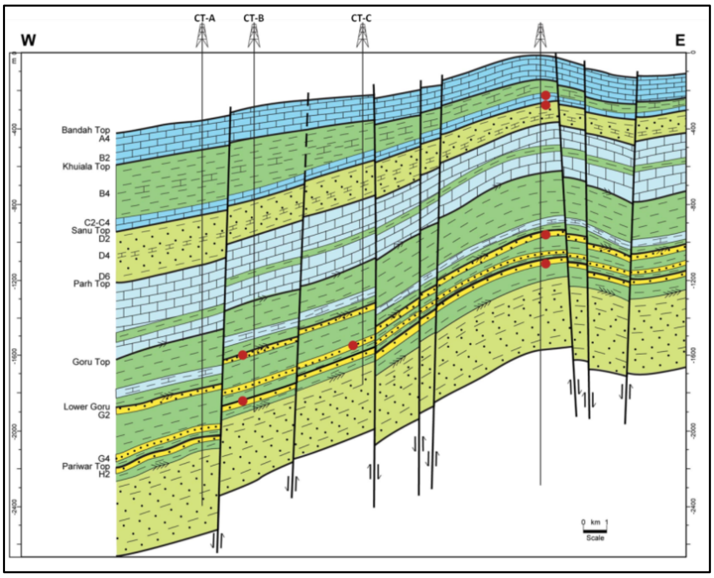

Fig. 5: Schematic Geological cross-section along the Chinnewala Tibba field in Jaisalmer Basin

Triangle juxtaposition was prepared in the depth interval 0-400m (TVDSS) in the well CT-A and CT-B taking well information and VShale curve of the well. Reservoirs (limestone and sandstone) and non-reservoirs are identified giving a cut-off as 35% to VShale curve (Figure 6 & 7). The juxtaposition diagram of CT-B shows that considering a throw of 40 m (average), the G2 sandstone reservoir is juxtaposed against non- reservoir (shale) in the footwall side and the H2 sandstone reservoir is also juxtaposed with shale (Figure 8). Also from the SGR diagram (Fig. 4.22) it can be seen that value of SGR in case of G2 reservoir is more than 40%. Thus the fault acts as a cross sealing fault and well

CT-C was found dry at G2 and H2 level. The juxtaposition diagram of CT-A shows that considering a throw of average 70m (Figure 8), both the G2 and H2 sandstone reservoir is juxtaposed against sand reservoir in the footwall side and thus there is lateral continuity. So, the fault fails to act as sealing fault and is a cross leaking fault.

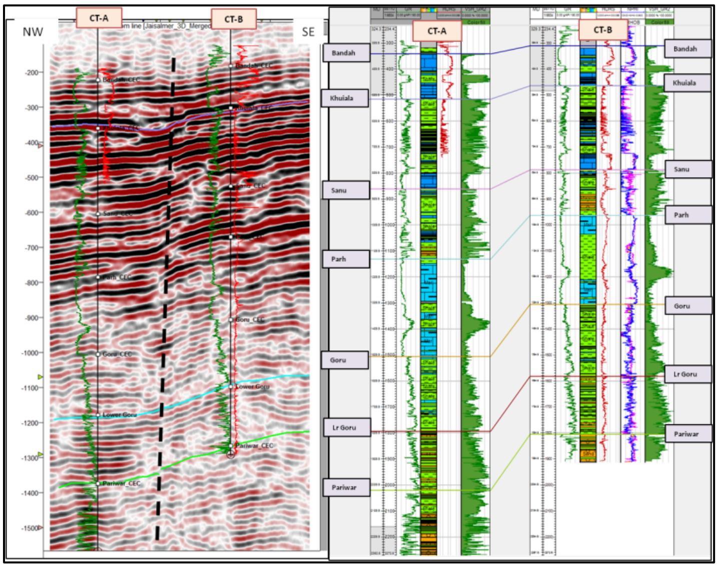

Fig. 6: Seismic and well section passing through well CT-A and CT-B with calculated VShale

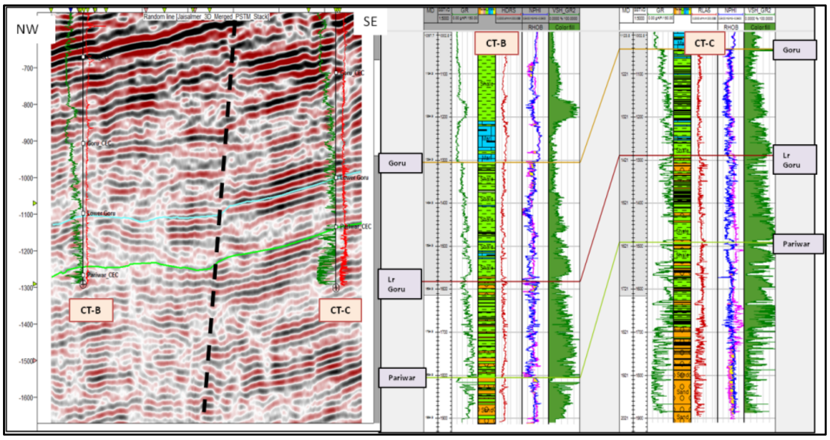

Fig. 7: Seismic and well section passing through well CT-B and CT-C with calculated VShale

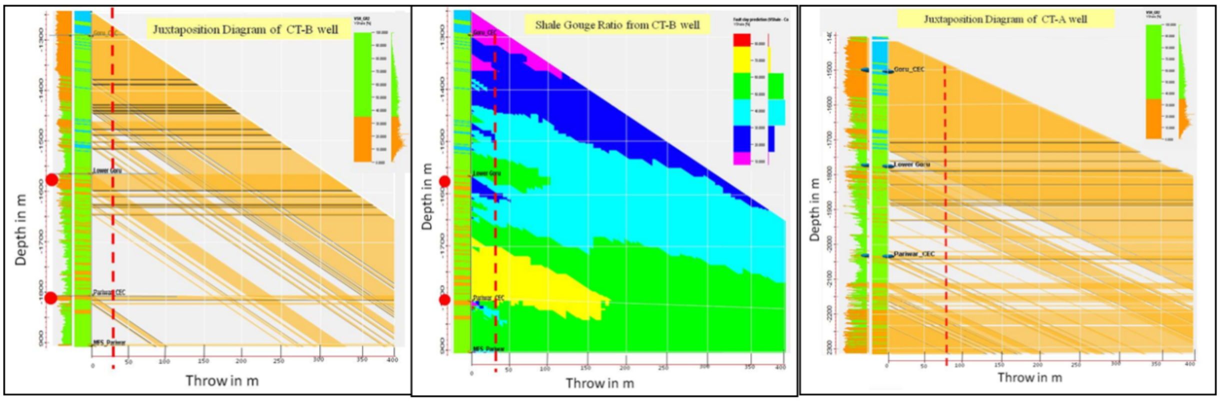

Fig. 8: 1D Juxtaposition Diagram and Shale Gouge Ratio of well CT-B and 1D Juxtaposition Diagram of well CT-A

Conclusion

- ManheraTibba structure in Jaisalmer Basin is under-filled at all reservoir levels except at C2-C4 (Khuiala) which is having maximum fill because the fault passing through the central part of the ManheraTibba field is acting as a cross-sealing and dip leaking fault at all other levels except at C2-C4 level (Khuiala), where it is acting as a cross-leaking and dip-leaking fault.
- In Chinnewala Tibba area, one fault (between the well CT-A and CT-B) is acting as both cross and dip leaking fault due to juxtaposition of sand with sand. Thus no entrapment is found in well CT-A at G-2 and H-2 reservoir levels whereas CT-B is gas bearing at both G2 and H2 levels. The other fault between CT-B and CT-C acts as a cross sealing fault with juxtapositional advantage and high SGR ratio along the fault. Thus the well CT-C was found dry at G2 and H2 level while gas is discovered in both reservoirs in well CT-B.
- Analysis reveals that SGR > 20% is helping in creating a successful cross-sealing entrapment thus helping in successful hydrocarbon accumulation. Most of the accumulations of Jaisalmer sub basin are under-filled as pool size is smaller than trap size. This can be attributed to the dip-leaking nature of the entrapment causing fault systems.
- Since the fault system present in Jaisalmer sub basin is dominantly breaching (both cross-leak and dip leak), hope lies in the juxtapositional relationship of the reservoirs across the fault or high shale gouge ratio along the fault generating cross-sealing for successful hydrocarbon entrapment.

** The views expressed in the paper are those of the authors only and need not necessarily be of ONGC.*

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