Estimating Fault Seal and Capillary Sealing Properties in the Visund Field, North Sea

A study carried out for Norsk Hydro

Abstract

This study investigates the difference in seal/leakage mechanisms across the A-Central Fault, a major trap bounding fault located in the westerly dipping fault block of the Visund Field, Brent Province, North Sea. The Shale Gouge Ratio (SGR) algorithm is used to predict fault-zone composition, using subsurface mapping and petrophysical data. These data are then used to model threshold capillary pressure (P_c) and from this derive an estimate of maximum possible hydrocarbon column height.

Modelling suggests that the self-juxtaposed reservoirs are likely to have poorer sealing potential and therefore across-fault leakage can occur in these regions. However, the Brent-Statfjord juxtapositions are predicted to have higher SGR, and subsequently, higher P_c and hydrocarbon column heights (predicted oil: 25-250 m or gas column: 15-150 m). Observed data confirm these suppositions.

Keywords: Fault seal, shale gouge ratio, capillary seal, T7

Introduction and Geological Background

The Visund Field is located in a westerly-dipping fault block in the Brent Province of the North Sea. Oil and gas occur in the Brent and Statfjord reservoirs. Several faults compartmentalise the reservoirs, one of which is the “A-Central” Fault (see Figure 1 and 2). This study aims to investigate across-fault membrane seal along the A-Central Fault. This is achieved through conventional prediction of the fault zone composition using the Shale Gouge Ratio (SGR) algorithm (Yielding et al., 1997), based on available subsurface mapping and petrophysical data. The SGR is then used to estimate the probable threshold capillary pressure, P_c, in areas where reservoir units are juxtaposed across the fault. The results are then reviewed in light of observed hydrocarbon column heights and spill/seal mechanisms. The current technical note is a re-evaluation and representation of the work of Yielding et al., 2004.

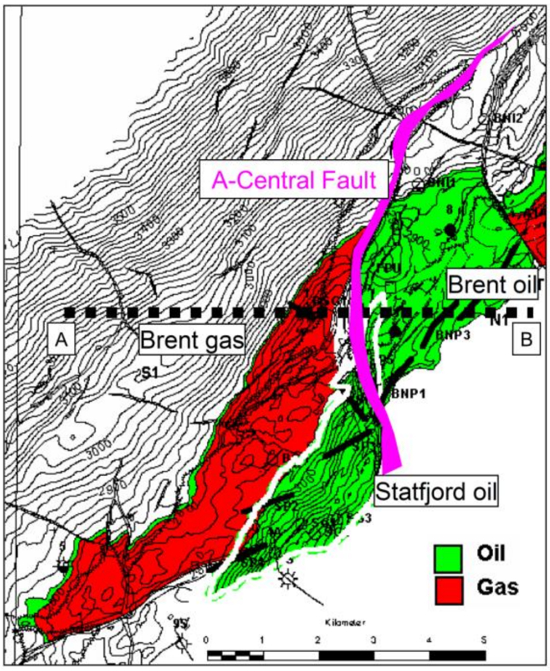

Figure 1 Location map of the Visund Field showing geological structure and well locations

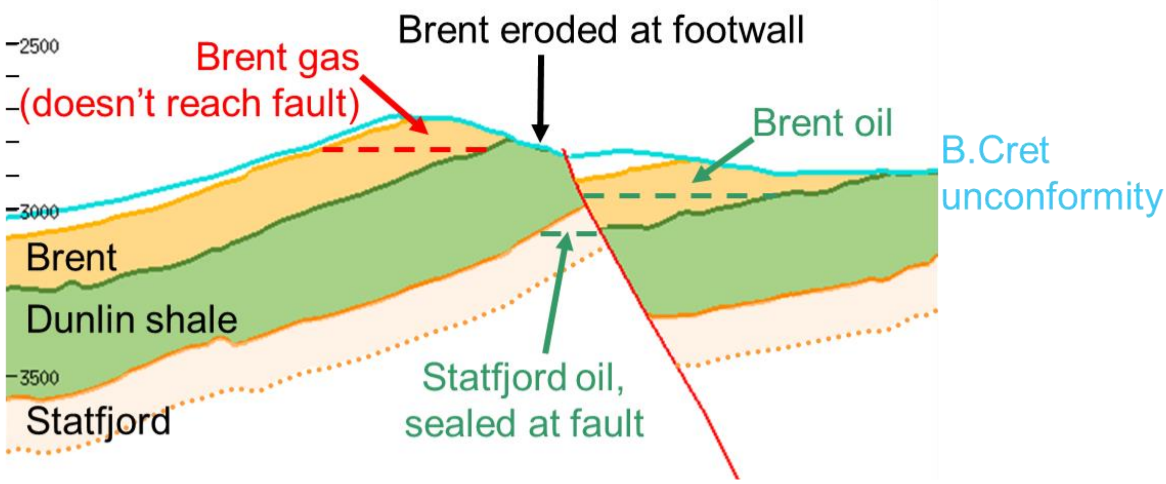

Figure 2 W-E oriented cross section (location indicated on Figure 1) through the A-Central Fault showing footwall and hanging wall stratigraphy

Methods

3D Seismic Interpretation, Fault Seal Analysis and Across-Fault Capillary Sealing Properties

Detailed 3D seismic horizon interpretation, including the Brent and Statfjord horizons, was imported to T7. The interpretations were used to construct a 3D structural model.

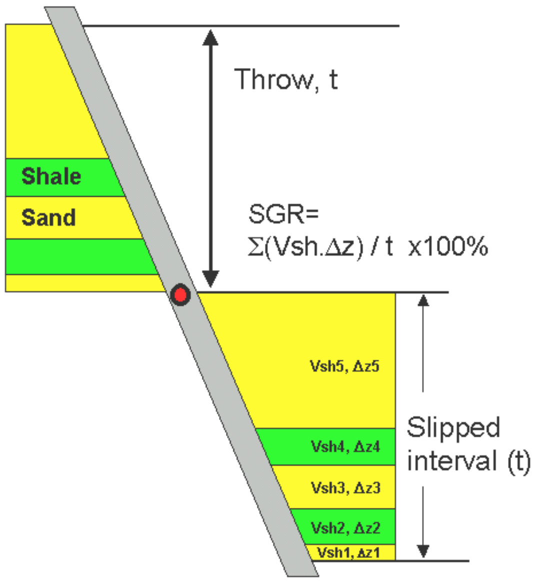

Figure 3 Definition of the Shale Gouge Ratio, after Yielding et al., 1997, and Freeman et al., 1998. At any point on the fault surface the SGR is equal to the net shale/clay content of the rocks that have slipped past that point. If lithotypes are incorporated into the fault zone in the same proportions as they occur in the wall rocks, then SGR is an estimate of the fault zone composition.

Horizons, such as the Brent and Statfjord, were extrapolated to the A-Central Fault surface, and their footwall and hanging wall intersections mapped in 3D. This enabled the creation of a juxtaposition plot, or Allan Diagram, so that the footwall and hanging wall sands could be visualised at the fault surface, and any areas of sand-sand juxtaposition could be easily identified.

After detailed structural QC, reservoir attributes (derived from petrophysical logs) were automatically mapped onto the FW and HW; for purposes of this study only VShale was considered.

The likely SGR values along the fault plane were then computed using the Yielding et al. (1997) method where intra-fault material is considered to be a product of mechanical smearing of country rock material (Figure 3). The relative proportion of phyllosilicate material is therefore both a function of faulted rock composition and the degree of displacement along the fault plane. Finally, the P_c can be determined from seal failure envelopes (i.e. the cut-off on a SGR vs across-fault pressure mapping, above which hydrocarbon accumulations do not occur: Figure 7, Bretan et al., 2003).

Results

The Allan diagram for A-Central Fault is shown in Figure 4. It can be seen from Figure 4 that the Brent is self-juxtaposed at the northern end of the fault, as is the Statfjord. Also, the Statfjord sands in the footwall are juxtaposed against the Brent sands in the hanging wall towards the southern end of the fault. At this point, it may seem just from the Allan diagram that the across-fault seal in this region (i.e. the Brent-Statfjord juxtaposition) should be poor due to the juxtaposed reservoirs. However, it is known that the footwall Statfjord sands are oil-bearing and the Brent sands in the hanging

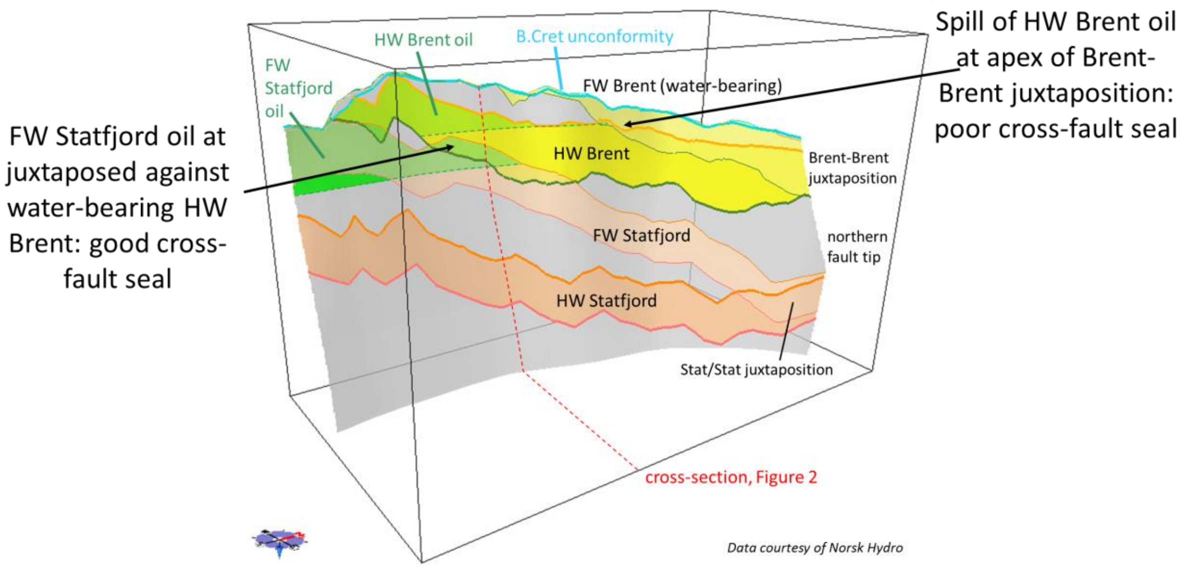

Figure 4 Allan diagram along the A-Central Fault. Pale yellow: Brent sands in the footwall. Dark yellow: Brent sands in the hanging wall. Pale orange: Statfjord sands in the footwall. Dark orange: Statfjord sands in the hanging wall. Brent self-juxtaposition and Statfjord self-juxtaposition is present at the northern end of the fault. Brent sands in the hanging wall are also juxtaposed against Statfjord sands in the footwall towards the southern end of the fault in the vicinity of the Visund trap.

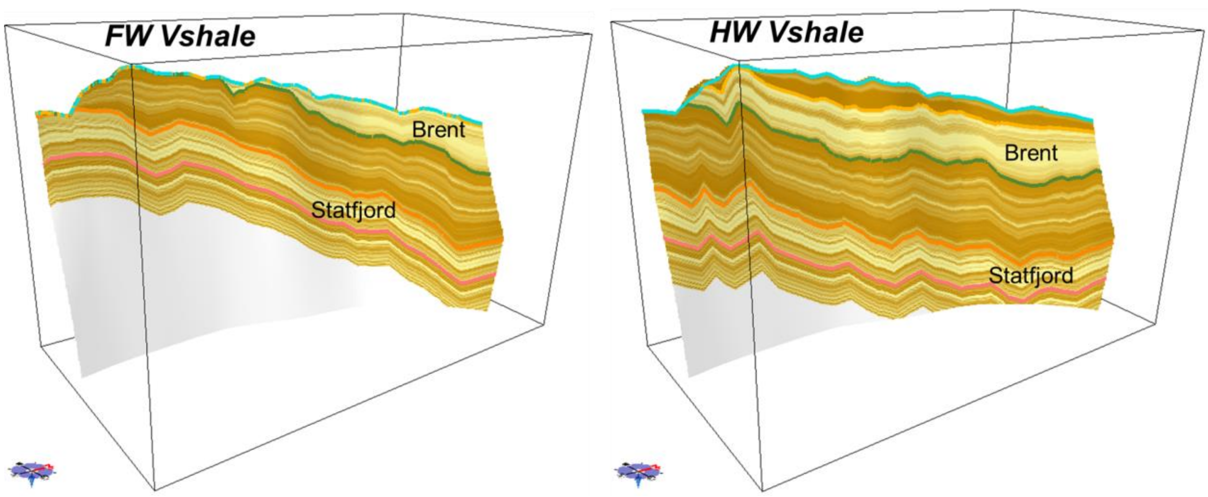

Figure 5 VShale mapping from local wells to the A-Central Fault surface displayed as footwall VShale and hanging wall VShale. Brown colours indicate areas estimated to have a higher proportion of shale; yellow/cream colours indicate areas estimated to have a higher proportion of sand.

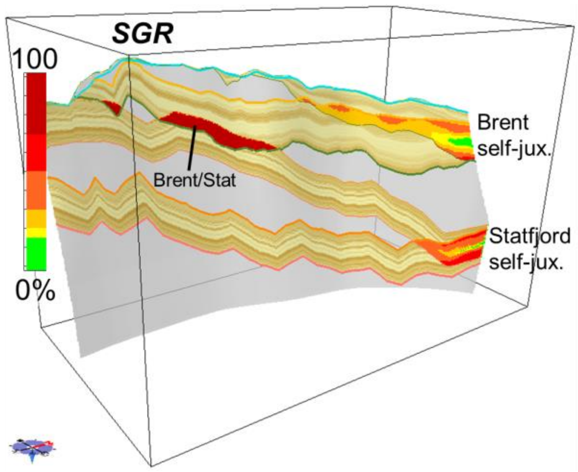

Figure 6 (Left) VShale mapping displayed only in the footwall and hanging wall sand intervals along the A-Central Fault surface. Brown colours indicate areas estimated to have a higher proportion of shale; yellow/cream colours indicate areas estimated to have a higher proportion of sand. Areas of sand-sand juxtaposition are coloured for the SGR. It can be seen that the areas of Brent self-juxtaposition and Statfjord self-juxtaposition (towards the northern end of the fault), SGR values are variable ranging between low SGR (<10) and high SGR (>70), indicating a low probability of fault seal. However, in the region of Brent-Statfjord juxtaposition, predicted SGR values are high (>70) indicating a high probability of fault seal.

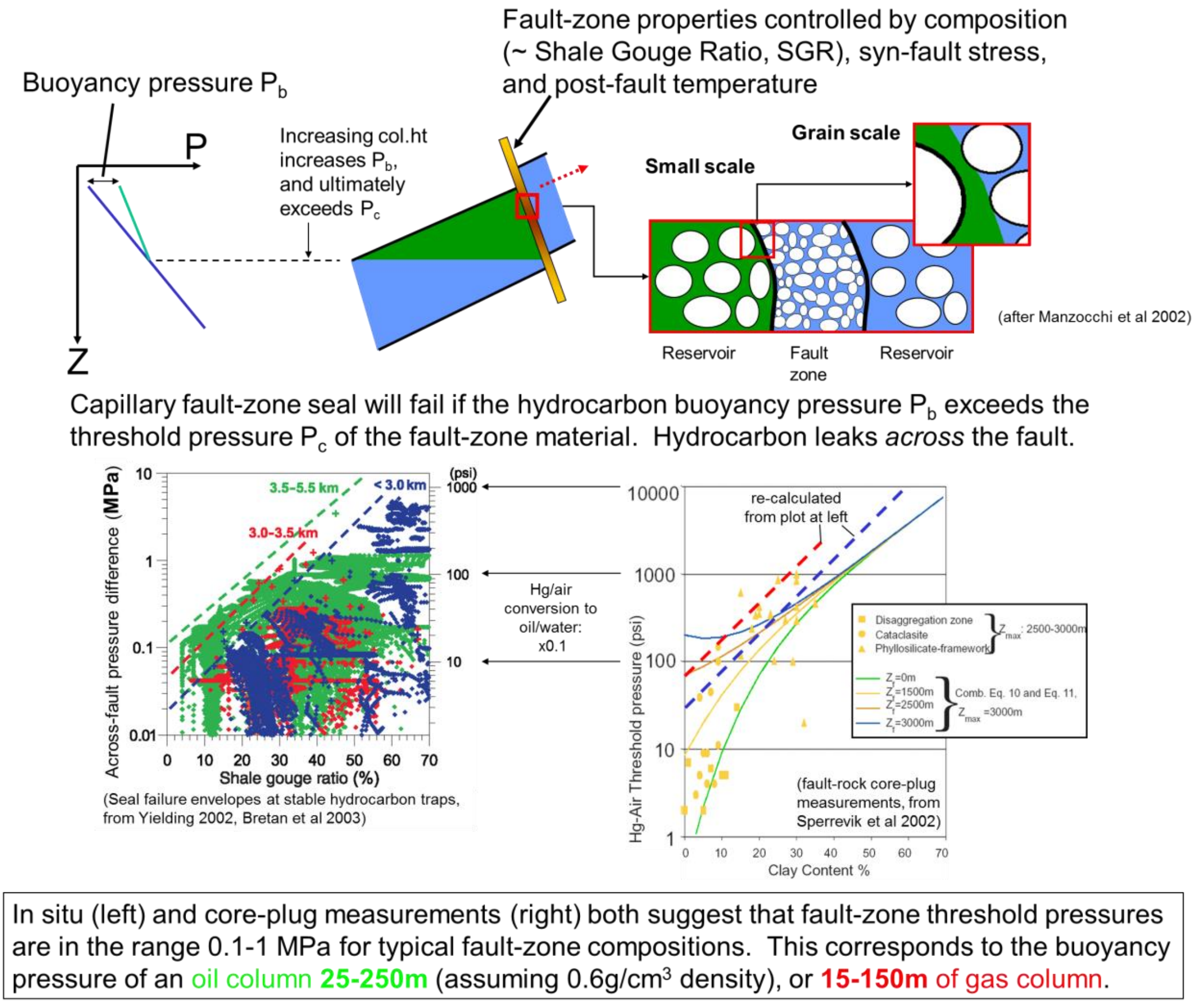

Figure 7 Estimated capillary sealing properties of the A-Central fault-zone, calculated from the SGR and geohistory, using published relationships (Manzocchi et al., 2002, Sperrevik et al., 2002, Yielding, 2002, and Bretan et al., 2003). Both in situ and core-plug measurements suggest that fault-zone threshold pressures can support a corresponding buoyancy pressure of a 25-250 m oil column or 15-150 m gas column

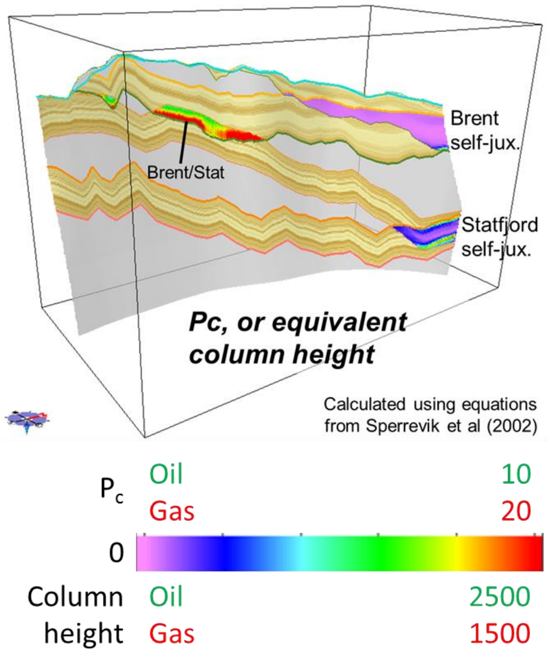

Figure 8 Estimates of supportable hydrocarbon column heights using the equations from Sperrevik et al., 2002. Blue/purple colours indicate low capillary pressures (P_c) and a corresponding low oil/gas column height. Red/orange colours indicate high capillary pressure (P_c) and a corresponding high oil/gas column height. In the region of Brent self-juxtaposition and Statfjord self-juxtaposition (towards the northern end of the fault) it can be seen that P_c and column heights are predicted to be variable, but overall will be low. In the region of Brent-Statfjord juxtaposition (towards the southern end of the fault) it can be seen that P_c and column heights are predicted to be significantly higher.

wall are water-bearing. This implies that there might be a good across-fault seal provided by the presence of phyllosilicate material in the fault gouge, and this will be further investigated in terms of SGR.

The next step in fault seal analysis is to map the VShale from the wells on to the A-Central Fault surface. This was derived by interpolation between VShale logs from a number of local wells. Figure 5 shows the mapped VShale in the footwall and hanging wall of A-Central Fault.

The VShale template is then used to estimate the upscaled fault-zone composition using the SGR algorithm (from Figure 3). SGR can be regarded as a proxy for phyllosilicate content of the fault-zone. It indicates significant clay smear at the Brent-Statfjord overlap (high SGR), but the low-SGR Brent self-juxtaposition is probably characterised by "disaggregation zone" fault rock. The results of the fault seal analysis along A-Central Fault can be seen in Figure 6.

It can be seen from Figure 6 that in the areas of Brent self-juxtaposition and Statfjord self-juxtaposition, predicted SGR values are variable ranging between low SGR (<10%) and high SGR (>70%). At the low predicted SGR values the fault is unlikely to seal. However, in the location where the Statfjord in the footwall is juxtaposed against the Brent in the hanging wall, predicted SGR values are high (>70%) therefore the fault is highly likely to seal.

Finally, the P_c of the fault-zone can be determined via the SGR and geohistory, using published relationships, as described in Figure 7. The results indicate that the in situ (left on Figure 7) and core-plug measurements (right on Figure 7) both suggest that fault-zone threshold capillary pressure are in the range of 0.1-1.0 MPa for typical fault-zone compositions. This corresponds to the buoyancy pressure of an oil column between 25-250 m (assuming 0.6 g/cc density), or 15-150 m of gas column.

These hydrocarbon column height results can be expressed in terms of the equations from Sperrevik et al., 2002 (see Figure 8). In the region of Brent self-juxtaposition and Statfjord self-juxtaposition (towards the northern end of the fault) it can be seen that P_c and derived column heights are likely to be variable, but the pressure of low P_c windows will allow leakage. This is consistant with the hanging wall Brent OWC being controlled by the Brent self-juxtaposition. In the region of Brent-Statfjord juxtaposition (towards the southern end of the fault) it can be seen that P_c and derived column heights are predicted to be significantly higher. The footwall Statfjord reservoir contains >200m of oil but its ultimate spill point is not clear.

Discussion and Conclusions

The results indicate that the Brent-Statfjord overlap could support many hundreds of metres of hydrocarbon column before leaking. However, the Brent self-juxtaposition has capillary threshold pressures of ≤ 0.25 MPa, which would only support a few tens of metres of hydrocarbon column, assuming an oil density of 0.6 g/cm^3. This explains the fault controlled spill point of the HW Brent oil.

References

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