Case Study

ANALYSING FAULT-SEAL CAPACITIES IN FIELD APPRAISAL: A CASE STUDY FROM OSEBERG SYD

A study carried out for Norsk Hydro

A fault seal study has been performed on faults in the Oseberg Syd area, located within Block 30/9 of the Norwegian sector of the North Sea.

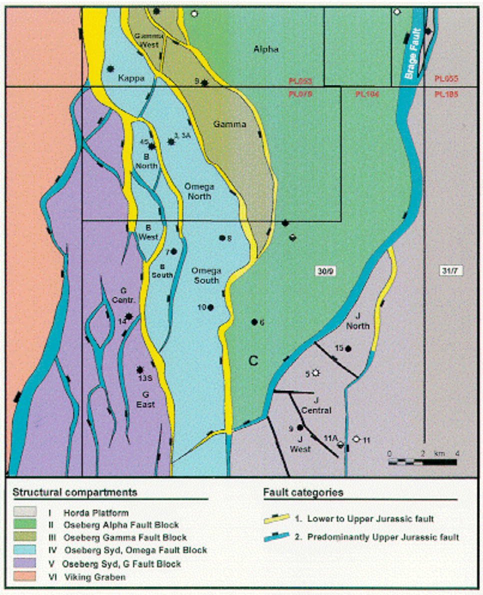
Geological Setting of the Oseberg Syd Field

Structure of the Oseberg Syd area:

Oseberg Syd is located within Block 30/9 on the Norwegian Continental Shelf between the Horda Platform and the Viking Graben, an area of Mesozoic extension. The study area comprises some 15 - 20 elongated fault blocks. Most faults within the Oseberg/Oseberg Syd region strike N-S to NNW-SSE, subparallel to the Viking Graben, in an anastomosing pattern. The areal extent of each fault block ranges from 250 km2 to less than 10 km2.

Almost all of the individual fault blocks that have been drilled contain oil and gas. In the western part of Block 30/9 (Omega, B and G structures), the main reservoir unit comprises the predominantly transgressive marine sands in the upper part of the Brent Gp (the Tarbert Fm), whereas channel sands within the Lower and Upper Ness Fms constitute the main reservoir units in the C and J structures.

Even without correction for differential compaction, the section demonstrates a spectacular thickness increase of nearly 100 % within the Brent, Dunlin and Statfjord Formations across the major fault between the Gamma and Omega structures.



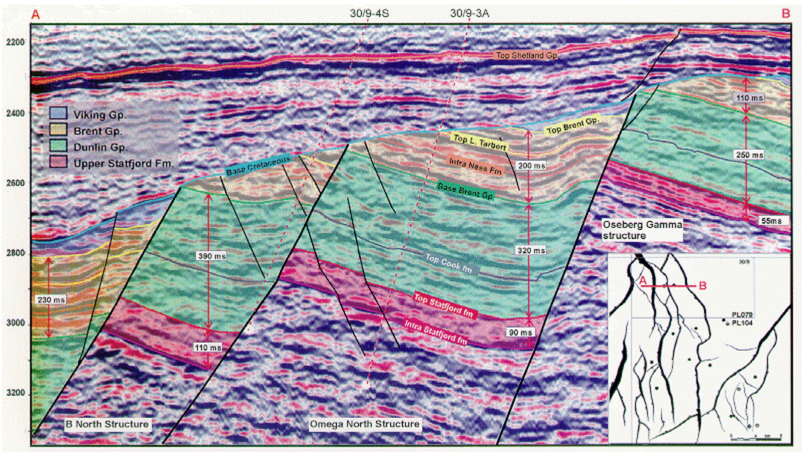
The Oseberg Area, Norway

Reservoir Properties:

The Brent Group reservoir consists of sandstone units within the Tarbert, Ness and ORELN Formations. In addition to the mapped horizons, 5 to 7 zones were recognised within the Brent Group on the basis of well data. These were included in the fault seal analysis by posting them onto the fault grid either:

(i) at a fixed distance above or below a primary horizon, or

(ii) at a fixed percentage of the interval between two primary horizons.



Seismic section showing typical faulting and stratigraphy.

Although the study was focused on the Brent reservoir, parameters for an additional overlying sand in the Heather Formation and the underlying Dunlin Group were added to allow calculation of fault properties where these units juxtapose the Brent reservoir.

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Due to the general complexity of the area (relatively small fault blocks and separate fluid contacts within different compartments) a better understanding of reservoir separation, fault linkage and likelihood for seal along the individual faults is crucial in order to address productivity and effects of static seal during production.

Improvements in the seismic database in the Oseberg/Oseberg Syd area allowed for the interpretation of a large number of seismic reflectors within the Jurassic succession, facilitating the confident mapping of thickness variations across faults.

The objectives of the study were:

1: To provide geometric descriptions of a total of 16 block-bounding and internal faults.

2: To investigate potential leakage/seal at reservoir juxtapositions for these faults.

Achieving the Objectives through TrapTester Fault Seal Analysis

A total of 16 bounding and internal faults in the Oseberg Syd area were analysed. The fault seal analysis was performed in the depth domain, since this allowed:

(a) direct comparison with fluid contacts observed in wells, and

(b) incorporation of additional geological information such as zone isochores.

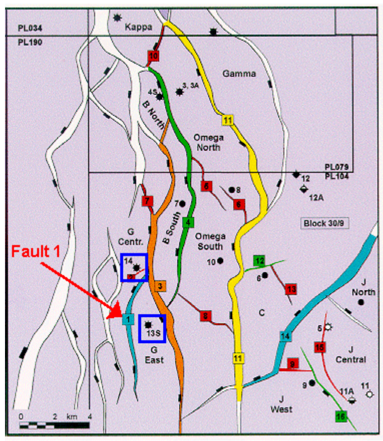
Fault 1: a sealing fault

In this discussion, we concentrate initially on Fault 1 which is located in the south-west part of the study area in the G area (fault highlighted by the red arrow).
Well 13S is located in the footwall of fault 1 and well 14 in the hangingwall (blue boxes). The wells have different hydrocarbon columns, and so fault 1 provides a good calibration point with respect to the SGR calculation.

Reservoir Juxtaposition Plot:
In addition to the mapped horizons, additional intra-Brent and Heather formation zones from isochores have been posted onto the fault.

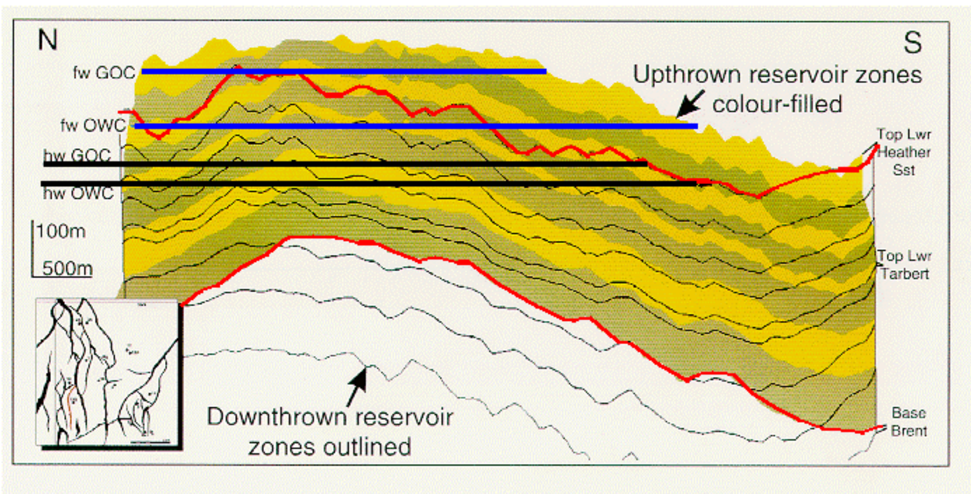
Since the maximum fault throw (ca. 175m) is approximately half the total thickness of the Brent reservoir thickness, there is a considerable area of reservoir juxtaposition (Brent-Brent overlap).

Hydrocarbon contacts can also be shown on the reservoir juxtaposition plot. Footwall contacts are shown in blue and hangingwall contacts in black.



Fault map of the Oseberg Syd area showing location of fault 1 (arrowed)

The hangingwall oil-water contact (hw OWC) is probably controlled by a structural spill-point (saddle) along the southern part of the fault. The fault is therefore not at seal capacity, and the calibration derived below represents a minimum potential for seal on this fault surface.



Reservoir Juxtaposition plot (strike projection looking east) showing footwall intervals (solid colour) and hangingwall intervals (outline). Area between the red lines represents region of reservoir overlap.

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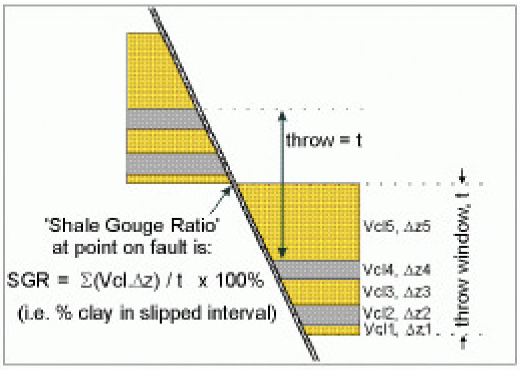
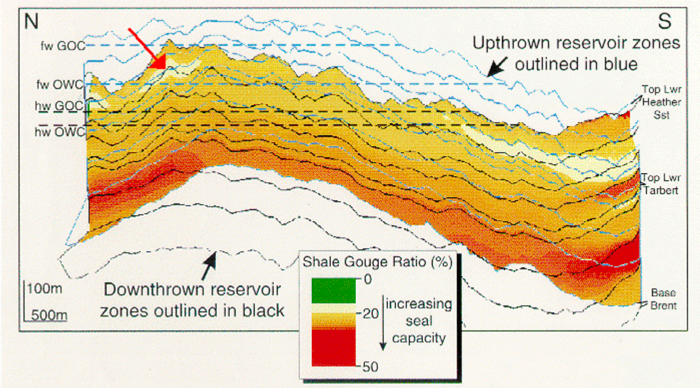
Shale Gouge Ratio:



Shale Gouge Ratio is the percentage shale or clay material that has slipped past a point on the fault



Reservoir juxtaposition plot showing area of reservoir overlap colour filled with Shale Gouge Ratio (SGR). Low SGR values in pale yellow; high SGR values in red

Petrophysical analysis of the well data were used to define the shale fraction in each stratigraphic unit. In combination with detailed juxtapositions and compositional data for all layers, the Shale Gouge Ratio (SGR) was calculated to provide an estimate of the composition of the fault zone (fault zone % shale).

Since the fault displacements are generally greater than the zone thicknesses, the calculated SGR values are relatively homogeneous (>20%). However, the significant area is that of lower values(in yellow, <20%) near the upper part of the reservoir overlap zone (highlighted by red arrow).

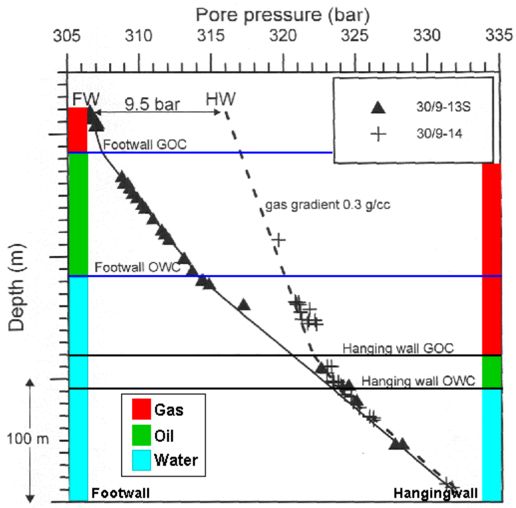
Reservoir Pressure Profile:

Reservoir pressure profiles were constructed from RFT data in wells13S and -14. The Brent-Heather sand sequence in this area forms a single pressure compartment. The aquifer is continuous around the southern end of the fault.

On the hangingwall side (well 14), there are deep oil-water and gas-oil contacts, giving a thin (30m) oil rim under a thick gas cap.

On the footwall side (well 13S), both the OWC and GOC are structurally higher and the oil rim much thicker.

Extrapolation of the hangingwall gas gradient implies that the across-fault pressure difference reaches about 9.5 bars at the level of the footwall GOC. Inspection of the juxtaposition pattern shows this geometry occurs near the crest of the hangingwall structure, about 1km from the north end of the fault.



Pressure profiles for wells 13S (footwall) and 14 (hangingwall)

Calibrating SGRs with across-fault Pressure Differences:

Fault 1 demonstrates static sealing since it separates two hydrocolumns of different heights. At the crest of the structure, the maximum across-fault pressure difference between the different hydrocarbon columns is ca. 9.5 bar.

At each grid node on fault 1, the difference between the footwall and hangingwall pressures is the in-situ pressure drop across the fault. The across-fault pressure values can be plotted against the SGR values.

One significant question in fault seal analysis is: which parts of the fault are capable of holding back a large pressure difference for a relatively small SGR?

From the cross-pot of pressure difference vs SGR, an SGR of about 18% is capable of sustaining a pressure difference of almost 8 bar (highlighted by the red box).

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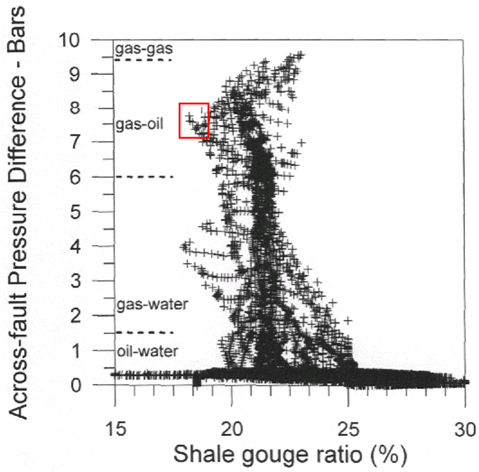
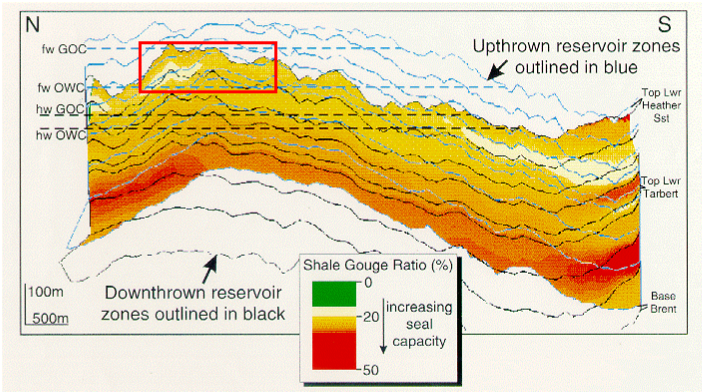


Cross-plot of SGR vs across-fault pressure difference



SGR diagram showing the area on the fault (in red) with the highest across-fault pressure difference for the lowest SGR

The data points highlighted in the cross-plot above correspond to the crest of the structure as shown in the diagram below. This part of the fault is separating a large gas column in the hangingwall from a smaller oil column in the footwall.

Fault 2: a non-sealing fault

Fault 2 is a c. E-W fault between well 14 and Fault 1.

Prior to the drilling of this well, the fault was assumed to be a block-bounding fault. However, DST testing of well 14 indicated the fault to be open, as the closest barrier to flow was interpreted to be 810m away (Fault 2 is only 350-450m to the south of the well).

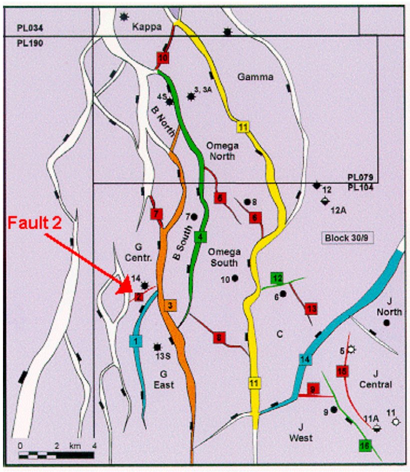
The fault has a maximum displacement of about 15-20m at its centre and consequently the different units in the Tarbert formation are self-juxtaposed. The SGR values in the Tarbert Fm juxtaposition are close to 15%.

The analyses of this fault and Fault 1 suggest that:

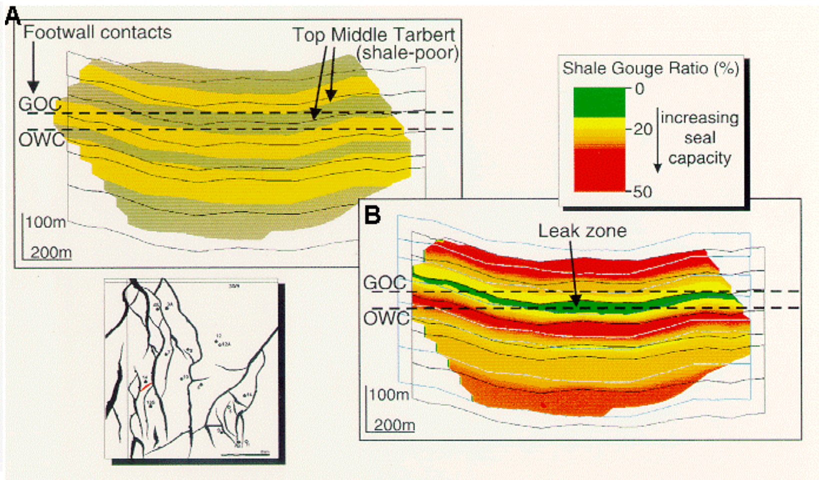
(i) SGR below or close to 15% corresponds to no seal, and

(ii) SGR above ca. 18-20% corresponds to significant seal.

This very tight range remained consistent throughout the dataset.



Fault map showing location of fault 2 (arrowed in red)



Fault plane diagrams showing reservoir overlaps (A) and SGR (B).

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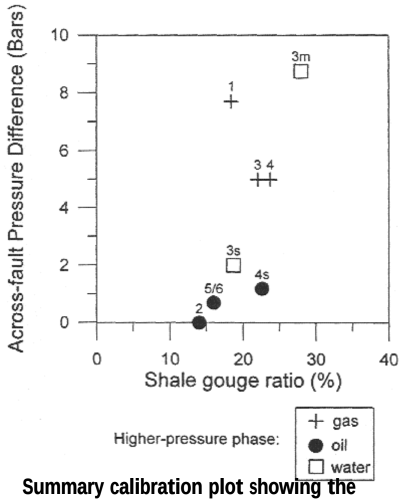
Summary for all analysed faults

The summary diagram shown below illustrates the observed relationship between SGR and across-fault pressure difference for all analysed faults.

Each point represents the "critical" part of the fault surface, i.e., maximum pressure difference for small SGR values. One fault can have several values depending on how many compartments are present on each side of the fault. For example the points for Fault 4 represent the segments where Omega North is juxtaposed against B North and B South, respectively.

1:	**Fault 1.**	**G-Central (30/9-14) against G-East (30/9-13S)**
2:	**Fault 2.**	**Intra-G-Central (-14 DST)**
3:	**Fault 3.**	**B-North (-4S) against B-South (-7)**
3m:	**Fault 3m.**	**G-Central (-14) against B-South (-7)**
3s:	**Fault 3s.**	**G-East (-13S) against B-South (-7)**
4:	**Fault 4.**	**B-North (-4S) against Omega North (-3, -3A)**
4s:	**Fault 4s.**	**B-South (-7) against Omega North (-3, -3A)**
5/6:	**Faults 5/6.**	**Omega north (-8) against Omega south (-10)**



Summary calibration plot showing the on-set of sealing vs SGR

The following relationship between onset of sealing and calculated SGR is observed:

SGR < 15%	no seal expected
15% < SGR < 18%	slight seal expected (<1 bar pressure difference or 30 m difference in OWC)
SGR > 18%	considerable seal expected (e.g. 8 bar pressure difference or up to 240 m difference in OWC)

Also note that approximately the same SGR values can support different across-fault pressure differences depending upon whether Gas or Oil is the highest pressure phase.

The relationship between onset of sealing and SGR was used to make predictions for faults where sufficient well control points are lacking. SGR distributions were used to predict likely seal capacities and therefore constrain the occurrence of hydrocarbons in undrilled compartments.

Key Points arising from the study:

1: Fault-surface modelling of the faults using TrapTester Fault Seal Analysis provided a framework in which to visualise the reservoir juxtapositions, seal attributes and across-fault pressure differences.

2: Juxtaposition seal of reservoir against non-reservoir was assessed from fault-plane diagrams.

3: Additional seal at reservoir juxtapositions in Oseberg Syd is considered to be predominantly due to clay smearing because of the relatively shaly nature of the Brent group and the shallow burial depths during faulting (<500m). Estimates of the percentage shale in the fault zones were made by calculating the shale gouge ratio (SGR) at all points of reservoir overlap for each fault using Vshale values from adjacent wells.

4: RFT data from wells either side of a static sealing fault provided a calibration of the value of SGR required to seal a fault plane. This, together with data from a non-sealing fault, provided the following fault-seal guide-lines:-

> SGR values < 15% no seal expected
>
> SGR values of 15-18% were consistent with adjacent fault blocks having small pressure differentials (<1 bar or 30 m difference in OWC)
>
> SGR values of >18% corresponded to significant seal (c. 8 bar pressure difference or up to 240 m difference in OWC).

This SGR calibration was consistent with observed fluid contacts and pressure data in all the Oseberg Syd wells.

5: The SGR distributions for faults lacking sufficient well control points were used to predict likely seal capacities and therefore constrain the occurrence of hydrocarbons in undrilled compartments.

Based on the publication by Fristad, Groth, Yielding and Freeman, "Quantitative fault seal prediction: a case study from Oseberg Syd", in "Hydrocarbon Seals: Importance for Exploration and Production" edited by Moller-Pedersen and Koestler NPF Special Publication 7, pp 107-124. 1997.

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