

D01

## Petroleum Leakage in the Snorre Oilfield, North Sea - A Case for Change in Cap-rock Wettability and Dynamic Seal Risking

O.A. Jokanola\* (ConocoPhillips), A.C. Aplin (Newcastle University), S.R. Larter (University of Calgary) & K.K. Kurtev (Newcastle University)

### SUMMARY

---

Snorre is a leaky commercial oilfield that supports ~300 m oil column in the Tampen Spur area of the North Sea. The field contains undersaturated oil with no gas cap. Pervasive evidence of oil and gas leakage into the cap-rock is well documented (Leith and Fallick 1997, Bond 2000). Oil migration may alter the wetting state of the cap-rock. Today, the reservoir sands are ~12 MPa overpressure. Log derived pore pressure for the Shetland Group mudstone cap-rock indicates a normal compaction state. This pressure disequilibrium between the reservoir and the cap-rock suggest that reservoir overpressure may have post-dated compaction and geologically recent. Phase behaviour models of the petroleum fluids indicate that a gas cap should exist in the trap if the reservoir was normally pressured. The observed oil column is in equilibrium with the average column height potential of the cap-rock estimated from pore size distribution data. This may imply that the cap-rock is at maximum supportable column height today. In addition, subsequent petroleum charge has leaked into the cap-rock possibly at a rate similar to the reservoir charge rate. These data suggest that the Snorre field capped by oil-wet cap-rock is a case example of a dynamic seal.

### **1. Introduction**

In this study we applied an integrated geological approach involving geochemical, petrophysical, pore pressure and mercury injection data along with some numerical modeling in evaluating containment and leakage in the Snorre oilfield. Capillary sealing mechanism is effective where the pore system of the mudstone seal is wholly or partially water wet. In leaky mudstone cap-rocks like in Snorre and thermally mature source rocks like the Kimmeridge Clay Formation in the North Sea, the migration of petroleum through these mudstones may significantly alter their pore wetting state hence their sealing integrity must be evaluated differently. Where wetting state of the mudstone seals are altered and become oil-wet, such seals lose their capillary effect but act more as permeability barriers (Aplin et al., 2006).

### **2. Pore pressure distribution**

Reservoir pore pressure analyses of the DST/RFT data collected from the Snorre field suggest that the sands are ~ 12 MPa overpressured. A 300 m oil column of density ~ 800 kg/m<sup>3</sup> is also constrained from the pressure data. However, log derived pore pressure suggest that the clay rich mudstones within the field especially the Cretaceous Shetland Group cap-rock are normally compacted. This pressure disequilibrium between the sandstones and the mudstones may be explained by possible geologically recent pore pressure inflation of the reservoir sands via fluid transfer from the high pressure source kitchen area that charged the structure.

### **3. Petroleum geochemistry**

Results of oil-oil correlations using biomarker data from the reservoir oil and the extractable organic matter (EOM) from the leaky, thermally immature cap-rock (<0.5 %Ro) coupled with the occurrence of anomalous concentration of wet thermogenic gas in the cap-rock provides evidence of leakage in the field. The field wide occurrence of leaked oil and gas in the cap-rock suggest that pervasive leakage has occurred at some point in the geologic past and may continue to date. Whole oil chromatograms of EOM from the leaky mudstone cap-rock indicate the gradual but progressive removal of relatively higher molecular hydrocarbons (HMW > nC<sub>19-25</sub>) and the enrichment in low molecular weight hydrocarbons (LMW- nC<sub>17-18</sub>) towards the migration front in the cap-rock. The ratio of LMW/HMW hydrocarbons shows a correlation with the specific surface area:porosity ratio in the mudstones (Figure 1). This process is believed to be influenced by capillary condensation. However, core flooding experiments suggest that pore wetting state may change with petroleum migration through the pore networks of siltstones (Bond 2000; Bennett et al., 2004). Results of numerical oil mixing models using sterane and hopane concentrations from the EOM of the Shetland Group cap-rock of Troll field (a non-leaky adjacent field) and the Snorre reservoir oils as end members indicate that up to 40% by volume of oils from the reservoir may have migrated into the cap-rock thus mixing with the organic matter from the cap-rock. If indeed, the wetting state of the cap-rock does change due to oil leakage; leaky seals lose their capillary effect and instead act as permeability barriers.

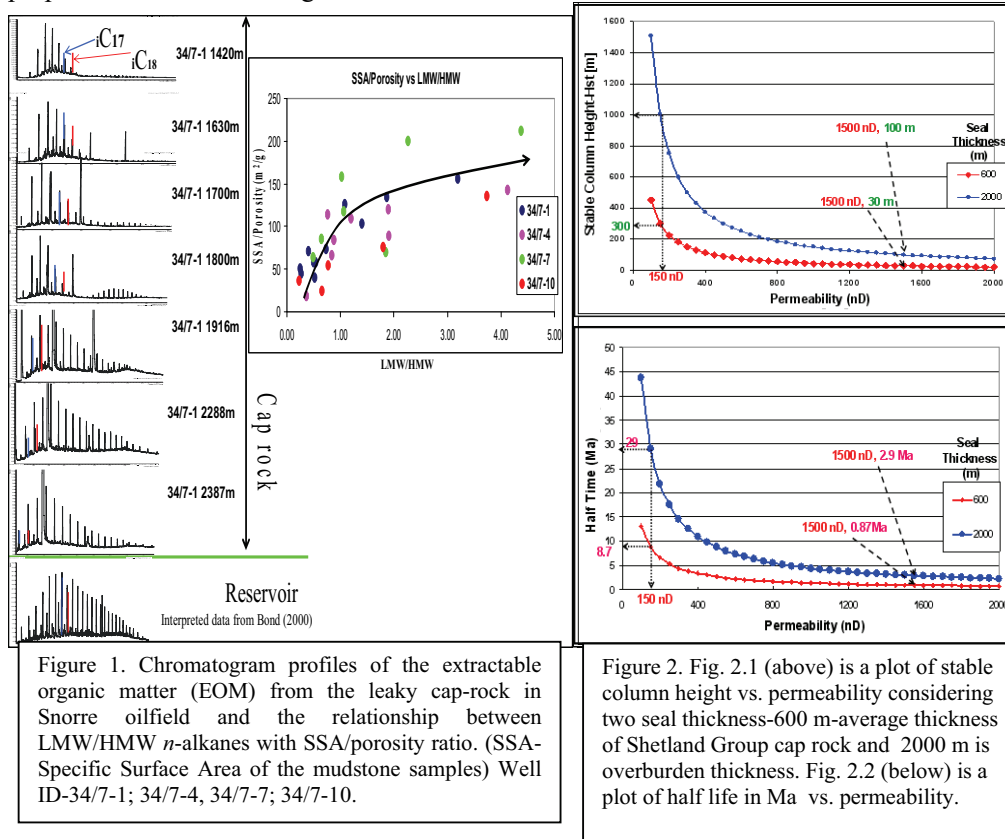
### **4. Dynamic seal risking**

Snorre field is susceptible to hydraulic seal failure because the pore pressure at the crest of the structure is ~80% of the lithostatic pressure and the estimated retention capacity (4.5 MPa) is < 7MPa (Garenstroom et al., 1993). However, the field wide documentation of leaked oil and gas in the cap-rock may suggest a leakage pathway involving the pore network of the mudstone seal rather than localized fractures or sets of fracture networks except where the fractures are microfractures. These fracture networks are not readily discernable on the available log data from the field. On the other hand, the average oil column height from mercury injection analyses is in equilibrium with the observed oil column. This state of equilibrium may suggest that the existing oil column is sustained by a balance between reservoir oil charge and leakage rates. Results of a Darcy flow based dynamic seal risking model where an average seal permeability is 150 nD and a thickness of 600 m is applied (Figure 2), showed that if reservoir charge were to cease, half of the 300 m oil column would be lost in <10 ma (half life is the time it takes for half of the column to dissipate if charge

were ceased). This calculations further supports that the field's oil column is sustained by continuous charge.

## 5. Conclusions

Seal risking in the Snorre field is investigated using an integrated geological approach where evidence of leakage and changes in the character of the leaking petroleum fluid towards the migration front is documented. Numerical mixing models involving biomarker concentrations suggest that several tens of volumes of oil may have migrated into the cap-rock. The stripping of HMW hydrocarbons towards the migration front in the leaky seal appears to be controlled by the specific surface area to porosity ratio of the cap-rock. Similarly, lab based core flooding experiment (Bennett 2004) supports the fact that the pore wetting state of siltstones and potentially mudstones seals can be altered by the migration of live oil. In this case, the cap-rock ceases to act a capillary seal but rather as a permeability barrier. These seals should be assessed from a dynamic stand point where permeability and thickness are key seal properties that affect leakage rates.



## 6. References:

- Aplin, A. C. Kurtev, K., & Larter, S.R., (2006) Dynamic Evaluation of Leaking Fault and Top Seals. *CSPG/CSEG/CWLS Joint Conference*, Calgary, Canada, Abstract.
- Bennett, B. Buckman, J.O., Bowler, B.F. J., & Larter S.R., 2004, Wettability alteration in petroleum systems: the role of polar non-hydrocarbons *Petroleum Geoscience*, **10**, 271–277.
- Bond, K. J., 2000, *Mudstone cap-rocks as vertical migration pathways: Case studies from the Norwegian sector of the North Sea*. PhD thesis, University of Newcastle upon Tyne, UK.
- Gaarenstroom, L., Tromp, R.A.J., de Jong, M.C., & Brandenburg, A.M., 1993, Overpressures in the Central North Sea: implications for trap integrity and drilling safety. *In: Parker, J. R. (Eds.) Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference*, 1305–1313. Geological Society, London.
- Leith, T.L., & Fallick, A.E., 1997, Organic geochemistry of cap-rock hydrocarbons, Snorre Field, Norwegian North Sea, *Seals traps and the petroleum system* (Ed: R.C. Surdam), *The American Association of Petroleum Geology Memoir*, **67**, 115-134.