# Caprock mudstones from UK North Sea hydrocarbon fields as analogues for seals in geological $CO_2$ storage

Yutong Shu[1] Mark Wilkinson[1] Niklas Heinemann[1]

[1]University of Edinburgh

## Abstract

The retention capacity of caprocks above potential $CO_2$ storage sites in saline aquifers is likely to be unknown, but is critical as caprocks inhibit the migration of supercritical $CO_2$ to other strata. The major sealing mechanism for most caprocks is capillary sealing. The critical factor is the size (radius) of pore throats of the caprock, the narrowest passages that the non-wetting phase fluid (petroleum or $CO_2$) must passes through in order to travel through a volume of rock. The smaller the radius of the connected pore throats, the larger the displacement pressure required, and the higher the potential sealing capacity. The lack of samples of the seal rock in many potential storage sites makes the direct measurement of pore throat radius or capillary entry pressure impossible.

As an alternative to the traditional method of Mercury Injection Porosimetry (MIP) for the measurement of pore throat radius, caprocks of oil and gas fields in the North Sea have been used as analogues. The method uses the balance of the buoyancy force equation and Washburn equation (1921), where, for the maximum hydrocarbon column height that a seal can retain:

$$P_b = \Delta\rho g h \le \frac{2\sigma\cos\theta}{r} = P_c$$

Where $P_b$=buoyancy force of the target column; $\Delta\rho$ = the density difference between brine and the target phase; $g$=acceleration due to gravity; $h$=column height; $P_c$=capillary pressure; $\sigma$=interfacial tension (IFT); $\cos\theta$ = contact angle; $r$ = pore throat radius.

In total 140 reservoirs of UK North Sea have been studied, 53 of which have both sufficient data to allow calculation and where capillary pressure is plausibly the limiting factor for hydrocarbon sealing. Fields with a hydrocarbon column height controlled by spill point are excluded from analysis. The cumulative percentage and probability distribution of the effective pore throat radii of the shale caprocks in the UK North Sea oil fields has been established, which could be used as a reference for the saline aquifers in $CO_2$ storage siting. Monte Carlo simulation was utilized to incorporate likely uncertainties in the input parameters. The cumulative distribution from this study is as follows:

$$F(x) = \frac{100}{1 + \exp(0.3152 - 0.006998x + \frac{92.28}{x})} \qquad R^2 = 0.9862$$

Where $x$ is effective pore throat radius in nanometer; $F(x)$ is cumulative distribution of the associated effective pore throat radius. The new model has dramatically narrowed the range of effective pore throat radii (37nm to 1700nm) compared to Yang and Aplin (1998) using Mercury Injection Porosimetry (MIP). This reduces the range of pore throat radii that might be included in a probabilistic assessment of the storage capacity of a saline aquifer under an untested shale seal rock that is thought to be similar to the North Sea examples studied here.

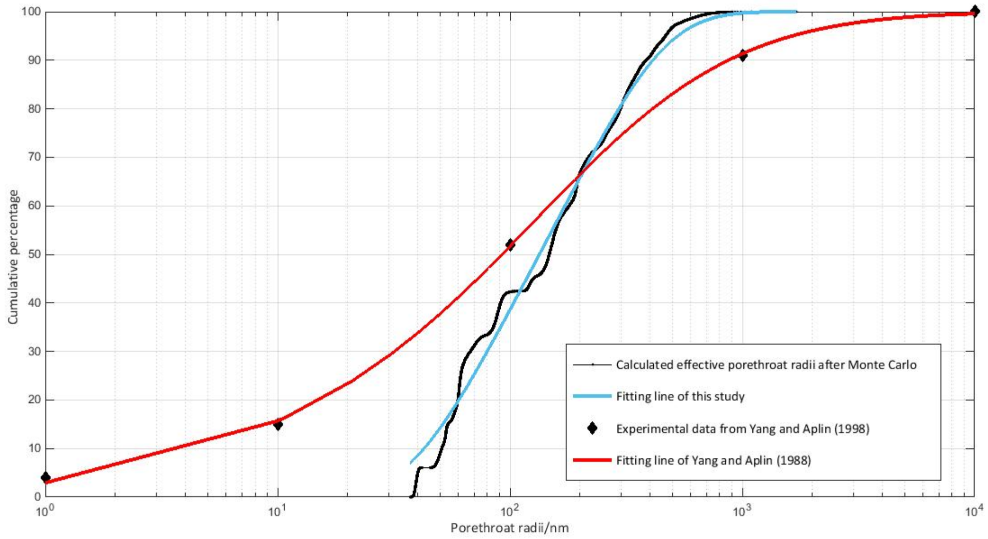

Figure: comparisons of cumulative percentage of pore throat radii of this study and that of Yang & Aplin (1998). The black line is the calculated effective pore throat radii after Monte Carlo simulation; the blue line is the fitting model of the cumulative percentage (see equation above); the red line is the fitting model of the cumulative percentage of Yang and Aplin from the Norwegian Margin.

The controlling factors for effective pore throat radii might include the degree of faulting and fracturing, burial depth, and caprock thickness. Faulting and fault sealing show no significant correlation with calculated pore throat radius. For burial depths of less than 3000m, there is a linear correlation between depth and the effective pore throat radii; for burial deeper than 3000m there is no correlation. This is interpreted to show that pore throat radius is controlled by diagenesis during deeper burial, while mechanical compaction is dominant during shallow burial. Caprock thickness shows only a weak correlation with effective pore throat radii, perhaps because of variable overpressure of the mudstone as a result of disequilibrium compaction. Overpressure in caprocks could result in two distinct effects on retention capacity: on one hand, overpressure in caprocks will inhibit compaction, resulting in higher porosities, larger pore throats and hence lower seal efficiency; on the other hand, differences in overpressures between the reservoirs and overlying seal will affect the critical balance between buoyancy and capillary resistance. This can dramatically increase seal efficiency.

## References

Yang, Y. and A. C. Aplin (1998). "Influence of lithology and compaction on the pore size distribution and modelled permeability of some mudstones from the Norwegian margin." Marine and Petroleum Geology **15**(2): 163-175.