Inverse modelling of nano- to macro-scale voidage within tight-oil shale

G. Peter Matthews, Katie L. Jones and Giuliano M. Laudone

PoreXpert Ltd., Plymouth, UK

POREXPERT

UNIVERSITY OF PLYMOUTH

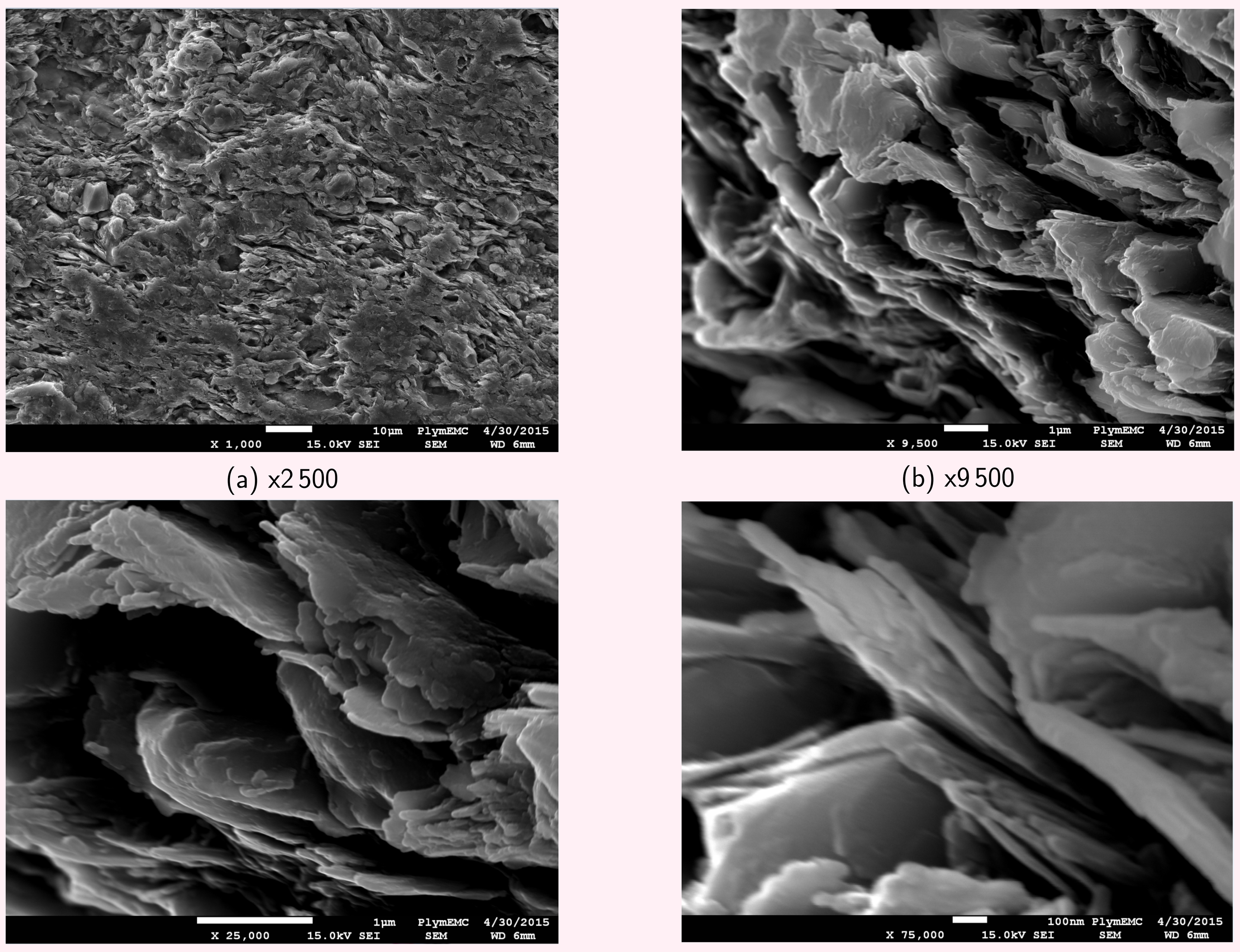
Summary

- We present a major new advance in the ability to characterise the nano-voidage of intact, rather than crushed, black shale samples.
- The method is based on extending the range probed by mercury porosimetry from 4 nm down to 1 nm by use of an intelligent (Bayesian) inverse pore-level model.
- The resulting model allows estimates of the whole-sample permeability to gas and oil which are not dependent on crushed-sample particle sizes.

Materials & Methods

Black shale samples were supplied by BG Group. The results presented here refer to a sample taken from a bore at a known depth. The sample was cleaned with isopropanol, rather than the more commonly used toluene, in order to remove the infiltrated mud, whilst leaving any kerogen and bituminous material [(1)].

SEM images of the sample (Figure 1), show the complexity of shale at all size levels and a larger porous space than anticipated.



(a) x2 500 (b) x9 500

(c) x25 000 (d) x75 000

Figure 1: SEM images of shale at increasing magnifications.

A GeoPyc 1360 pycnometer was used to measured the envelope (external) volume of the sample. The volume of the solid phase after cleaning was measured with helium at 200 kPa pressure, using a Pycnomatic ATC pycnometer. Together, the measurements show an accessible porosity of 7.7% for this sample.

Mercury intrusion was measured with a PASCAL 140 and 440 porosimeters, from just above vacuum to 400 MPa applied pressure.

Modelling

PoreXpert is a software package, available for trial as detailed below, for the construction of void networks by inverse modelling of percolation characteristics. The void structure of a porous material is represented as a series of interconnected unit cells with periodic boundary conditions, Figure 2. The network model can generate structures with the correct porosity, and percolation properties which closely match mercury porosimetry. It fits experimental data intelligently with a Bayesian approach guided by an annealed ameoboid simplex [(2)].

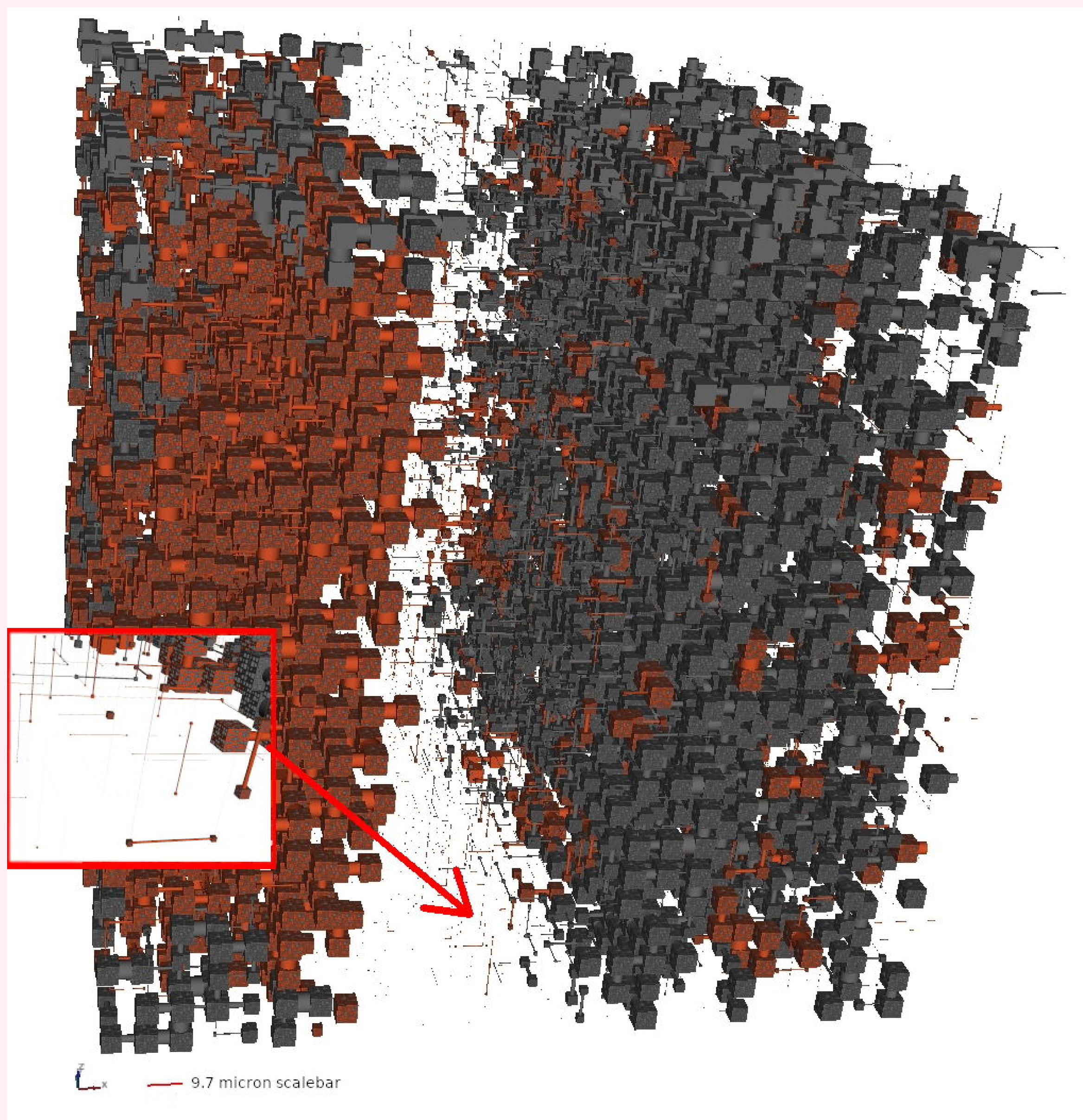


Figure 2: PoreXpert unit cell for shale sample. Oil-wet, injected to 51% by volume with brine (grey). Scale bar length 9.7 μm. Many void features are invisibly small, as indicated by the detail box. The transparent region corresponds to the solid matrix, with voids shown solid. Void clusters are rendered.

Results & Discussion

A major problem is that mercury injected up to a maximum pressure of 400 MPa only probes void features down to a diameter of 4 nm. However, much of the porosity of importance in the recovery and transport of tight oil comprises pores below 4 nm in diameter. Other workers have therefore attempted to generate void structures at this size level, based for example on Markov chain stepwise reconstruction of pore:solid probabilities estimated from electron micrographs. The results tend to be unconvincing, and not representative of complete samples.

Our approach based on PoreXpert provides an approach which bridges the gap between 1 nm and 4 nm, by propagating the microstructure relative to macro-structure, and setting the value of porosity at 1 nm as equal to the porosity measured by helium displacement (7.7%), Figure 3 [(2)].

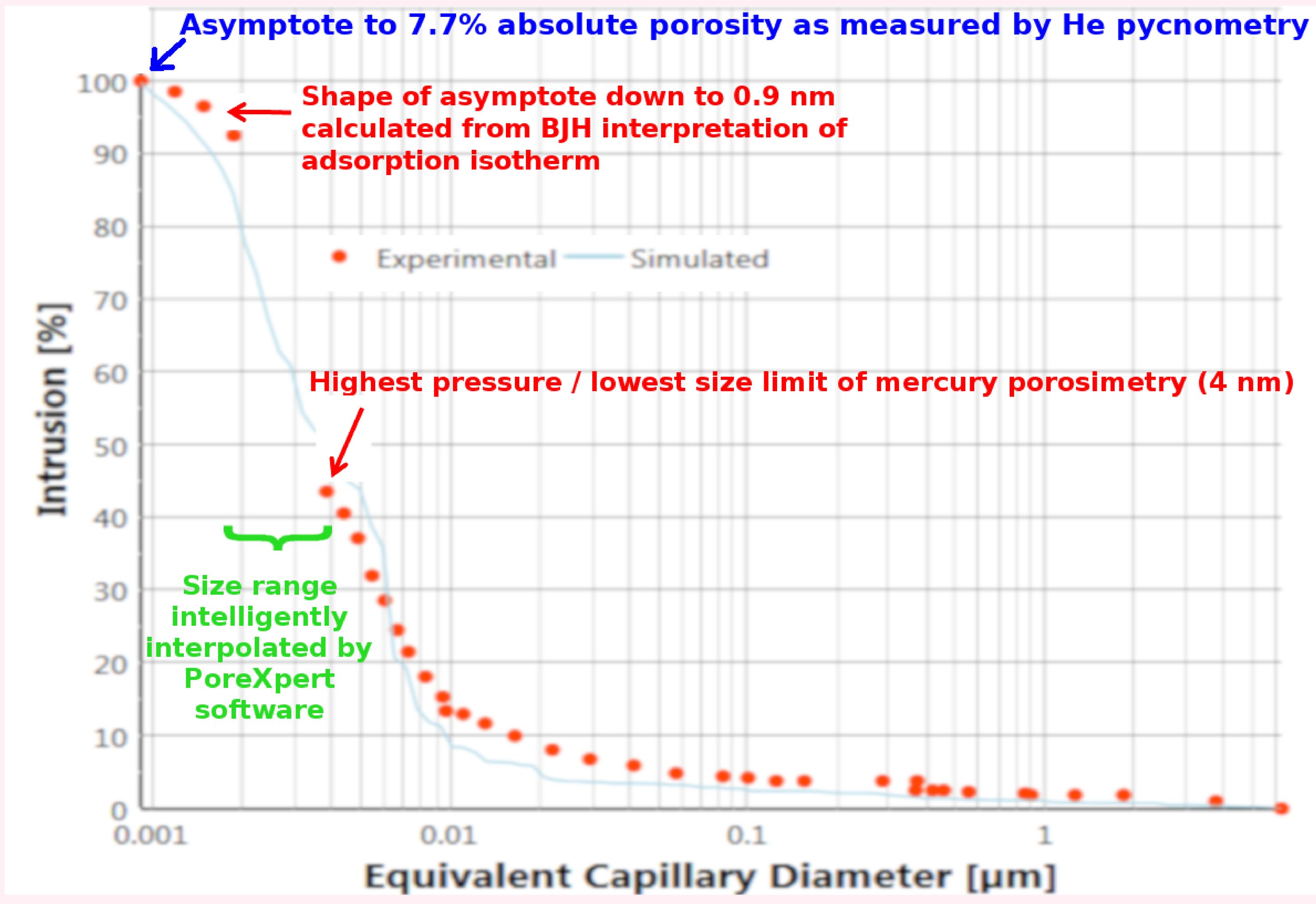


Figure 3: Hg intrusion curve and region interpolated by PoreXpert.

The unit cell shown in Figure 2 is based on new numerical analysis which, for the first time, identifies those voids that are likely to be clusters, Figure 4 [(3)]. The unit cell can be used to model pore-level transport processes, such as absolute and relative permeability and diffusion, and to predict how such transport can be optimised in order to improve tight oil yield by 1% absolute or more.

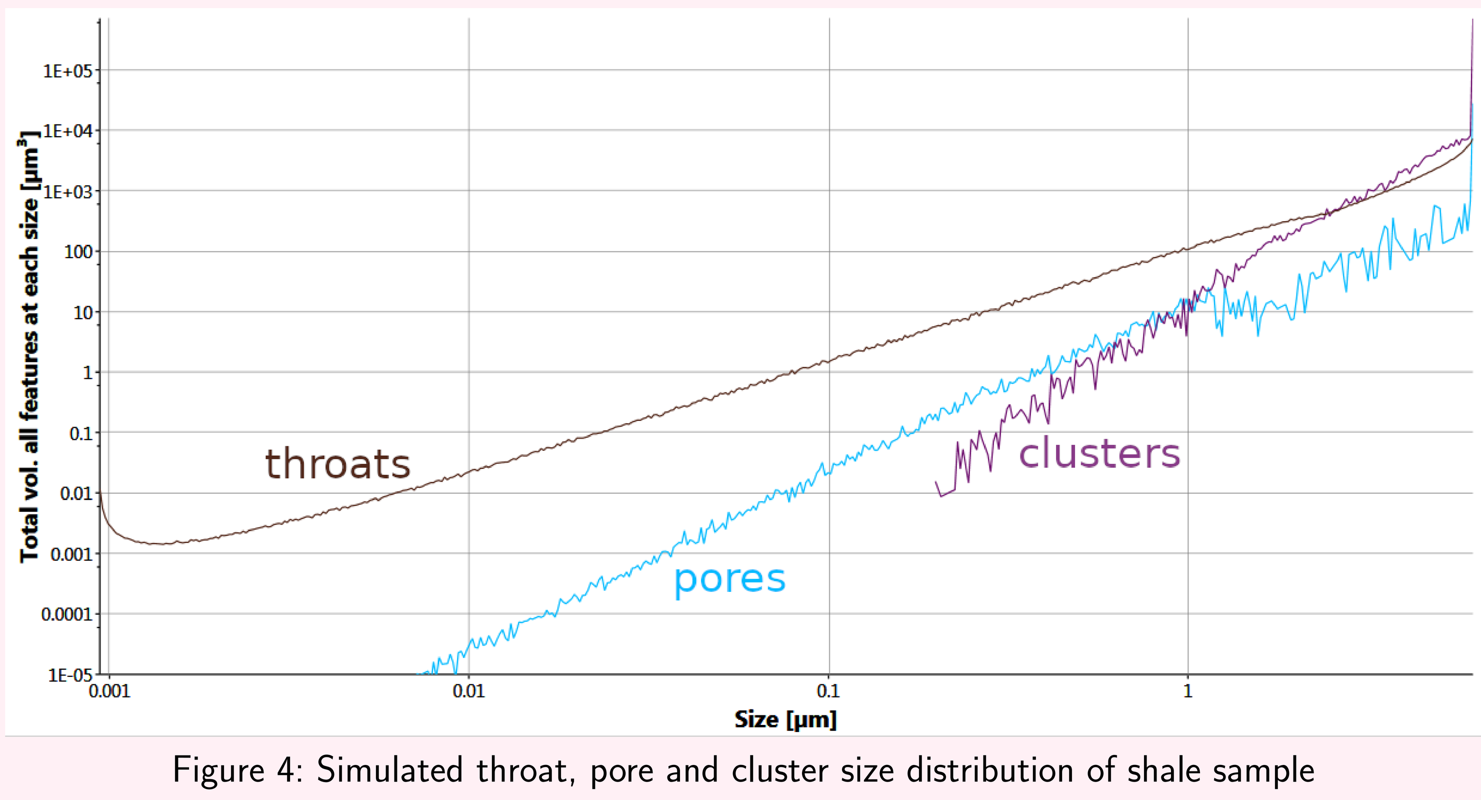


Figure 4: Simulated throat, pore and cluster size distribution of shale sample

Conclusions

- Sample preparation, including cleaning, can affect porosity and pore size distribution measurements.
- Inverse modelling of Hg intrusion in black shale, coupled with adsorption measurements and pycnometry, provides a fully realistic, feature-integrated void structure model, from meso- down to nano-scale.
- The approach provides a powerful now tool for calculating relative permeability, and for improving tight oil recovery under standard and enhanced conditions.

References

(1) Cornwall, C. (2001). The preservation or removal of solid bituminous material, as part of the core analysis programme on the Elgin-Franklin field. *SCA*, 2001-48.

(2) Laudone, G.M., Gribble, C.M., & Matthews, G.P. (2014). Characterisation of the porous structure of Gilsocarbon graphite using pycnometry, cyclic porosimetry and void-network modeling. *Carbon*, 73, 61-70.

(3) Matthews, G.P., Levy, C.L., Laudone, G.M., Jones, C.J., et al. (2018). Improved Interpretation of Mercury Intrusion and Soil Water Retention Percolation Characteristics by Inverse Modelling and Void Cluster Analysis. *Transport in Porous Media*, 124, 631-653. (Open Access - already downloaded 1000 times!)

Further information and software trial

For further information and a software trial, please read our references, visit the website http://www.porexpert.com and email us at matthewsgpeter@gmail.com.

Disclaimer

Current work, including ether EOR, is confidential, so the results here are illustrative only, based on a BG Group sample.