POREXPERT

A new dimension in Special Core Analysis

Enhanced oil recovery

Void structure

Relative permeability

PORE**XPERT**

is an *inverse* modeller for better understanding the behaviour of pore fluids

Inverse models go models *backwards* from an *effect* back to a *cause*

The effect is the percolation characteristic of the sample, usually measured by mercury porosimetry and helium pycnometry for rock samples

The *cause* is the three-dimensional void network within the sample

Once the three-dimensional void network is known, the behaviour of fluids within the voids can be modelled, for example brine displacing tight oil

Commercial benefits

- Current retrieval of oil from a unconventional reservoirs, such as those in North and South Amercia, is typically 7%
- PoreXpert is designed to increase the yield by:
  - providing improved relative permeability estimates for existing reservoir models
  - giving an improved understanding of tight-oil retrieval in huff-puff scenarios
  - giving improved guidance for where to frack based on better characterisation of shale subsamples from cores
  - providing improved understanding of the reduction in yield with time, and hence better estimates of total field capacity
- Overall, our aim is to increase the typical yield from 7% to 8%
  - giving an increase in profit of several millions of GB pounds or U.S. dollars for an outlay of less than £200k

POREXPERT

POREXPERT gives a much more accurate void structure representation than traditional special core analysis.

So simulations of oil and brine behaviour are also more accurate, answering questions such as:

- Where is the tight oil when trapped in the sample?
- How does the oil behave?
- Can it be retrieved by water-flood?
- What is the relative permeability, dependent on the flow rate and oil wettability of the rock?

Traditional approach for special core analysis

- Extract sample from core
  - then crush to powder
- Characterise experimentally
  - Mercury porosimetry
  - Pressure-pulse permeability
- Generate void network model
  - based on first derivative (slope) of the intrusion curve which implies a capillary bundle model
  - typically hierarchical (separate networks of small and large voids)
  - often in only 2 dimensions
  - typically triangular cross-section bonds connecting zero-volume voids
- Model the behaviour of oil, and estimate relative permeability
  - with the help of semi-empirical equations such as Brooks-Corey

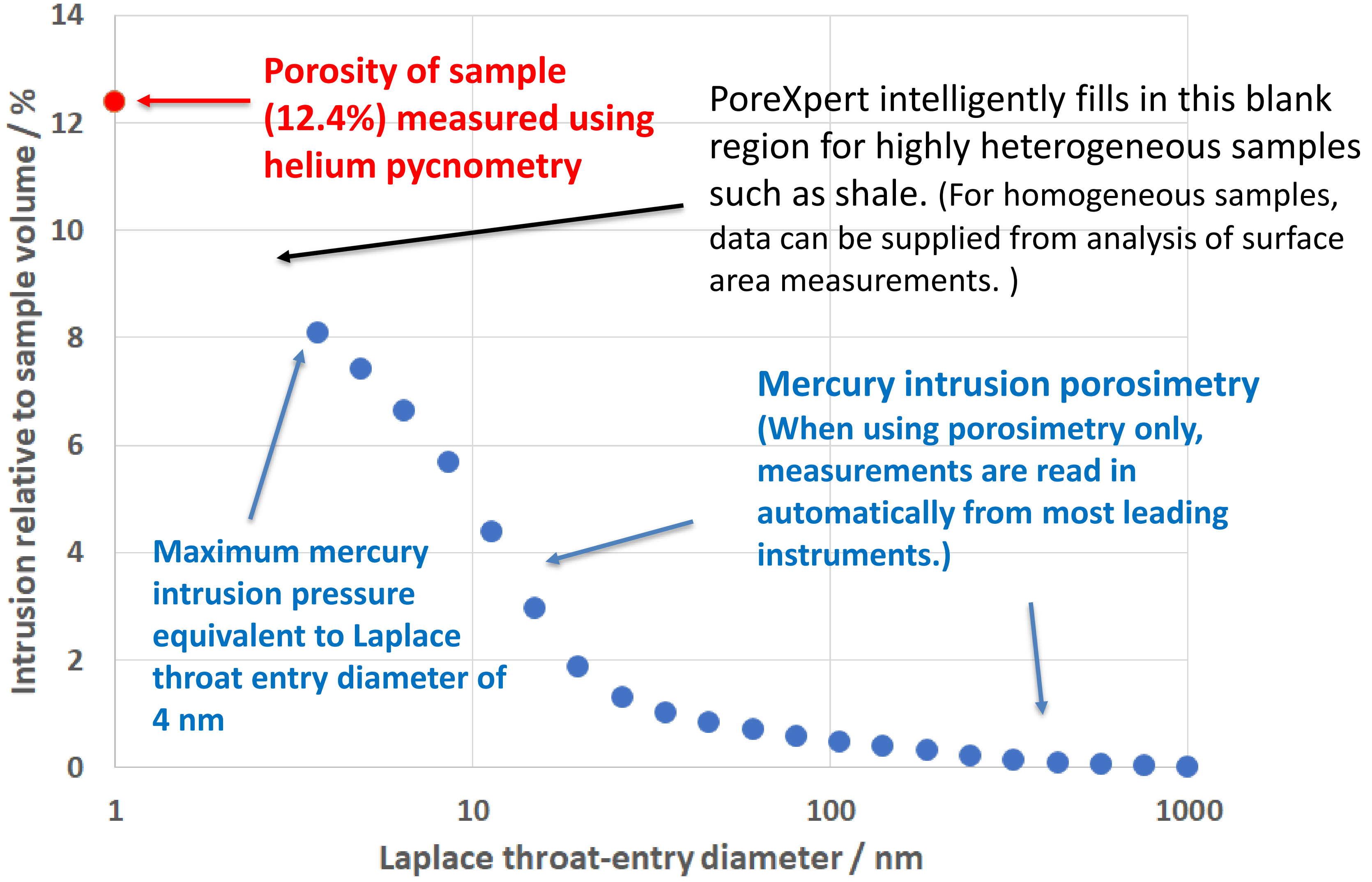
Resulting in: Estimates based on much guesswork

POREXPERT approach

- Extract sample from core
  - and create 1 cm cube subsamples
- Characterise experimentally
  - Mercury porosimetry
  - Helium pycnometry
  - Measure surface area and interpret with e.g. BJH or density functional theory
- Generate void network model
  - based on inverse modelling of entire mercury intrusion cure, extended to nanometre scale using the experimental techniques above
  - completely integrated behaviour of voids of all sizes
  - fully 3-dimensonal
  - cylindrical thoats connecting cubic pores or explicit void-cluster zones, with sizes of all features derived directly from the inverse modelling
- Model the behaviour of oil, and simulate relative permeability
  - using *a priori* physical behaviour, correctly scaled to nanometre level

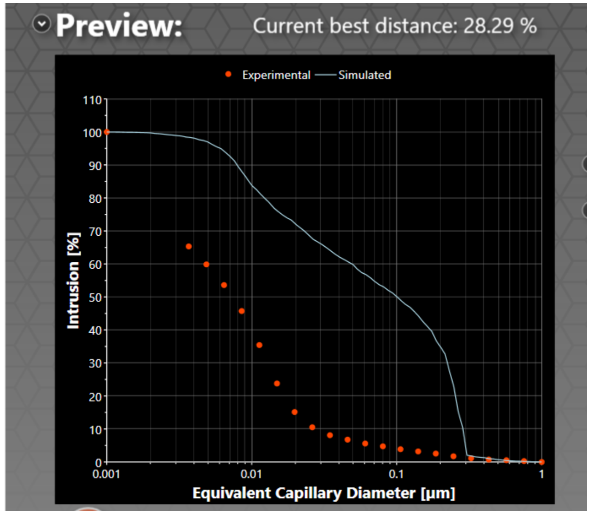
More accurate estimates to assist oil recovery

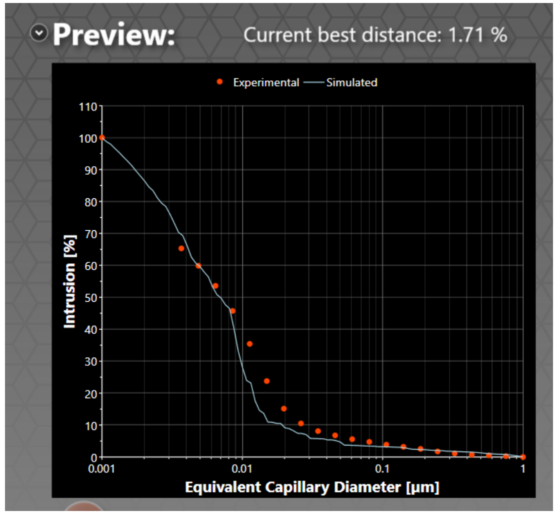
PoreXpert at work – data input

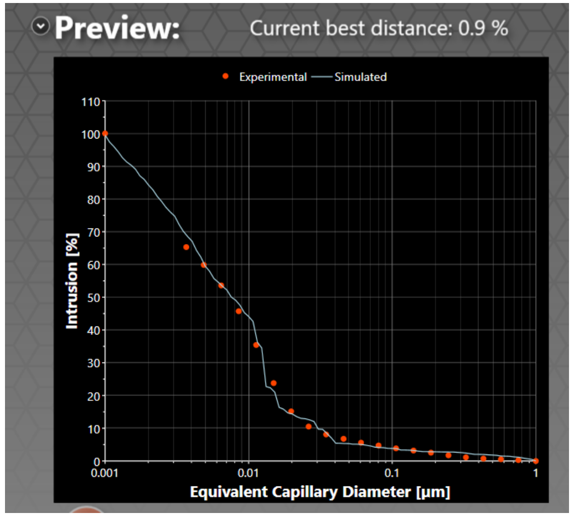


PoreXpert at work – inverse modelling

- Using rudimentary artificial intelligence, PoreXpert generates a series of void structures with characteristics progressively closer to your experimental data





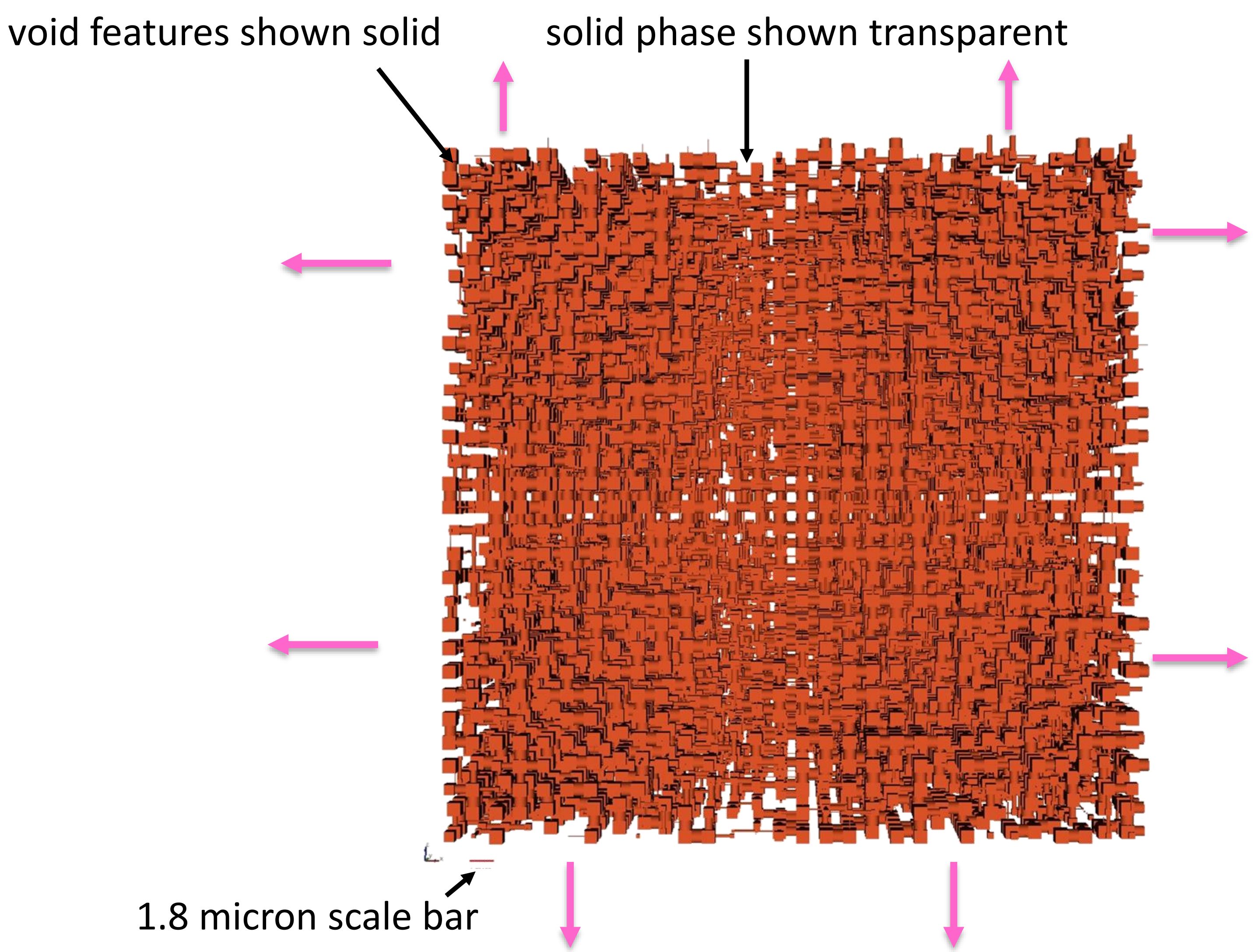


Discrepancy between simulation and experiment: 28.29% → 1.71% → 0.9%

PoreXpert at work – simulating the void structure

- PoreXpert shows the simulated void structure as a ‘unit cell’
  - a unit of structure that joins to replicates of itself in every direction

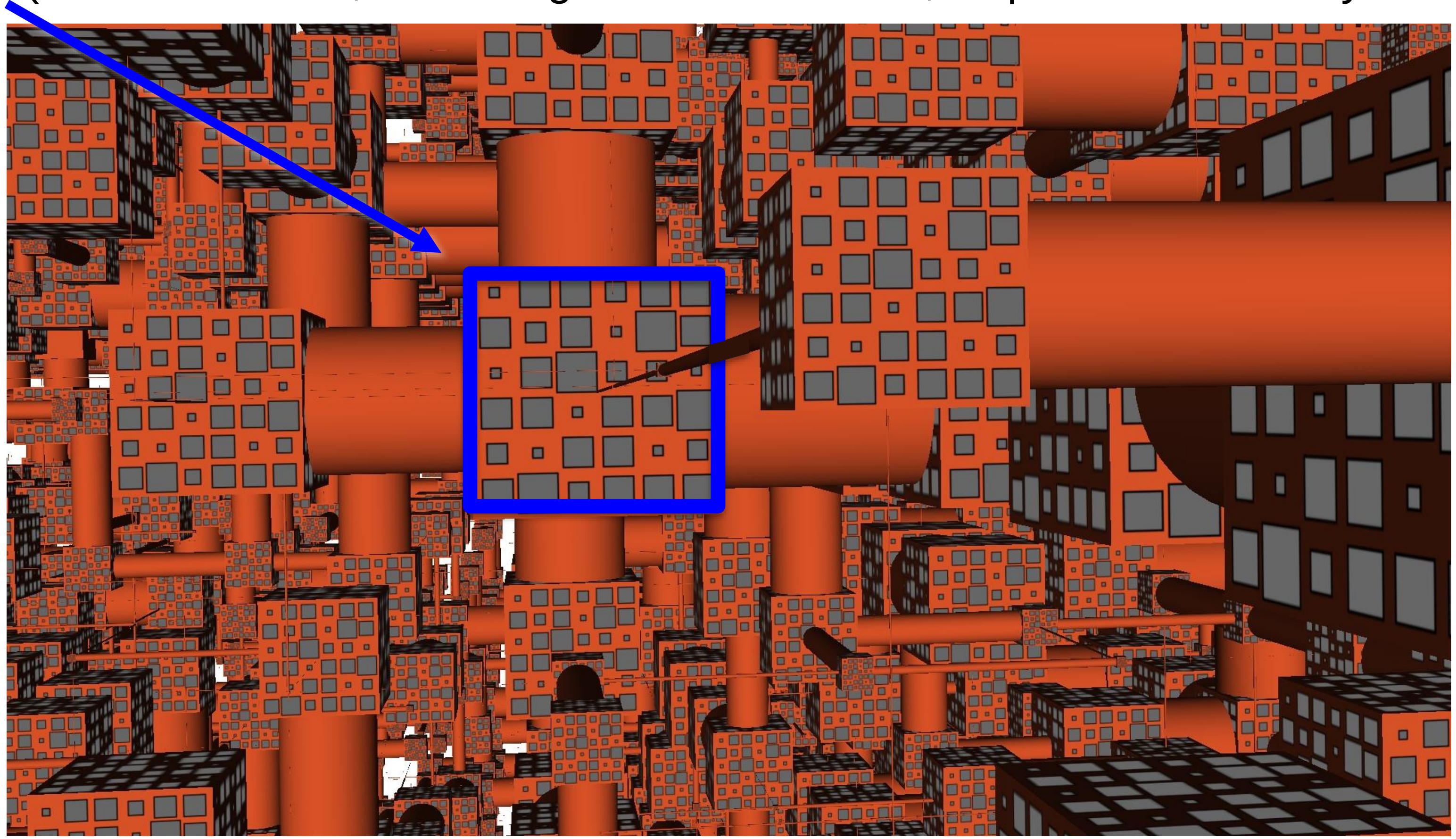
PoreXpert at work –
the 'unit cell'



there is a 'periodic boundary condition' – i.e. the unit cell connects to infinite replicates of itself in every direction

PoreXpert at work – locating void clusters

- Using complicated mathematics and logic (see the Further Reading slide) PoreXpert calculates the position of pores that appear to be single, but are likely to be clusters of smaller voids. They are marked with a pattern as shown. (As can be seen, in this region of the unit cell, all pores are actually clusters.)

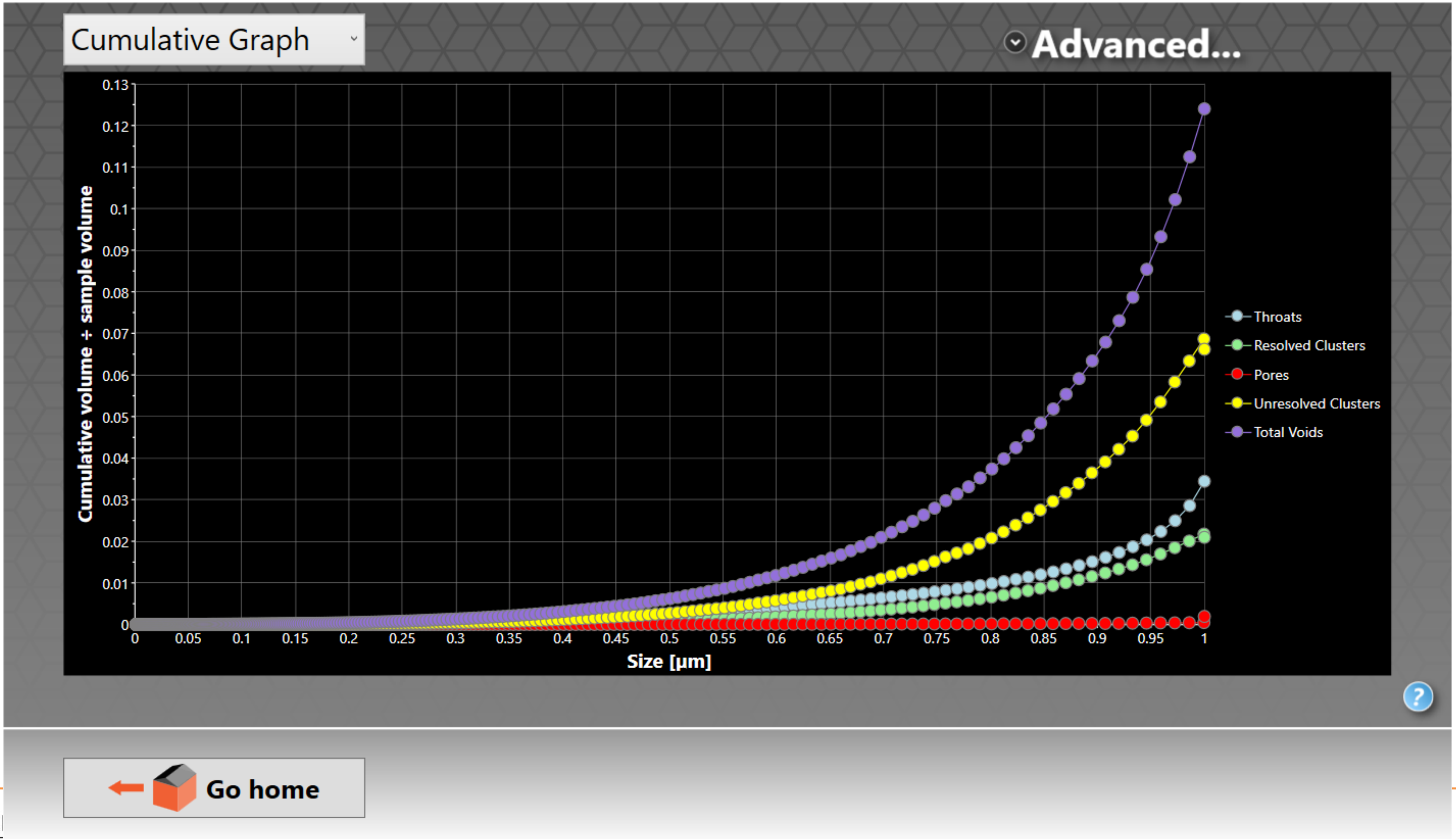


PoreXpert at work – calculating void sizes

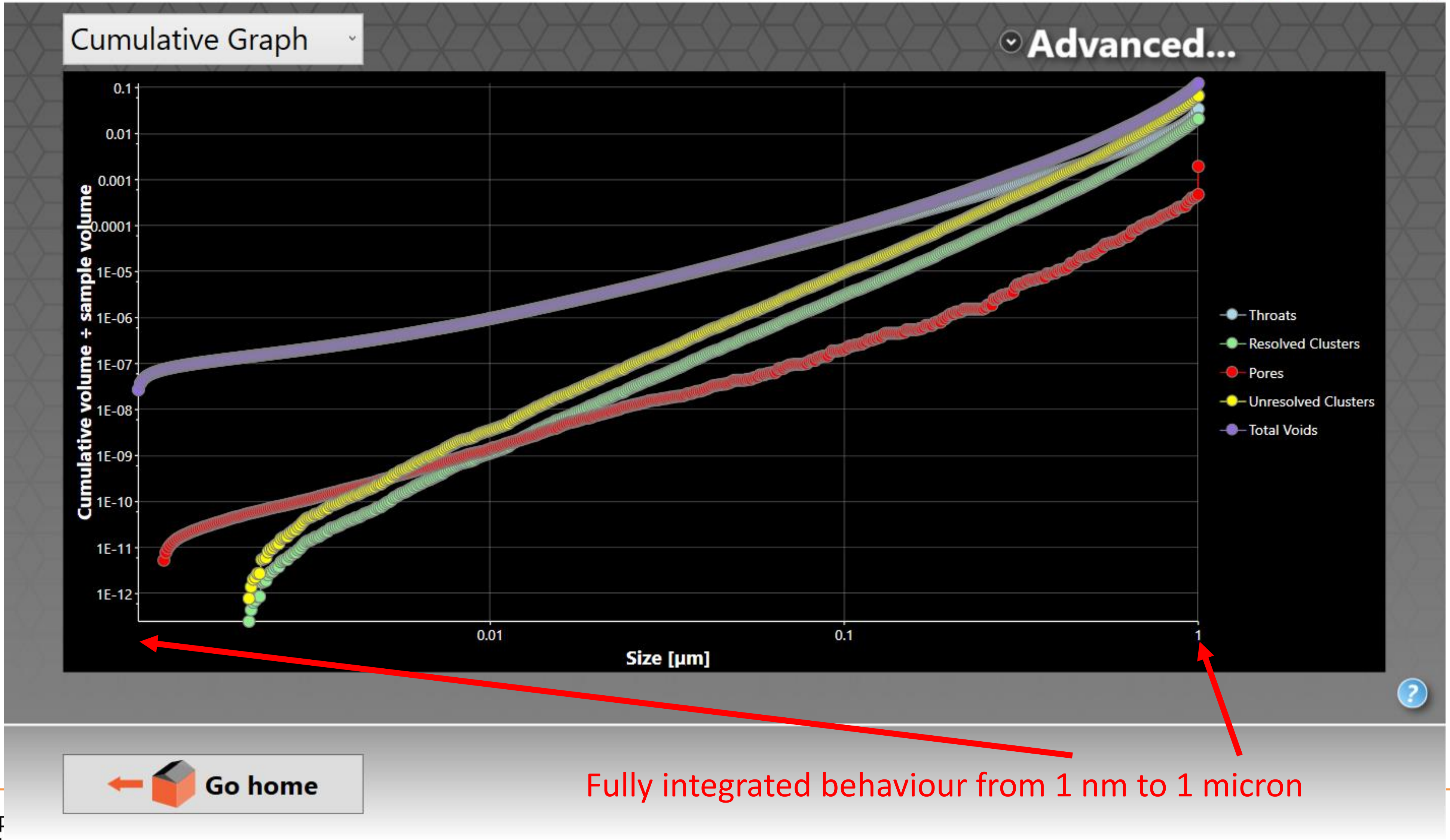
- After identifying void clusters, PoreXpert displays the sizes of all types of voids
- The distributions can be shown in many ways:
  - with linear axes or logarithmic axes, as shown in the next two slides
  - any area zoomed into using a drag of your mouse
  - output as character separated (.csv) numerical files for input into other graphing and simulation software
- The examples in the next two slides show two different, successive ways that clusters are identified
  - ‘Resolved’ clusters are identified from when they are intruded relative to the applied mercury pressure at the surface of the sample
  - ‘Unresolved’ clusters are identified from the shape of the overall void size distribution
  - for full details of the calculation, see the Further Reading slide

Shale
Size Distribution

Linear axes



Shale
Size Distribution Logarithmic axes

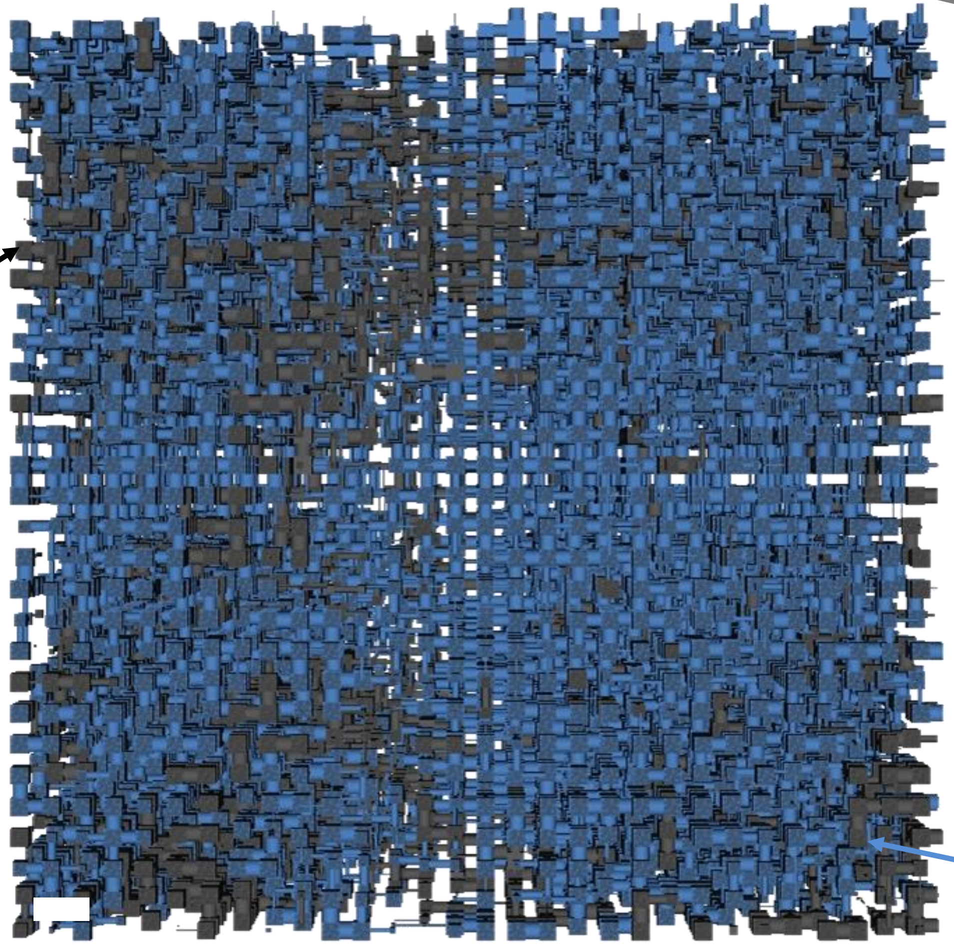


Fully integrated behaviour from 1 nm to 1 micron

The PoreXpert unit cell
showing brine injection recovery of tight oil from oil-wet shale

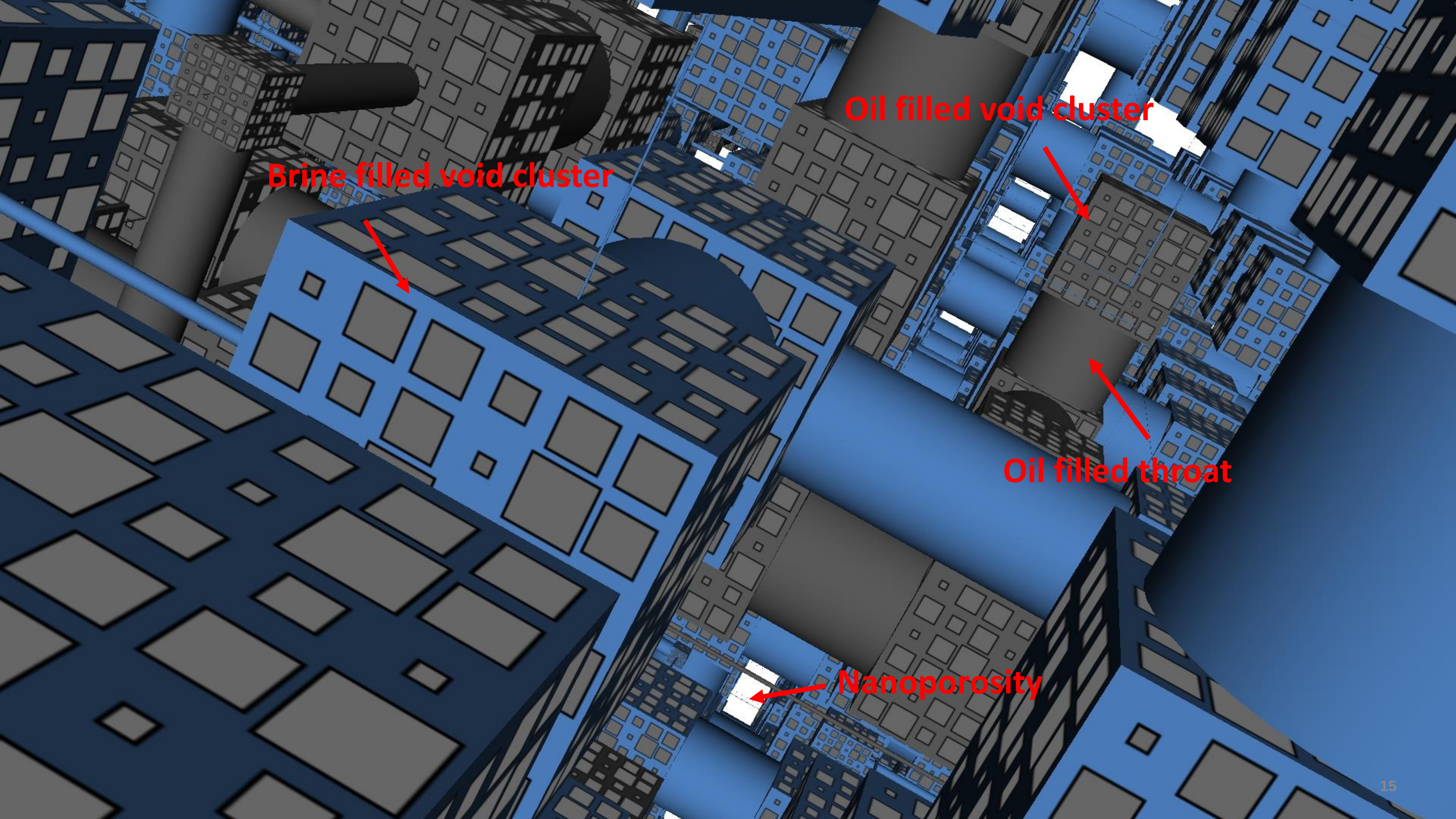
voids containing tight oil shown grey

pore clusters shown stippled



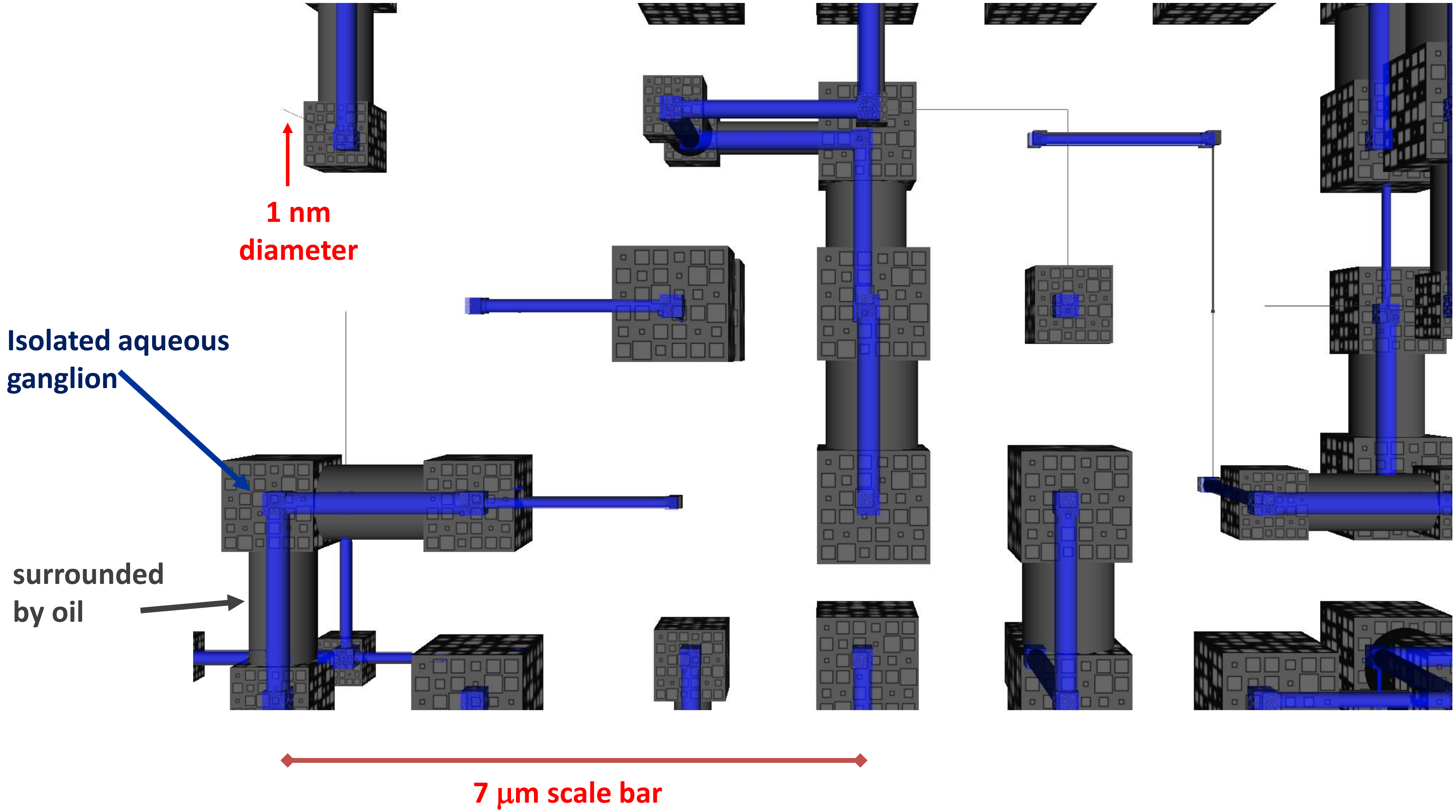
Virtual reality, operated by the user's mouse and illustrated with a video in the next slide, allows closer inspection (but not direct manipulation) of the void features and their contents

voids containing brine shown blue

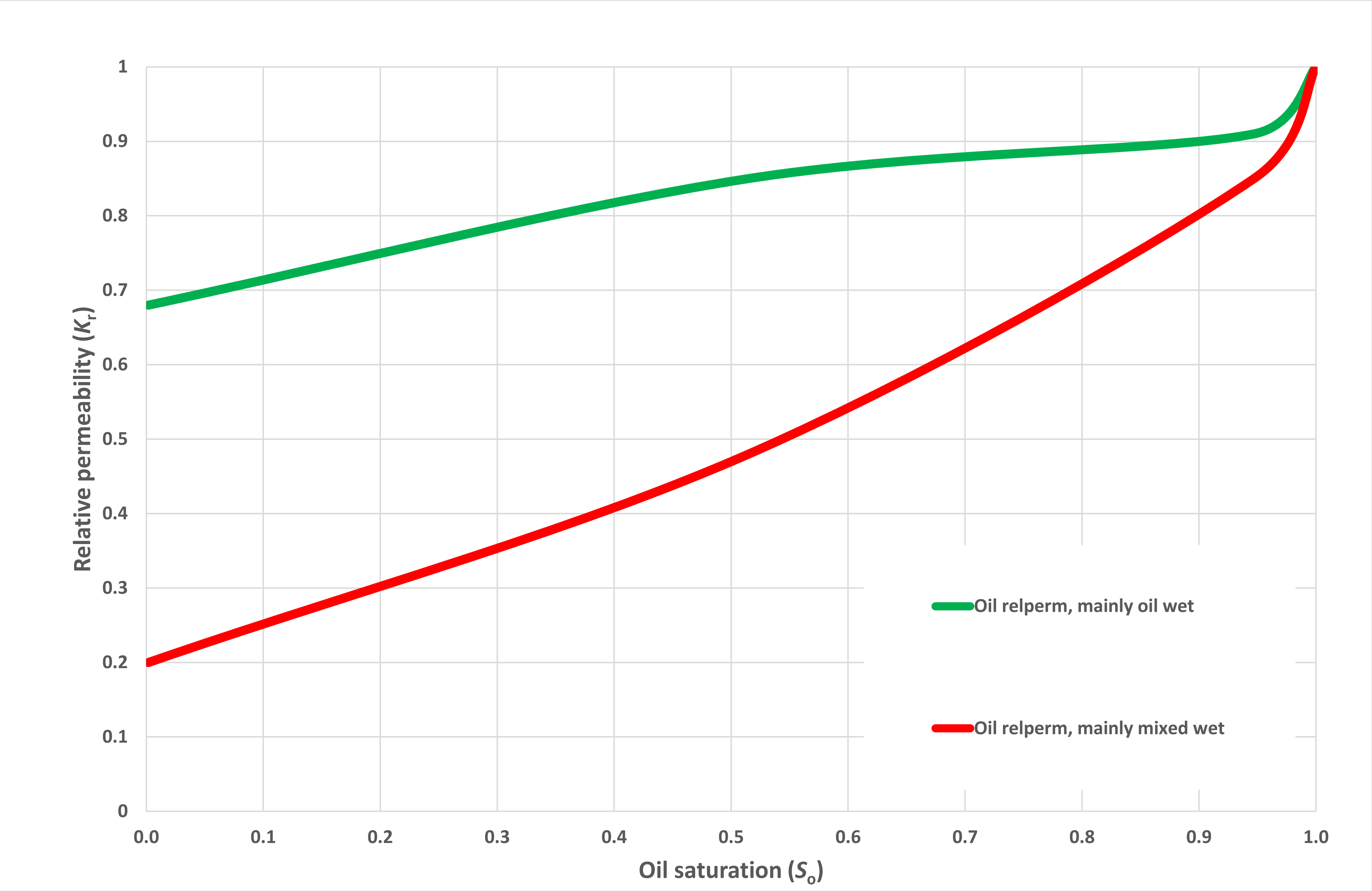

Oil filled void cluster
Brine filled void cluster
Oil filled throat
Nanoporosity

Calculation of relative permeability

- Map the positions of the static fluids
  - For example, in the case of the relative permeability of oil in oil-wet shale, map the positions of the disconnected aqueous ganglia


1 nm
diameter
Isolated aqueous
ganglion
surrounded
by oil
7 µm scale bar

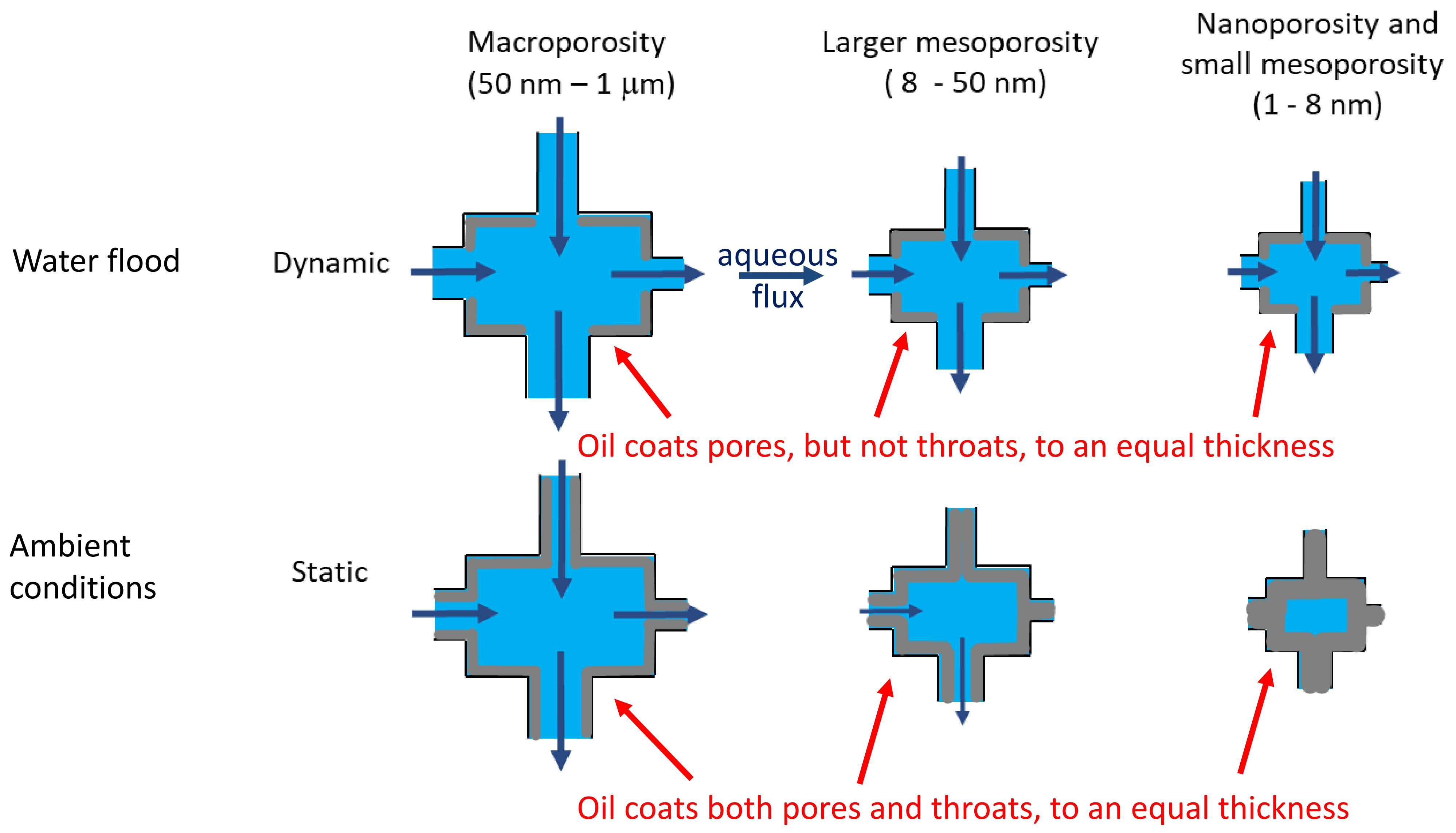
Oil relperm for a generic tight-oil shale



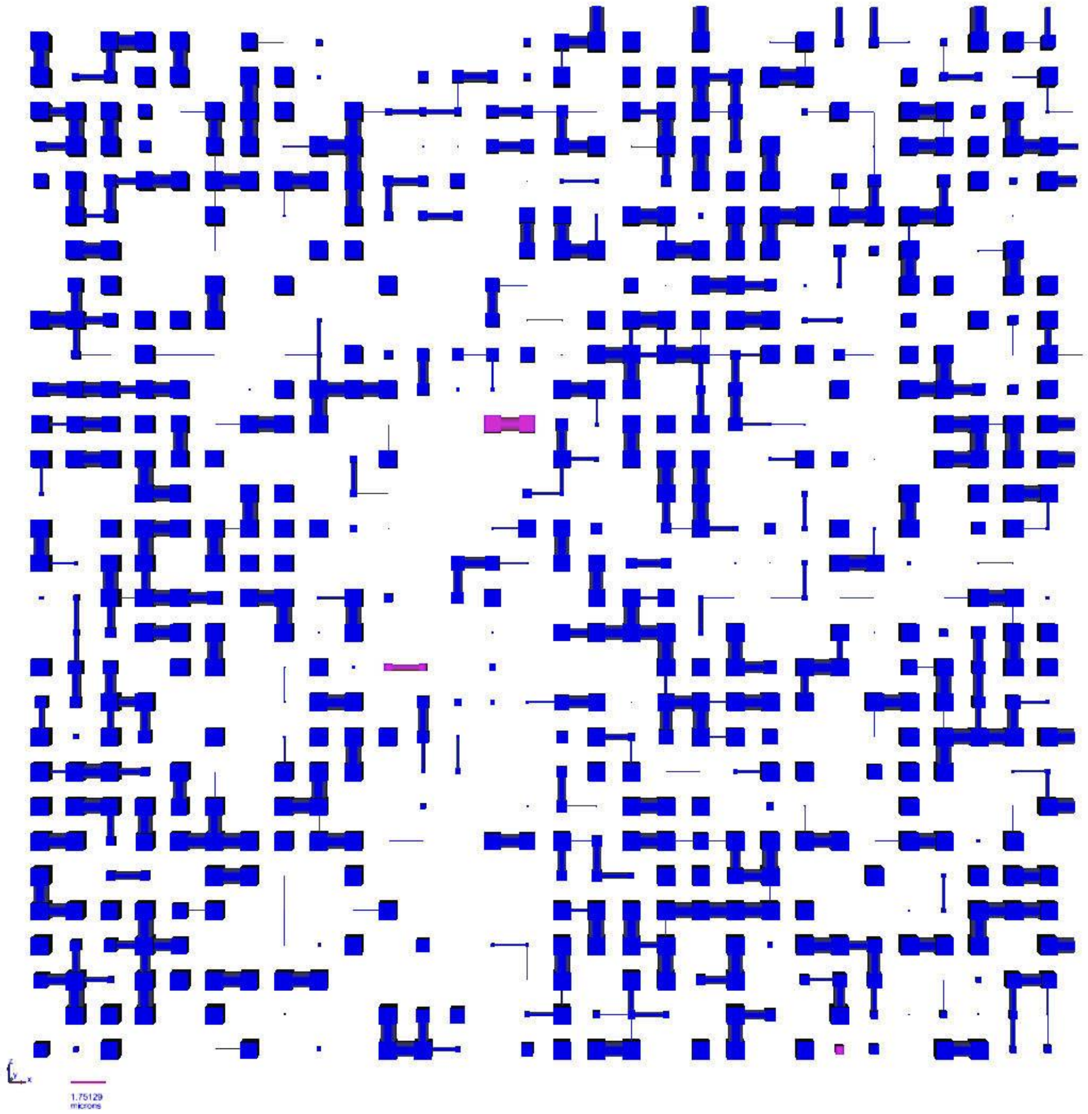
Calculation of relative permeablity

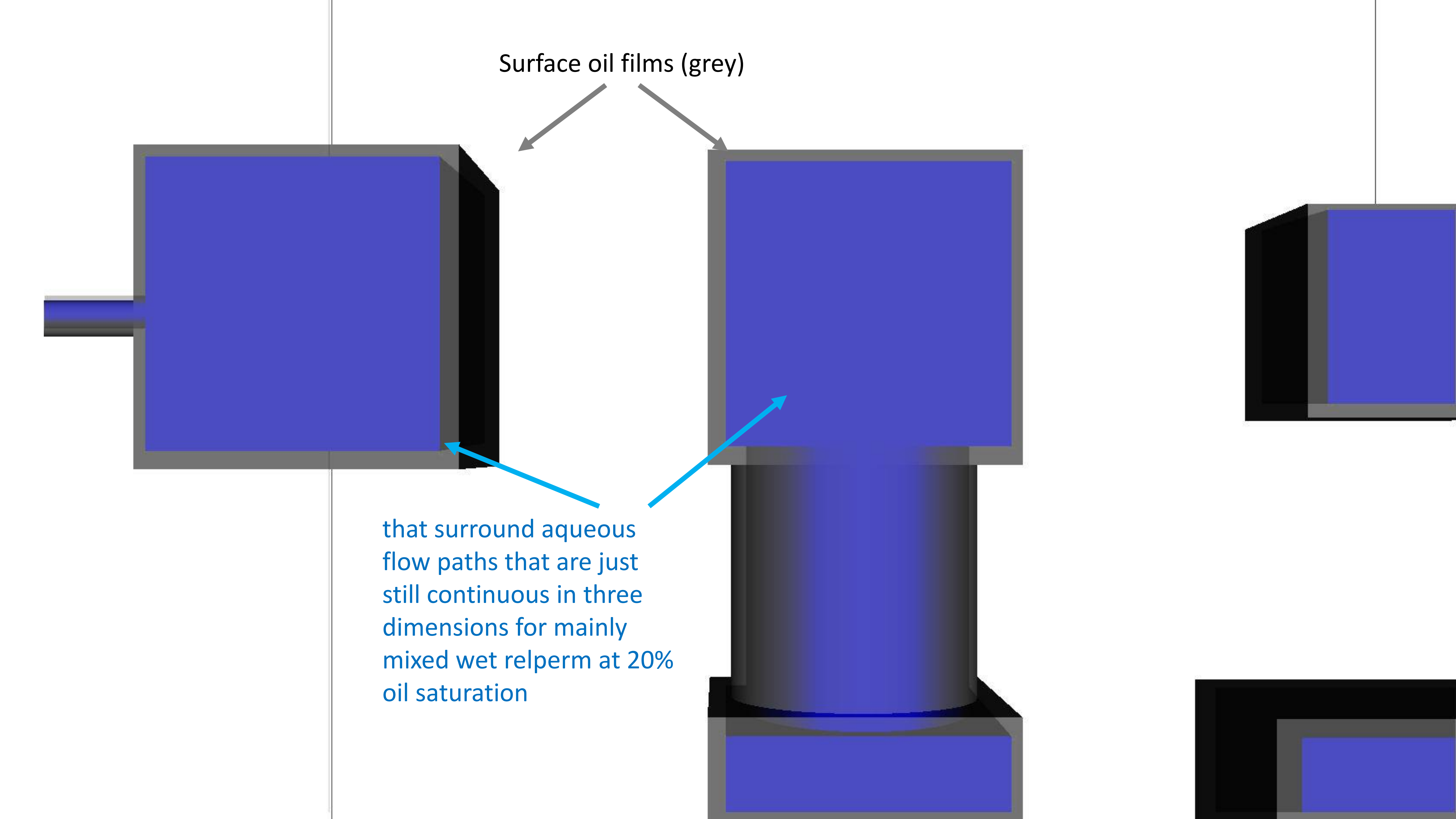
- Map the positions of the static fluids
  - For example, in the case of the relative permeability of oil in oil-wet shale, map the positions of the disconnected aqueous ganglia
  - For the case of the relative permeability of water in oil-wet shale, map the positions of the connected aqueous flow path impeded by a surface film of oil
- Uniquely, PoreXpert models the difference between relperm in quasi-static conditions, and relperm during dynamic conditions, such as during water flood

The difference between dynamic and quasi-static aqueous relperm



Map of aqueous occupation in surface layer at 20% oil saturation

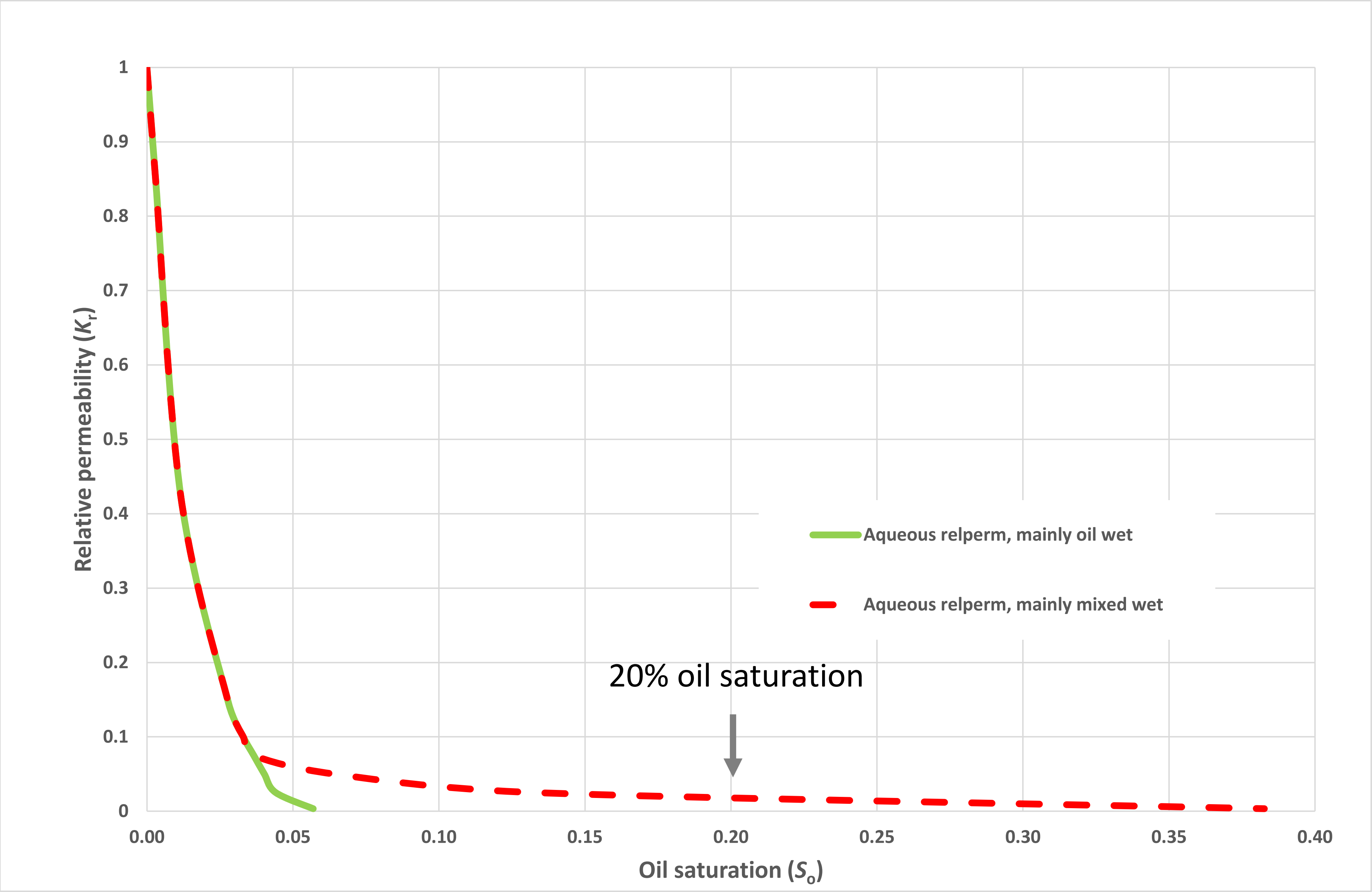



Surface oil films (grey)
that surround aqueous flow paths that are just still continuous in three dimensions for mainly mixed wet relperm at 20% oil saturation

Calculation of relative permeablity

- Map the positions of the static fluids
  - in the case of the relative permeability of oil in oil-wet shale, map the positions of the disconnected aqueous ganglia
  - for the relative permeability of water in oil-wet shale, map the positions of the connected aqueous flow path impeded by a surface film of oil
- Uniquely, PoreXpert models the difference between relperm in quasi-static conditions, and relperm during dynamic conditions, such as during water flood
- PoreXpert also models the difference between relperm in shales and other rock of varying wettability

Aqueous relperm for a generic tight-oil shale



Calculation of relative permeablity

- Map the positions of the static fluids
  - in the case of the relative permeability of oil in oil-wet shale, map the positions of the disconnected aqueous ganglia
  - for the relative permeability of water in oil-wet shale, map the positions of the connected aqueous flow path impeded by a surface film of oil
- Uniquely, PoreXpert models the difference between relperm in quasi-static conditions, and relperm during dynamic conditions, such as during water flood
- PoreXpert also models the difference between relperm in shales and other rock of varying wettability
- Not only does PoreXpert model relative permeability, it also gives an estimate of the unmeasurably small picoDarcy permeabilities of shales, which change by orders of magnitude with oil saturation. So it reveals differences in both absolute and relative permeabilty between different sampes
  - all of which can be demonstrated after a substantive expression of your interest

Further reading

- A more detailed version of this presentation, with Topic headers and a video link: https://www.porexpert.com/downloads/software-applications/
- Comprehensive user manual and tutorials: https://www.porexpert.com/downloads/product-download/
- Frequently asked questions: https://www.porexpert.com/support/faq/
- Open Source publication about the patented identification of void clusters: https://link.springer.com/article/10.1007/s11242-018-1087-1
- Validation of the PoreXpert simulations against experimental results: https://www.porexpert.com/help2/index.html?validation.htm
- Textbook explaining relative permeability: Chapter 7 of M.Blunt, 'Multiphase Flow in Permeable Media – a pore-scale perspective', Cambridge University Press, 2017.

  The current modelling builds on, and aims to improve, the approach described there.

Contact us, and testimonials

- Free software trial https://www.porexpert.com
- Consultancy https://www.porexpert.com/consultancy/
- Enquiries https://www.porexpert.com/contact-us/

PoreXpert v2 provides me with a large improvement over the package that came with the porosimeter

Robert Pattillo, Reno Refractories Inc., Alabama

...we are very impressed with your work. We've sent samples to other groups for analysis and none have even come close to the information you've given us.

Jeffrey Alvaji, QuestAir Technologies Inc., Canada

...congratulations for new version of your software. It is very user-friendly!! I think it will increase consistently the use of model worldwide

Prof. Francesco Morari, Università di Padova, Italy

You and your team have produced a great tool – which seems to only improve with time

Walt Pavlakovich, General Manager Tech. Service, World Minerals Inc., California

And thank you for watching!