TWIN SAMPLES AS QC TOOL IN CAPILLARY PRESSURE MEASUREMENTS AND MODELING:

FROM MICP TO CENTRIFUGE TOWARDS AN INTEGRATED RESERVOIR MODEL

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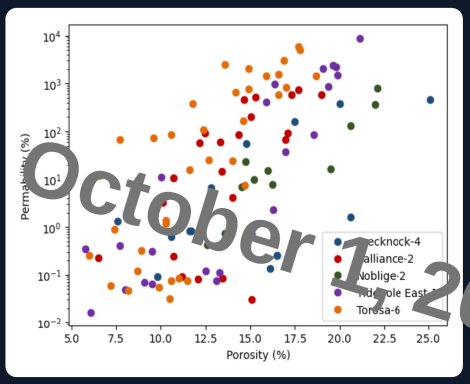
Iulian Hulea and Adam Moss

"the SHM man" : SHM is really easy, really easy to get wrong !

The dataset and the problem

Key message: twin samples are an effective QC tool, once porosity and Pc range share the same reference.

1. **The dataset:** Public, Geoscience Australia NOPIMS database (7 wells, >100 twin pairs)
2. **Data covered, acquisition methodology, sample size**
3. **Bring the measurements to the same reference**
4. **QC the measurements**
5. **Methodology employed**
6. **Conclusions and recommendations**



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Data eligibility: plugs and porosity

All analysis performed by Corelabs in Perth, Australia

All plugs cleaned using hot Soxhlet & dried at 95 °C in a dry oven.

All plugs had routine helium porosity and Klinkenberg permeability measured at a nominal confining pressure of 800psi. For the purposes of this study this is referred to as 'Ambient'.

The porosity of every centrifuge plug has also been measured using pre and post brine saturation masses and an immersed mass. We refer to this porosity as the 'Archimedes porosity'

Helium porosity has been measured on every MICP plug trim.

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Data eligibility: capillary pressure

All wells had centrifuge (CF) air-brine primary drainage capillary pressure measured.

The centrifuge tests were run at zero confining pressure for all wells.

The raw centrifuge data has been corrected for saturation profile effects and the 'end face water saturations' are used.

For the centrifuge tests the air-brine interfacial tension has been modelled. This is 73.36 Dynes/cm.

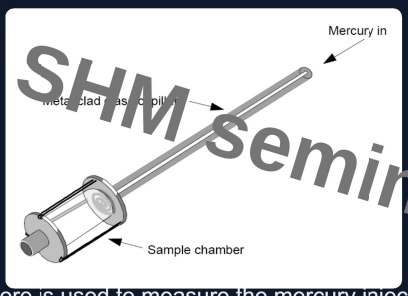
Every centrifuge plug had mercury injection capillary pressure (MICP) measured on a plug trim.

MICP corrections: closure/conformance; Hg–air γ = 485 dyn/cm, θ = 140°

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Mercury Injection Capillary Pressure

In a mercury injection experiment mercury is the non-wetting phase and air/vacuum is the wetting phase.





A Micromeritics Autopore is used to measure the mercury injection capillary pressure curves for these samples.

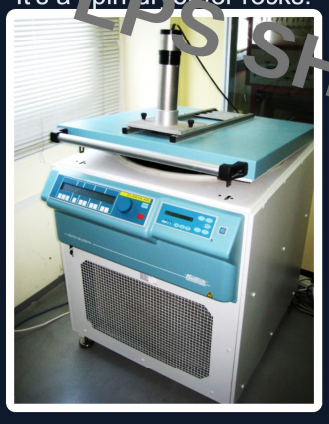
Max pressure : **60,000psi =** 0.004 microns diam. This represents a gas column of about **3 km** (gas–water, $\Delta\rho$ = 0.9 g/cm^3)

Sample held in penetrometer. Sample size limited - typically 4 to 12 cm^3

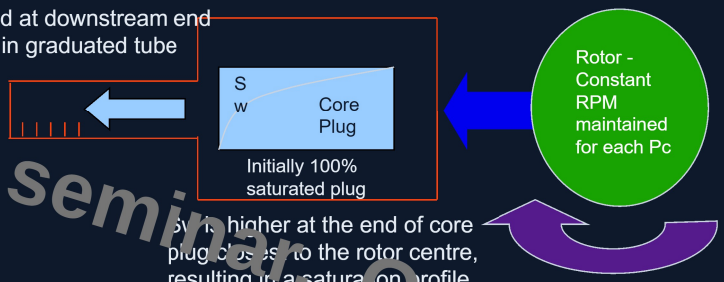
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Centrifuge Capillary Pressure

It's a spin-dryer for rocks!



Looking down on the top of the centrifuge



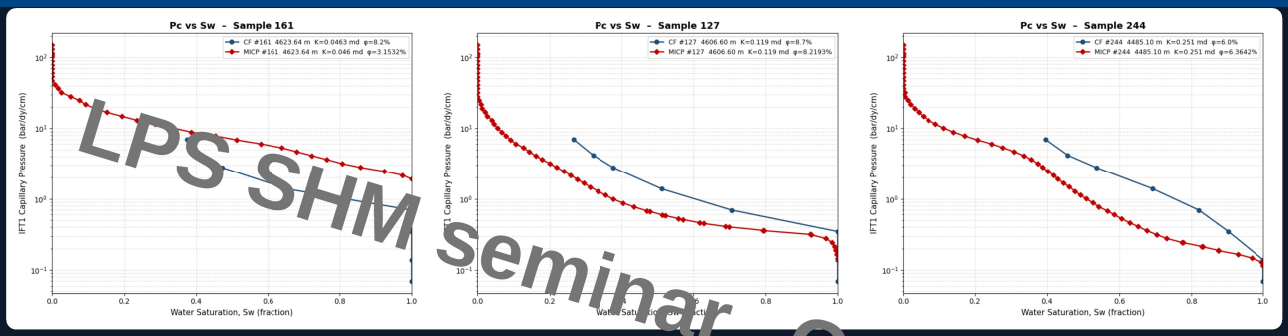
$$Pc = \Delta\rho\,(r_e^2 - r_i^2)\,RPM^2$$

The lab used the Forbes method to correct these data The saturation profile

The centrifuge samples were 1.5inch diameter & 5cm long, total volume 57 cm^3 i.e. 5-10 times bigger than the MICP samples.

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What do we worry about?



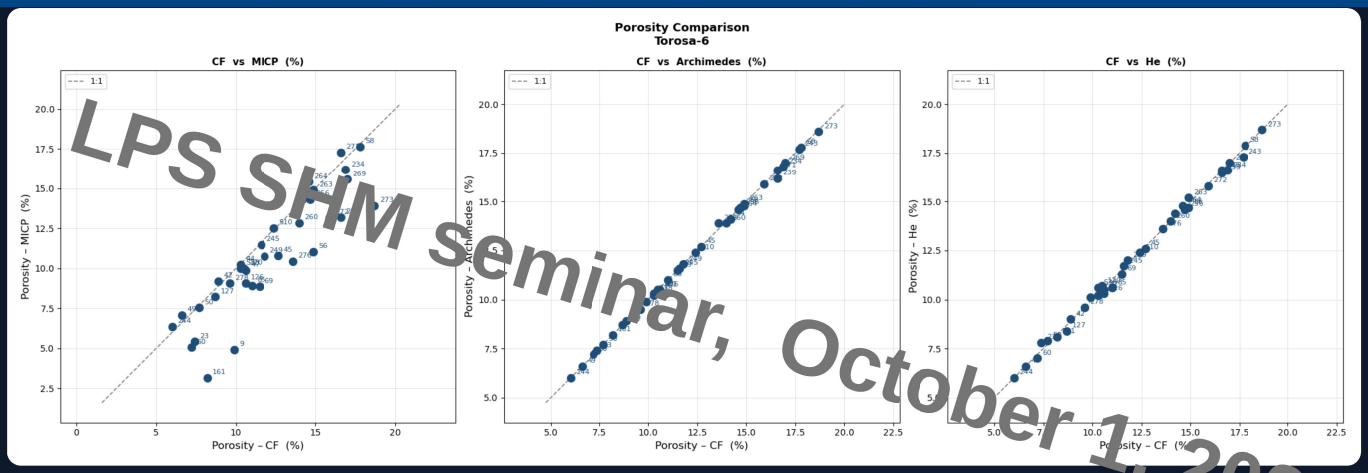
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$Pc=2\ \sigma \cos(\theta_{fl})/r_p$

$Pc_IFT1 = Pc/\sigma \cos(\theta_{fl}) = 2/r_p$

Is this kind of agreement acceptable? How should we map the difference?

Porosity: three measurements

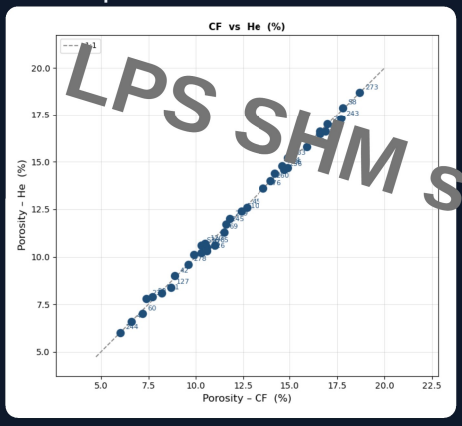


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One sample porosity ...3 measurements! Which one do we trust?

Porosity: He vs CF

Example: Torosa-6



For Torosa-6, there is on average a 0.15 PU difference in the helium (He) porosity and that used in the centrifuge calculations, likely within measurement uncertainty.

These differences can be attributed to stress (He at 800 psi vs CF at 0 psi), samples swelling when brine saturated or possibly not being fully brine saturated.

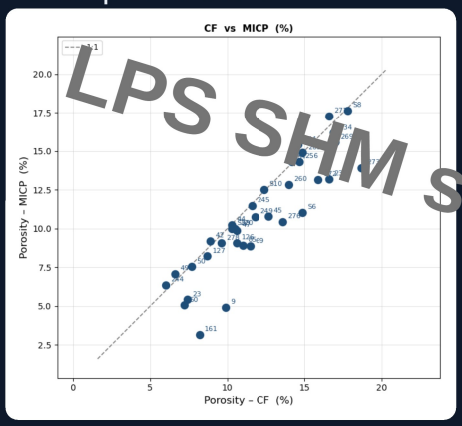
The centrifuge (CF) porosity is almost identical to the Archimedes (Arch) porosity.

Note: the CF and Arch porosities are not always identical. These small/occasional differences cannot be explained using the information in the SCAL reports. The difference is probably due to the saturated samples being reweighed just before the start of the centrifuge tests, hence the slightly different porosity.

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Porosity: MICP vs CF

Example: Torosa-6



For Torosa-6, there is on average a 1.45 PU difference in the mercury injection porosity (MICP) porosity and centrifuge calculations.

The MICP pore volume is calculated using the volume of mercury that intrudes the samples at the highest capillary pressure, for this data set, and most 'modern' MICP data, that is 60,000psi. (Even at this Pc, clay-bound micro-porosity may not be intruded).

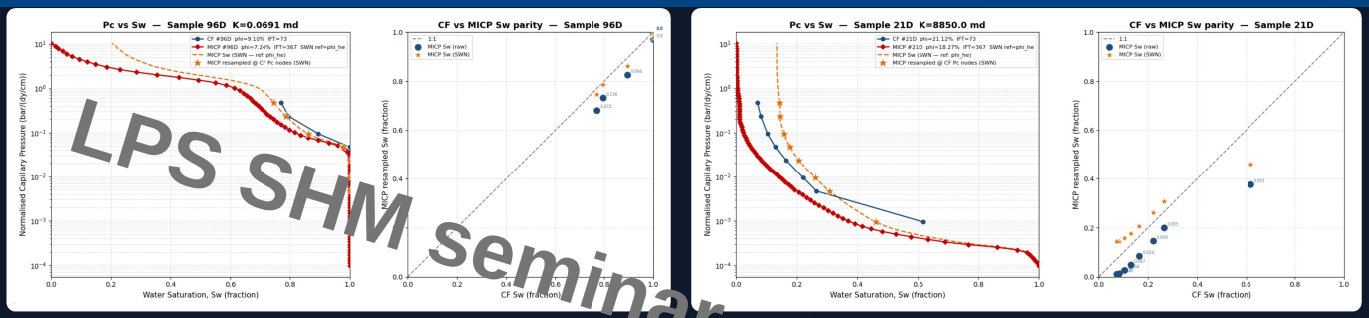
The difference may also be due to 'swelling' and 'contraction' effects due to one sample being brine saturated and one being dry (clays may be altered by cleaning and drying).

Finally, the differences could be due to heterogeneity!

PROPOSAL: we 'correct' the MICP data so that the derived Sw is 'scaled' to the CF or even the He porosity

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RED: MICP, ORANGE: MICP Porosity corrected, BLUE: CF

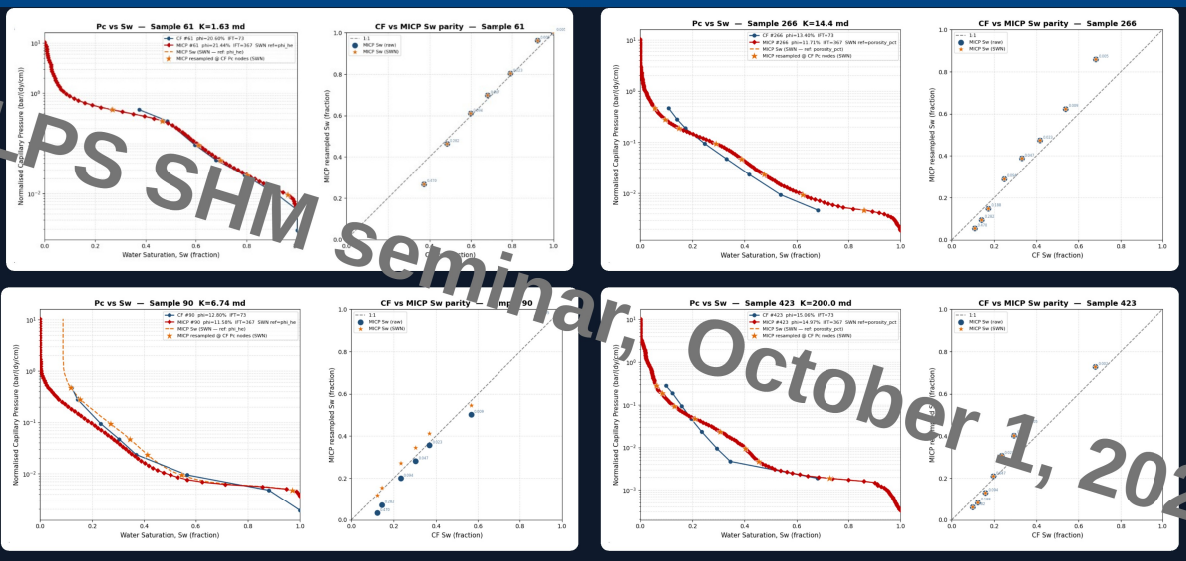


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The MICP Sw values are rescaled/normalised to the He porosity (we could also use the CF porosity).

MICP points are 'resampled' so the normalised capillary pressures match those in the **CF experiments**.

RED: MICP, ORANGE: MICP Porosity corrected, BLUE: CF



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"the SHM man" - TWIN SAMPLES AS QC TOOL IN CAPILLARY PRESSURE- LPS OCTOBER 2026

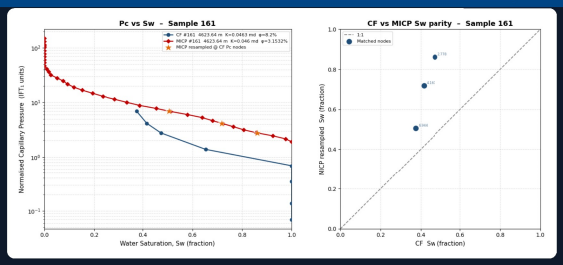
Compare CF to MICP: mapping difference

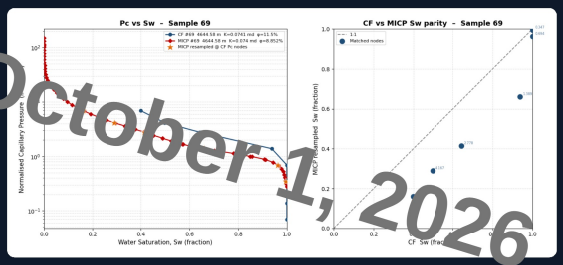
1. Pc_IFT1
2. Error calculation

```
res= sw_cf - sw_micp

rmse = np.sqrt(np.mean(res ** 2))
```

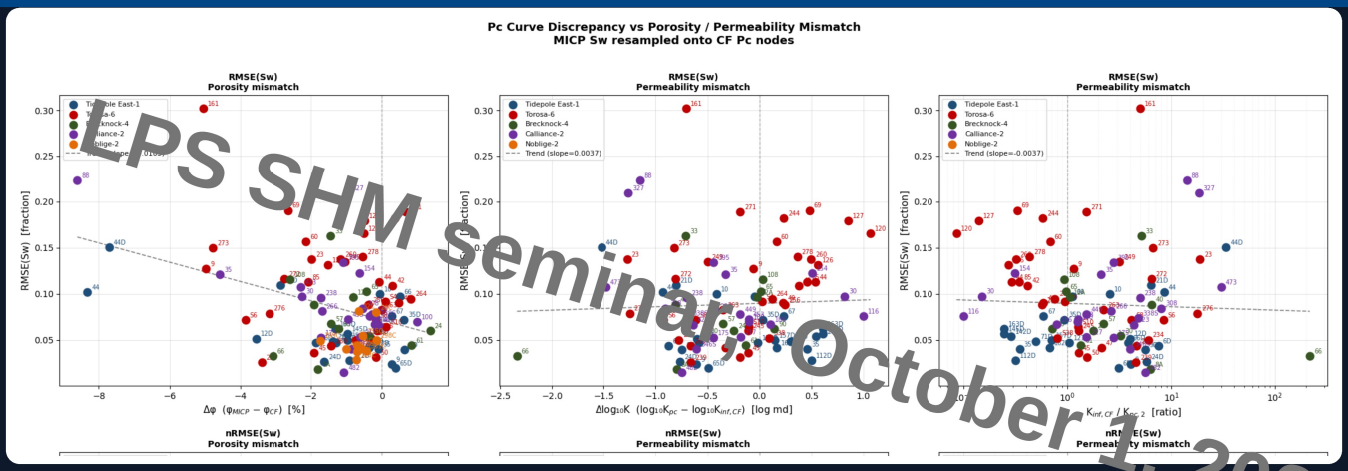
3. Porosity-permeability correlation





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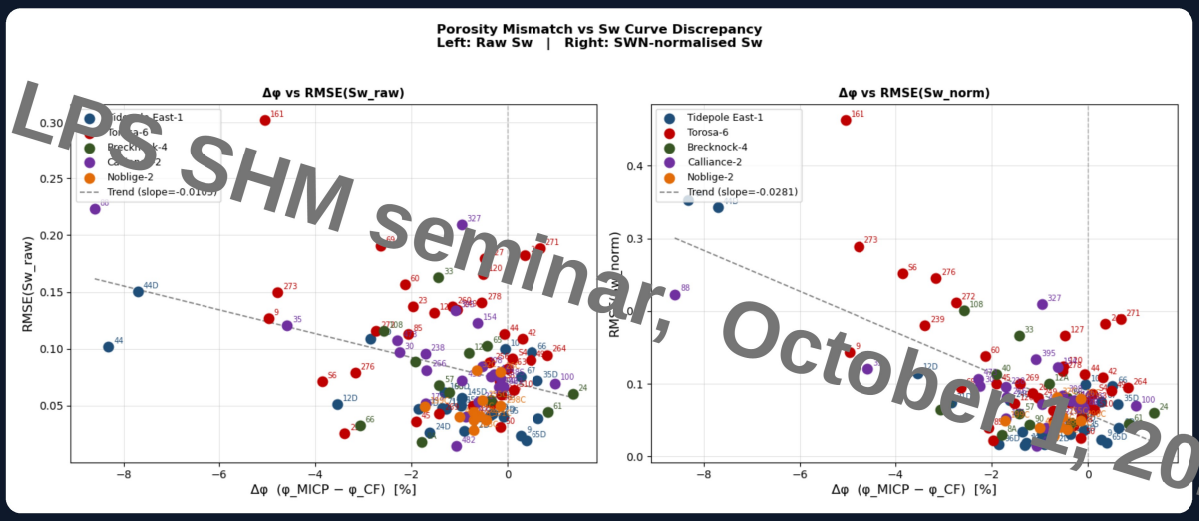
Error correlation to por/perm



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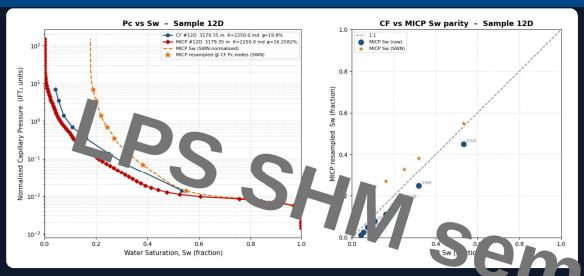
Mismatch error does not correlate with permeability

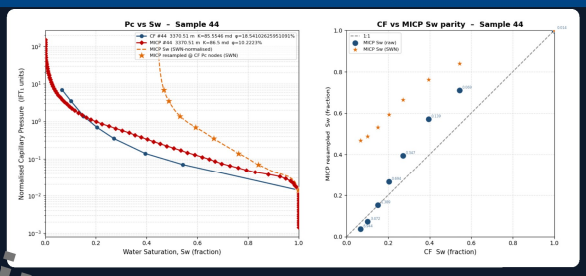
Δ porosity: best predictor of mismatch

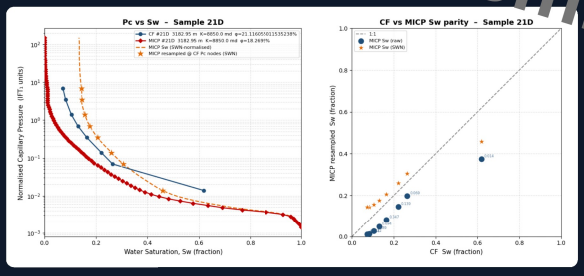


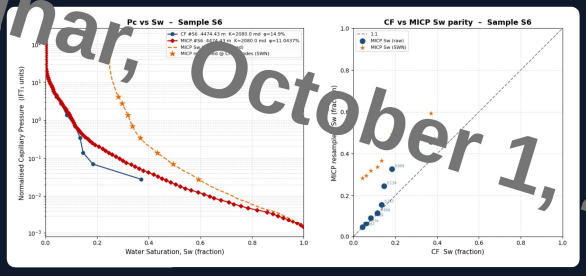
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Porosity correction does not always help









Orange: corrected

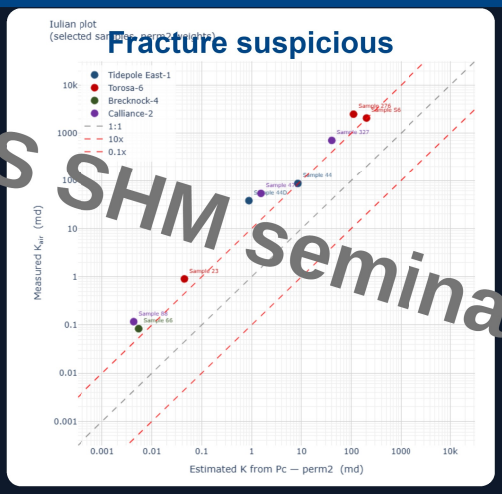
Red: original

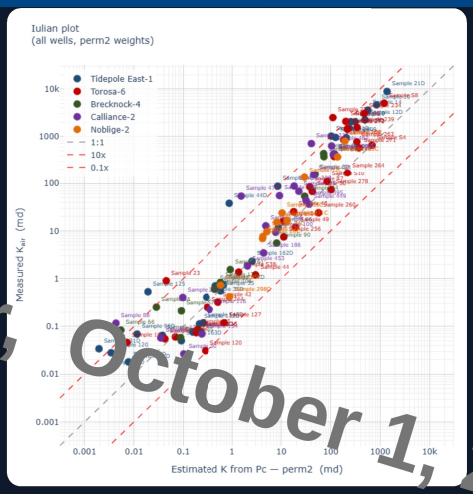
Random examples

Likely cause of misfit: trim–plug heterogeneity

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QC tools: Iulian plot



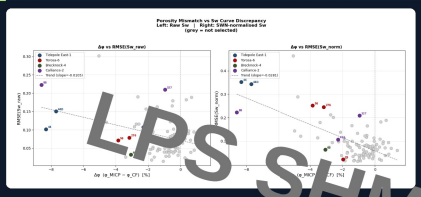


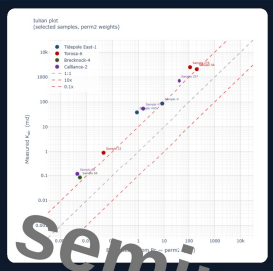
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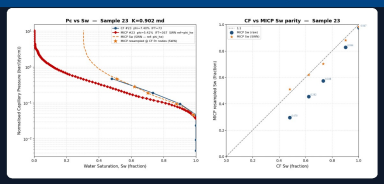
Efficient method to QC Pcs **and SHMs** vs associated permeability /models

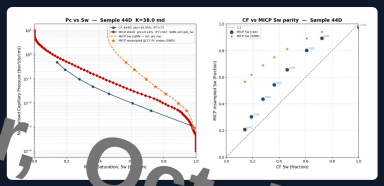
Hulea et al.,AAPG Bulletin, 96, p. 1627-1642 (2012).
Hulea et al., IPTC-18587-MS (2016).
Hulea IN, SPE-164251 (2013).

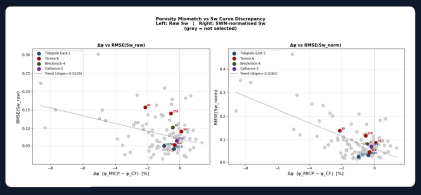
Contrast fracture suspicious vs 'default'

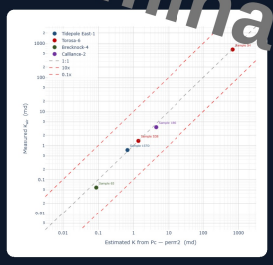


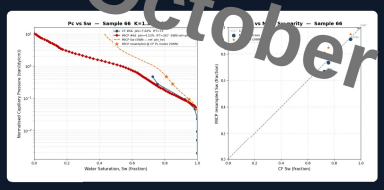








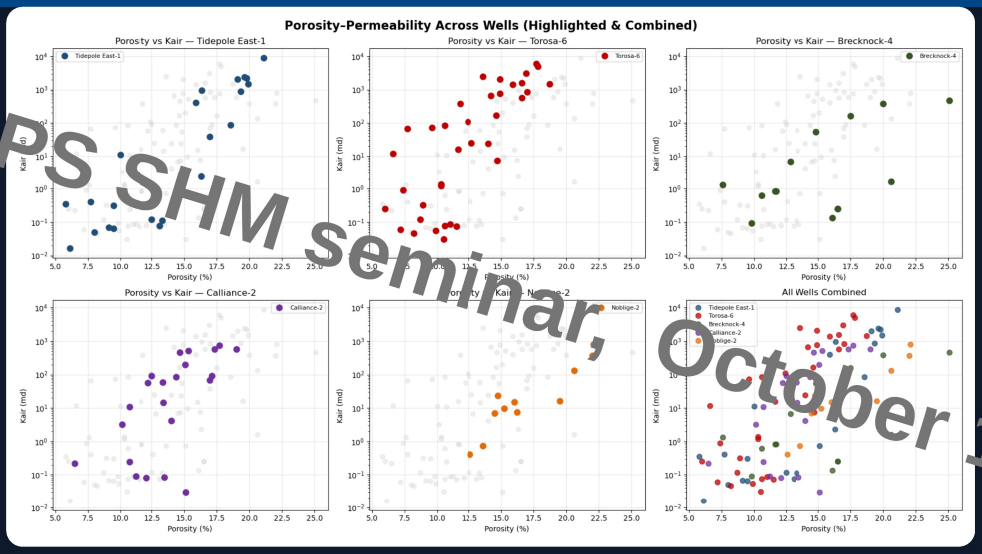




Plugs flagged as fracture-suspicious show the largest Sw errors

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Poro-perm per well: modelling



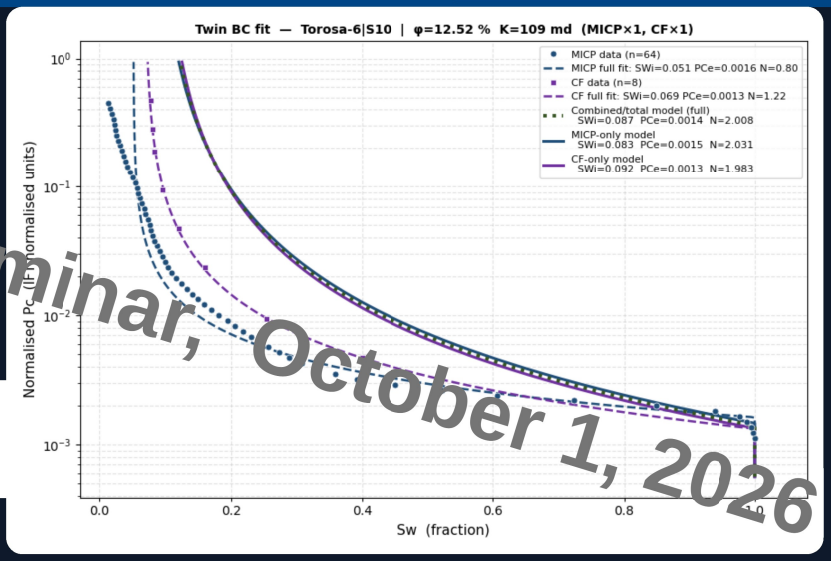
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Models as a tool for comparison

Prepare models using the same constraints on both datasets
1. MICP
2. MICP constrained to CF max Pc
3. CF

Brooks-Corey, Pc_IFT1, etc
We fit 3 params each time:

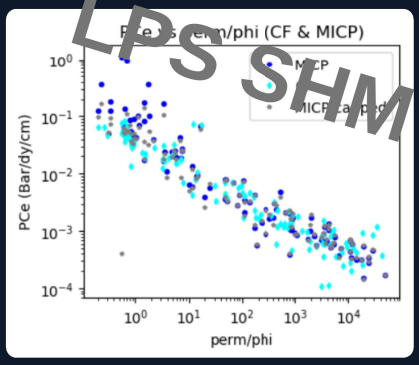
$$S_w = S_{wi} + (1 - S_{wi}) \left(\frac{P_{ce_{\mathrm{IFT1}}}}{P_{c_{\mathrm{IFT1}}}} \right)^{1/N}$$

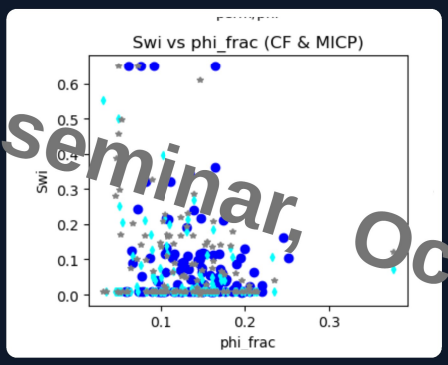


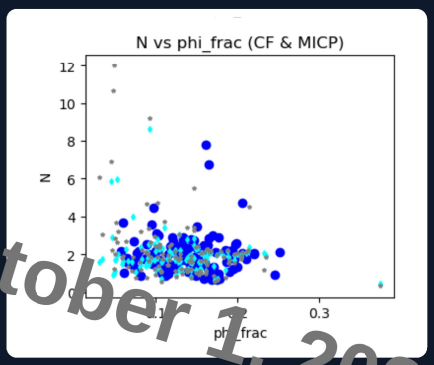
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CF / MICP models: parameter dependency

Individual parameter dependency on plug properties.



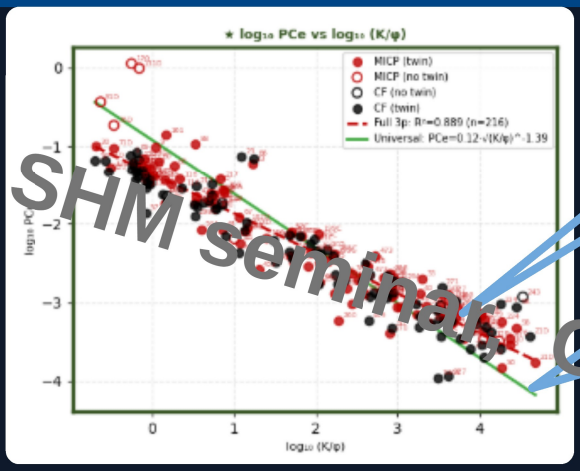




Pce to k/Phi stands out, something we already knew

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CF / MICP models: entry pressure



THIS model

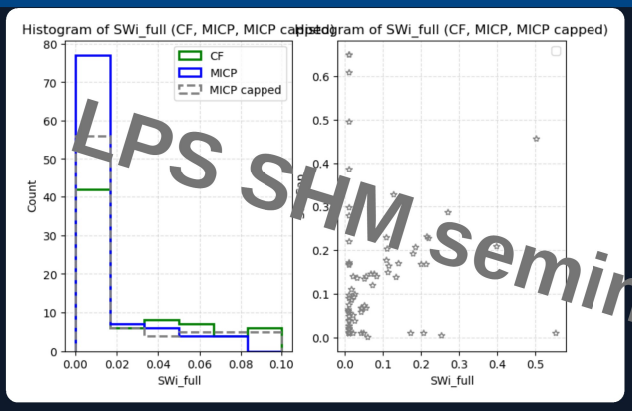
Universal model

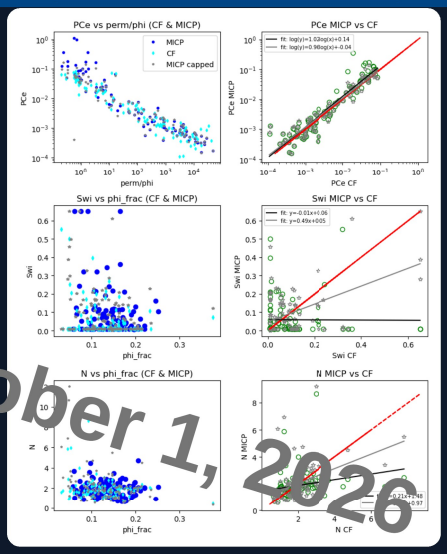
Entry pressure can be predicted

Hulea IN, SPE-193164 (2018)

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CF / MICP models: effect of Pc range

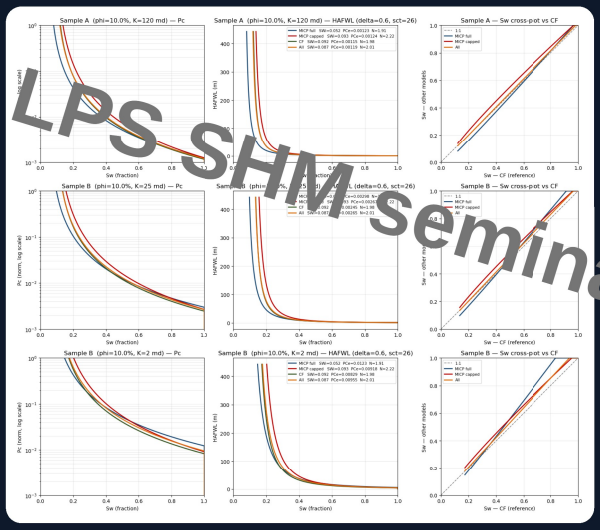




Individual parameters shift as the MICP Pc range is reduced to CF. Swi changes most: it is driven by the high-Pc MICP data, hence clip MICP to the reservoir column height.

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Models: MICP / CF / MICP reduced

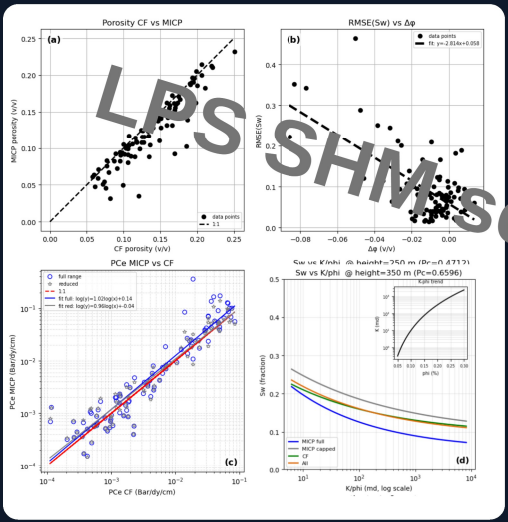


MICP uncapped stands out.

Hulea IN, SPE-193164 (2018)

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High level results



1. Clip MICP data at a maximum Pc equivalent to the maximum hydrocarbon column height in your reservoir:.
2. MICP porosity: normalise MICP Sw to He or CF pore volume.
3. Handle reported porosity with care: read the lab SCAL report thoroughly (stress, cleaning and drying conditions).
4. The MICP–Archimedes porosity difference is a good proxy for whether trim and plug are true twins (threshold ≈ 2 PU).
5. Plugs flagged as fracture-suspicious show the largest Sw errors.
6. Using the same constraints, comparable models are obtained regardless of the dataset used (multimodal samples not treated separately).

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Path forward

We are still looking for other fluid combinations twins (oil/brine vs MICP).

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