NMR-MICP Integration & Permeability Estimation: A New Free Petrophysics Software

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Outline

- Background Theory
- Motivation & Goals
- Main software features
- Conclusions and considerations for the future

NMIP

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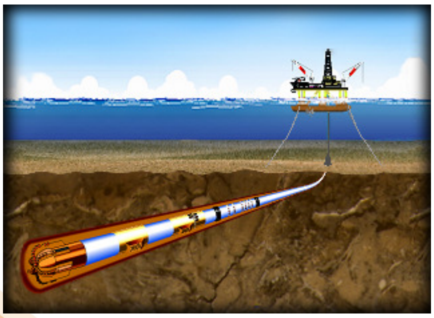
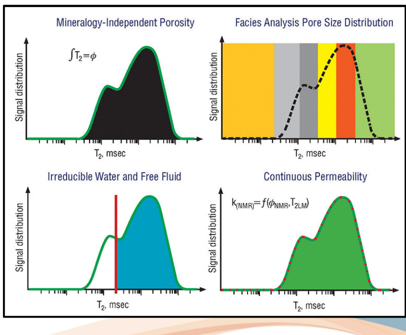
NMR in Formation Evaluation

Provides a single measurement (T2 distribution), can be used to estimate porosity (ϕ), pore size distribution (PSD), irreducible water saturation (SWI) and Permeability (k) of formations

(1)



(2)



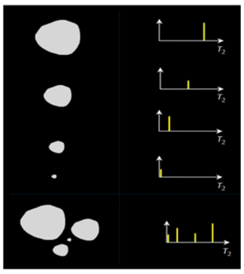
(1) http://accutech.metadot.com/index.pl?r=1

(2) www.spe.org/jpt/article/10327-technology-update-24

NMR Petrophysics

$$\frac{1}{T_2} = \frac{1}{T_{2surface}} = \rho_2 \left(\frac{S}{V}\right)_{pore}$$

(3)

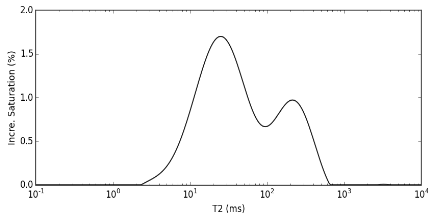


Estimating permeability (k)

$$k = a\phi^b \left(\frac{V}{S}\right)_{pore}^c \quad \& \quad \left(\frac{V}{S}\right)_{pore} = \rho_2 T_2$$

$$k_{NMR} = a\phi^b (\rho_{eff} T_{2rep})^c$$

$$k_{SDR} = a'\phi^b (T_{2logmean})^c$$

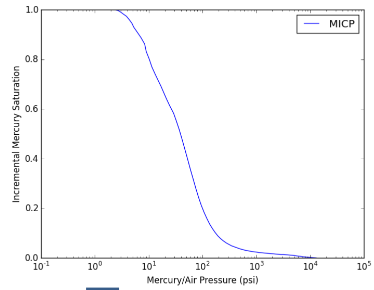


Is Surface Relaxivity ρ_2 homogeneous throughout a formation ?

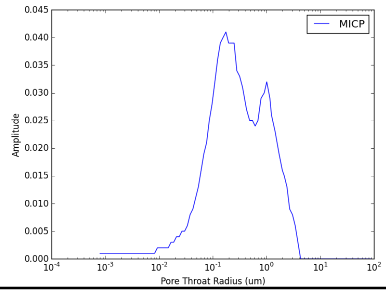
(3) From "*NMR Logging - Principles ans Applications* "

MICP

- Laboratory Experiment to obtain the Cappilary Pressure curve from rock samples, by injecting Mercury.
- The Cappilary Pressure curve can be converted to a “pore throat size” distribution.
- This distribution can be used to estimate permeability and several other types of petrophysical data.
- $K_{MICP} = a\phi^b {R_{t_{rep}}}^c$
- Can’t be used downhole.
- Destroys the sample.



$$R_t = \frac{2\sigma|cos\theta|}{P_c}$$

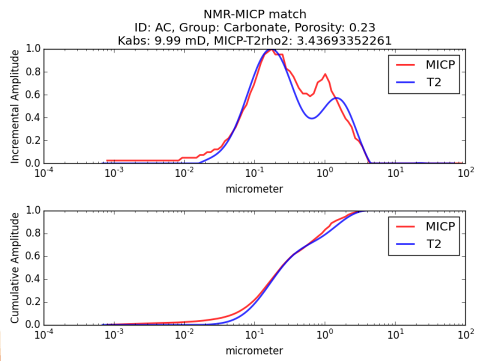


NMR-MICP Integration

MARSCHALL, D.et al: ***Method for correlating NMR relaxometry and mercury injection data***. *SCA Conference*, 9511, p. 1-12, 1995.

- Found a simple way to correlate the PTD from MICP with the pseudo-PSD from NMR.
  - $R_t = \gamma\rho_{eff}T_2$

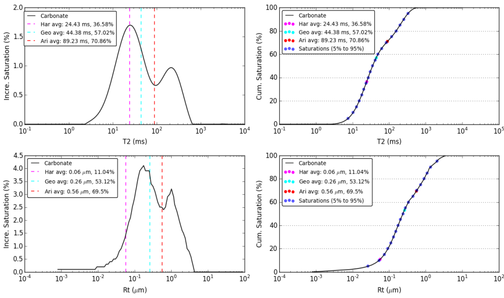
$$K_{NMR-MICP} = a\phi^b\left(\rho_{eff}T_{2_{rep}}\right)^c$$



NMR-MICP Integration

RIOS, E.H.; et al. ***NMR permeability estimators under different relaxation time selections: a laboratory study of cretaceous diagenetic chalks***. SPWLA, 55th Annual Logging Symposium, 2014

- Different metrics to obtain the **representative** value from T2 and Rt distributions.
  - $K_{NMR} = \alpha\phi^b T_{2_{rep}}{}^c$
  - $K_{MICP} = \alpha\phi^b R_{t_{rep}}{}^c$



- Sized-Scaled estimators – Simple match between MICP (PTD) and NMR (PDS).
  - $s_{Hg_{rep}} = \frac{R_{t_{rep}}}{T_{2_{rep}}}$
  - $K_{S_{Hg}} = \alpha\phi^b \left(s_{Hg_{rep}} T_{2_{rep}}\right)^c$

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Motivation

Which is best?

And why?

N *core/log* entries with:

- N *porosities*
- N *permeabilities*
- N T_2 *distributions*
- N Rt *distributions*
  - $2N *$ *3 pythagorian means*
  - $2N *$ *19 cutoffs (5% to 95%)*
    - N * *484 sHgs matches*
  - N *NMR-MICP* $\rho_{1,2_{eff}}$
    - *different pore shapes* (γ)

$K_{NMR} = a'\phi^b (T_{2_{rep}})^c$

$K_{MICP} = a\phi^b (R_{t_{rep}})^c$

$K_{S_{HG_{rep}}} = a\phi^b (S_{HG_{rep}} T_{2_{rep}})^c$

$K_{NMR-MICP} = a\phi^b (\rho_{2_{eff}} T_{2_{rep}})^c$

Different a,b,c:
- Constant
- Constrained
- Unconstrained

Then Calculate:
- R^2
- Standard Error

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Goal

- Handle big datasets RCA and SCAL data or log.
- Automate calculations of all required parameters (means, cutoffs and ρ values) from NMR and MICP distributions.
- Enable fast evaluation of these permeability estimators.
- Facilitate the interpretation of results and comparison with the others models.

Speed-up the process for studying and evaluating these permeability estimators.

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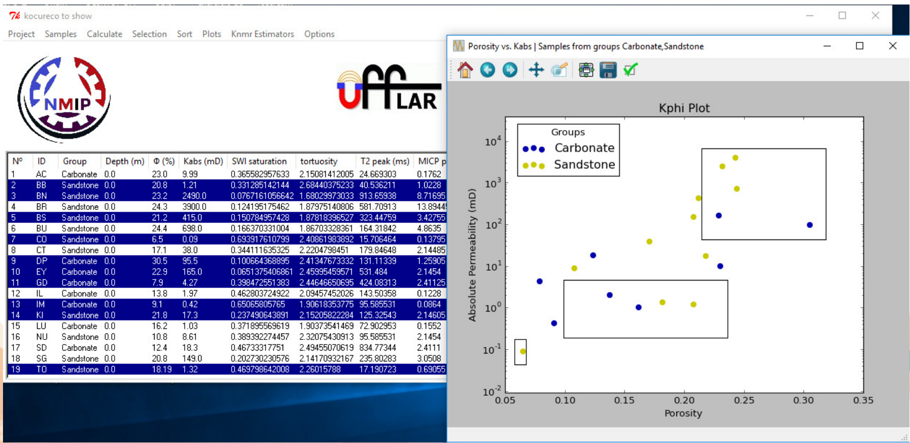
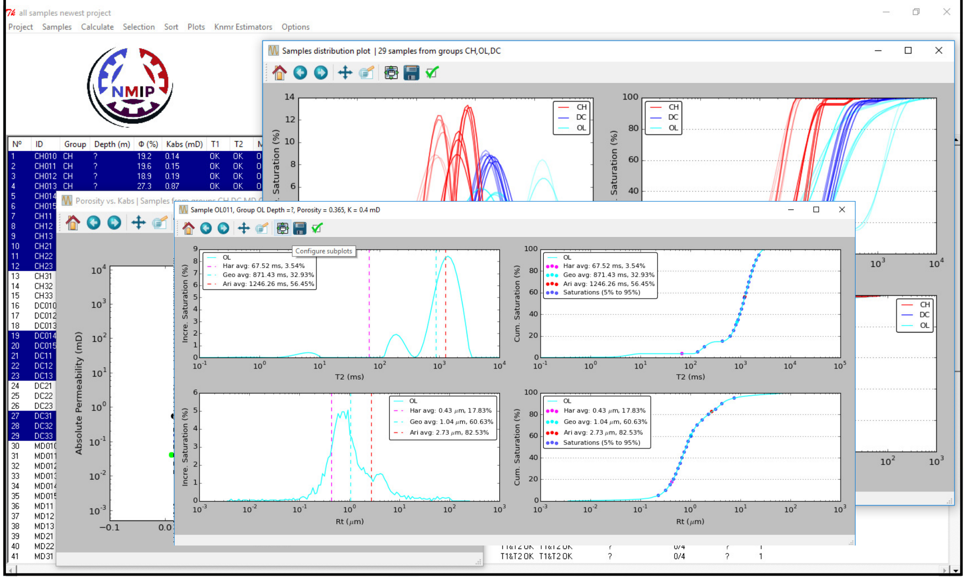
1- Sample Management

- Samples' Table for selecting subsets of data
- Interactive Cross-Plots
- Use the "**Group**" to segregate different formations, etc...



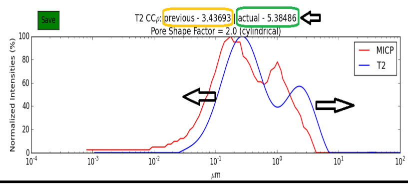
Nº	ID	Group	Depth (m)	Φ (%)	Kabs (mD)	SWI saturation	tortuosity	T2 peak (ms)	MICP p
1	AC	Carbonate	0.0	23.0	9.99	0.365582957633	2.15081412005	24.669303	0.1762
2	BB	Sandstone	0.0	20.8	1.21	0.331285142144	2.68440375233	40.536211	1.0228
3	BN	Sandstone	0.0	23.2	2490.0	0.0767161056642	1.68029973033	913.65938	8.71695
4	BR	Sandstone	0.0	24.3	3900.0	0.124195175462	1.87975140806	581.70913	13.8944
5	BS	Sandstone	0.0	21.2	415.0	0.150784957428	1.87818396527	323.44759	3.42755
6	BU	Sandstone	0.0	24.4	698.0	0.166370331004	1.86703328361	164.31842	4.8635
7	CO	Sandstone	0.0	6.5	0.09	0.693917610799	2.40861983892	15.706464	0.13795
8	CT	Sandstone	0.0	17.1	38.0	0.344111635325	2.2204798451	179.84648	2.14485
9	DP	Carbonate	0.0	30.5	95.5	0.100664368895	2.41347673332	131.11339	1.25905
10	EY	Carbonate	0.0	22.9	165.0	0.0651375406861	2.45995459571	531.484	2.1454
11	GD	Carbonate	0.0	7.9	4.27	0.398472551383	2.44646650695	424.08313	2.41125
12	IL	Carbonate	0.0	13.8	1.97	0.462803724922	2.09457452026	143.50358	0.1228
13	IM	Carbonate	0.0	9.1	0.42	0.65065805765	1.90618353775	95.585531	0.0864
14	KI	Sandstone	0.0	21.8	17.3	0.237490643891	2.15205822284	125.32543	2.14605
15	LU	Carbonate	0.0	16.2	1.03	0.371895569619	1.90373541469	72.902953	0.1552
16	NU	Sandstone	0.0	10.8	8.61	0.389392274457	2.32075430913	95.585531	2.1454
17	SD	Carbonate	0.0	12.4	18.3	0.46733317751	2.49455070619	834.77344	2.4111
18	SG	Sandstone	0.0	20.8	149.0	0.202730230576	2.14170932167	235.80283	3.0508
19	TO	Sandstone	0.0	18.19	1.32	0.469798642008	2.26015788	17.190723	0.69055

1- Sample Management

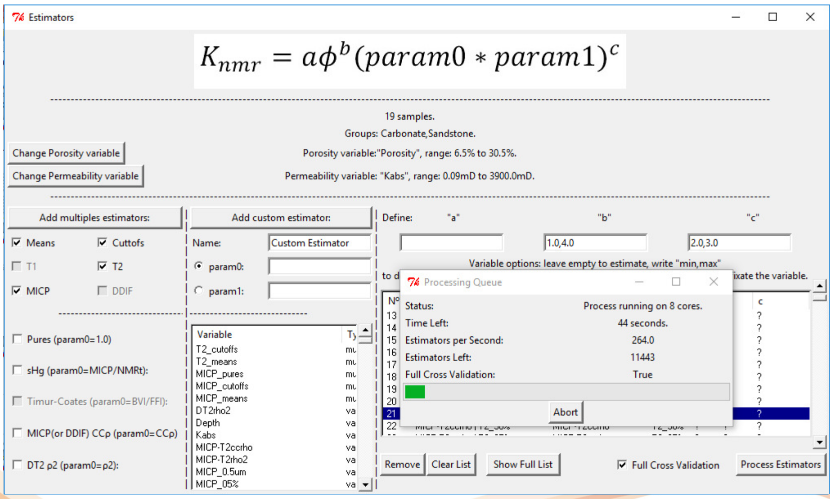


2- Automation

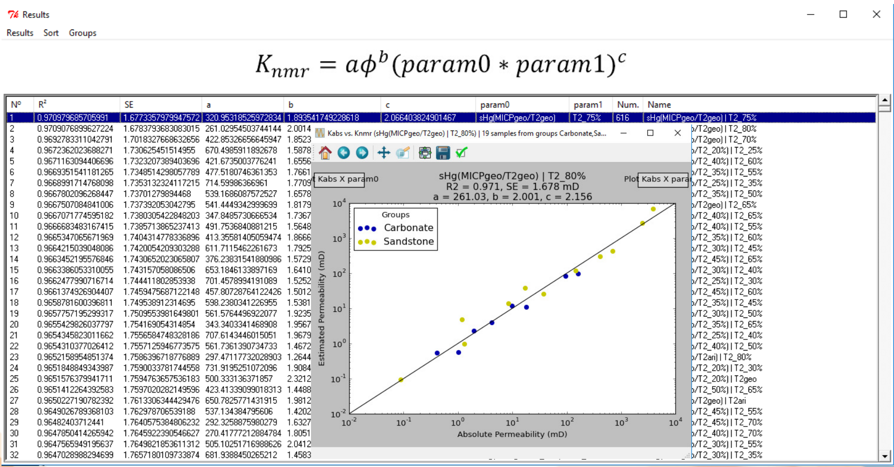
- NMIP imports all input data from Excel spreadsheets:
  - NMR T2 distributions
  - MICP Rt distributions
  - Routine Core Analysis (porosity, absolute permeability, etc...)
  - Any other petrophysical input.
- NMIP automatically tries to calculate:
  - All Pythagorian means (harmonic, geometric or “logarithmic”, arithmetic).
  - Saturations cutoffs from 5% to 95%, with a 5% step
  - sHg matches with all possible combinations
  - NMR-MICP direct matching (Cross-Correlation)
- Create arbitrary cutoffs from NMR or MICP data.
- Run Custom Python Scripts.
- Possibility to edit the NMR-MICP match.



3- Permeability ESTIMATION



4- Results

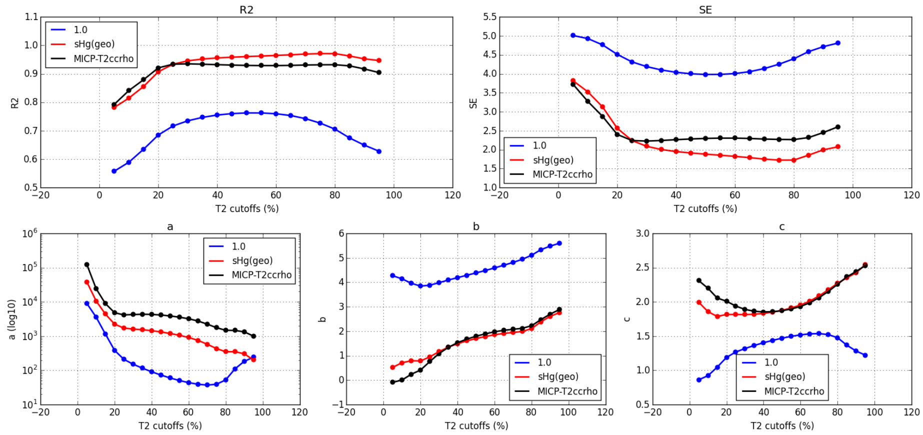


4- Results

$$k_{NMR} = a\phi^b(1.0 * T_{2\,cutoffs})^c$$

$$k_{NMR-MICP} = a\phi^b(\rho_{eff} * T_{2\,cutoffs})^c$$

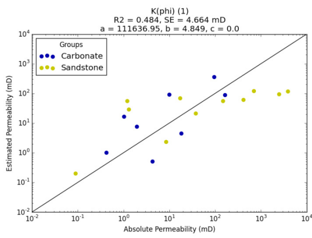
$$k_{S_{Hg\,geo}} = a\phi^b(S_{Hg\,geo} * T_{2\,cutoffs})^c$$



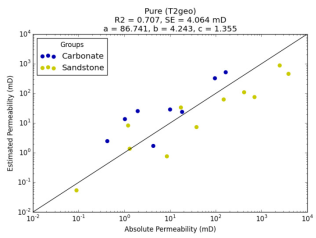
K estimation improved

Classical *k* estimations

$$K_{\phi} = a\phi^b$$

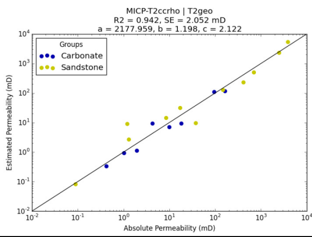


$$K_{SDR} = a'\phi^b(T_{1,2\,log})^c$$

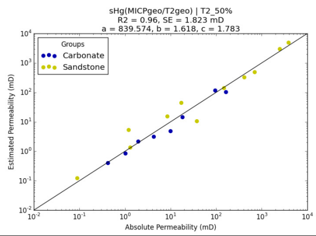


NMR-MICP estimations

$$K_{NMR} = a\phi^b(\rho_{2\,(T_2\&R_t)}T_{1,2\,log})^c$$



$$K_{S_{HG\,rep}} = a\phi^b(S_{HG\,log}T_{1,2\,50\%})^c$$



Conclusions

- Success in accomplishing our goals.
- Positive feedback from pilot users.
- Project is open for ideas and suggestions.
- UFFLAR will register it as a free software.

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Acknowledgments

- **UFFLAR - UFF**
- **BG**
- **SCHLUMBERGER**
- **ANP**
- **RIO OIL AND GAS**

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Thank you!

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NMIP characteristics

- Written in python 2.7, using the default GUI API "Tkinter"
- Uses some of python's free scientific modules:
  - Numpy – for fast numerical calculations.
  - Scipy – collection of mathematical algorithms (interpolation, minimization)
  - Matplotlib – for creating interactive plot figures.
- Imports and exports core data using excel files (convenient).
  - Modules: xlsxwriter, xlrd and xlwt
- Online license verification is required on startup (although, the software is completly free).
- Only works on Windows (for now).

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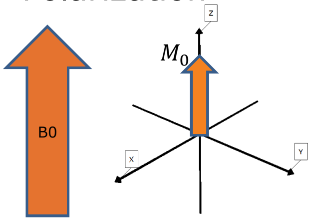
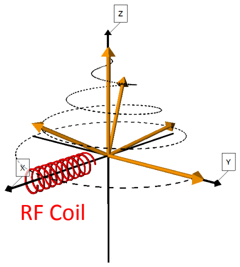
NMR physics in 4 steps

Polarization

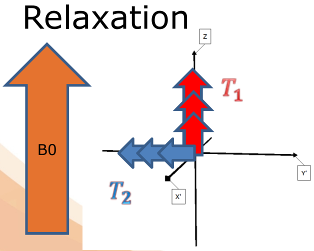


RF Pulse

Excitation

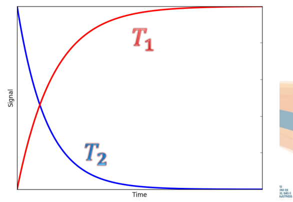


Relaxation



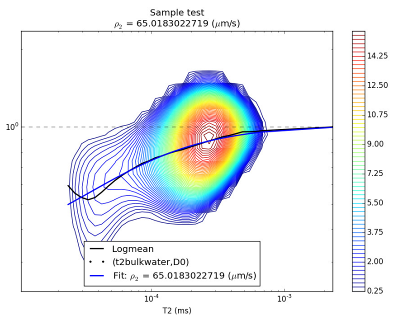
Signal

Detection



ρ_2 from DT2 maps

- Extraction of the surface relaxivity ρ_2 from Diffusion T2 maps, by fitting a model to the logmean of a DT2 Map.



$$K_{NMR} = \alpha' \phi^b \left(\rho_{1,2} T_{2_{rep}}\right)^c$$

PERMEABILITY PREDICTION IMPROVEMENT USING 2D NMR DIFFUSION-T_2 MAPS

Andre Souza[1], Giovanna Carneiro[1], Lukasz Zielinski[2], Ralf Polinski[3], Lawrence Schwartz[4], Martin D. Hürlimann[4], Austin Boyd[1], Edmilson Helton Rios[5], Bernardo Coutinho Camilo dos Santos[5], Willian Andrighetto Trevizan[5], Vinicius de França Machado[5], Rodrigo Bagueira de Vasconcellos Azeredo[6]

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[2] Schlumberger Houston Formation Evaluation Center, Houston, TX, USA.
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[4] Schlumberger-Doll Research Center, Cambridge, MA, USA.
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[6] Federal Fluminense University, Niterói, RJ, Brazil.

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ABSTRACT

When estimating permeability (*k*) from NMR logs, a key assumption is that the surface relaxivity (ρ_2) parameter, which scales the relationship between transverse relaxation time (T_2) and the surface-to-volume ratio (*S/V*) of the pore system, remains constant. With this assumption, the ρ_2 parameter can be accounted for in the premultiplier of the SDR permeability equation. However, the presence of clays and/or heavy minerals in complex reservoirs can have a significant effect on ρ_2, and the permeability estimate can be significantly improved if this variation is accounted for. Recently, Zielinski and coworkers proposed a method for deriving ρ_2 from the two-dimensional (2D) diffusion-relaxation time maps, or D-T_2 maps, as an alternative to the traditional methods that rely on the matching NMR T_2 distributions and mercury porosimetry (MICP) or BET surface area measurements. This methodology is based on the fact that the translational self-diffusion coefficient (D) of a fluid saturating a porous media has its diffusional displacements restricted by collisions with the pore walls, so that D becomes a function of the pore size distribution, i.e. the T_2 distribution. In the present work we applied this novel approach for obtaining ρ_2 directly from NMR measurements and used it to improve the classical SDR permeability estimator. The equation used to estimate permeability with this new methodology was called k_ρ. We have applied this improved k estimation technique to a set of benchmark quarried rock cores, whose results have shown a significant decrease in data dispersion and in the predicted error, when compared to the classical SDR equation. The ability to acquire D-T_2 correlation maps downhole makes the new methodology presented here very promising in heterogeneous wells where previous estimators show sometimes poor correlations.

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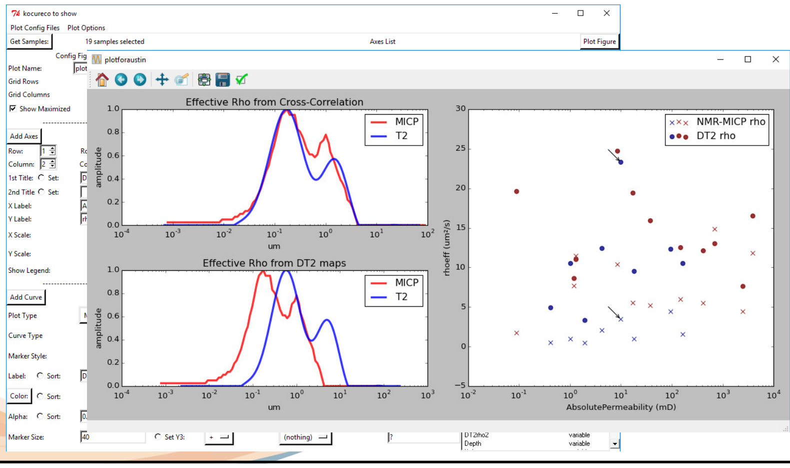
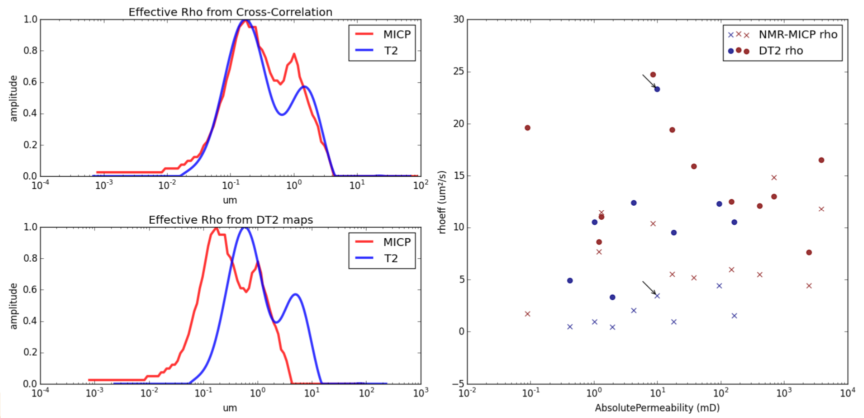
Custom Interactive Plots

- Set plot "configurations" to produce custom interactive figures with available data
- The configurations can also be stored, shared and reused.



Swap between samples



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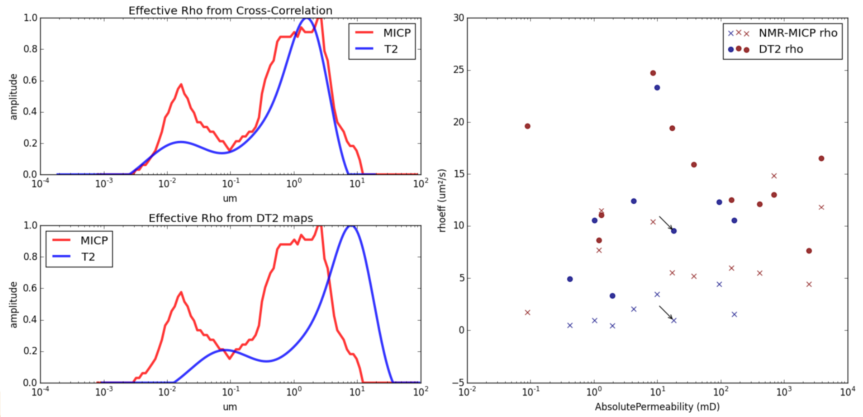
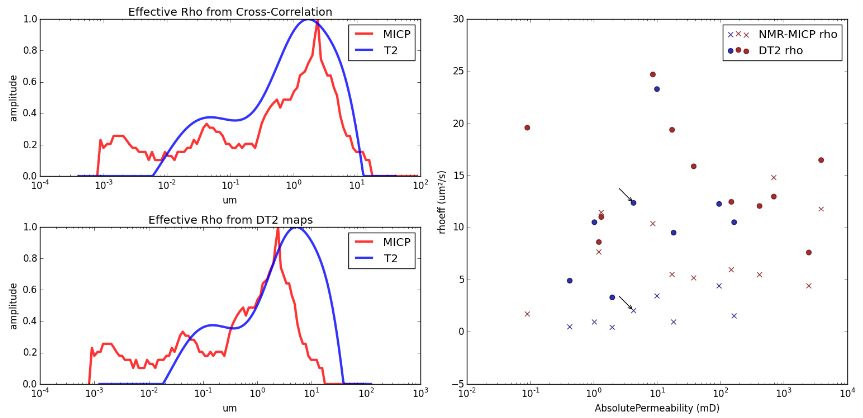
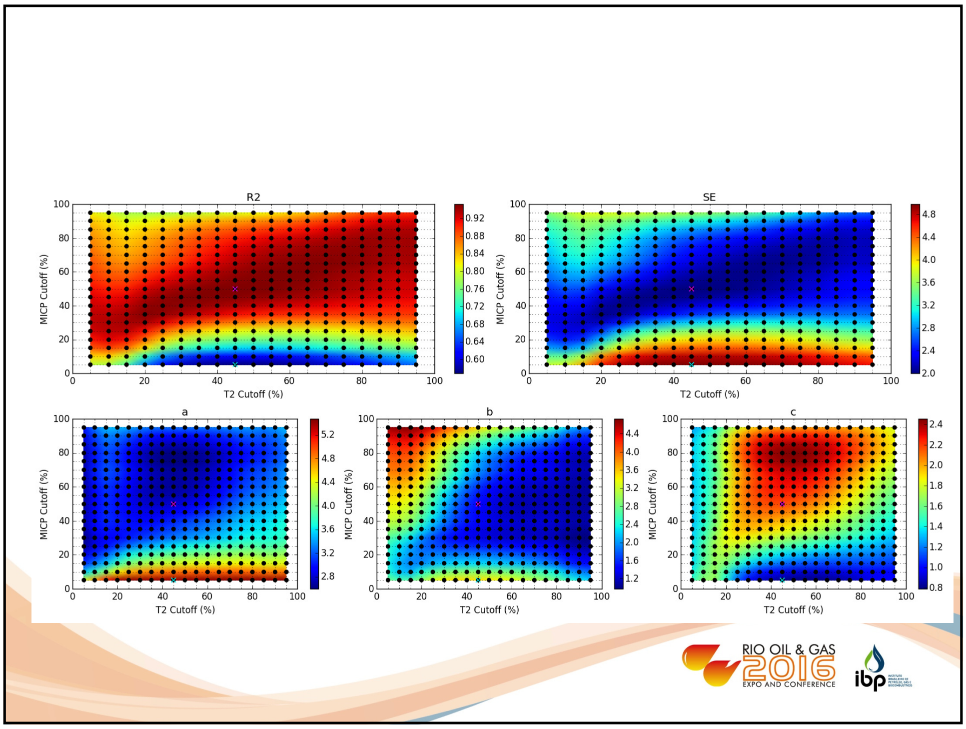
Swap between samples



Swap between samples




R2
SE
a
b
c
MICP Cutoff (%)
T2 Cutoff (%)
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