

Improve NMR estimation of water content and distribution in unsaturated bedrocks - an insight of the data quality

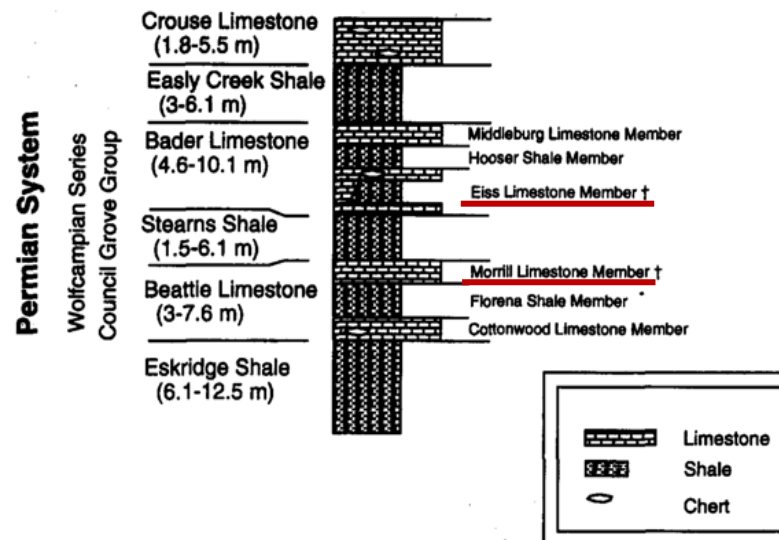
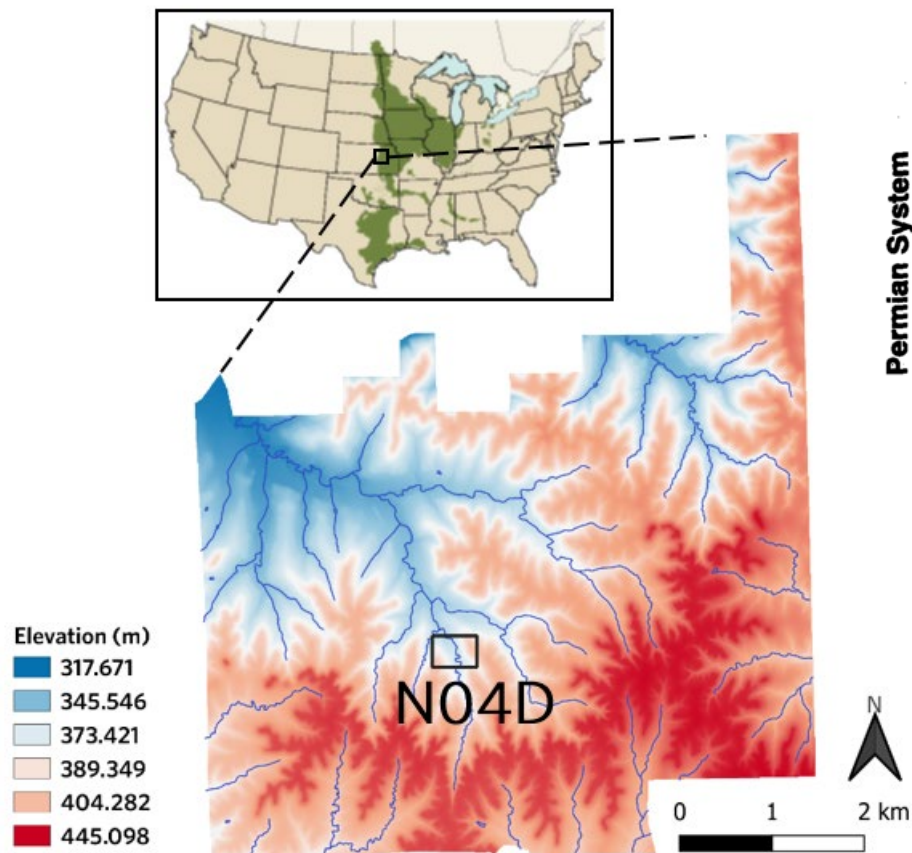
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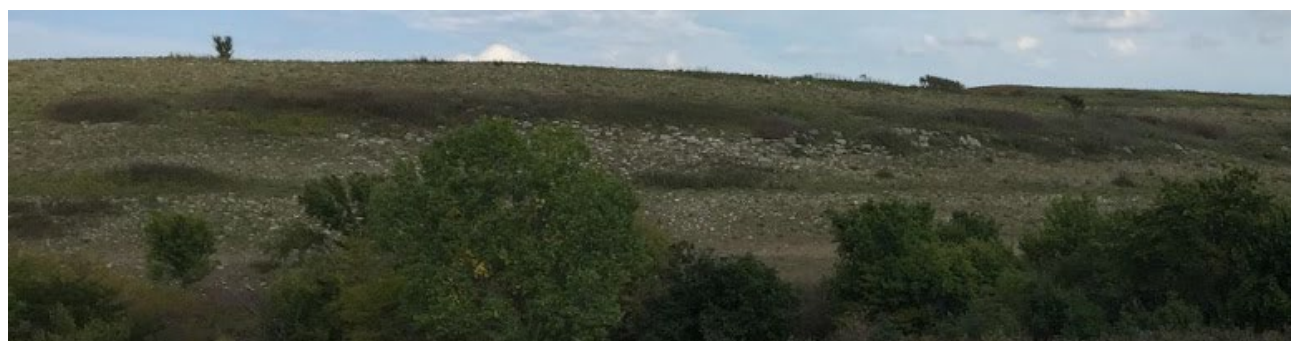
2. Institute of Meteorology and Geophysics, University of
Vienna, Vienna, Austria.

Research Site: Konza Prairie

The Konza Prairie Biological Station (KPBS) and Long-Term Ecological Research (LTER) site

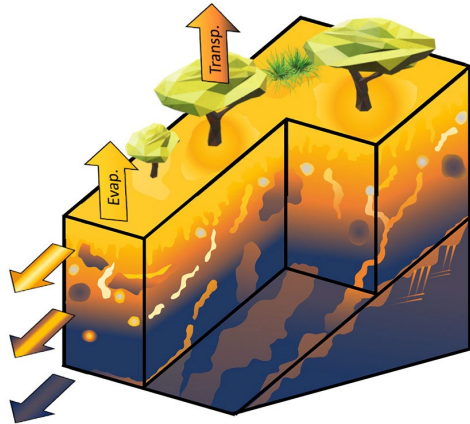


- Tall grass prairie.
- Low disturbance.
- Research infrastructure – 35 groundwater wells



Carbonate benches at the northeastern side of the Kings Creek

Advantages of NMR in critical zone



Characterizing water dynamic is the essential part of critical zone hydrology.

Water content:

Stemflow, Surface runoff, Pipe flow, Perched water table, etc..

Water distribution:

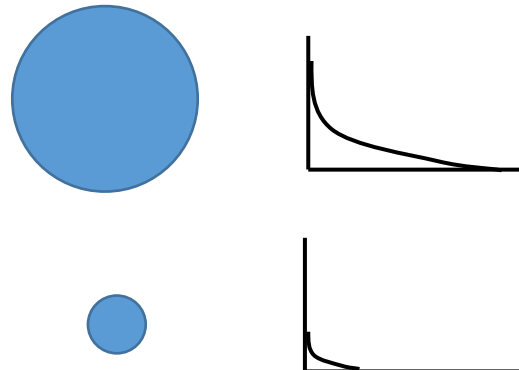
Spatial distribution: Water type and environment (gravitational water, capillary water, hygroscopic water)

Temporal distribution: Residence time

Water content

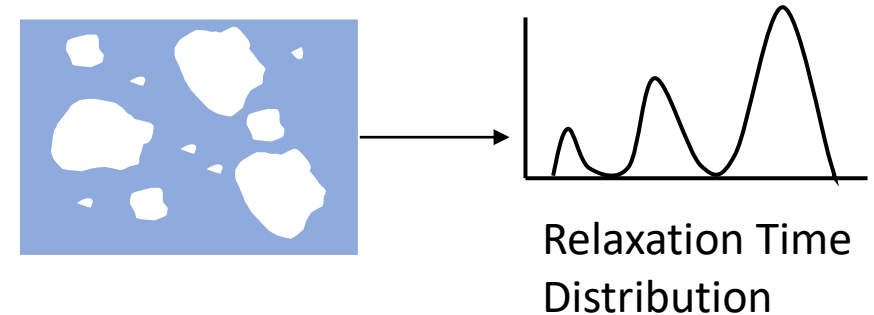
NMR signal is proportional to water content

NMR can be a direct and inexpensive tool for those purposes:

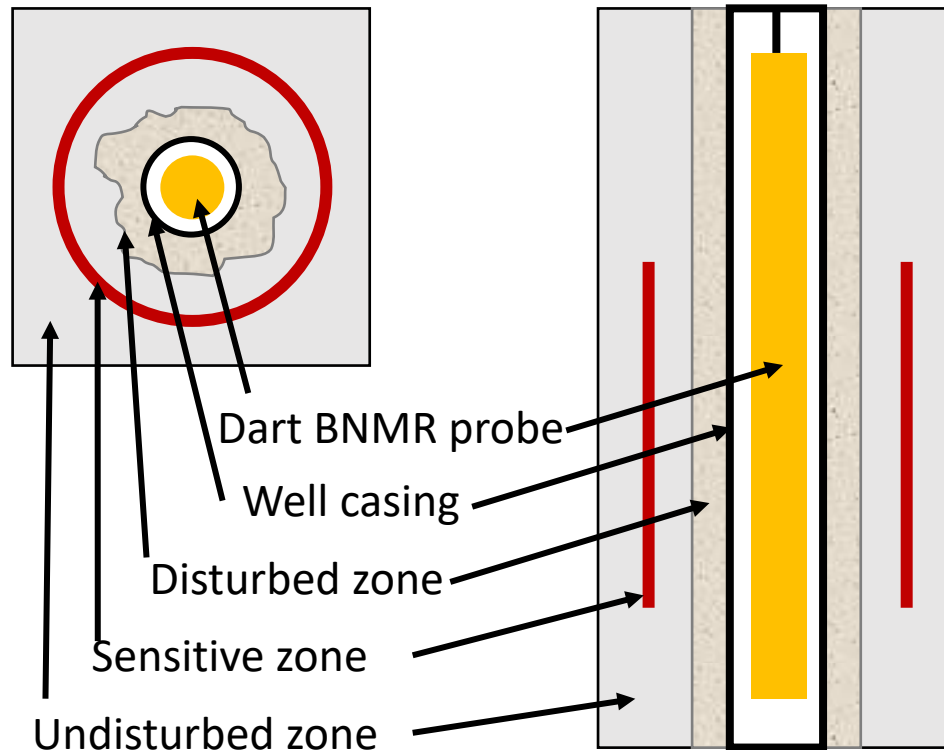


Water distribution

Relaxation spectra is related to pore size distribution



Equipment



Unclear range of disturbed zone and limited frequency range

Minimum measurement interval

Data acquisition

Limited relaxation time range:

Echo time $500\mu\text{s}$, 200 echoes, maximum 100ms

Low signal to noise ratio (SNR):

As low as single digit SNR

Data interpretation

Raw data processing:

Smoothing and trimming of data

Inversion methods:

Regularization methods and weighting of multi-modals

Objectives of this study:

- Investigate the potential errors introduced by low data quality of bNMR measurement in complex unsaturated critical zone.
- Propose a method to overcome such shortcomings and improve the interpretation of existing bNMR data

Data acquisition

Limited relaxation time range:

Echo time 500 μ s, 200 echoes, maximum 100ms

Low signal to noise ratio (SNR):

As low as single digit SNR

Data interpretation

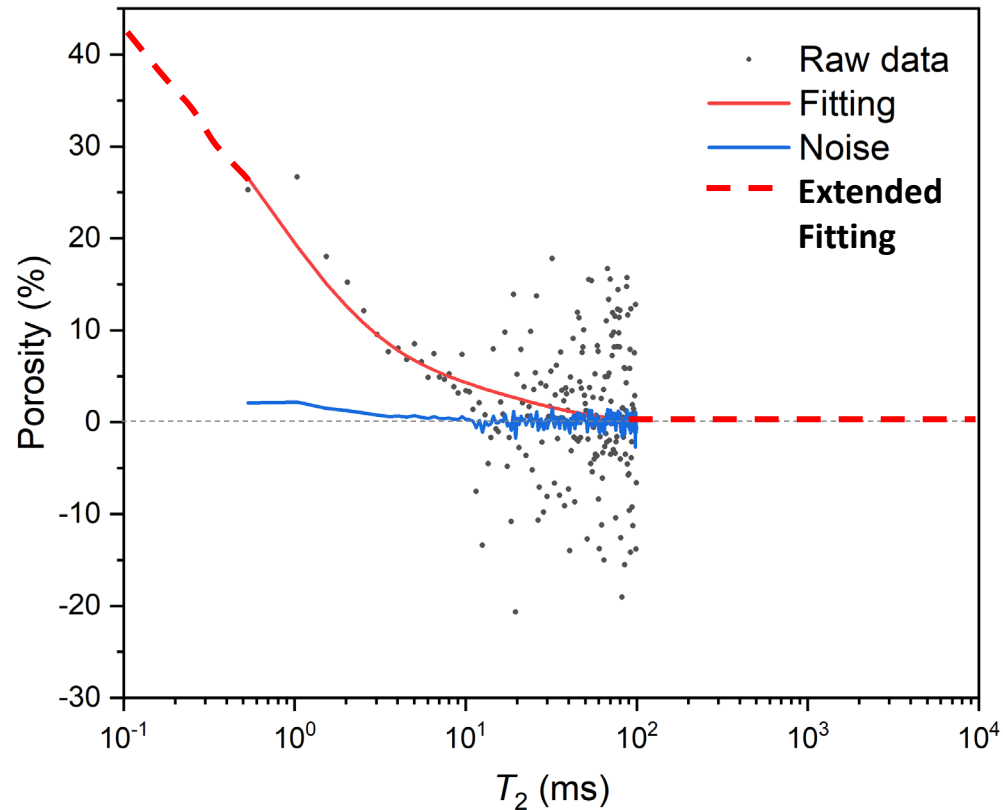
Raw data processing:

Smoothing and trimming of data

Inversion methods:

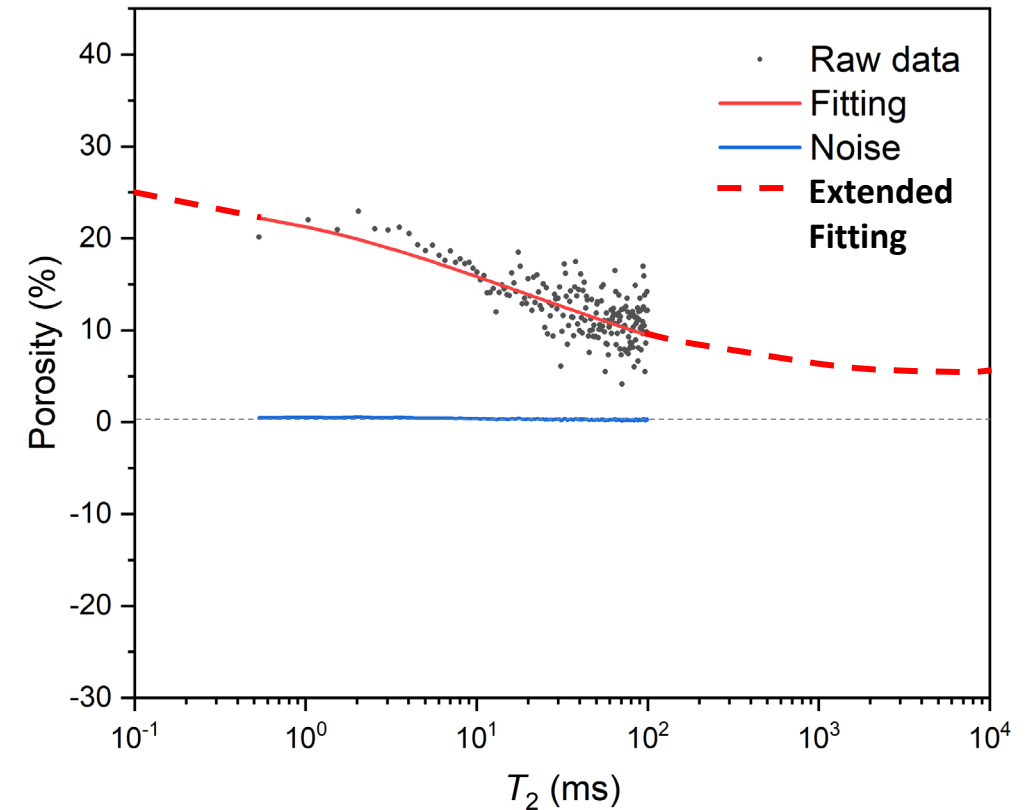
Regularization methods and weighting of multi-modals

A shale formation example



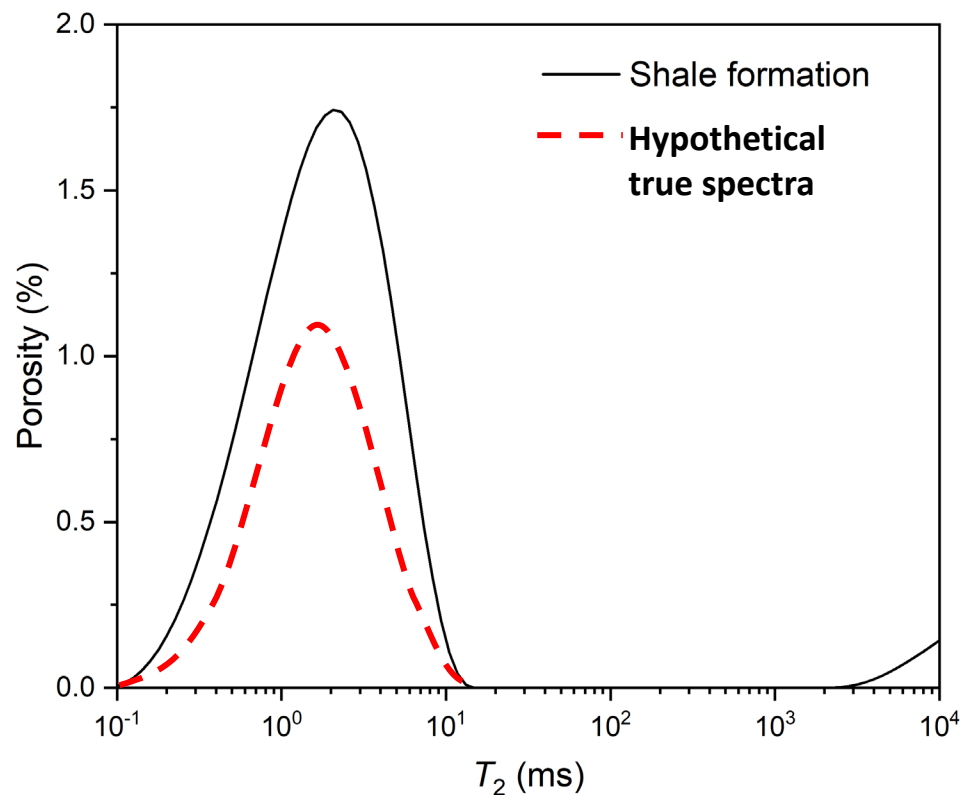
Hypothesis: Overestimation at lower T_2

A carbonate formation example



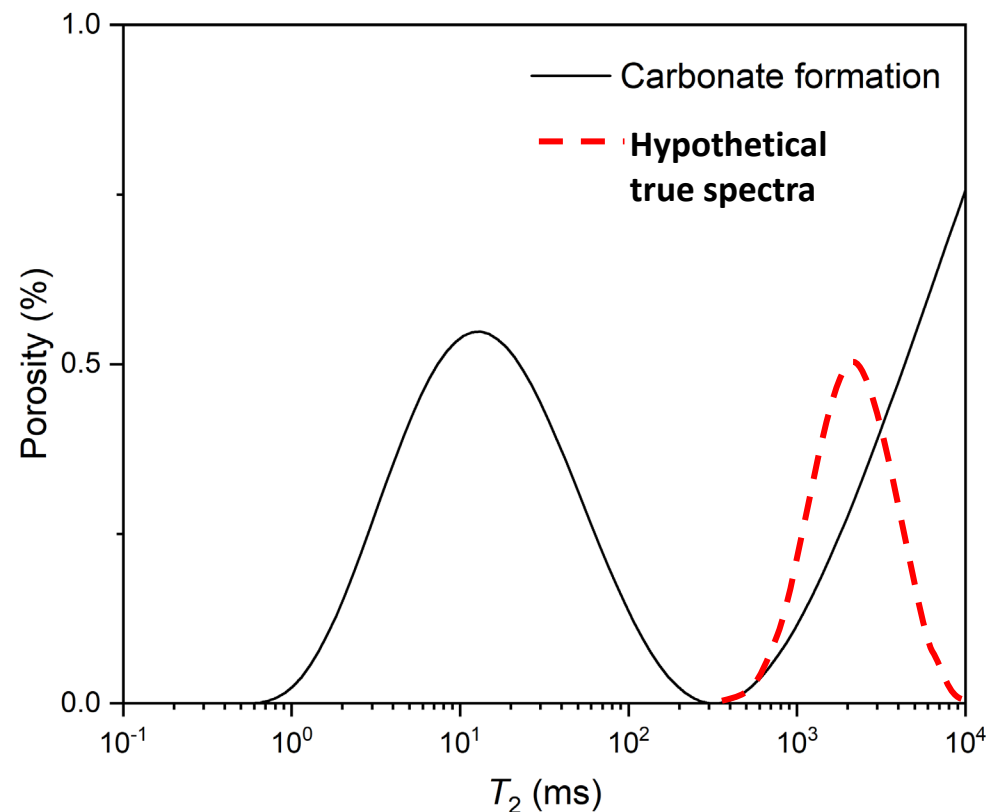
Unrelaxed high T_2 tail

A shale formation example



Hypothesis: Overestimation at lower T_2

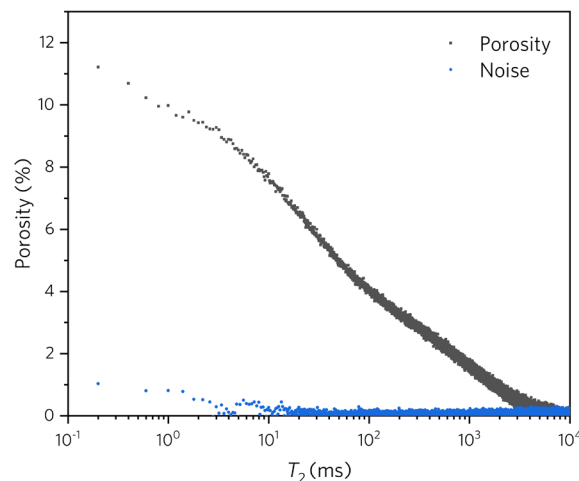
A carbonate formation example



Unrelaxed high T_2 tail

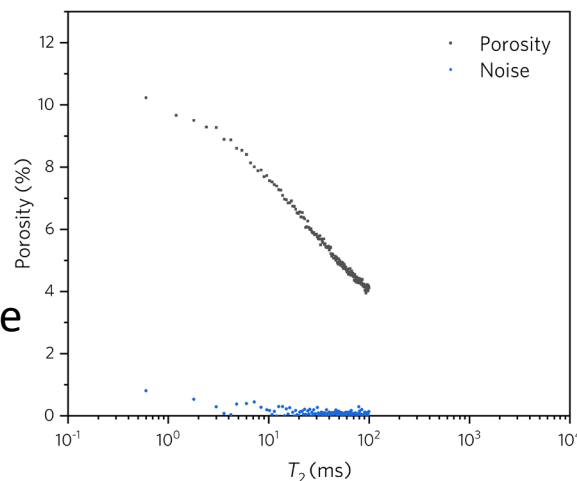
Workflow of synthetic study

Raw data



Trim
Down sample

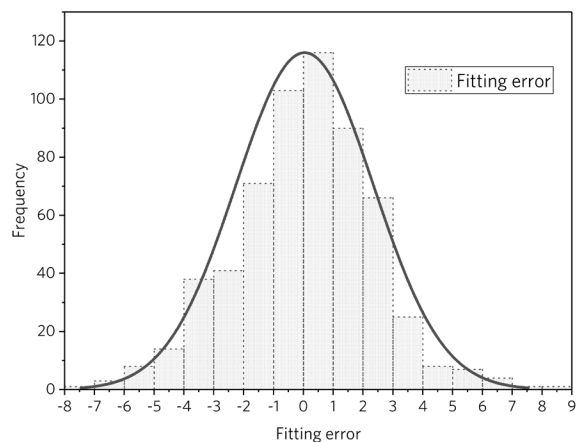
Synthetic decay 1



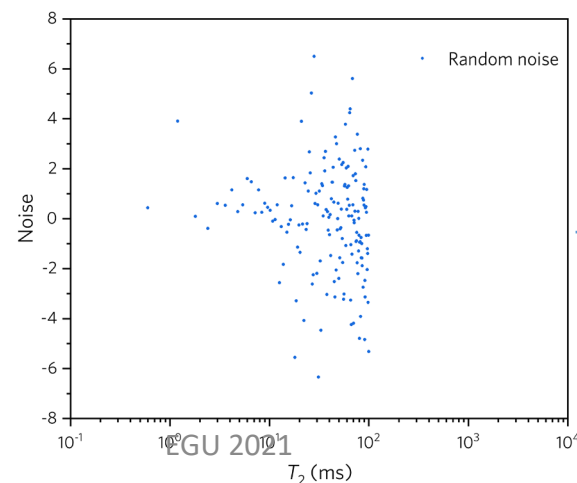
Inversion

Synthetic decay 2

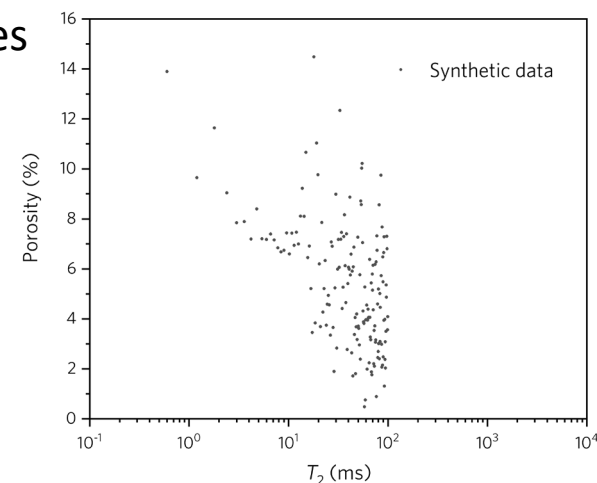
Fitting error from bNMR



Generate
random
noise
1000x



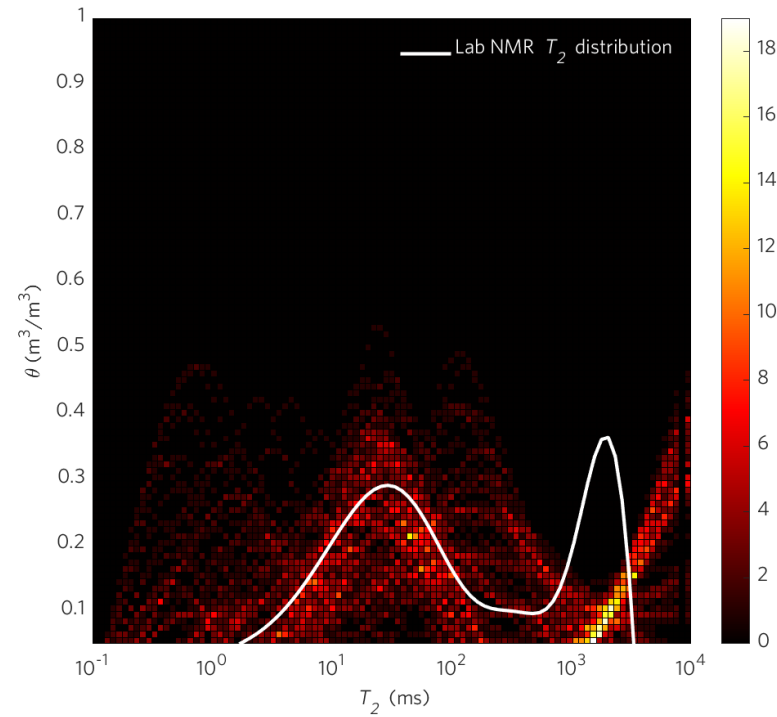
Add noises
to the
modified
data
1000x



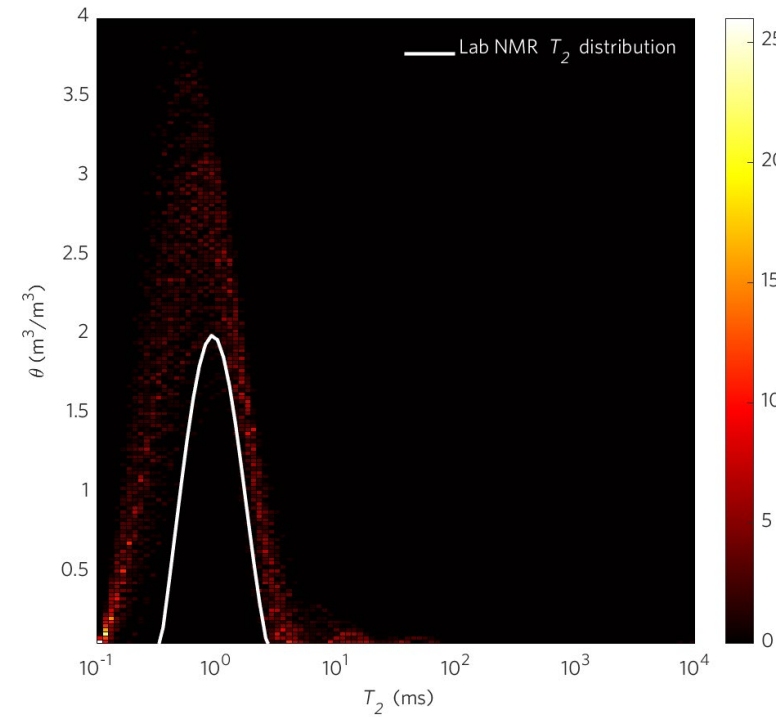
9

Carbonate

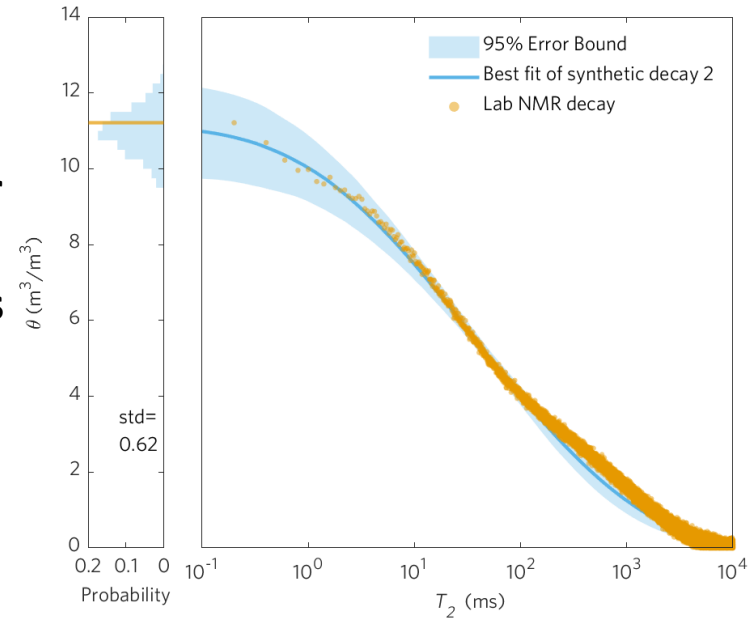
T_2 distribution



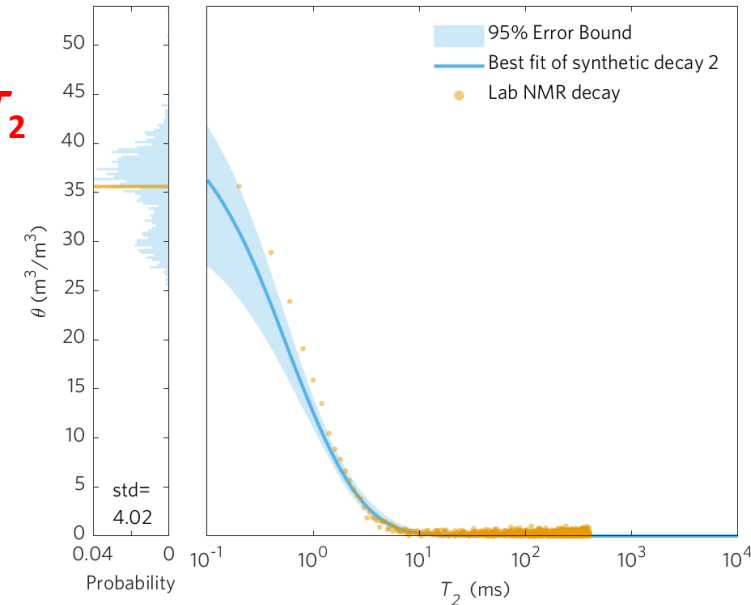
Shale



Volumetric water
content(VMC)
And fitted decays



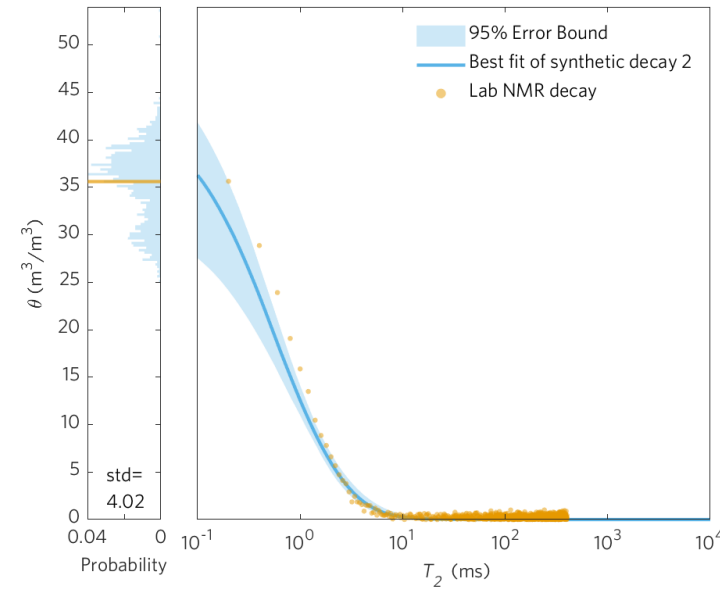
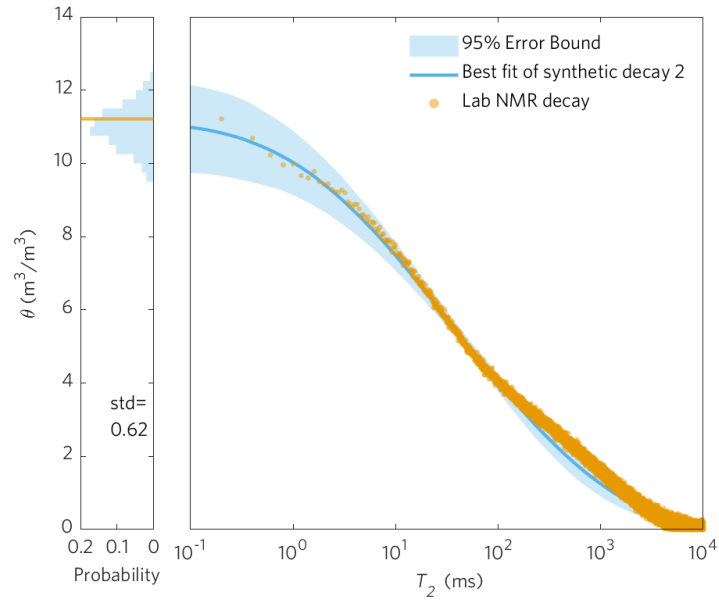
- Poor recovery at high T_2
- VMC uncertainty is higher when low T_2 dominate



Carbonate

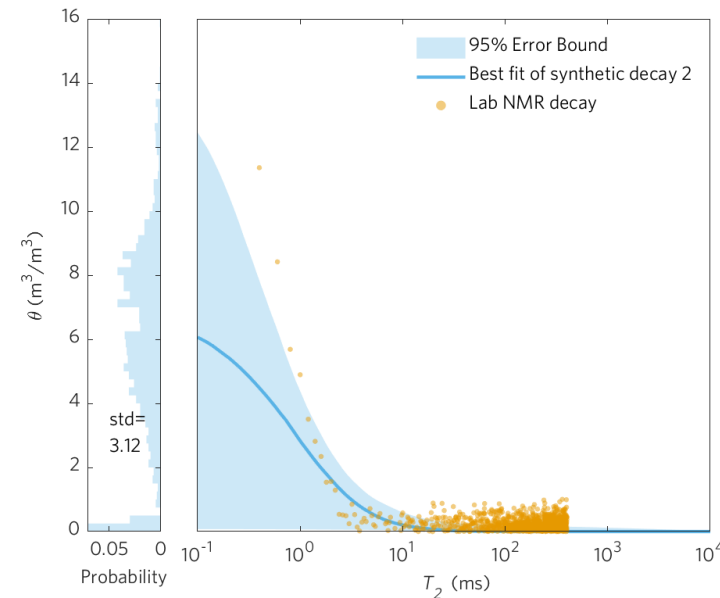
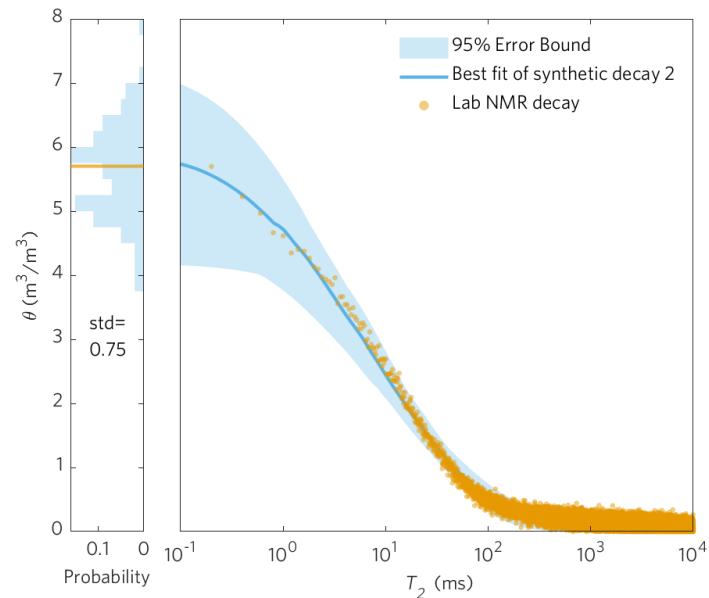
Shale

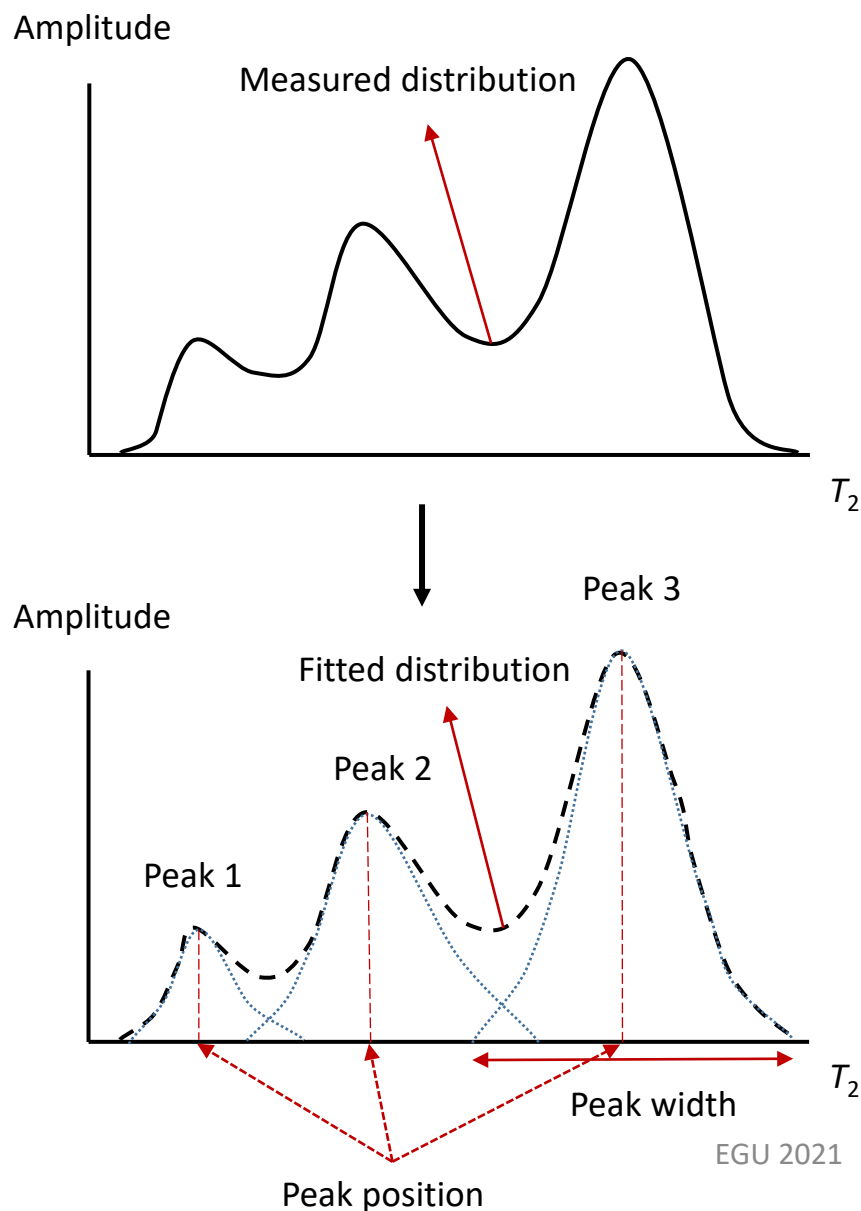
10



- Lowering the saturation does not affect uncertainty of VWC estimation much

100%
saturation



**Peak
Decomposition**

EGU 2021

Fully controllable peak
parameters:

- Peak number

- Upper and lower margins

- Fitting function (Gaussian
as default)

Outcomes including:

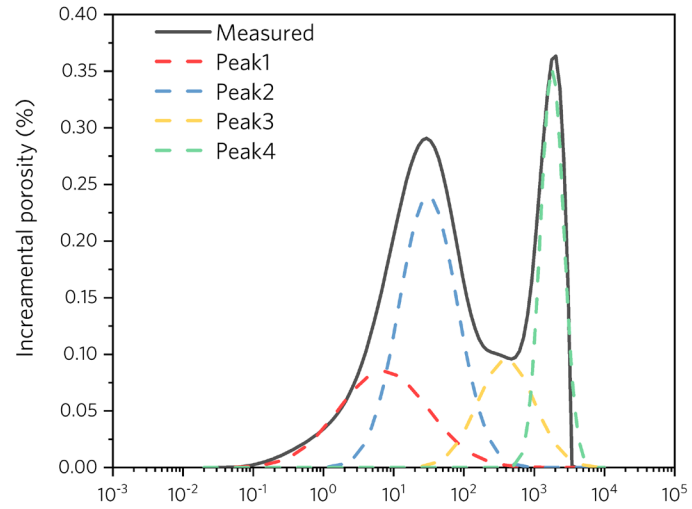
- Peak position (T_2)

- Peak width

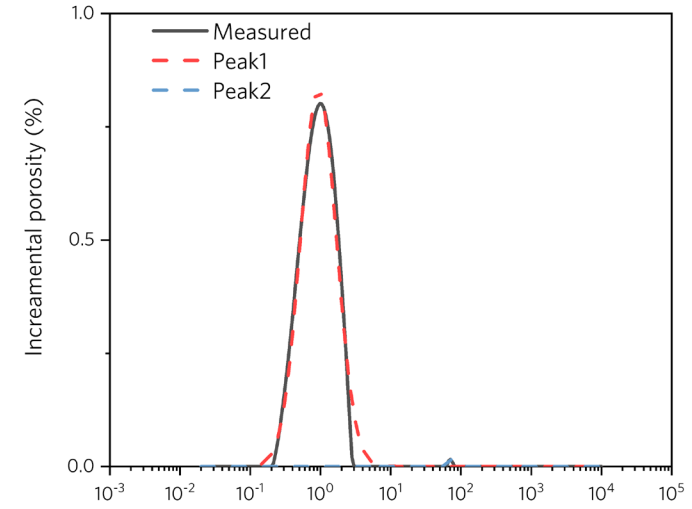
- Peak weight (Porosity)

Lab NMR

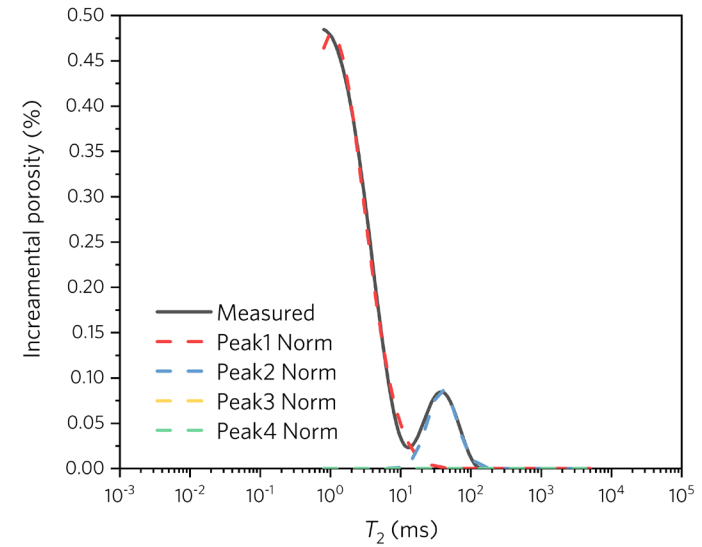
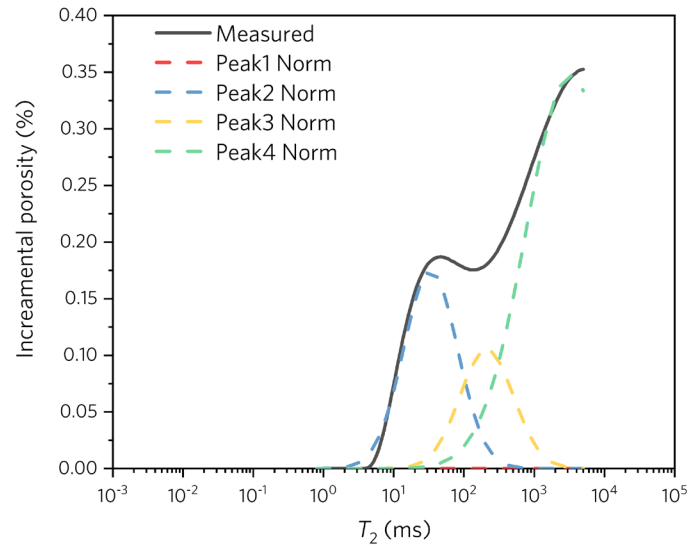
Carbonate



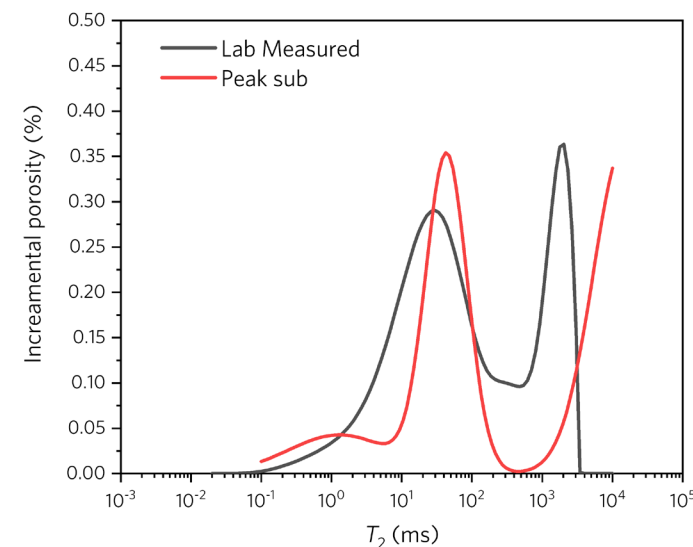
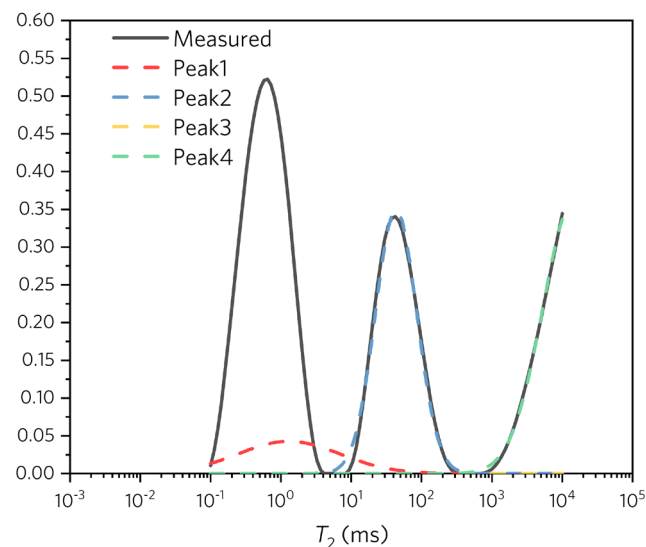
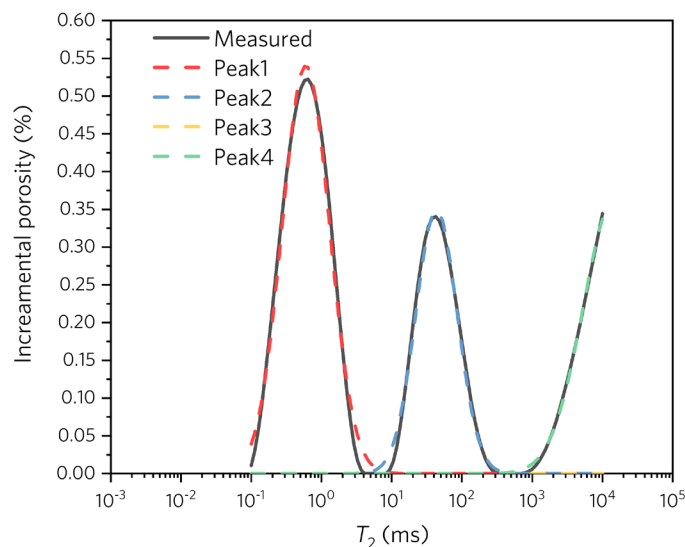
Shale



Borehole
NMR



M2 synthetic

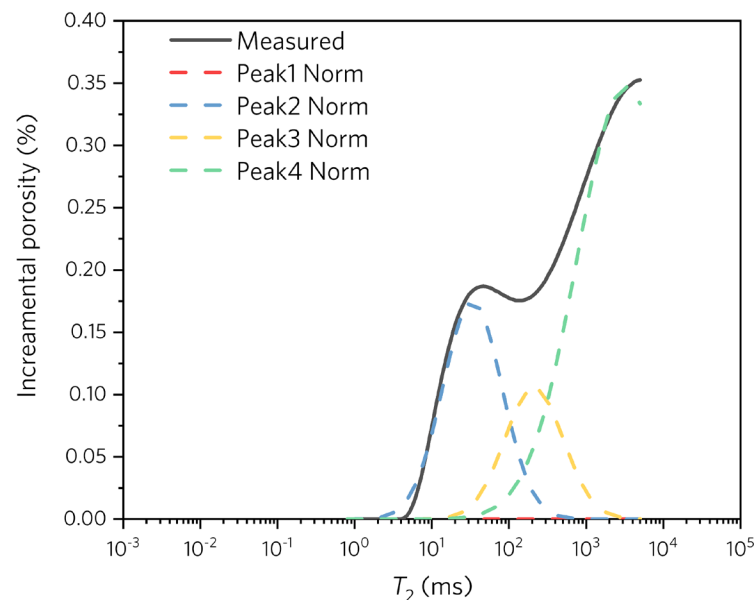


Porosity: 16.8% $\rightarrow$ 9.6%

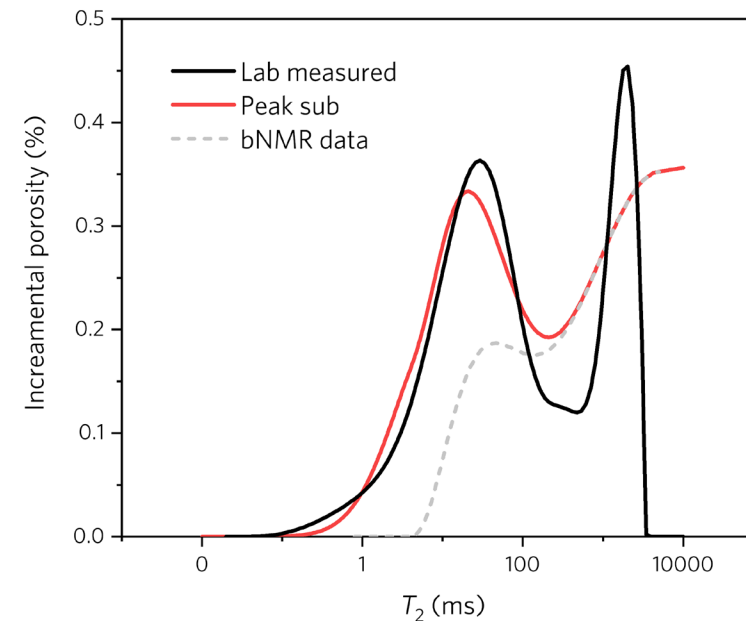
Much closer to the original porosity of 11.2%

Therefore, the overestimation of volumetric water content is mostly contributed by the overestimation of lower T_2 , which can be solved by peak decomposition and peak substitution technique.

M2 Borehole



Peak sub



Porosity: 10.1% → 11.4%

Closer to the original porosity of 11.2%

Note that the synthetic and borehole data overestimated and underestimated the porosity, respectively. However, proposed peak decomposition-peak substitution technique works just fine under such two different conditions.

Currently, data acquisition of borehole NMR is facing some limitations: limited relaxation time range, low signal to noise ratio, etc. Those limitations brought in contaminated data which need careful calibration before using.

- Our synthetic study shows that limited relaxation time range often leads to less accurate recovery of T_2 spectra at long relaxation time.
- This synthetic study also shows that the low SNR results in misprediction of volumetric water content at lower T_2
- The proposed peak decomposition-peak substitution technique is meant to counter such limitations and works in both synthetic study and actual borehole NMR data. The proposed technique can improve the relaxation time distribution and volumetric water content derived from borehole NMR.

Limitations:

- The bNMR data does not always match the lab measured core data due to the uncertainty of coring position and different saturations.
- If implementation to broader geologic settings is desired, a huge sample size is needed to generalize the trend of the T_2 distribution and volumetric water content.

Future directions:

- Adjusting every interval of bNMR data to achieve a full well correction.
- Peak decomposition and substitution can also be applied to surface NMR to improve the estimation of water content.