Monitoring of Subsurface Contaminant Remediation at the former Moab Uranium Mill Tailings site by In-Situ Nuclear Magnetic Resonance

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2023 Bioremediation Symposium

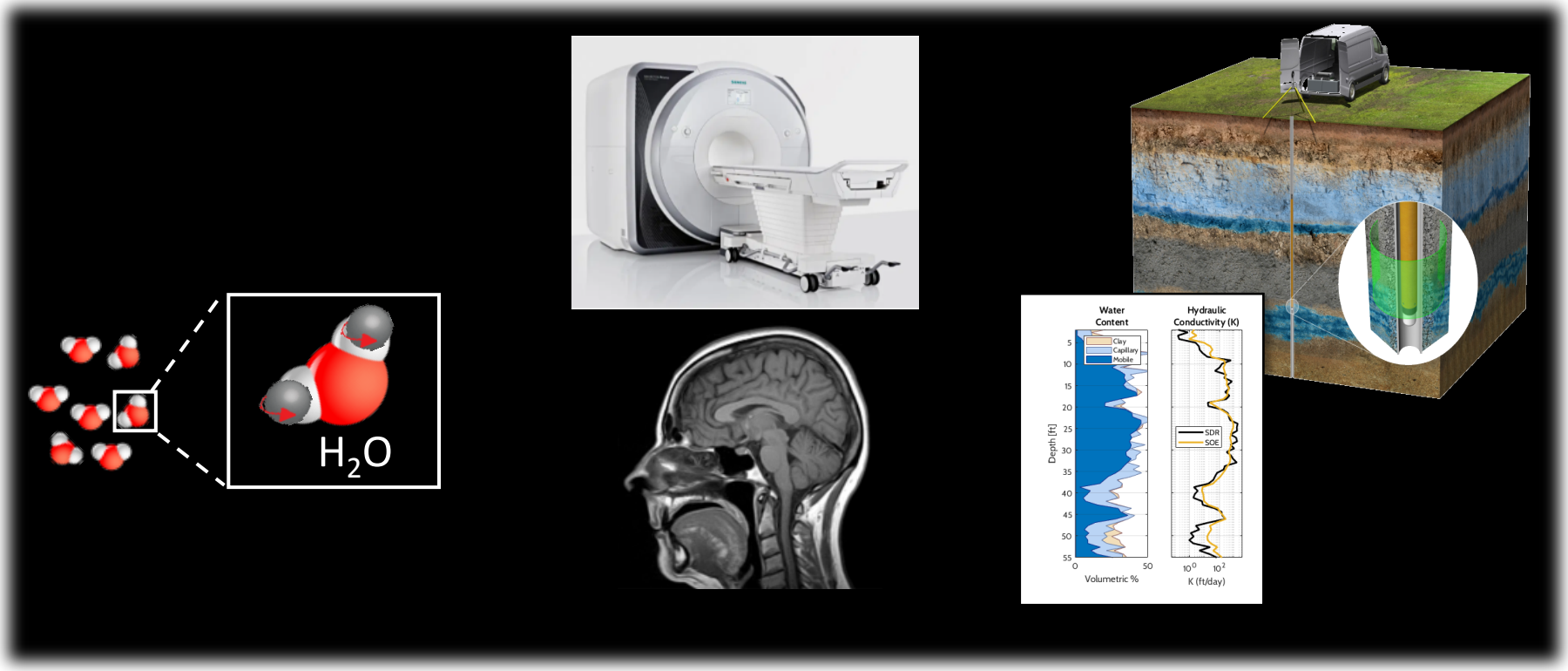
Austin, Tx

Introduction:

- Advancements in remediation engineering have delivered innovative strategies for cleanup incorporating biological, geochemical, and hydrogeologic processes.
- Efficient and safe monitoring of environmental remediation processes of soil and groundwater is challenging
- Conventional methods rely largely on direct well fluid sampling and soil coring.
- The need to measure pore-scale properties of the formation along the remediation process

NMR approaches can be used to efficiently monitor remediation processes in-situ

Nuclear Magnetic Resonance (NMR)



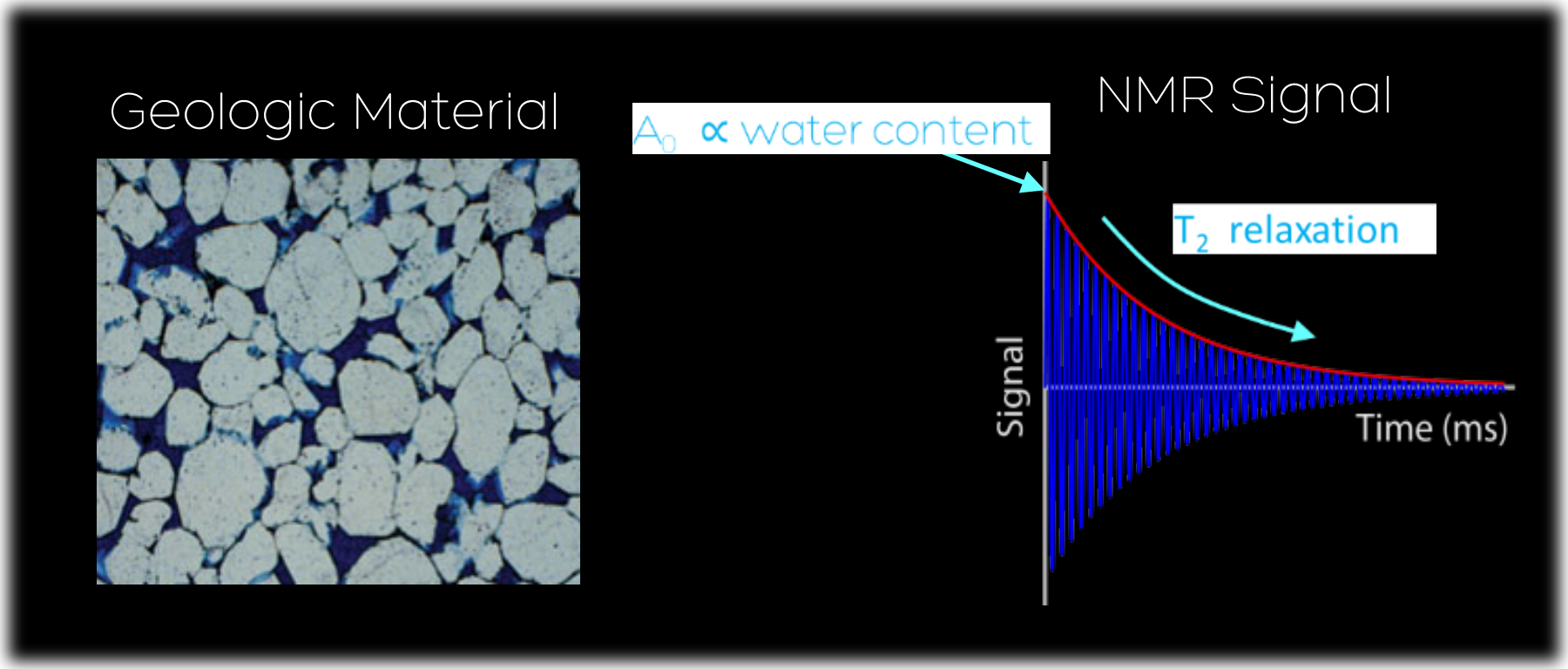
Direct Detection of Hydrogen Nuclei

Medical MRI

NMR Geophysics

VISTACLARA NMR GEOPHYSICS

Hydrologic Properties from NMR



NMR Directly Measures

- Water Content, Porosity
- NMR Relaxation Times, Relative pore size

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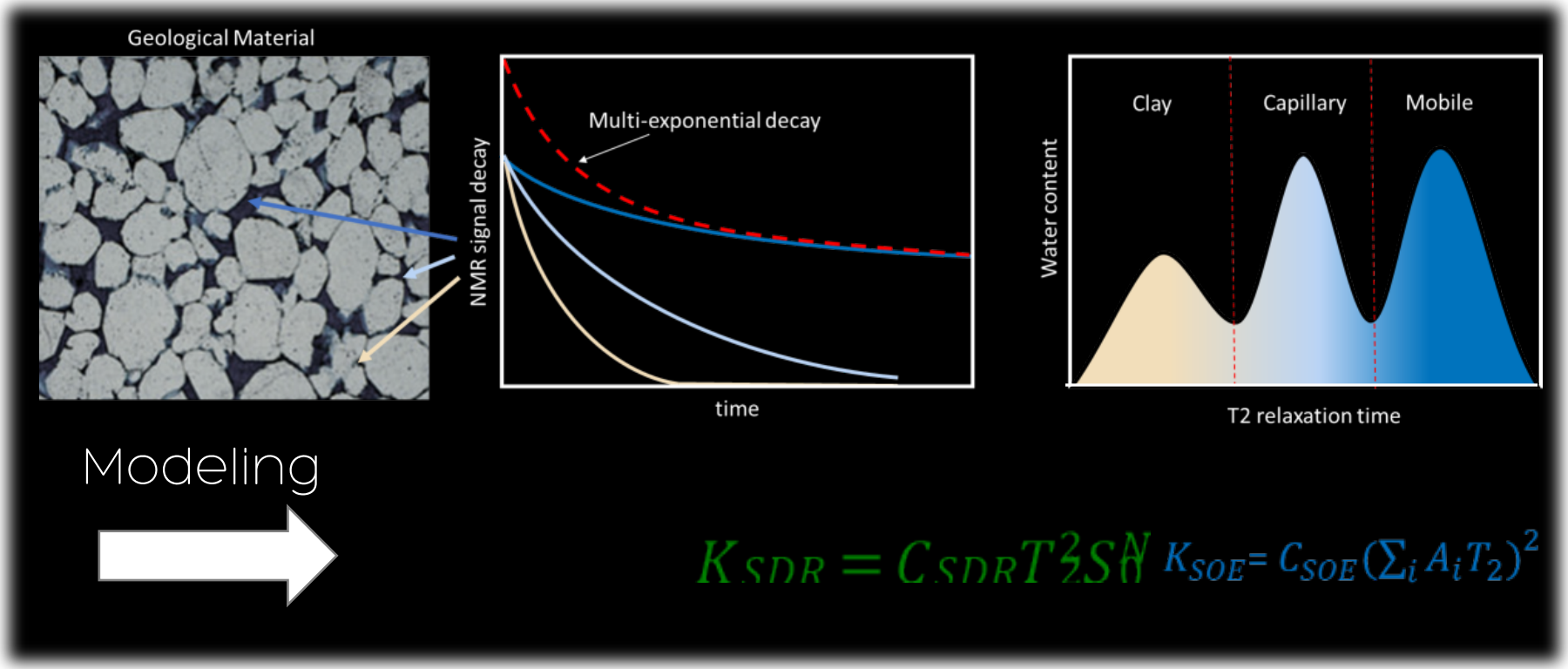
Hydrologic Properties from NMR



NMR Directly Measures

- Water Content, Porosity
- NMR Relaxation Times, Relative pore size

NMR Estimates

- Pore Size Distribution, Bound/Mobile Porosity
- Hydraulic Conductivity

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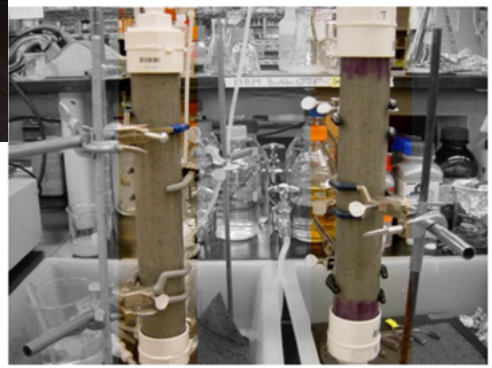
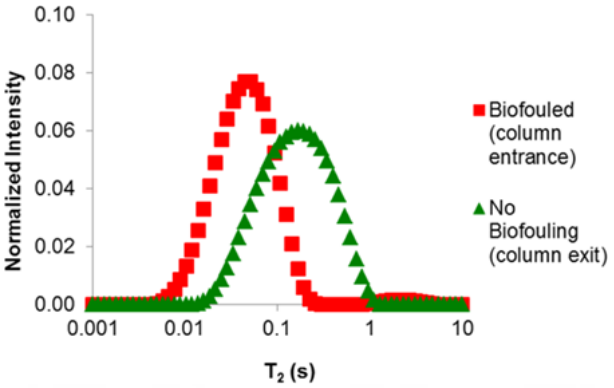
Previous work using NMR

In-situ detection of biofilm in porous media

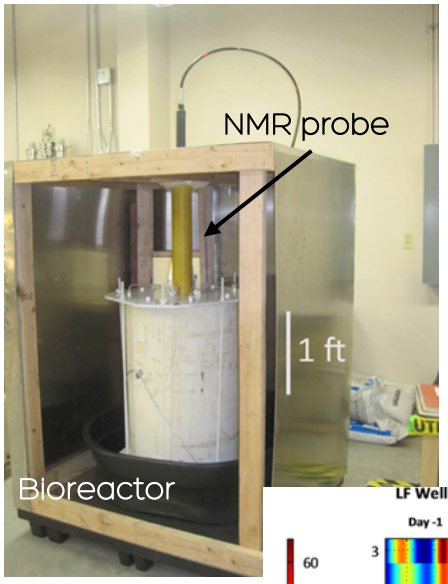
Benchtop NMR sensor

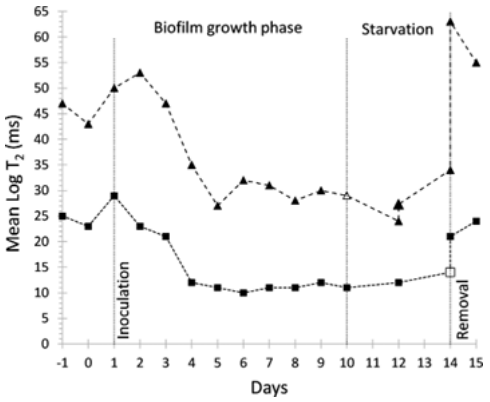


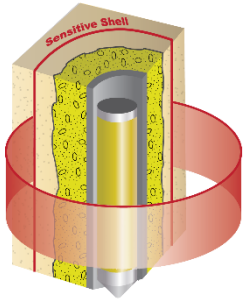


Sanderlin et al, 2013

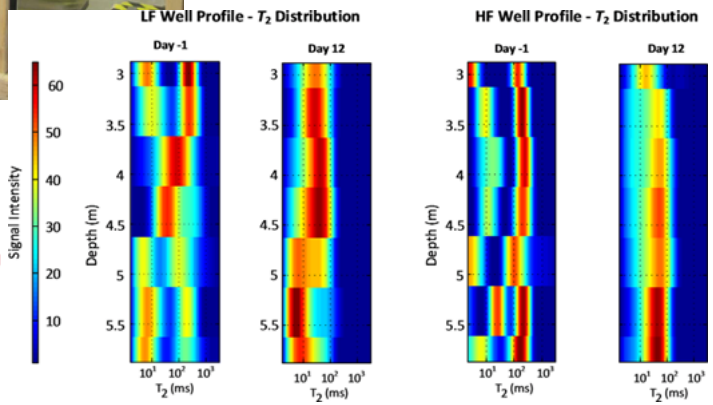
Borehole NMR logging sensor







Javelin® NMR
Deep View Sensitivity

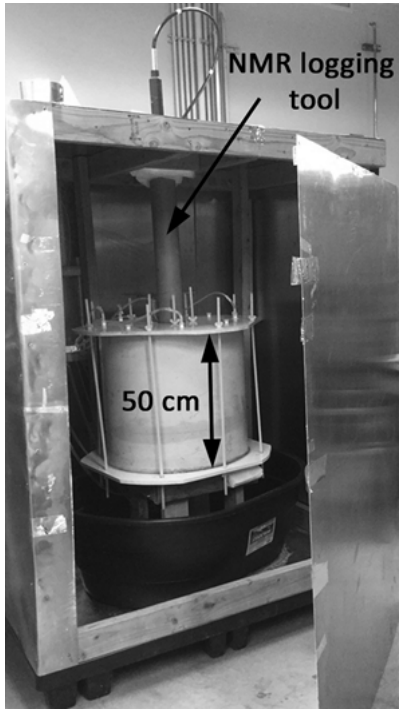


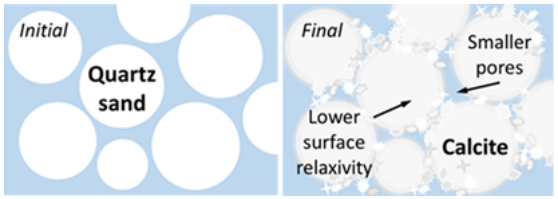
Kirkland et al. 2015

Previous work using NMR

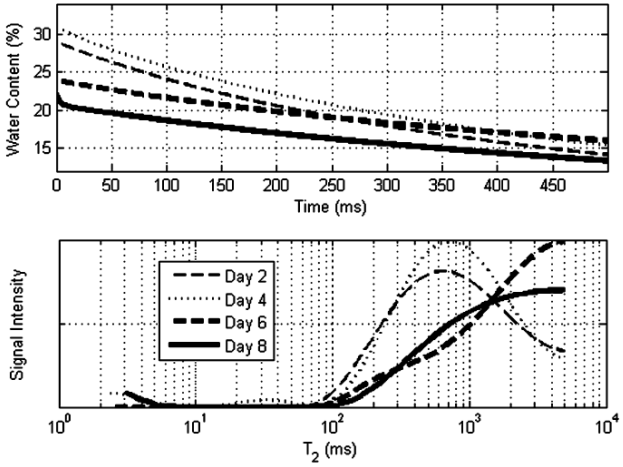
In-situ detection of microbially induced calcite

Borehole NMR logging sensor





NMR monitoring results

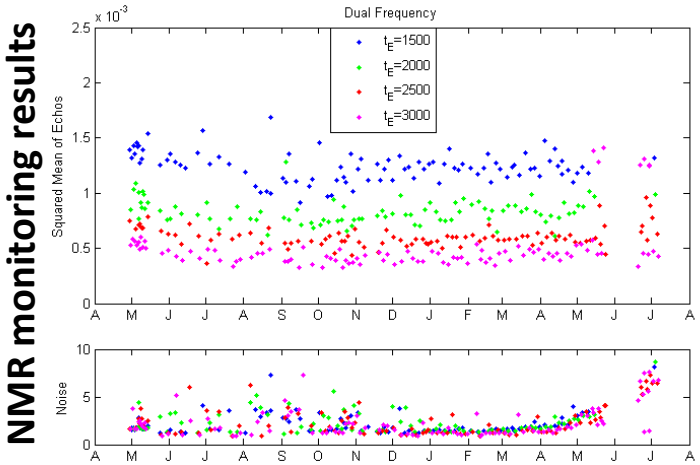


Kirkland et al. 2015

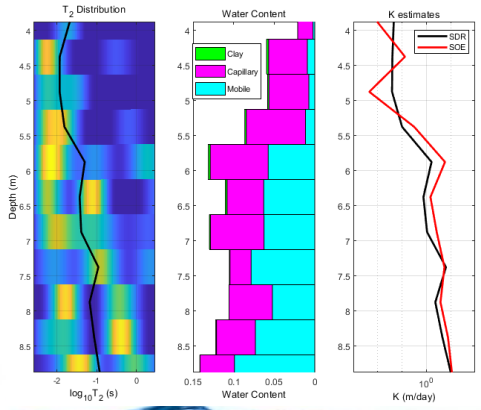
Previous work using NMR

NMR Monitoring of Geochemical and Mineralization Changes

- Hypothesis: Formation of mixed-valence minerals, such as magnetite, over time would reduce the NMR relaxation time decreasing the hydraulic conductivity
- Unattended NMR logging system for 15 months at Rifel, CO.



- No change in hydraulic conductivity was detected over time.
- The data are repeatable and stable (low variance) over the very long 15-month interval.



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Moab UMTRA

https://www.energy.gov/em/moab/overview-moab-umtra-project

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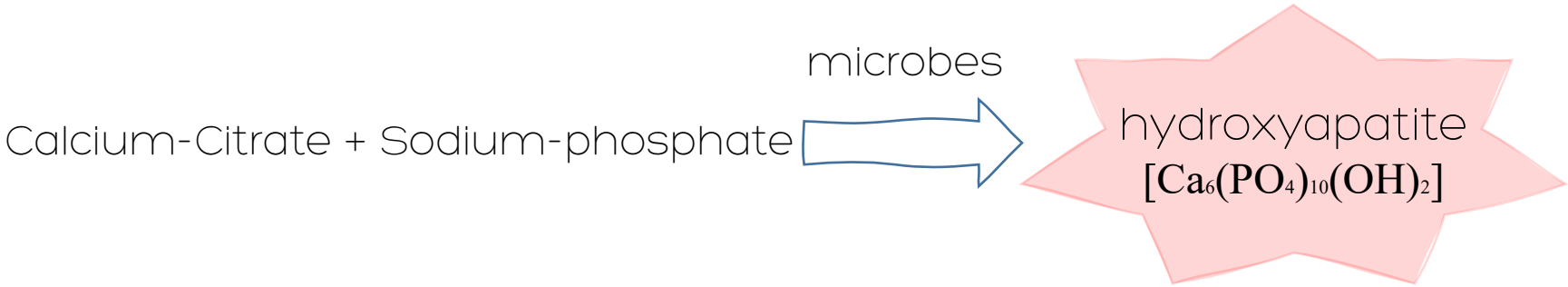
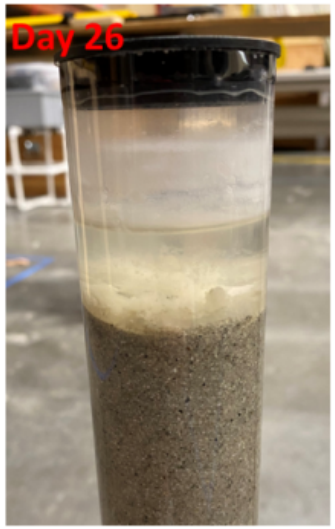
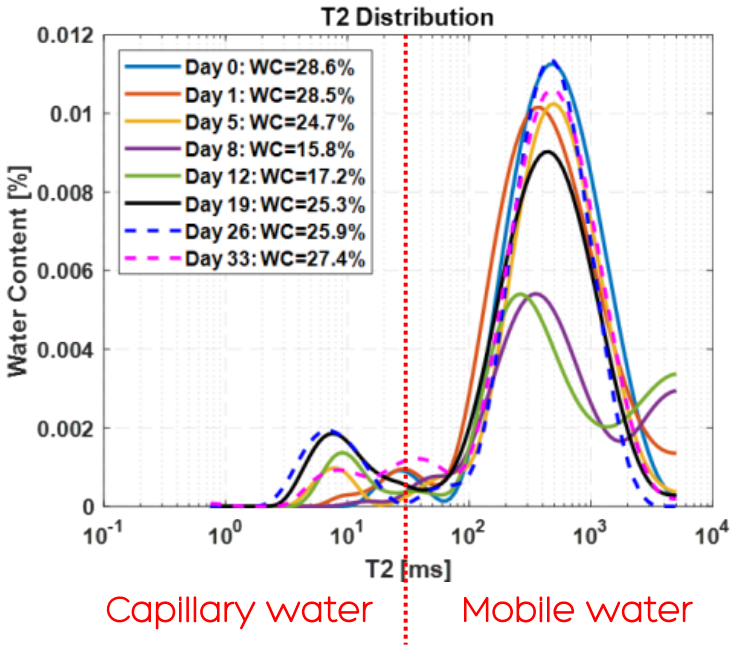
Hydroxyapatite precipitation reaction



- Permeable barriers for containment of radioactive contaminants and heavy metals
- Strongly absorbs uranium, strontium, lead, and selenium
- Low water solubility
- High stability under reducing and oxidizing conditions
- Available and low cost

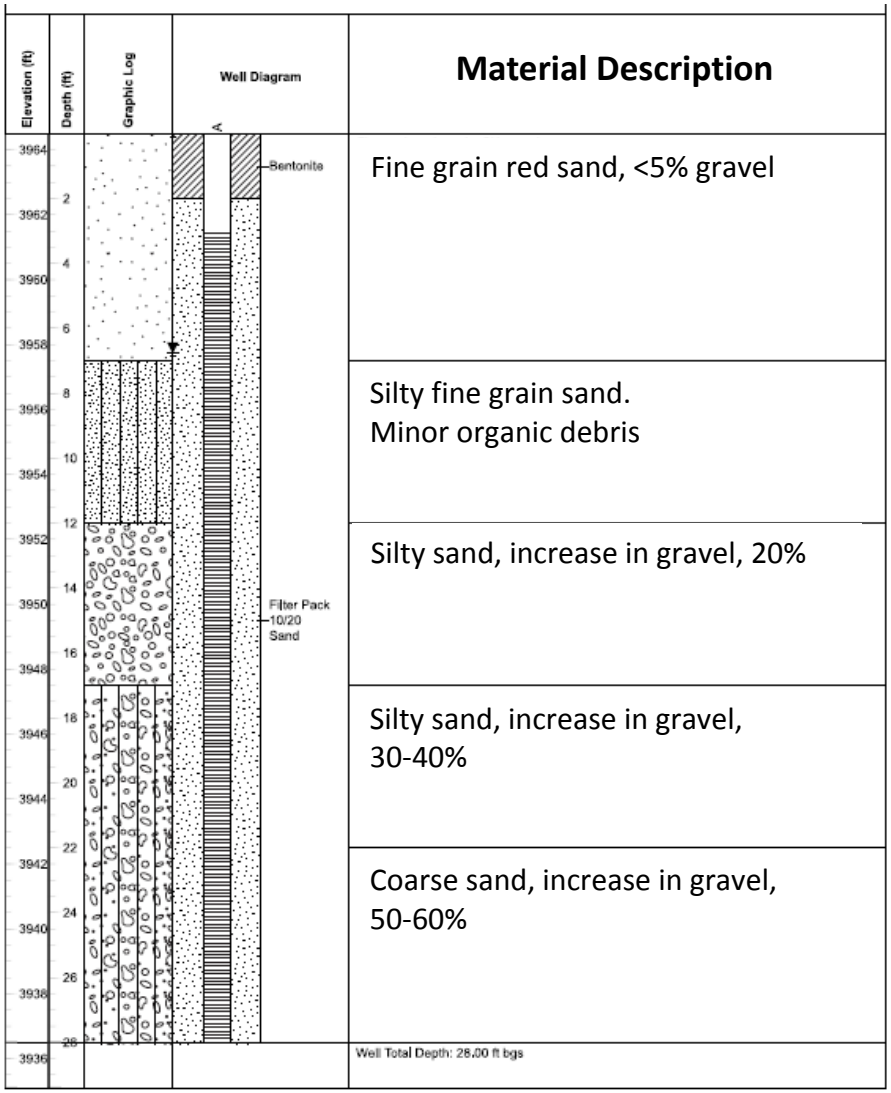
Lab experiments with silica sand





- Dart NMR probe was used for NMR monitoring
- Significant change in water layer above the silica sand during the first week, due to massive gas formation
- Mobile water content decreasing and capillary water increasing over time
- White precipitation is observed between and on top of the silica sand after three weeks into the monitoring

Lab experiments with Moab UMTRA core samples



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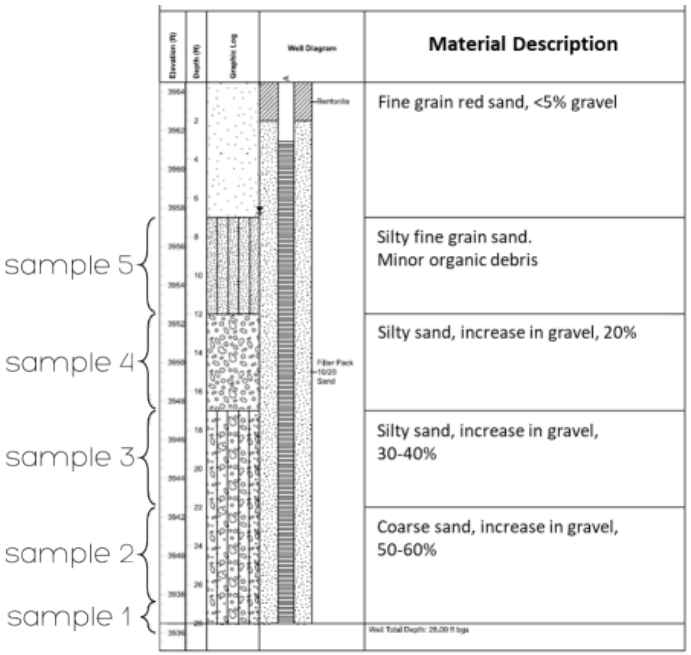
Lab experiments with Moab UMTRA core samples



Day 0

Day 8

Day 15

Day 29

Iron sulfide minerals

- Massive gas ($C0_2$) build up during the first week of monitoring
- Hydroxyapatite and iron sulfide (FeS) minerals precipitations happen simultaneously over time

Lab experiments with Moab UMTRA core samples

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Day 8

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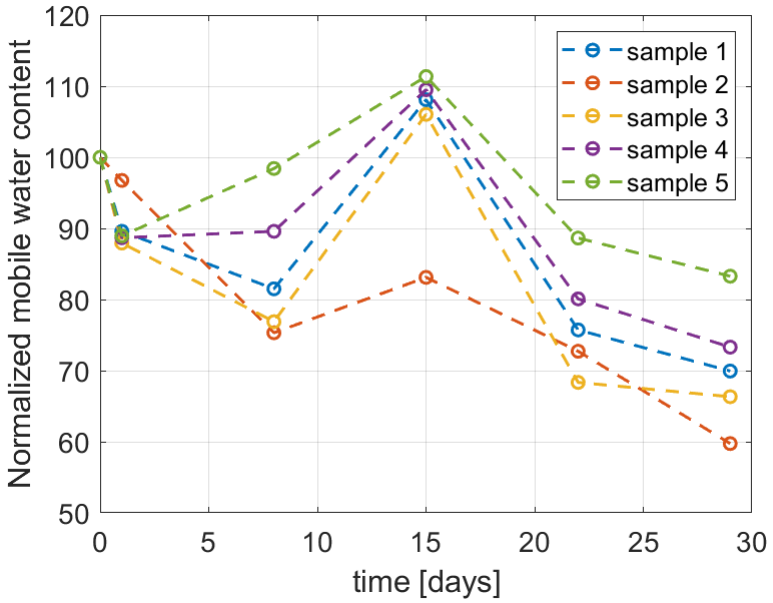

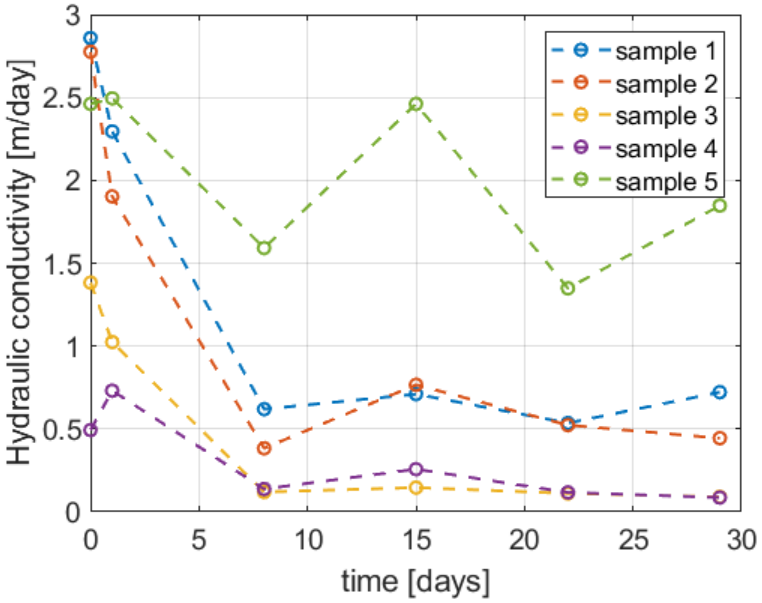

- Helios NMR core analyzer was used for monitoring
- Mobile water content decreasing and capillary water increasing over time, associated with apatite formation
- Significant drop in hydraulic conductivity during the first week

Remote NMR Monitoring System Overview

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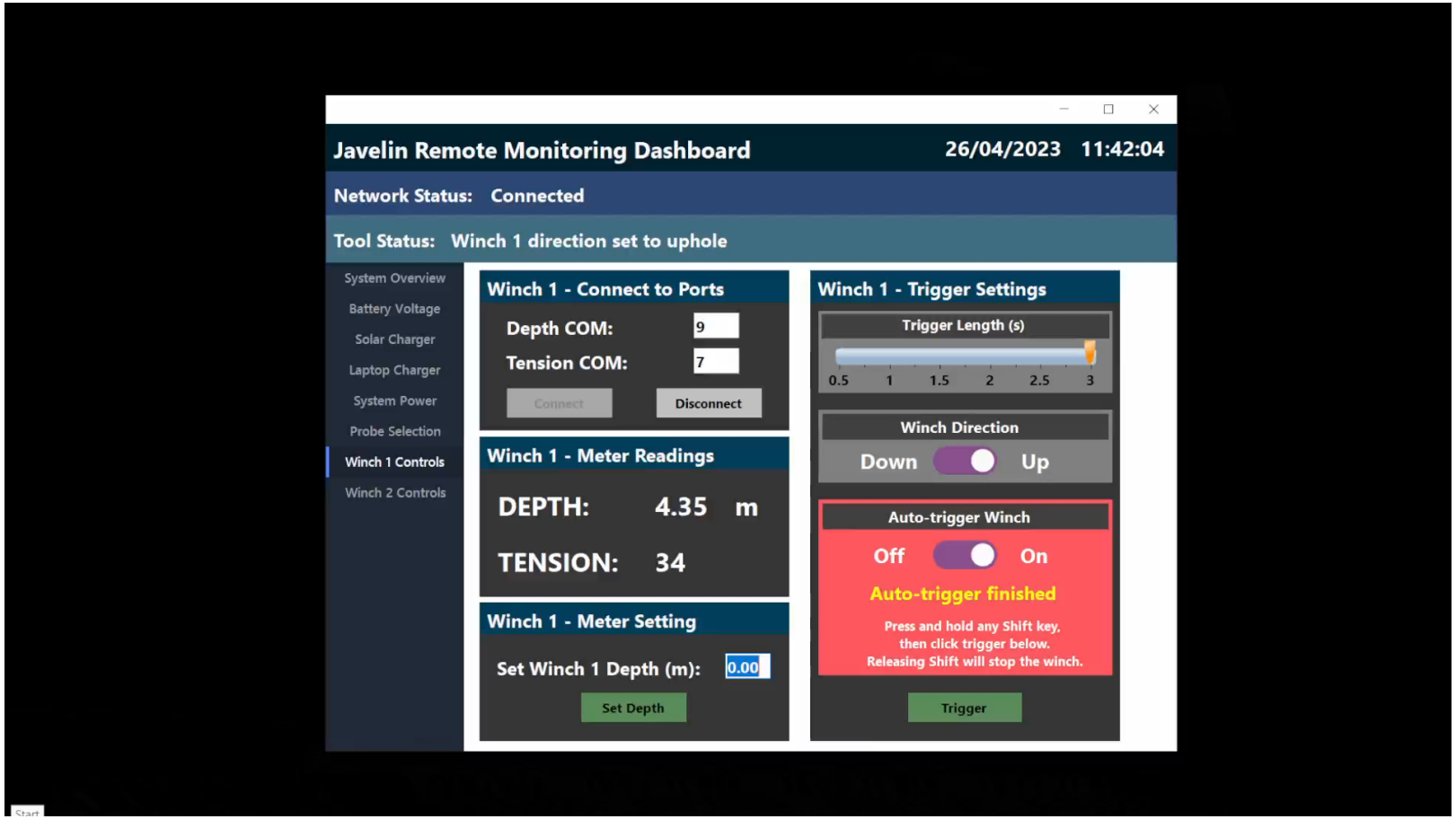
Remote NMR Monitoring System Overview



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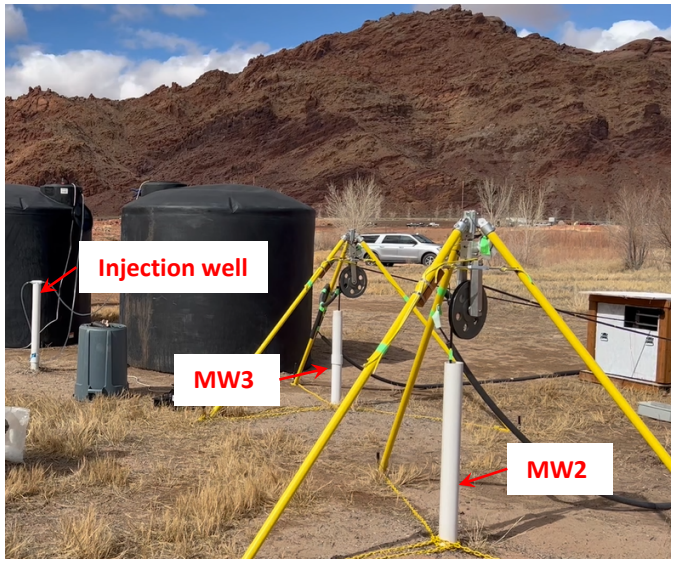
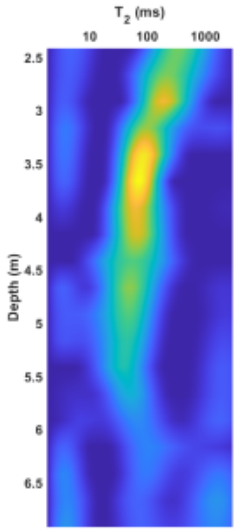
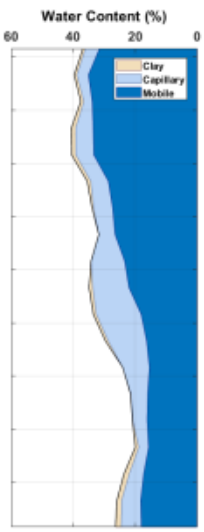
Injection of calcium-citrate and sodium-phosphate

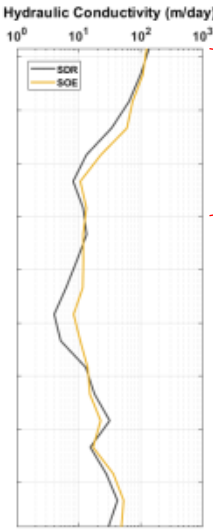
Results of Remote NMR monitoring-before injections



MW2







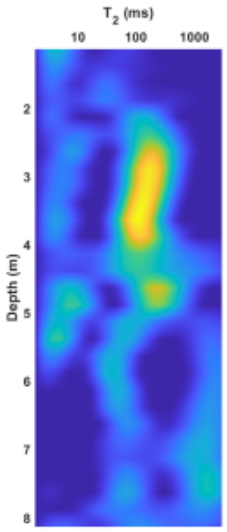
Drilling details

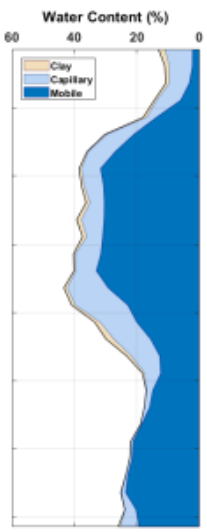
Fine grain sand

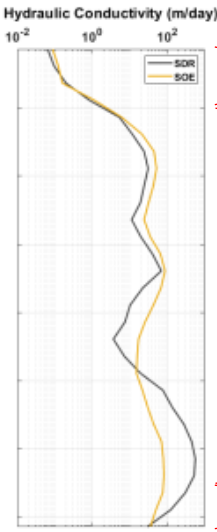
Silty sand, 25% gravel

Silty sand, 40% gravel, minor amounts of clay

MW3







Fine grain sand, <5% gravel

Coarse grain sand, 30% gravel, increase in silt and clay

Coarse grain sand, minor silt, 60% gravel

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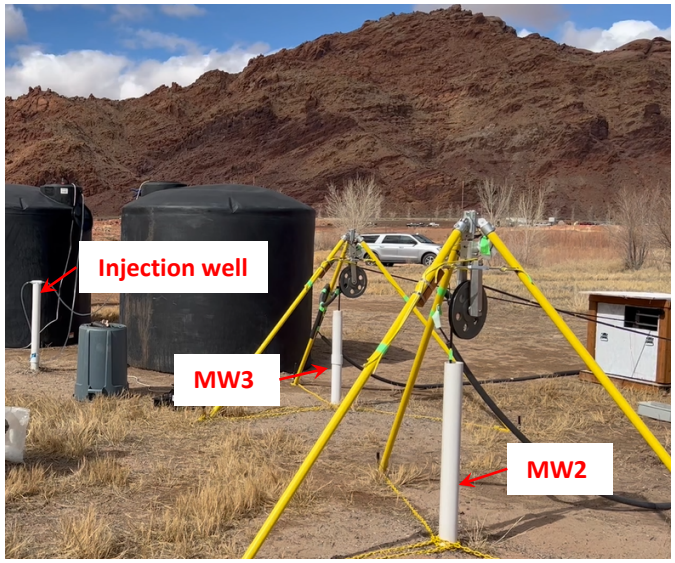
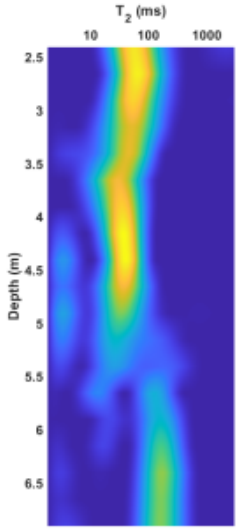
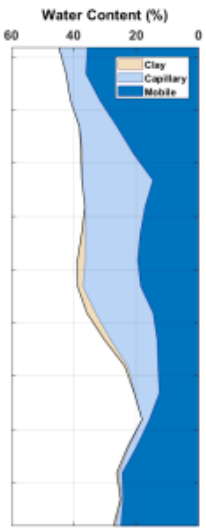
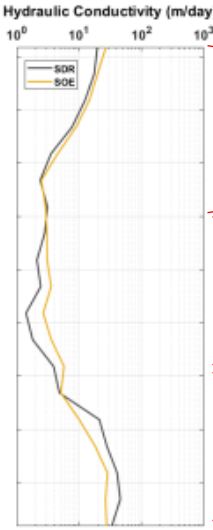
Results of Remote NMR monitoring-After injections



MW2







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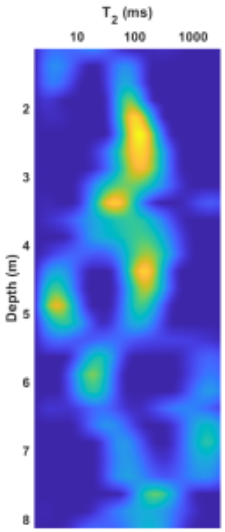

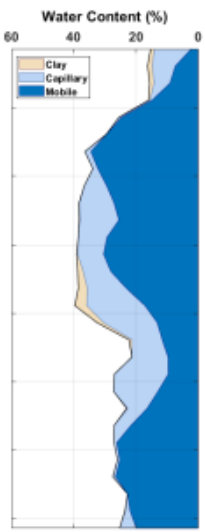

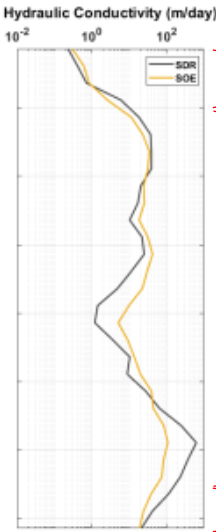

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Coarse grain sand, 30% gravel, increase in silt and clay

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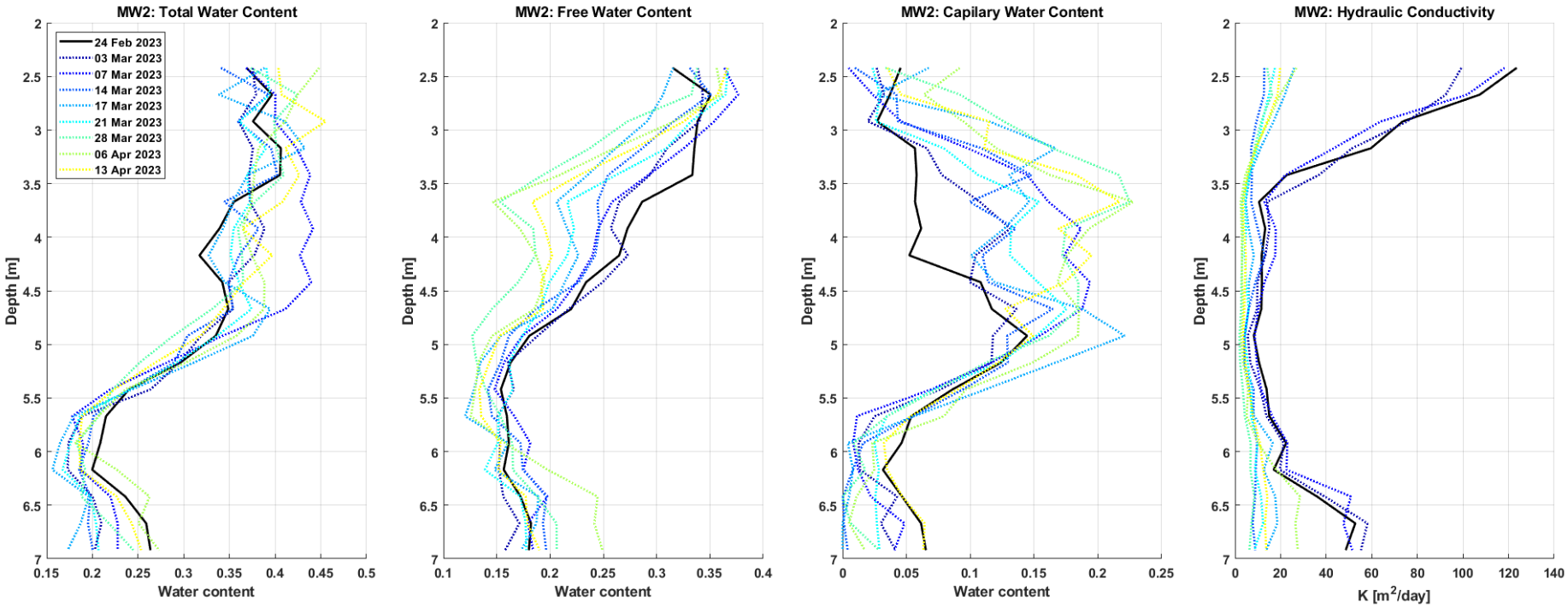
Results of Remote NMR monitoring

MW2

24 Feb 2023 -baseline
02 Mar 2023- 1st injection
16 Mar 2023- 2nd injection
05 Apr 2023- 3rd injection



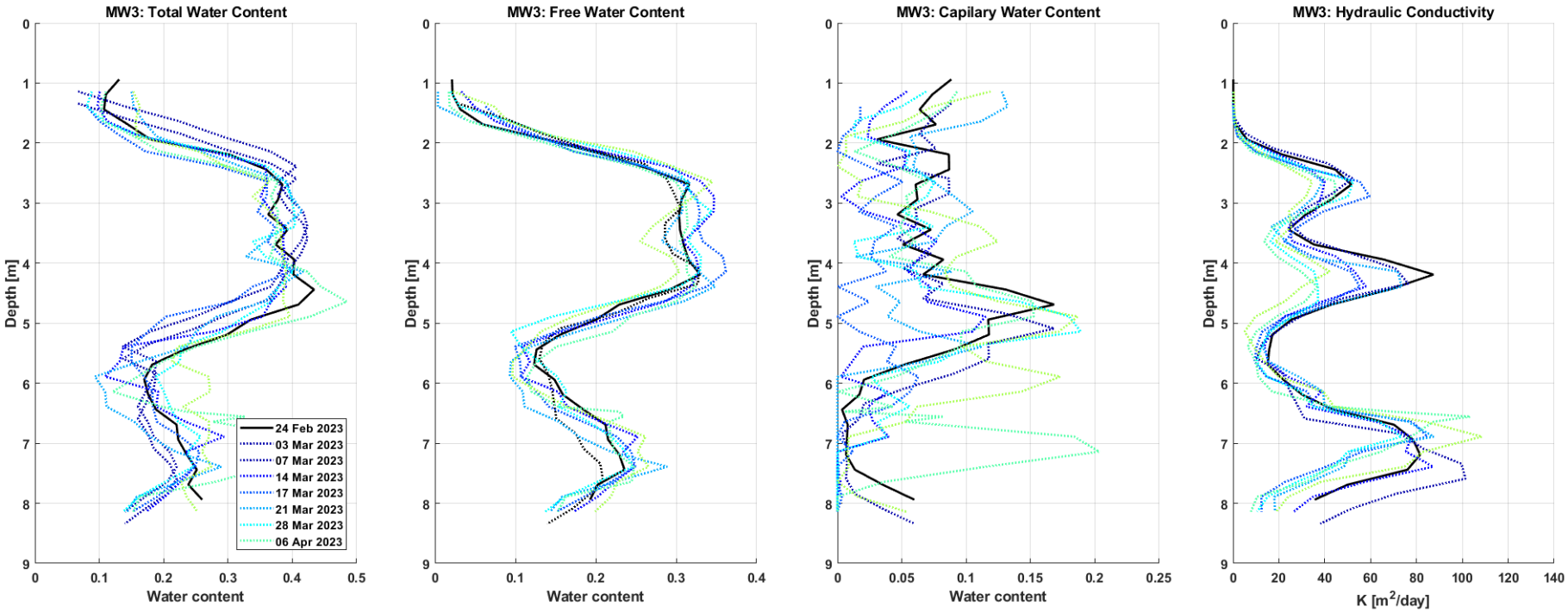
- Significant decrease in mobile water content over time
- Significant increase in capillary water content over time
- Dramatic decrease in hydraulic conductivity

VISTACLARA NMR GEOPHYSICS

Results of Remote NMR monitoring

MW3

24 Feb 2023 -baseline
02 Mar 2023- 1st injection
16 Mar 2023- 2nd injection
05 Apr 2023- 3rd injection



- No significant changes were observed over time in this well

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Remote NMR Monitoring System Evacuation

May 2nd, 2023
Evacuation day

May 3rd, 2023
Flooding, 2 feet water around the wells

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Conclusions

Hydrogeological NMR measurements provide unambiguous information on hydrogeological properties:

- Direct detection and measurement of water content
- Relative pore size distribution
- Bound and mobile water fractions
- Estimation of hydraulic conductivity and transmissivity

NMR logging technology can provide:

- High resolution site characterization
- Efficient monitoring of remediation processes in-situ
- Remote, unattended long-term monitoring provides a very large cost savings when compared with repeated physical mobilizations to the site

Thank you!

Acknowledgements

This work was supported by US Department of Energy Grant Number DE-SC0020798.. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the US Department of Energy.

Special thanks to:

- Moab UMTRA personnel

daryamorozov@vista-clara.com

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