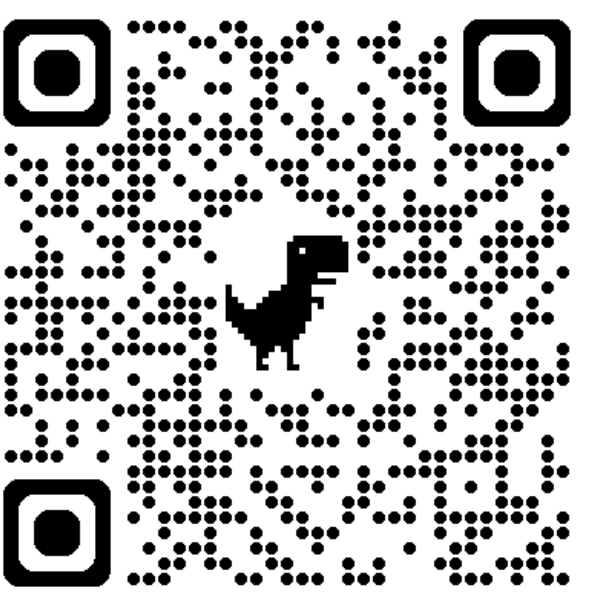




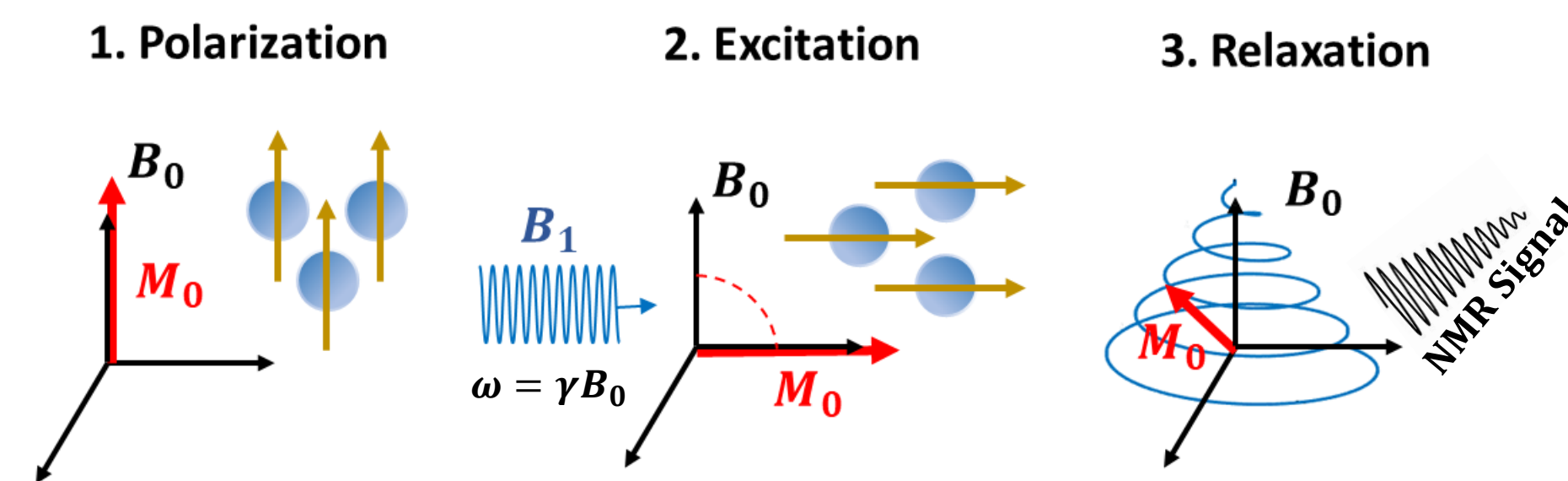
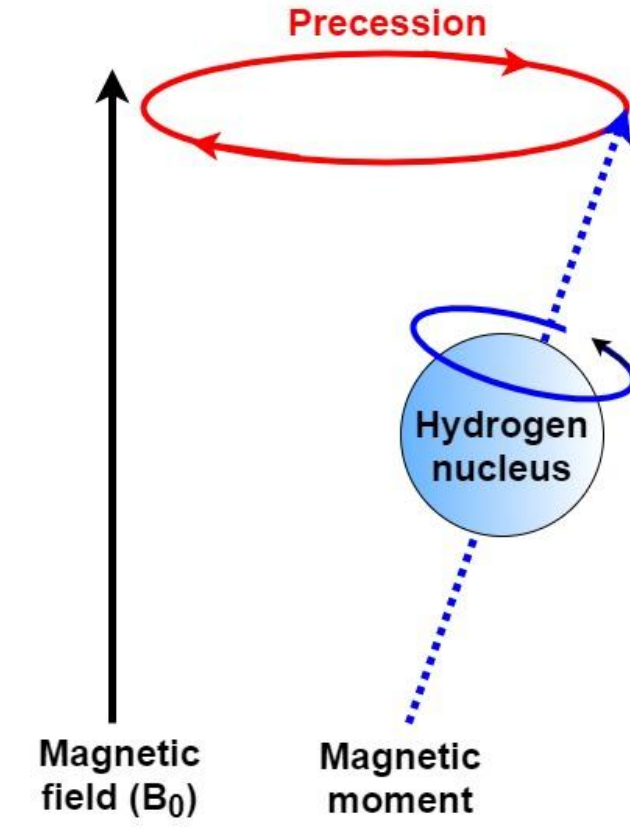
Why to use Nuclear Magnetic Resonance (NMR)?

Non-invasive physical method to **directly** detect the magnetic moment of hydrogen protons. The method is used in chemistry (high-field NMR spectrometers), medicine (MRI scanners), and geophysics (NMR borehole logging tools). In geosciences, NMR enables the direct detection of hydrogen nuclei in subsurface fluids, allowing for the quantitative determination of total water content (or saturated porosity), pore size distribution, pore type classification, and estimates of hydraulic conductivity.

How is the NMR measurement done?

To conduct NMR experiment we need:

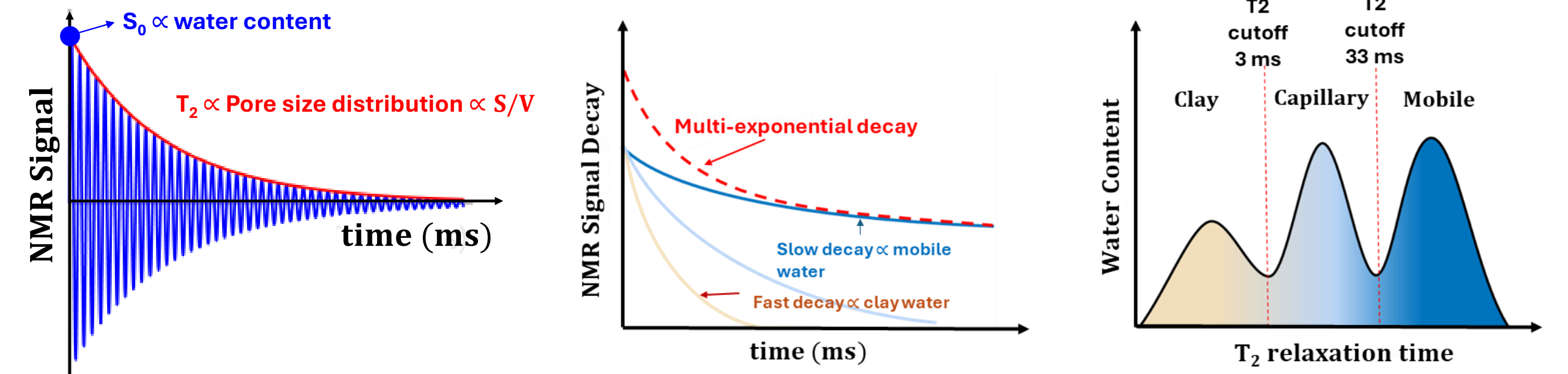
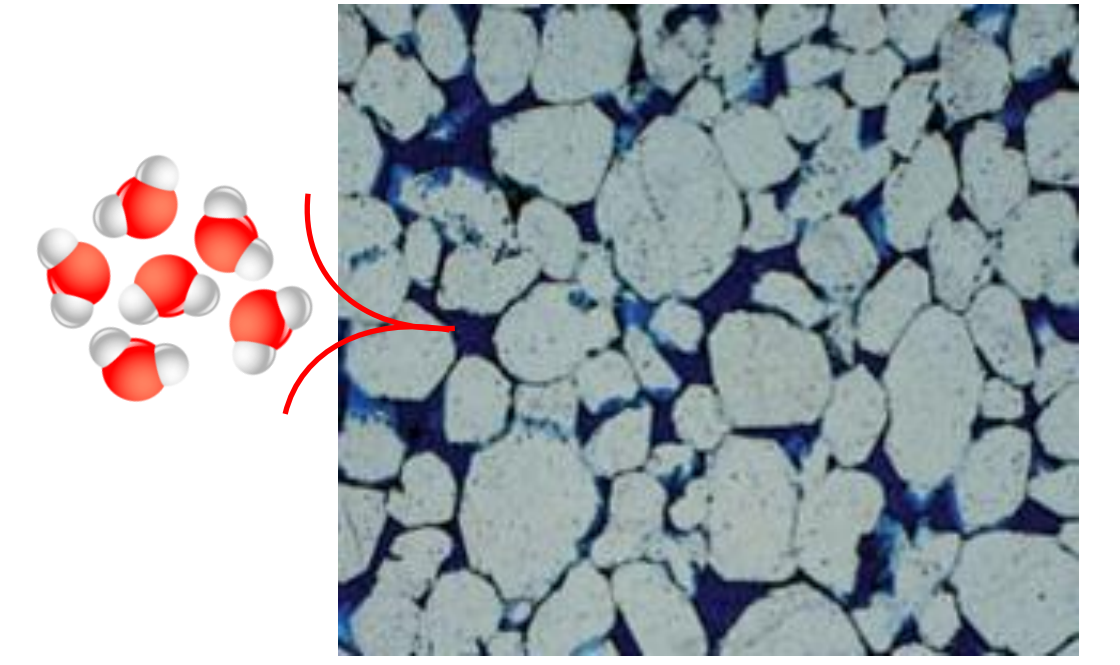
- Static magnetic field (B_0)
- Nuclei with nonzero nuclear spin number (e.g., ^1H , ^{19}F), meaning an odd number of protons and/or neutrons
- Alternating electro-magnetic field (B_1) for spins excitation, applied at Larmor frequency of the spins of interest
- NMR Signal detector (antenna)



What can we measure with NMR?

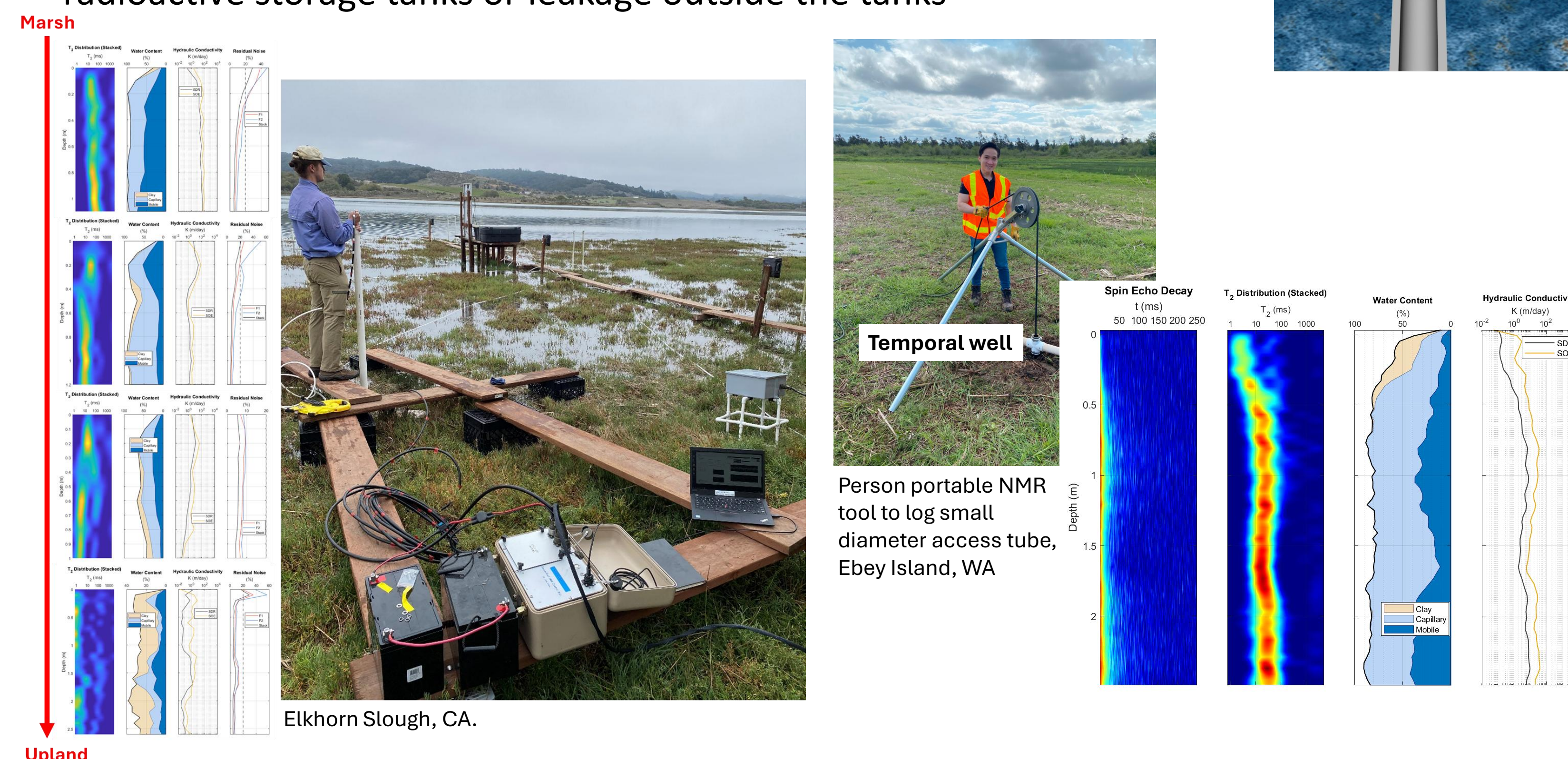
- Volumetric water content
- Bulk/effective porosity (if formation is saturated)
- Relative pore-size distribution
- Hydraulic conductivity

$$K_{KC} = \frac{\phi}{\tau(S/V)^2}$$



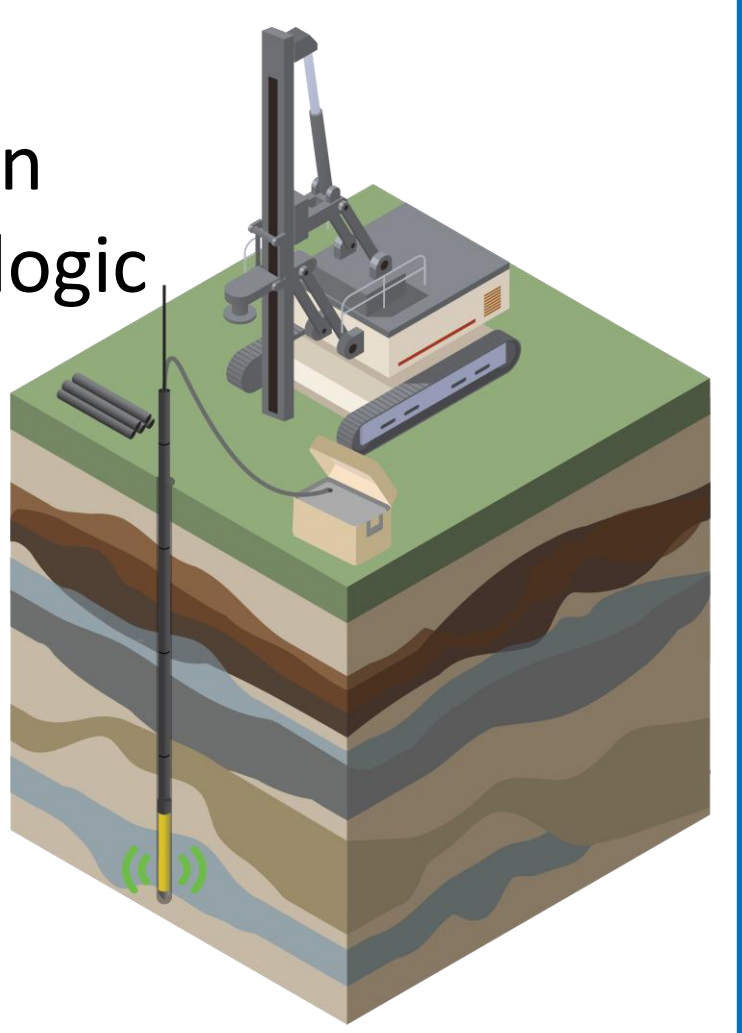
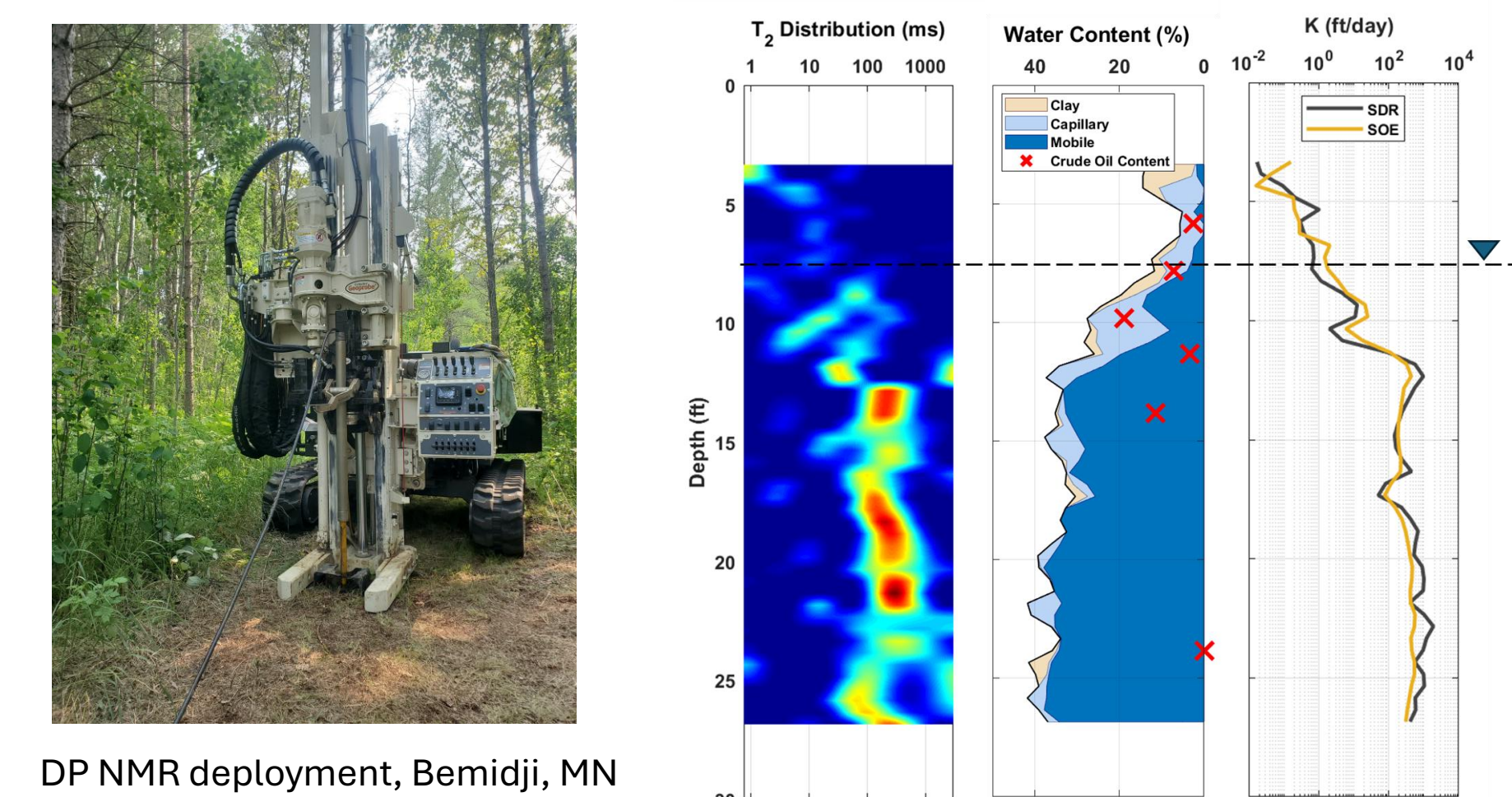
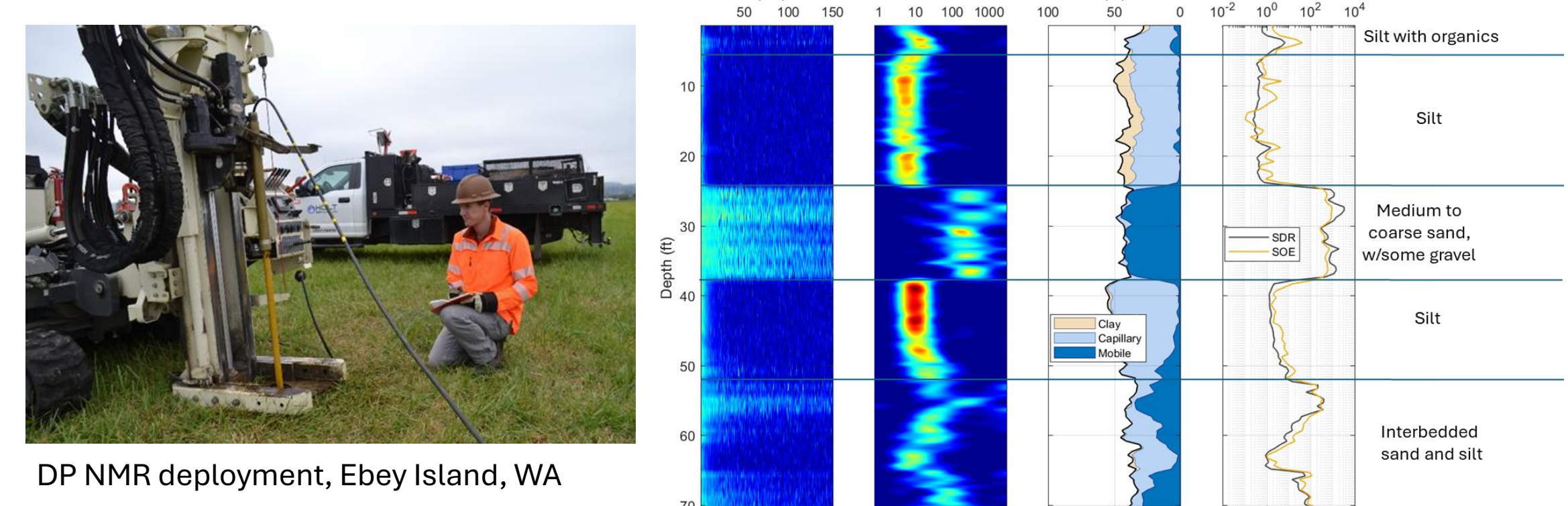
Hand-deployable Dart NMR

- Person-portable and battery-powered NMR logging instrumentation
- Can be deployed in small diameter open or PVC-cased wells with IDs of 3.8 cm to 5 cm (1.5 to 2 inches)
- The Dart probe can be logged manually or using a small winch and cable to collect the NMR signals
- NMR data is collected in two sensitive shells with diameters of 12.5 and 15 cm (5 and 6 inches)
- Can be used for in-situ monitoring of waste bed liquor levels within radioactive storage tanks or leakage outside the tanks



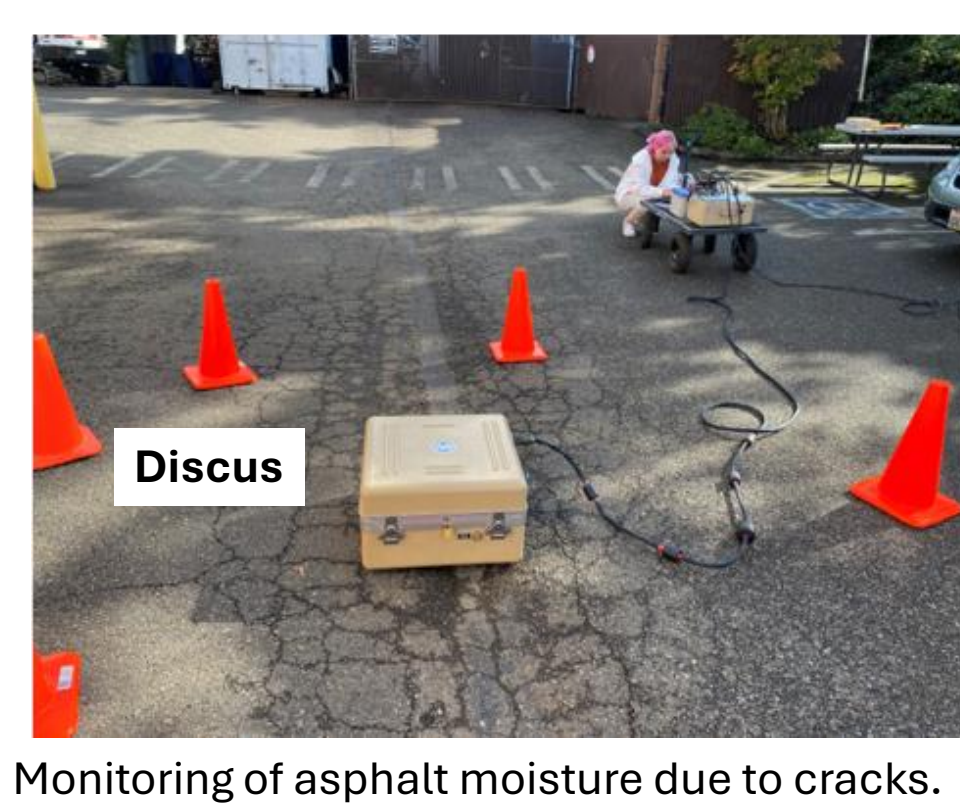
Direct Push (DP) Dart NMR

- Person-portable and battery powered NMR logging instrumentation
- Very high-resolution in-situ NMR measurements of hydrogeologic properties of the native formation
- Can be deployed using Direct Push or CPT machines
- Low impact, no contaminated drilling waste

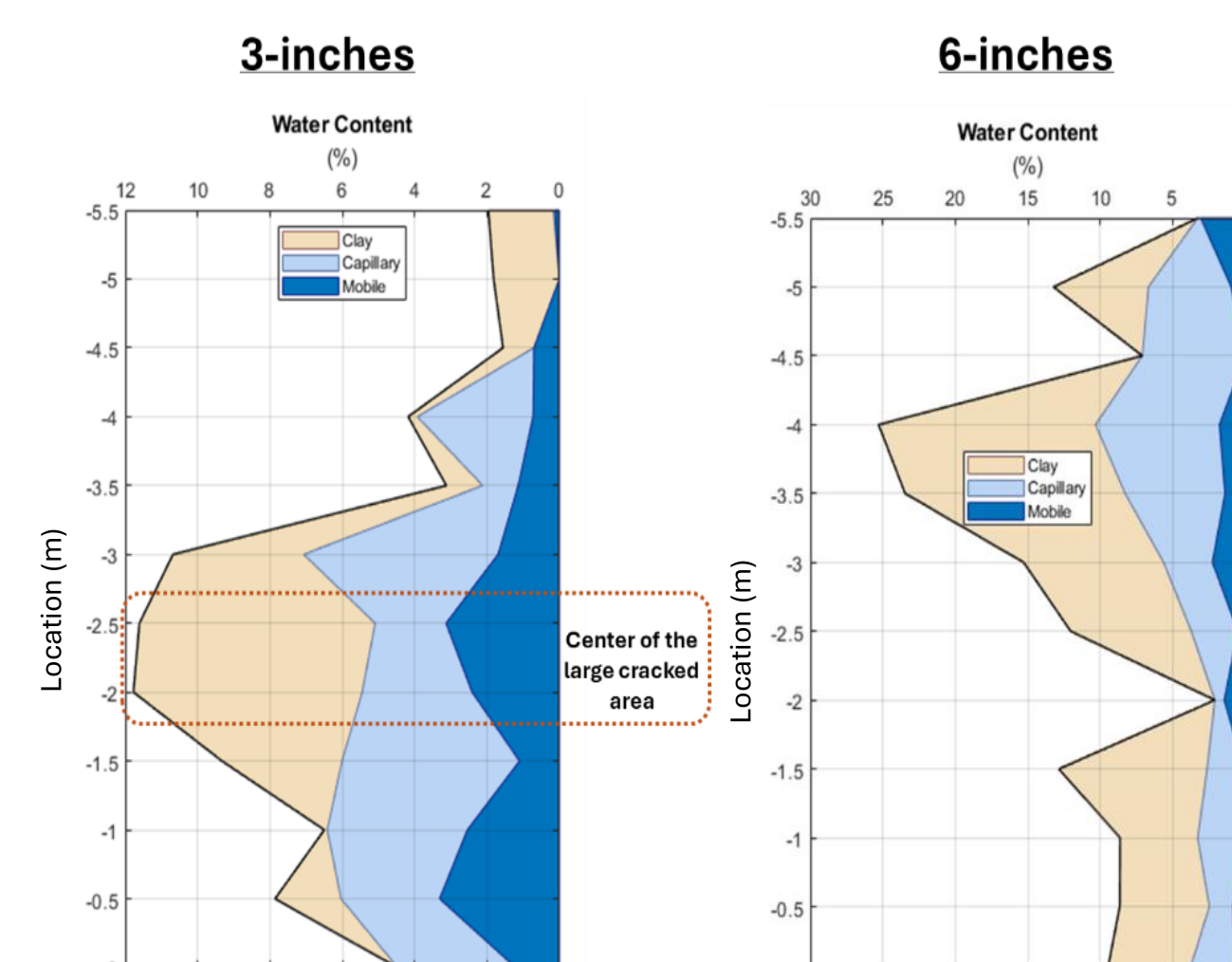


Non-invasive characterization of shallow subsurface: Discus

- Portable technology allowing multi-frequency operation at two independent, sensitive zones located at 3-inch and 6-inch below the ground surface
- Quantification of variations in hydraulic characteristics of soil as a function of depth
- Innovative noise-canceling technology to increase SNR and reduce susceptibility to electromagnetic interference
- Operated from Dart control unit

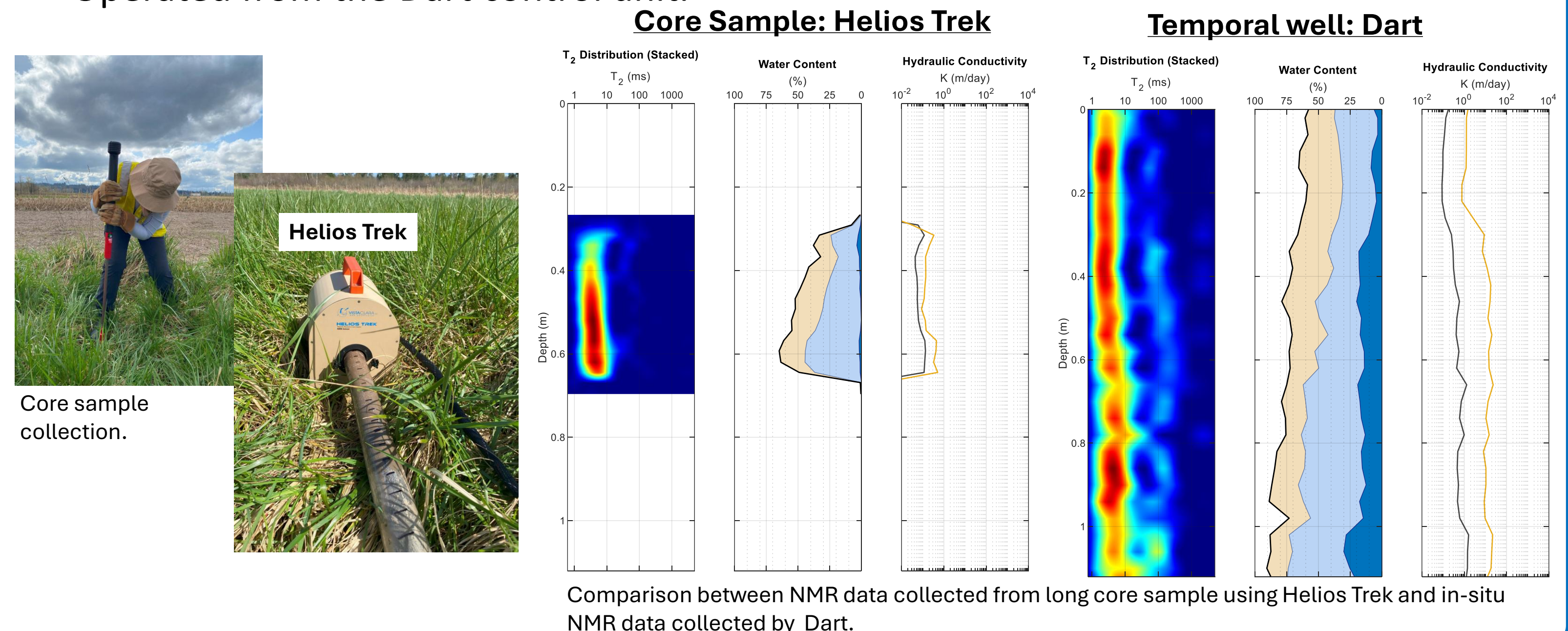


Monitoring of asphalt moisture due to cracks.



Portable NMR core analyzer

- Hand-portable, lightweight, and high-resolution NMR technology for rock and soil core analysis
- Measurements can be taken in both laboratory and field settings immediately after sample collection.
- Operated from the Dart control unit.



Conclusions

NMR measurements provide real-time unambiguous information on hydrogeological properties of the native formation by directly measuring the signal of water in the pore spaces. Portable NMR technologies provide wider application in remote settings where conventional drilling methods are not available. This powerful technology directly measures the volumetric water content porosity and relative pore size distribution, and provides quantitative estimates of the bound and mobile water fractions and hydraulic conductivity.

In environmental remediation projects, portable NMR tools provide fast, high-resolution and precise measurements of hydrogeologic properties for improved conceptual site models. Portable NMR tools are also useful for monitoring changes in moisture content and/or geochemical changes to the pore-space due to seasonal weather changes or remediation activities.