

# MEASURING SOIL WATER CONTENT

## NMR INSIGHTS AND OTHER PERSPECTIVES

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# OUTLINE

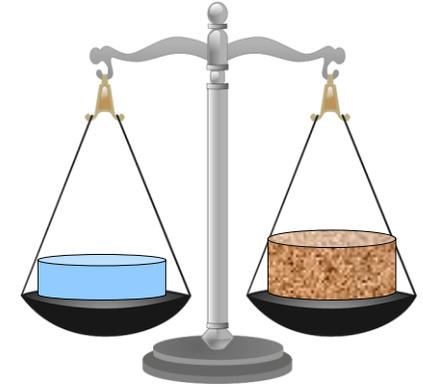
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- Methods for measuring soil water content
- NMR methodology
- NMR results for investigating PFAS
- Lessons learned
- Other geophysical strategies

# MEASURING WATER CONTENT IN SOIL

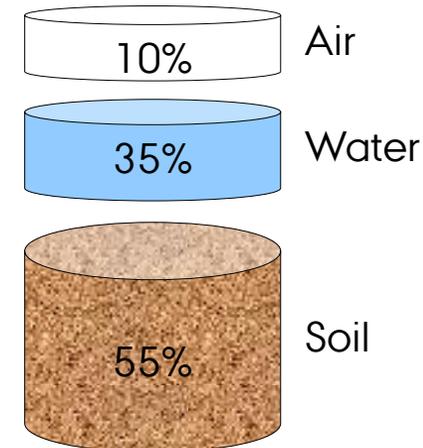
## Gravimetric Method (Oven Drying) – gravimetric water content

- Weigh sample – Dry sample – Weigh sample – Tare weight
  - Not affected by soil texture or salinity
  - Considered the “ground truth”
  - Cannot be done in the field + Time-consuming + Need for sample
  - No temporal variability



## *In-situ* Time-Domain Reflectometry (TDR) Sensors – volumetric water content

- Water has a much higher dielectric constant (~80) compared to soil solids (3–7) and air (1).
  - Instant recordings + non-destructive + time-lapse
  - Affected by soil texture, salinity, and calibration
  - Requires good soil-probe contact

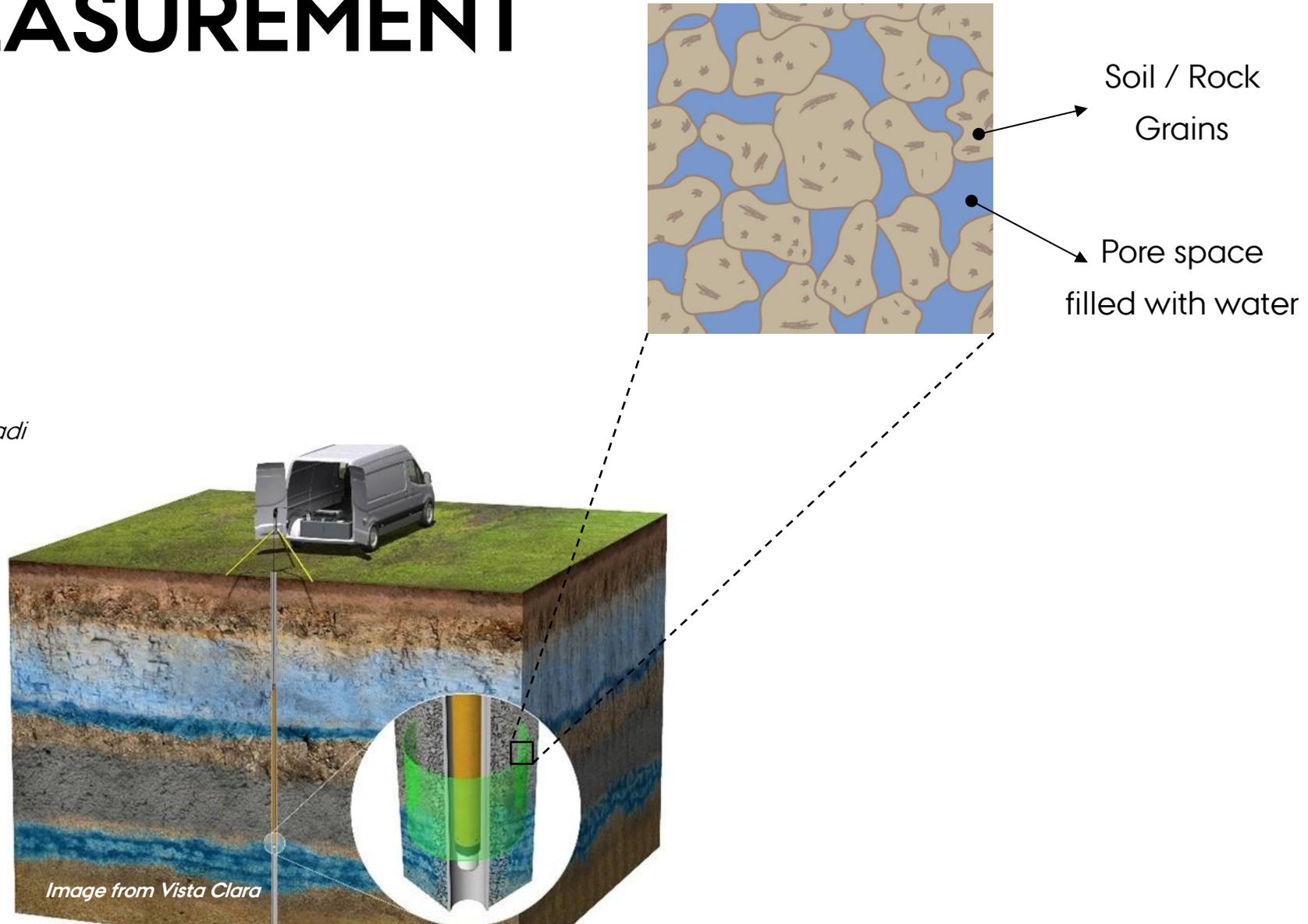


## *In-situ* Nuclear Magnetic Resonance – volumetric water content

- Measures hydrogen nuclei in water molecules
  - Direct measure of water content + non-destructive + time-lapse
  - Sensitive to bound vs. free water and pore size distribution
  - Limited information around the borehole

# NMR MEASUREMENT

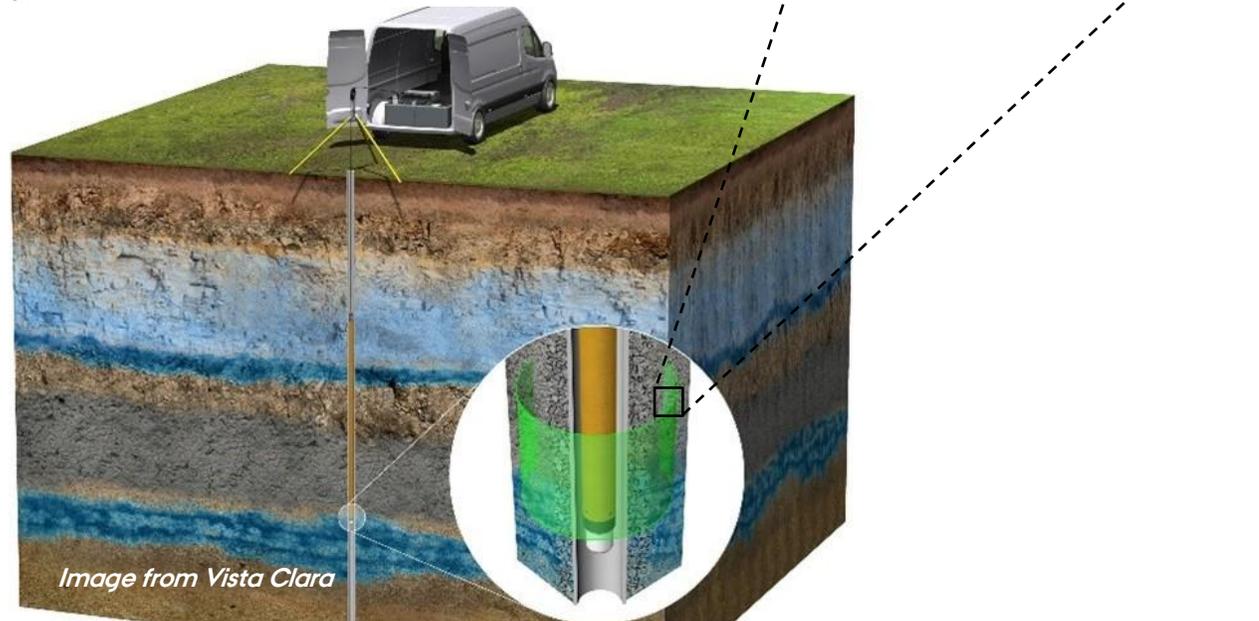
*Graph provided by Reza Mashhadi*



# NMR MEASUREMENT

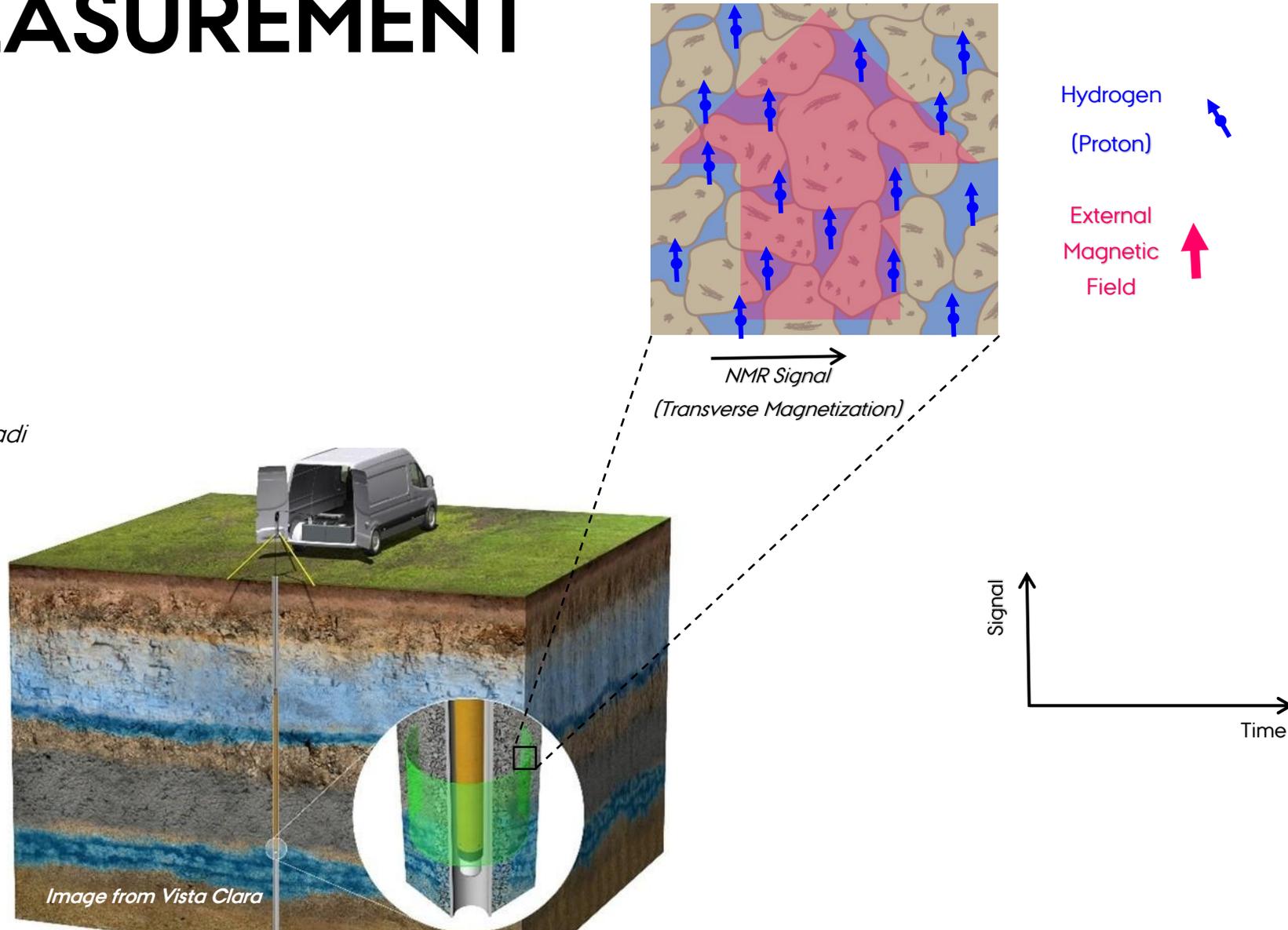
Hydrogen  
(Proton) 

*Graph provided by Reza Mashhadi*



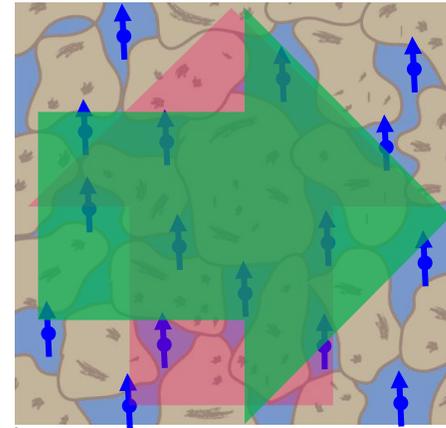
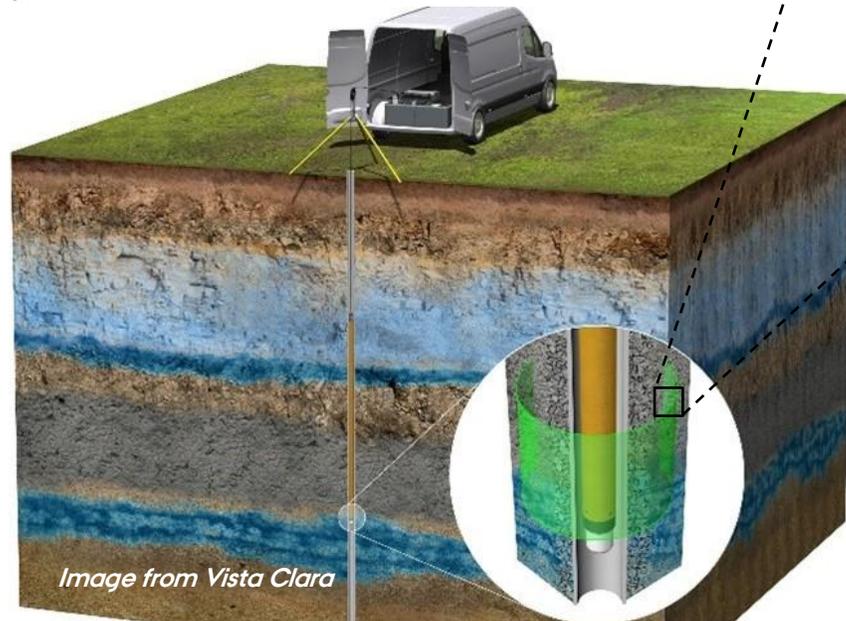
# NMR MEASUREMENT

Graph provided by Reza Mashhadi



# NMR MEASUREMENT

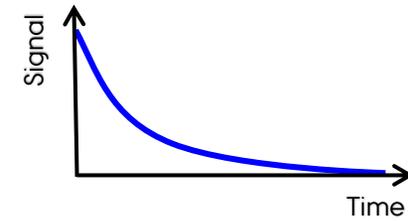
Graph provided by Reza Mashhadi



Hydrogen  
(Proton)

External  
Magnetic  
Field

Oscillating  
Magnetic  
Field



# NMR BACKGROUND

NMR signal originates from water

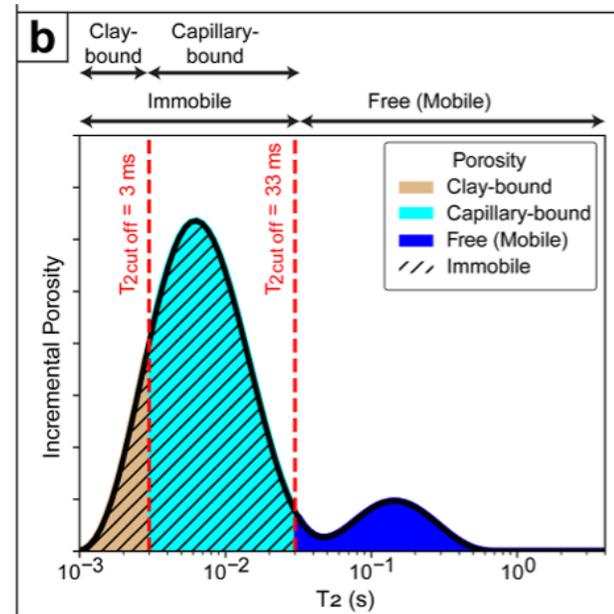
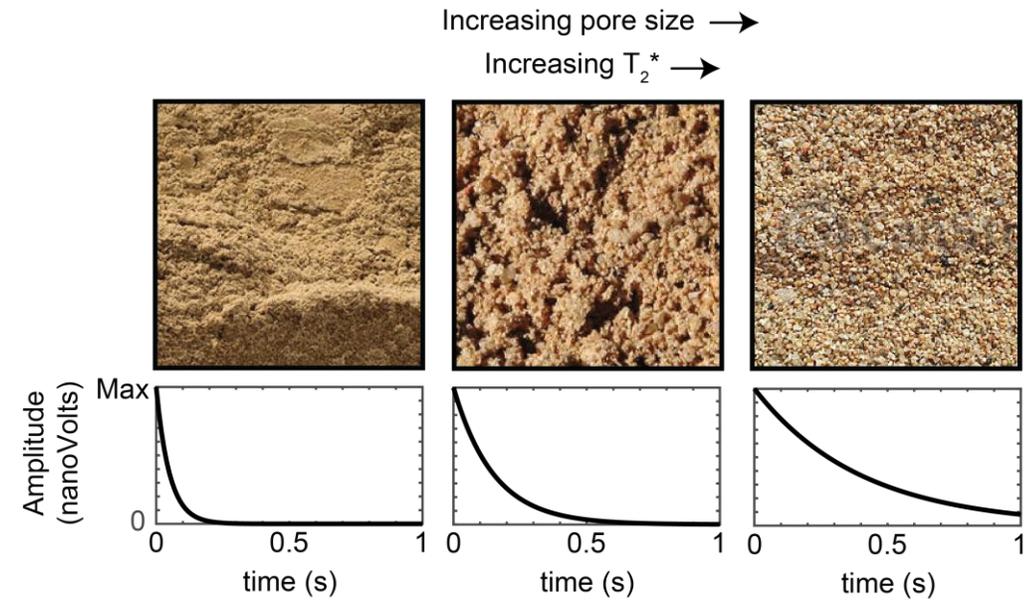
- amplitude -> porosity or water content
- time-dependence -> pore-sizes/permeability

In fully saturated soil:

- NMR water content (or porosity)  $\approx$  Total water content (or porosity)

In partially saturated soil:

- NMR measures only water moisture or water-filled porosity



*Smaller pores  $\rightarrow$  higher  $S/V \rightarrow$  shorter  $T_2$*

# THE DART TOOL

*Diameter: 1.40in (36mm)*

*Length: 61in (155cm)*

*Weight: 7lb (3.2Kg)*

Sensitive Diameters (from tool center):

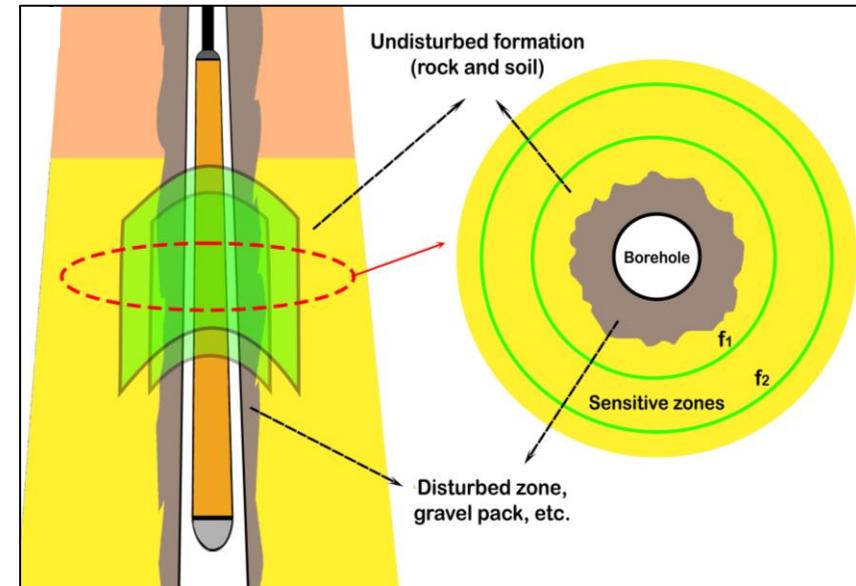
Frequency 1: 13cm

Frequency 2: 15 cm

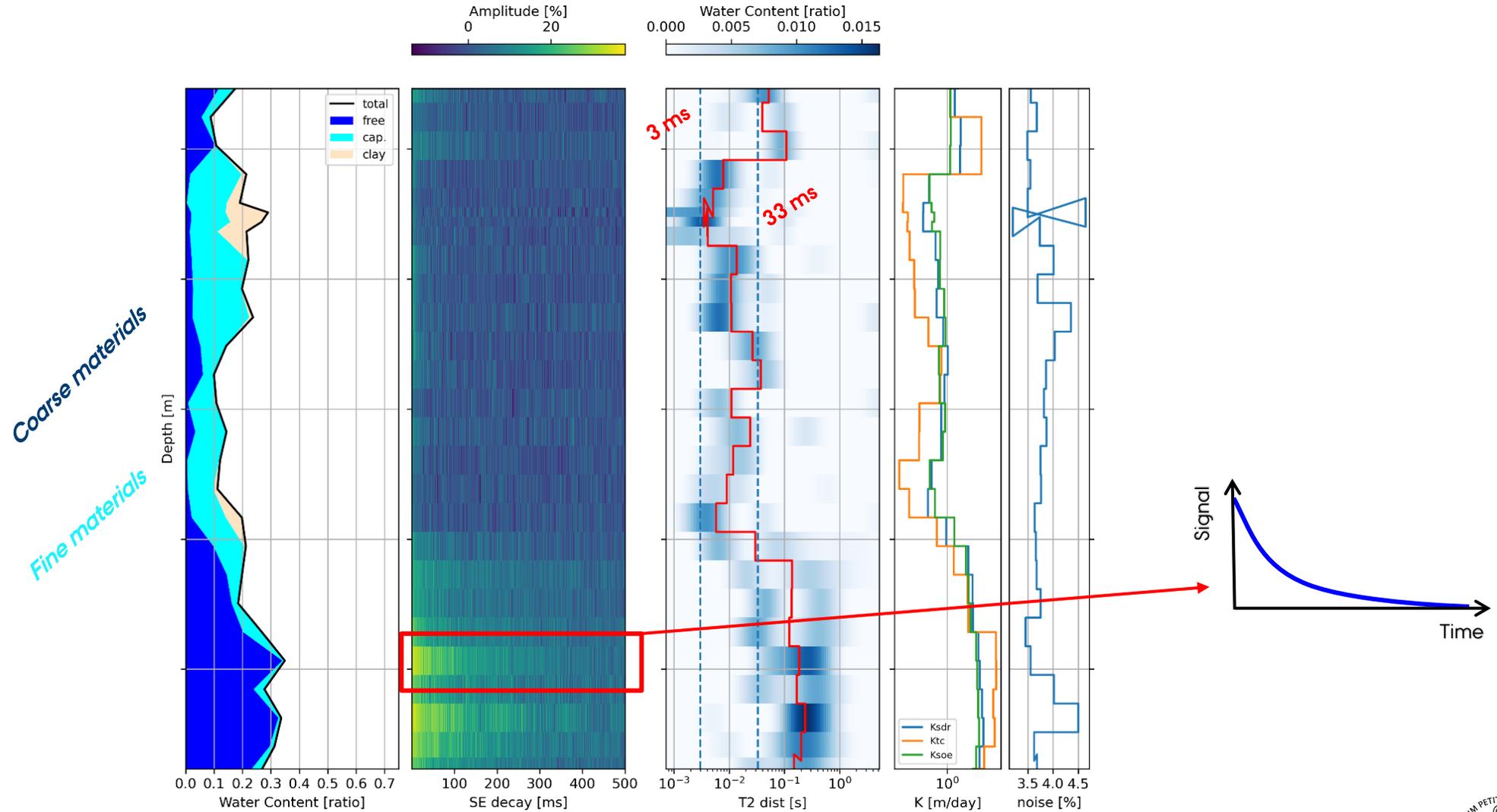
Vertical Resolution: 22 cm

Data measurement rate: **~9m/hour**

Compatible with narrow boreholes (<6-8 cm diameter) and with direct push (Geoprobe)



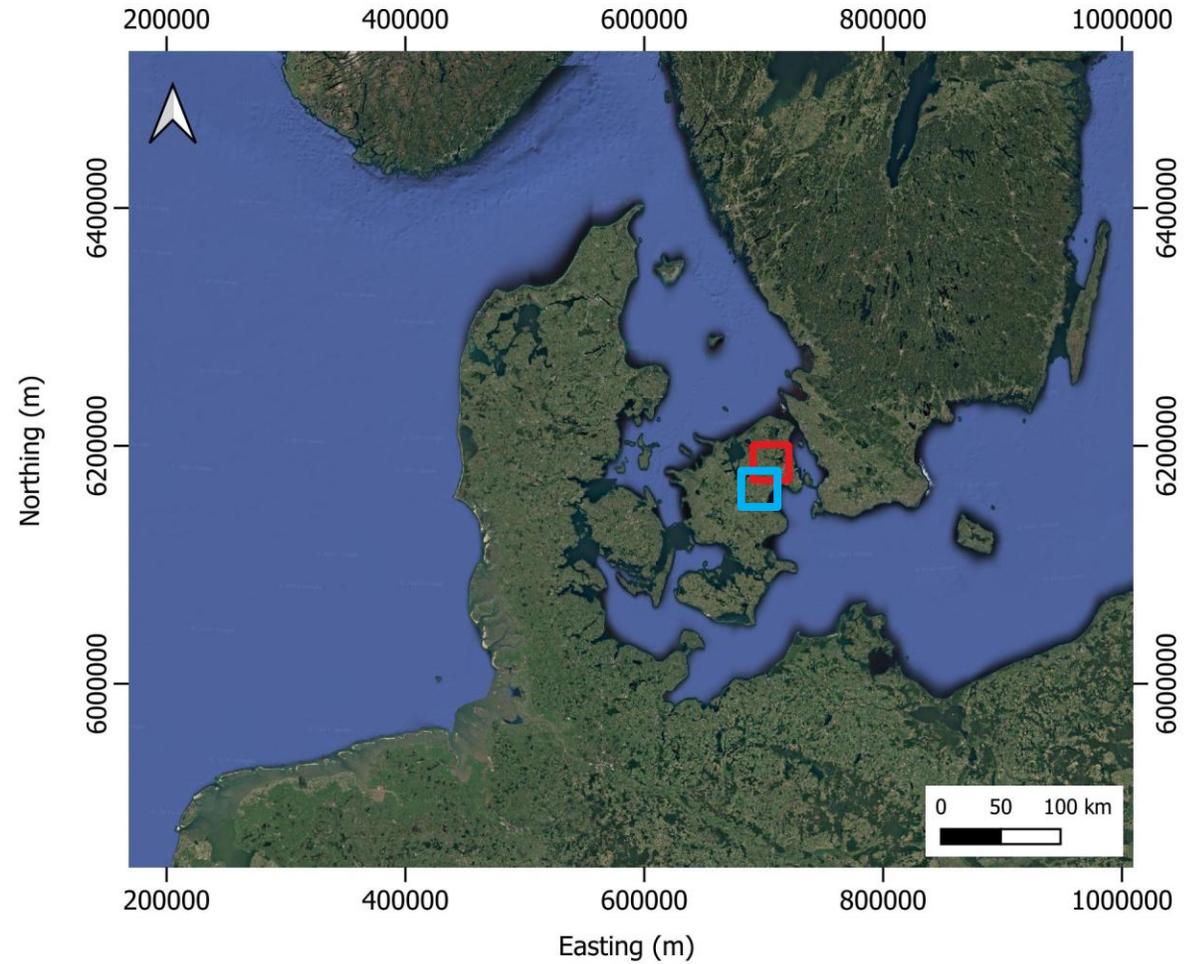
# B-NMR EXAMPLE



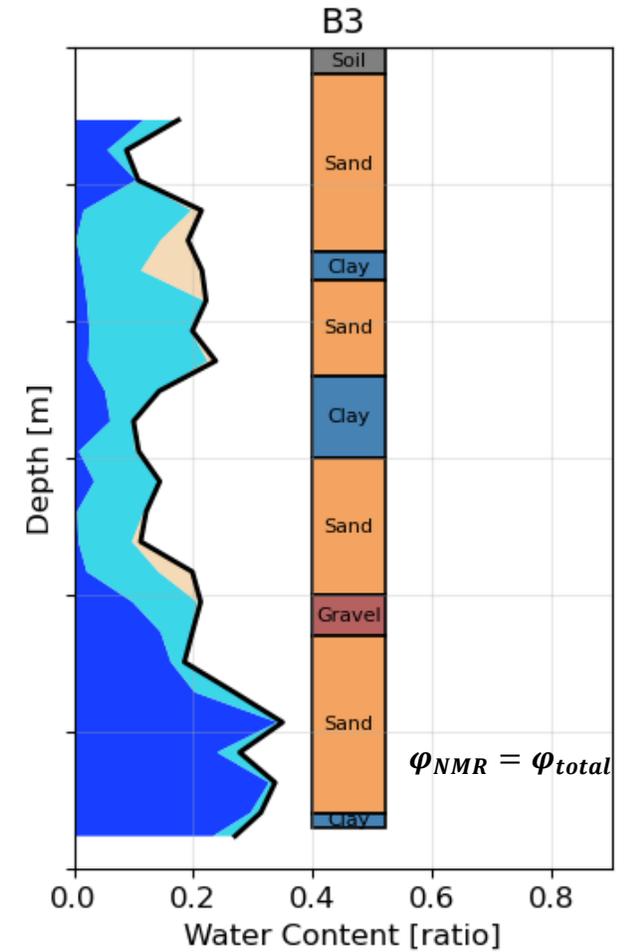
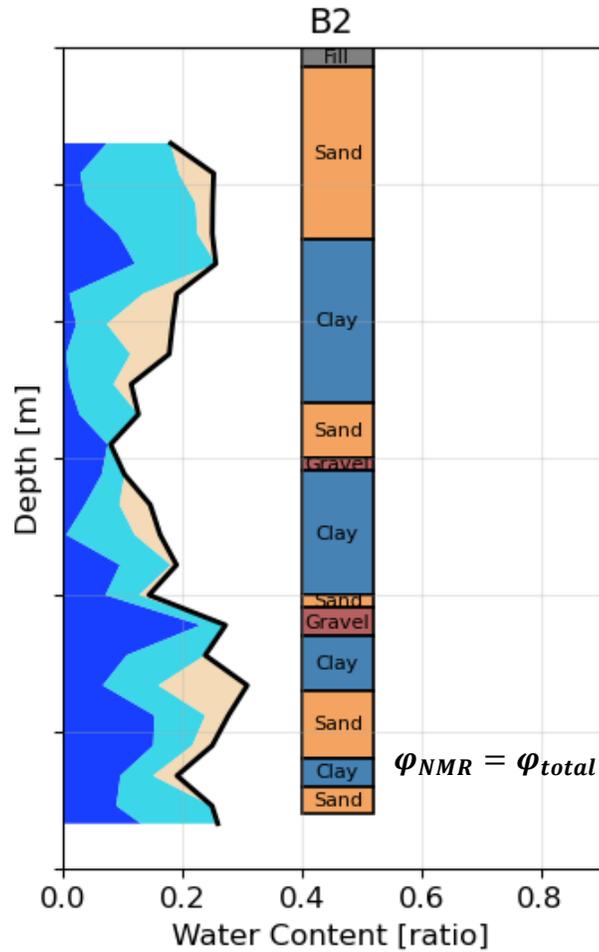
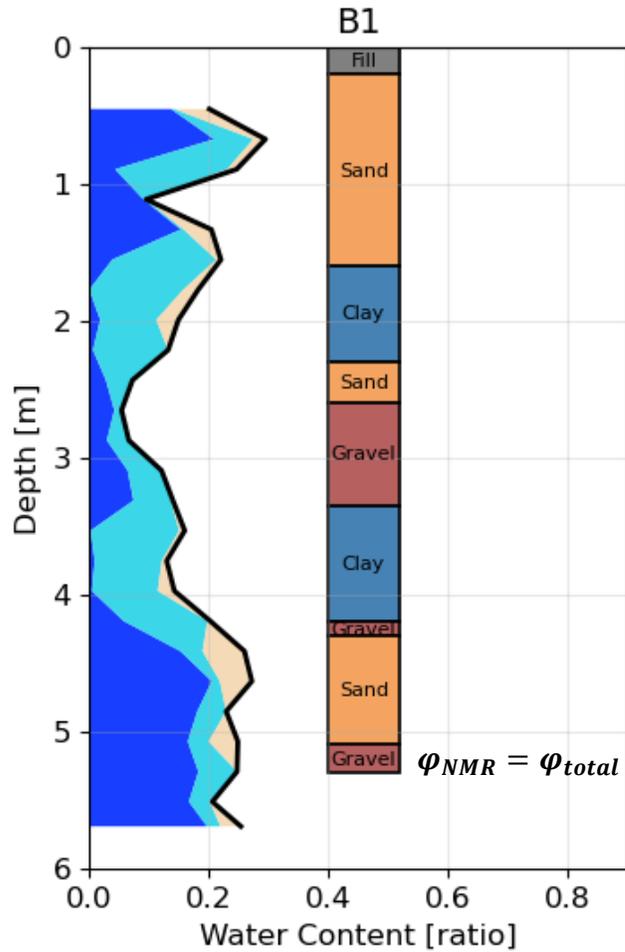
# SURVEY AREAS

## Site 1

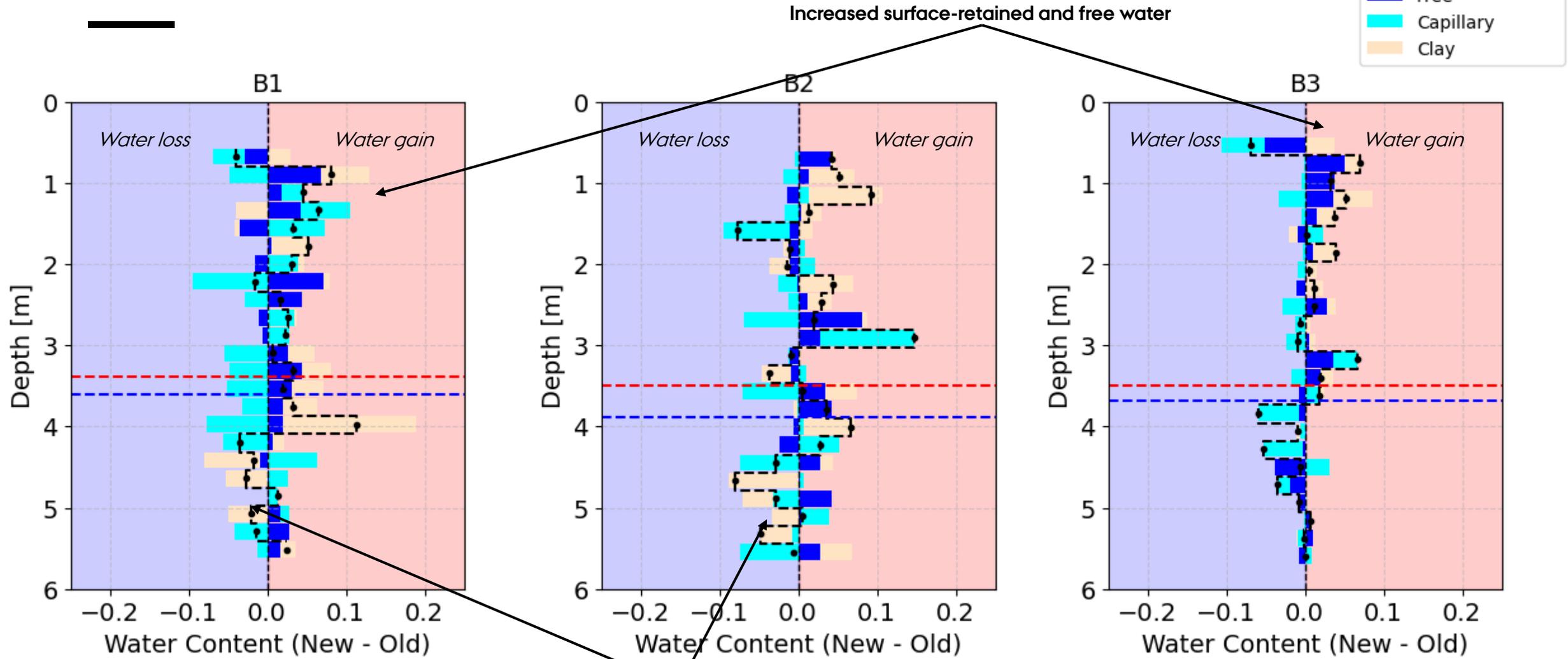
- Three boreholes
- 4-6 m separated
- Nov/Mar/Jun/Sep
- Length ~6 m
- 22 cm interval



# NOVEMBER 2024

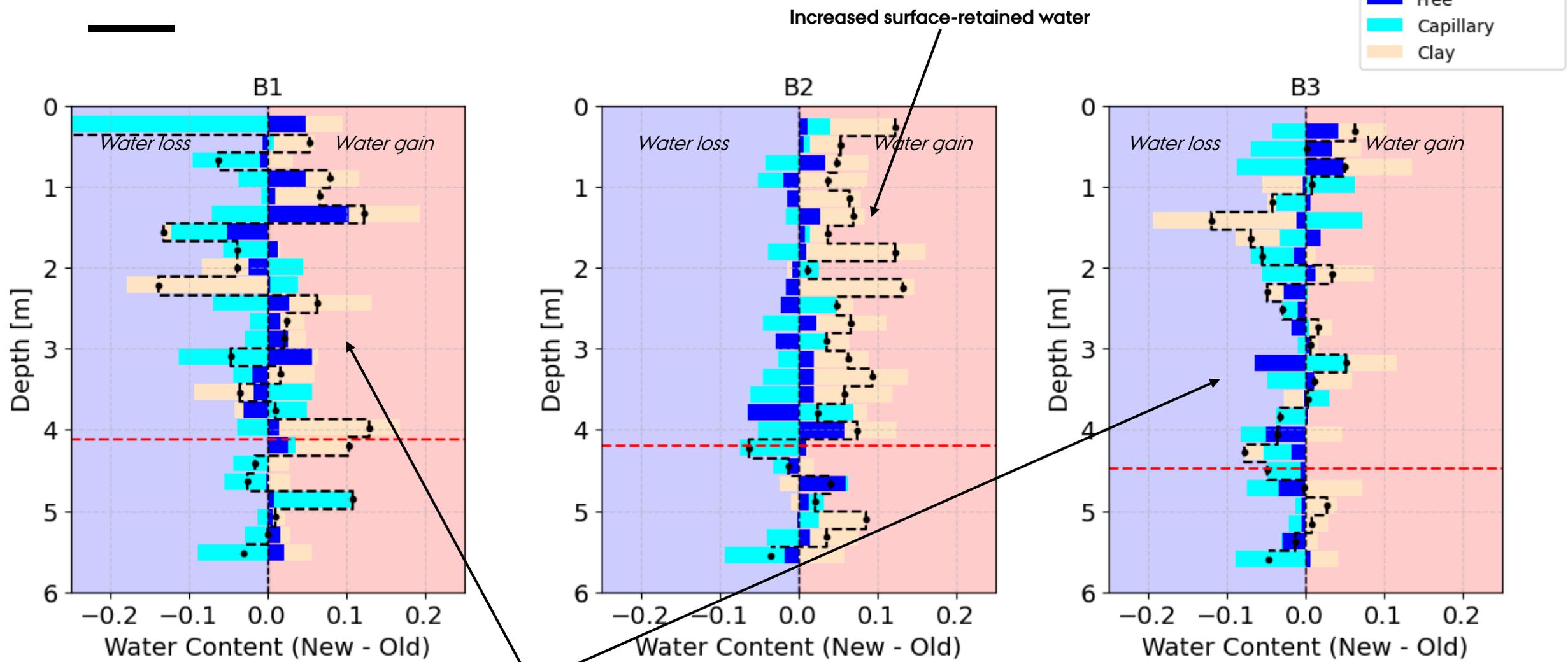


# MARCH 2025



Small desaturation? entrapped gas? temperature effect?

# SEPTEMBER 2025

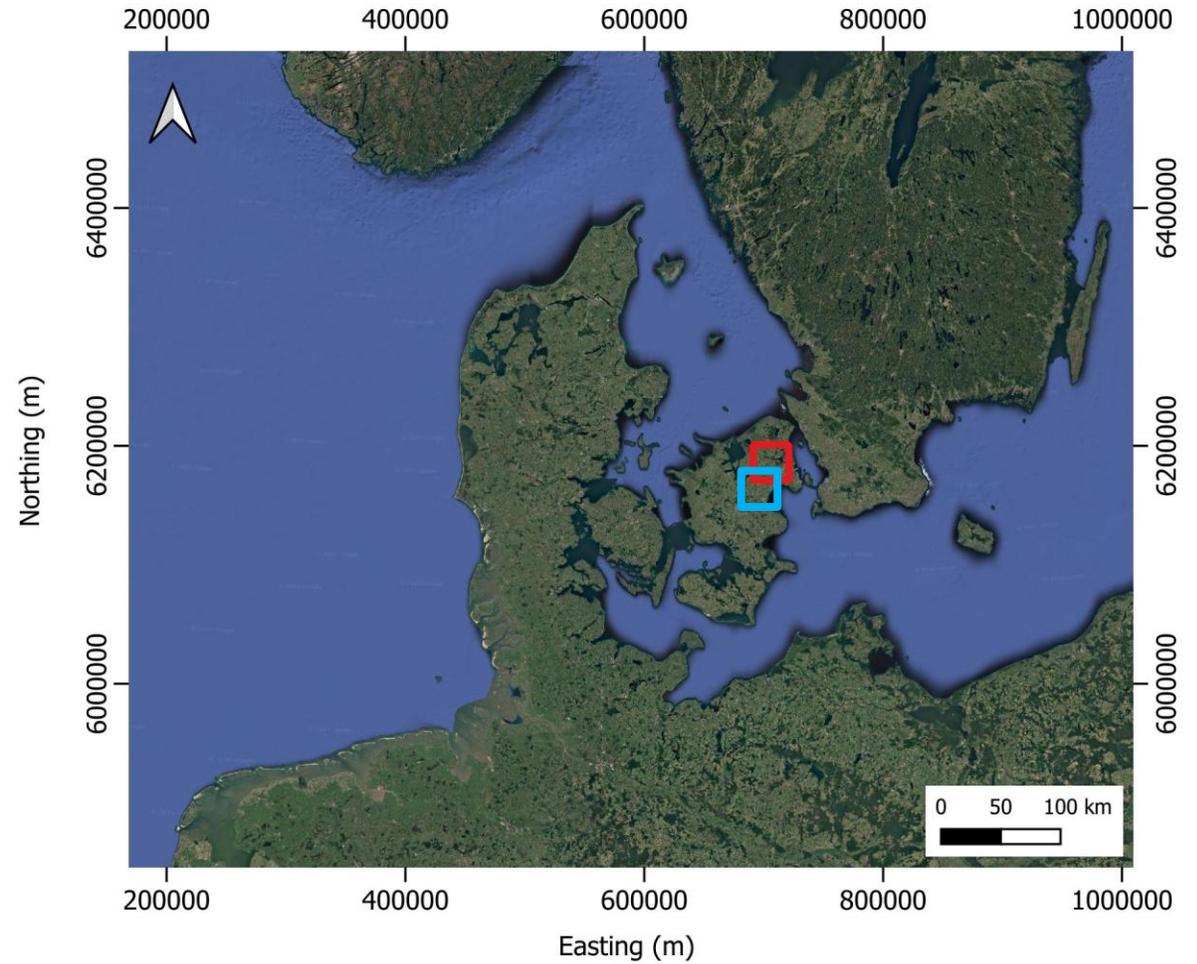


structural flow or preferential redistribution?

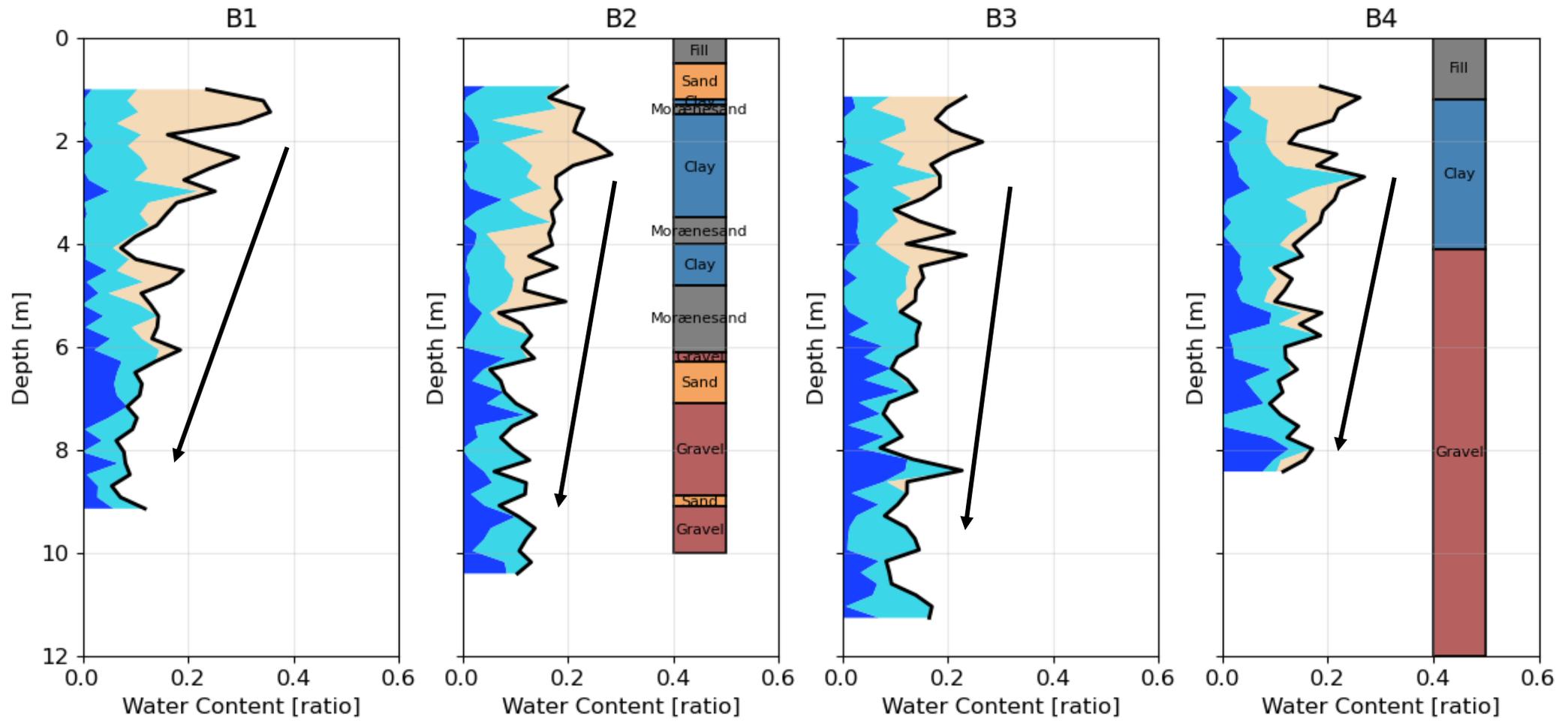
# SURVEY AREAS

## Site 2

- Four boreholes
- 4-6 m separated
- Mar/Jun/Sep
- Length ~12 m
- 22 cm interval
- Unsaturated zone



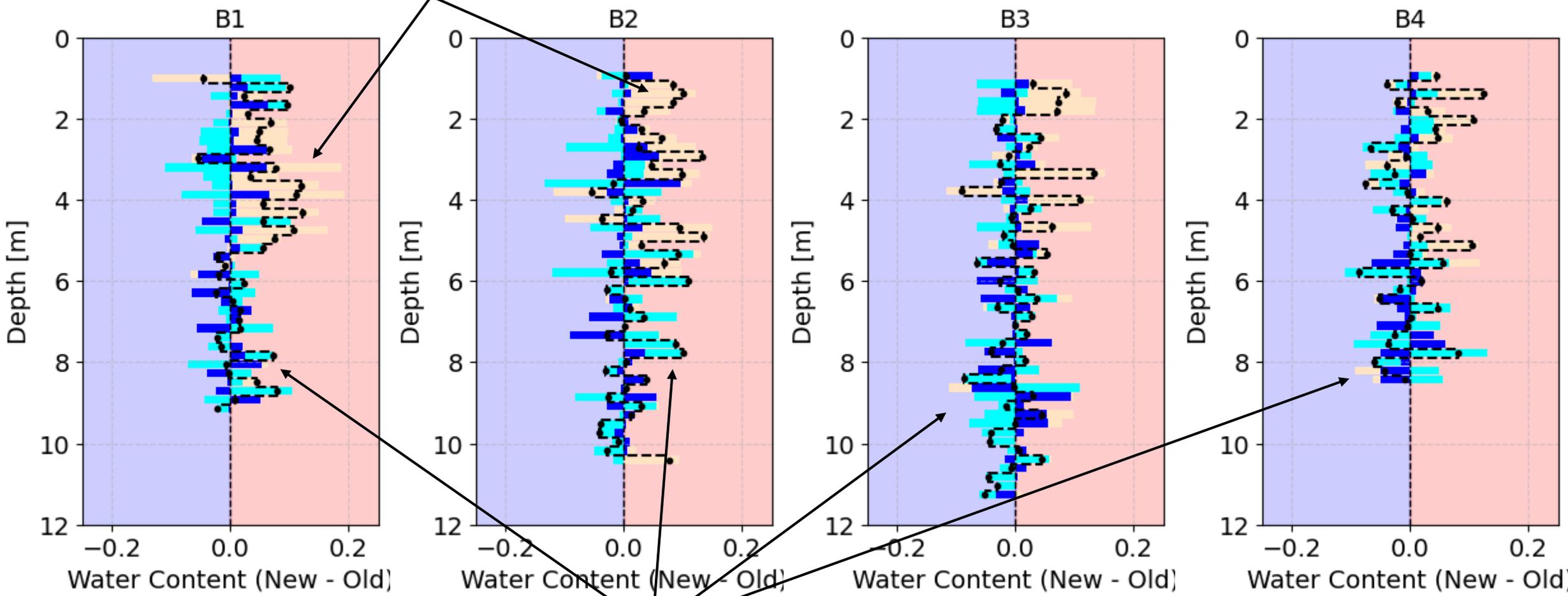
# MARCH 2025



# JUNE 2025



Increased surface-retained water



Changes in capillary-bound and free water

# LESSONS LEARNED

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Rapid on-site data collection: 1-2 hours per borehole

Provides information about:

- porosity,
- pore size distribution, and
- distribution of immobile and mobile water

**Water content + porosity → useful for PFAS investigations**

Follows heterogeneity in the vadose zone at meter scale

NMR supports monitoring:

- changes in water content over time
- (re)-distribution of water

# GEOPHYSICAL STRATEGIES TO ESTIMATE SOIL PROPERTIES

Electrical resistivity tomography (ERT)  
Spectral induced polarization (SIP):

- Grain size distribution
- Water content
- Saturation

Stronger links between geophysics and other methods – more research studies

Applied Clay Science 43 (2009) 493–502

Contents lists available at ScienceDirect

Applied Clay Science

journal homepage: [www.elsevier.com/locate/clay](http://www.elsevier.com/locate/clay)

Non-invasive monitoring of water content and textural changes in clay-rocks using spectral induced polarization: A laboratory investigation

A. Ghorbani <sup>a,h,\*</sup>, Ph. Cosenza <sup>c</sup>, A. Revil <sup>d,e,f</sup>, M. Zamora <sup>a</sup>, M. Schmutz <sup>g</sup>, N. Florsch <sup>h</sup>, D. Jougnot <sup>d,f</sup>

Journal of Hydrology

Volume 643, November 2024, 131994

Research papers

Quantification of soil water content by machine learning using enhanced high-resolution ERT

Fansong Meng <sup>a</sup>, Jinguo Wang <sup>a</sup>, Yongsheng Zhao <sup>a</sup>, Zhou Chen <sup>a</sup>

Journal of Hazardous Materials

Volume 480, 5 December 2024, 135829

Spectral induced polarization (SIP) measurements across a PFAS-contaminated source zone

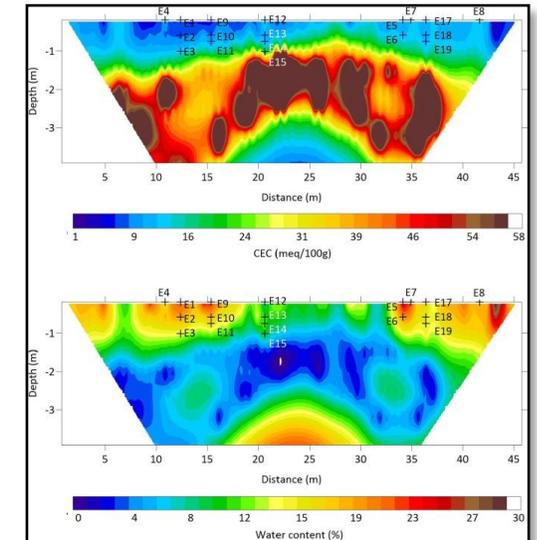
Ethan Siegenthaler <sup>a</sup>, Sam Falzone <sup>a</sup>, Charles Schaefer <sup>b</sup>, Dale Werkema <sup>c</sup>, Lee Slater <sup>a,d</sup>

Geoderma

Volume 403, 1 December 2021, 115380

Field-scale estimation of soil properties from spectral induced polarization tomography

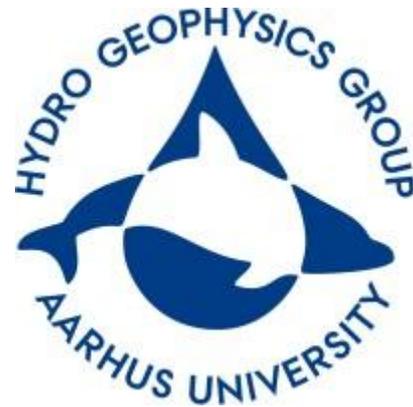
A. Revil <sup>a</sup>, M. Schmutz <sup>b</sup>, F. Abdulsamad <sup>c</sup>, A. Balde <sup>b,d</sup>, C. Beck <sup>e</sup>, A. Ghorbani <sup>f</sup>, S.S. Hubbard <sup>d</sup>



$$\theta = \left[ \frac{1}{\sigma_w} \left( \sigma_\infty - \frac{M_n}{R} \right) \right]^{1/m}$$

$$\text{CEC} = \frac{M_n}{\theta^{m-1} \rho_g \lambda}$$

# ACKNOWLEDGMENTS



# THANK YOU FOR YOUR ATTENTION

Questions?



AARHUS  
UNIVERSITY