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2024

Document Version:
Publisher's PDF, also known as Version of record

Link to publication

Citation for published version (APA):
Martin, T., Günther, T., Weller, A., Kass, A., Grombacher, D., Butron, C., Mendoza, A., & Dahlin, T. (2024). *Estimating hydraulic properties from IP and NMR measurements at field and laboratory scale*. Poster session presented at 7th International IP workshop, Lund, Sweden.

Total number of authors:
8

Estimating hydraulic properties from IP and NMR measurements at field and laboratory scale

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Motivation

- Infrastructure projects depend on reliable subsurface characterization.
- Information about groundwater is crucial to protect resources and avoid stability problems.
- Development of a reliable methodology for spatially mapping the aquifer properties.

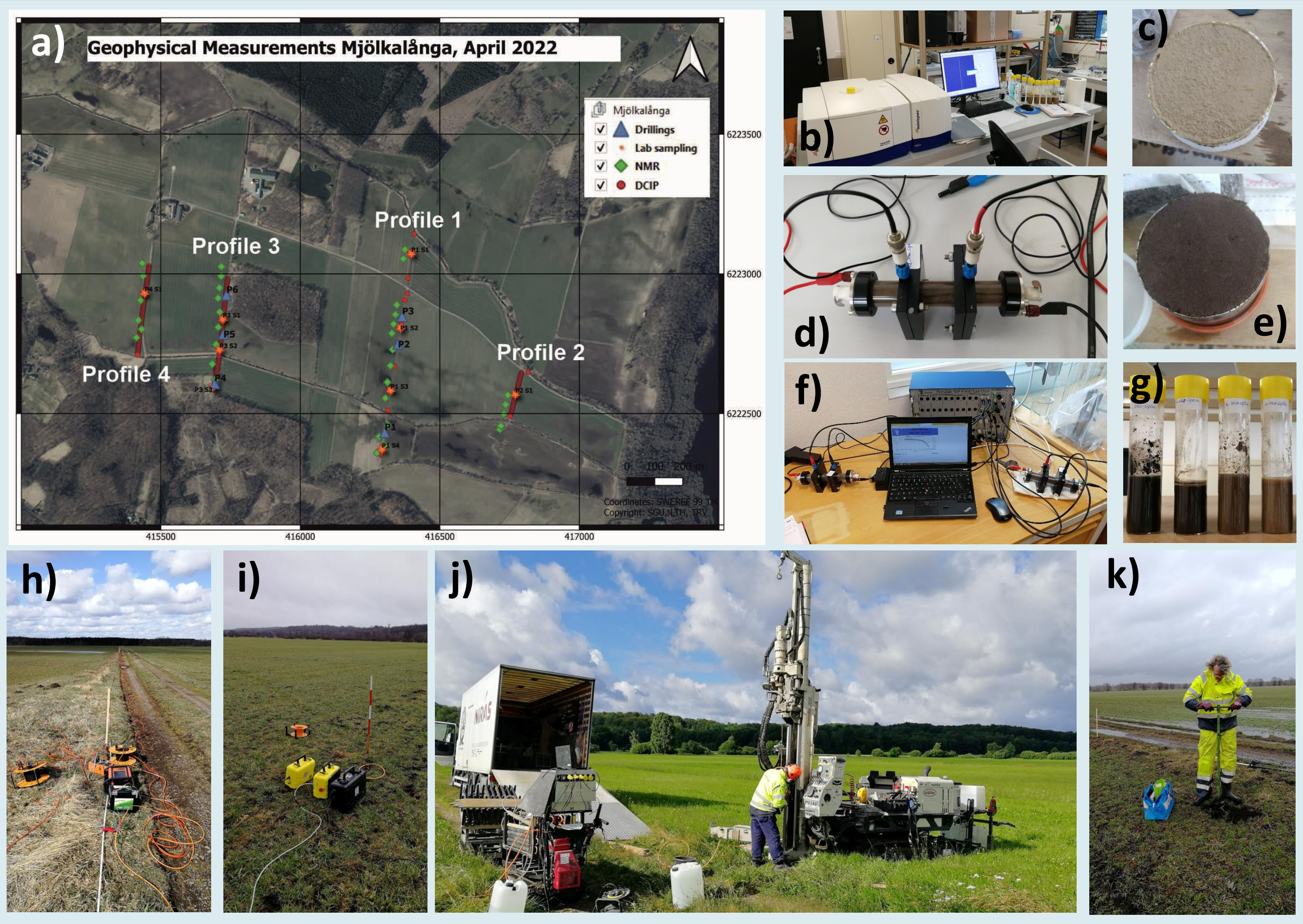


Fig. 1: a) Testsite Mjölkalånga in the South of Sweden with profiles and drilling points, b) – g) laboratory measurements with NMR (b) and SIP (f) as well as field measurements, h) DCIP, i) MRS, j) HPT & slug tests, k) auger drilling.

Material & Methods

- Test site Mjölkalånga: post glacial sediments, low anthropogenic noise level
- Using DCIP (direct current induced polarisation), MRS (magnetic resonance sounding), hydraulic profiling tool (HPT) and slug tests in the field
- SIP, NMR and *K*-measurements in the lab
- Calculation of hydraulic conductivity *K* [m/s] based on equations

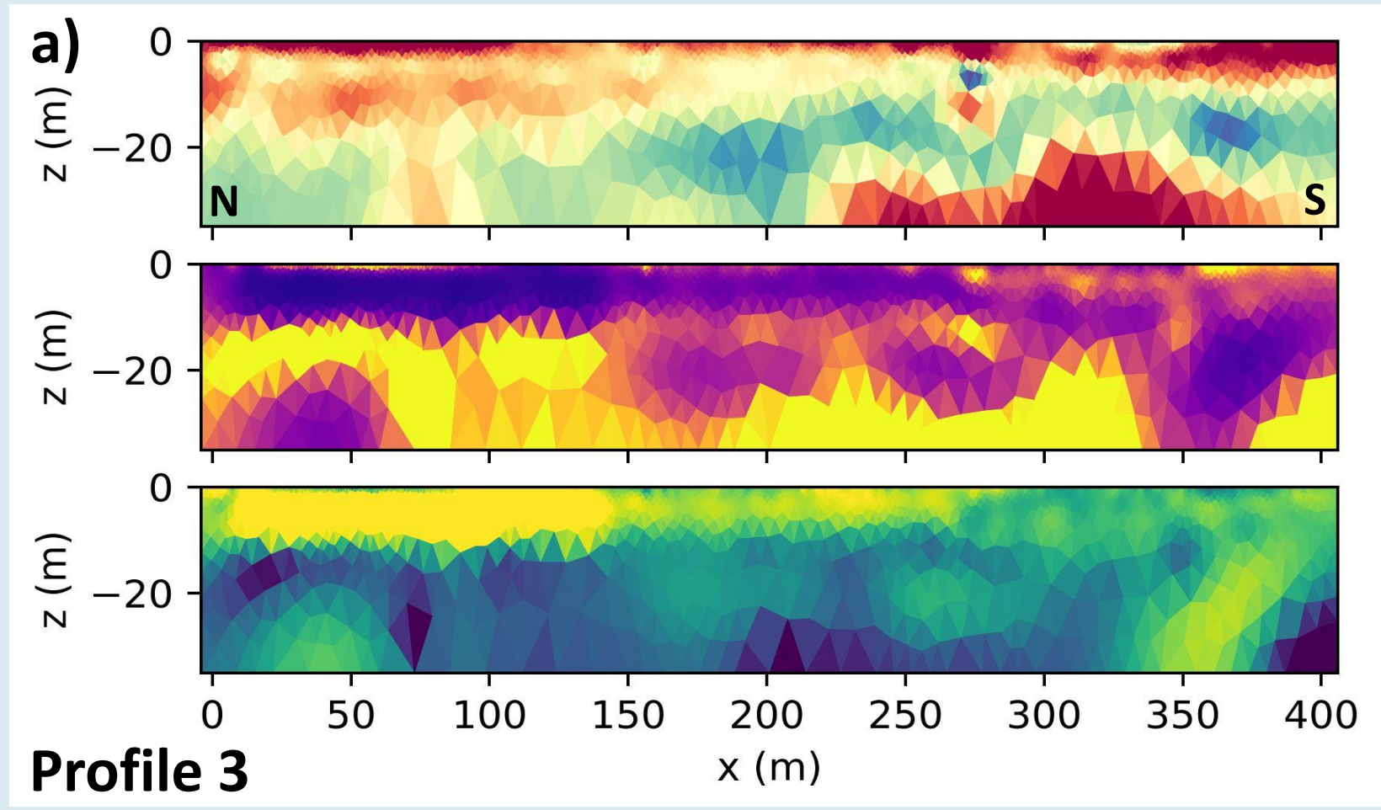
$$K_{SIP} = \frac{3.47\ 10^{-9}\ \sigma_0^{1.11}}{\sigma''^{2.41}} \qquad \text{(Weller et al. 2015)}$$

$$K_{NMR} = b\ \phi\ T_{2ML}^2 \qquad \text{(Knight et al. 2016)}$$

with σ'' = imaginary conductvity [mS/m], σ_0 = low frequency conductvity [mS/m], b = 0.654 (after calibration), Φ = porosity, T_{2ML} = relaxation time [s]

Field measurements

- Both DCIP profiles show variation and a general trend of decreasing resistivities with depth → coarse sandy material on top, clayey parts at depth
- Calculated hydraulic conductivity *K* decreases with depth and increasing total chargeability (Fig. 2)



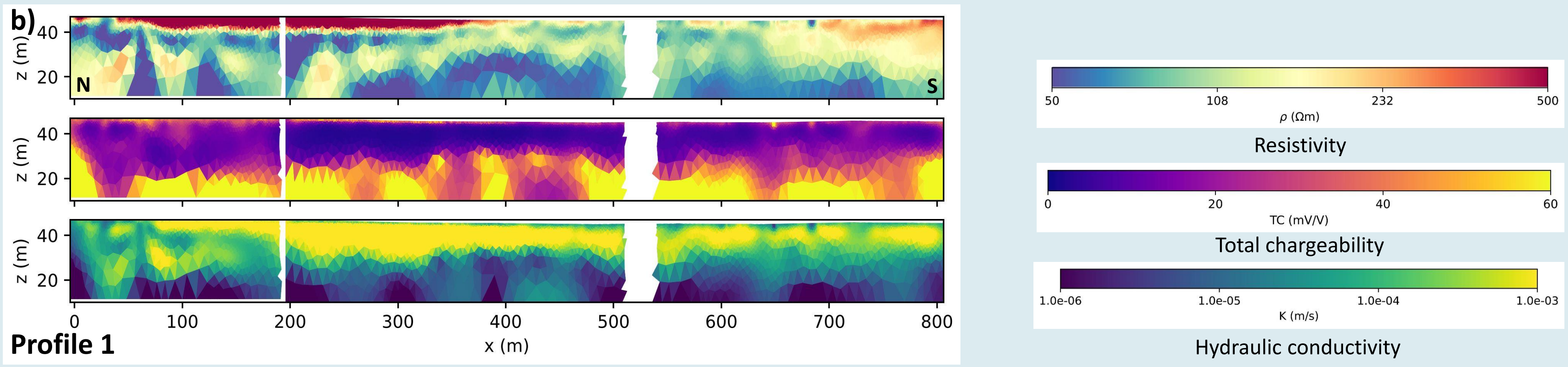
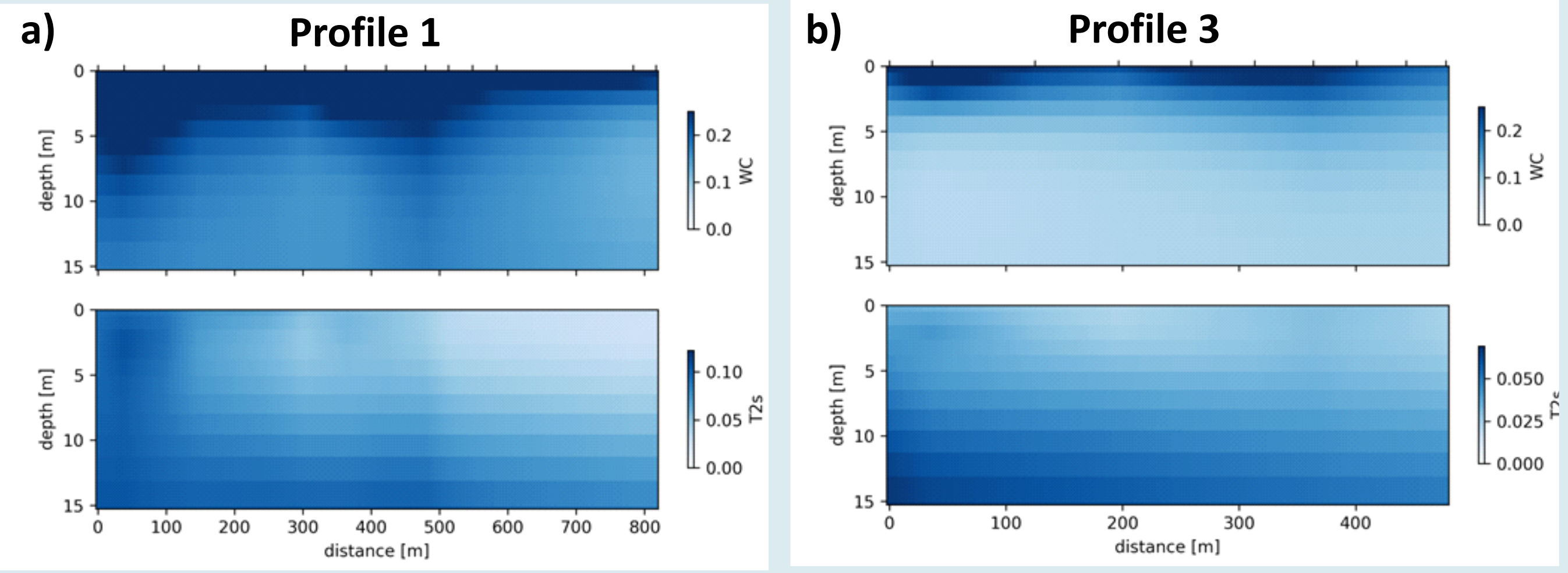


Fig. 2: DCIP results for profile 3 (a) and profile 1 (b). Top: resistivity ρ, middle: total chargeability TC, bottom: hydraulic conductivity K. Respective colour scales to the right.



- MRS results show decreasing water content (WC) and increasing relaxation time (T2s) with depth (Fig. 3)

Fig. 3: MRS results in Mjölkalånga for a) profile 1 and b) profile 3.

Laboratory measurements

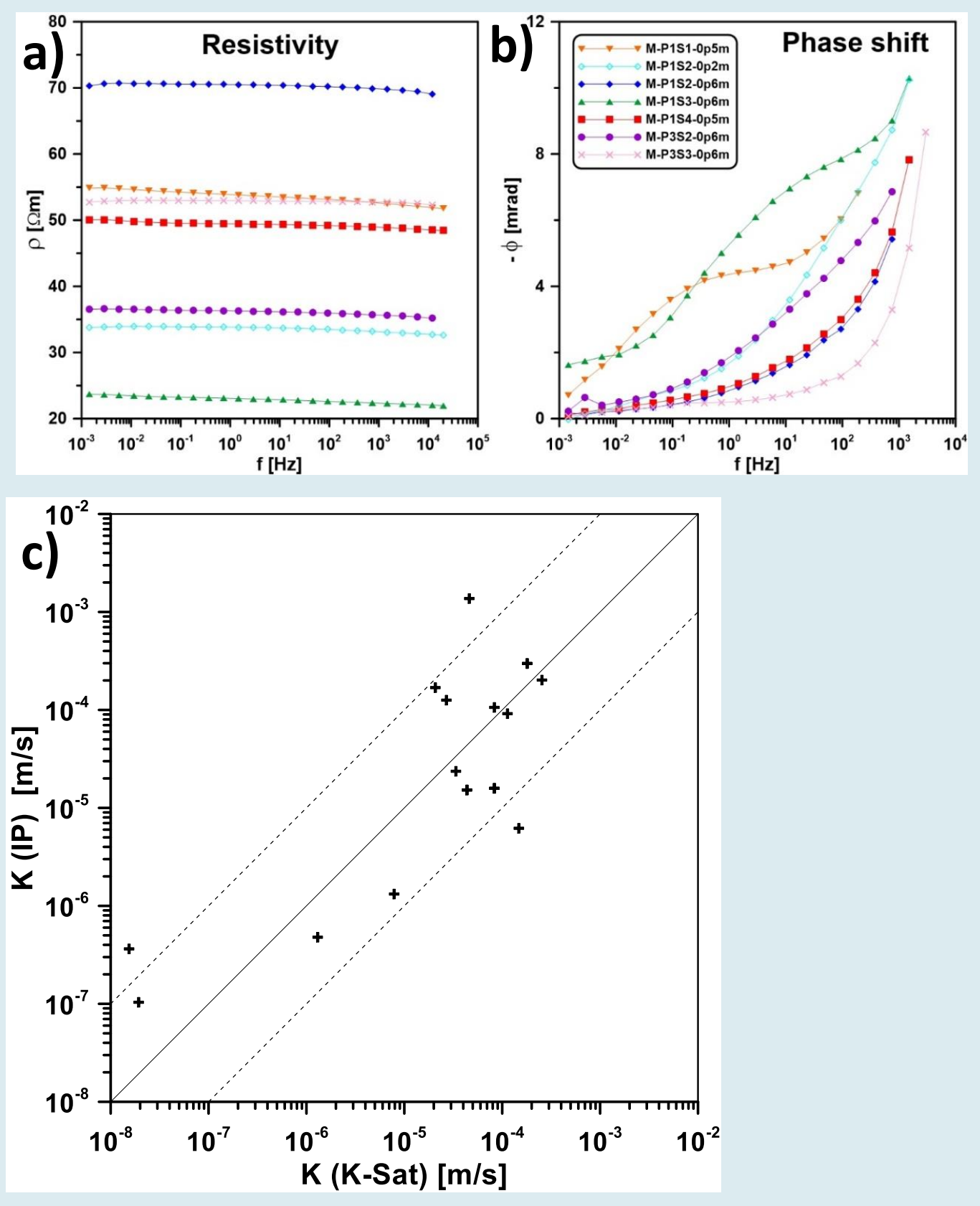


Fig. 5: SIP results for different samples, a) resistivity, b) phase shift and c) cross plot of K from SIP and measured K after calibration.

- SIP results show variations in both resistivity (Fig. 5a) and phase shift (Fig. 5b)
- Crossplot for K_{IP} ~ *K* shows good correlation (Fig. 5c) after calibration
- NMR results for different samples show variations (Fig. 6a)
- Crossplot K_{NMR} ~ *K* shows moderate correlation (Fig. 6b) after calibration

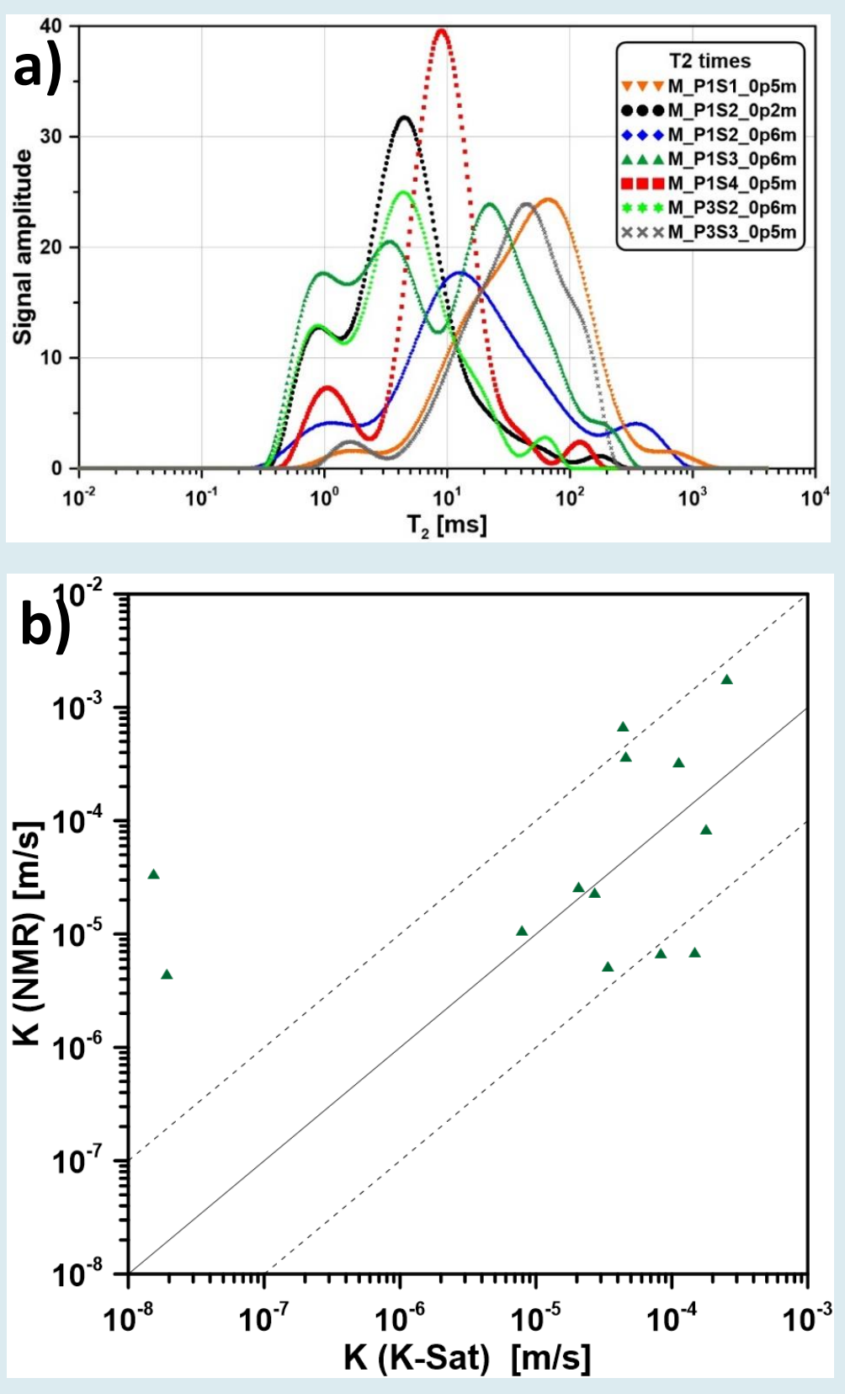


Fig. 6: a) NMR relaxation time distribution for different samples, b) cross plot of K from NMR and measured K after calibration.

Hydraulic testing

- HPT and slug tests reveal decreasing *K*-values with depth (Fig. 4)
- Variations in laboratory *K*-value results (Tab. 1)

Sample	Mode	K [m/s]
Milk_P1_S1-0p5m	CH	4.36E-05
Milk_P1_S2-0p2m	CH	8.31E-05
Milk_P1_S2-0p6m	CH	1.80E-04
Milk_P1_S3-0p2m	CH	2.08E-05
Milk_P1_S3-0p6m	FH	1.54E-08
Milk_P1_S4-0p5m	CH	2.69E-05
Milk_P3_S2-0p6m	CH	3.37E-05
Milk_P3_S3-0p5m	CH	4.62E-05
Milk_P4_S1-0p5m	CH	2.55E-04
Milk_P2_81m-0p5m	CH	1.13E-04

Tab.1 Hydraulic conductivities values based on laboratory K measurements. CH – constant head, FH – falling head.

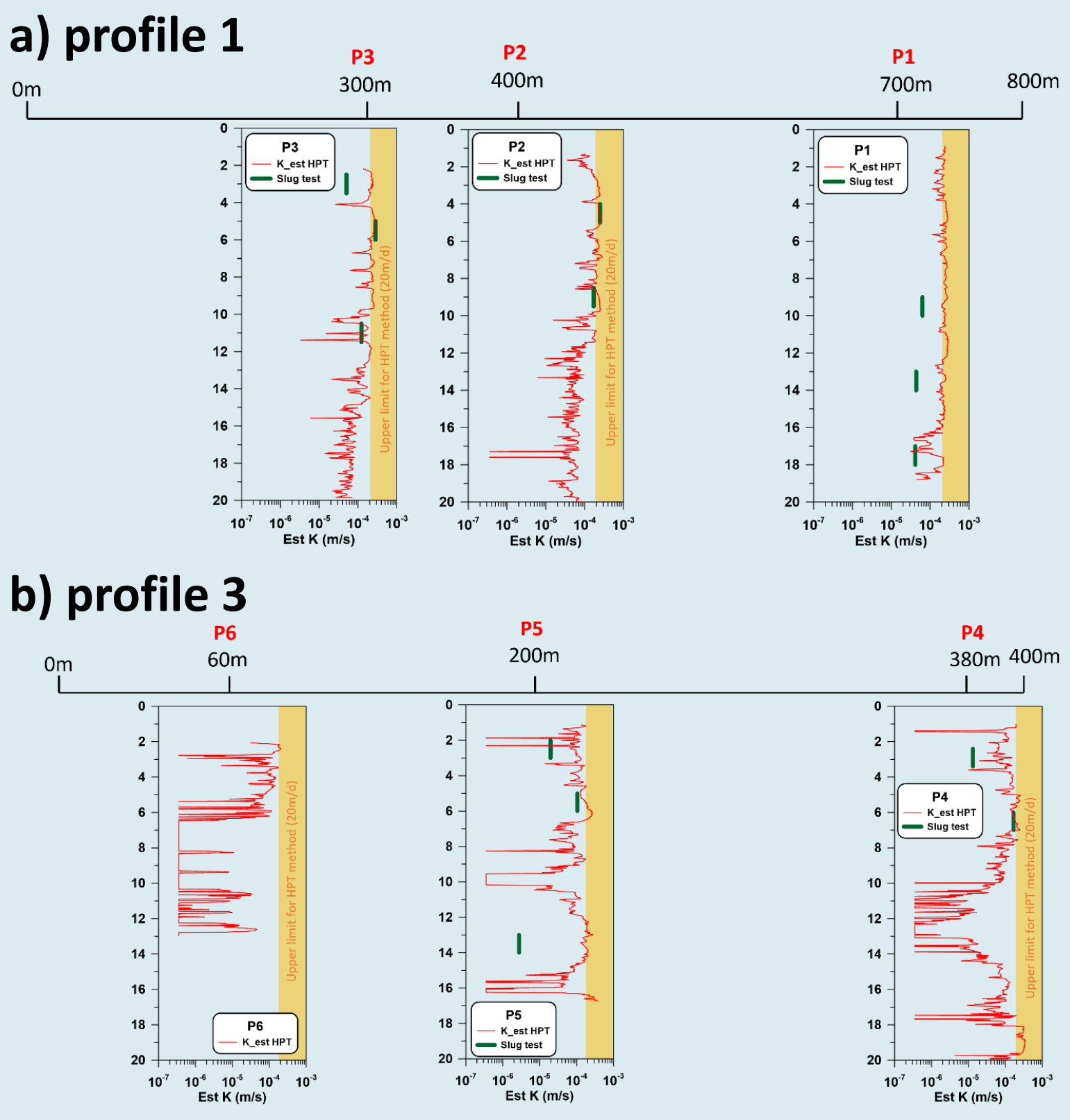


Fig. 4: HPT (red line) and slug test (green bars) results for a) profile 1, b) profile 3.

Comparison

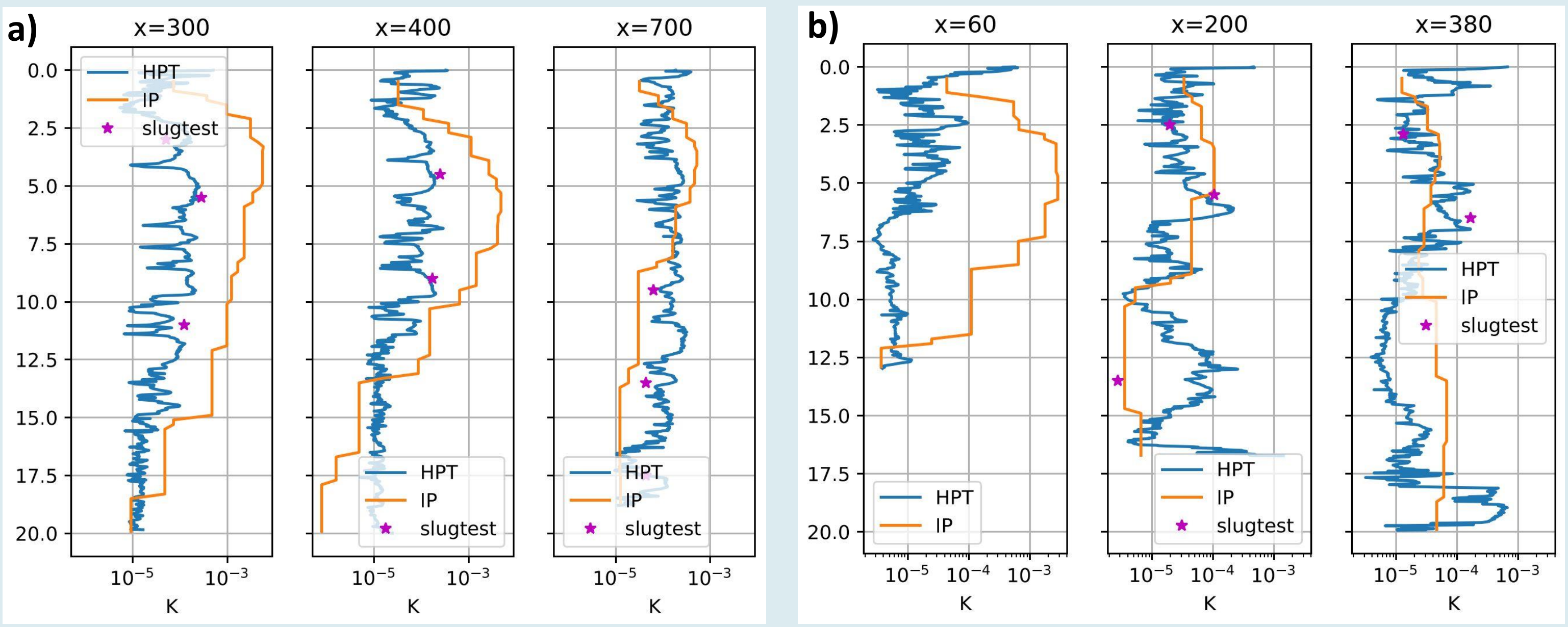


Fig. 7: K-values from HPT (blue line), SIP measurements (orange line) and slug tests (pink stars) for all six boreholes; a) for profile 1, b) for profile 3.

- Calculated K-values from spectral analysis of field TDIP measurements show fair correlation with slug tests and HPT results for each drilling with some overestimated values from spectral IP measurements (Fig. 7)

Discussion & Outlook

- *K* can be calculated from lab IP/NMR parameters within one order of magnitude in the lab
- Deviation caused by variation in the volume of sample material, packing, saturation, and laboratory settings
- New approaches needed to reliably calculate *K* from spectral field TDIP measurements
- Borehole measurements planned, including sampling for laboratory analysis and NMR noise level consideration

References: Weller et al 2015: *Permeability prediction based on induced polarization: Insights from measurements on sandstone and unconsolidated samples spanning a wide permeability range*, Geophysics, 10.1190/GEO2014-0368.1. Knight et al. 2016: *NMR Logging to Estimate Hydraulic Conductivity in Unconsolidated Aquifers*, Groundwater, Vol 54 No.1

Acknowledgement: This research project was funded by Trafikverket, the Swedish transport authority (grant number: 2020/122405). We also thank Kristy Heng, Ulrike Werban, Simon Rejkjaer, Myriam Schmutz, Stephan Costabel, Mike Müller-Petke for their support during field and lab measurements and interpretation.

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International IP WS, May 2024