Induced Polarization and Hydraulic Permeability

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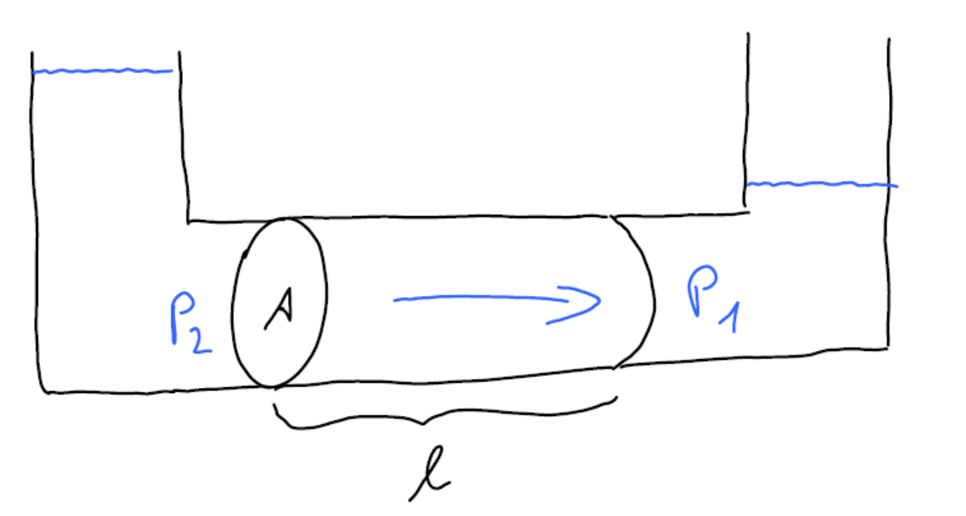
Hydraulic permeability (k)

Darcy's law

$$Q = k \cdot \frac{(p_2 - p_1) \cdot A}{\eta \cdot l}$$



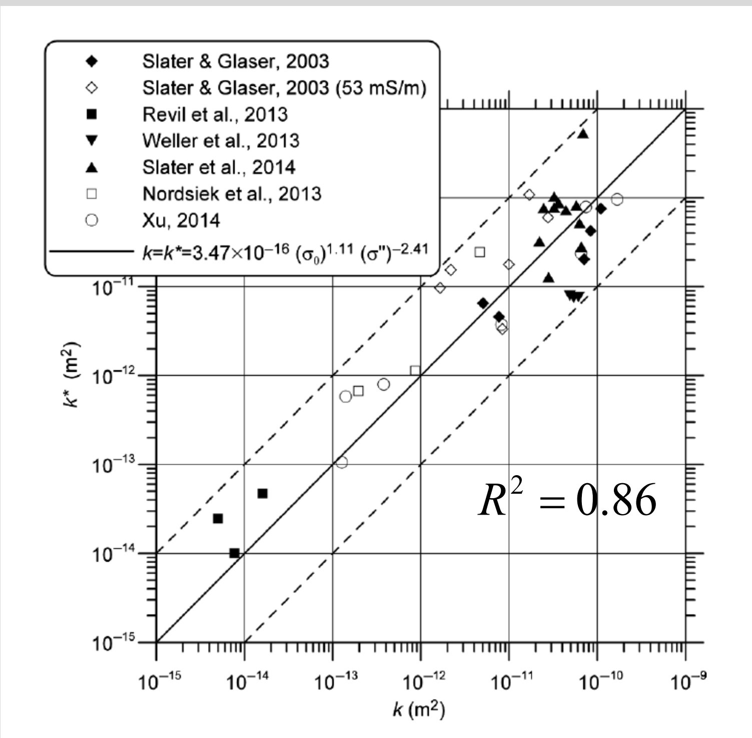
***Q*=discharge *in* m^3/s**
η = viscosity in kg/m·s

***k* = hydraulic permeability in m^2**

$$1 Darcy = 10^{-12} m^2$$

IP vs k: unconsolidated samples

Weller et al. (2015): Correlate *k* directly with $\sigma_0 \, (or \; \sigma_{bulk}) \; and \; \sigma''$

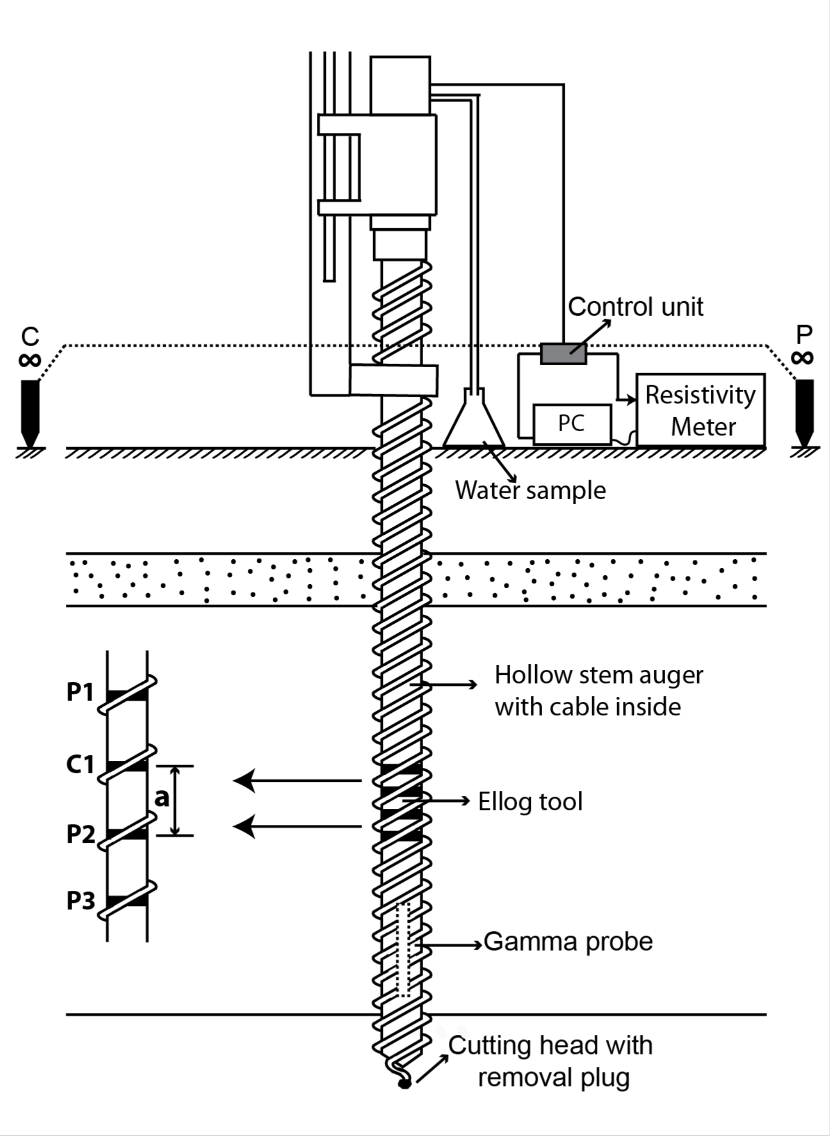


$$k^* = \frac{3.47 \times 10^{-16} \sigma_0^{1.11}}{\sigma''^{2.41}}, \qquad (24)$$

- **Frequency 1 Hz**
- **Water conductivity 0.1 S/**
- **Electrolyte Na Cl**

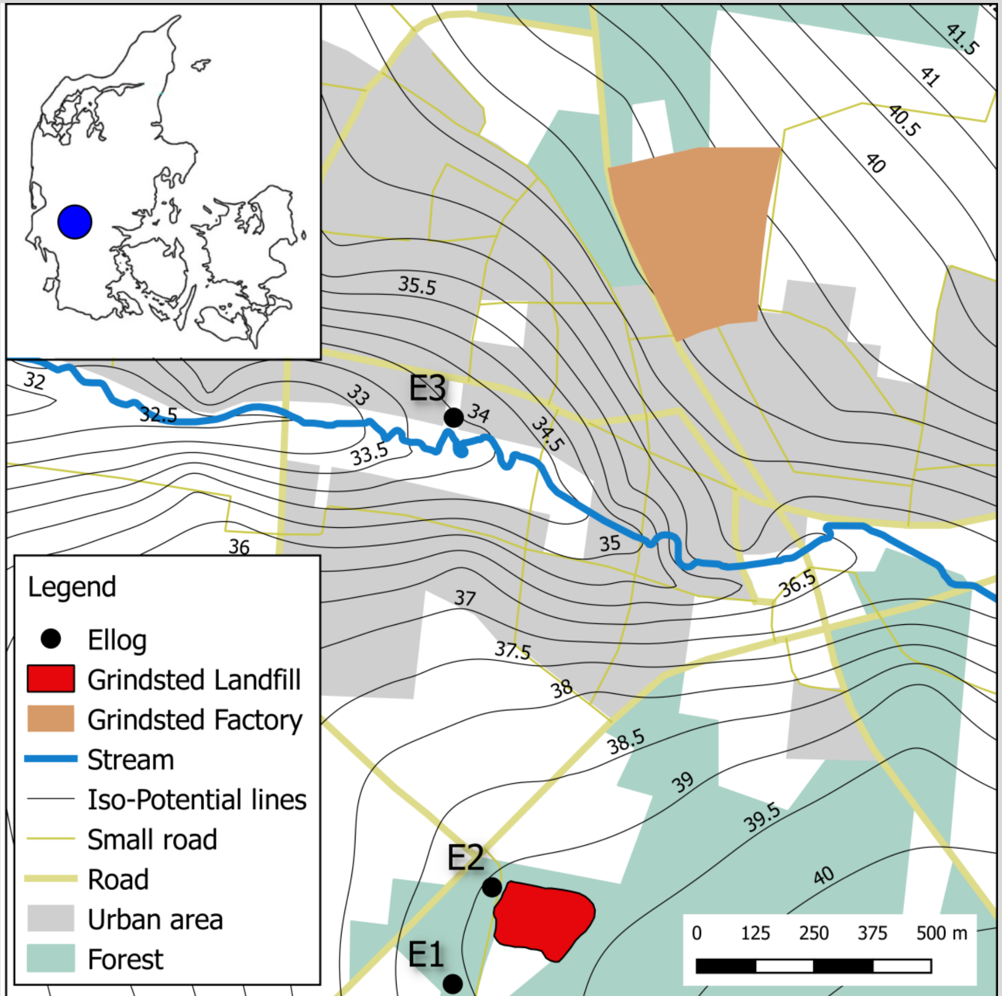
El-log method

- **“logging-while-drilling” technique**
  - Direct current (DC) measurements
  - Full-decay time-domain induced polarization (TDIP)
  - Gamma radiation
- **Measurements on ”undisturbed” formation**
  - A laboratory in the field?



The Grindsted survey

- **3 El-logs: 30 m, 27 m and 10 m deep**

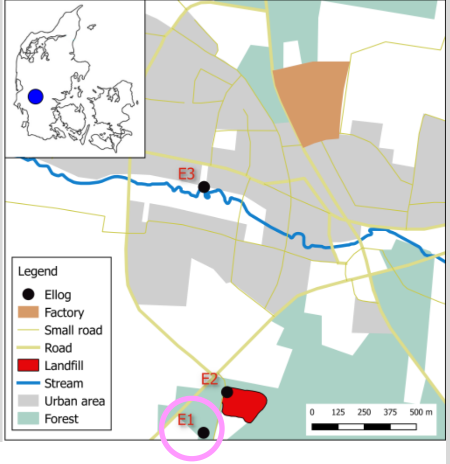


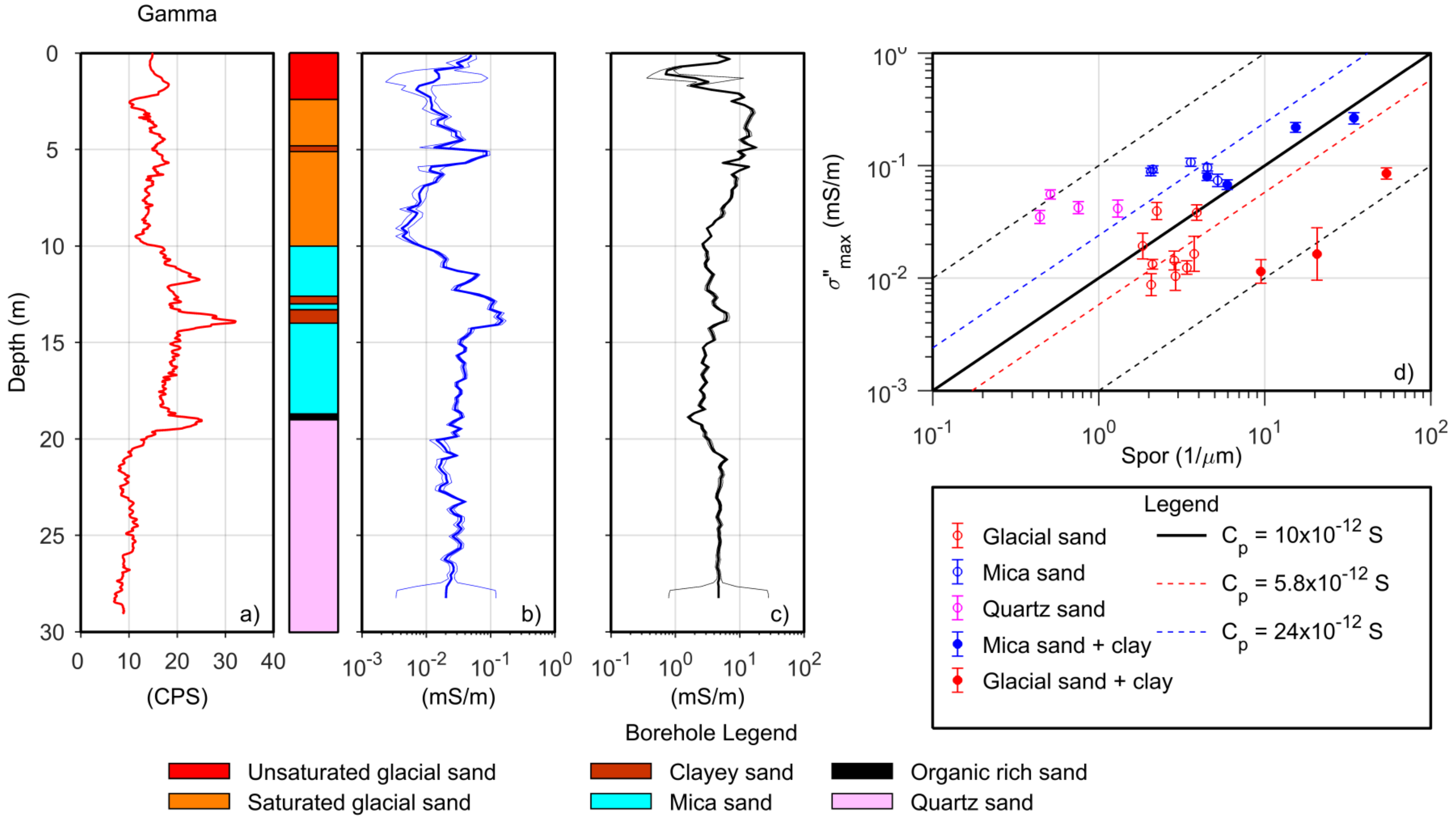
The Grindsted survey

- 3 El-logs: 30 m, 27 m and 10 m deep
- Grain size analysis (GSA) on 58 samples (19, 25 and 14 samples, respectively)
- 9 Slug tests (ST) (2, 6 and 1 slug tests, respectively)

Results

- **Inversion and S_{por}**





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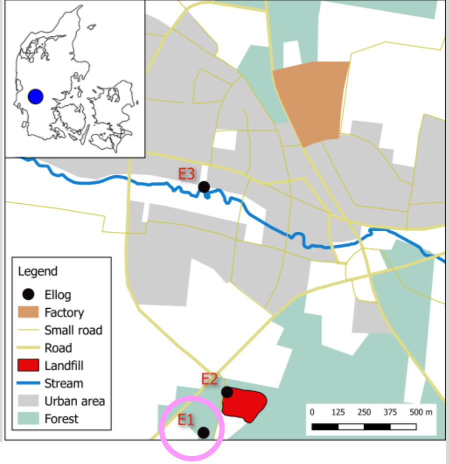

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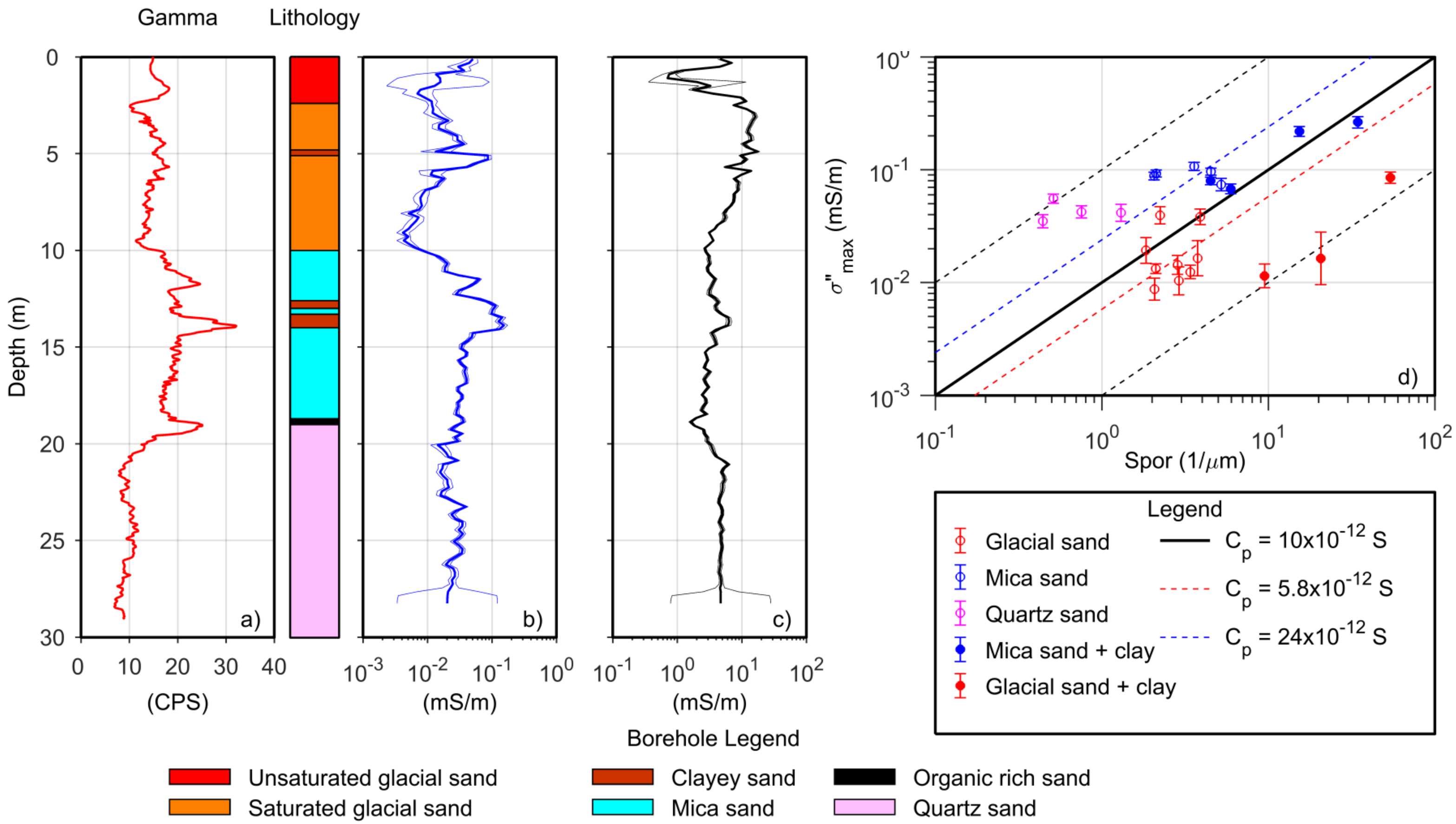

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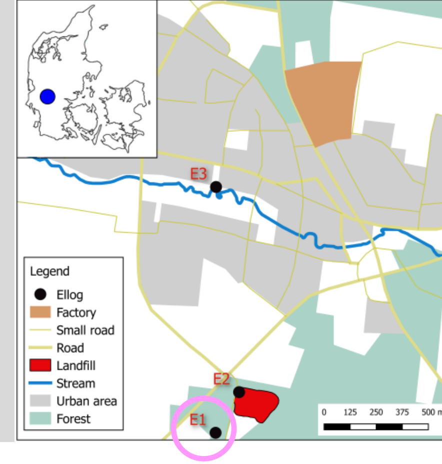

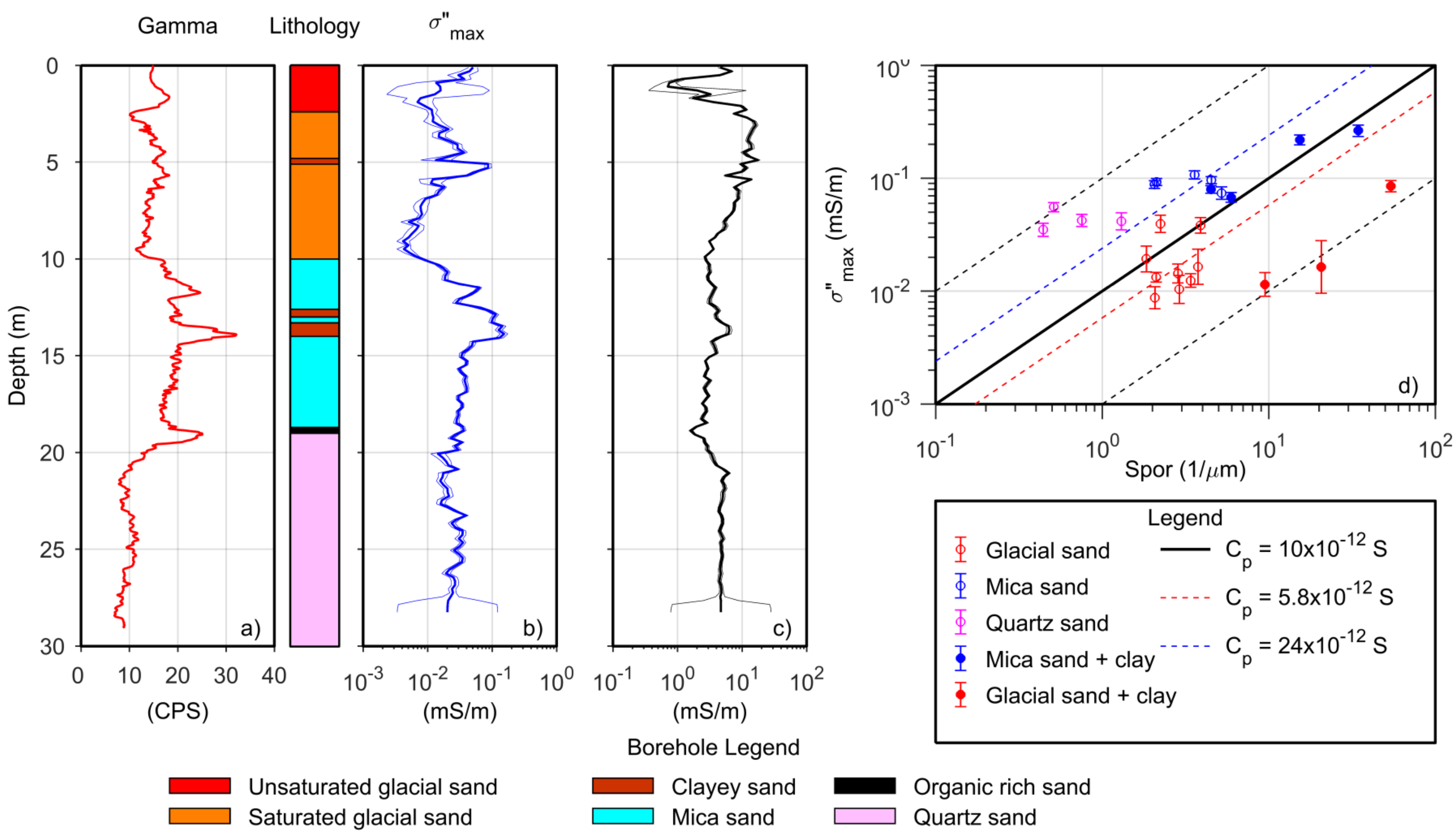

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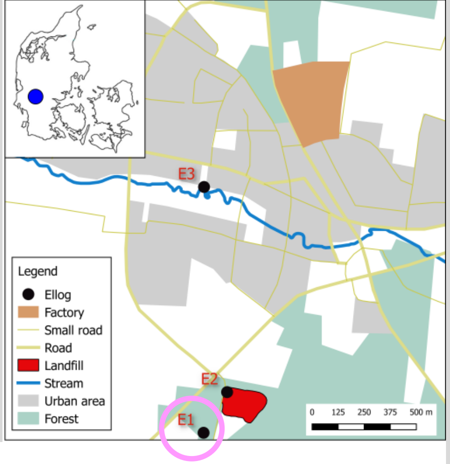

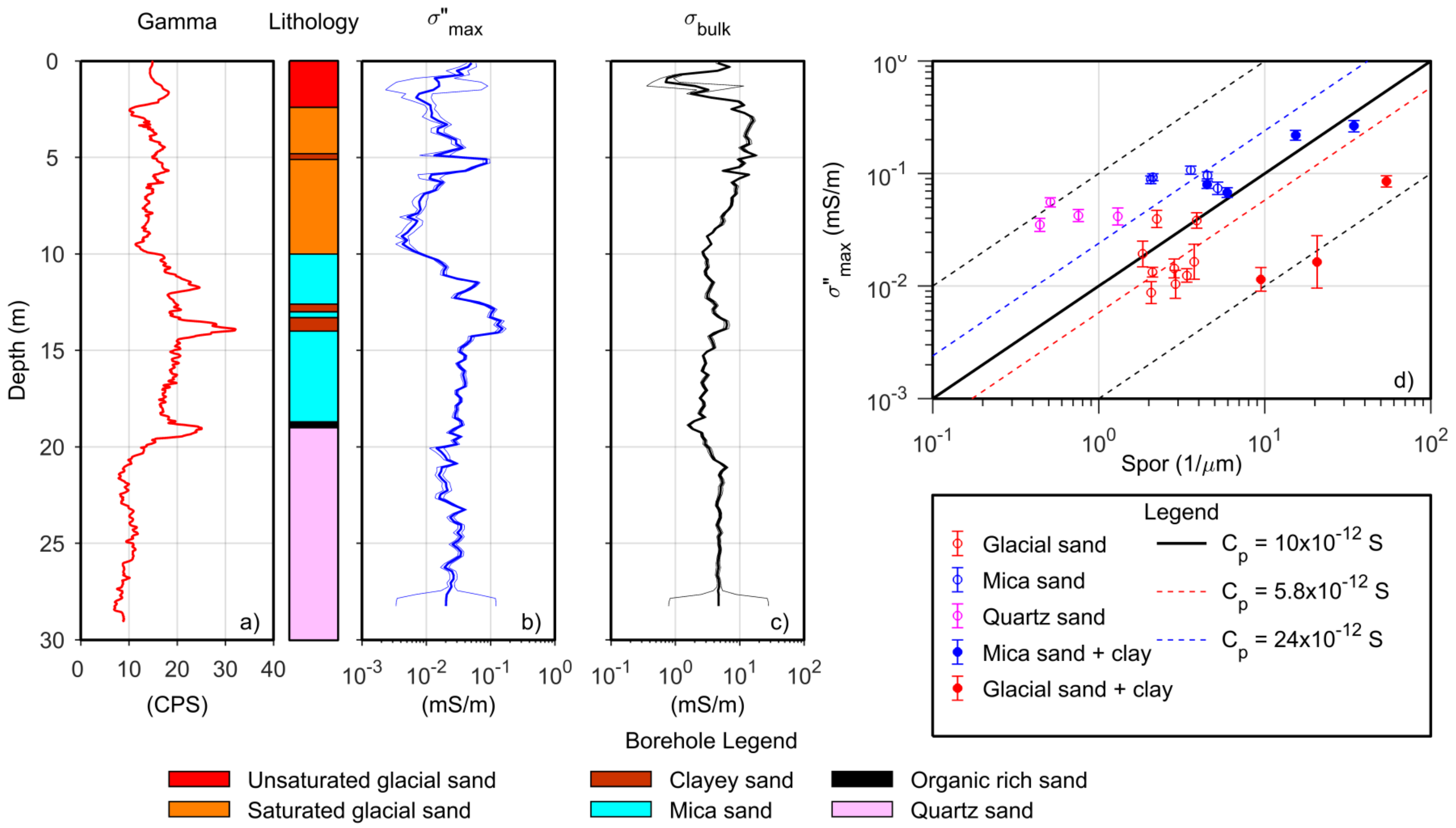

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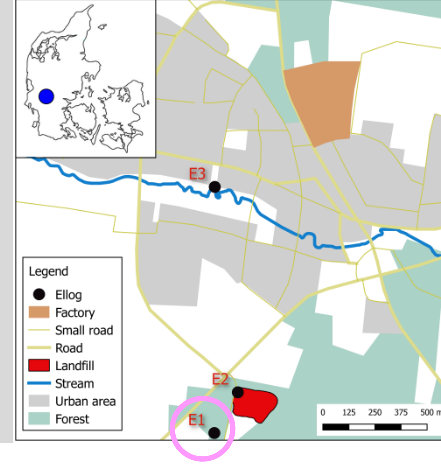

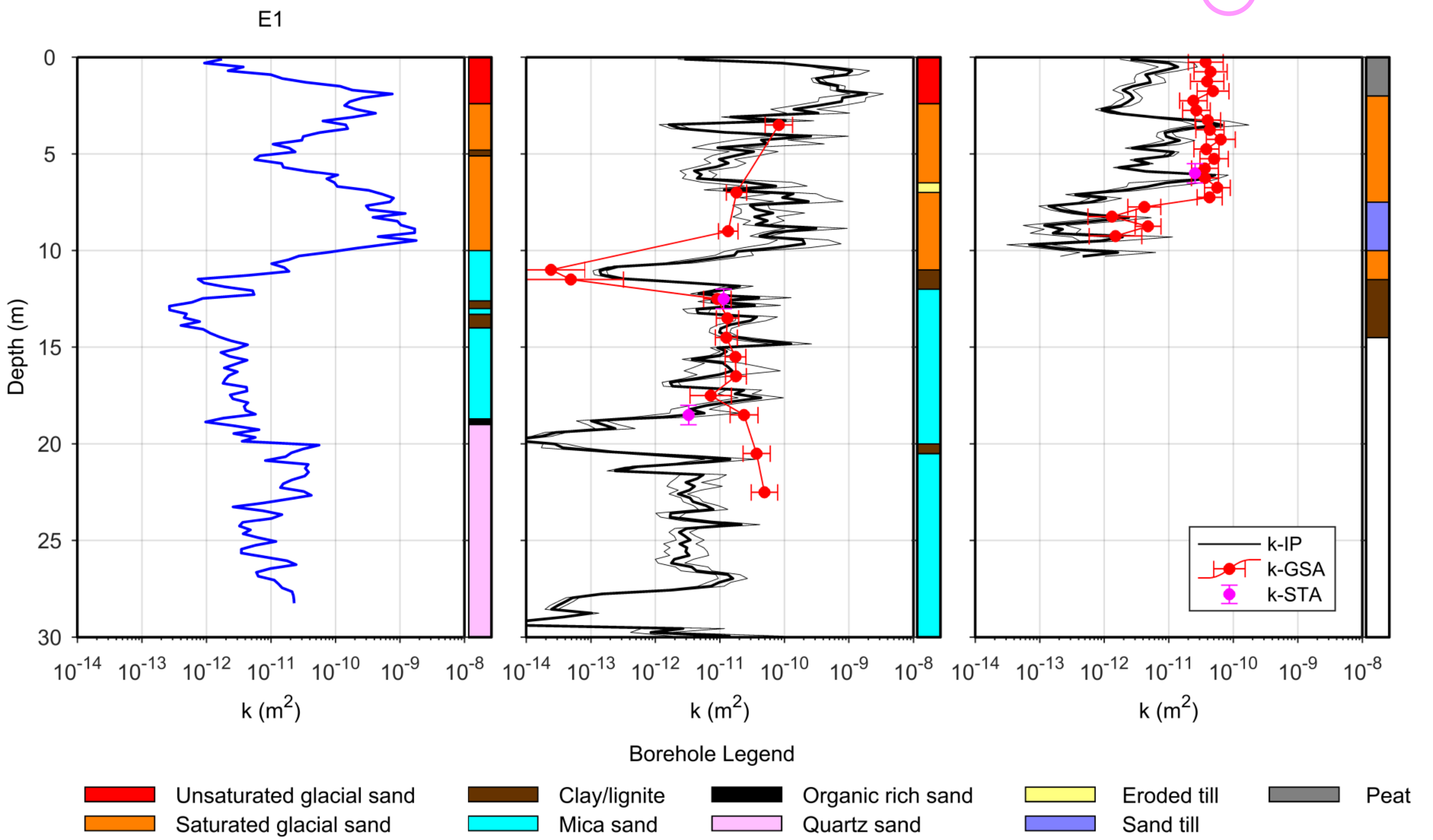

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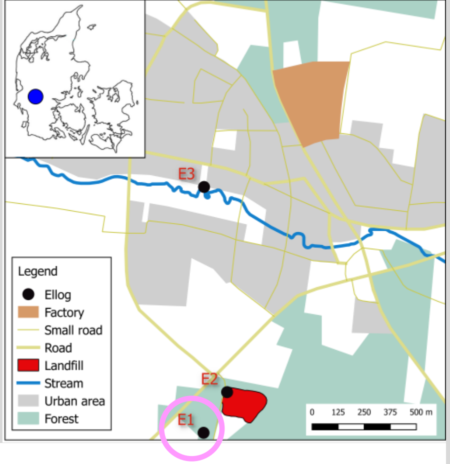

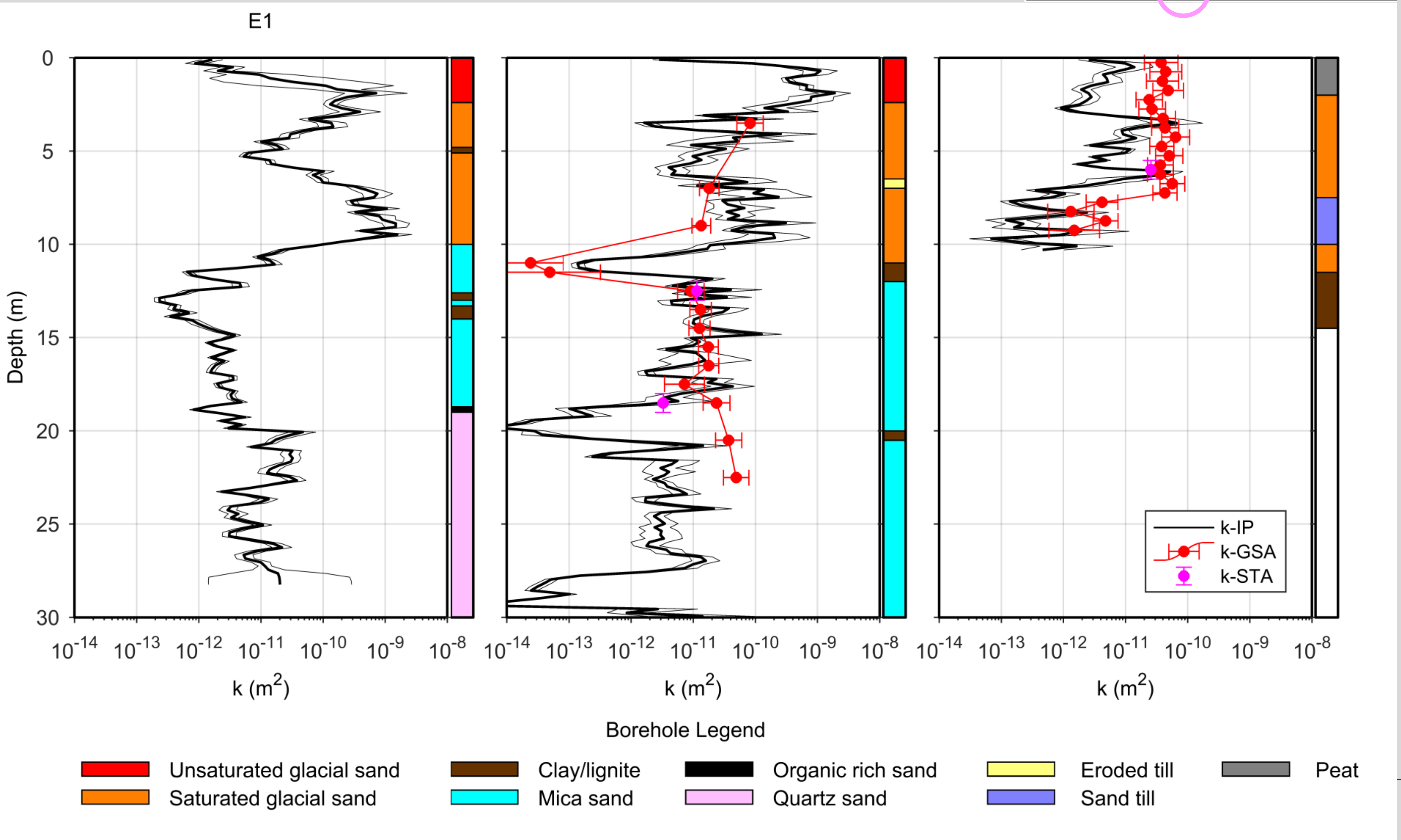

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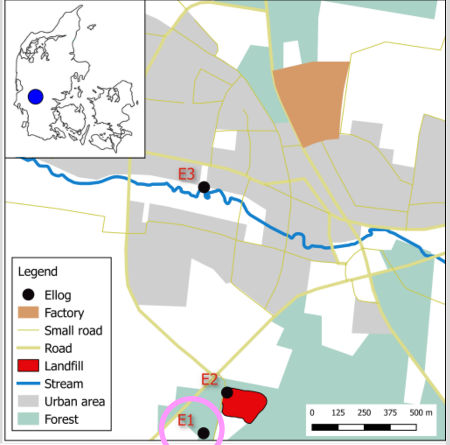

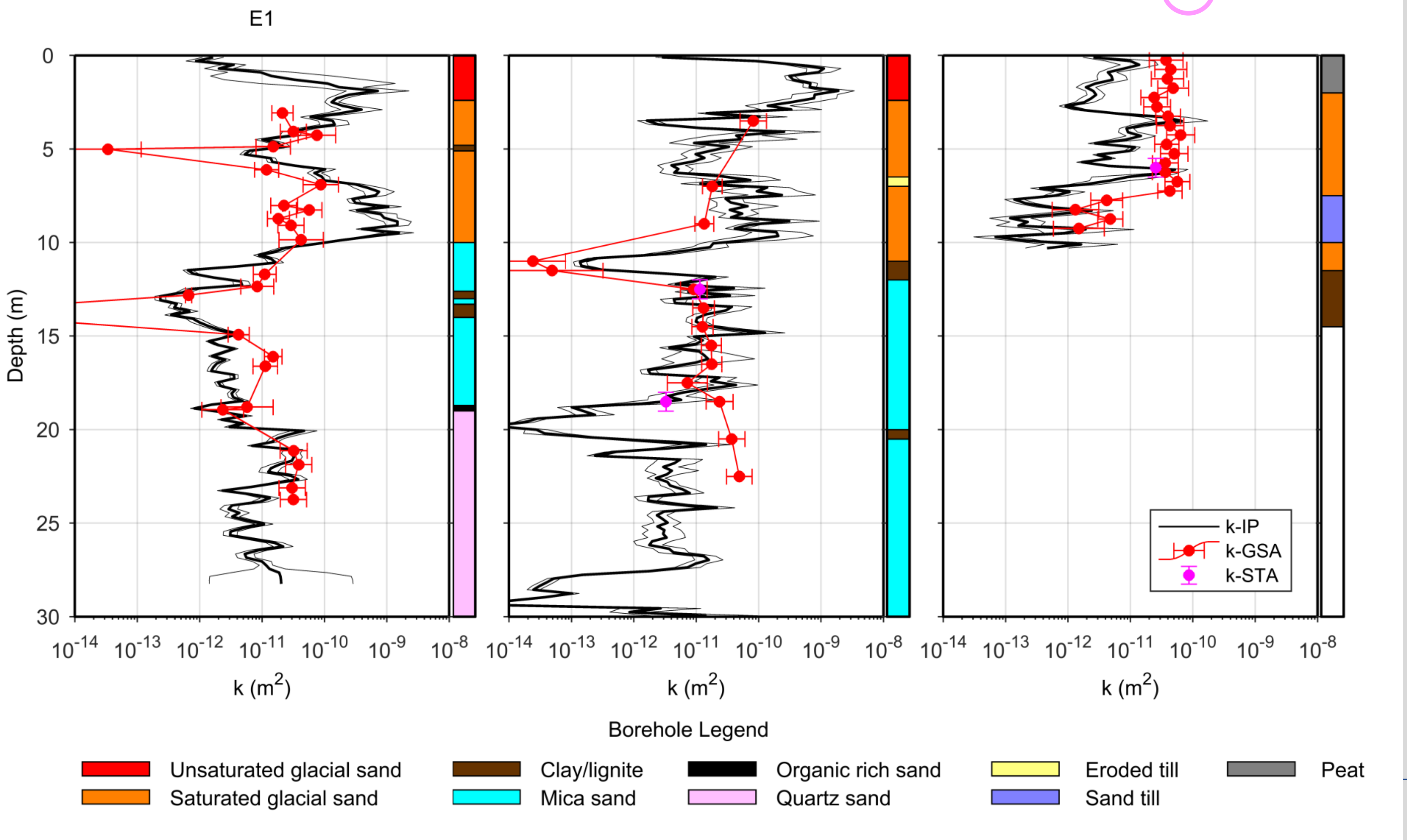

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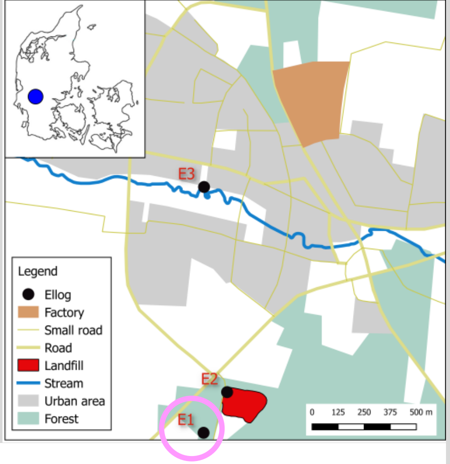

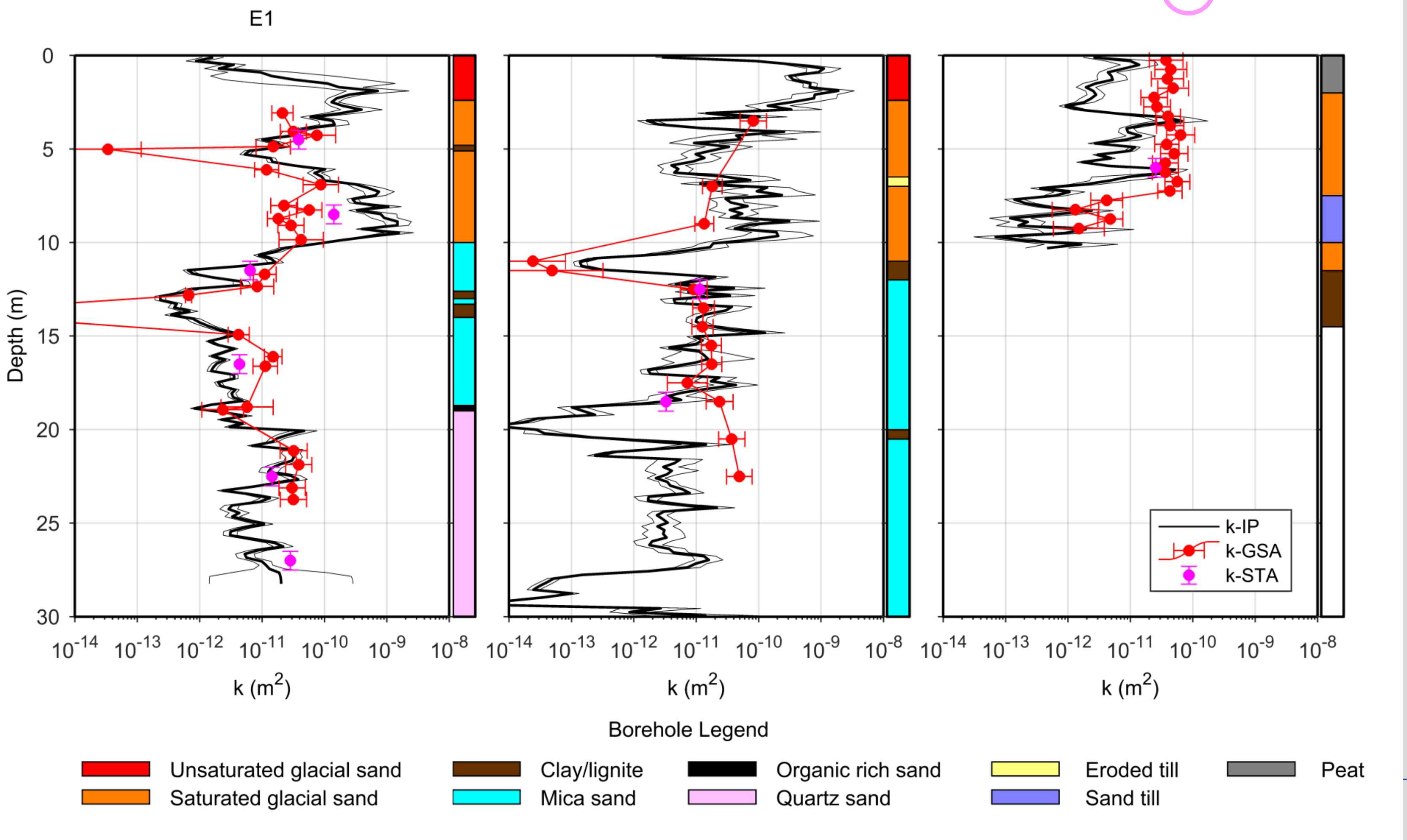

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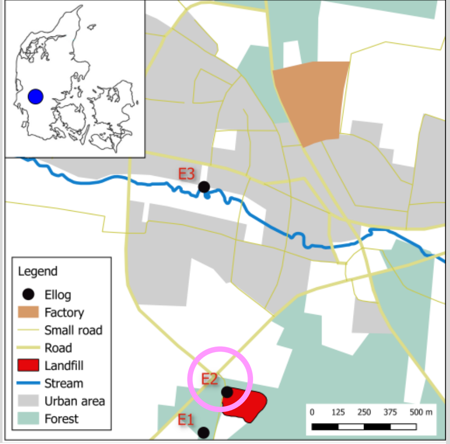

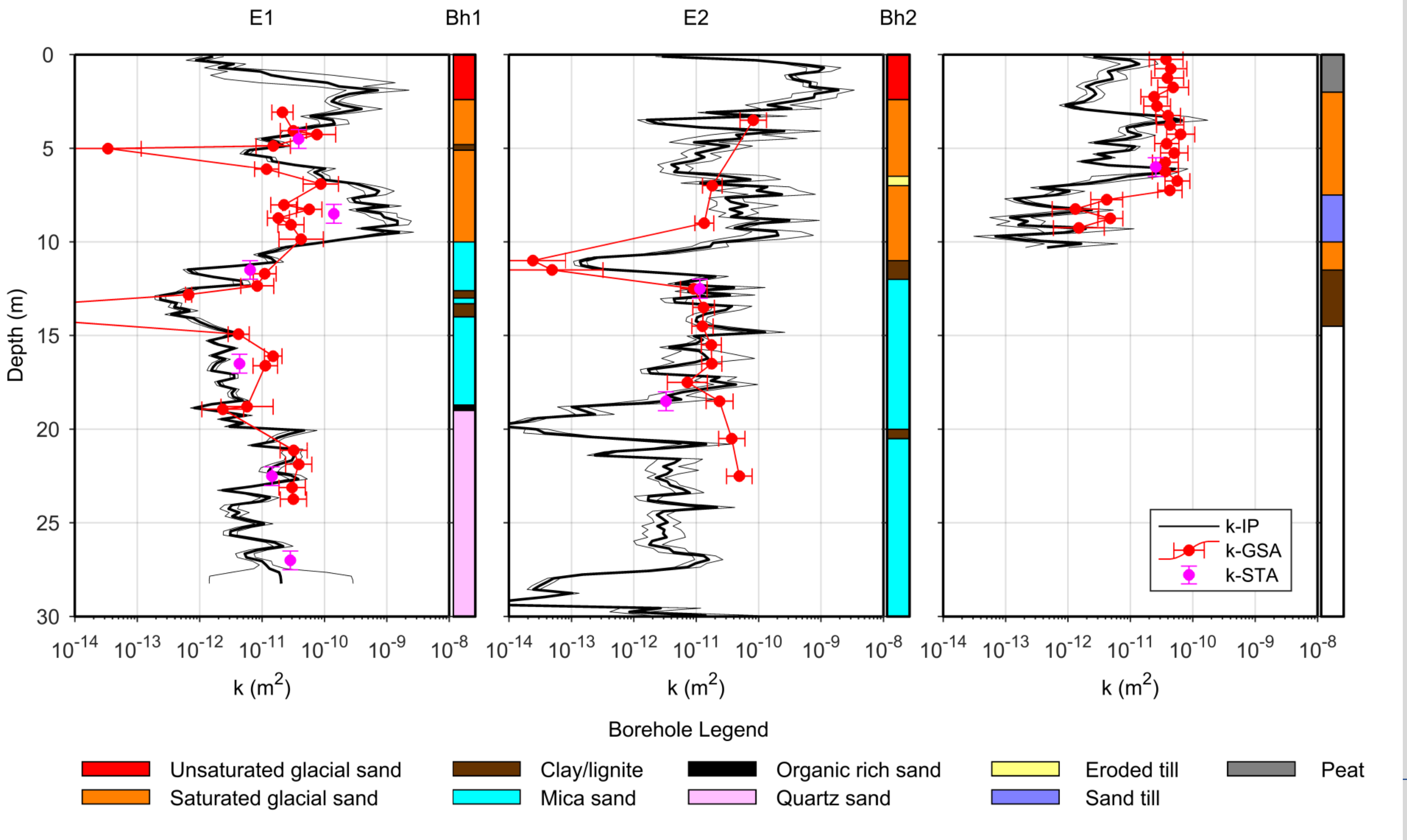

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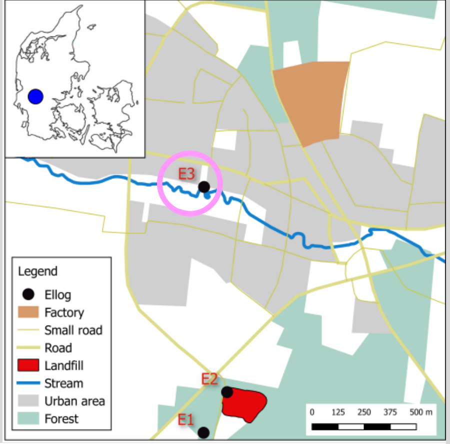
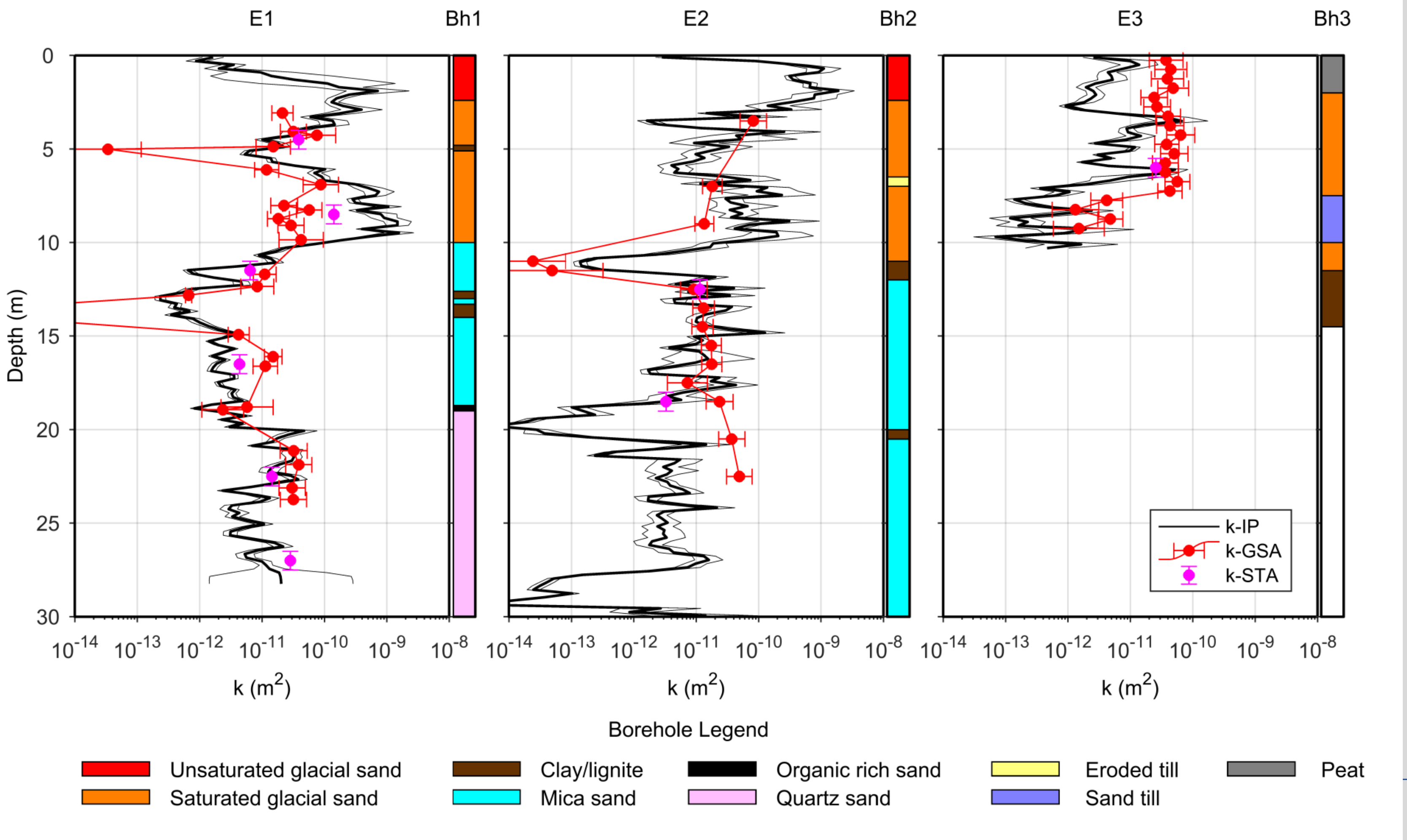
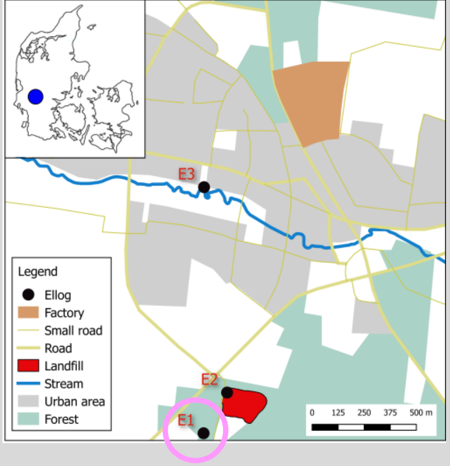
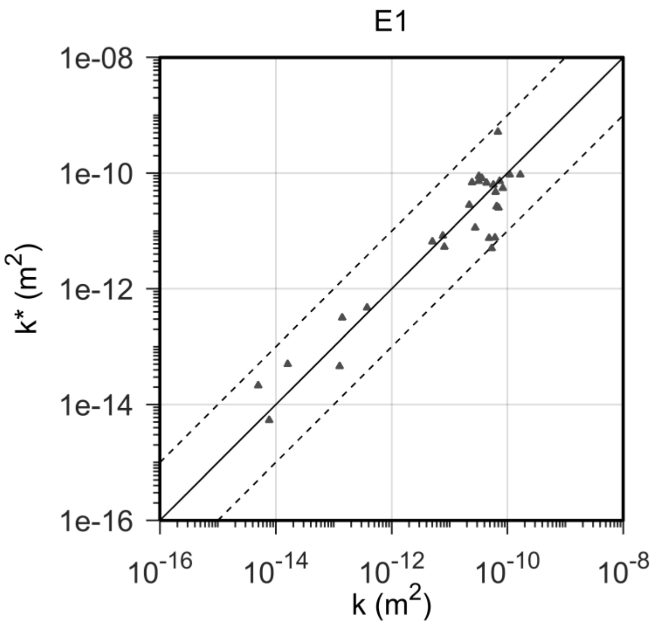




Results

- **IP and k: crossplots**





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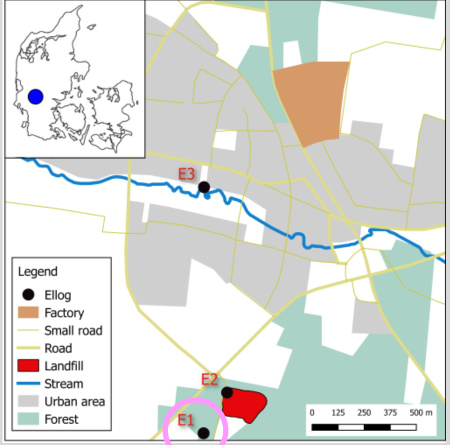

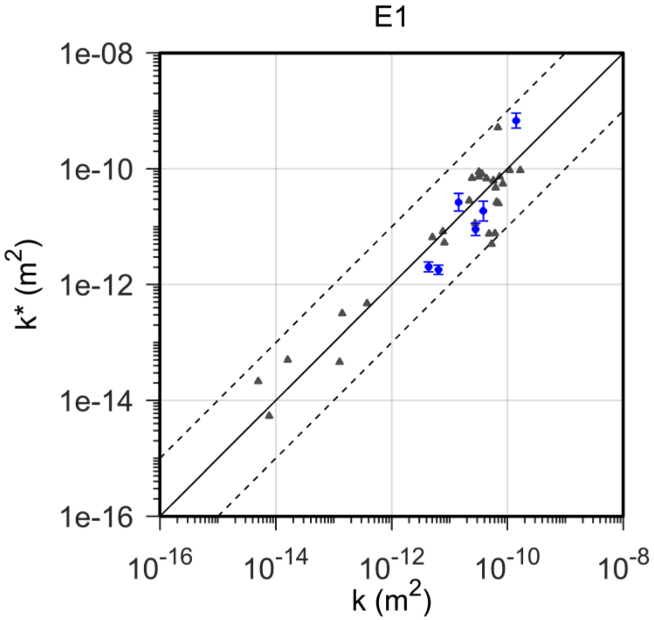

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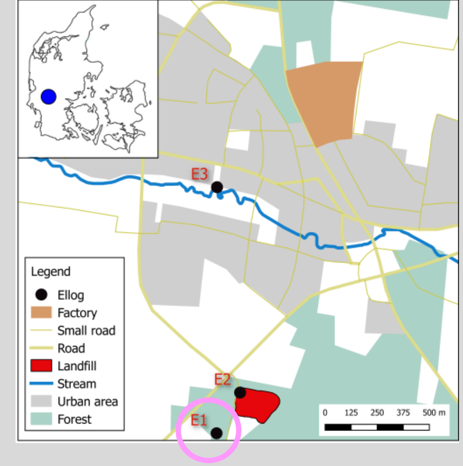

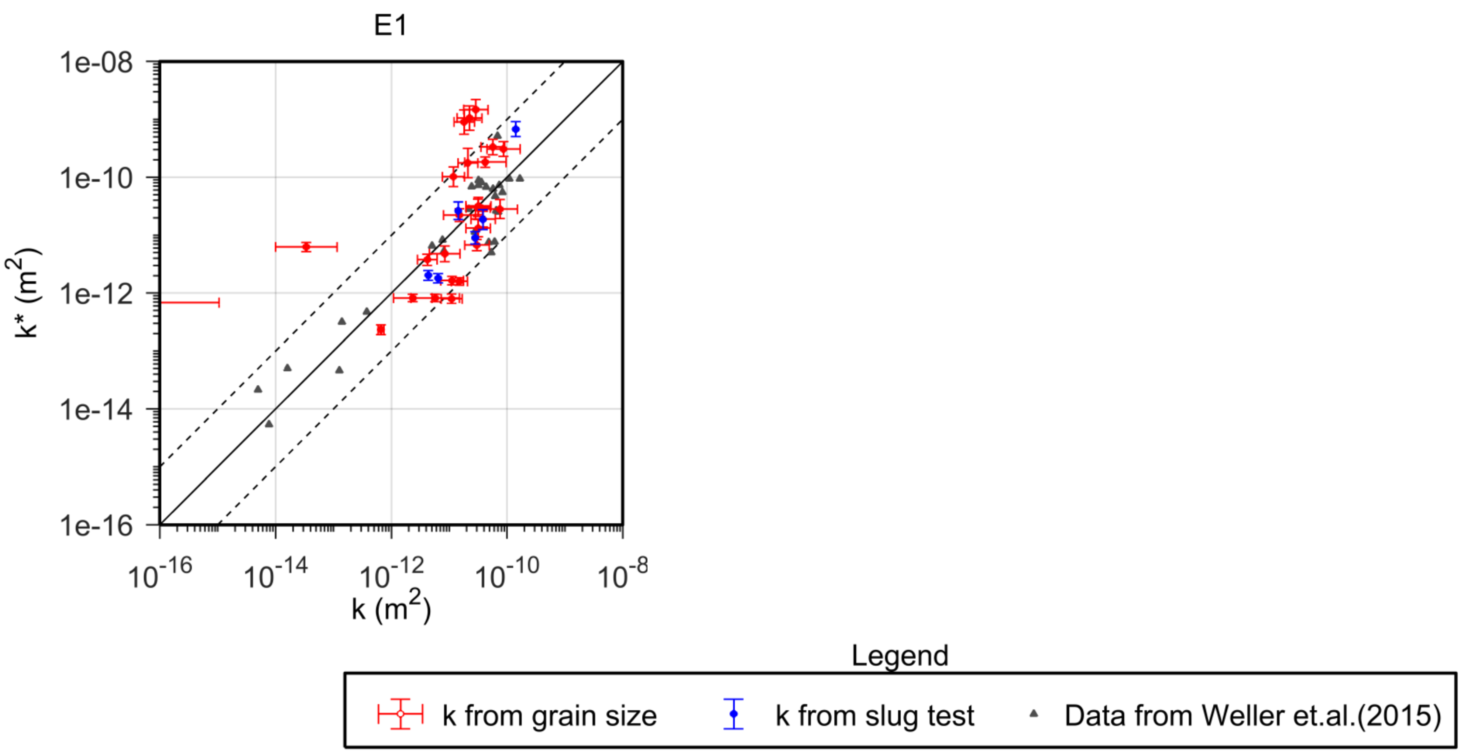

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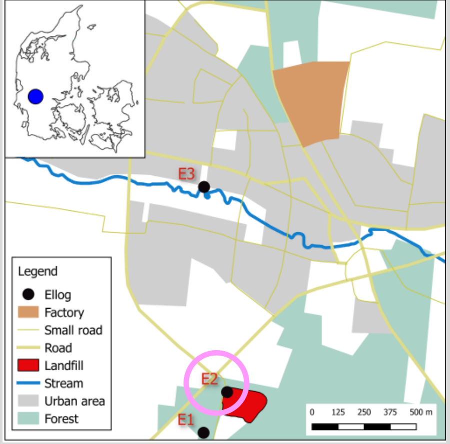

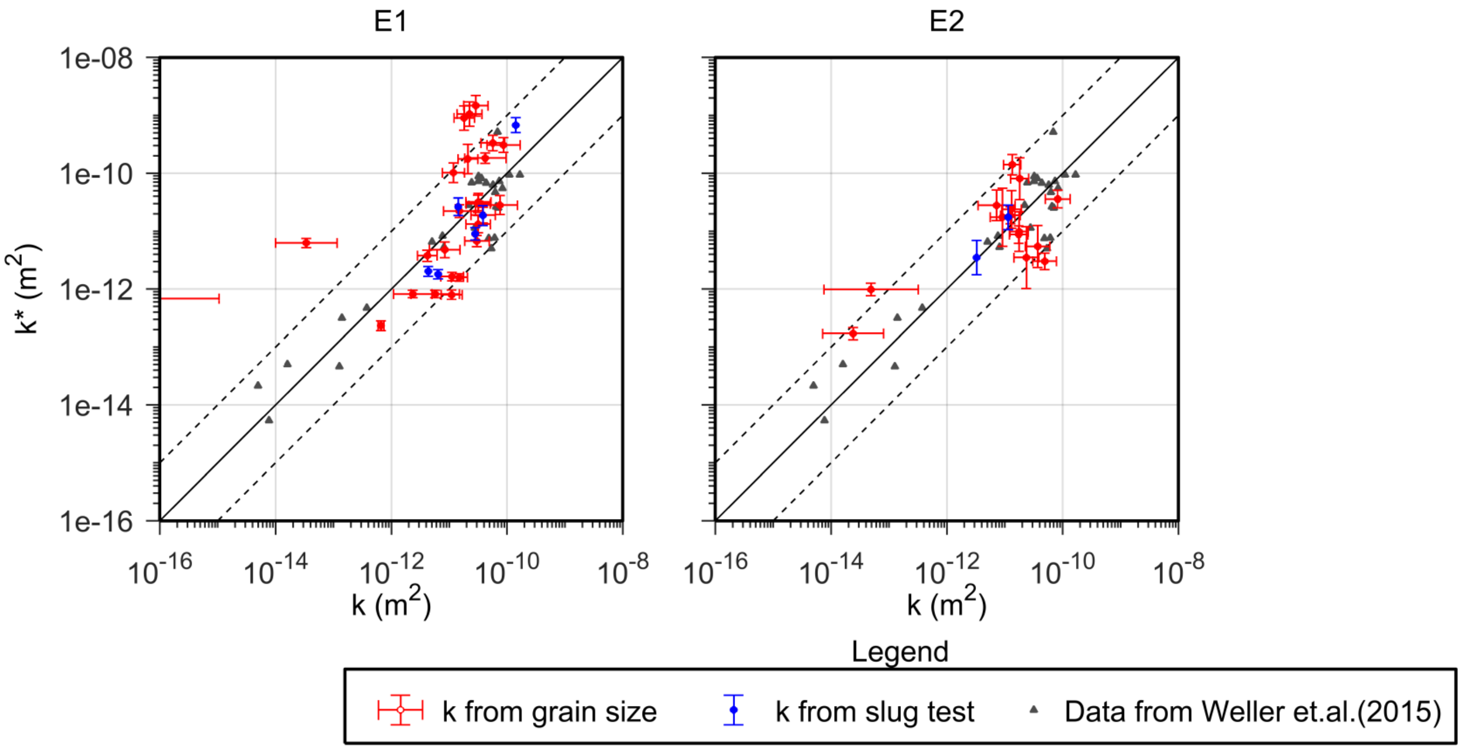

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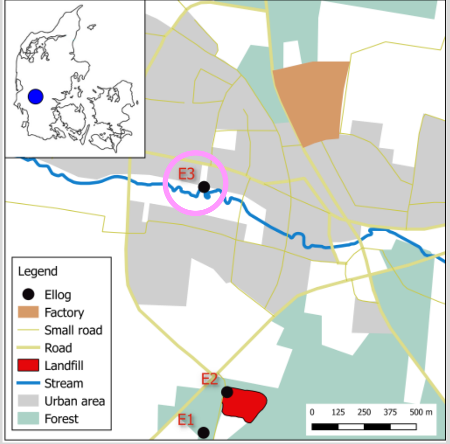

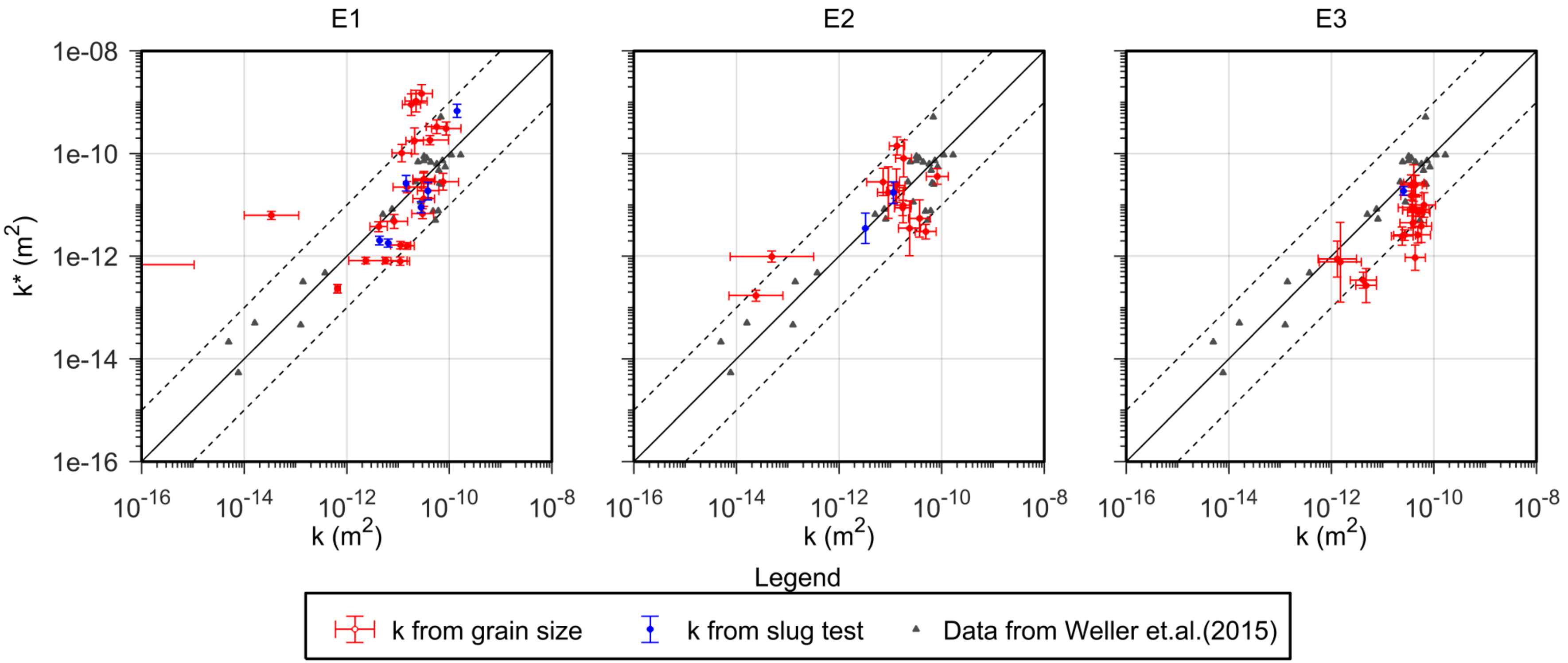

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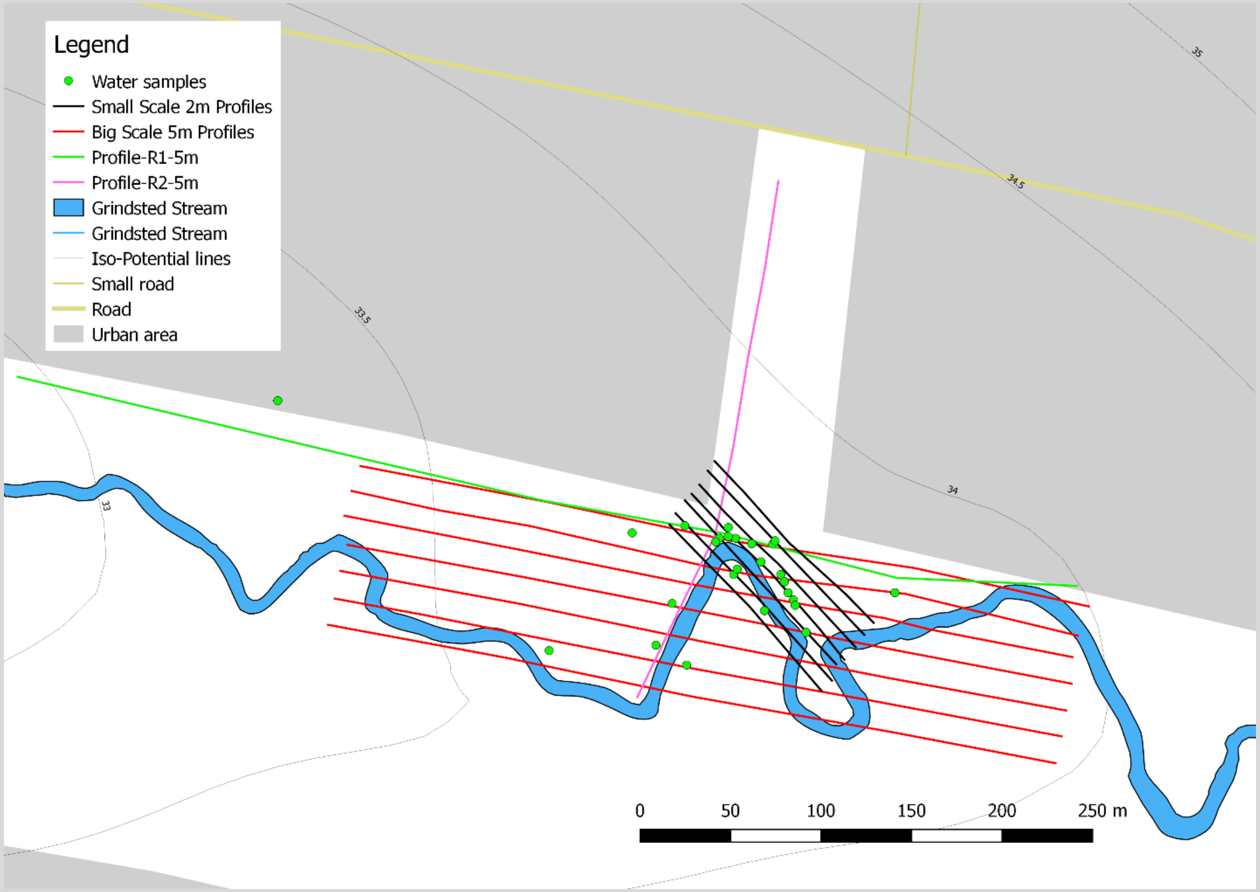
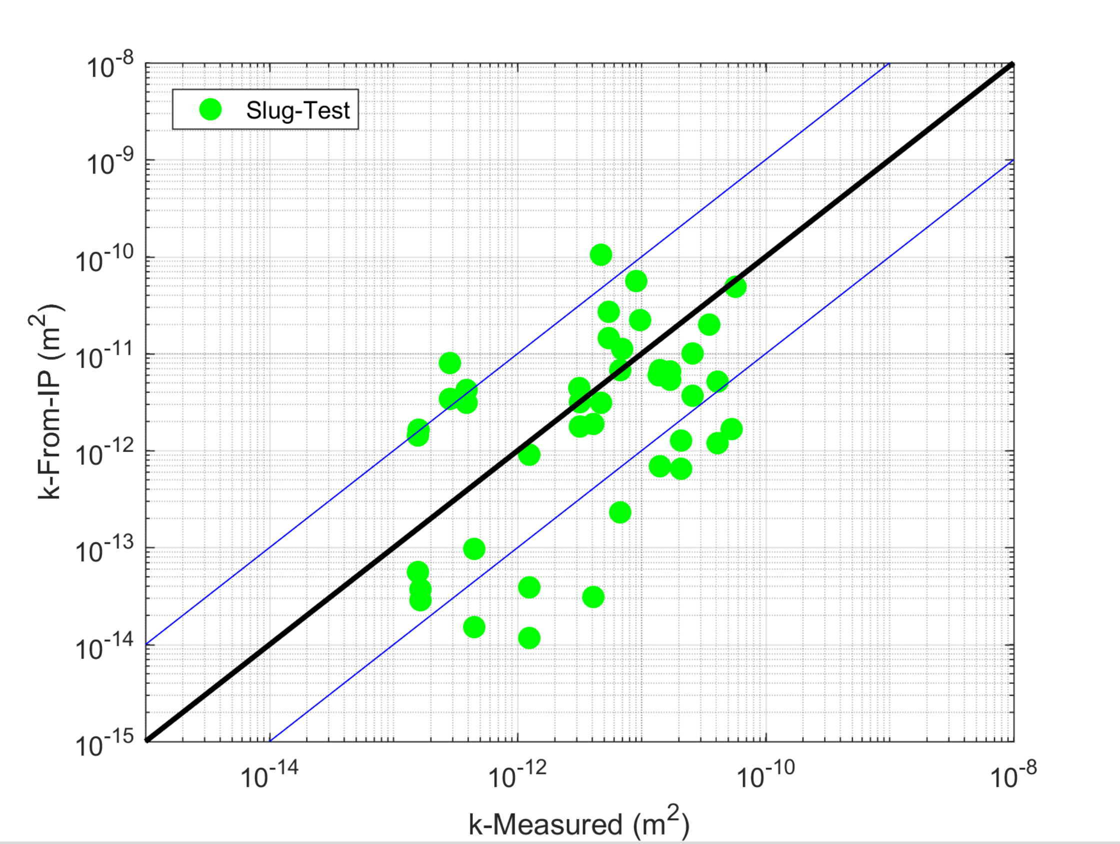
Grindsted


Legend
Water samples
Small Scale 2m Profiles
Big Scale 5m Profiles
Profile-R1-5m
Profile-R2-5m
Grindsted Stream
Grindsted Stream
Iso-Potential lines
Small road
Road
Urban area
35
34.5
33.5
34
33
0
50
100
150
200
250 m

Results

- **Mapping of hydraulic permeability from surface DCIP**



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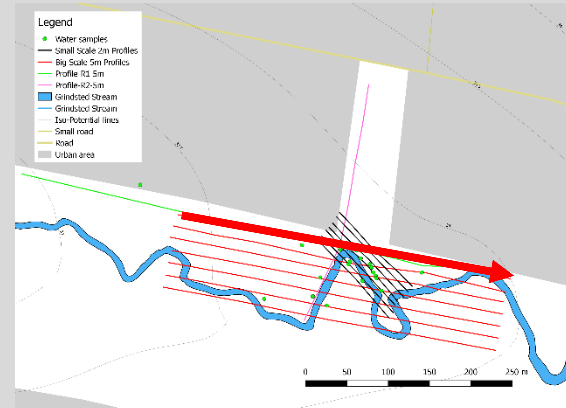
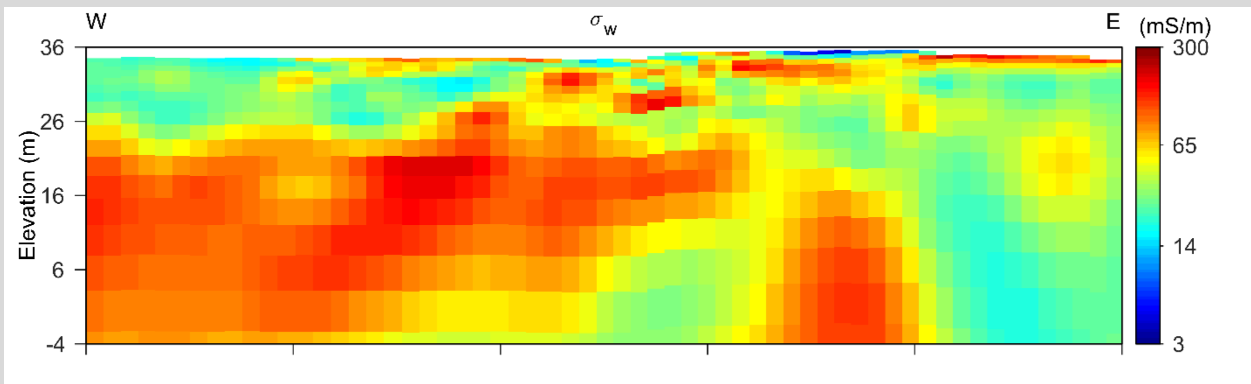
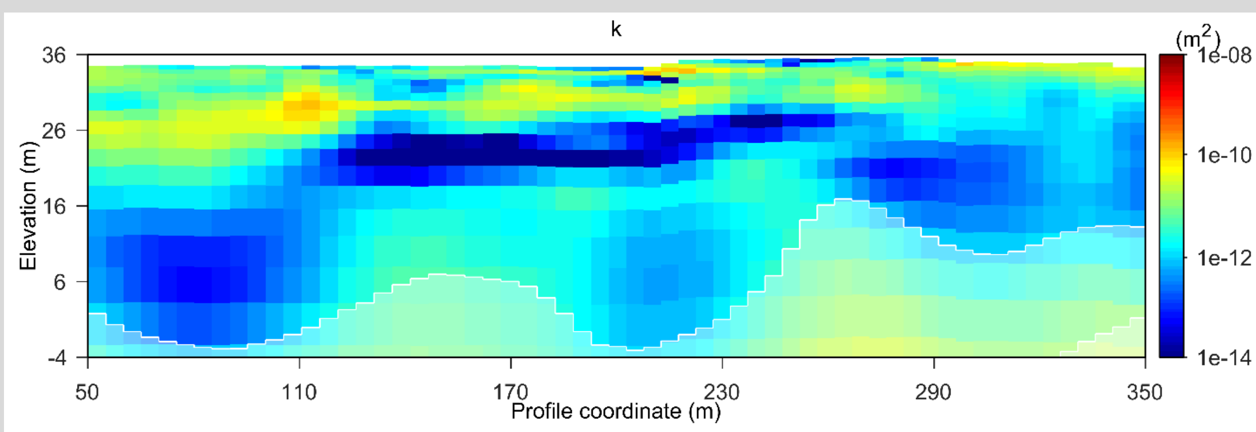
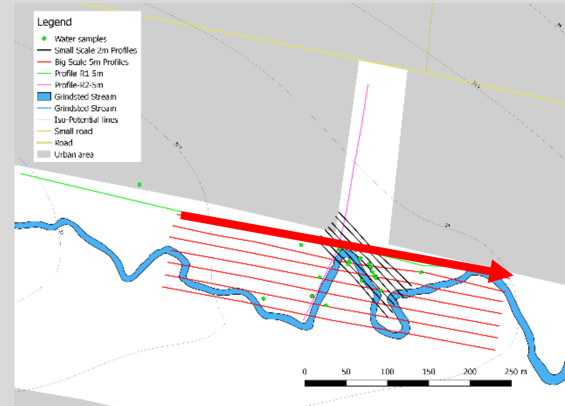






s Group
RSITY

Results



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Road
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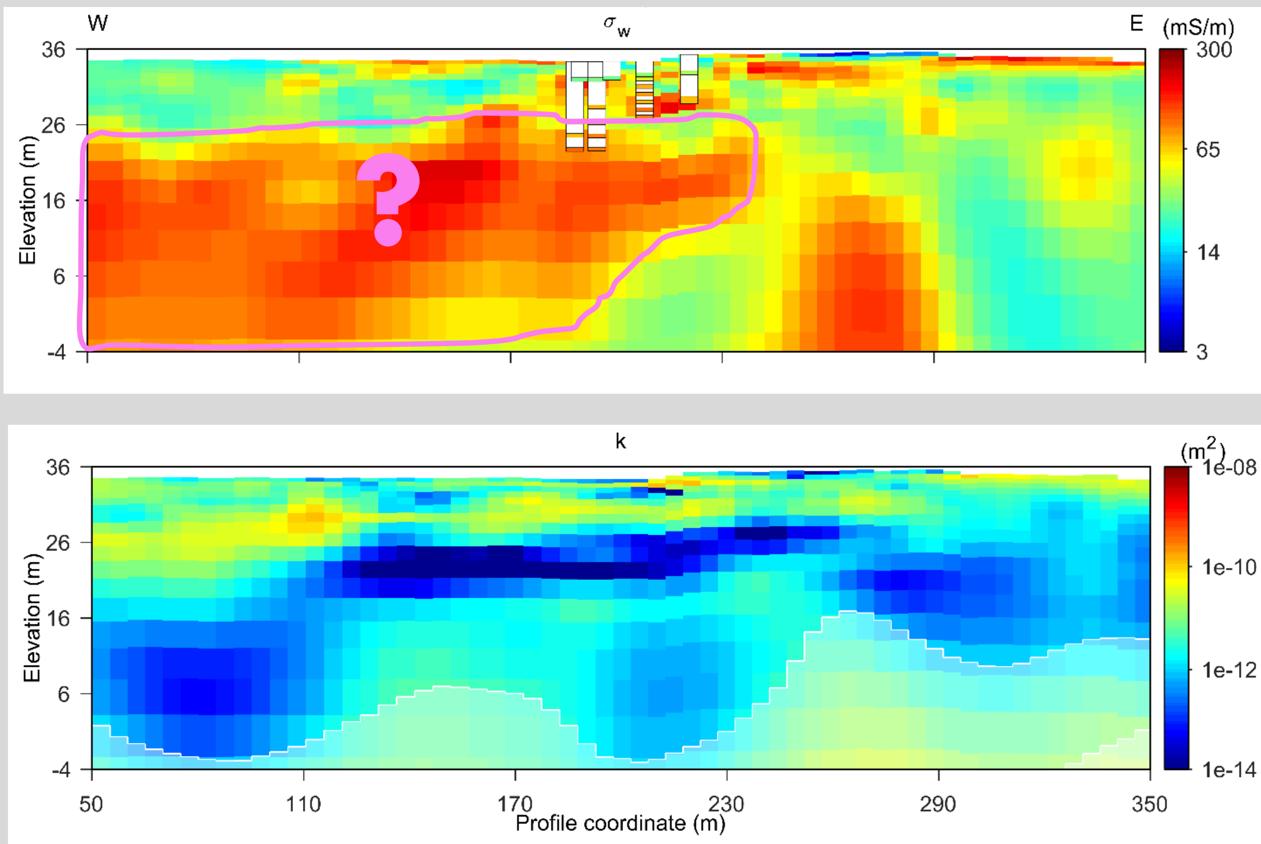
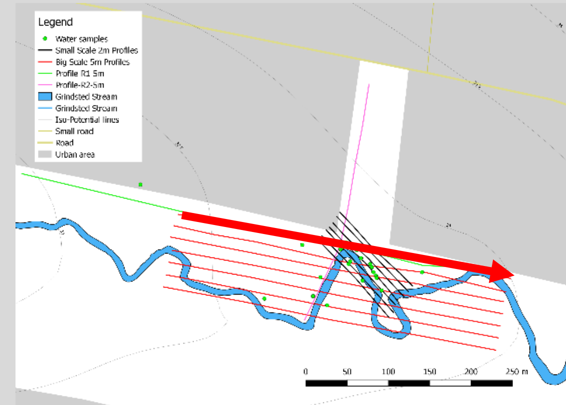


W
σ_w
E
(mS/m)
300
65
14
3
36
26
16
6
-4
Elevation (m)
?
k
(m^2)
1e-08
1e-10
1e-12
1e-14
36
26
16
6
-4
Elevation (m)
50
110
170
230
290
350
Profile coordinate (m)

Results



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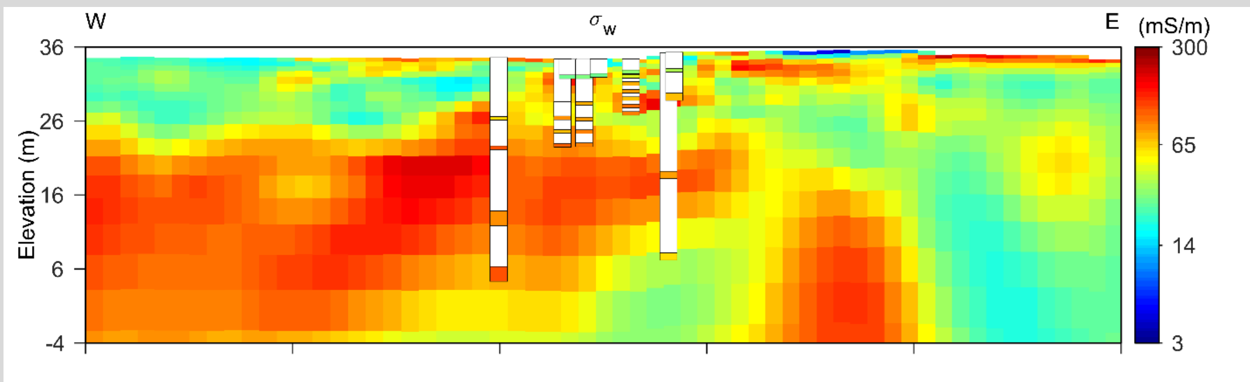

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Elevation (m)
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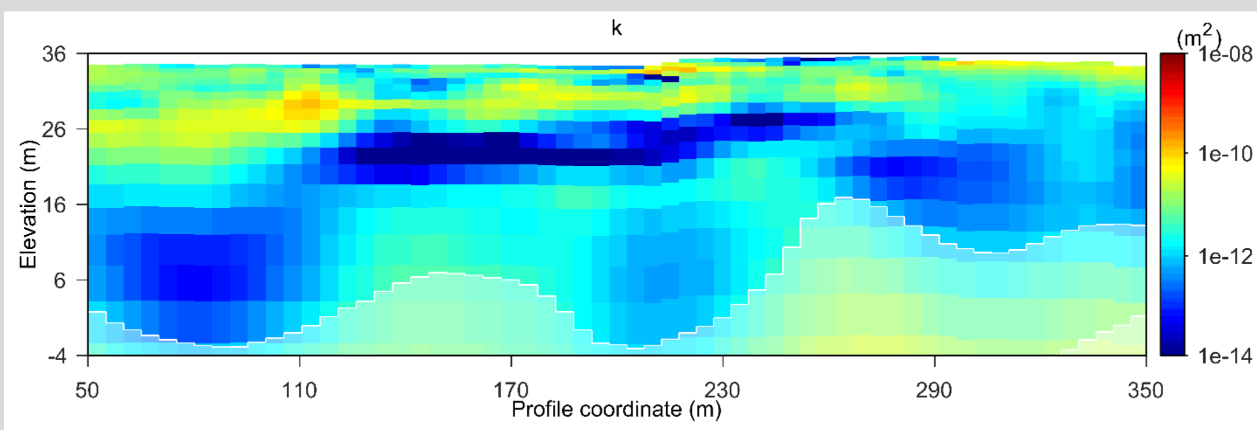

k
(m^2)
1e-08
1e-10
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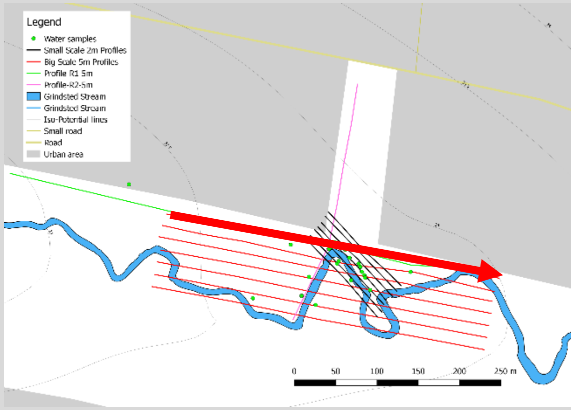

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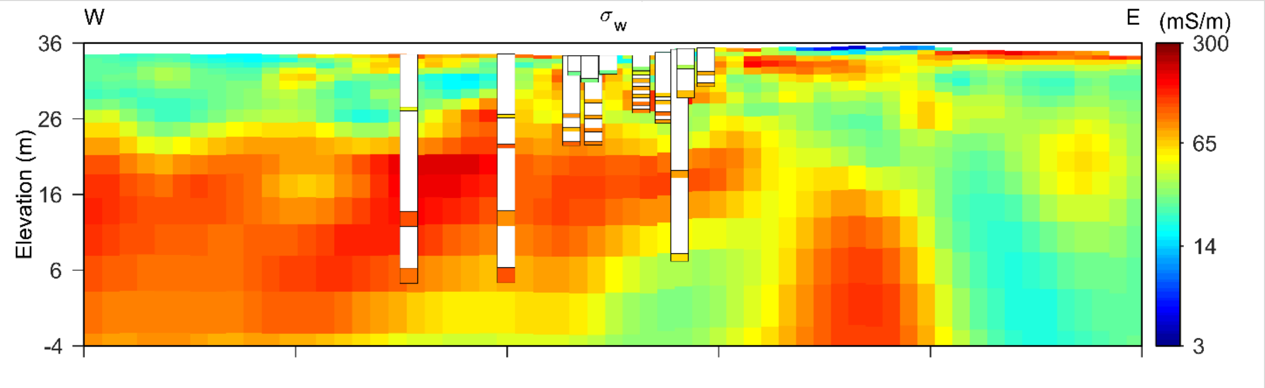

W
σ_w
E
(mS/m)
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65
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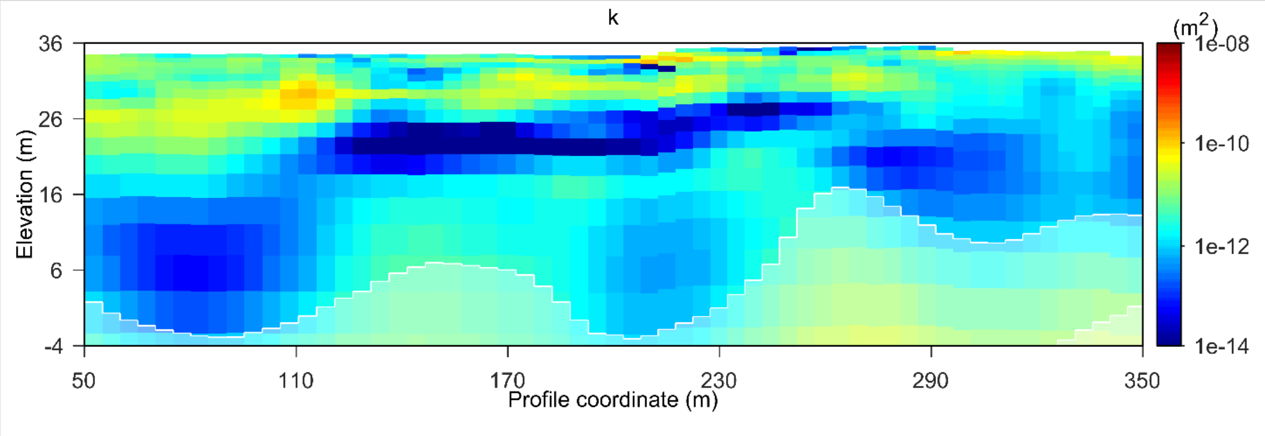

k
(m^2)
1e-08
1e-10
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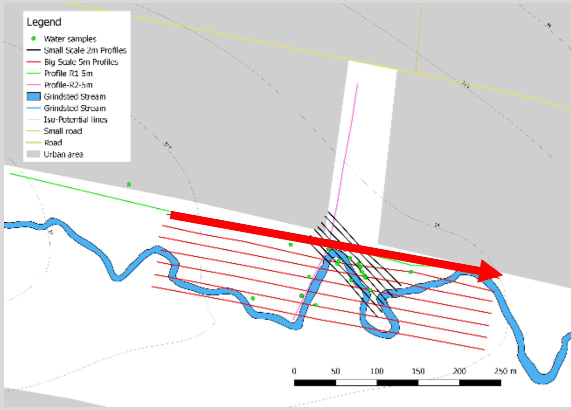

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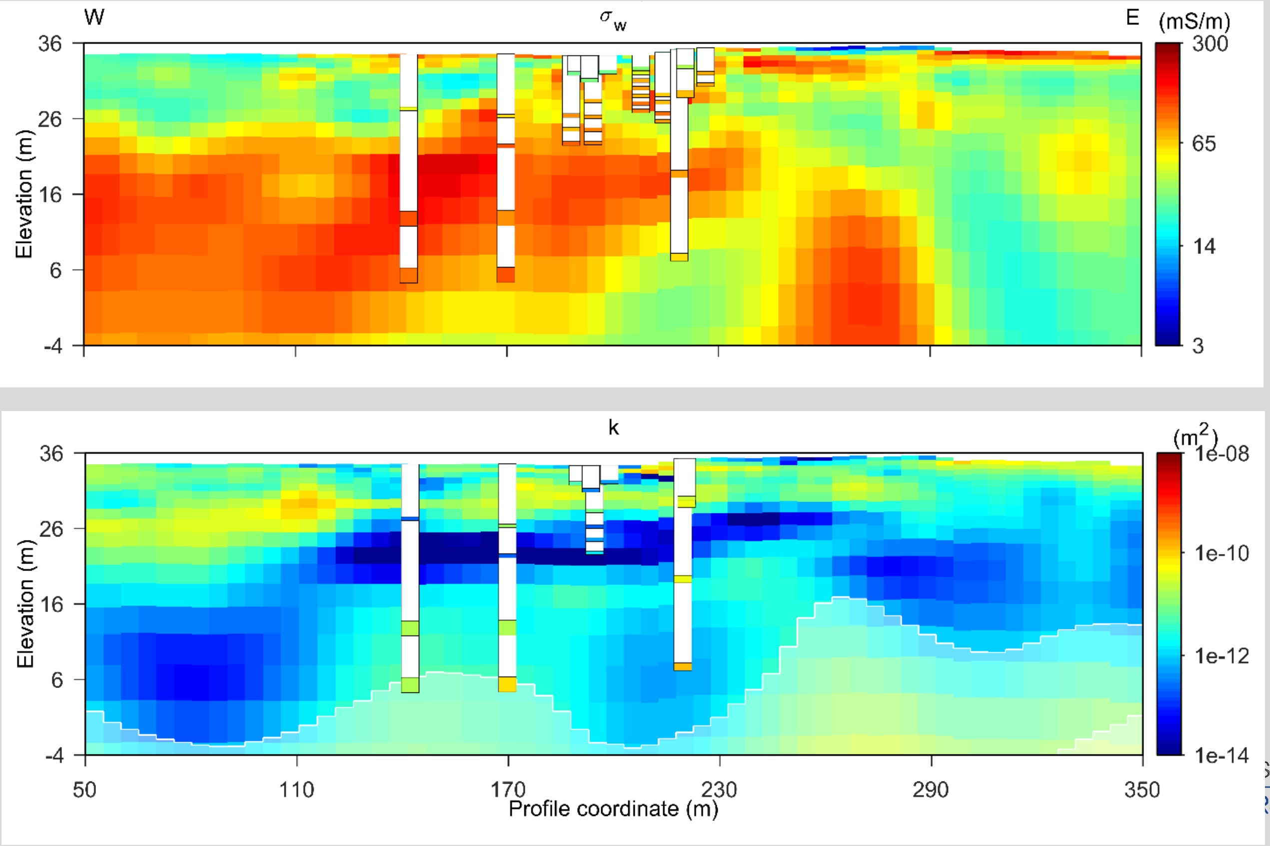

W
σ_w
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(mS/m)
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65
14
3
36
26
16
6
-4
Elevation (m)
k
(m^2)
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1e-10
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Profile coordinate (m)

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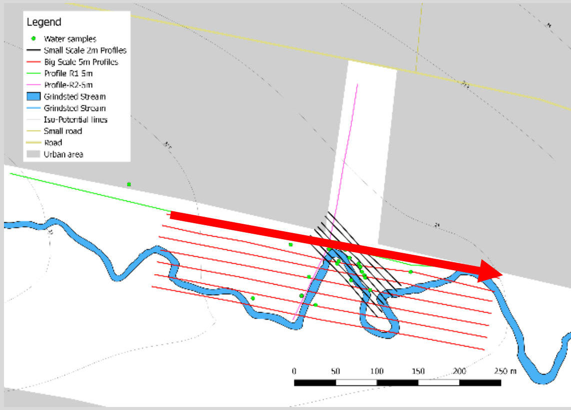
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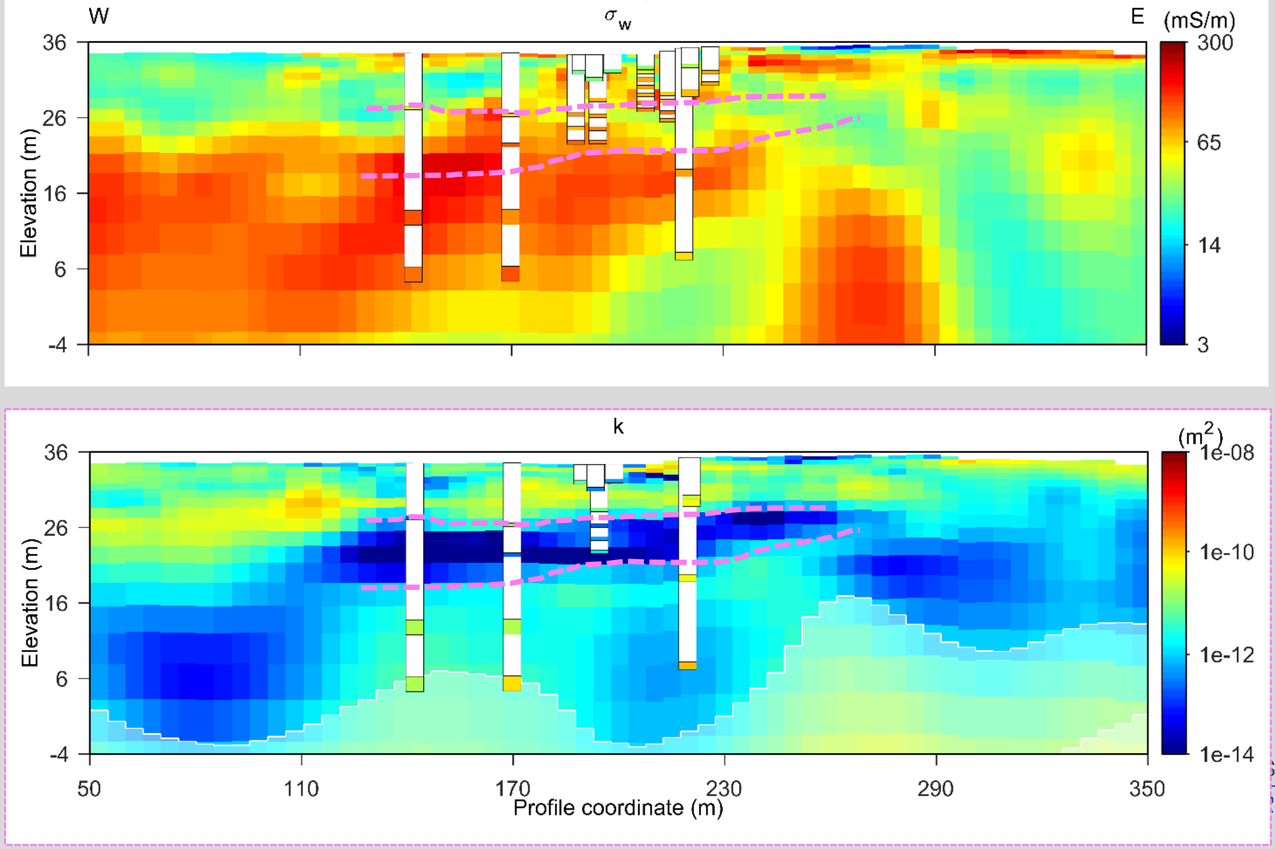
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14
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Elevation (m)
k
(m^2)
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1e-10
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1e-14
50
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170
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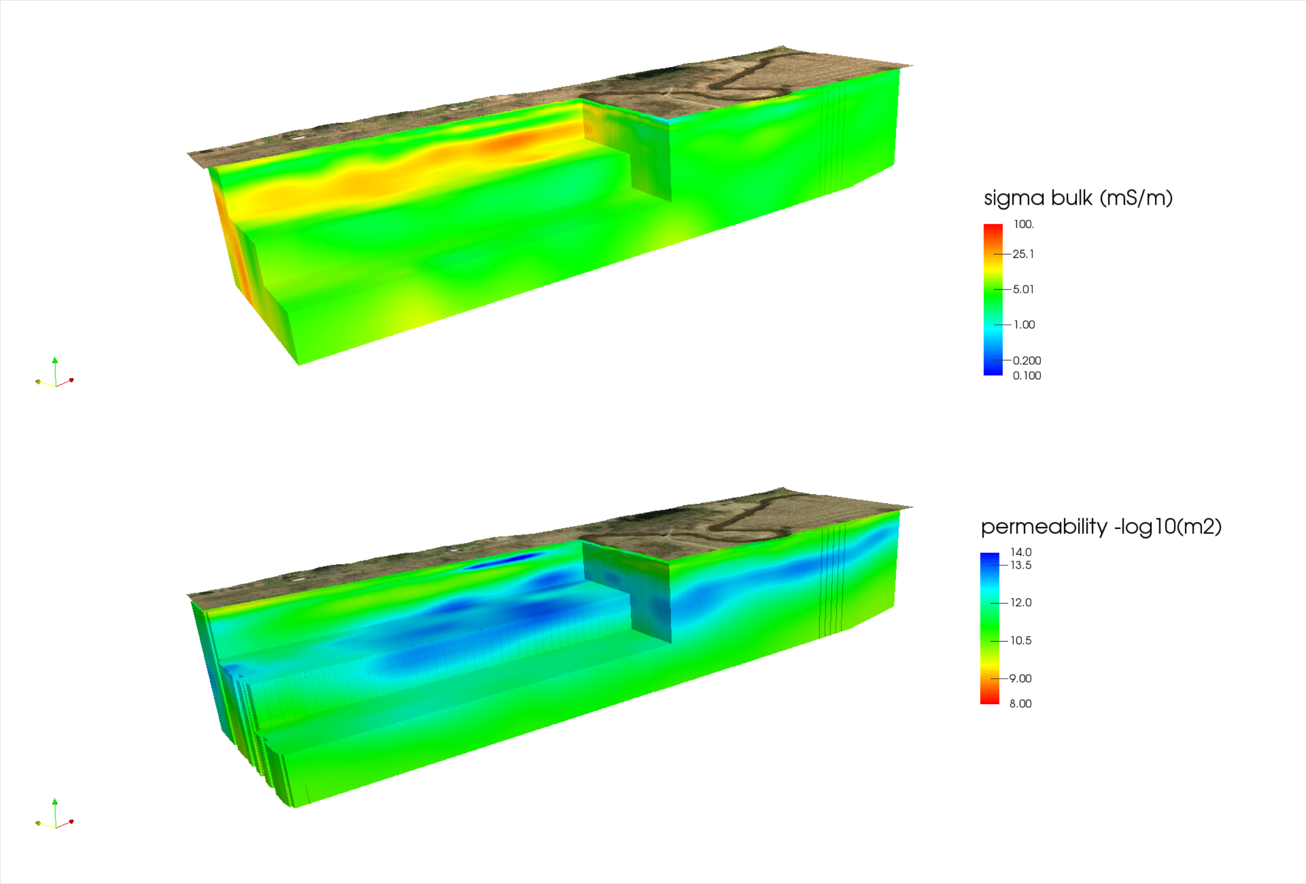
290
350
Profile coordinate (m)

3D model



sigma bulk (mS/m)
100.
25.1
5.01
1.00
0.200
0.100
permeability -log10(m2)
14.0
13.5
12.0
10.5
9.00
8.00

Conclusion

- **Hydraulic permeabiliy mapped through IP!**

  But with limitations:

  - Only in unconsolidated samples
  - Only in saturated media
  - No other significant source of IP present (oil spills, mineralizations etc. Etc.)