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# Induced polarization for the spatial characterization of biogeochemical hot spots

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# Introduction

- Biogeochemical hot spots are spatially limited areas where processes such as sulfate or iron reduction take place in high reaction rates compared to the surrounding area.
- Biogeochemical hot spots are of major interest due to the possible emission of greenhouse gases (carbon dioxide).

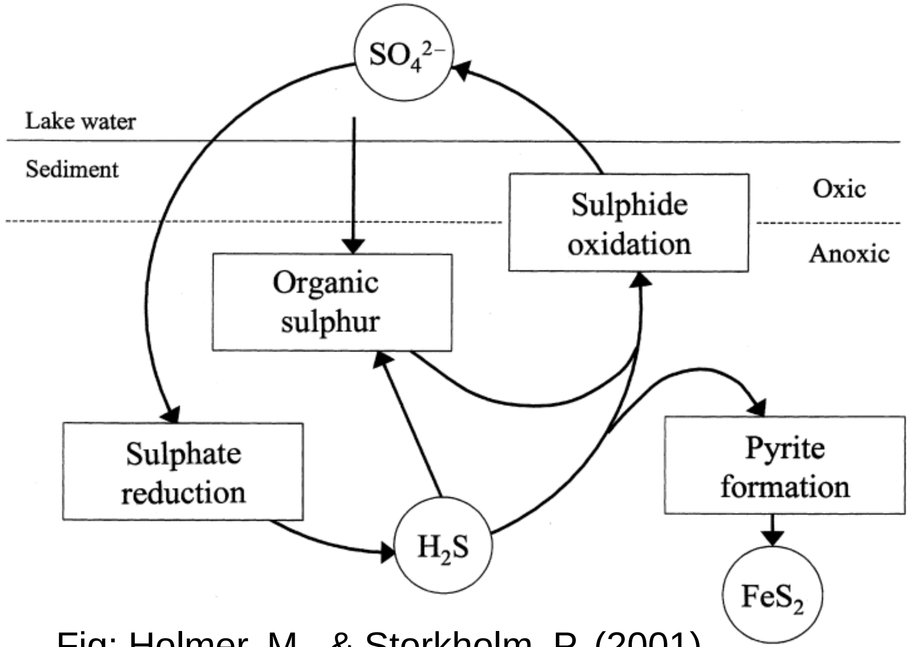



Fig: Holmer, M., & Storkholm, P. (2001).

# Objective

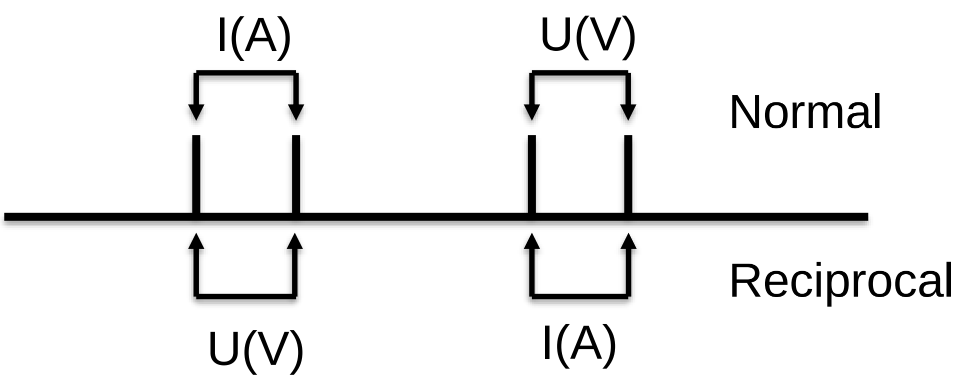
- Biogeochemical hot spots are sensitive environments classical geochemical sampling methods (e.g., piezometers or suction cups) bring oxygen into anoxic areas.
- Delineate field scale biogeochemical hot spots and their geometry without disturbing the system
- Resolve the granite bedrock and the overlying peat
  - If the granit is resolved, we can focus on the changes in the peat

⇩

- Noninvasive geophysical method – induced polarization
- Hypothesis:
  - Granite has lower polarization response than peat
  - biogeochemical active areas have higher polarization response than peat

# Induced polarization

- Induced polarization (IP)
  - Imaging 4-electrode array
    - Two electrodes used for current injections, two electrodes used for voltage measurements
    - Interchange electrode pairs → normal and reciprocal measurements
  - Impedance is measured → complex conductivity/resistivity
  - Developed for detecting metallic minerals




$$Z = \frac{U}{I} = |Z| \cdot e^{i\varphi}$$

$$\rho * = \frac{1}{\sigma *} = \sigma' + i\sigma" = |\sigma| e^{i\varphi}$$

Z – impedance, U – voltage, I – current, $\varphi$ – phase shift, ρ – resistivtiy, σ – conductivity, $i = \sqrt{-1}$

# Induced polarization

- In the presence of an external electrical field the electrons in a metallic conductor relocate along the conductor‘s surface
- In the electrolyte the charged conductor attracts ions
- Migration currents charge the electrolyte around the poles of the conductor
- The charging continues until it reaches the equilibrium

Bücker et al., 2018

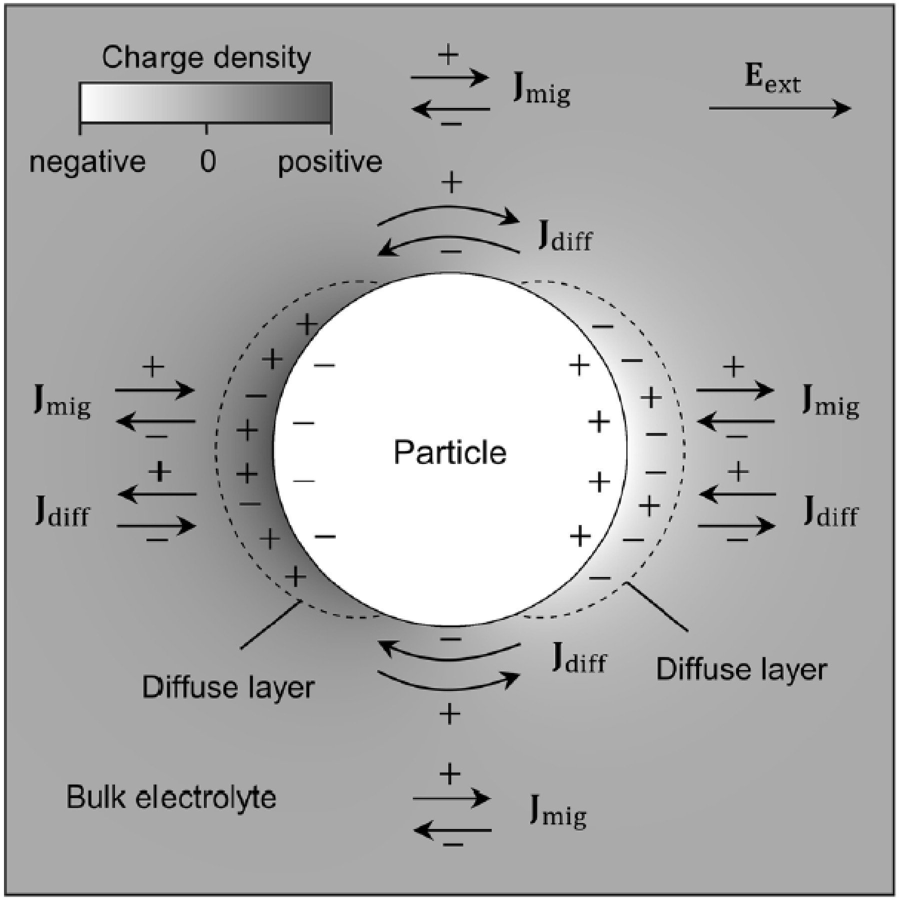
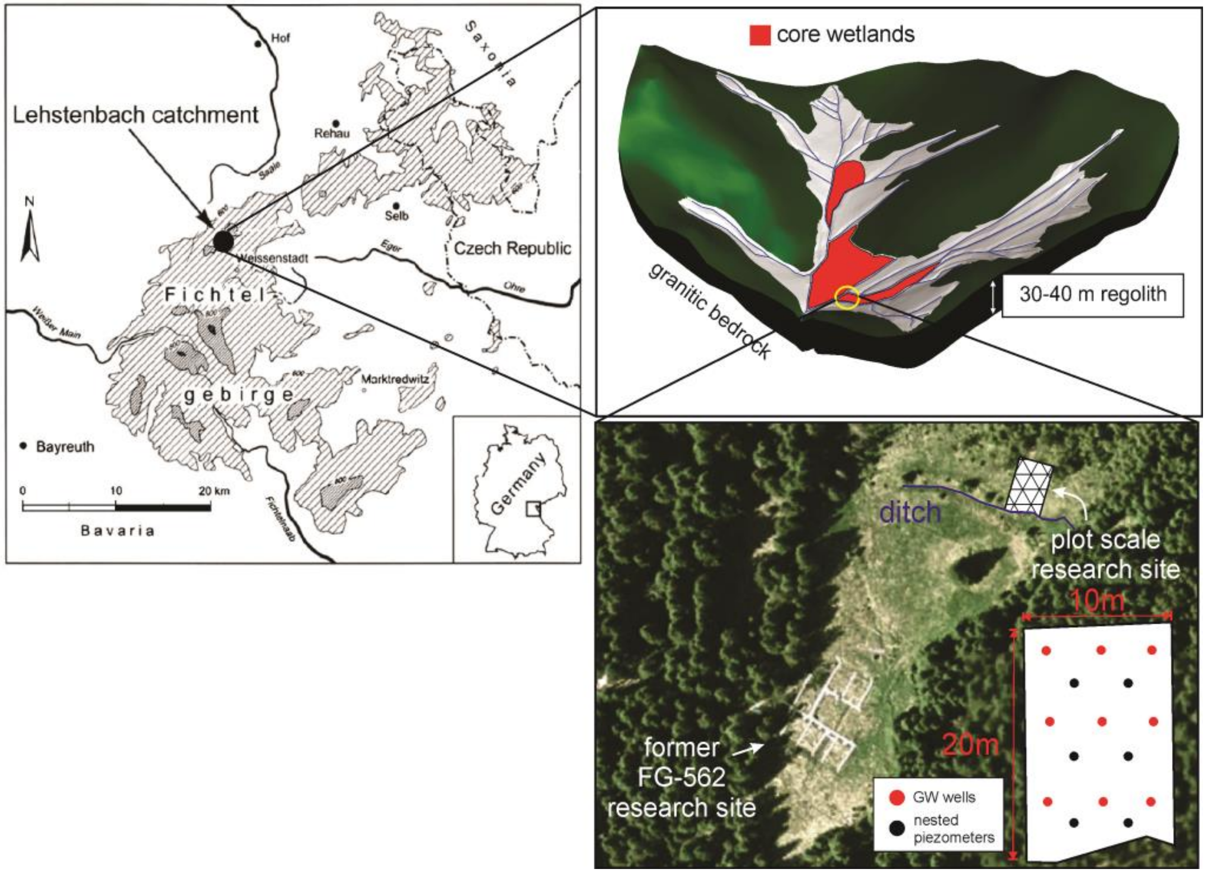



Fig: Bücker et al., 2018

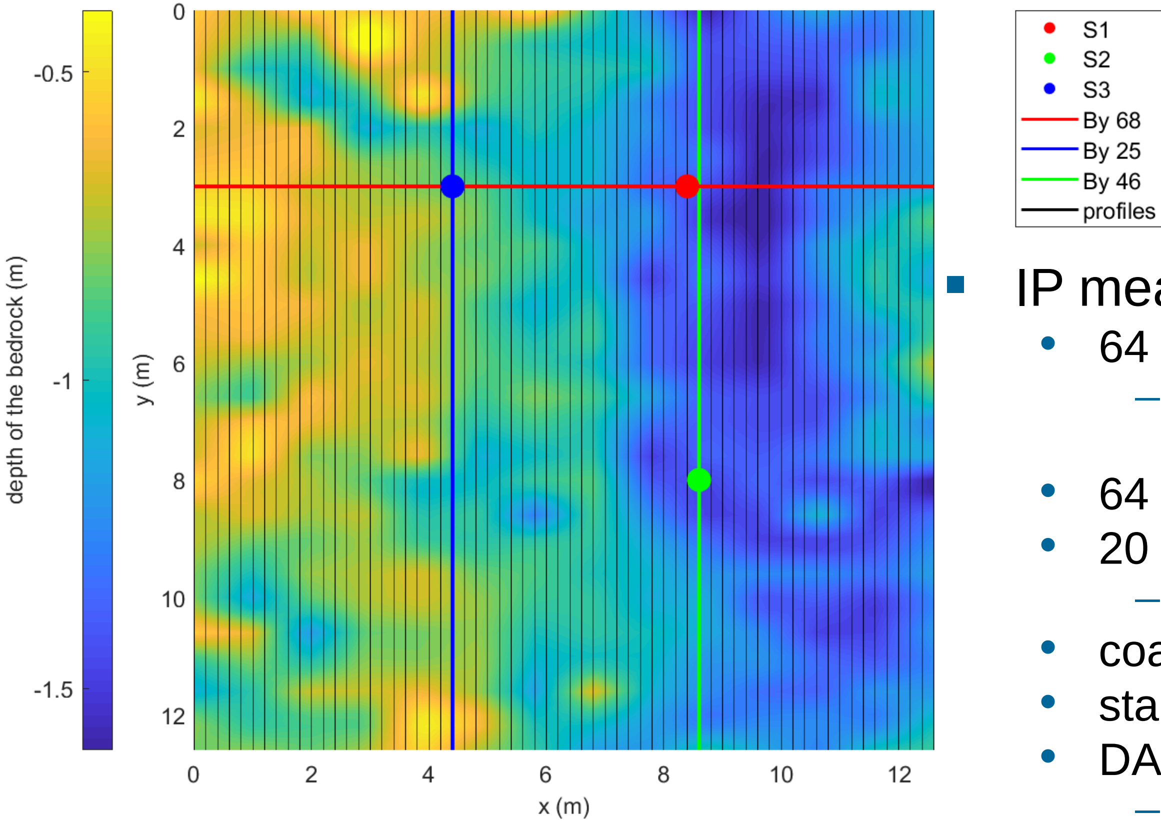
$J_{mig}$- migration current
$J_{diff}$- diffusion current
$E_{ext}$- external electric field

# Study site

- Lehstenbach catchment in Bavaria (Germany).
  – Granite bedrock
  – Riparian wetland: peat soil, with the vegetation peat moss (Sphagnum) and purple moor-grass (Molinia caerulea)



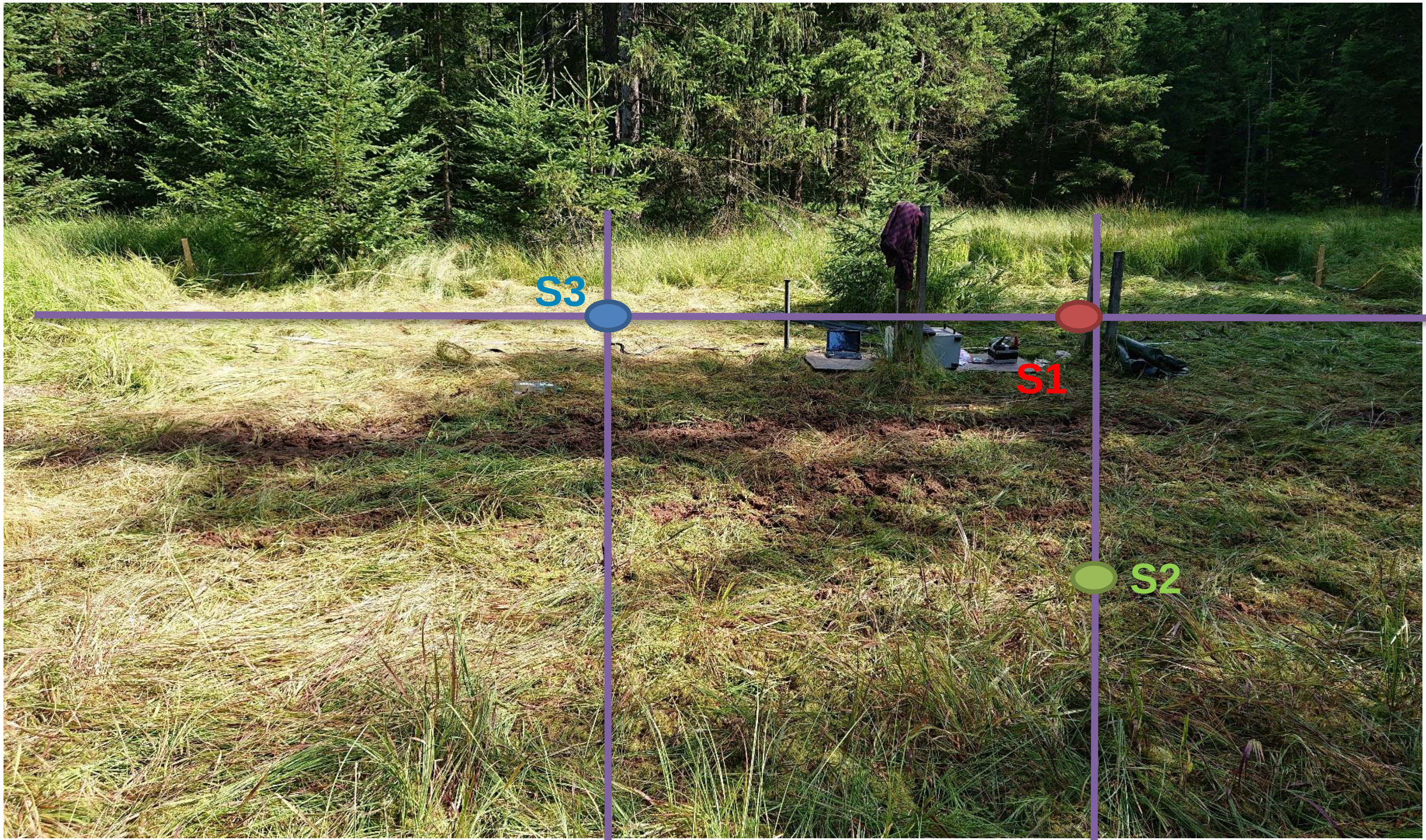
# Experimental setup




- Thickness of the peat was measured by sticking a metal rod of 0.5 cm diameter into the soft ground until it reached a solid surface.

- IP measurements at 1 Hz
  - 64 profiles (black lines)
    - 3 profiles presented here:
      - **By 25, By 46** and **By 68**
  - 64 electrodes per line
  - 20 cm separation
    - between electrodes and lines
  - coaxial cables
  - stainless steel electrodes
  - DAS1 unit
    - Multi-Phase Technologies
- Geochemical analysis
  - Fluid samples
    - 3 locations:
      - **S1, S2** and **S3**
  - Freeze core
    - 2 locations:
      - **S1** and **S2**

# Experimental setup



# Pictures of the site

Electrode

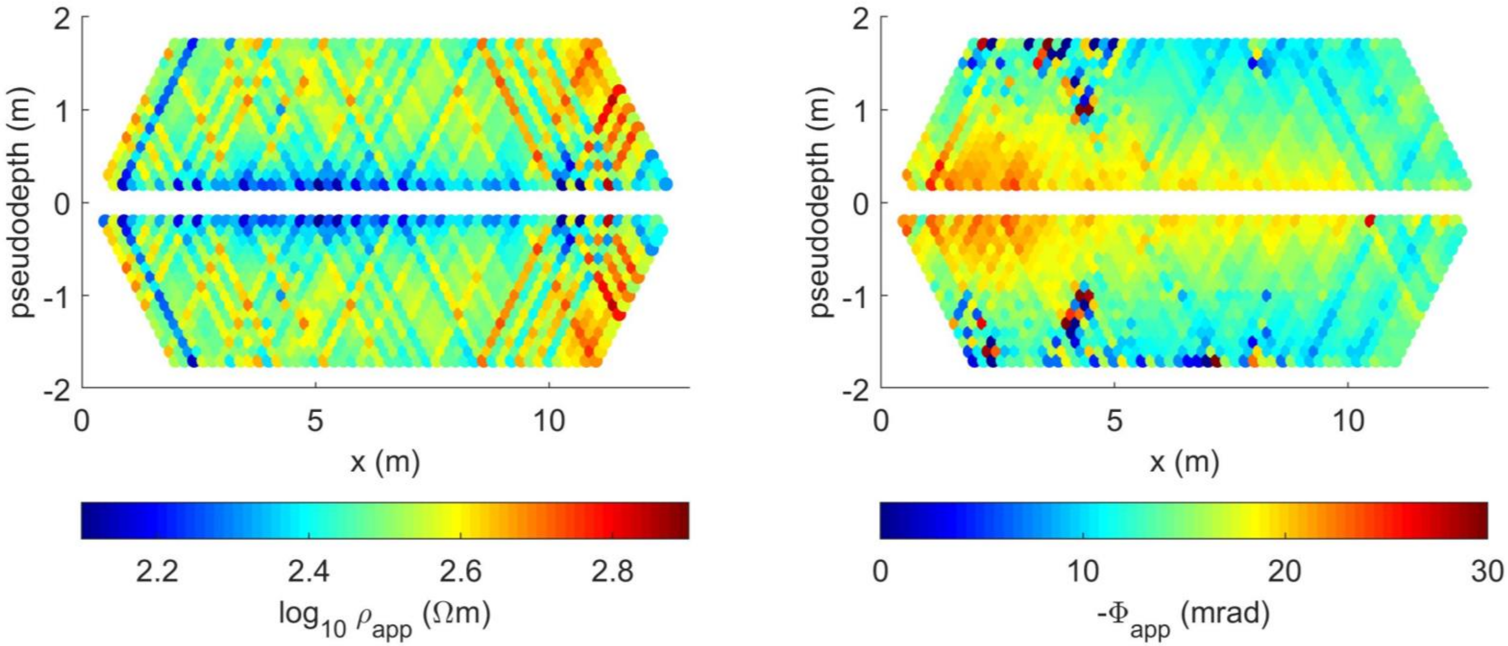
Sphagnum


Thick grass and moss,
electrode spacing: 20 cm

Measurement setup
and DAS1 instrument

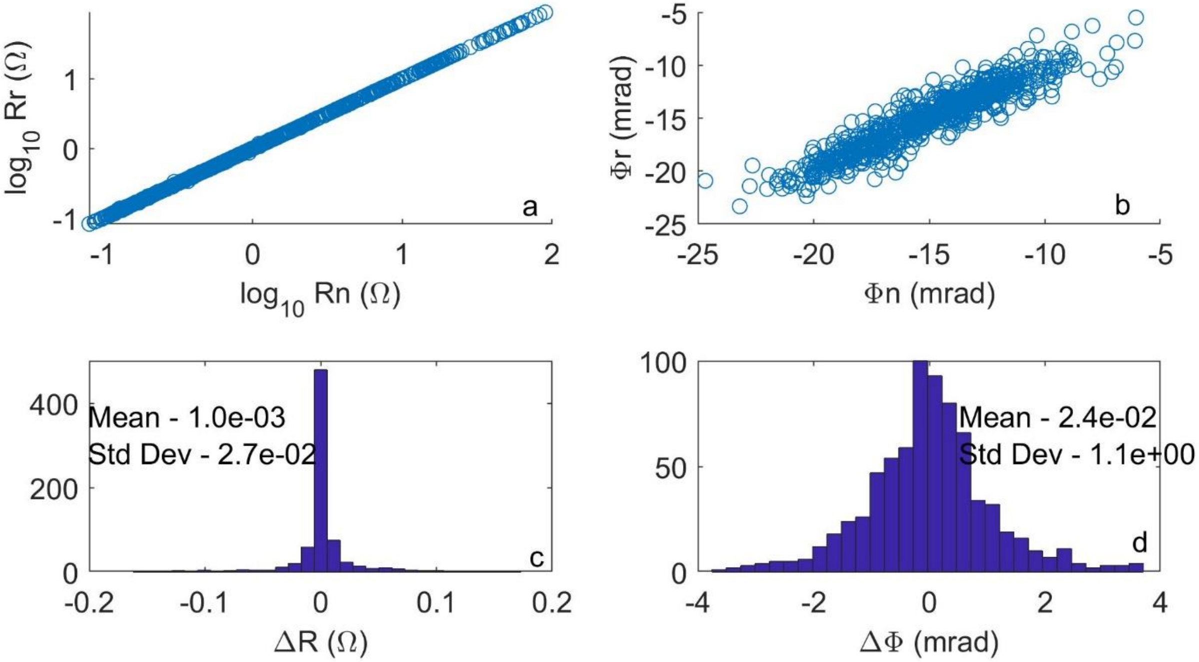
# Data quality

- Normal – reciprocal measurements
- The pseudosection of By 25 in terms of apparent resistivity ($\rho_a$) and apparent phase ($\phi_a$).
- Data collected with coaxial cable show high data quality



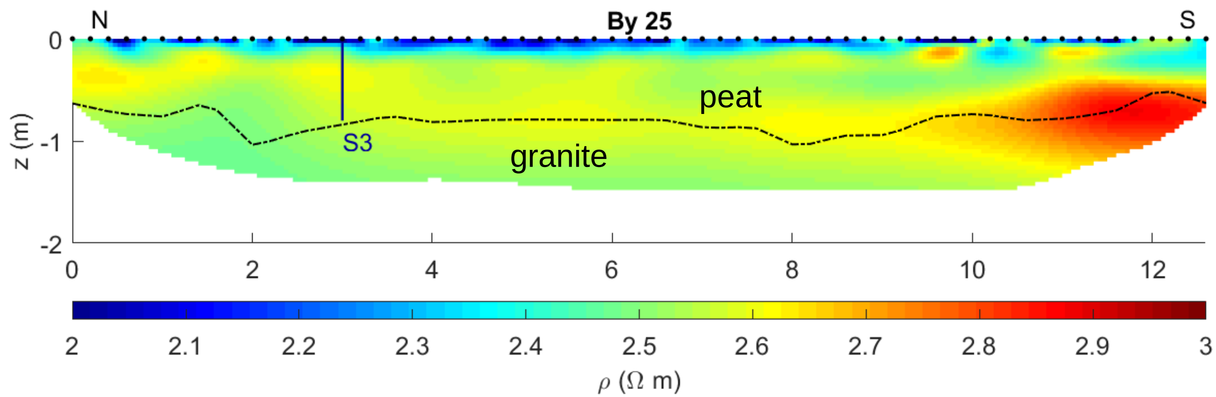
# Normal-reciprocal analysis

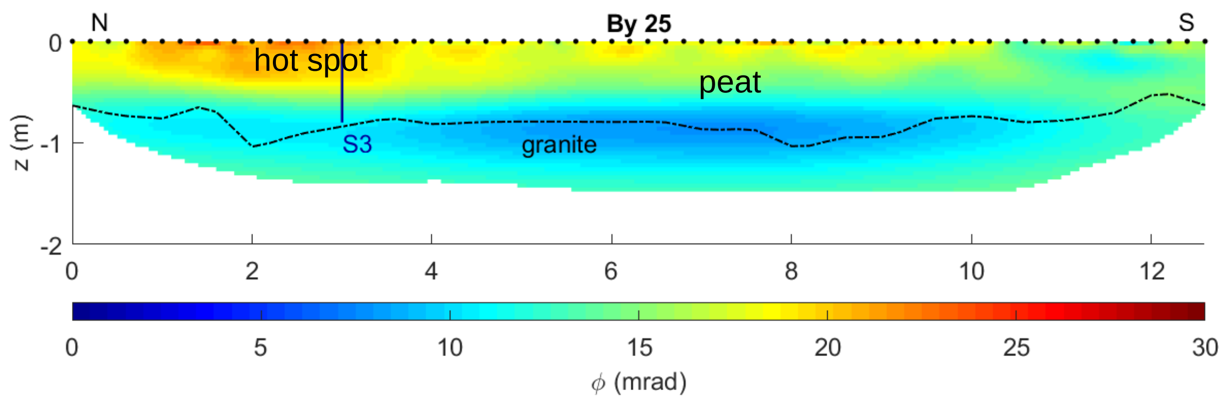
- Analysis of the normal and reciprocal misfit helps to identify outliers and to define error model parameters (Flores Orozco et al., 2012).
- The histograms of the misfit show normal distribution with low standard deviation ($\sigma_R$=0.027, $\sigma_\phi$=1.1).



# Results

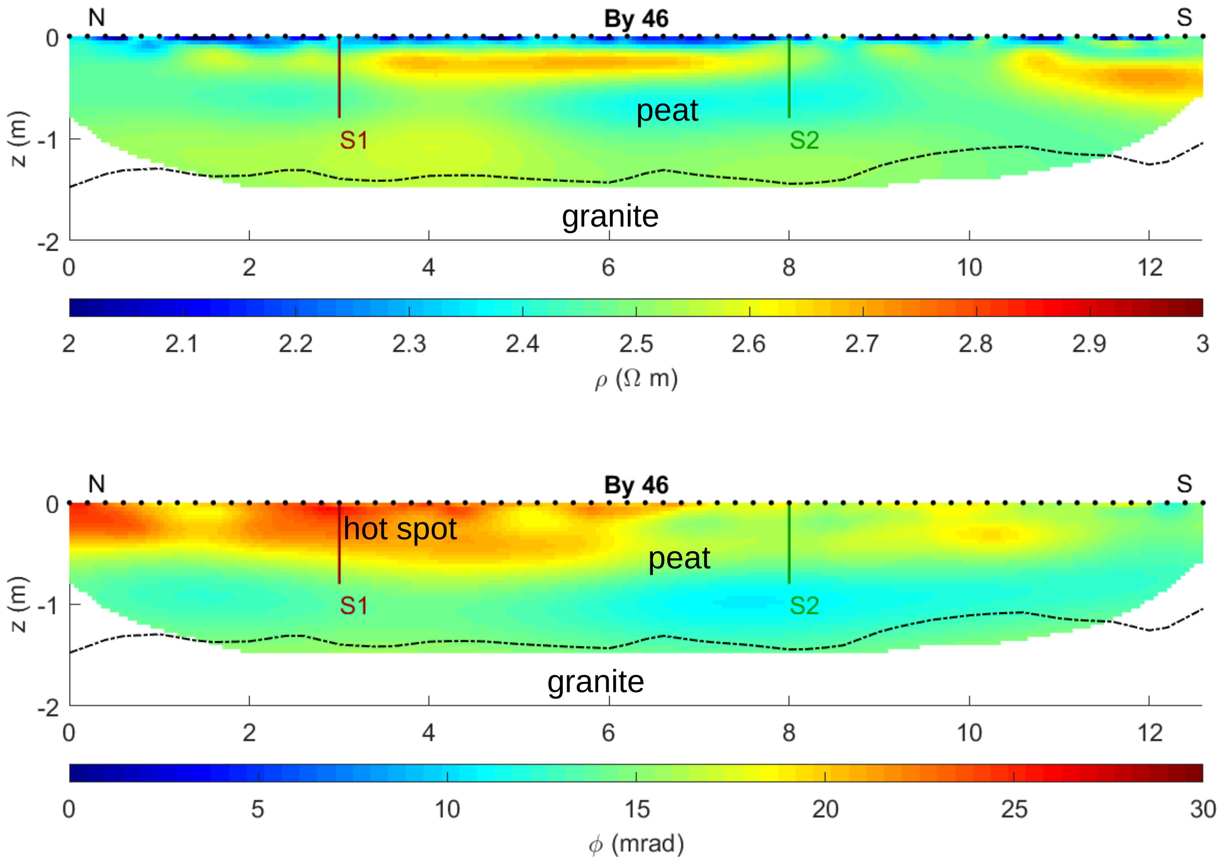
- Phase values help to resolve the granite and the peat
  - $\varphi < 13$ mrad - granite
  - $\varphi > 13$ mrad -peat
- Varying values in the peat, top 10-20 cm – low resistivity and high phase: hot spot
  - $\rho < 200\ \Omega m$ (however, only in the top 10-20 cm below surface)
  - $\varphi > 22$ mrad (spatial changes in the phase values)



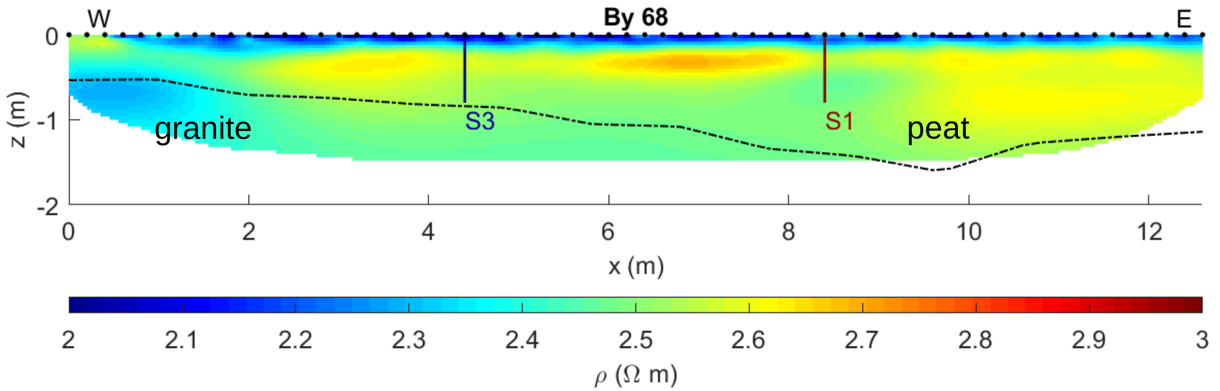
# Results

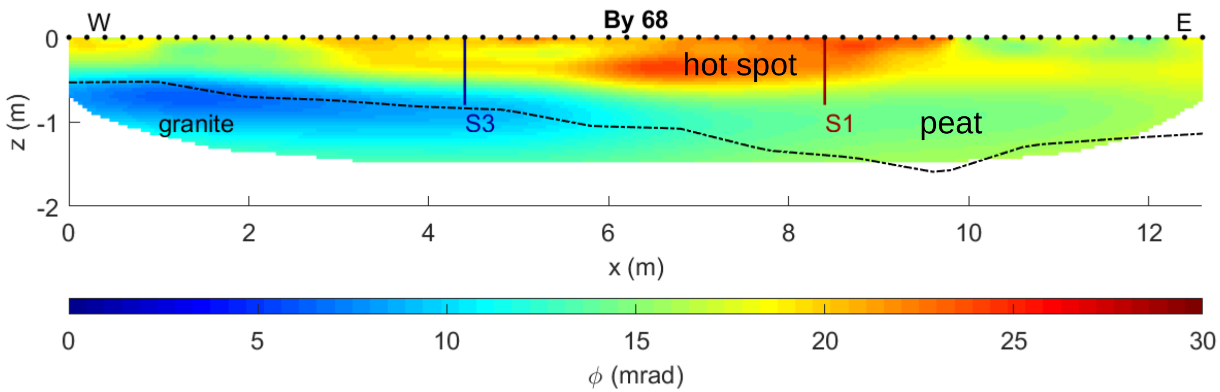
- Granite is below the sensitivity of the electrode configuration at By 46 → we cannot resolve the granite at By 46



# Results

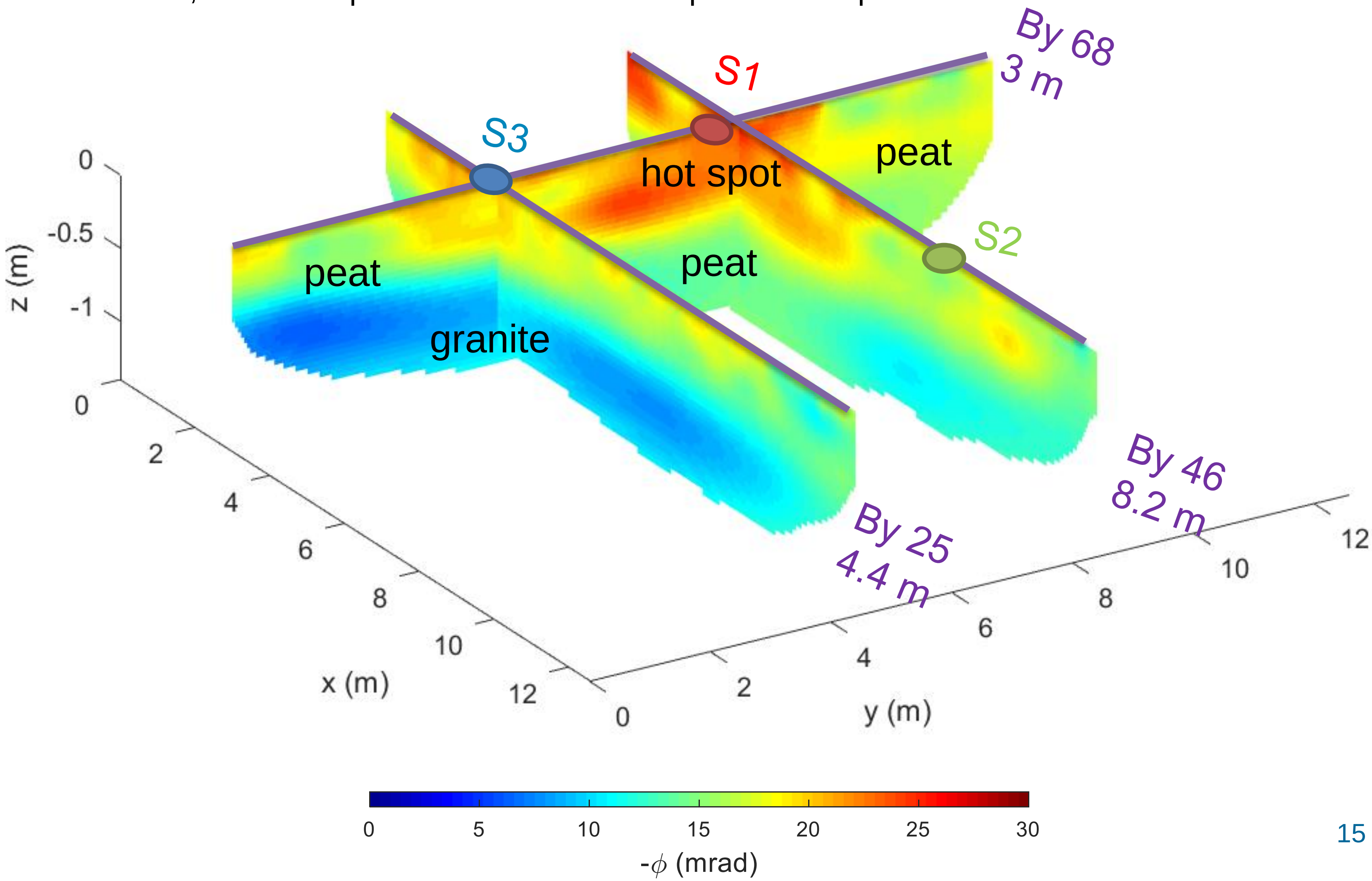
- By 68 is a perpendicular profile to the previous By 25 and By 46
- Validate the geometry of the phase distribution we measured at By 25 and By 46



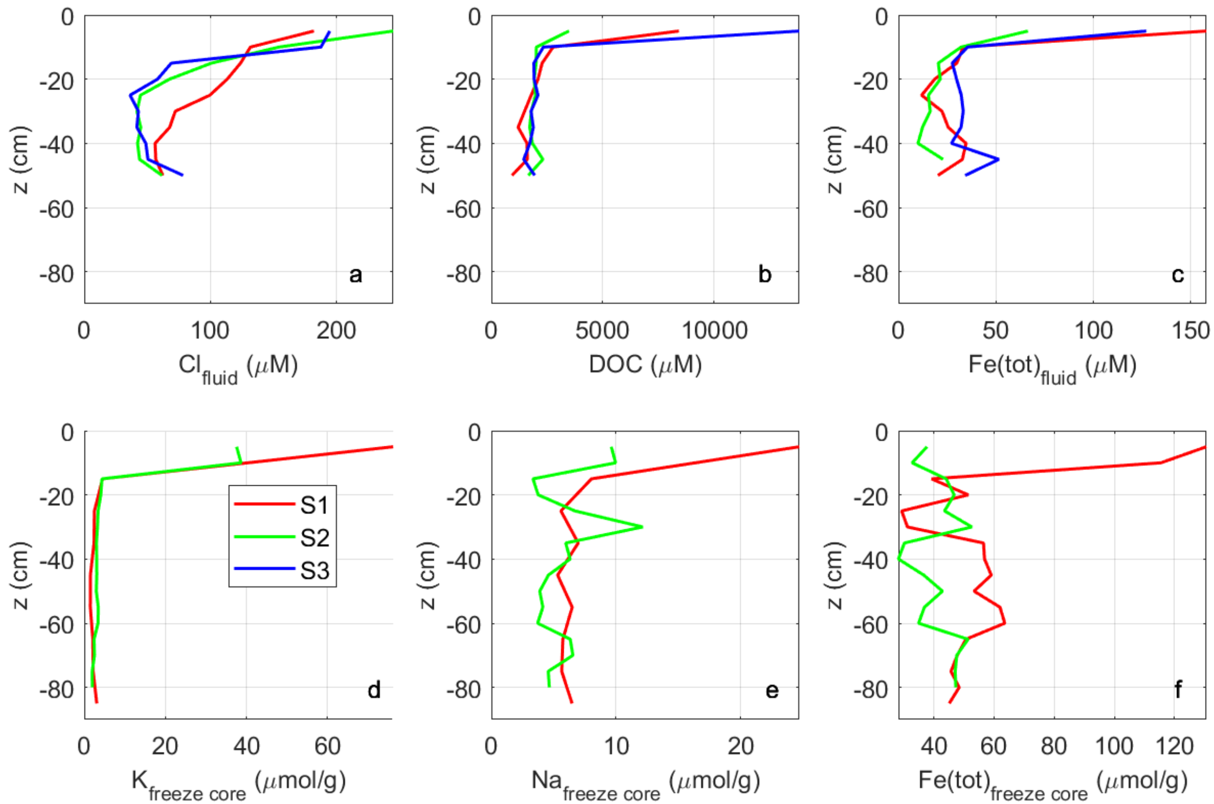
# IP results

- The IP in the peat is varying between 13 and 30 mrad → varying biogeochemical activity
  - Peat, where the phase >22 mrad we interpret as hot spot



# Geochemical analysis

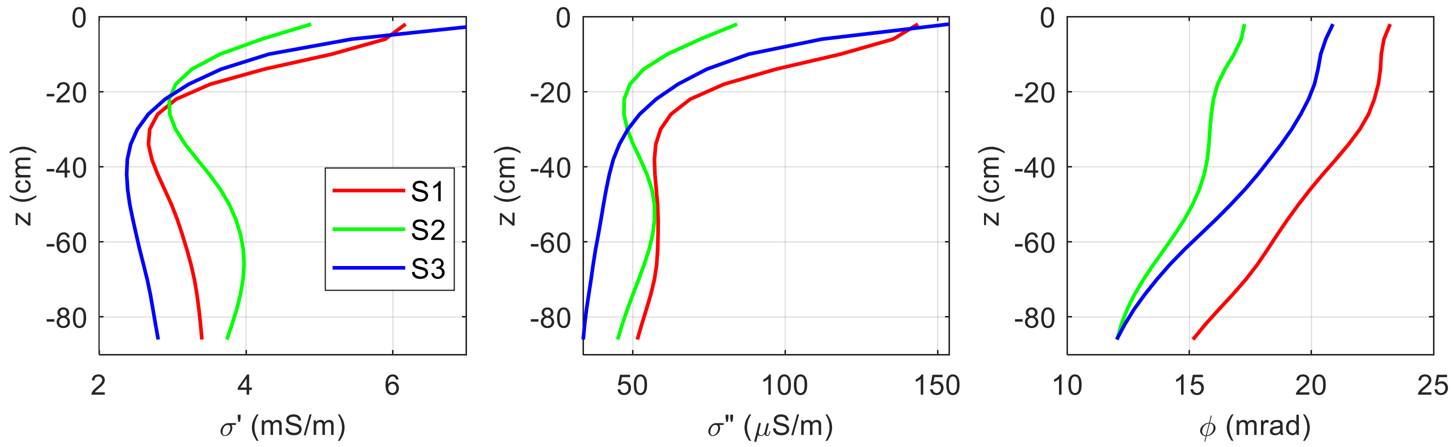
- High dissolved organic carbon (DOC), iron ($Fe_{tot}$), potassium (K) and sodium (Na) concentrations at S1 and S3 in the top 10-20 cm → indicator for biogeochemical hot spots.



# IP analysis

- The conductivity (σ‘) and polarization (σ“) are high at the surface and steeply decrease with depth across the top 20 cm
- The decrease of the phase (ϕ) is less pronounced than σ‘ or σ“
- The conductivity, polarization and phase in the top 20 cm at S1 and S3 are remarkably higer than at S2

- Corresponding to the geochemical analysis (DOC and iron), the top 20 cm at S1 and S3 are interpreted as biogeochemical hot spots
- σ‘>5 mS/cm and σ“>80 µS/cm → Hot spot



# Conclusion

- We characterized biogeochemical hot spots and resolved the peat-granite interface with induced polarization
- IP results could be verified by
  - the manually measured peat thickness
  - the geochemical analysis
    - Dissolved organic carbon (DOC), iron (Fe), potassium (K), sodium concentration (Na) correlates to the polarization (σ“)
    - Chloride (Cl) concentration correlates to the conductivity (σ‘)

# References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