Direct Current-Induced Polarization Constrained by Ground Penetrating Radar for Improved Delineation of Geological Boundaries at test sites around Lake Bolmen, Sweden

Pugacheva, Polina; Martin, Tina; Günther, Thomas; Igel, Jan

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P. Pugacheva[1], T. Martin[2], T. Günther[3], J. Igel[3]

[1] Technical University of Munich, TUM School of Engineering and Design, Chair of Non-destructive Testing, Munich, Germany,
[2] Lund University, Division of Engineering Geology, Lund, Sweden,
[3] Leibniz Institute for Applied Geophysics, Hanover, Germany

1. Motivation and Objective

Problem:
Brownification (brown color) of water in Lake Bolmen in Sweden arises due to the presence of higher levels of dissolved organic carbon (DOC) or iron (Fe) originating from coniferous forests and peatlands, transported through rivers, streams, and drainage.

Consequences:
Result in an increase in drinking water treatment and harms the aquatic ecosystem [1], [2].

Objectives:
- Characterizing the geology and thickness of soil layers.
- Assessing the potential of using structural constraints from GPR in DCIP inversion to identify geological horizons and layers with different chargeabilities.

Fig. 1: Photo of brown water at lake Bolmen.

2. Study Area: Lake Bolmen

- Located in South-Western Sweden.
- Twelfth largest lake in Sweden:
  - Area: 184 km²
  - Coastline length: 330 km
  - Average water depth: 6.2 m
- Geology: Dominated by granite and granitic gneiss.
- Depth to bedrock: Varies between 3 and 8 meters.
- Soil: Overlying bedrock includes peat, till, sandy till, and glaciofluvial sediments.

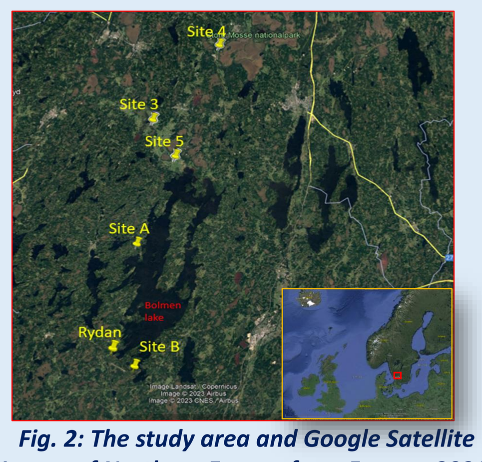

Fig. 2: The study area and Google Satellite Image of Northern Europe from Favaro, 2021.

3. Methods

Acquisition
- Carrying out DCIP and GPR field measurements

Processing
- Preparing/cleaning IP data for inversion in Workbench software
- Processing of GPR data in ReflexW software
- Picking of reflectors at the soil/bedrock interface

Inversion
- Inversion of DCIP data in pyGIMLi software
- Performing structurally constrained inversion in pyGIMLi

Interpretation
- Interpreting the structurally constrained inversion models

Fig. 3: DCIP field measurement setup.

Fig. 4: top - GPR field measurement setup, bottom – 170/600 MHz GPR antenna used during the measurements.

GPR Processing Flow:
- Static correction
- Subtract-mean(dewow)
- Divergence compensation
- Gain function
- Bandpass frequency filter
- Average xy-filter
- Running average

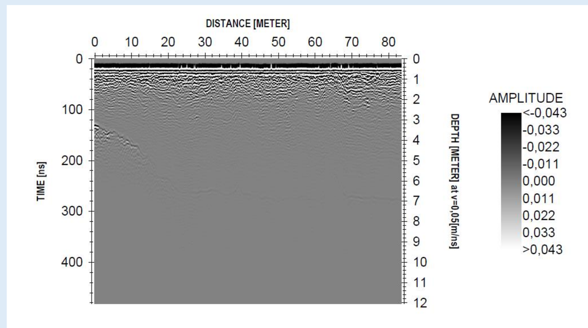

Fig. 5: Raw data from the 170 MHz antenna.

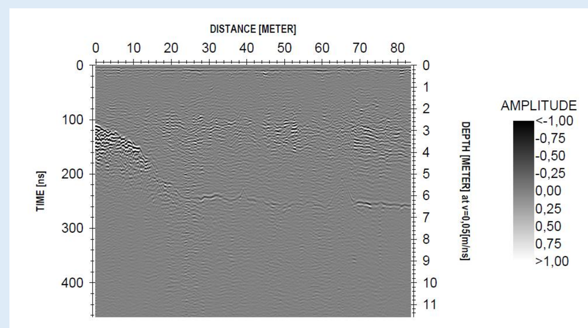

Fig. 6: Processed data from the 170 MHz antenna.

4. Results

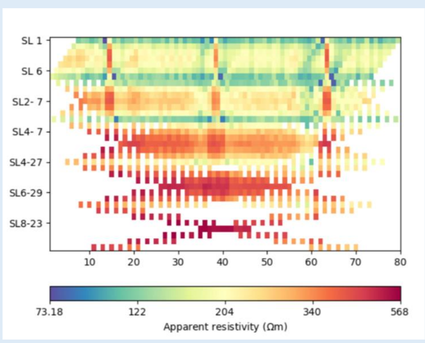

Fig. 7: Pseudosection of apparent resistivity data from Site B, Line No. 1.

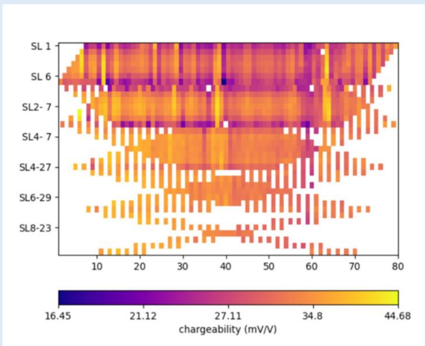

Fig. 8: Pseudosection of chargeability data from Site B, Line No. 1.

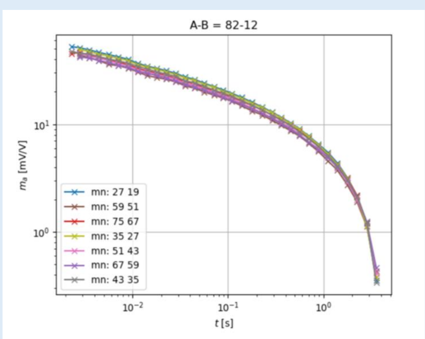

Fig. 9: Exemplary decay curves from Site B, Line No. 1.

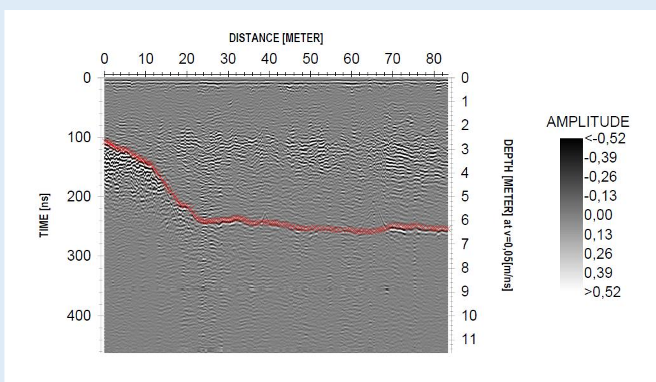

Fig. 10: 170 MHz antenna data for Site B, Line No. 1 after processing. The reflector used for structurally-constrained inversion is shown in red.

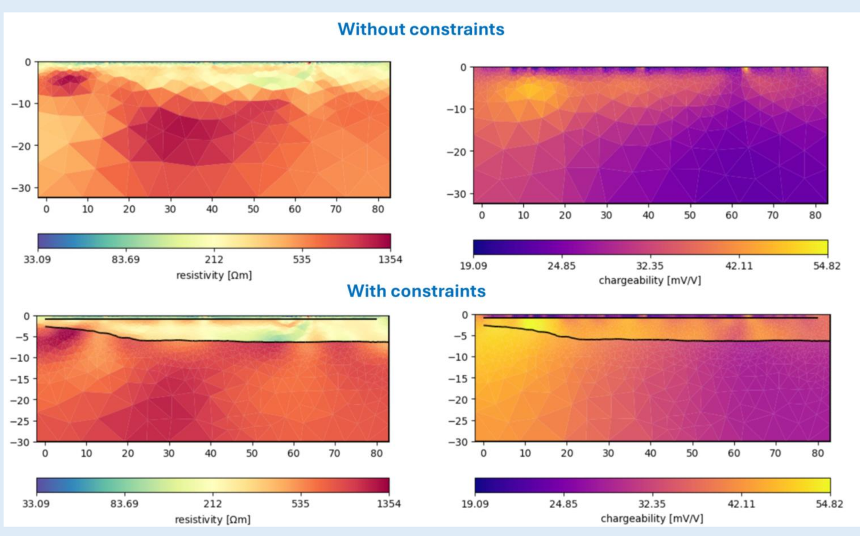

Fig. 11: Inversion results for resistivity (left) and chargeability data (right) with (top) and without constraints (bottom) for Site B, Line No. 1.

- Top Low Resistivity Layer: <100 Ωm, thin, heterogeneous soil layer.
- Intermediate Resistivity Layer: 100-200 Ωm, different peat sequences.
- High Resistivity Layer: >600 Ωm, Granitic gneiss.
- Chargeability Anomalies: Few surface anomalies, linked to ditches.

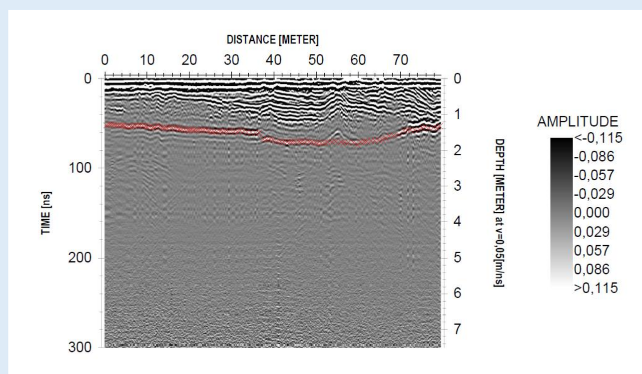

Fig. 12: 170 MHz antenna data for Site 3, Line No. 1 after processing. The reflector used for structurally-constrained inversion is shown in red.

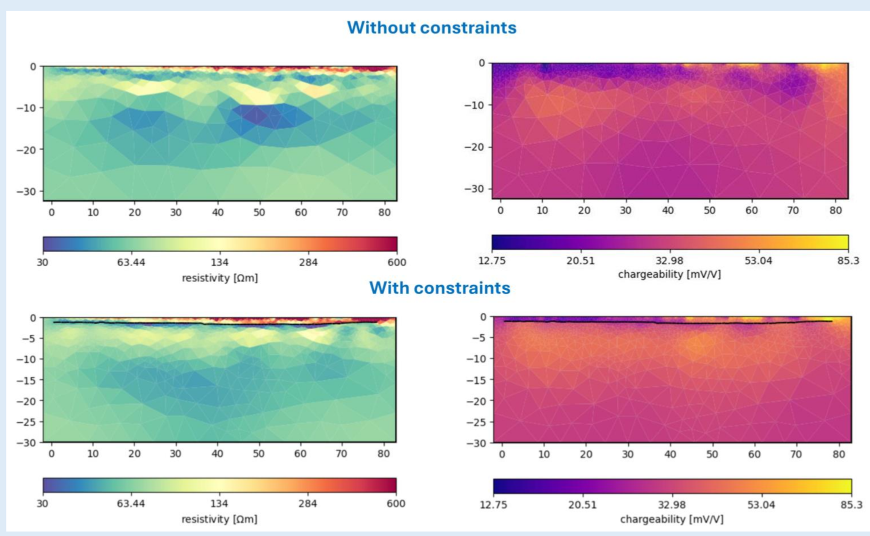

Fig. 13: Inversion results for resistivity (left) and chargeability data (right) with (top) and without constraints (bottom) for Site 3, Line No. 1.

- Top High Resistivity Layer: 150-600 Ωm, heterogeneous soil layer.
- Low Resistivity Layer: 50-130 Ωm, heterogeneous.
- Chargeability Anomalies: Higher chargeability anomalies at shallow depth.

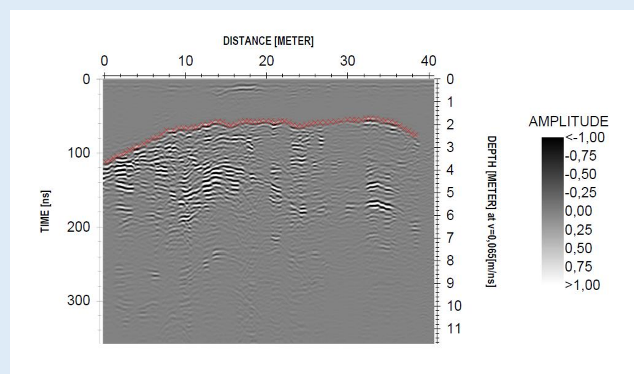

Fig. 14: 170 MHz antenna data for Site Rydan, Line No. 2 after processing. The reflector used for structurally-constrained inversion is shown in red.

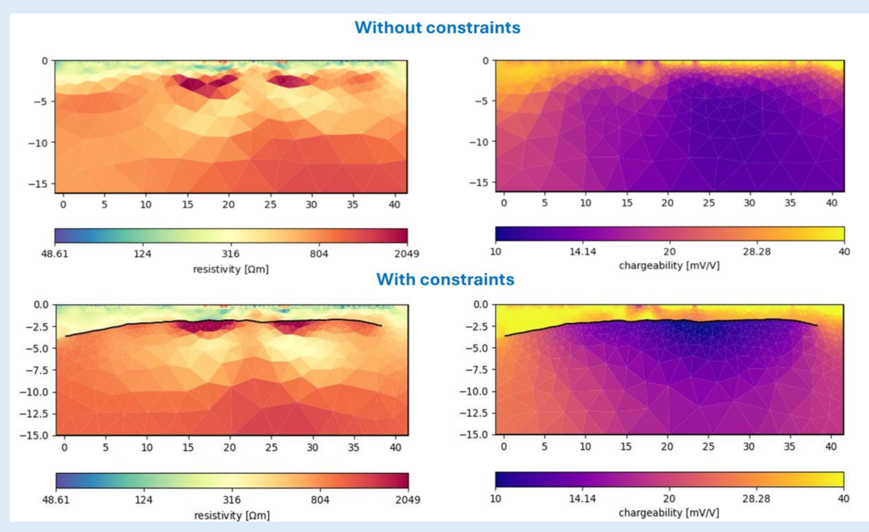

Fig. 15: Inversion results for resistivity (left) and chargeability data (right) with (top) and without constraints (bottom) for Site Rydan, Line No. 2.

- Top Resistivity Layer: 120-300 Ωm, heterogeneous soil layer.
- High Resistivity Layer: 300-2000 Ωm, very heterogeneous, likely glaciofluvial sediments and till.
- Chargeability Anomalies: Higher chargeability values starting from the surface and continuing to a depth of ca. 2.5 meters.

5. Conclusions

- In the majority of sites integrating reflectors from GPR data into the mesh enhanced the precision of delineating the DCIP boundary between bedrock and soil, as well as distinguishing between various chargeability layers.
- Some high-chargeability anomalies have been found to be associated with the location of ditches.
- The first information about the hydrogeological system regarding the bedrock depth and soil thickness could be better obtained through the structurally-constrained inversion model.

6. Future Work

- To enhance further interpretation, it is recommended to improve the analysis by incorporating data from soil and water samples, as well as boreholes.
- Continuous monitoring of the different riparian zones with geophysical (DCIP) and hydrological methods.
- Model the hydrogeological system in the Lake Bolmen area, the interaction of groundwater with surface water (especially with drainage ditches), and surrounding soils.
- An optimized riparian zone design in terms of size and structure.

7. Acknowledgements

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8. References

[1] Albrecht, E., Hannonen, O., Palacín-Lizarbe, C., Suni, J., Härkönen, L.H., Soininen, N., Kukkonen, J. and Vainikka, A., 2023. Browning of boreal lakes: Do public perceptions and governance meet the biological foundations?. Ecological Applications, p.e2856.

[2] Klante, C., Hägg, K. and Larson, M., 2022. Understanding short-term organic matter fluctuations to optimize drinking water treatment. Water Practice & Technology, 17(10), pp.2141-2159.

[3] Martin T, Günther T, Orozco AF, Dahlin T. Evaluation of spectral induced polarization field measurements in time and frequency domain. Journal of Applied Geophysics. 2020 Sep 1;180:104141.

[4] Favaro, M., 2021. Assessment of Groundwater Flow to Lake Bolmen. Master Thesis, Lund University.

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