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Improving Groundwater Resource Mapping in Complex Geological Regions Using Constrained Inversion of Seismic and ERT Data

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OGER

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1. Introduction

Developing new groundwater resources is increasingly challenging due to rising demand, climate impacts, and competing land use. In complex geological settings, conventional drilling based approaches are costly and provide only limited one dimensional data for three dimensional subsurface characterization. The OGER project investigates the use of non invasive geophysical methods to improve the spatial resolution of subsurface models while reducing dependence on exploratory drilling. This study applies electrical resistivity tomography (ERT) inversion, guided by structural constraints derived from seismic data and borehole information, at two glacially influenced sites in northern Germany.

2. Study Areas

Figure 1. Locations of the study areas in Northern Germany.

2a. Geological Setting

Hude

The Hude site comprises unconsolidated Plio–Pleistocene sands overlying Miocene clays. Key aquifers include Pliocene fluvial and Elster glaciofluvial sands, confined by laterally variable Lauenburg clay. Geophysics aids in resolving clay thickness and aquifer connectivity.

Hamburg-Sülldorf

This site lies in the North German Basin and contains Quaternary sands over Miocene clays. glaciofluvial sands form aquifers, confined by Drenthe till and Lauenburg clay. In the eastern W-E section (Fig. 3), it is unclear whether the sandy layer represents Elster aquifer sands or Pliocene fine sands, a distinction currently being investigated using geophysics.

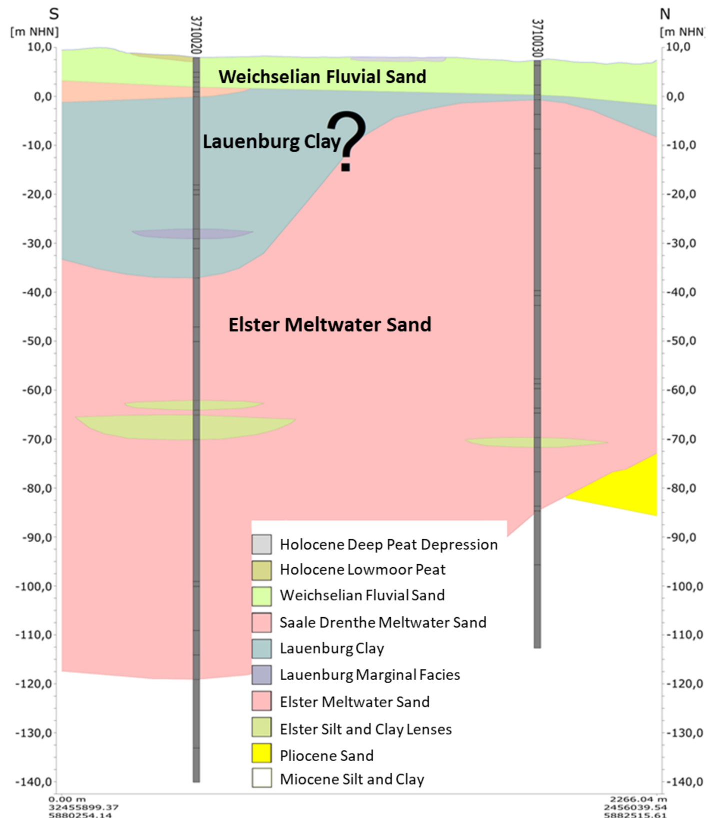

Figure 2. North-south stratigraphic cross-section in Hude with boreholes 3710020 and 3710030, illustrating lateral variability of aquifers and confining units.

Source: Provided by OOWV (unpublished project material).

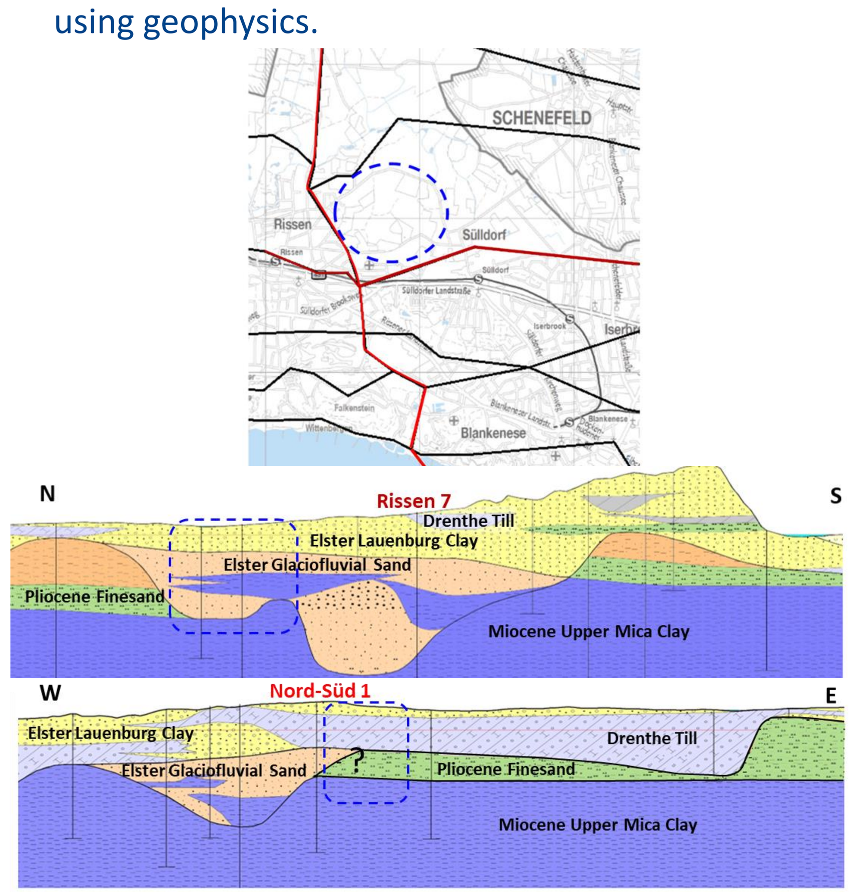

Figure 3. Regional geological cross-sections in Hamburg-Sülldorf, with the study area outlined (blue dashed line) and two key sections (in red) that align with geophysical profiles; corresponding stratigraphic sections below illustrate lithological units and the approximate extents of the measured profiles.

Source: Provided by HW (unpublished project material).

2a. Geophysical Survey Layout

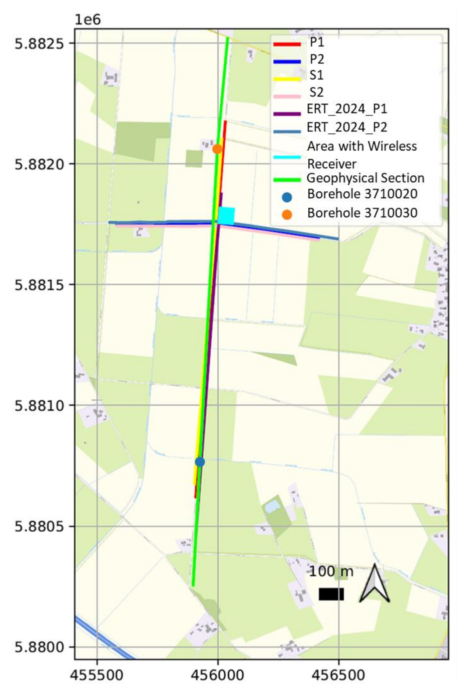

Figure 4. Seismic, ERT profiles and borehole locations in the Hude area.

Profile labels: P = P-wave, S = S-wave, ERT_[year]_P# indicates profile number.

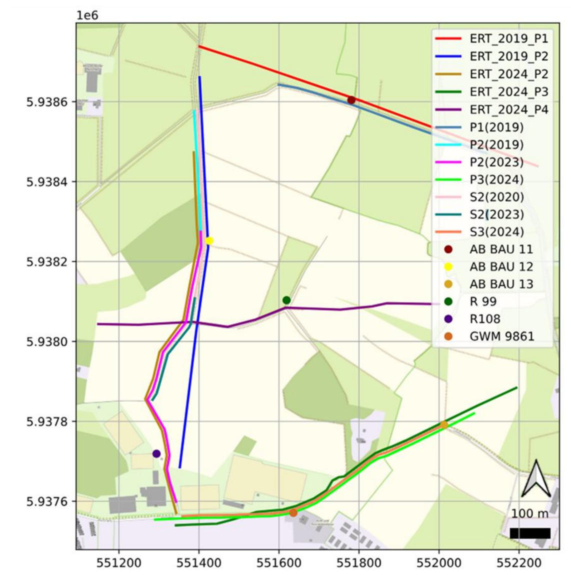

Figure 5. Seismic, ERT profiles and borehole locations in the Hamburg area.

Profile labels: P = P-wave, S = S-wave, ERT_[year]_P# indicates profile number.

3. Geophysical Data Integration

3a. Joint Interpretation

Hude

P- and S-wave seismic data were processed using *ProMAX* and interpreted using the lithology of the boreholes. Geological interfaces were picked and overlaid on both seismic and ERT profiles. Vertical Seismic Profile (VSP) data were measured at both boreholes, and the derived velocity-depth trends show strong correlation with seismic reflectors and resistivity contrasts.

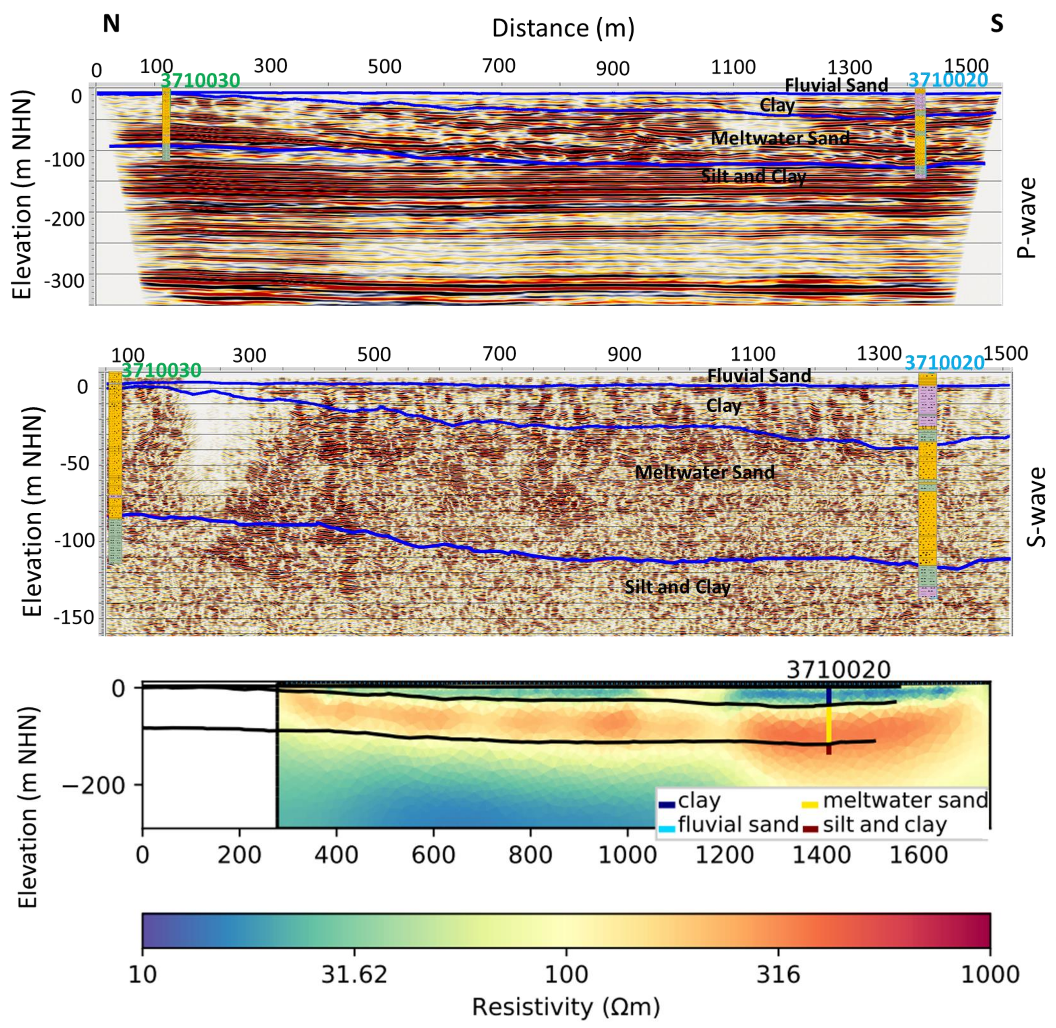

Figure 6. Interpreted seismic sections along profiles P1 (P-wave) and S1 (S-wave) with overlaid borehole lithology (3710020 and 3710030). ERT section along ERT_2024_P1 with horizons derived from seismic interpretation and borehole 3710020.

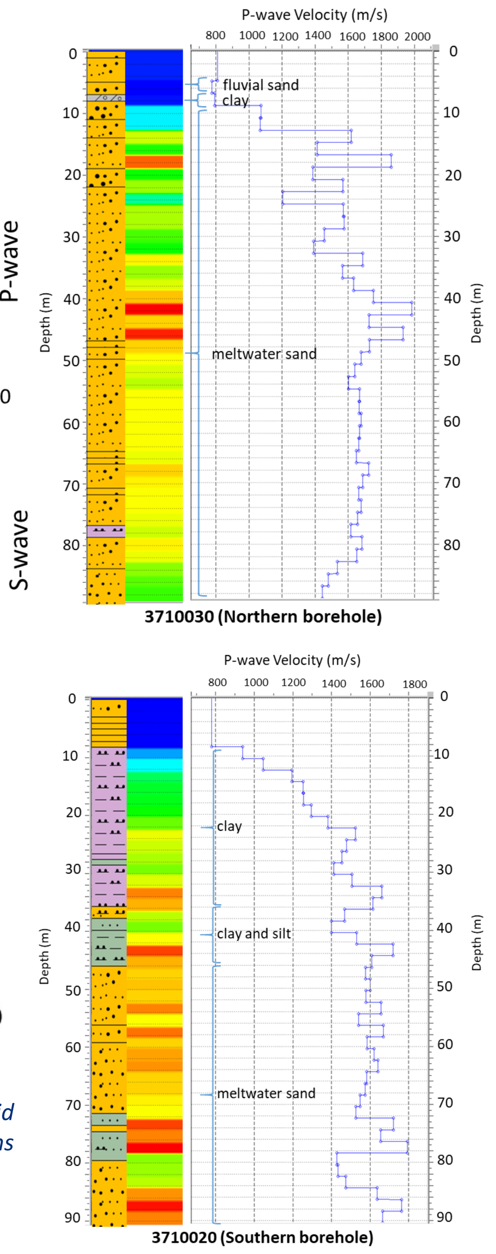

Figure 7. Vertical Seismic Profile (VSP) velocities for the boreholes, supporting lithological contrasts.

Hamburg-Sülldorf

Similar to the Hude dataset, seismic sections (P- and S-wave) were processed using *ProMAX* and interpreted with reference to borehole lithology. Picked geological horizons were transferred to the ERT profiles to support hydrostratigraphic interpretation. The alignment of seismic reflectors with borehole-defined units provides a consistent structural framework across datasets.

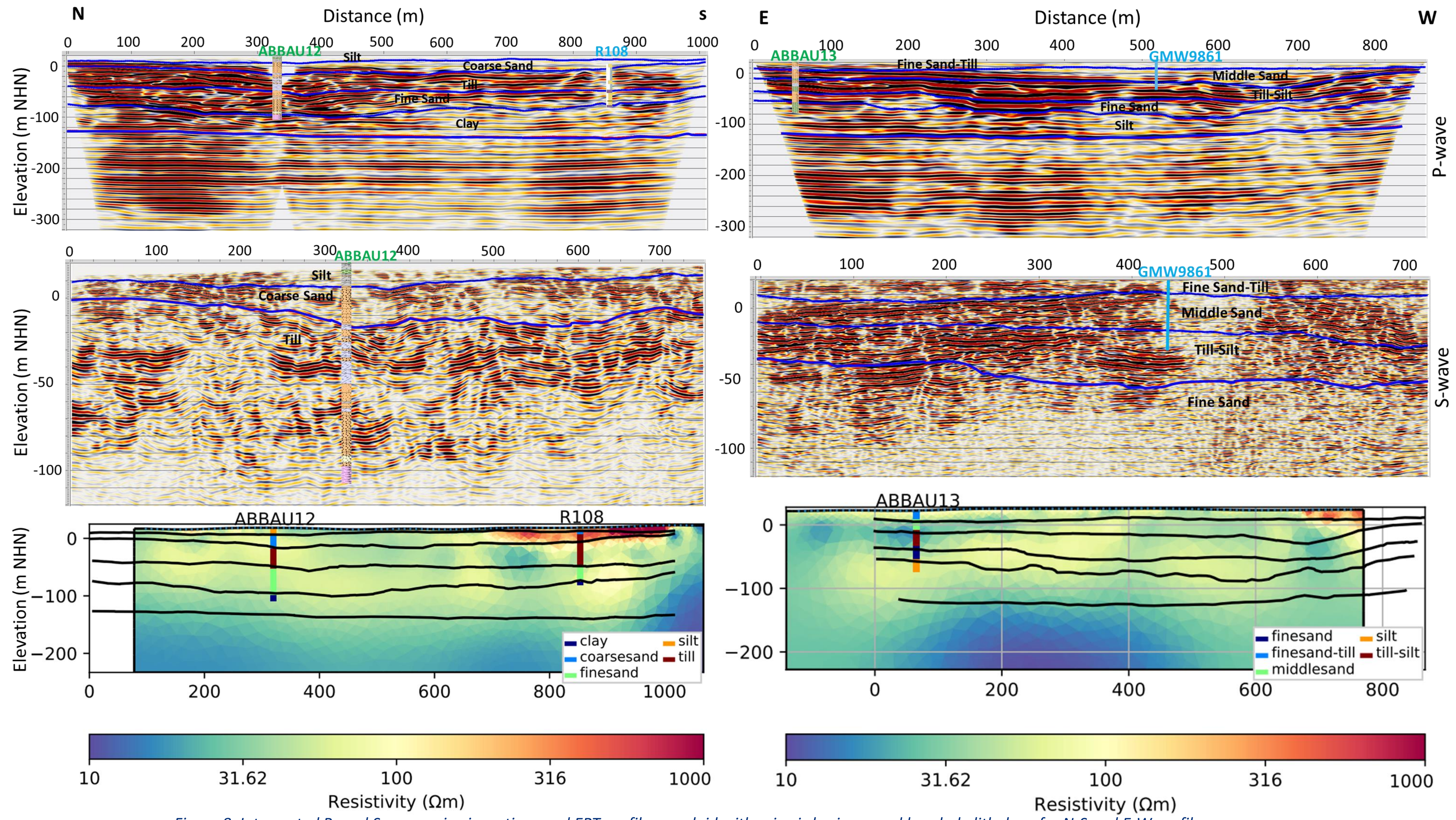

Figure 8. Interpreted P- and S-wave seismic sections and ERT profiles overlaid with seismic horizons and borehole lithology for N-S and E-W profiles.

N-S profiles: Combined P-wave data from profiles P2 (2019 & 2023), S-wave from S2 (2020 & 2023), and ERT from ERT_2024_P2.

E-W profiles: P-wave from P3 (2024), S-wave from S3 (2024), and ERT from ERT_2024_P3.

3b. Inversion

Structurally Constrained Inversion

ERT inversion was implemented in *pyGIMLi* using geostatistical regularization and seismic horizons as structural constraints. The inversion resolves subsurface contrasts linked to clay and meltwater sand layers, revealing their distribution along the profile. A high-resistivity zone within the clay aligns with a known surface canal, possibly indicating disturbed or coarser backfill material. Though its extent is unclear, it may locally reduce aquitard integrity and should be considered in site vulnerability assessments.

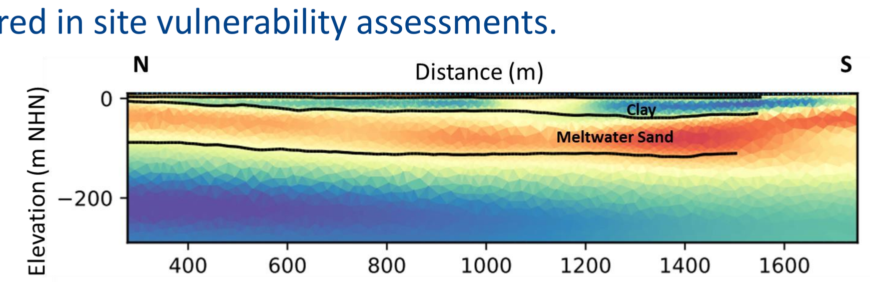

Figure 9. ERT Inversion with geostatistical regularization (Correlation Lengths=[150, 10], Lam=200).

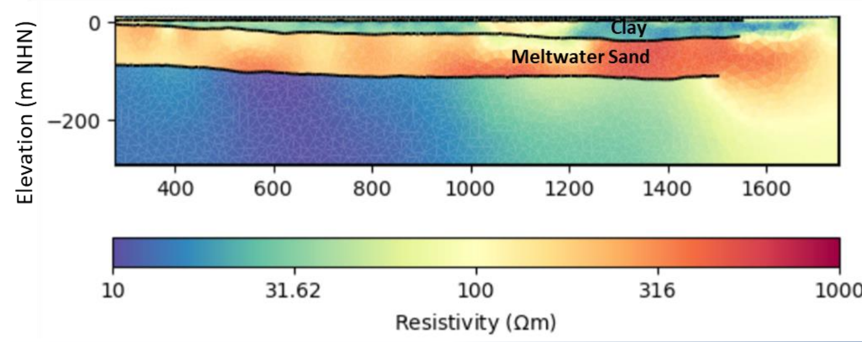

Figure 10. ERT inversion constrained with seismic horizons.

Borehole-Based Inversion

Borehole resistivity logs were first used for inversion independent of ERT data in pyGIMLi, with geostatistical regularization guiding spatial continuity between boreholes. The result served as the starting model for ERT inversion, which also applied geostatistical regularization to improve structural clarity. The N-S profile captures Elster aquifer sands with high resistivity, while the E-W profile reveals Pliocene fine sands with lower resistivity, indicating it does not intersect the water-bearing formation.

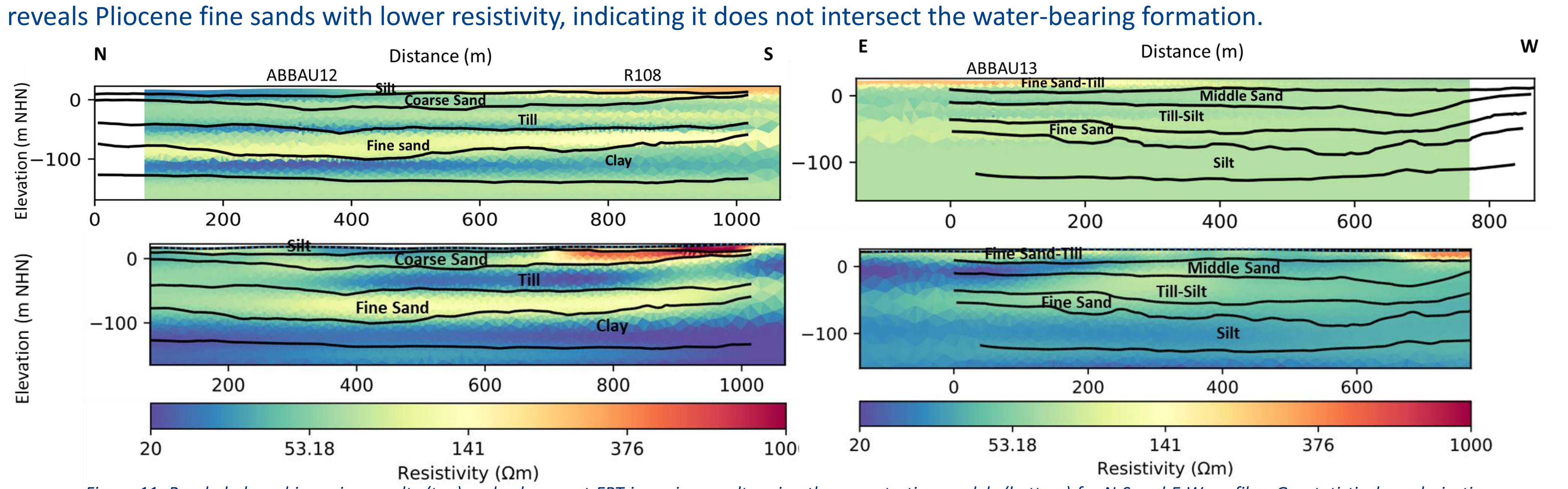

Figure 11. Borehole-based inversion results (top) and subsequent ERT inversion results using these as starting models (bottom) for N-S and E-W profiles. Geostatistical regularization was applied in both inversion approaches (Correlation Lengths = [150, 10], Lam = 200), geological horizons from interpreted seismic profiles overlaid for comparison.

4. Conclusion and Outlook

This study demonstrates the value of integrating ERT, seismic and borehole data, and existing geological information for improving subsurface characterization in glacially influenced settings. The use of structural constraints from seismic interpretation and borehole data in inversion enhances the resolution and geological consistency of resistivity models. Results highlight the potential of the approaches to improve delineation of aquifers and confining units, validate geological models and reduce uncertainties in hydrogeological interpretation.

Further evaluation is underway, with future improvements planned through travel time tomography, full waveform inversion, and joint inversion of seismic and ERT to enhance model clarity and support hydrogeological planning.

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