What is between these two wells?

Cross Borehole Georadar for identifying migration pathways at contaminated sites

Background and Objectives

A large part of the northern hemisphere has quaternary deposits consisting of glacial clay till. In many practical applications, understanding of the nature and structure of fractures, sand stringers and lenses in clay till is crucial in developing conceptual models of contaminant transport.

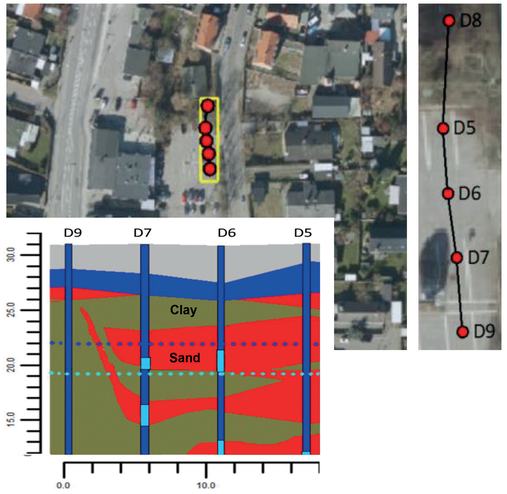
Cross borehole Georadar (or Ground penetration radar-GPR) may be effectively used in this context (Looms et al., 2018).

The aim of this project is to investigate whether GPR can be used at urban/industrial sites to examine the composition of the subsurface between boreholes. Specific objectives include:

- Applicability of the method in an urban setting and existing boreholes with bentonite seal.
- Operational parameters such as distance between boreholes and time required per measurement.
- What is the gain of using crossing ray paths compared to the simpler case, where predominantly horizontally travelling waves are used?
- How GPR measurements add to the conceptual understanding of the site.

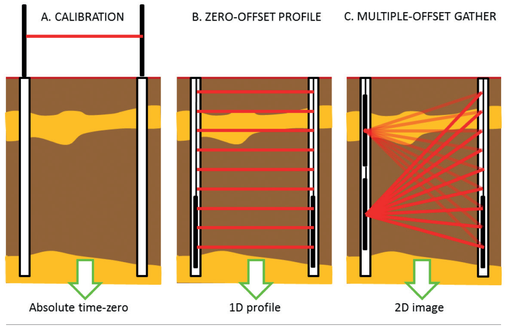
The site

The site is located in eastern Denmark and the geology is characterized by a heterogeneous till: mostly sandy in the northern end and mostly clay in the south.



The method

Ground-Penetrating Radar (GPR) is used to map sand lenses in the glacial till between boreholes /1/.

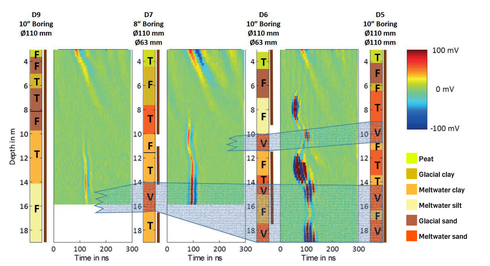


The calibration mode measures the arrival time of the electromagnetic signal through air and determines the Absolute Time Zero (ATZ). The **Zero-Offset Profile (ZOP)** measures with transmitter and receiver in identical depth positions. This simple approach determines the average dielectric properties between the boreholes at different depths.
The **Multiple-Offset Gather (MOG)** allows for crossing wave paths and result in mapping of a 2D section.

Results and interpretation

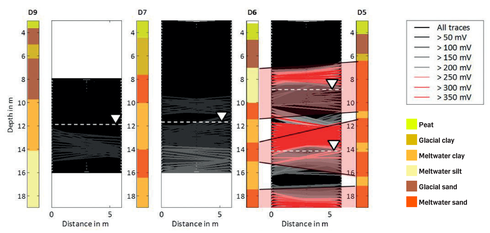
Surveys were performed using four boreholes:

- ZOP measurements took appr. 20 minutes while MOG measurements took 1 hour and 40 minutes each.



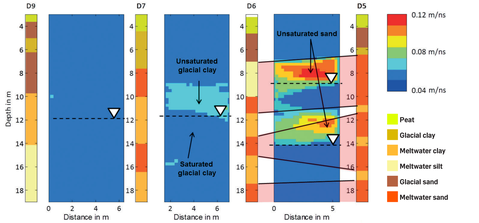
ZOP data, geological profiles and water content (shown with blue shades) based on borehole observations.

- Changes in arrival time and signal strength coincide with high water content (see D7-D6, D6-D5.
- Shorter arrival times at 7-8,5 and 11,5-13,8 m bgs. between D6-D7 indicate unsaturated sand.
- Stronger signals below 11 m bgs between D7-D6 and D6-D5 compared to D9-D7 indicate a more sandy layer.
- The brown markings along the boreholes indicate bentonite casing and show that the presence of casing didn't reduce signal strength.



MOG data and signal strength vs. geological profiles and water level.

- Wavepaths with low signal strength are shown with black and grey lines while wavepaths with stronger signals are shown with red lines.
- The strongest signals coincide with unsaturated layers.
- Likewise, shorter arrival times occur in the unsaturated sand and longer arrival times occur in saturated sand and clay

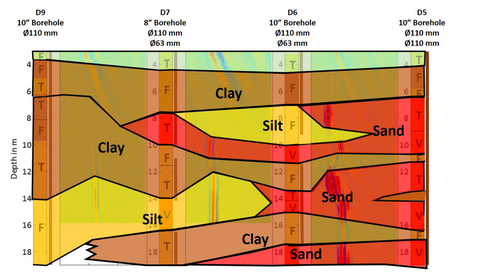


Geophysical inversion of MOG data, geological profiles and water level based on borehole observations.

- The geophysical inversion of MOG measurements reveal spatial heterogeneity.
- The higher velocities close to D5 indicate that the unsaturated sand is thicker in D5 than in D6.

Conclusions and perspectives

Based on the ZOP and MOG data and on interpretation of drilling profiles, a combined interpretation of the profile is proposed (top) and compared with the original geological model (see site description).



- Possible to use GPR in existing traditional boreholes. Bentonite plugs and isolation of boreholes did not show unambiguous influence on the survey results.
- **GPR data correlate well with observed geology and especially well with water saturation observations**.
- Suited for practical use at operational scale via fast measurements.
- ZOP measurements can determine if the geology is sandy and MOG can show the orientation and extent.
- **Adds value to a project when complex geology** is suspected to dominate the site. The method has proved useful to determine the link between geological layers and groundwater aquifers. This **allows for an assessment of groundwater and pollutant flow paths** and proves an alternative to pumping tests when this is either too difficult or too costly.

References

1 Majken Caroline Looms, Anja Klotzsche, Jan van der Kruk, Thomas Hauerberg Larsen, Anders Edsen, Nina Tuxen, Nancy Hamburger, Johanna Keskinen, and Lars Nielsen (2018). "Mapping sand layers in clayey till using crosshole ground-penetrating radar." GEOPHYSICS, 83(1), A21-A26.

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