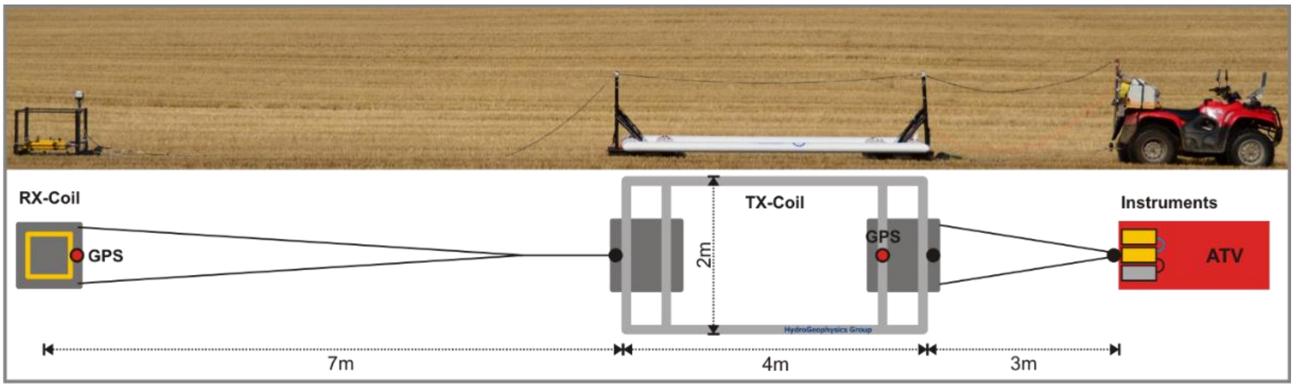

The tTEM system

There is growing need for detailed investigation of the top 30-50 meters of the subsurface which is critical for infrastructure, water supply, aquifer storage and recovery, farming, waste deposits, construction, etc. Existing geophysical methods are capable of imaging this zone; however, they have limited efficiency when it comes to creating full 3D images with high resolution over dozens to hundreds of hectares. We present a new and highly efficient towed transient electromagnetic system, tTEM, which is capable of imaging the subsurface to a depth of 70 meters with high horizontal and vertical resolution. The system is capable of producing 3D coverage with models in a 10x10 m grid, while maintaining mapping speed of 15-20 km/h and a daily production of 60-80 hectares

The system is compact, easy to mobilize, and can even be operated by boat. As demonstrated in this white paper, the system has successfully been used for applications such as mapping raw materials, investigating contaminated sites, and mapping shallow geology for aquifer vulnerability assessment. It has also successfully been used for investigating the geological setting at artificial recharge sites and as detailed geological input for hydrogeological modeling. In many parts of the world, the potable groundwater is under stress due to saltwater intrusion. Fresh-and saline water are characterized by large resistivity contrasts, making the tTEM system highly suitable for assessing drinking water quality with respect to saltwater intrusion. As seen here, the system is effective in describing geological structures due to glacial processes, but can also be employed in other complex geological settings such as coastal settings, deltas, estuaries and fluvial environments.

Fact sheet

- 3D coverage: 10x10 m grid
- Depth of investigation: 70 m
- Mapping speed : 15-20 km/h
- Daily production with 3D grid coverage : 60-80 hectares
- Line spacing: 1-25 m, lateral resolution: 5-10 m
- Operated by boat or ATV
- Dual moment water-cooled system
- Transmitter period: 0.6 ms (LM) and 1.4 ms (HM)
- Peak current: 30 Amp (HM)
- Transmitter moment: 19 & 240 Ampm2 (LM/HM)
- Receiver coil: Z-direction, 9.5 m offset
- Turn-off time (LM): 2.5 microseconds

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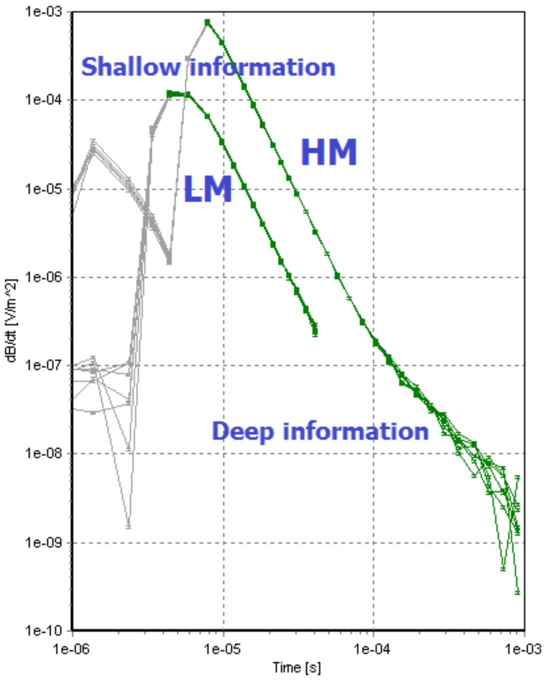
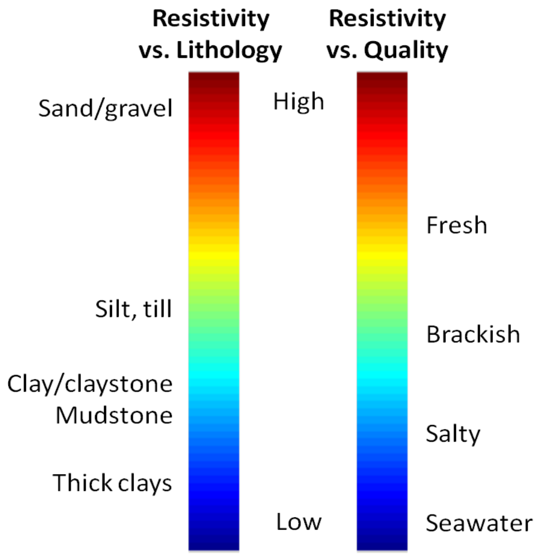
Measurement scheme

The transmitter loop is used to produce a high intensity primary current that creates (secondary) electric eddy currents in the ground. When the primary current in the coil is turned off abruptly the secondary magnetic field in the subsurface begins to decay. The decay rate of the secondary field with time is measured in the receiver coil resulting in a TEM sounding. The sounding consists of a low-moment (LM) and high-moment (HM) measurement as seen in the figure below.





Technical details

The overall design goal was to develop a system capable of fast imaging, from the surface to a depth of 50 to 70 m with high vertical and lateral resolution. Data has to be bias-free and the system transfer function completely known. To achieve this goal, the system uses a one-turn 2 x 4 m^2 transmitter loop mounted on a frame with sledges that is towed by an all-terrain vehicle (ATV). The receiver coil is a 650 kHz suspended induction coil towed behind the transmitter in a 9 m offset configuration. The system transmits a low and a high moment (LM, HM) to collect both shallow and deep information. The LM transmits at 2.8 A with a turn-off time of 2.6 µs and a first usable gate at 4 µs (time from beginning of the ramp) while the HM transmits 30 A. The repetition frequencies for the two moments are approximately 2000 Hz and 800 Hz. The transmitter is water-cooled to keep the current ramp completely repeatable; the temperature for the transmitter is kept at 45 °C (+/- 2 °C) and the high moment current is kept at 30 A (+/- 1 A). A full dataset is obtained every 0.8 s - corresponding to a 5 m spacing between soundings, with a production speed of 15 to 20 km/h. Data are processed and inverted using methods directly adopted from airborne electromagnetics. Typical line spacings are 10 to 20 m. With this setup, one can typically map an area of approximately one square km in a day.

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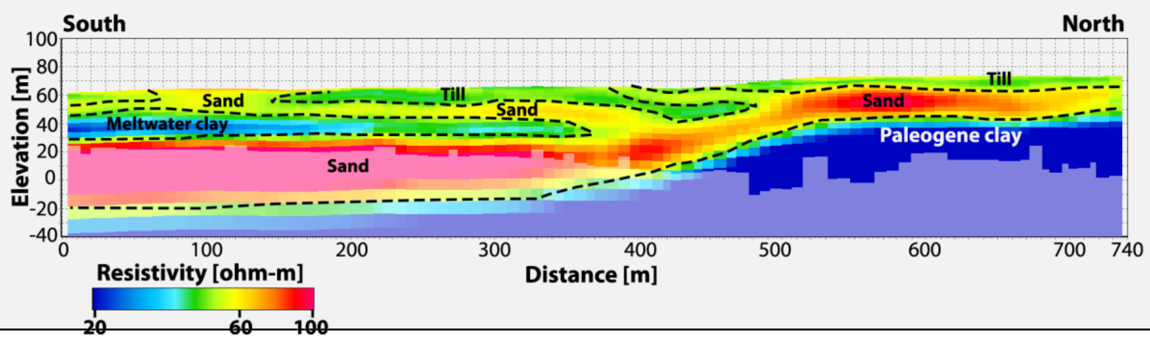
Typical uses

- Soil mapping, geological mapping, regional hydrogeological models
- Mapping of dump sites
- Identifying salt water intrusion and leachate
- Mapping of raw materials (sand, clay, limestone, ….)
- Hazard mapping (land slide prone areas, permafrost, ….)
- Geotechnical mapping (highways, old foundations, climate changes, local infiltration of rain water, …).

Added value

- The methods are cost-effective – large areas can easily and quickly be mapped since the methods are towed by motorized vehicle or boat.
- High near-surface resolution and depth of investigation
- Dense data sampling of 5 m in-line and typically 10-20 m between the lines, resulting in 3D coverage
- The resulting 3D geological models can be used as decision tool in water management

Example



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Case – Mapping raw materials (sand/gravel/limestone)

Aim and application

with the tTEM method, one measures the soils electrical resistivity, which relates to the geological setting. For instance, clay is characterized by a low resistivity, and sand and gravel have high resistivities. This makes the method ideal for mapping raw material such as gravel and sand, since these deposits have a high resistivity contrast against clay, and hence stand out clearly in the measurements. Sand and gravel is often used in construction in Denmark, especially in connection with construction of new roads. By means of the tTEM method, one can map at speeds of 3-5 meters per second and still obtain unique measurements for every 5 m. Typically, mapping is done in the spraying tracks on farm fields, so the effective measurement grid is 10x5m. With the method, large areas are scanned, and should subsequently be seen as a tool to map soil structures, before carrying out follow-up raw material drillings. By combining tTEM and drillings, a 3D image of the potential raw material deposits can be constructed. By applying the mentioned mapping strategy, one can find the optimal location for the drillings and reduce the number of drillings. The end result is a more accurate assessment of the raw materials spatial extent and location.

Example – Jeksen, Denmark

Figure 1 shows an application example. The raw material mapping took 40 minutes, and in total 5.7 km of data was collected in a 10x10 m grid. Figure 1 shows one profile, where the thickness of the raw material deposits (sand) varies strongly within a distance of only 650 meters.

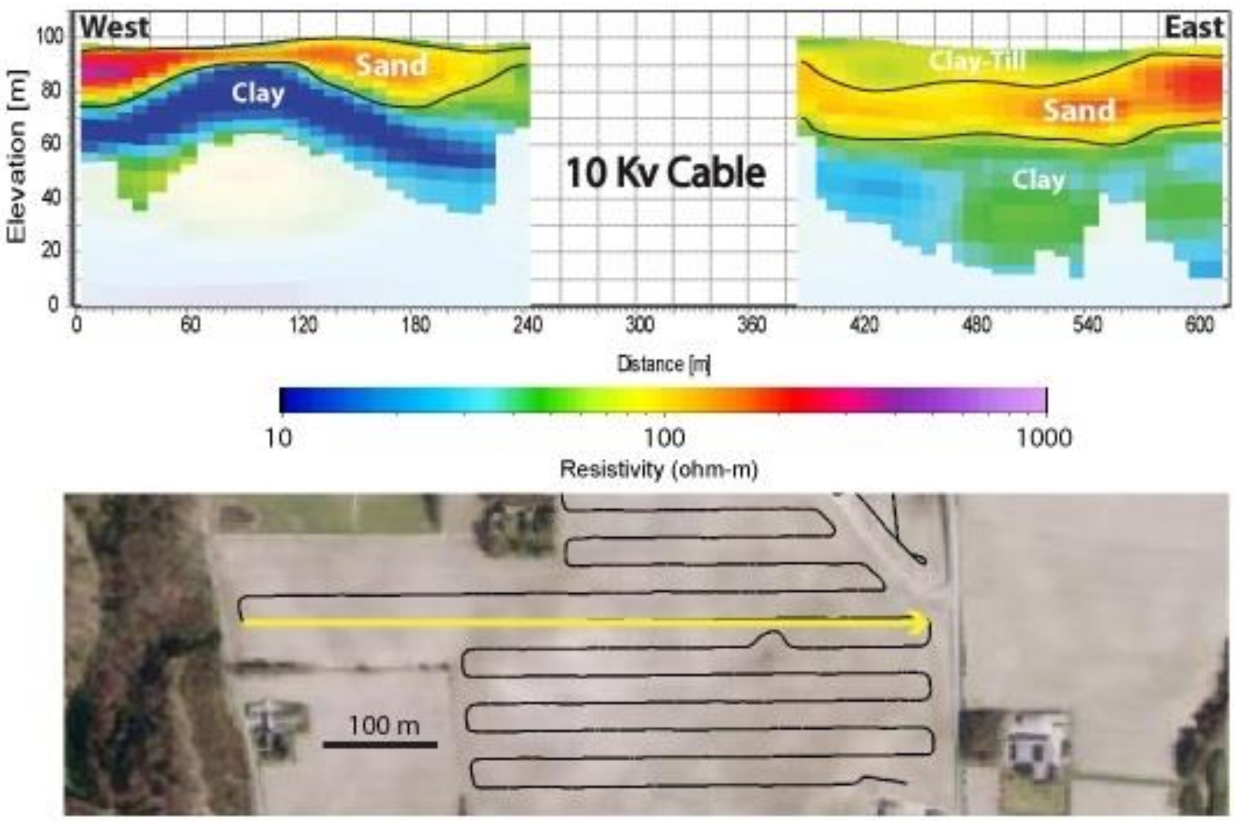

Figure 1. Profile from Jeksen. Mapping af raw materials, in this case sand deposits.

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Case - Optimized risk assessment of polluted sites

Aim and application

The tTEM method can cost-effectively map large areas, and should be seen as a tool to map soil structures before conducting follow-up drillings. By using geophysics in an early stage of the project, one can get a better overview of the geological setting around a polluted site (landfill, former machine station, chemical factory etc.), and hence optimize the location of investigation and remediation drillings. The acquired geological knowledge from the tTEM mapping can likewise be included in connection with assessment of spreading of leachate, since one can map the extent and location of clay and sand layers with great accuracy. Clay layers will, if they are thick enough, act as a barrier for spreading of the pollution, whereas connected saturated sand layers acts as highways for dispersal of leachate.

Example - Vildbjerg, Denmark

At a machine station in Vildbjerg, Denmark, there is pesticide pollution. The water flow is oriented southeast from the polluted site, and hence directly towards the town of Vildbjerg waterwork extraction drillings. The tTEM mapping took two hours, and in total, 24 km of data were collected in a dense 10x10 meter grid. Figure 2 shows the thickness of the shallow mica clay layer according to the tTEM measurements (searched out based on a 30 ohm-m threshold). Superimposed is also the mica clay thickness from the four drillings in the area. Below the mica clay there are alternating thin layers of quartz sand and mica clay. Vildbjerg waterworks extracts water from the quartz sand deposits. As seen in the tTEM results, the thickness of the mica clay cap is more than 15 meters, and there are no holes in the clay layer. Subsequently, there is little to no risk for dispersal of the pollution towards the extraction drillings. This knowledge will be difficult and costly to gain solely by means of drillings.

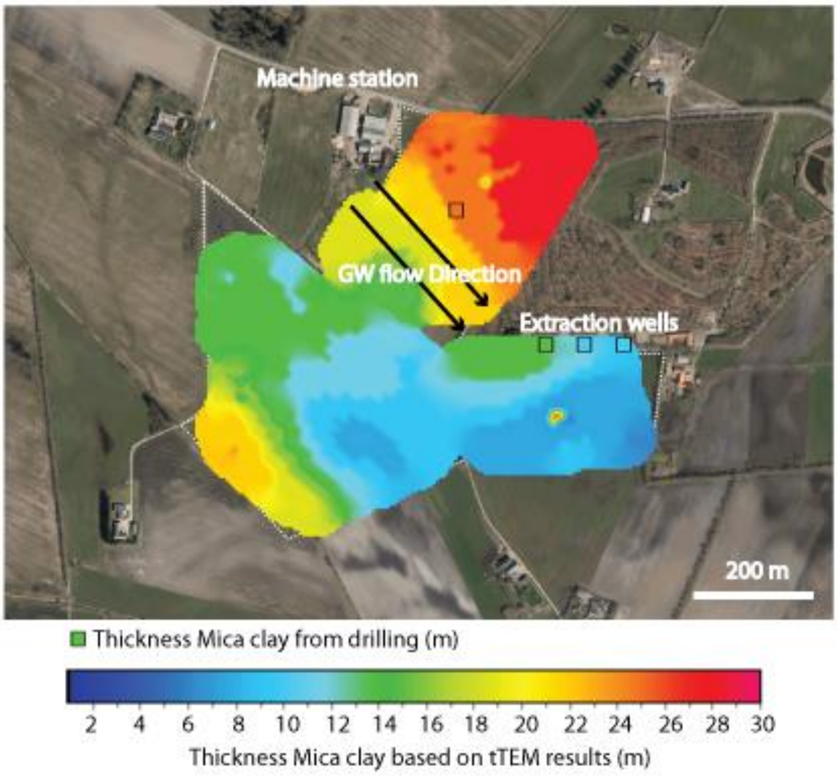

Figure 2. Thickness of mica clay from drillings and tTEM results (30 ohm-m search threshold)

Case – Aquifer vulnerability mapping

Aim and application

In many countries the drinking water is located in groundwater aquifers. Maintaining a high water quality and quantity is often a challenging task for water management, and sets high demands to the data which decision are based upon. This is epically relevant when dealing with the issue of high nutrients loads due to farming. To maintain clean water, one needs to do a detailed vulnerability mapping of the aquifers, to identify areas with high risk of aquifer pollution and zones were nutrients poses a little threat. Due to the mapping speed and areal coverage of the tTEM method, combined with the acquired 3D resolution, it makes the method highly suitable for vulnerability mapping, that is identifying the zones where there are no thick clay covers above our groundwater aquifers.

Example – Gedved, Denmark

The tTEM system was used to investigate the geological setting for a 156-hectare farm in Gedved, Denmark. The survey was conducted as a part of the Topsoil project, funded by the European Union. The Topsoil project addresses a number of issues having to do with ground- and surface-water, including the improvement of both water quality and quantity. The aim of the survey was to obtain a detailed 3D image of the geological layers in the area, in order to assess the vulnerability of the local aquifer to contamination from agricultural activity. As a rule of thumb, local aquifers are considered protected if there is more than 15 meters of capping clay. Figure 3a highlights the survey area; the farmer owns all the mapped fields and lives right in the center. The fields were mapped in less than two days, producing 11,925 tTEM soundings (red dots in Figure 3a). The line spacing was 20 to 30 m, while the model spacing along the lines was 10 m, resulting in a full 3D resolution of the farm fields.

The models are visualized as mean-resistivity maps and profiles to obtain spatial and in-depth knowledge of the geological structures. Figure 3b shows a mean-resistivity map from 15 to 20 meters depth and Figure 3c shows a profile located in the western part of the survey area. From the mean-resistivity map and profile it is evident that, even on local field-scale, the local shallow geology can be very complex. North of the farm, there is a layer of Paleogene clay that is more than 40 m thick, which rises to within 5 m of the ground surface. If this were true everywhere, one would consider the deep aquifers well protected (in Denmark groundwater is typically extracted from aquifers at around 70 m depth); however, as seen in the mean-resistivity map, the Paleogene clay has been affected by glacial processes, introducing incised sand valleys in the clay layer. These sand valleys act as pathways for water transport, and hence nutrients. As seen in the profile, the shallow and thin sand layers (both in thickness and in spatial distribution), connect with deeper sand aquifers, which act as fluid pathways from the surface, that then pose a potential threat to drinking water quality. We only know this because of the large lateral and vertical resolution of the system; this much information would be difficult to obtain using other geophysical methods (line spacing of 20 to 30 m is not feasible with AEM, and providing the same coverage with ERT would be next to impossible and extremely costly).

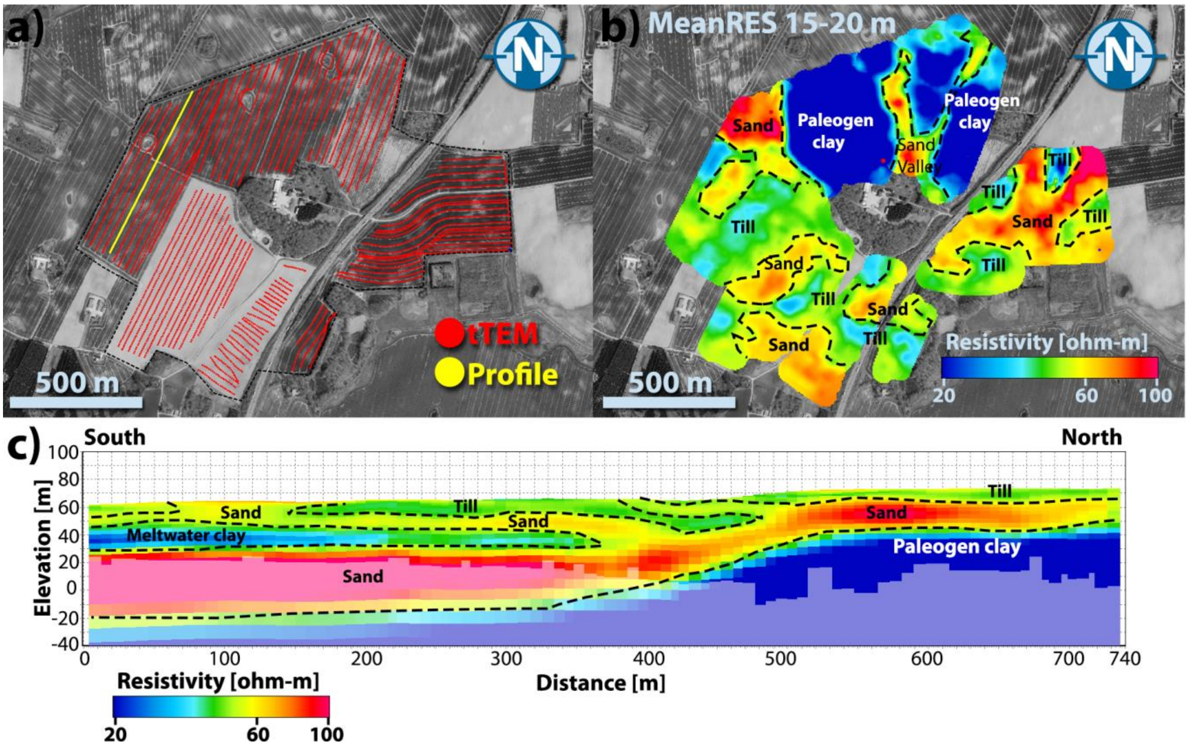

Figure 3. Gedved tTEM survey. a) Survey lines (red dots) and profile location (yellow line). b) Mean resistivity map depth 15-20 m. c) South-north striking profile. The location of the profile is highlighted in Figure 3a. The models have been 50% faded below the depth of investigation.