

Environmental geophysics



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Welcome readers to this issue's column on geophysics applied to the environment. This interesting piece from Esben Auken and his Aarhus University-based HydroGeophysics group (with contributions by researchers Jesper Bjergsted Pedersen and Pradip Kumar

Maurya) came across my desk earlier this month. As many of you know, it is on a subject of great interest to me - the use of towed ground EM designed to resolve the shallow subsurface.

So, over to Esben and his team...

A new towed geophysical transient electromagnetic system for near-surface mapping

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In this article, we (the HydroGeophysics group) present a new towed geophysical transient electromagnetic system (tTEM), developed here at Aarhus University, Denmark, for mapping the top 50–70 m of the subsurface.

The development of this system has been driven by the fact that geophysical methods capable of imaging this zone either have limited efficiency when it comes to creating full 3D images, or they do not have sufficient imaging depth. Some examples of applications that require this high level of information include: optimal location of artificial recharge sites, assessment of contamination risk from point sources and landfills, road construction, development of flow models for surface-groundwater interaction, etc.

Traditionally, this zone is mapped using boreholes, electrical resistivity tomography (ERT) or airborne electromagnetics (AEM). However, these geophysical methods lack the capability to make cost-effective, high-resolution maps of areas ranging from just a few hectares up to a few thousand hectares. ERT is a proven method that covers this

depth range with the needed resolution. However, ERT typically produces 2D profiles, and mapping more than a few hectares in 3D is time-consuming and expensive (Auken et al., 2014; Maurya et al., 2017). Ground Conductivity Meters (GCM) are efficient for mapping large areas but the depth of investigation is limited to 5 to 8 m (Christiansen et al., 2016). Airborne electromagnetic systems such as SkyTEM (Sørensen and Auken, 2004) are able to map extremely large areas, but are relatively expensive to mobilise for smaller areas, and in most cases do not sufficiently resolve very shallow layers, both vertically and horizontally (Auken et al., 2017). Hence, there is an unmet need for geophysical methods capable of characterising the shallow subsurface in full 3D. In the following sections, we will give an overview of the tTEM system design, demonstrate a case study, and discuss a few possible applications.

The basic design of the tTEM system is shown in Figure 1. 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 (STF) completely known. To achieve this goal the system uses a one-turn $2 \times 4 \text{ m}^2$ 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 amps with a turn-off time of 2.6 μs and a first usable gate at 4 μs (times from beginning of the ramp), while the HM transmits 30 amps. The repetition frequencies for the two moments are approximately 2000 Hz and 800 Hz. The transmitter is water-cooled in order to keep the current ramp completely repeatable; the temperature for the transmitter is kept at 45 degrees Celsius (± 2 degree Celsius) and the high moment current is kept at 30 amps ± 1 amp. A full dataset is obtained every 0.8 sec - corresponding to a 3 to 4 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. Typically line spacings are 10–20 m (interestingly this corresponds to the distance between spraying tracks on farm fields). With this setup one can typically map an area of approximately one square km in a day.

The tTEM system was, in the example we are presenting here, used to investigate the geological setting for a 156 hectare farm in Gedved, Denmark. The survey was conducted as a part of the European Union funded project *Topsoil*. The *Topsoil* project addresses a number of

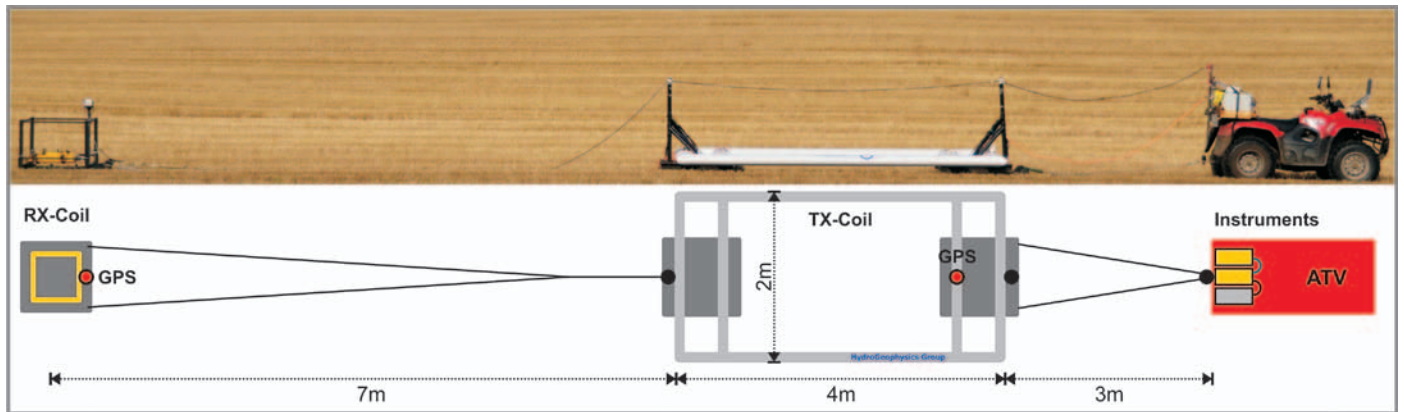


Figure 1. The tTEM System.

issues having to do with groundwater/surfacewater, 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 m of capping clay. Figure 2a highlights the survey area; the farmer owns all the mapped fields and lives right in the centre. The fields were mapped in less than two days,

producing 11 925 tTEM soundings (red dots in Figure 2a). The line spacing was 20–30 m, while the model spacing along the lines was 10 m, resulting in a full 3D resolution of the farm fields. After data collection, noisy soundings (due to culture related mostly to nearby roads) were culled and the data was inverted using a spatially constrained inversion.

The models are visualised as mean-resistivity maps and profiles to obtain spatial and in-depth knowledge of the geological structures. Figure 2b shows

a mean-resistivity map from 15 to 20 m depth and Figure 2c 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,

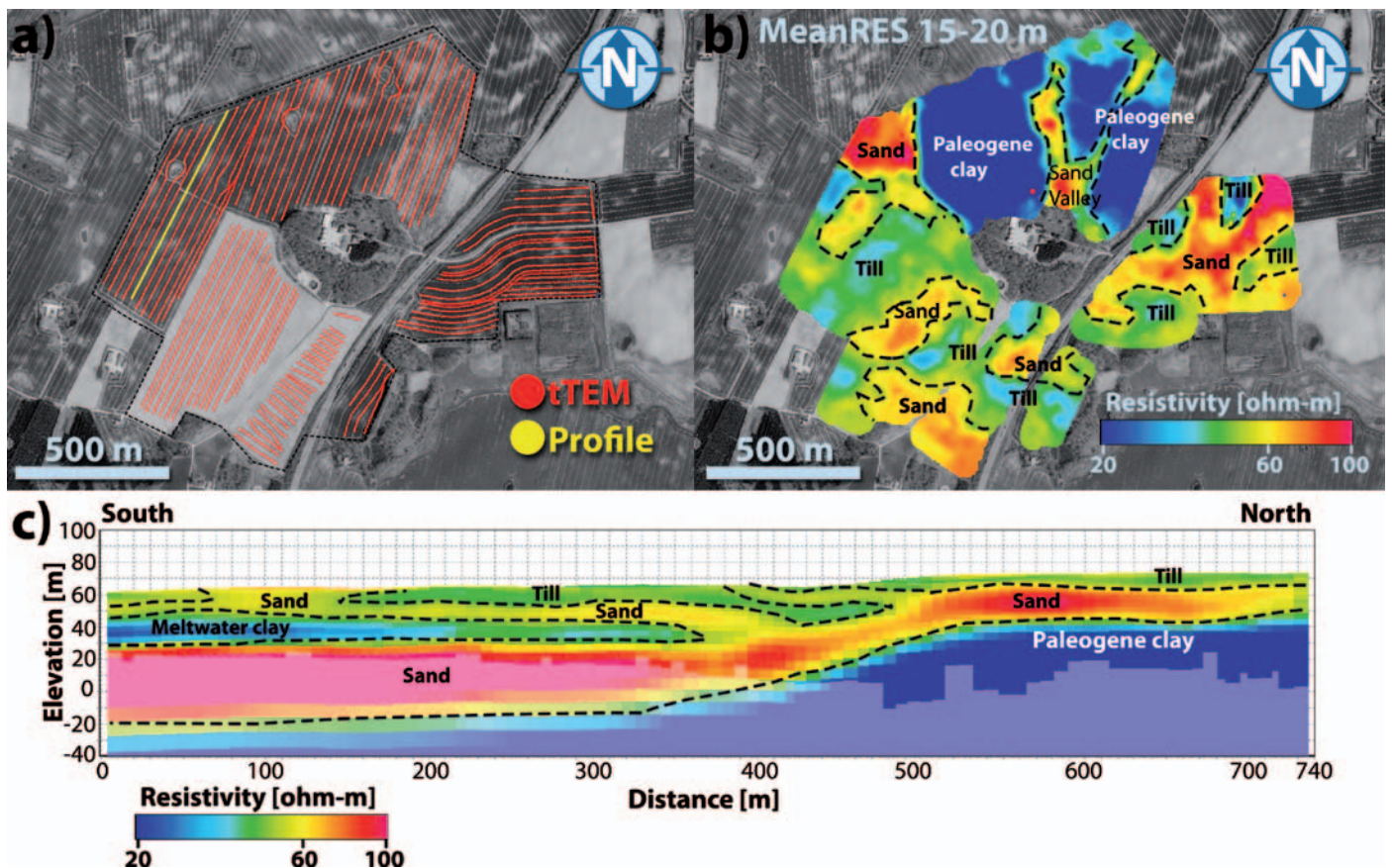
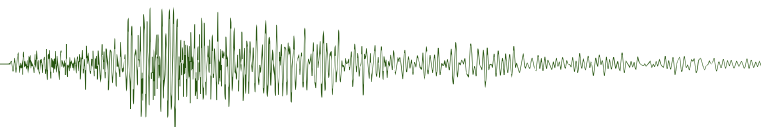


Figure 2. Gedved tTEM survey. (a) Survey lines (red dots) and profile location (yellow line). (b) Mean resistivity map depth 15–20 m. (c) South-north striking profile. The location of the profile is highlighted in Figure 2a. The models have been 50% faded below the depth of investigation.



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 20–30 m is not feasible with AEM, and providing the same coverage with ERT would be next to impossible and extremely costly).

We have used the tTEM system to collect high resolution data on a number of other studies. These include, for example, mapping the location and depth of raw construction materials (especially if underlain by low resistivity clay layers); investigating contaminated sites; mapping zones of nitrate retention in the shallow geology; investigating artificial recharge

sites (see <http://hgg.au.dk/projects/stanford-ttem/> for a description of some work we did in the Tulare Irrigation District in California); saltwater intrusion; and, of course, detailed geological input for hydrogeological modelling.

As seen in the case study, the system is effective at describing geological structures due to glacial processes and, obviously, would be useful in other complex geological settings. In an upcoming project, we will experiment with towing the system behind rubber dinghies to map the resistivity of the hyporheic zone.

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