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# Lithological characterization of a contaminated site using Direct current resistivity and time domain Induced Polarization

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## SUMMARY

Characterization tools for contaminated sites have become advanced with the continued development of geophysical methods. Resistivity methods and time-domain induced polarization methods have proven their capability to delineate the subsurface properties by complementing each other. In the present study a large contaminated site in Denmark was investigated using direct current resistivity and time domain induced polarization (DCIP). For this purpose 14 profiles were collected alongside a stream in order to investigate the contamination and delineate the lithological units.

2D inversion using a cole-cole model of two selected profiles are presented. They show that the resistivity model alone cannot depict the geology as inferred in the borehole. However, when including the models of chargeability and mean relaxation time the geological units are clearly defined, which helps in identifying the possible contaminations.

**Key words:** Time Domain Induced Polarization, Cole-Cole model

## INTRODUCTION

Groundwater and surface water can be contaminated due to various types of human activities e.g. waste from residential, commercial, industrial, and agricultural activities. Especially in cities with an industrial history this is often a severe problem. In order to evaluate the risks, characterization of the contaminated sites in terms of geology and contaminant leachate is needed. This characterization is often carried out using limited drill hole information, but a much more detailed picture of the subsurface can be obtained by dense surface-based geophysical methods.

Multi-electrode direct current (DC) resistivity and induced polarization(DCIP) methods have proven their capability to delineate the contaminant mass from the host geology, as contamination strongly influences the resistivity and chargeability of the subsurface (Gazoty et al., 2012). The method has recently advanced in terms of data acquisition techniques (Dahlin et. at., 2002) and processing and inversion optimizations (Auken et al., 2009).

In this study we investigated a contaminated site using DCIP measurements along a stream in the city of Grindsted (southern part of Denmark) where a pharmaceutical industry deposited massive amounts of chemicals on a number of sites.

## METHODS AND RESULTS

### DCIP Methodology

Direct current resistivity and Induced polarization methods (DCIP) have been extensively used in environmental studies. The resistivity method is based on the fact that distribution of electrical potential in the subsurface depends on the resistivities around a current injecting electrode. In normal practice two electrodes are used for injection and another pair of electrodes measures the potential. The IP method is based on the chargeability effects of the subsurface. When measuring in the time-domain and when the subsurface is chargeable, the voltage does not drop immediately to zero following the current shut down, but rather it decays slowly over a few seconds. The magnitude of the polarization and the shape and length of the decay depend on subsurface parameters such as ion content and type, clay content, and pore structure to mention a few. Time-domain IP data are recorded along with the traditional DC data using the same measurement setup.

Recent developments in the field of data acquisition such as multichannel measurements (Dahlin et al., 2002) have made the time-domain DCIP method more robust, faster and more convenient to perform in the field. Combined with advancements in the numerical modelling of IP data including modelling of transmitter waveform and low-pass filters enable us to retrieve the Cole-Cole parameters from time-domain measurements of the entire decaying IP signal (Fiandaca et al., 2012). The cole–cole model (Pelton et al., 1978) is a commonly used empirical model which involves the parameters resistivity, chargeability, relaxation time, and frequency exponent.

### Field Site and Geological Settings

The investigated study area is located in the region of southern Denmark, Grindsted. Two of Denmark's 122 locations classified as "large contaminated sites" are located here (Grindsted factory and Grindsted landfill). Contamination from the landfill and factory site is posing great risks to Grindsted stream and a large impact from contaminations have been observed in the stream (Nielsen et al., 2014).

The geology of the Grindsted area consists of an upper 10-12 m quaternary sand layer and a lower tertiary sand layer, locally separated by silt and clay layer (Heron et al., 1998). Below this layer, we have a regional micaceous sandy layer approximately 65 m thick, which is underlain by a clay layer at 80 m depth.

### Data Acquisition

The site was investigated with the collection of 14 DCIP profiles (Figure 1) covering both the north and the south bank of the river. The profiles are will be treated in a full 3D framework, but here we will present selected 2D results. Out of the 14 profiles, seven profiles were 410 m long with 5 m electrode spacing and other seven profiles were 126 m long with 2 m electrode spacing. The survey was performed using the gradient array (Dahlin and Zhou, 2006) and we used the ABEM Terrameter LS for the data acquisition.

### Results

The processing and inversion of the DCIP data were carried out using Aarhus Workbench (Auken, 2009). Processing of DCIP data involves removal of outliers from apparent resistivity data and culling of disturbed IP decays. Data were inverted using the 2D DCIP inversion code developed by Fiandaca et al. (2013) .This inversion routine uses the cole-cole model to invert the DCIP data, which gives four model parameters namely resistivity (ρ), chargeability ($m_0$), relaxation time (τ) and frequency exponent (C). The inversion code also models the full waveform and stack sizes.

Figure 2 presents the inversion results of two representative profiles (profile 3 and 6) located at the northern bank of the river. The cole-cole parameters shown from top to bottom are resistivity (ρ), chargeability ($m_0$), relaxation time (τ) and frequency exponent (C). The borehole located on profile 6 (shown as blue dot in figure 1) is presented as a bar with the different geological units indicated. The bar colour code represents major lithological unit identified in borehole (Brown: sand, light blue: sand mixed with clay, blue: clay).

It can be seen that the low resistivity anomaly in both profiles does not clearly represent the clay rich layers seen in the borehole. This could be attributed to the combined response of clay layer and the contamination present in the sandy aquifer above and below the clay layer in the north western part of the profile.

However, in the chargeability section a high chargeability layer agrees very well with the clay layers. This layer clearly stands out also in the tau section. The bottom of the high chargeable layer indicates the lower boundary of the clay layer.

To show this boundary in the resistivity section, a red dashed line is drawn in both profiles. We can see that in the north-western part of both profiles the low resistivity signature is continuing in the sandy aquifer, which possibly indicates the presence of contaminations.

These observations indicate that the IP response is mostly dominated by the clay rich layers, which helps in identifying the lithological units more adequately than the resistivity section alone.

In the presentation we will show results in 3D combining the results of all the lines to visualize the delineation of a possible contamination.

## CONCLUSIONS

DC resistivity and the time domain induced polarization method were used at a contaminated site for characterizing the contaminants and lithology. The results are presented in terms of Cole-Cole parameters.

The major lithological unit could not be interpreted from the resistivity section alone, but the chargeability section clearly delineate the major lithological boundaries observed in a borehole. Identification of the geological units allows for speculations on possible contaminations identified in the resistivity section.

## ACKNOWLEDGMENTS

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## REFERENCES

Auken, E., A. Viezzoli, and A. V. Christiansen, 2009, A Single Software For Processing, Inversion, And Presentation Of Aem Data Of Different Systems: The Aarhus Workbench, Adelaide, ASEG.

Dahlin, T., V. Leroux, and J. Nissen, 2002, Measuring techniques in induced polarisation imaging: Journal of Applied Geophysics, v. 50, p. 279-298.

Dahlin, T., and B. Zhou, 2006, Multiple-gradient array measurements for multi-channel 2D resistivity imaging: Near Surface Geophysics, v. 4, p. 113-123.

Fiandaca, G., E. Auken, A. Gazoty, and A. V. Christiansen, 2012, Time-domain induced polarization: Full-decay forward modeling and 1D laterally constrained inversion of Cole-Cole parameters: Geophysics, v. 77, p. E213-E225.

Fiandaca, G., J. Ramm, A. Binley, A. Gazoty, A. V. Christiansen, and E. Auken, 2013, Resolving spectral information from time domain induced polarization data through 2-D inversion: Geophysical Journal International, v. 192, p. 631-646.

Gazoty, A., G. Fiandaca, J. Pedersen, E. Auken, and A. V. Christiansen, 2012, Mapping of landfills using time-domain spectral induced polarization data: The Eskelund case study: Near Surface Geophysics, v. 10, p. 575-586.

Heron, G., P. L. Bjerg, P. Gravesen, L. Ludvigsen, and T. H. Christensen, 1998, Geology and sediment geochemistry of a landfill leachate contaminated aquifer (Grindsted, Denmark): Journal of Contaminant Hydrology, v. 29, p. 301-317.

Nielsen, S. S., Tuxen, N., Frimodt Pedersen, O., Bjerg, P. L., Sonne, A. T., Binning, P. J., Fjordbge, A. S., and Aabling, J. (2014). Risikovurdering af over adevand, somer påvirket af punktkildeforurenet grundvand, miljøprojekt nr 1572. Technical report, Miljøministeriet. Miljøstyrelsen

Pelton, W. H., S. H. Ward, P. G. Hallof, W. R. Sill, and P. H. Nelson, 1978, Mineral discrimination and removal of inductive coupling with multifrequency IP: Geophysics, v. 43, p. 588-609.

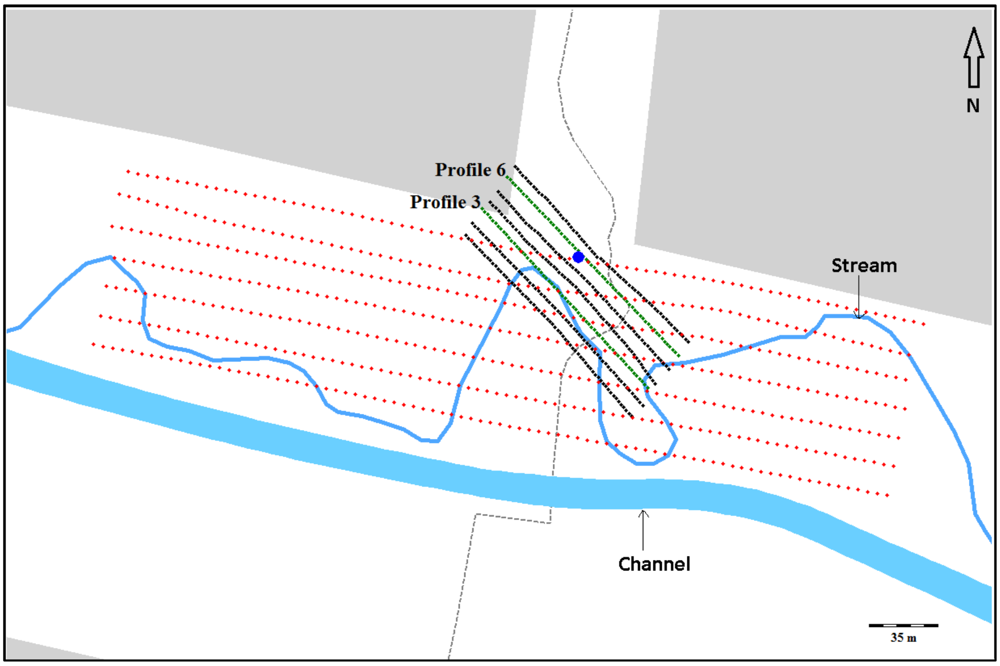

*Figure 1 Location of DCIP profiles. Location of the borehole is shown as blue dot on profile 6.*

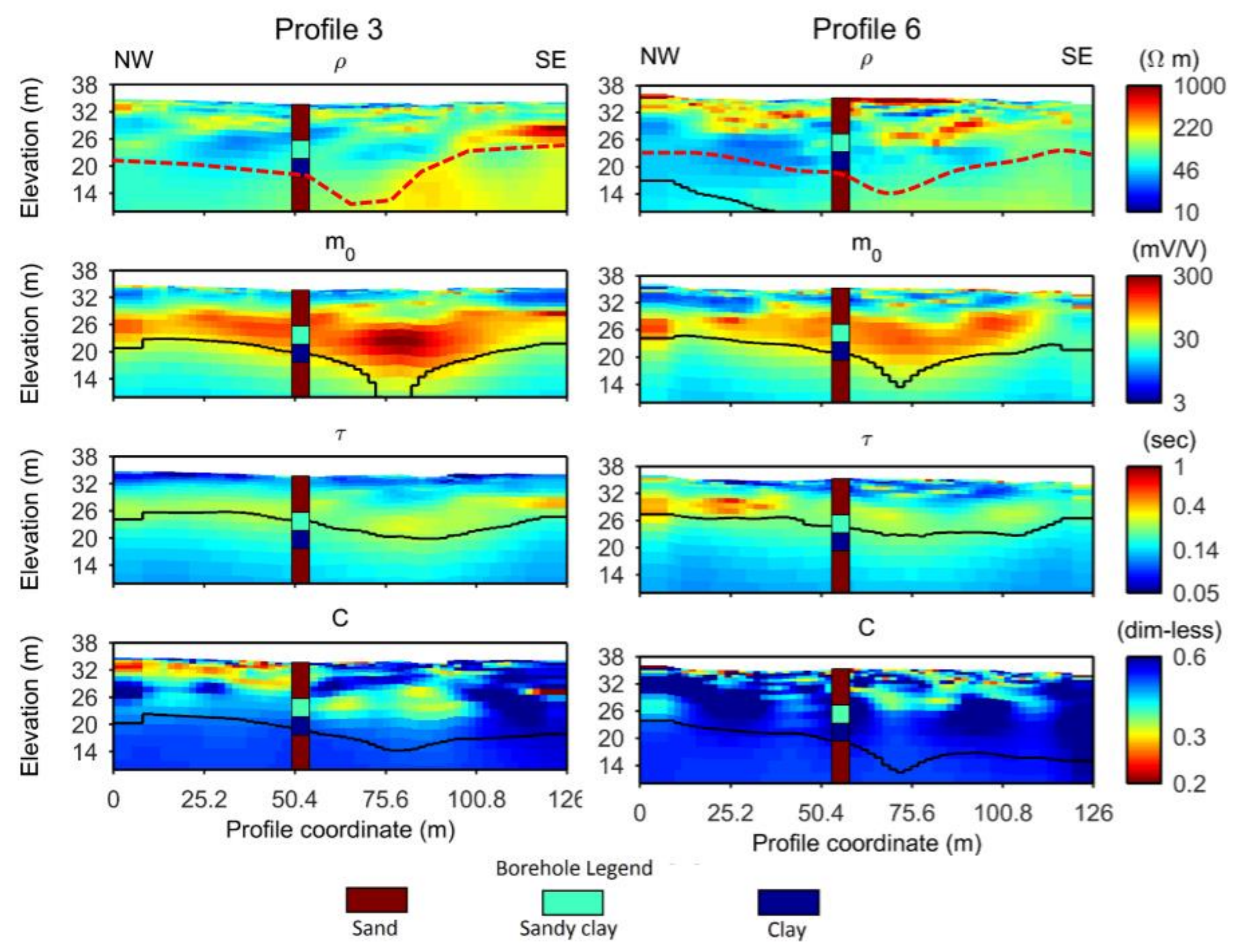

*Figure 2 DCIP inversion results from profile 3 and 6. Cole -Cole parameter shown from top to bottom are resistivity (ρ), chargeability ($m_0$), relaxation time (τ) and frequency exponent(C). DOI is shown by continuous black lines and dotted line in resistivity section shows the interpreted lower boundary of the clay layer.*