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Johansson, Sara; Fiandaca, Gianluca; Dahlin, Torleif

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PO Box 117
221 00 Lund
+46 46-222 00 00

We Olym 02

Field Application of Resistivity and Spectral Time Domain IP to Investigate Goelectrical Signatures of Free-phase PCE

S. Johansson* (Engineering Geology, Lund University), G. Fiandaca (Department of Geoscience, Aarhus University) & T. Dahlin (Engineering Geology, Lund University)

SUMMARY

Soils beneath former dry cleaning sites are often contaminated with the chlorinated hydrocarbons PCE and its degradation products, which are highly toxic and cancerogenic. In this study, resistivity and time domain induced polarization (DCIP) were measured at a former dry cleaning site in order to investigate if the source contamination of PCE could be detected. 80 meter long 2D-profiles were measured across the site with the ABEM Terrameter LS instrument. The DC and full IP decay data were inverted using the 2-D DC/IP inversion algorithm developed by Fiandaca et al. (2013), giving access to the spectral information contained in the IP decays. The inversion parameters DC resistivity (ρ), chargeability (m_0), the relaxation time (τ) and the frequency factor (C) were compared to reference data from boreholes. The reference data consisted of geological classification and concentration of free-phase chlorinated hydrocarbons, obtained from soil samples. A high resistive anomaly was observed at a location along the profile where soil sampling have confirmed high concentrations of free-phase chlorinated hydrocarbons. High IP-effects, in terms of the spectral parameters m_0 and C , was seen next to this area. It is suggested that the IP-effects arise in a zone next to the free-phase source plume.

Introduction

Soils beneath former dry cleaning sites are often contaminated with PCE (tetrachloroethylene), which has been the most widely used chemical in this context since the mid-20th century. PCE and its degradation products, especially VC (vinylchloride), are toxic and cancerogenic. Only a small amount of VC dissolved in the groundwater can cause serious pollution of the groundwater.

The conventional method to delineate PCE contaminations in the soil is to drill boreholes, collect samples of the soil and groundwater and send these to laboratory analysis. Densely spaced sampling is required for a reliable perception of the extent of the contamination, but there are often economical restrictions leading to an inadequate number of samples and a large over- or underestimation of the size of the contamination.

In this study, resistivity and time domain induced polarization (DCIP) were measured at a former dry cleaning site in southern Sweden. The aim of the measurements was to investigate if the source contamination of PCE could be detected with DCIP. The site is heavily contaminated and situated over a major aquifer, which makes the situation severe. In addition, a protected wetland is closely situated east of the site.

Methods and Materials

Chlorinated hydrocarbons belong to a group of fluids referred to as DNAPLs (Dense Non-Aqueous Phase Liquids). All pure DNAPLs are non-polar fluids and electrical insulators. As implied by the name, DNAPLs are denser than water and they therefore tend to sink through the soil until they reach a low-permeable layer (e.g. the bedrock), provided they exist in the soil as a so-called free-phase. A free-phase product can exist as a continuous phase or a residual saturation (Ajo-Franklin et al. 2006, and references therein).

The source product, PCE, has a relatively low solubility in water and therefore resides in the same location in the soil for a long time. During the degradation process (dechlorination), one chlorine atom at a time is replaced by a hydrogen atom, eventually leading to the end product ethylene. Each degradation step leads to a higher solubility of the resulting chlorinated hydrocarbon and therefore a more wide spread plume following the groundwater movement.

The aim of the DCIP measurements was to investigate how well the soil contaminated with free-phase PCE could be delineated with DCIP. Presence of free-phase PCE was expected to give rise to high-resistive anomalies and IP-effects, as previously indicated by e.g. Cardarelli & Di Filippo (2009).

Several drillings together with soil and groundwater samplings have been made at the site, providing reference data approximately showing where in the soil the main presence of free-phase chlorinated hydrocarbons can be expected. Parallel DCIP profiles were measured across the contaminated site, using the ABEM Terrameter LS instrument using separated cables for transmitting current and receiving potentials. The mean length of the profiles was about 80 meters, and spacing between the profiles and between the in line electrodes were both 2.5 meters. The pole-dipole array was used with the remote electrode located approximately 500 meters away.

The DC and full IP decay data were inverted using the 2-D DC/IP inversion algorithm developed by Fiandaca et al. (2013). The inversion code takes into account the current waveform in the forward computations, allowing for a quantitative interpretation of the IP parameters (Fiandaca et al. 2012). This gives access to the spectral information contained in the IP decays, retrieved in terms of the Cole-Cole model (Pelton et al. 1978). The inversion parameters include DC resistivity (ρ), chargeability (m_0), the relaxation time (τ) and the frequency factor (C).

Results and Discussion

The inverted results from one of the measured 2D lines are shown and compared with geology in Figure 1. The geology at the site is dominated by sandy chalk till with an indistinct transition to calcareous sandstone somewhere below -12 meters below the soil surface. Generally, the till is overlain by a 2-3 meters thick layer of clay. In the right part of the profile, in the direction towards the wetland, the thickness of the sediments increases.

Two anomalies with higher resistivity are seen in the left part of Figure 1. The most prominent one coincide with the borehole SL601. At first, the anomaly seems to agree well with the geological transition from low-resistive silty clay to till. However, this is not consistent with the probable continuation of till or bedrock at levels lower than approximately 15 meters below the soil surface, nor with the resistivities in the till at the location of borehole S507.

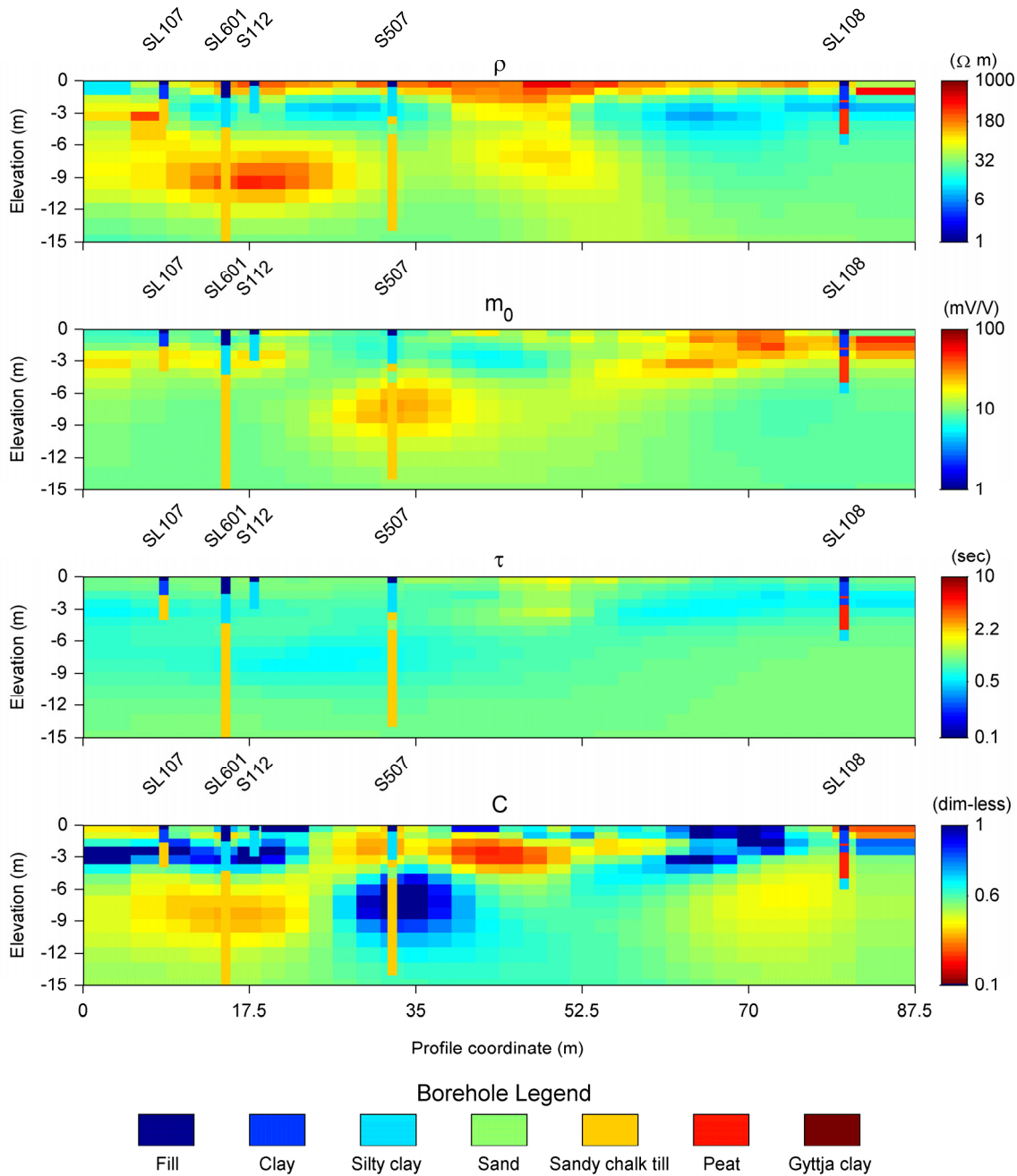


Figure 1 Inverted DCIP data and borehole data with geological classification. The top profile shows the resistivity, followed by the Cole-Cole parameters m_0 , τ and C .

In figure 2, the inverted profiles of the resistivity and the Cole-Cole parameters are compared to soil sampling results. The sampling results represents the total amount of free-phase chlorinated hydrocarbons (in between 0.1 - 300 mg/kg TS from blue to red). White colour represent levels where no samples has been taken.

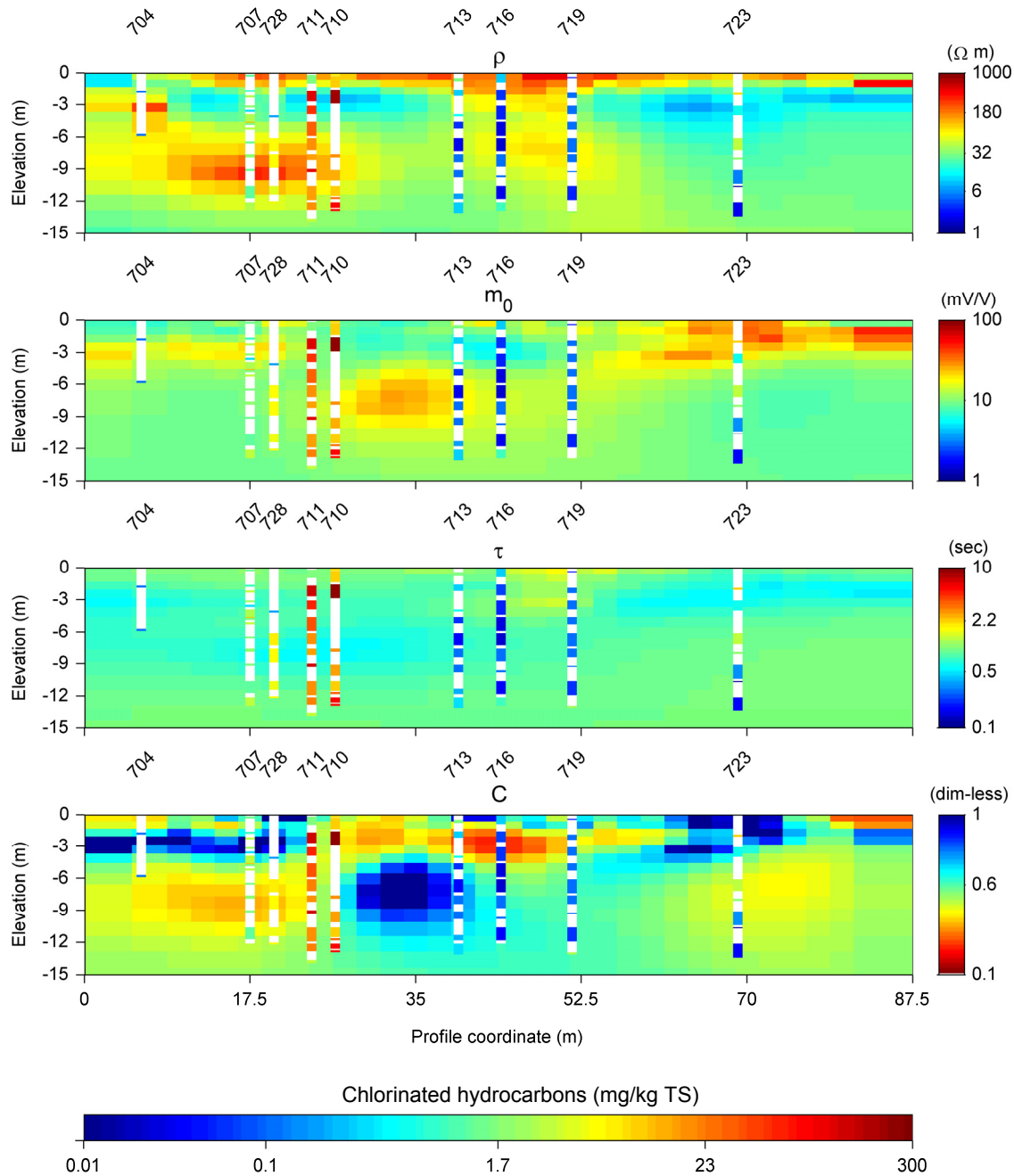


Figure 2 Inverted DCIP data and borehole data with total amount of free-phase chlorinated hydrocarbons in the sampled soil (mg/kg TS). The white coloured levels have not been sampled. The top profile shows the resistivity, followed by the Cole-Cole parameters m_0 , τ and C .

In Figure 2, it can be seen that high or medium high concentrations of chlorinated hydrocarbons have been observed in the boreholes corresponding to the high resistive anomaly (707, 728, 710 and 711). It is therefore likely that the high-resistive anomaly could, at least partly, be described by the presence of free-phase chlorinated hydrocarbons replacing ground water in the soil pores. No distinct IP-effects could be seen at this location except for relatively low values of the Cole-Cole parameter C .

The largest m_0 anomaly is seen at the location of the borehole S507, see Figure 1. The anomaly is situated in the till, where no IP-effects were expected.

No soil sampling of chlorinated hydrocarbons corresponding to this anomaly has been made, see Figure 2. The IP-effects are located right next to the boreholes where high concentrations have been observed. One interpretation may be that the degradation of the PCE at the interface between the ground water and the free-phase source plume enhances IP effects around the plume. The degradation of chlorinated hydrocarbons leads to more chloride ions solved in the groundwater. Locally higher salinity in combination with residual presence of hydrocarbons in the soil pores, leading to restricted or varying ion mobility, could be possible reasons to the polarization of the soil.

Conclusions

The goal for the future is to be able to use geophysics in combination with drilling and sampling for the challenging task to characterize free-phase chlorinated hydrocarbon plumes. Our results indicate that DCIP seem to be a promising method for imaging this kind of contamination. A high resistive anomaly was seen at a location along the profile where soil sampling have confirmed high concentrations of free-phase chlorinated hydrocarbons. High IP-effects, in terms of the spectral parameters m_0 and C , was seen close to the presumed free-phase source contamination. In this zone, degradation of the free-phase chlorinated hydrocarbons can be expected at the interfaces with the groundwater.

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