

Noninvasive Contaminant Site Characterization Using Geophysical Induced Polarization

by

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Introduction

The electrical impedance response of rocks/soils is a complex function of pore solution chemistry, the microgeometry or grain size distribution of rock/soil sample and the surface geochemical properties of the rock/soil/pore fluid system. The response is controlled by physicochemical surface mechanisms that result in a broad distribution of relaxation times. The broadband frequency response is often termed spectral induced polarization (SIP) and the step-function response is termed time domain induced polarization (TDIP).

The Earth Resources Laboratory (ERL) at the Massachusetts Institute of Technology (MIT) has been involved for several years in a broad foundational study of TDIP and SIP for contaminant site characterization. This ongoing study encompassed laboratory studies of coupled effects of rock/soil microgeometry and contaminant chemistry on Induced Polarization (IP), an investigation of electromagnetic coupling (EMC) noise, and development of 3D modeling and inversion codes.

It has been established that SIP responses of contaminated rocks can be used to characterize and identify contaminants and in some cases provide information on interface chemistry (Olhoeft, 1985,1992), (Börner et. al, 1993), (Vanhala, 1997a, 1997b), (Lesmes and Morgan, 2001), (Lesmes and Frye, 2001). Börner et. al. (1993) conducted laboratory studies of the effects of organic and inorganic contaminants on the complex conductivity responses of clay, and shaly sandstone samples, over the frequency range of 10^{-1} to 10^3 Hz. Their results showed that the frequency range of interest extends beyond 1KHz. Soininen et. al. (1994) showed from laboratory core samples that the ability to differentiate low grade dissemination and net-textured compact ore depends on the information derived from spectral IP phase above 1 kHz. Lesmes and Morgan showed that it is possible to invert for grain size distribution from sufficiently broadband SIP data and therefore can effectively decouple geo-chemically controlled responses from microgeometry controlled ones.

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Field Implementation Limitation

However, careful consideration of electromagnetically coupled (emc) noise sources suggests it will be a major limitation to the use of 3D field SIP at higher frequencies (typically > 100 Hz). Different mechanisms responsible are inductive coupling due to changing magnetic field of the oscillating current source, wire-to-wire, wire-to-ground or ground-to-wire capacitive couplings, etc. The effects of electrode capacitive response were also investigated. These losses are not accounted for by present models and are therefore model noise sources that have to be accounted for. Figure 1 shows a modeled spectral response of the three most prominent of these noise

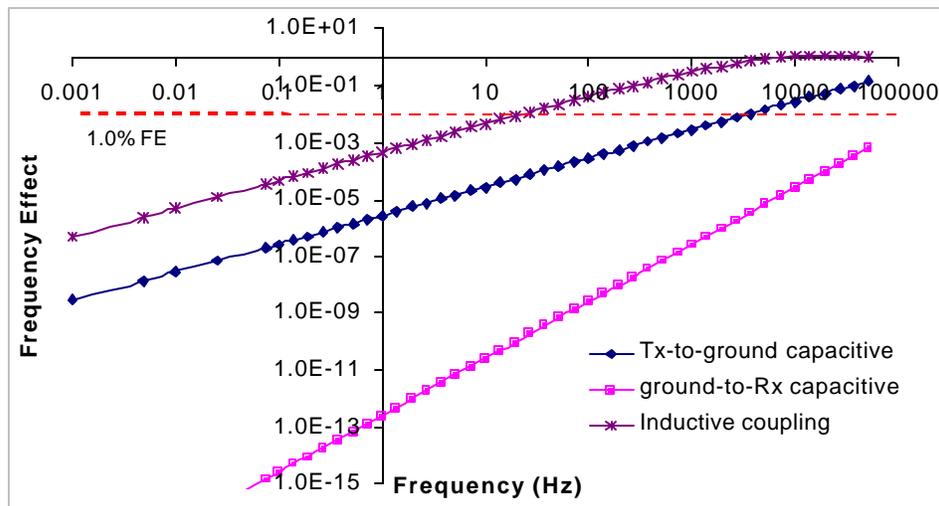


Figure 1: Coupling effects for a parallel Dipole (spacing, $N=10$, and Transmitter and Receiver circuit separation, $h=10\text{m}$).

sources and reveals that the most important of this is inductive electromagnetic coupling. Inductive coupling grows with the transmitter-receiver separation and changes with the orientation. For 3D-field geometry, where the transmitter-receiver separations are typically large, this will present severe limitations to the use of SIP to discriminate between contaminant types and will reduce any such gain from laboratory SIP. The conclusion from this study is that emc will limit the usable frequency of SIP to below 100Hz for the majority of field surveys, especially in the case of 3D where dipole spacings are inherently large. To circumvent this problem the IP problem has been re-formulated to include electromagnetic induction as part of the contributing mechanisms to the field measurements and is an ongoing research effort at ERL.

Selected Results

FS-12 Plume at MMR

The ERL have developed 2D and 3D inversion algorithms (Shi, 1998) for processing TDIP data to IP chargeability and SIP data to a complex resistivity map of the subsurface. An example of the application of TDIP to contaminant mapping and detection is to data collected in fall of 1996 at the FS-12 plume of the Massachusetts Military Reservation (MMR). An example is presented here of the application of the 2D TDIP method to map contaminant plumes with data collected in the fall of 1996, and analyzed for the FS-12 plume at the Massachusetts Military Reservation (MMR), Cape Cod, Massachusetts. FS-12 is due to a break in a subsurface fuel pipeline in the early 1970's leaking approximately 70,000 gallons of fuel. The contaminants of interest are benzene and ethyl dibromide (EDB) because they have the highest concentrations and therefore likely related to the IP effects and secondly because of their health risk.

The data have been inverted to give resistivity and chargeability tomograms to depths of 300 feet and horizontal extent of 1400ft as shown in figure 2. We also processed the IP time domain signals for short and long times separately and produced a time domain gross spectral chargeability difference. Both the chargeability and spectral chargeability difference show good agreement with the known location of the plume from monitoring wells.

The IP mapping provides detailed information that cannot otherwise be obtained from the sparse borehole distribution.

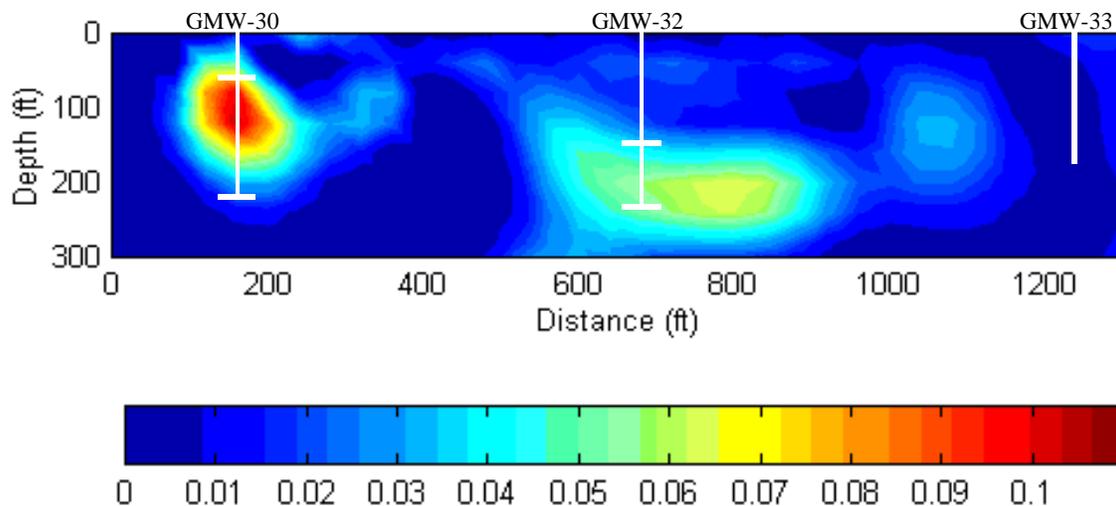


Figure 2: Chargeability tomogram showing the distribution of contaminant plumes

TCE/PCE Plume at SRS

The ERL performed SIP and TDIP measurements at the A-14 Outfall during the summer of 2001 as a participant in a DOE sponsored exercise to assess the state-of-the-art in cross-borehole IP technology for delineating subsurface contaminants. The results of this exercise were inconclusive because the ground truthing phase of the operation failed to detect any concentration of NAPL above a requisite threshold of 40-50 $\mu\text{g/g}$. It is our understanding that this threshold level is based upon analytic chemical partition analysis, which is dependent upon the physicochemical properties of the soil, its pore-fluid, and organic constituents (Cohen and Mercer, 1993), and therefore represents a necessary and sufficient condition to confirm the presence of NAPL. Therefore, since the ground-truthing phase never found PCE concentrations in excess of $\sim 3\mu\text{g/g}$, there is no irrefutable evidence of NAPL; hence, the objective of the 2001 exercise could not be completed. Nonetheless, the ERL's inversion results agree well with the ground truth, considering the sparseness of the CRS (ground-truth) boreholes, low concentrations of 'PCE' ($< 3\mu\text{g/g}$), and despite poor electrodes. Furthermore, the ERL developed a unique array configuration that alternated current-bearing and potential measuring electrodes (thereby avoiding electrode memory concerns) and that capitalized on diagonal current dipoles (which greatly reduced artificial 'layering' tendencies in the data inversion).

Figure 3a-c shows an interpolated panel of PCE concentration as measured during the FY01 ground-truthing phase **(a)** (Riha and Rossabi, 2002), SIP phase response **(b)**, and TDIP chargeability **(c)** along one survey panel (panel between boreholes MES-2/MES-4). The small region of anomalous PCE concentration spatially agrees well with the anomaly locations as derived by both SIP and TDIP. This result is, unfortunately, open for interpretation since the groundtruth analysis cannot definitively identify this anomaly as PCE. However, if it is PCE, then our result is especially profound, as it would indicate that properly implemented IP could detect PCE levels well below the threshold imposed on chemical partitioning analysis.

PCE-IP ground truth comparison at the A-14 Outfall

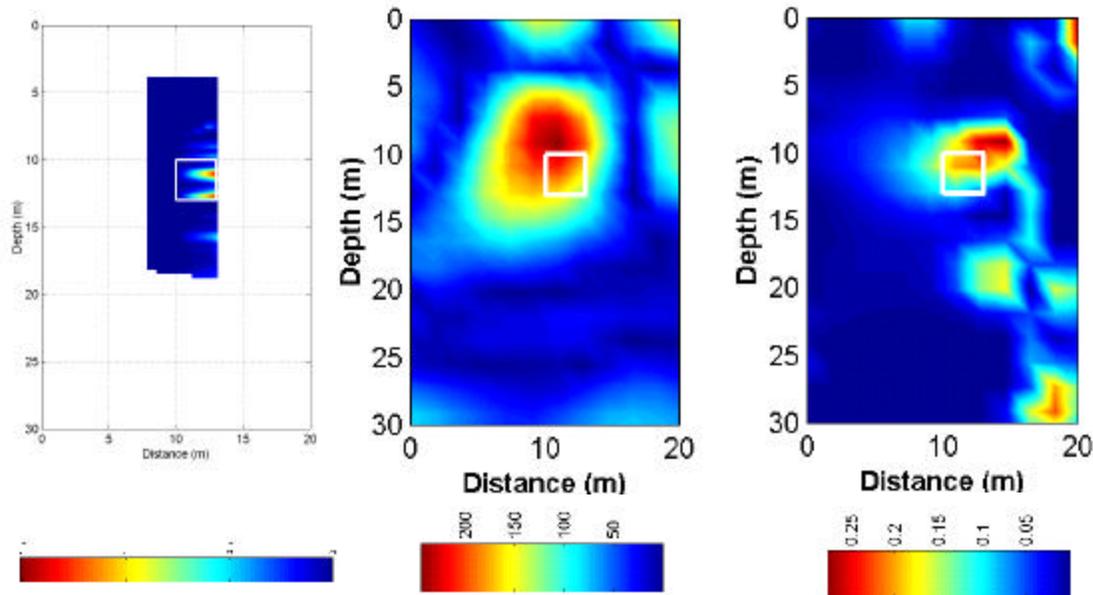


Figure 3 Comparison of the ground-truth PCE anomaly (**a**), the ERL's SIP anomaly (**b**), and the ERL's TDIP anomaly (**c**). Panel **a** has been generated by taking a slice along the MES-2/MES-4 panel from the volumetric PCE concentration (interpolated from the CRS series of boreholes, taken during the FY01 ground-truth exercise). Panels **b** and **c** are the ERL's inversion results along the MES-2/MES-4 panel. MES-4 is located on the right-hand side of all three panels.

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