Integrating ERT and IP measurements with traditional environmental sampling – ambiguity reduced or increased? A DNAPL case study from Norway

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To reduce costs for brownfield investigations while increasing the predictability of contamination plumes, non-invasive and cost efficient investigations methods are needed in addition to classic investigation tools as sampling and drilling. Due to the development of sophisticated equipment and computing tools the combined deployment of Electric Resistivity Tomography (ERT) and Induced Polarization (IP) is a promising tool and of interest for groundwater and contaminated land related issues.

The case study presented here is a small-scale wood preservation plant, located in Central Norway, on which creosote has been applied extensively since 1935. The main sources of the contamination were leaking installations related to a single source that has been stopped. For the environmental risk assessment 56 shallow drillings were conducted on site, soil samples for chemical analyses taken and a drainage installed to stop further spreading. Creosote is a coal-tar distillation product and belongs to the group of dense non-aqueous phase liquids (DNAPL). While being banned in the E.U. it is still widely used for the preservation of wood and abundant as a subsurface contaminant. Due to its density (1.00 – 1.17 g cm^{-3} at 25 °C), it sinks in the groundwater until reaching low permeable barriers and therefore is hard to detect and remediation actions are costly. Furthermore, the low solubility of these fractions makes DNAPL a long time groundwater hazard (Priddle et al. 1994). Being a low conducting and non-polar material makes it a good target for geoelectrical (ERT and IP) mapping.

Our lab test with creosote saturated sandstone showed that even small amounts of creosote lead to a high increase in resistivity and concurrent very low chargeability effects. However defined small scale tests can only be guidelines for field observations Previous ERT/IP measurements (Bazin 2011) were conducted on site using different experimental setups (with different protocols and cable types) and processing software (Res2Dinv, Em1dinv). The latter takes Cole-Cole parameters into account for the inversion process but is currently not available as a commercial tool (Fiandaca et al. 2012). These investigations were a good basis for a first characterization of the site.

Additional ERT/IP measurements were carried out in late 2013 using again the ABEM Terramter LS (12 channels, 81 electrodes) to delineate the plume: four additional high resolution profiles (1 m spacing, 45 to 80 m length) were carried out with the Gradient-Plus protocol. Processing was carried out using Res2Dinv (Loke 2013), limiting the potential of IP-data processing. Data and drilling information were displayed in 3D using RockWorks 16.

According to drilling information, the subsurface can be summarized as followed (Fig. 1):

- Backfill, consisting of peat, woodchips and sawdust: 0.0 – 3.0 m depth (dry: 400 – 1500 Ωm saturated: 20 – 80 Ωm)
- Coarse grained (sand, gravel) sediments: 0.0 – 5.0 m depth (dry: 500 – 2000 Ωm, saturated: 100 – 500 Ωm)
- Fine grained (silty sands and gravels) sediments: 3.0 – 5.0 m depth (saturated: 800 – 300 Ωm)
- Bedrock (Granite and Shale/Limestone): 300 – 2000 Ωm

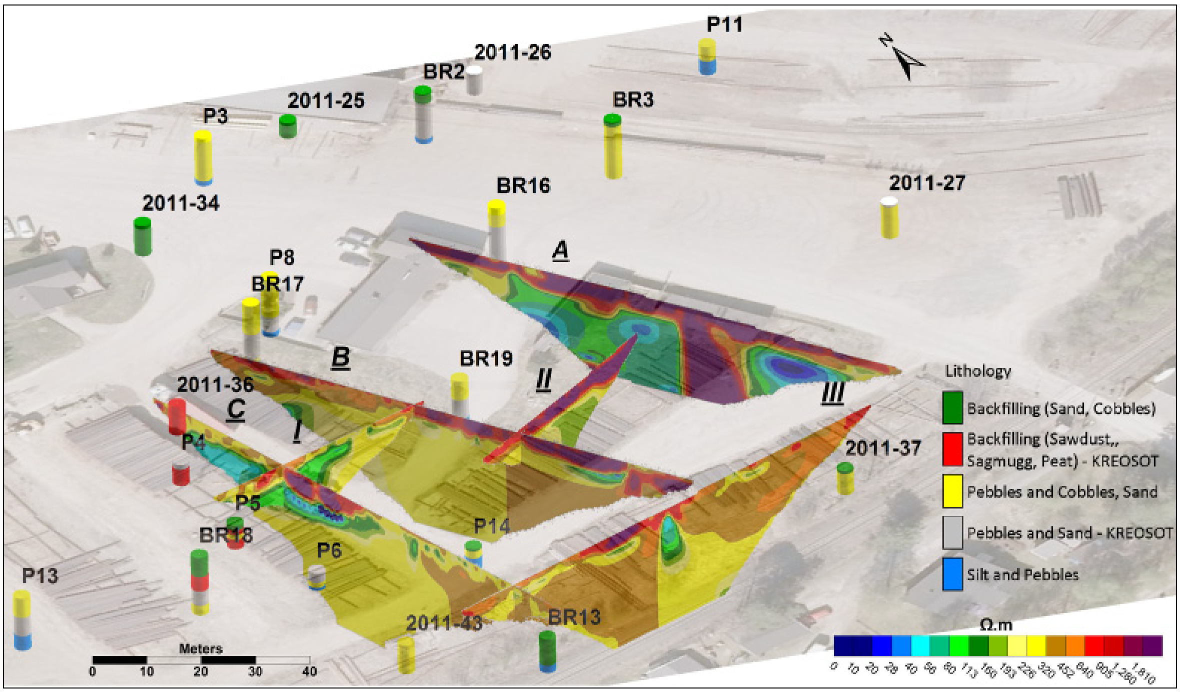

Fig. 1: 3D-visualization of resistivity sections.

Median groundwater levels are between 2.5 – 3.5 m below surface. High concentrations of creosote in the soil (up to 42 gr kg^{-1}) result in up to 1.5 m of free phase on the groundwater table. Bedrock starts at 4 m depth on. Due to glacial processes, the topography of the bedrock is subject of uncertainty and may show large variations. The ERT models reveal high resistivities (> 600 Ωm) along all six profiles limited to the vadose zone which coincide with areas of very low chargeability (5 – 9 mV V^{-1}). Furthermore the extent of these high resistivities decreases away from the contamination source in western direction (Profile A-B-II-C, Fig. 2) and a sharp boundary exists below that depth (2.5 – 3.5 m depth). We therefore suggest that these areas are creosote contaminated backfilling and sediments.

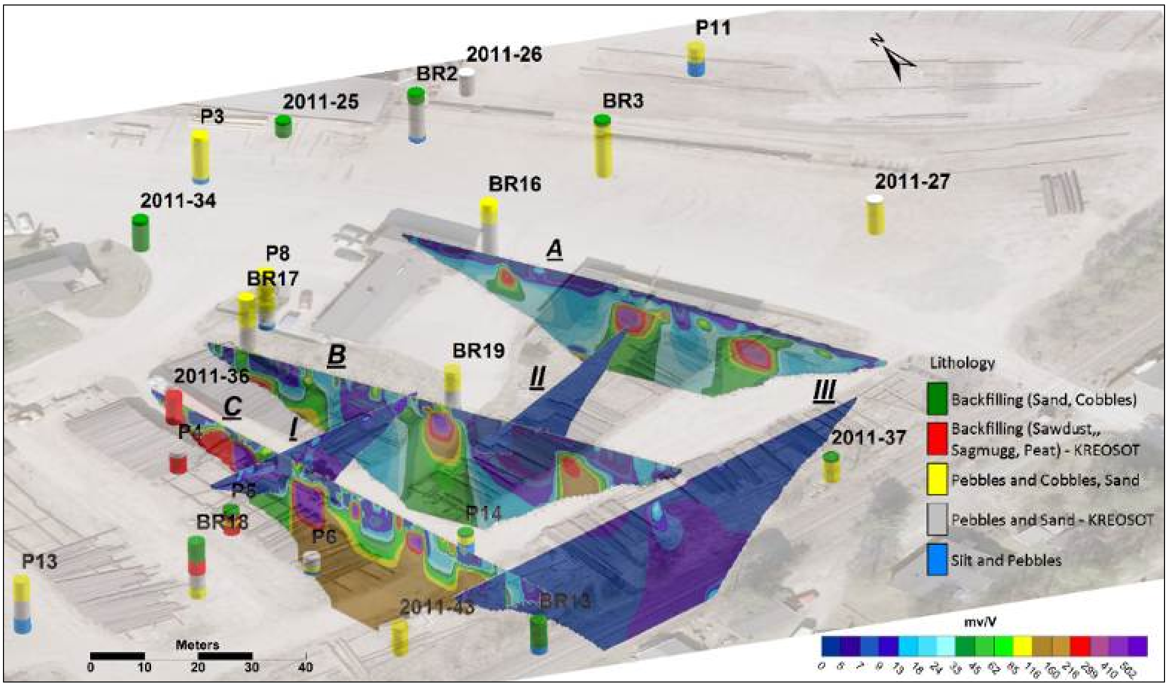

Fig. 2: 3D-visualization of IP sections.

For the groundwater saturated area the ambiguity is manifold. Most resistivity values down to the maximum penetration of about 15 m are homogenous and vary between 200 to 500 Ωm (yellow to brown on Fig. 1) with no visible boundaries that could indicate a potential sediment-bedrock contact. This also applies to the chargeability (profiles A-B and I-II-III: 5 – 50 mV V^{-1}). Additionally some areas show very low resistivity patterns between 10 – 100 Ωm which cannot be related to the known geology or contaminant. Profiles A-B-C (Fig. 1) show furthermore isolated chargeability anomalies (> 300 mV V^{-1}) of unknown nature. Thanks to the 3D-visualization it was possible to recognize them as linear features which are probably of anthropogenic origin (subsurface installations). At last, Profile C shows from 4 m depth a continuous chargeability anomaly (150 mV V^{-1}) which cannot be interpreted.

We conclude that with our complementary approach it was possible to map the extent of the residual creosote in the vadose zone while the integrated 3D model for the saturated area remains difficult to interpret and subject of further analysis. The 2011 as 2013 surveys showed good matching resistivity distributions which gives confidence in the reliability and repeatability of the acquisition method. Nevertheless further development of our IP-inversion tools is necessary. Full Cole-Cole inversion of profile B data showed the superiority compared to "RES2DINV-style" bulk IP inversion (Bazin et al. 2011). This would improve IP's potential as a commercial tool for environmental site assessment.

References:

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