Characterization of Abandoned Mine Tailings by Means of Frequency- and Time-Domain Induced Polarization Imaging

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Introduction

Induced Polarization (IP) imaging datasets were collected in both time domain (TDIP) and frequency domain (FDIP) for the characterization of abandoned mine tailings and in order to assess possible down-gradient transport of sulphide minerals. The study area is characterized by low but measurable concentrations (5% metal content) of fine minerals. Metallic minerals are associated to enhanced induced polarization effects by the so-called electrode polarization mechanism. This study aims at the evaluation of the applicability of TDIP and FDIP at the field scale and its capability to quantify metallic volumetric content.

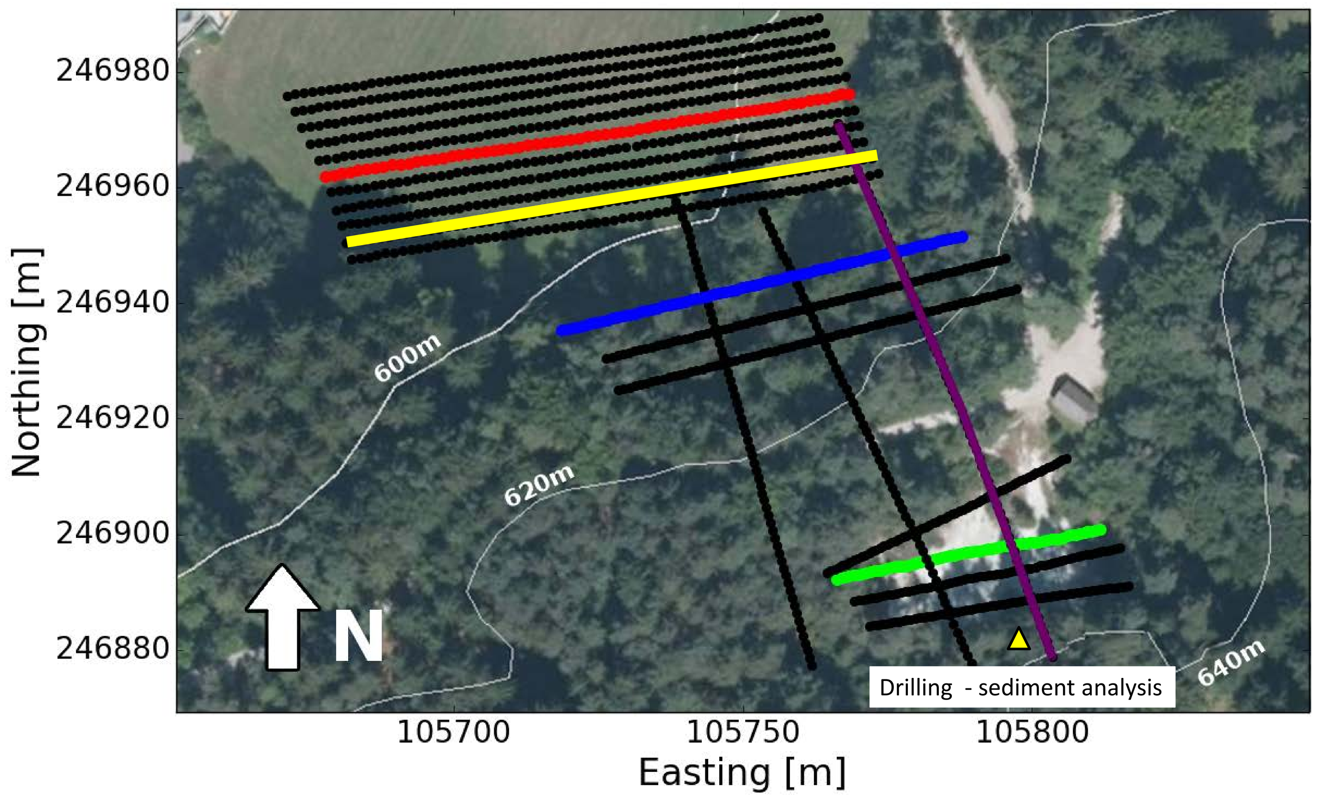

Figure 1. Overview of the site and distribution of IP profiles. Colored profiles were measured in both FD and TD for comparison.

Site characterization, TDIP and FDIP

IP imaging datasets were collected in 21 profiles, consisting of 3 north-south and 18 east-west profiles. The distribution is shown in Figure 1. As the general depth of investigation was about 5 m only, electrode separations in the profiles range between 0.75 and 1.5 m. For the general characterization of the site single frequency FD data were collected using a multiple-gradient configuration[1]. The colored profiles in Figure 1 were collected in both FDIP (with multiple frequencies) and TDIP using a dipole-dipole configuration. The inversion of the data was performed with ERTLab (3D inversion) and CRTomo[2].

In Figure 2 we present the imaging results for an exemplary dataset collected in a south-north profile. Imaging results for data collected in both TDIP and FDIP are very consistent as observed in previous studies[3]. Electrical images in Figure 2 reveal an unexpected anomaly characterized by high resistivity values.

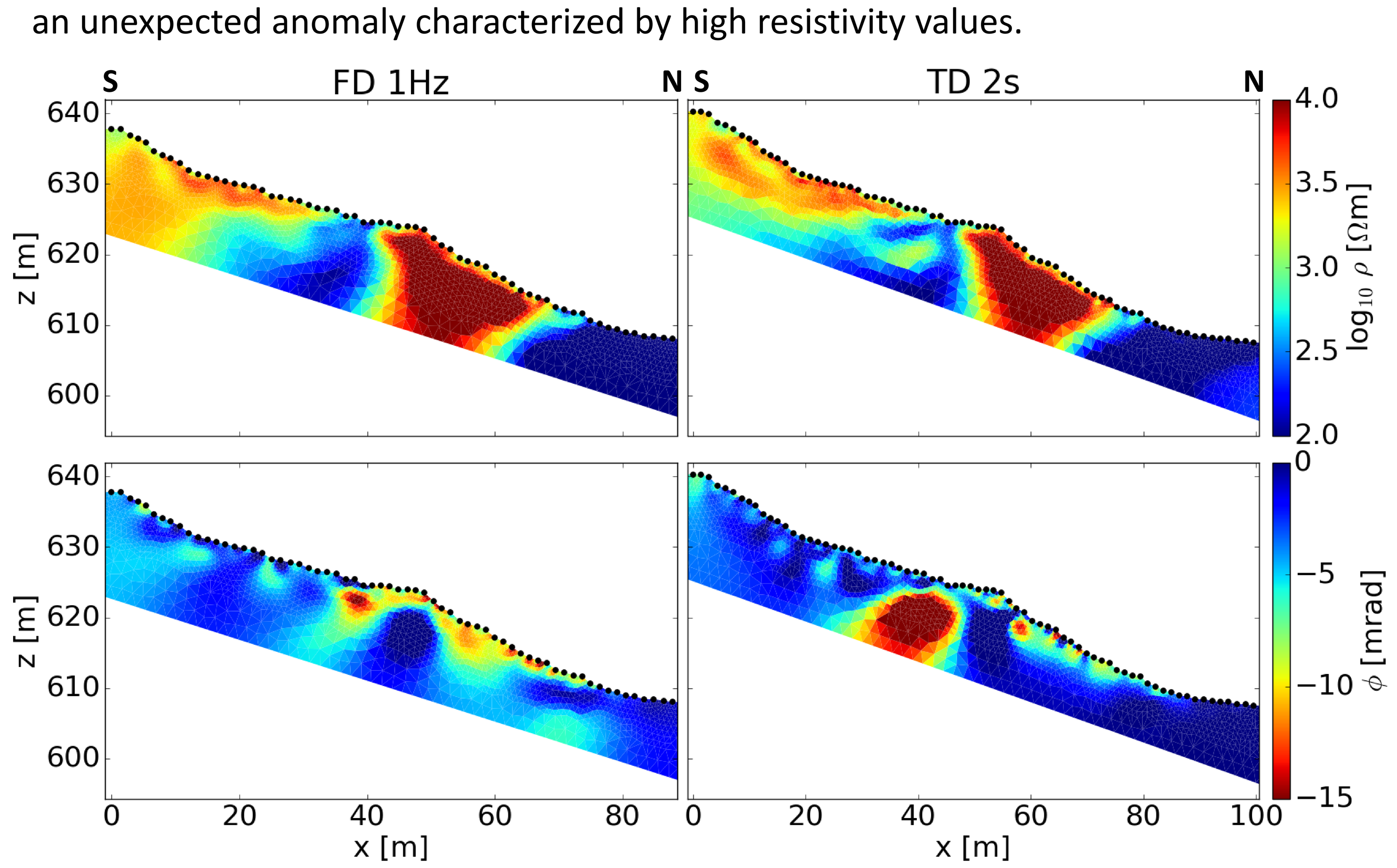

Figure 2. Imaging results for a south-north profile (see purple line figure 1.) expressed in terms of the magnitude (ρ) and phase-shift (φ) of the complex electrical resistivity. Column 1 represents results obtained after inversion of FDIP measurements at 1Hz and column 2 represents results obtained after inversion of TDIP measurements with 2s pulse length.

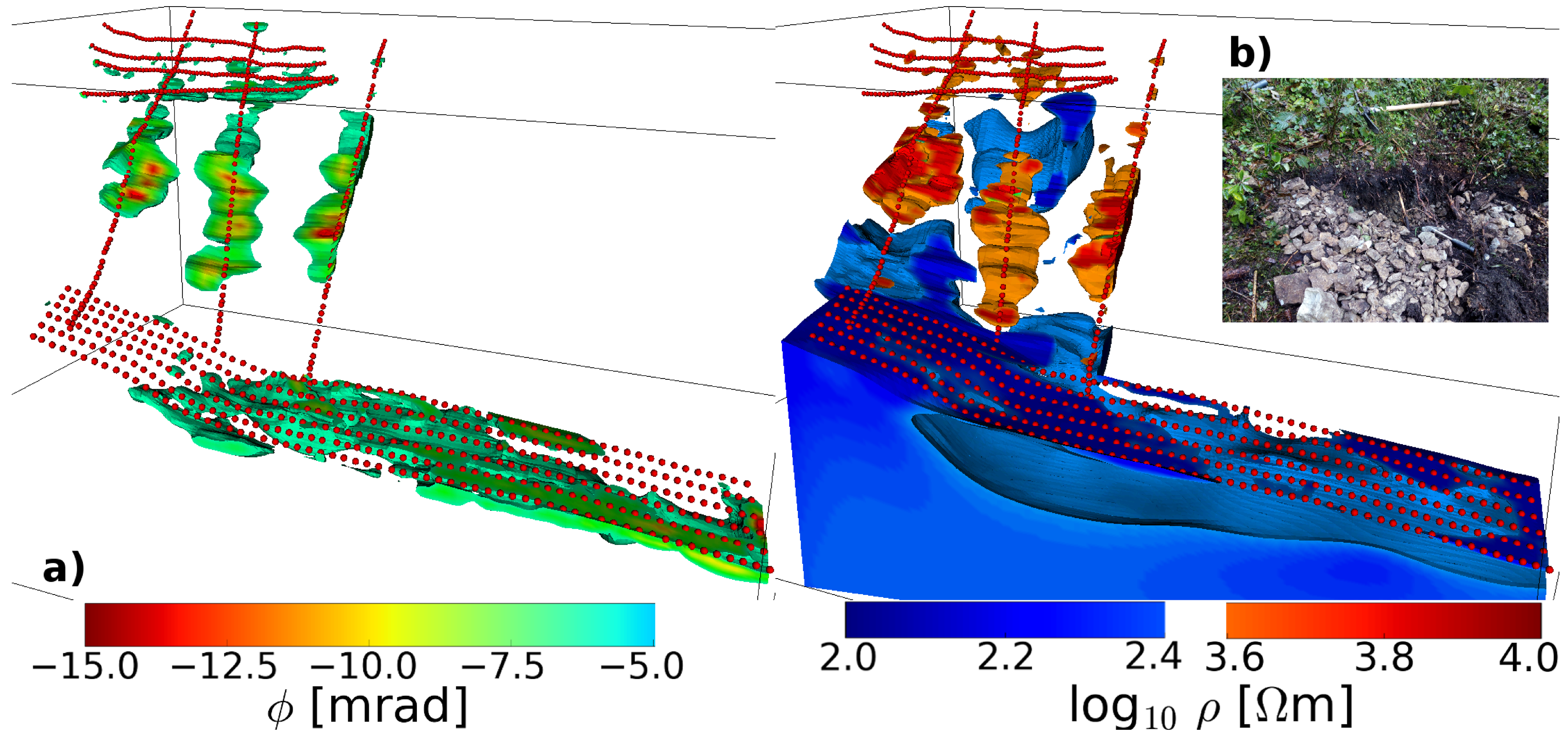

Figure 3. a) Isovolumes representing areas with higher phase-shift values (left side) as well as constraining high and low resistivity values (right side) as obtained after 3D inversions of FDIP measurements at 1 Hz. b) Materials after removal of soil cover. Boulders with some metal content are associated with resistive anomaly.

Geometry of the tailings

Figure 3a presents isovolumes of the phase-shift and magnitude of the complex electrical resistivity derived from 3D inversions of the mapping profiles. Based on the electrical images, the site can be classified in three main units:

1) The reported tailings (southern part of the study site) characterized by high resistivities and moderate phase-shift values related to fine sand and measurable concentrations of metallic minerals (5% volumetric metal content).
2) The unreported tailings (down-gradient in the forest) characterized by very high resistivities (>10^4 kΩm) and elevated phase-shift values (<-10 mrad) related to deposits of boulders with some metal content (Figure 3b).
3) The grassland characterized by low resistivies and intermediate phase-shift values as typical for sediments with higher clay content.

Spectral induced polarization

To investigate the frequency dependence of the electrical properties in the study area, we collected data in the frequency bandwidth from 0.5 to 225 Hz in selected profiles. Representative results for data collected in the reported tailings are presented in Figure 4, which clearly reveal changes in the IP effect for data collected at different frequencies suggesting a critical frequency at 5 Hz. High frequency results (> 75 Hz - not shown here) are likely affected by EM-coupling due to small electrode separations (0.75 m) while using cables with 5 m electrode separation.

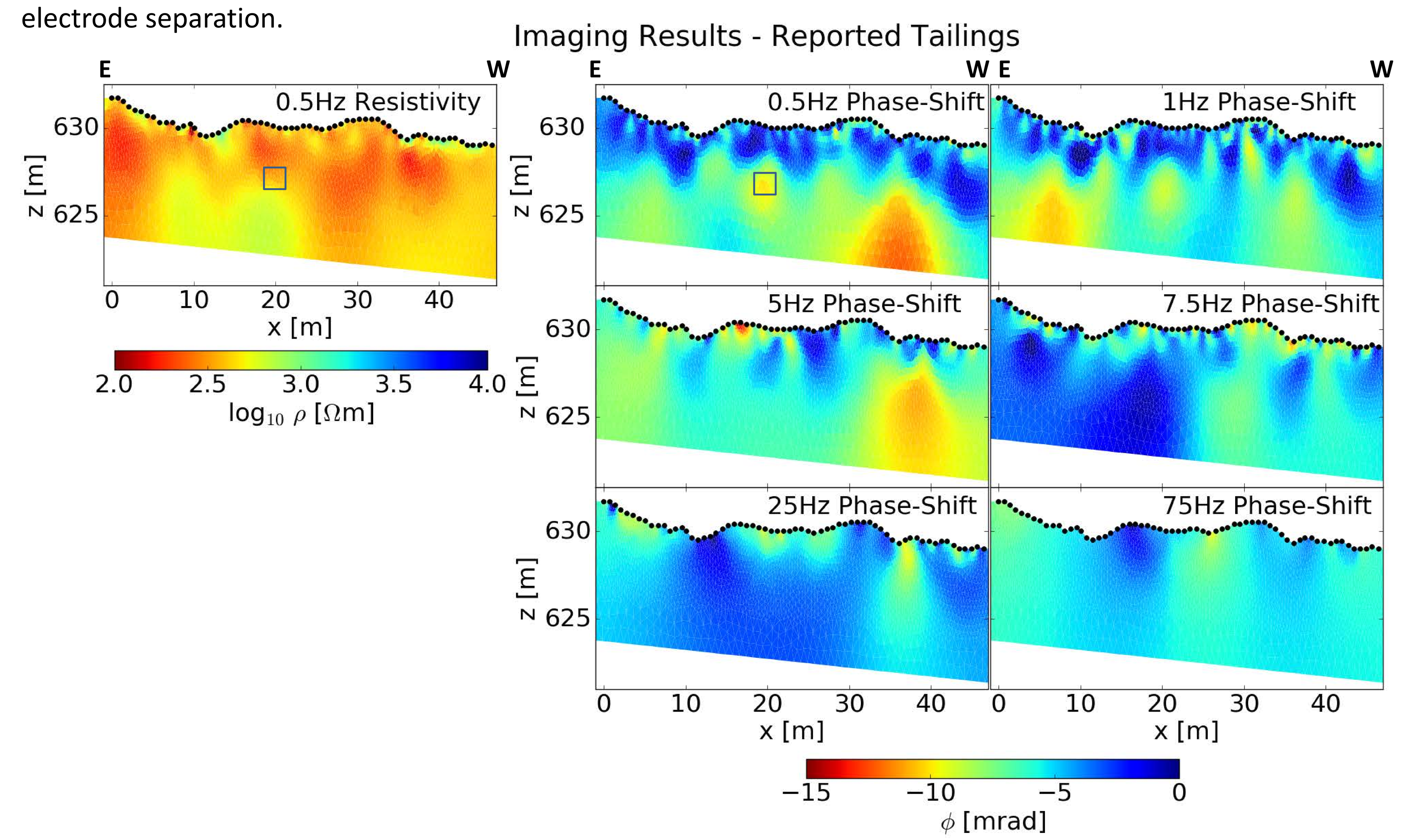

Figure 4. Imaging results for SIP datasets collected in one profile in the reported tailings (as indicated by the green line in Figure 1). Electrical images clearly reveal changes in the IP effect for different frequencies.

Interpretation

Figure 5 shows the frequency dependence of the magnitude and phase-shift of the complex electrical resistivity for selected pixel values extracted from measurements performed in the grassland (yellow line marked in Figure 1) and the reported tailings (green line marked in Figure 1). The magnitude values for the data measured in the tailings are higher than those solved for the grassland as tailings are mainly medium to fine sands; whereas in the grassland higher clay concentrations have been reported. Nonetheless, sediments for both regions reveal modest phase-shift values. The low polarization effect observed at the mine tailings is unexpected, considering that accumulation of metallic minerals should enhance electrode polarization mechanisms associated with larger IP values.

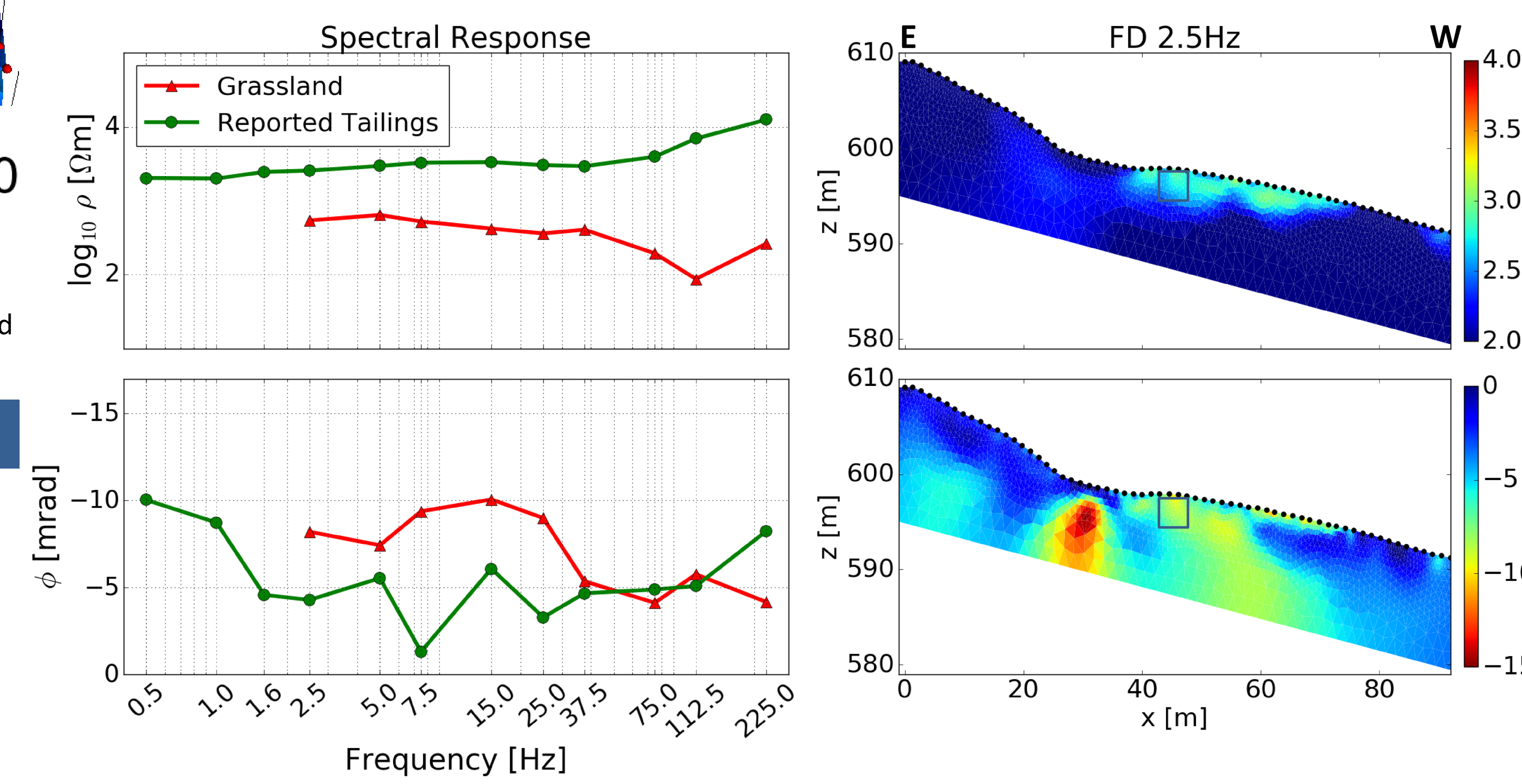

Figure 5. Imaging results for the grassland profile for FD measurements at 2.5Hz (yellow line marked in Figure 1). Column 1 shows the frequency dependence of the magnitude and phase-shift for selected pixels of the according profiles (grassland/reported tailings).

Chemical analysis of samples taken in the reported tailings (see Figure 1) however showed only low concentrations of iron minerals (<5%). Further analysis also revealed that the metallic minerals are related to secondary mineralization, leading to metallic minerals coated by other materials like carbonates, as presented in Figure 6. Hence, the low IP effect might be explained by reduced electrode polarization effects, as the metallic surface is not in direct contact with the current flow. Coating also revealed a decrease in the IP effect of metallic nano- and microparticles[4].

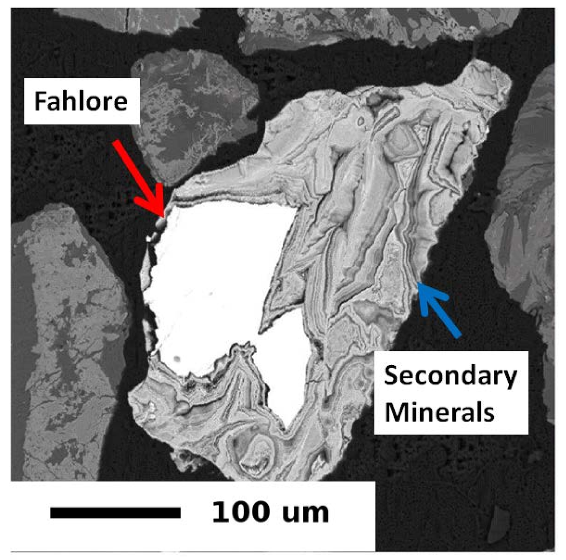

Figure 6. Coating of fahlore with secondary minerals (mostly carbonates) could lead to a reduced polarization effect.

Conclusion and Outlook

Our results confirm the potential of the IP method to characterize the occurrence of metallic minerals in the subsurface, even if the size and concentration of such minerals in mine tailings is much lower than those observed in mining exploration. Although not a primary objective of the study, IP imaging results permitted the identification of an unreported mine heap, associated to the anomaly characterized by high electrical resistivity values. Such finding is very important to better understand the processes within the tailings. The unreported mine heap is characterized by larger materials, in the size of gravels and boulders, with initial results revealing a larger concentration of metallic minerals. However, further SIP measurements and geochemical analysis are required to fully characterize the characteristics of this unreported heap.

Other future activities will include the inversion of datasets using a full-wave form approach[5] and the recollection of SIP datasets in the reported tailings utilizing cables with smaller electrode separations (in order to minimize EM-coupling).

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