Inductive Induced Polarization Effects: the Loupe EM synthetic case study

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Introduction

The Loupe electromagnetic profiling system (Street et alii, 2018) is a two-operator, portable, time-domain electromagnetic system mounted on backpacks, designed to image electrical conductivity in the near-surface at high spatial and vertical resolution. This particular configuration (visible in *figure 1*), as well as drastically speed up the acquisition procedure, allows to acquire data where the topography and logistic are too complex for a standard EM loop. This extends the EM application to a great number of environments.

Figure 1. Loupe EM system configuration for an acquisition in the Val Sabbia (BS) mountainous area.

For the Loupe system, a quick transmitter waveform turn-off (10 µs) allows to get a good resolution in the near surface while the of 20 A of peak current and 13 turns in the coil allow to reach a good depth of investigation, exceeding 50 m.
With this work we aim to assess if and how the system is sensitive to Induced Polarization (IP) effects.

IP effects on EM data have been studied since the early '80s (e.g. Spies, 1980; Lee, 1981), and have re-gained attention in recent years thanks to the ability to invert for IP effects on EM data in terms of Cole-Cole models (e.g. Viezzoli et al., 2017; Lin et al, 2019; Couto et al., 2020; Grombacher et al., 2021). However, the importance of IP modelling in EM data is still often overlooked, and false structures (incorrect conductivity-thickness parameters) may be recovered when IP is not properly modelled (Viezzoli et al. 2017). In order to study the IP effect on the Loupe system, we focused on a simple but representative case: a two-layer model with a chargeable cover over a resistive bedrock. This case may represent targets suitable for the Loupe system: mine wastes; permafrost; weathered covers over bedrock on mountainous areas. The study is performed varying the electrical properties of the cover layer, and its thickness, in order to highlight quantitatively the significance of the IP effect.

Method

In order to define how the Induced Polarization affects the Loupe electromagnetic response, we compute the forward response (following Auken et al., 2015) from a large amount of two-layer models, consisting of a chargeable cover over a resistive bedrock. The model space is defined in terms of the Cole-Cole resistivity model, as defined by Pelton et al. (1978):

$$m_{IP} = \{\rho_j, {m_0}_j, c_{j,} thk_j\}, \;\; j = 1,2 \qquad \text{(eq. 1)}$$

Table 1 contains the Cole-Cole parameters used for simulating the first chargeable layer, in all combinations. The second layer instead has been always considered a purely resistive layer at 1000 Ω*m. For each Cole-Cole two-layer model, we calculate a corresponding purely resistive two-layer model (using the DC resistivity value of the Cole-Cole model), and we compare the responses.

Chargeable first layer				
Rho [Ω*m]	**m0** [mV/V]	**Tau** [s]	**C**	**Thk** [m]
1	5	1e-04	0.5	5
2	8	3e-04		20
3	13	1e-03		
4	20	3e-03		
6	30	1e-02		
10	50	3e-01		
15	80	1e-01		
25	125	1		
40	199			
65	315			
100	500			

Table 1. Parameter values of the first layer.

The amount of distortion produced by IP for each forward response is computed as the mean absolute percentage difference over the entire response, as follows:

$$Distortion = \sum_{j=1}^{n} \frac{100}{n} \left\| \frac{fwr_{NOIP\,j} - fwr_{IP\,j}}{fwr_{NOIP\,j}} \right\| . \qquad \text{(eq.2)}$$

Where n represents the number of gates above the noise floor, set to 1e-12 V/Am^4 at 1 ms, in order to quantify only detectable IP effects; $fwr_{NOIP\,j}$ represents the jth gate of the forward response computed disregarding IP; $fwr_{IP\,j}$ is the jth forward response computed with IP.

Results

An example of comparison of forward responses with/without IP for the X and Z components of the Loupe system is shown in *figure 1*. The model, described in the textbox, represent a simplified but common geology, with a thin conductive, slightly chargeable cover that overlies a resistive second layer. As clearly evident, the transients affected by IP are heavily distorted, both for the X and for the Z component, culminating in the change of sign of the modelled signal.

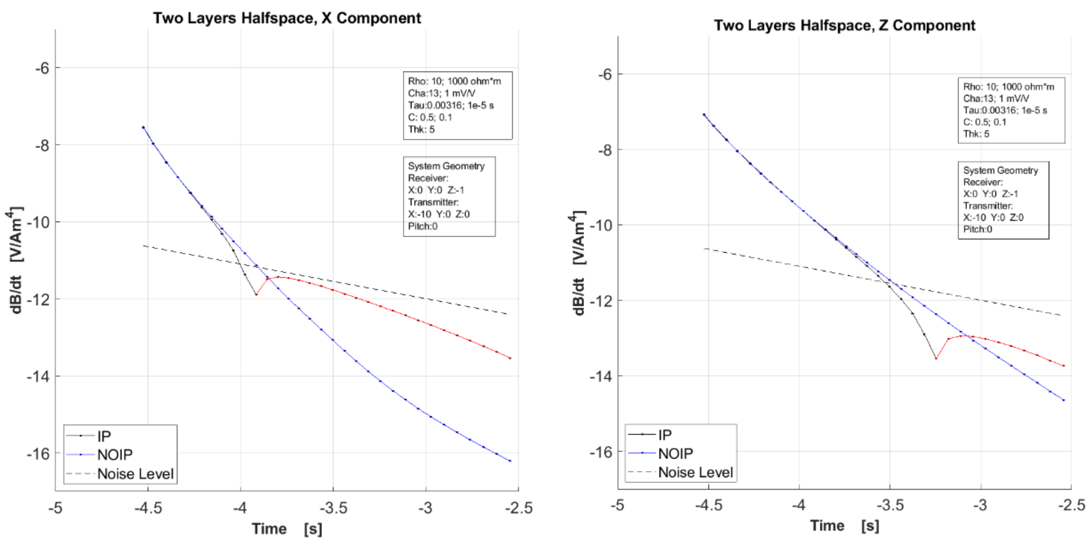

Figure 2. Comparison of the forward responses for the two layers model, for the X and for the Z component. The electrical parametrisation of the model is defined in the textbox, with the first value, of each parameter, referred to the first layer. In red are displayed the negative voltages.

Below, *in figure 3*, follows an example of representation of the results in a 2D map, representing in color the distortion, as computed following equation 2, as a function of chargeability and resistivity of the first layer.

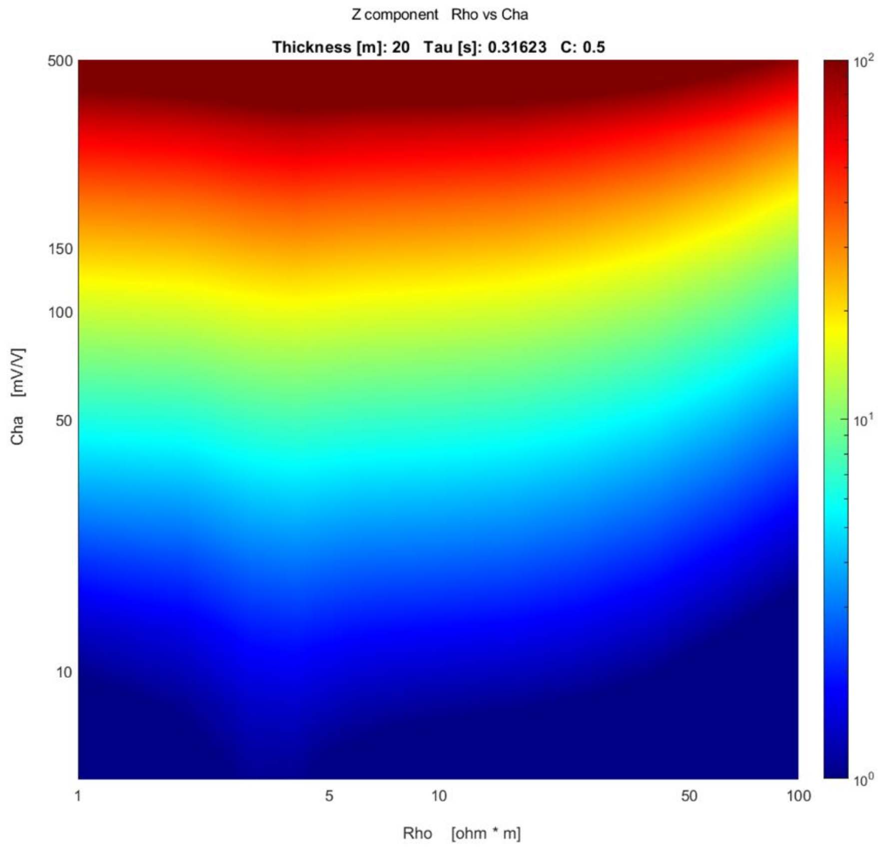

Figure 3. Representation of the IP Distortion (eq.2) for the Loupe Z component, for two layers models. The first layer thickness, Tau and C parameters are kept fixed in the title, while the Resistivity and Chargeability vary along the axes. The colorscale represents the difference, in percentage, between the IP affected halfspace and the purely resistive halfspace forward responses.

IP affects significantly the forward response even with low values for chargeability and high values for the time constant. The increase of the distortion follows the increase in chargeability, and already from 10 mV/V an error higher of 5% is reached. This spread of IP effects is linked to the two-layers configuration with resistive bedrock: the IP EM vortex currents, which flow in opposite direction of the eddy currents, propagate slowly in the second layer and dominate the current flow. In this configuration it is also interesting to see how even for a time constant of 0.3 ms it is possible to detect the IP effects above the noise level, also with a 75 Hz instrument.

Conclusions

The results presented in this study are surprising: in a two-layer environment with a chargeable cover over a resistive bedrock, even small chargeability values (e.g. 10 mV/V) creates significant effect in the responses measurable with the portable Loupe System, also with detectable data change of sign. Furthermore, these effects are not confined to low values of the time constant of the Cole-Cole model (e.g. below 1 ms), but persist also for tau values in the range of seconds. These results imply that the IP effect cannot be overlooked when operating with the Loupe system, for instance in surveys involving mine wastes, permafrost and weathered covers over bedrock on mountainous areas.

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