Discretization-free debye decomposition of spectral induced polarization data

*Charles L. Bérubé, Polytechnique Montréal, Montréal, QC, Canada*

*Rihana Benzetta, Polytechnique Montréal, Montréal, QC, Canada*

Spectral induced polarization (SIP) is a non-invasive geophysical method that aims to image the subsurface's electrical properties in the mHz to kHz range. Applications of SIP include, but are not limited to, mineral exploration, shallow landslide risk assessment, groundwater exploration, and soil organic matter content evaluation. SIP measures the frequency-dependent and complex-valued resistivity of geomaterials. These measurements are then commonly interpreted using a Debye decomposition curve fitting scheme to obtain the relaxation time distribution characterizing the investigated geomaterials. Debye decomposition approximates the complex resistivity of geomaterials as a summation of Debye impedances. A significant limitation of available Debye decomposition algorithms is that they require prior discretization of the relaxation time domain to yield estimates of each relaxation time's corresponding chargeability. Over-discretization of the time domain leads to an over-parametrization of the optimization problem, whereas under-discretization yields poor curve-fitting results. Selecting an appropriate discretization of the time domain is thus a subjective process. This study aims to propose a new SIP data decomposition approach that does not require discretizing the relaxation time domain. The approach relies on a variational autoencoder neural network, a probabilistic generative model, to which we add a physics-informed optimization objective based on the Debye decomposition formulation. First, the variational autoencoder is trained on one million artificial SIP data generated through Monte Carlo sampling of random relaxation time distributions. We then validate the neural network on synthetic SIP data predicted by the Pelton Cole-Cole and Dias empirical models and by the "perfectly polarizable interfacial polarization" petrophysical model. Finally, we test the new approach on SIP data measured on sand and graphite mixtures in the laboratory and on SIP data collected in the field over graphitic schist outcrops of the Canadian Malartic gold deposit in Quebec, Canada. Compared with previously published Debye decomposition algorithms, the main advantages of the new approach are : (1) jointly estimating relaxation times and their corresponding chargeability values without prior discretization and (2) accelerating the estimation of the relaxation time distribution uncertainties within a Bayesian framework.