# Empowering mineral exploration: Leveraging invertible neural networks for magnetotelluric data inversion and uncertainty quantification.

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## Abstract

As global demand for clean energy continues to escalate, ensuring a responsible and sustainable supply of critical minerals becomes paramount. This raises the need to improve and enhance the efficiency and accuracy of the processes and techniques involved in mineral exploration. The magnetotelluric (MT) technique which utilizes simultaneous measurements of the Earth's natural magnetic and electric fields as an electromagnetic induction source to map out the electrical conductivity variations in the Earth has been one of the very useful and widely applied method in mineral, geothermal, hydrocarbon and groundwater exploration. However, just like other geophysical methods, MT inversion suffers from severe non-uniqueness. Since the usefulness of an inverse solution hinges on understanding its uncertainty, it becomes important to quantify the uncertainties associated with each solution. We propose employing Invertible Neural Network (INN) as an alternative method for efficient estimation of resistivity structures and associated uncertainties. The INN establishes bijective mappings between resistivity models and MT measurements, incorporating a latent variable to capture the information loss during the forward process. Unlike conventional Bayesian inversion methods relying on computationally intensive Markov Chain Monte Carlo (McMC) sampling, INN offers fast inversion and uncertainty estimates with reduced computational overhead. To quantify model uncertainty, we simply drew 1000 samples from the posterior distribution by inputting the MT response and 1000 realization of normal Gaussian noise into INN and running it backward. We created 110,000 synthetic 1D resistivity models paired with MT responses, reserving 100,000 for training and 10,000 for testing. Numerical results based on synthetic data demonstrate INN's efficiency to adequately approximate the posterior distribution for the resistivity models with enhanced computational efficiency. We further applied this approach to a set of field data from East Tenant Region in Australia (Figure 1). Results from INN are highly consistent with previous studies and drilled wirelog data. Our work highlights the great potential of INN for solving the general electromagnetic inverse problem and quantifying its uncertainty.

## Acknowledgments

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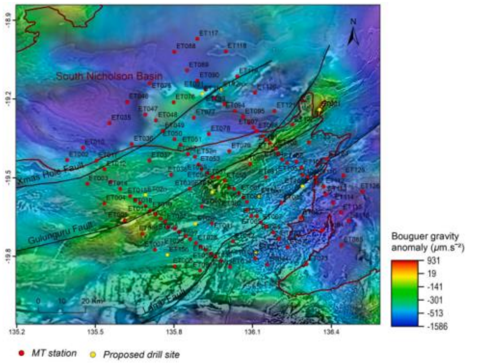

Figure 1: Broadband and AMT stations in the East Tennant region (Jiang et al., 2023).Black lines show the trace of major faults interpreted from seismic reflection and potential-field data (Clark et al., 2021).Background map is Bouguer gravity anomaly map (Nakamura, 2016).

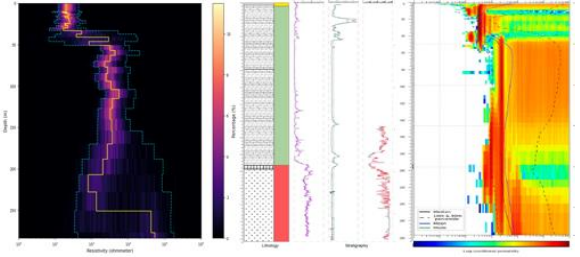

Figure 2: (left) Posterior prob. dist. from INN, yellow line is the maximum a posteriori model (map), (middle) lithology, stratigraphy, wireline logs, and (right) predictions from RjMcMc (Jiang et al), at site ET008.

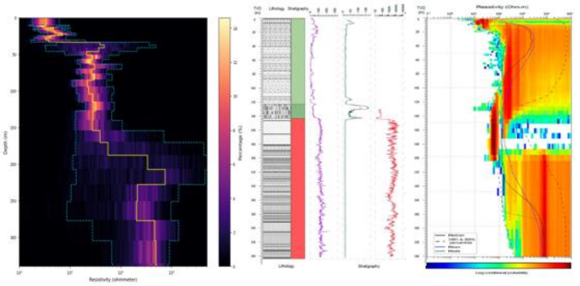

Figure 3: (left) Posterior prob. Dist. From INN, yellow line is the maximum a posteriori model (map), (middle) lithology, stratigraphy, wireline logs, and (right) predictions from RjMcMc (Jiang et al), at site ET10n.