Ground-tunnel wide field electromagnetic method and its application in Dongguashan Copper Mine, China

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SUMMARY

The Ground-Tunnel Wide Field Electromagnetic Method (GTWFEM), which employs a ground-based controlled source and tunnel receivers to acquire full-space frequency-domain electromagnetic field responses and subsurface electrical structure information, has the potential to enhance the accuracy of deep mineral exploration. We first introduced the basic principles of the GTWFEM, derived the calculation method for the full-space frequency-domain electromagnetic fields and their corresponding full-wave apparent resistivity. We also conducted research on the denoising data processing method and the three-dimensional inverse algorithm for the tunnel observation. We have carried out a case study of GTWFEM in Dongguashan Copper mine, China. The results show that effective controlled source response data can be obtained in a kilometer underground, which proves the feasibility of the method.

Keywords: mineral exploration, electromagnetic sounding, controlled source, tunnel, full-space

INTRODUCTION

The Wide Field Electromagnetic Method (WFEM) is a type of controlled source frequency domain electromagnetic method, which has many advantages compared with conventional methods, such as single-component measurement, anti-interference capability, and deeper sounding depth (He 2010, 2018). The Ground-Tunnel Wide Field Electromagnetic Method (GTWFEM) uses a ground-based controlled source and tunnel receivers to obtain full-space electromagnetic field responses. By conducting data observations closer to the target body underground, it can effectively avoid the influence of ground terrain and obstacles, filter out surface noises, and may improve the resolution of underground small-scale geological bodies. Therefore it shows a good application potential of deep mineral exploration. However, the application of the GTWFEM faces challenges such as theoretical complexity, low signal to noise ratio, and lack of specialized tools for data processing and inversion.

METHODS

Compared to conventional ground-based controlled source electromagnetic methods (e.g. Strangway 1973), the main difference of GTWFEM lies in the placement of the receivers within tunnels at a certain depth underground, allowing for close observation of deep targets. The receivers include single component sensors or their combinations. The transmitting source, usually using a horizontal electric dipole, are positioned on the surface, which is similar to conventional controlled source electromagnetic methods (as shown in Figure 1).
After obtaining the observed electric or magnetic fields, they can be substituted into the analytic equations of the underground field components under the condition of an equivalent uniform half-space model, and the corresponding full-wave apparent resistivity can be calculated using the bisection method (He 2010; Liu et al. 2020).

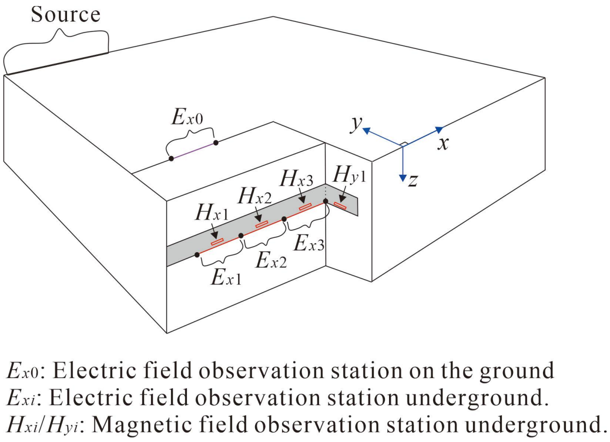

Figure 1. Measurement scheme of GTWFEM. In the underground tunnel, it is possible to measure the single-component electric field along the tunnel direction, as well as the magnetic fields of different components.

RESULTS

The Dongguashan copper mine is located within the urban area of Tongling City, Anhui Province. It has multiple tunnels within kilometers underground, which is available for experiments. Using the above observation scheme, we have obtained a batch of GTWFEM observation data, including hundreds of ground sites and underground sites at the depths of 0m, -875m, -930m, -960m, and -1000m.

Power spectra

In response to the special signal-to-noise environment of tunnel observations, research on noise classification processing technology was carried out, such as using clustering analysis technology to suppress vibrational noise and array processing technology to separate coherent noise. Figure 2 and Figure 3 show spectra of typical sites on the ground and 1 km underground. It can be seen that the signals of the transmitted frequencies are submerged in the background noise in the high-frequency part, while it shows a relatively high signal-to-noise ratio (SNR) in the low-frequency band for underground sites, which is consistent with the theoretical expectations. After denoising processing, the SNR in the low-frequency band could be further improved and be used for apparent resistivity calculation. It is worth noting that data above 50Hz is of lower quality and can not be used in subsequent inversion unless better results could be obtained after further processing.

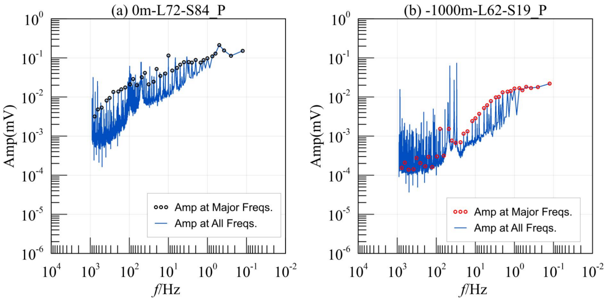

Figure 2. Spectra of typical sites on the ground (a) and 1 km underground (b).

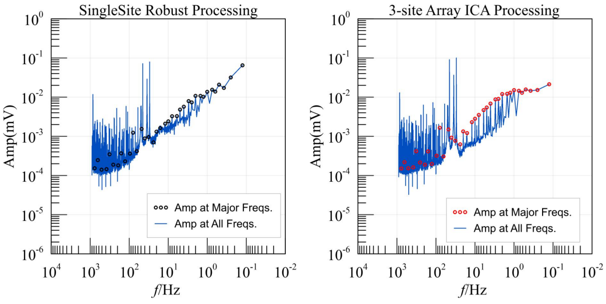

Figure 3. Spectra of a typical underground site at the depth of 1 km processed by single site robust estimation (left) and array independent component analysis (ICA) algorithm (right).

Apparent resistivity

The full-wave apparent resistivity was calculated using the power spectra data after denoising processing (Figure 4). It can be seen that although the overall data quality of tunnel observation is not as good as that of the surface observation, the curve is still relatively continuous, and the data in the low-frequency band can reflect the information of the geoelectric structure.

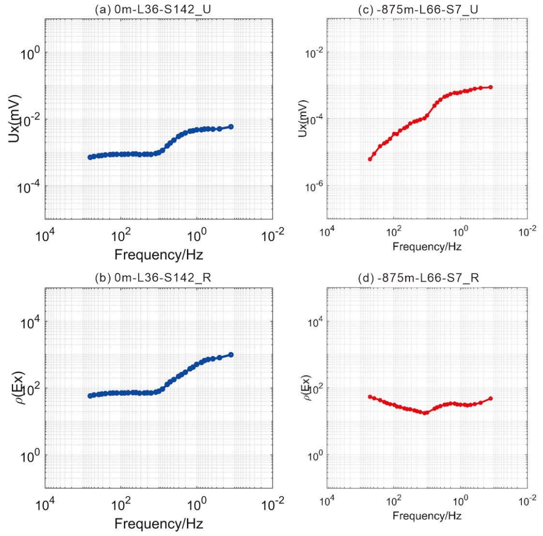

Figure 4. Calculated voltage (top) and apparent resistivity (bottom) of typical sites on the ground (left: a,b) and 1 km underground (right: c,d).

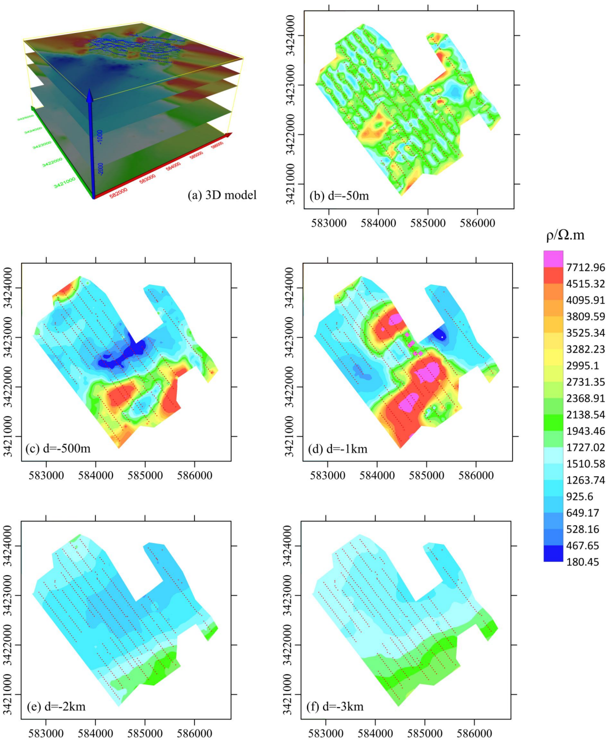

Figure 5. 3D electrical model (a) and its slices at different depths (b~f) of the Dongguashan copper mine.

3D Inversion

In response to the characteristics of the tunnel observation, research on 3D inversion techniques of full-space electromagnetic responses was carried out, such as refining the tunnel model with an octree grid, suppressing non-uniqueness with constrained inversion, and improving model accuracy with joint inversion of ground and tunnel data (Liu et al., 2024). With the 3D inversion, a 3D electrical model of the Dongguashan copper mine was obtained (Figure 5). Combined with existing geological information, the inversion results were comprehensively interpreted, the main stratigraphic boundaries and the spatial distribution of the rock bodies were inferred, and suggestions for drilling layout were made based on the results.

CONCLUSIONS

Under the condition of surface transmission and tunnel observation, it is possible to calculate the full-wave apparent resistivity, and to carry out frequency-domain electromagnetic sounding. After denoising processing, effective controlled source electromagnetic responses can also be obtained at depths of kilometers underground. Utilizing octree grid, constrained inversion, and 3D joint inversion of surface and underground data, a more reliable electrical model was obtained for Dongguashan Copper Mine.

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