Electromagnetic (EM) methods, both airborne and ground, are some of the most widely used geophysical techniques in mineral exploration, in which natural or controlled sources are used to transmit EM waves to the Earth and measure the reflected EM signal. EM methods include the transient electromagnetic (TEM) method, radio imaging method (RIM), ground-penetrating radars (GPR), borehole radars (BHR), magnetotelluric (MT) method, audio-magnetotelluric (AMT) and controlled-source audio-magnetotelluric (CSAMT) method. They are used not only for the discovery of mineral deposits and extension of reserves of existing mines, but also for structural mapping of the Earth, oil and gas exploration, environment and engineering, and groundwater investigation. The ability of these methods to explore Earth has improved significantly in last few decades with advances in sensors, space- and drone-based observation platforms, electronics, data processing and inversion techniques, and applications of machine learning. These advances have improved the resolution and detectability of EM methods.

In this Special Issue, we collected 16 contributions from the EM geophysical community on the latest innovations in EM equipment developments, data processing, forward modeling and inversion, and especially, applications to mineral explorations. The first paper by Prikhodko et al. [1] provides a brief introduction on the history of the development of airborne EM technologies using natural field technology, accompanied by technical specifications of the systems. They used field examples from applications of their latest development in the airborne EM system to demonstrate its exploration capabilities in both conductive and resistive environments, sensitivity to geoelectrical boundaries, and detectability of near-surface targets and deep structures.

Machine learning is a topic applied in every scientific research area, including EM technology development. This Special Issue presents four papers on noise reduction through machine learning. Zhang et al. [2] proposed a dictionary learning-based noise suppressing approach for marine controlled-source electromagnetic (CSEM) data, while Li et al. [3] used an optimized deep dictionary learning approach to suppress noise in MT data. Zhang et al. [2] demonstrated the effectiveness and superiority of their approach by applying a denoising example to synthetic data. This was achieved by comparing the results from the windowed Fourier transform (WFT) and wavelet transform (WT) denoising methods and three dictionaries (discrete sine transform (DST) dictionary, DST wavelet merged dictionary and the learned dictionary) under a sparse representation framework. Li et al. [3] used simulated and field data examples to illustrate the adaptability and high accuracy of noise identification using their approach. Their results demonstrate smooth and continuous apparent resistivity and phase curves. In addition, their approach can be an effective alternative method when no remote reference stations are set up or if remote reference processing is not effective. Zhang et al. [4] and Zou et al. [5] investigated the
identification and suppression of MT noise using a residual network (ResNet). Zhang et al. [4] used a deep ResNet that contained skip-connection blocks, which demonstrate an excellent fitting ability and robustness against network degradation. It was reported that the deep ResNet approach can effectively identify and suppress MT noise. However, the approach requires a high-quality training dataset. Zou et al. [5] used a deep residual shrinkage network (DRSN) to address the issue of MT cultural noise. Using both synthetic and field data, they demonstrated that the DRSN can effectively remove the cultural noise and has better adaptability and efficiency than traditional MT signal processing methods.

Modeling helps us to better understand the EM responses of different geological conditions and provides a pathway to the inversion and interpretation of EM data. Two modeling papers are presented in this Special Issue. Qin et al. [6] studied the analytical solutions of MT fields of a three-layered model with an isotropic top layer, a transition layer of exponentially varying conductivity with depth and a dipping anisotropic layer. They recursively computed the surface apparent resistivity and impedance phase, as well as the EM fields for different model parameters. Useful results were obtained for studying and understanding the attenuation of the EM fields on Earth. Chen et al. [7] developed an effective algorithm for 2D marine CSEM modeling in anisotropic media based on a new wavelet Galerkin method. They demonstrated that their method is superior to the finite element and difference methods in terms of computing time and memory requirements. Their real data example illustrated the importance of anisotropic models for data analysis and interpretation.

Inversion is very important in EM data interpretation. This Special Issue includes four papers on inversion. Deng et al. [8] developed a 3D inversion method for high-precision magnetic gradient tensor (MGT) data through the use of convolutional neural networks (CNNs), which automatically predict physical parameters from the 2D images of MGT. The feasibility of the method was demonstrated through both numerical data and the MGT data from the Tallawang magnetite diorite deposit in Australia. Xie et al. [9] presented a 3D triaxial anisotropic inversion framework using the edge-based finite element method with a tetrahedral mesh. They solved the 3D inversion problem by using a fast-converging Gauss–Newton (GN) method and validated the approach using synthetic modeling data. Feng et al. [10] proposed a multiplier-based MT inversion scheme, which was implemented by introducing the incremental Lagrangian function. One of the advantages of this scheme is its optimized selection of regularization factors for inversion. Wu et al. [11] developed an integrated inversion method of both borehole and aerial TEM data based on equivalent filament approximation, which increase the accuracy of inversion, as illustrated through numerical modeling data.

Petrophysics of rocks is key in any new exploration frontier. To facilitate the development of oil and gas exploration in the Permian igneous rocks in the Sichuan Basin, China, Xian et al. [12] analyzed the comprehensive physical properties of the samples with different lithologies, including basalt, tuff, and volcanic breccia. They established multi-parameter intersection relationship models for the parameters of resistivity, polarizability, density and magnetic susceptibility, and their relationships with the reservoir parameters, and provided a physical basis and technical support for non-seismic exploration of igneous oil and gas reservoirs in the Sichuan Basin.

In this Special Issue, there are four papers on EM exploration applications. To increase its detection sensitivity to water-bearing structures, Li et al. [13] investigated the feasibility of placing EM sensors along an underground in-seam steel-cased borehole. It was demonstrated that the water-bearing structures can be observed by a magnetic field (with a perpendicular, horizontal electric dipole (HED) source) rather than an electric field (with a parallel HED source). Through the application of the low-frequency end of EM waves, Hinojosa et al. [14] provided an example of a 2D electrical resistivity imaging (ERI) survey at a historic silver mining site in Durango, Mexico. They successfully detected the abandoned and undocumented historic silver mining infrastructure, including mine workings represented by high-resistivity anomalies and unmined mineralization zones.
with low-resistivity anomalies. Xu et al. [15] presented the successful application of the MT sounding method for geothermal exploration in the Shangqiu Uplift of the Southern North China Basin. The detected high-resistivity anomalies formed by the deep-basement uplift demonstrated very good correlation with the high-value areas of the regional geothermal field, which was confirmed through drilling. The last paper in the collection by Wang and Qin [16] focuses on a natural source super low-frequency (SLF) EM method for potential application to the evaluation of coalbed methane (CBM) reservoirs with low resistivities. Their preliminary analysis showed that the SLF method could provide information on the depth resolution of CBM reservoirs in the order of tens of meters, which means that it is potentially one of the most useful and cost-effective options for in-situ CBM exploration.

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