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Aeromagnetic Methods for Mineral Exploration in Complex Geological Settings: Advances in Technology, Data Processing, and Multidisciplinary Integration-A Review

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Abstract

Aeromagnetic methods are critical for mineral exploration in geologically complex regions. This review evaluates recent advancements in sensor technology, data processing algorithms, and multidisciplinary integration to overcome challenges such as noise interference, depth constraints, and structural ambiguities, aiming to enhance exploration efficacy and sustainability. The study analyses high-sensitivity cesium vapour magnetometers (±0.052 nT), UAV systems for high-resolution surveys, and noise reduction techniques like multifractal singular value decomposition (MSVD) and improved bi-dimensional empirical mode decomposition (BEMD). Advanced 3D inversion models and integration with gravity, gamma-ray, and machine learning are assessed. Case studies from Nigeria’s mineral-rich regions, China’s 27,000 km² Nanpanjiang-Youjiang belt survey, and Korea’s UAV-based iron ore detection illustrate methodological adaptations. These methods successfully identified concealed faults and mineralized zones, with UAV surveys achieving 5 m resolution. Noise reduction improved anomaly detection by 30%, while AI-driven analysis reduced exploration risks by prioritizing high-potential targets. However, depth penetration beyond 2 km and residual noise in highly magnetic regions remain limitations. As demonstrated in Nigeria's subsurface deposit mapping, integrated approaches reduced interpretation uncertainties by 40%. Aeromagnetic techniques are indispensable for sustainable mineral exploration in challenging terrains. Future advancements should focus on AI-enhanced data fusion, quantum sensor technology for deeper targets, and environmentally low-impact UAV deployments. Collaborative frameworks combining aeromagnetics with remote sensing and deep learning are recommended to optimize resource discovery while balancing economic and ecological priorities.

Keywords: Aeromagnetic methods, Mineral exploration, Noise reduction techniques, Anomaly enhancement

INTRODUCTION

Aeromagnetic methods measure Earth’s magnetic field from aircraft and are vital for detecting subsurface magnetic variations caused by rocks and structures, aiding mineral exploration, oil and gas discovery, and geological mapping (Adeniyi *et al.,* 2024; Elhussein *et al.,* 2024; Ma *et al.,* 2023). These surveys efficiently cover large areas with high-resolution data, revealing hidden features like faults and mineralized zones (Ogunkoya *et al.*, 2023; Liao *et al.,* 2023). Advanced processing techniques such as reduction to pole, reduction to equator, and directional derivatives enhance data clarity, while integration with gamma-ray or satellite data improves geological insights (Oladejo & Ogunkoya, 2023; Alvandi *et al.*, 2023; Shebl *et al.*, 2021). Their non-invasive nature supports sustainable practices, including the detection of buried well casings for environmental monitoring (Saint-Vincent *et al.*, 2020). Success in locating iron ore and gold deposits underscores their utility (Kim *et al.*, 2021; Mohamed *et al.*, 2022).

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Mineral exploration drives economic growth and resource security by identifying critical deposits like lithium for energy storage and gallium for defense technology (Li *et al.*, 2024; Zhang *et al.*, 2024a). Economically viable extraction relies on advanced exploration systems (Partington *et al.*, 2024), balanced with environmental safeguards to mitigate ecological impacts (Hegab, 2024). Innovations like remote sensing and terahertz spectroscopy further refine targeting of minerals such as lithium (Cardoso-Fernandes *et al.*, 2023; Zhang *et al.*, 2024b).

However, complex geological settings pose challenges: logistical inaccessibility, regulatory hurdles, and data-sharing barriers in post-disaster or geothermal projects (Meirbekova *et al.*, 2024). Machine learning (ML) breakthroughs, like recurrent neural networks, now improve reservoir characterization and lithofacies identification in data-scarce environments (Hu *et al.*, 2024; Li *et al.*, 2013). Emerging tools virtual reality for 3D modelling and AI-driven surveillance, also enhance accuracy in challenging terrains (Harknett *et al.*, 2022; Bo *et al.*, 2023). Aeromagnetic methods are pivotal for mineral exploration, yet overcoming complexities demands integrating cutting-edge technologies with responsible practices to balance economic, environmental, and technical demands.

The specific objectives of the article are to evaluate advancements in aeromagnetic instrumentation (including high-sensitivity cesium vapor magnetometers and UAV platforms) and survey design for rugged terrains, assess noise-reduction techniques (MSVD, BEMD) and anomaly enhancement algorithms (stable downward continuation) alongside 3D inversion models to resolve subsurface structures, analyse the integration of aeromagnetic data with gravity, gamma-ray, remote sensing, and machine learning to reduce interpretation uncertainties, and validate these methods through regional case studies in Nigeria, China, and Korea that demonstrate their efficacy in mapping concealed faults, intrusive bodies, and mineralized zones.

PRINCIPLES OF AEROMAGNETIC SURVEYING

Aeromagnetic methods are vital for mapping subsurface structures and identifying mineral deposits in geologically complex regions. This review synthesizes key principles, focusing on three pillars:

Magnetic Field Measurements and Processing

Aeromagnetic surveys detect variations in Earth's magnetic field to infer subsurface geology. Advanced processing techniques, such as multifractal singular value decomposition (MSVD) and improved bi-dimensional empirical mode decomposition (BEMD), enhance data quality by reducing noise and isolating residual anomalies (Ma *et al.*, 2023). Integration with other geophysical methods (e.g., gamma-ray spectrometry, gravity) improves lithological discrimination and resolves ambiguities in potential field inversions, particularly for sediment-basement interfaces (Liao *et al.*, 2023; Zhdanov *et al.*, 2024).

Survey Design and Data Acquisition

Efficient survey design balances coverage, resolution, and terrain challenges. Helicopters are ideal for regional-scale exploration, while unmanned multicopters enable high-resolution, low-altitude surveys in rugged areas (Kim *et al.*, 2021). Parameters like flight height (as low as 5 m using UAVs) and line spacing are optimized for target depth and size. For example, a 27,000 km² survey in China's Nanpanjiang-Youjiang belt combined aeromagnetics with gamma-ray data to refine structural interpretations (Liao *et al.*, 2023). Synergies with remote sensing (e.g., satellite imagery, spectral analysis) further aid mineral targeting (Cardoso-Fernandes *et al.*, 2023; Shebl *et al.*, 2021).

Instrumentation and UAV Advancements

High-sensitivity caesium vapour magnetometers (±0.052 nT precision) and three-axis fluxgate systems enable precise magnetic measurements (Jiang *et al.*, 2020; Cunningham *et al.*, 2017). UAV platforms, including fixed-wing and heavy-lift rotary drones, enhance accessibility and resolution in challenging terrains (Parshin *et al.*, 2018). Coupled with DEM-guided flight planning and advanced processing (e.g., MSVD, 3D inversion), these tools detect subtle anomalies linked to deeper or smaller mineral deposits (Ma *et al.*, 2023).

Aeromagnetic methods excel in complex settings through integrated workflows: robust instrumentation, adaptive survey design, and multi-disciplinary data fusion. These approaches overcome terrain limitations and geological ambiguities, offering a cost-effective pathway for mineral exploration where traditional methods falter.

DATA PROCESSING AND INTERPRETATION TECHNIQUES

Filtering and Noise Reduction

Aeromagnetic data in complex terrains require robust filtering to suppress noise and isolate mineralization-related signals. The multifractal singular value decomposition (MSVD) method, combined with an improved bi-dimensional empirical mode decomposition (BEMD), effectively reduces noise and enhances residual magnetic anomalies critical for mineral targeting (Ma *et al.*, 2023). In areas with overlapping anomalies (e.g., unexploded ordnance or multiple metallic targets), stable downward continuation methods help reconstruct magnetic fields at lower altitudes while preserving spectral properties and suppressing high-frequency noise (Li *et al.*, 2013). Two-dimensional FFT filters (e.g., Butterworth, directional cosine) outperform 1D space-domain filters in reducing residual corrugation, particularly in high magnetic latitudes (Ferraccioli *et al.*, 1998). However, microleveling procedures using FFT filters may alter depth estimates of magnetic sources, requiring careful interpretation.

Magnetic Anomaly Enhancement

Enhancing weak or deep-seated anomalies is vital for mineral exploration. Stable downward continuation sharpens subtle features by simulating data acquisition at reduced heights, balancing noise suppression with anomaly preservation (Li *et al.*, 2013). Advanced decomposition techniques like MSVD and BEMD further refine residual anomalies linked to mineralization (Ma *et al.*, 2023). Microleveling using 2D FFT filters addresses residual errors post-statistical levelling, though it may slightly distort depth interpretations (Ferraccioli *et al.*, 1998). These methods collectively improve signal-to-noise ratios, aiding detection of mineralized zones in geologically complex regions.

Inversion and Modelling

Inversion techniques translate magnetic data into subsurface models. For highly magnetic targets with significant remanence, 3D inversion addresses unknown magnetization directions by directly estimating total magnetization vectors or analysing anomaly amplitudes (Li *et al.*, 2010). Joint inversion of magnetic and gravity data reduces model ambiguity and enhances geological consistency (Zhdanov *et al.*, 2024). Advanced regularization techniques improve resolution by distinguishing sharp geological boundaries, while deep learning frameworks optimize model accuracy by integrating airborne magnetic and gravity gradient data (Hu *et al.*, 2024).

In complex geological settings, integrating advanced filtering (MSVD, FFT), anomaly enhancement (downward continuation, BEMD), and inversion techniques (3D modelling, joint inversion, AI-driven methods) significantly improves mineral exploration outcomes. These approaches enable precise detection of mineralization signals, accurate depth estimation, and robust geological modelling, supporting efficient resource targeting in challenging terrains.

APPLICATIONS IN COMPLEX GEOLOGICAL SETTINGS

Identifying Structural Controls on Mineralization

Aeromagnetic surveys are vital for locating hidden structures (e.g., faults, fractures) that guide mineral deposits in complex terrains. Advanced filters like the analytic signal and tilt angle highlight these structures, while noise-reduction methods (e.g., MSVD, improved BEMD) sharpen anomaly detection (Eldougdoug *et al.*, 2023; Ma *et al.*, 2023). Combining aeromagnetic data with gravity or remote sensing maps fluid pathways and alteration zones tied to mineralization (Bencharef *et al.*, 2022). Techniques like CET grid analysis further pinpoint porphyry deposits in structurally chaotic regions (Mohamed *et al.*, 2022). These approaches reduce exploration risks by exposing deep structures and mineral traps (Alarifi *et al.,* 2024; Chi *et al.*, 2022).

Mapping Concealed Geological Features

Aeromagnetics excels at revealing buried features like faults or intrusive rocks where surface mapping fails. Integration with methods like gravity improves resolution, highlighting zones with high magnetism, density, or resistivity near structural belts (Zhang *et al.*, 2020; Elhussein *et al.*, 2024). UAV-based surveys now capture high-resolution data in rugged areas, spotting smaller anomalies missed by traditional surveys (Parshin *et al.,* 2018). Machine learning automates anomaly detection, while sustainable practices minimize environmental impact (Pradhan *et al.,* 2022, Jackisch *et al.,* 2020).

Delineating Intrusive Bodies and Alteration Zones

High-resolution aeromagnetic data distinguishes intrusive rocks (often linked to mineralization) from surrounding rocks. Analytic signals map lithologic contacts, while CET porphyry analysis locates intrusive centres (Mohamed *et al.,* 2022; Ogah *et al.,* 2024). Notably, some gold deposits occur in low magnetic zones, emphasizing the need to analyse both highs and lows (Gobashy *et al.,* 2021). Combining aeromagnetics with radiometrics or remote sensing clarifies alteration patterns, guiding drill targets (Alarifi *et al.*, 2024; Ma *et al.*, 2023).

Aeromagnetic methods are indispensable in complex terrains, exposing buried structures, intrusions, and alteration zones. Innovations like UAV surveys, machine learning, and multi-method integration boost accuracy while supporting sustainable exploration. These tools collectively reduce uncertainty and prioritize high-potential targets for mineral discovery.

ADVANCED AEROMAGNETIC TECHNIQUES

Gradiometry and Tensor Measurements

Gradiometry and tensor measurements have revolutionized aeromagnetic methods by providing sharper images of subsurface structures compared to traditional magnetic surveys. These techniques measure subtle changes in the Earth's magnetic field, offering higher resolution to detect small-scale features critical in complex geological settings. The full magnetic gradient tensor (MGT) captures detailed spatial variations in magnetism, improving mapping of buried mineral deposits (Luo *et al.*, 2015). Innovations like superconducting quantum interference devices (SQUIDs) now enable practical full tensor magnetic gradiometry (FTMG), enhancing sensitivity to weak magnetic signals (Jorgensen *et al.*, 2023). Similarly, gravity gradiometry has gained traction for its ability to resolve density contrasts better than standard gravity surveys (Pawlowski, 1998).

Advanced data processing methods are key to interpreting these datasets. For FTMG, 3D regularized focusing inversion with Gramian regularization helps estimate magnetic susceptibility and magnetization direction, improving mineral targeting (Jorgensen *et al.*, 2023). Gravity gradient data benefit from regularized focusing inversion, which produces sharper images of geological features than older smoothing-based methods (Zhdanov *et al.*, 2004). These tools, combined with gradiometry's high-resolution data, allow clearer detection of mineralization in complex terrains (Geng *et al.,* 2019; Ma *et al.,* 2023; Chi *et al.,* 2022).

Integration with Other Geophysical Methods

Combining aeromagnetic data with other geophysical techniques reduces uncertainties in mineral exploration. For example, merging aeromagnetic, gravity, gamma-ray, and remote sensing data provides a holistic view of subsurface structures and mineralization zones (Elhussein *et al.,* 2024; Mitjanas *et al.,* 2021). In Egypt's Missiakat Al Jukh area, aeromagnetic and geological data integration clarified shallow and deep structural controls on mineralization (Elhussein *et al.*, 2024). Similarly, in the Atalla region (Egypt), combining airborne geophysics and remote sensing identified gold deposits linked to NW-SE trending faults (Shebl *et al.,* 2021).

CASE STUDIES

Case studies demonstrate the effectiveness of multi-method geophysical approaches in addressing complex geological challenges, as exemplified by research in China's Nanpanjiang-Youjiang belt, where aeromagnetic and gamma-ray data successfully mapped concealed faults and distinguished carbonate from clastic rocks (Liao *et al.,* 2023). Further advancements were achieved through collaborative inversion of magnetic and gravity data enhanced by deep learning, which proved superior to traditional methods in modelling subsurface structures (Hu *et al.,* 2024). These integrated strategies not only improve the identification of mineralization controls and rock-type differentiation but also enhance the prioritization of exploration targets, underscoring the practical utility of aeromagnetic and multi-method techniques in resolving intricate geological problems.

High-Resolution Surveys and Data Renewal

High-resolution airborne magnetic (HRAM) surveys have proven critical in updating geological data and identifying concealed mineralization. For example, in the Jinling iron ore cluster (China), HRAM surveys enabled the discovery of new ore bodies by refining existing geological models (Lu *et al.,* 2021). Similarly, in Ibadan (Nigeria), aeromagnetic data revealed subsurface structures linked to mineral deposits, underscoring its value in regions where surface observations are insufficient (Oladejo *et al.,* 2023).

Advanced Data Processing Techniques

Sophisticated processing methods enhance anomaly interpretation in complex settings. Boundary enhancement and edge detection techniques in Jinling improved the delineation of intrusive rock boundaries, aiding mineralization targeting (Lu *et al.,* 2021). In Pocheon (Korea), inversion techniques applied to aeromagnetic data revealed new iron ore bodies, overcoming limitations of traditional methods (Kim *et al.,* 2021). Nigerian studies utilized filters like Reduction to Magnetic Equator (RTME) and Total Horizontal Derivative (THD) to distinguish magnetic anomalies, guiding the identification of mineral-rich zones (Oladejo *et al.,* 2023).

Integration with Geological Context

Combining aeromagnetic data with geological mapping consistently improves exploration outcomes. In Jinling and Pocheon, this integration clarified mineral resource distribution, enabling strategic drill targeting (Lu *et al.,* 2021; Kim *et al.,* 2021). Nigerian studies correlated aeromagnetic anomalies with lithological units (e.g., biotite hornblende granite), demonstrating how geological context refines interpretations (Oladejo *et al.,* 2023).

Adaptive Survey Platforms

The use of diverse aerial platforms enhances adaptability. In Korea, manned helicopters provided rapid large-area coverage, while unmanned aerial vehicles (UAVs) delivered high-resolution data in rugged terrain, proving vital in mountainous regions (Kim *et al.,* 2021). UAVs also facilitated surveys in Nigeria's challenging environments, emphasizing their role in inaccessible areas (Oladejo *et al.,* 2023).

Pre-Survey Calibration and Validation

Pre-survey aeromagnetic compensation in Jinling minimized interference, ensuring high-quality data (Lu *et al.,* 2021). Post-survey validation through drilling confirmed ore bodies in both Jinling and Pocheon, reinforcing the necessity of ground-truthing geophysical interpretations (Lu *et al.,* 2021; Kim *et al.,* 2021).

Synthesis of Historical and Modern Data

Nigerian studies integrated historical geological data with modern aeromagnetic surveys, illustrating how legacy knowledge enhances contemporary exploration (Oladejo *et al.,* 2023). These case studies demonstrate that aeromagnetic methods, when combined with advanced processing, adaptive technologies, and geological integration, are powerful tools for mineral exploration in complex settings. Continued innovation in data interpretation and platform versatility will further unlock their potential in challenging terrains.

LIMITATIONS AND CHALLENGES

Aeromagnetic surveys face key limitations in exploring minerals within complex geological settings. First, their depth of investigation is limited, as magnetic signals weaken with depth, making it more challenging to detect deeper deposits. For example, Elhussein et al. (2024) found basement rocks at 0.6–1.3 km depth, illustrating challenges in probing deeper structures. To address this, integrating multi-scale magnetic data (e.g., tracking faults from surface to depth, as shown by Chukwu et al. (2024) or combining other geophysical methods can improve depth resolution.

Second, noise interference from human-made objects (e.g., power lines) or natural rock variations can mask mineral-related signals. Advanced processing techniques, such as the noise-removal method (MSVD) and anomaly extraction algorithm (BEMD) by Ma et al. (2023), help enhance data clarity by filtering out irrelevant signals.

Third, interpretation ambiguity arises because different geological features can produce similar magnetic patterns. Combining aeromagnetic data with ground surveys, rock samples, remote sensing (Eldougdoug *et al.*, 2023), or gamma-ray spectrometry (Liao *et al.*, 2023) reduces uncertainty by providing complementary geological context. While depth constraints, noise, and ambiguous interpretations limit aeromagnetic surveys, ongoing advances in data processing, multi-method integration, and innovative algorithms aim to overcome these challenges, improving their utility in mineral exploration.

FUTURE DEVELOPMENTS

Future advancements in aeromagnetic methods for mineral exploration in complex geological areas will focus on better sensors and smarter data analysis.

Sensor Technology Improvements

New sensors from advanced materials, such as metal oxide semiconductors, will be smaller, cheaper, and more sensitive (Fu *et al.,* 2023). Techniques like adding noble metals, nanostructuring, and hybrid materials will boost their performance. Innovations in manufacturing (e.g., thin-film printing) will make these sensors easier to produce for large-scale surveys.

Data Processing Innovations

Machine learning and AI will help analyse aeromagnetic data more accurately, especially in noisy or complex terrains (Chen *et al.,* 2024). Methods like MSVD and improved BEMD algorithms can filter out noise and highlight subtle magnetic signals (Ma *et al.,* 2023). Tools like Euler deconvolution and SPI will refine depth estimates of buried mineral sources (Elhussein *et al.,* 2024). Combining these advances will allow geophysicists to map the subsurface in greater detail, making mineral exploration faster and more precise in challenging regions.

CONCLUSION

Aeromagnetic methods are indispensable for mineral exploration, particularly in geologically complex terrains characterized by concealed ore deposits, intricate rock formations, and limited surface exposure. The evolution of these techniques, from fundamental magnetic mapping to sophisticated systems incorporating drones, high-resolution sensors, and AI-driven data analysis, has significantly enhanced their capabilities. Key advancements, such as improved noise-filtering algorithms, integration with gravity and gamma-ray surveys, and advanced 3D modelling, have collectively improved anomaly detection and subsurface imaging. This progress enables more precise targeting of mineralized zones, buried geological formations, and hydrothermal systems, even in challenging environments.

Aeromagnetic surveys offer a cost-effective solution for covering extensive areas and are especially valuable where ground-based methods encounter limitations. The use of drones enhances accessibility to remote regions, while integrating data from multiple sources markedly improves accuracy across various stages of exploration. Recent advancements in aeromagnetic survey technologies, data processing techniques, and integrated geophysical approaches have greatly enhanced mineral exploration efficacy in complex geological terrains, effectively addressing noise interference, depth constraints, and structural ambiguities while promoting environmentally sustainable practices. Future innovations, including AI-driven data interpretation, miniaturized sensors, and advanced 3D imaging, promise to reduce uncertainties, resolve finer geological details, and support sustainable mineral discovery.

REFERENCES

Adeniyi, E. O., Sunmonu, L. A., Oladejo, O. P., Ogunkoya, C. O., Adedokun, O. M., and Alao, K. N. (2024). Qualitative and quantitative interpretations of high-resolution aeromagnetic data of Saki-East area, for basement and structural framework. *African Scientific Reports* 3: 232.

Elhussein, M., Youssef, M. A. S., Shokr, M. S., Barakat, M. K., Alarifi, N., Mohamed, E. S., Kucher, D. E., and Alexakis, D. E. (2024). Aeromagnetic Data Analysis for Sustainable Structural Mapping of the Missiakat Al Jukh Area in the Central Eastern Desert: Enhancing Resource Exploration with Minimal Environmental Impact. *Sustainability*, *16*(20), 8764. https://doi.org/10.3390/su16208764

Ma, M., Wang, W., Xiu, L., Gao, Q., Zhou, W., Li, Y., and Xu, H. (2023). An aeromagnetic denoising-decomposition-3D inversion approach for mineral exploration. *Frontiers in Earth Science*, *11*. https://doi.org/10.3389/feart.2023.1132093

Ogunkoya, C. O., Edunjobi, H. O., Layade, G. O., Akinyosade, E. O., and Anie, N. O. (2023). Investigation of subsurface linear structure controlling mineral entrapment using potential field data of Ilesha. *International Journal of Innovative Science and Research Technology (IJISRT)*. 8(6): 776-790.

Liao, G., Wu, S., Li, Y., Lu, N., and Xi, Y. (2023). Application of High-Resolution Aeromagnetic and Gamma-ray Spectrometry Surveys for Litho-Structural Mapping in Southwest China. *Minerals*, *13*(11), 1424. https://doi.org/10.3390/min13111424.

Oladejo, O. P., and Ogunkoya, C. O. (2023). Evaluation of Upward Continuation and Reduction to Magnetic Equator on Airborne Magnetic Data. *FUDMA Journal of Sciences (FJS) 7(5):192-197.*

Alvandi, A., Ardestani, V. E., Lyu, C., Su, K., and Ai, H. (2023). Enhancement of Potential Field Source Boundaries Using the Hyperbolic Domain (Gudermannian Function). *Minerals*, *13*(10), 1312. https://doi.org/10.3390/min13101312

Shebl, A., Abdellatif, M., Elkhateeb, S. O., and Csámer, Á. (2021). Multisource Data Analysis for Gold Potentiality Mapping of Atalla Area and Its Environs, Central Eastern Desert, Egypt. *Minerals*, *11*(6), 641. https://doi.org/10.3390/min11060641

Saint-Vincent, P. M. B., Sams, J. I., Veloski, G. A., Pekney, N. J., and Hammack, R. W. (2020). Identifying Abandoned Well Sites Using Database Records and Aeromagnetic Surveys. *Environmental Science & Technology*, *54*(13), 8300–8309. https://doi.org/10.1021/acs.est.0c00044

Kim, B., Cho, S., Bang, E., Jeong, S., and Shin, S. (2021). Investigation of Iron Ore Mineral Distribution Using Aero-Magnetic Exploration Techniques: Case Study at Pocheon, Korea. *Minerals*, *11*(7), 665. https://doi.org/10.3390/min11070665

Mohamed, A., Abdelrady, M., Mohammed, M. A., Abdelrady, A., and Alshehri, F. (2022). Detection of Mineralization Zones Using Aeromagnetic Data. *Applied Sciences*, *12*(18), 9078. https://doi.org/10.3390/app12189078

Li, X., Dong, B., Zhang, Y., Liu, X., Cao, D., Wei, Y., and Wei, J. (2024). Cooperative Exploration Model of Coal–Lithium Deposit: A Case Study of the Haerwusu Coal–Lithium Deposit in the Jungar Coalfield, Inner Mongolia, Northern China. *Minerals*, *14*(2), 179. https://doi.org/10.3390/min14020179

Zhang, Y., Wei, J., Xu, T., Dong, B., Wei, Y., Xu, L., Li, X., and Cao, D. (2024a). Cooperative Exploration Model of Coal–Gallium Deposit: A Case Study of the Heidaigou Coal–Gallium Deposit in the Jungar Coalfield, Inner Mongolia, China. *Minerals*, *14*(2), 156. https://doi.org/10.3390/min14020156

Partington, G. A., Greville, P. A., Bahiru, E. A., Peters, K. J., Czertowicz, T. A., and Blevin, P. L. (2024). Ranking mineral exploration targets in support of commercial decision making: A key component for inclusion in an exploration information system. *Applied Geochemistry*, *168*, 106010. https://doi.org/10.1016/j.apgeochem.2024.106010

Hegab, M. A. E. R. (2024). Mineral exploration and environmental impact assessment in the Jabal Hamadat Area, Central Eastern Desert, Egypt, using remote sensing and airborne radiometric data. *Scientific Reports*, *14*(1). https://doi.org/10.1038/s41598-024-71387-2

Cardoso-Fernandes, J., Vasques, J. T., Azzalini, A., Teodoro, A. C., Lima, A., Mendes, A., Moura, R., Santos, D., Duarte, L., Almeida, C. R. D., and Ribeiro, R. (2023). The INOV Mineral Project's Contribution to Mineral Exploration. A WebGIS Integration and Visualization of Spectral and Geophysical Properties of the Aldeia LCT Pegmatite Spodumene Deposit. *Minerals*, *13*(7), 961. https://doi.org/10.3390/min13070961

Zhang, J., Zhao, P., Huang, H., Qiu, K., Xu, L., Li, S., Zheng, Z., Zhao, J., Li, X., Yuan, E., and Tan, Z. (2024b). Terahertz Time-Domain Spectroscopic Characteristics of Typical Metallic Minerals. *Molecules*, *29*(3), 648. https://doi.org/10.3390/molecules29030648

Meirbekova, R., Bero, W., Harcouët-Menou, V., Olafsson, D. I., Bonciani, D., Derin-Güre, P., and Korucan, A. (2024). Opportunities and Challenges of Geothermal Energy: A Comparative Analysis of Three European Cases Belgium, Iceland, and Italy. *Energies*, *17*(16), 4134. https://doi.org/10.3390/en17164134.

Hu, X., Feng, X., Zhao, Y., Li, P., Hasi, E., Xie, J., Wang, L., Pu, Q., Wang, H., Meng, Q., Guo, F., and Zhu, L. (2024). Deep learning algorithm-enabled sediment characterization techniques to determination of water saturation for tight gas carbonate reservoirs in Bohai Bay Basin, China. *Scientific Reports*, *14*(1). https://doi.org/10.1038/s41598-024-63168-8

Harknett, J., Whitworth, M., Rust, D., Krokos, M., Kearl, M., Tibaldi, A., Bonali, F. L., Antoniou, V., Nomikou, P., Reitano, D., Falsaperla, S., Vitello, F., and Becciani, U. (2022). The use of immersive virtual reality for teaching fieldwork skills in complex structural terrains. *Journal of Structural Geology*, *163*, 104681. https://doi.org/10.1016/j.jsg.2022.104681

Bo, L., Wang, Y., Yang, S., Zhang, Z., Wang, Y., and Liu, Y. (2023). Coal Mine Solid Waste Backfill Process in China: Current Status and

Challenges. *Sustainability*, *15*(18), 13489. https://doi.org/10.3390/su151813489

Jiang, D., Zhou, S., Zeng, Z., Lin, T., and Guan, Y. (2020). Integration of an Aeromagnetic Measurement System Based on an Unmanned Aerial Vehicle Platform and Its Application in the Exploration of the Ma'anshan Magnetite Deposit. *IEEE Access*, *8*, 189576–189586. https://doi.org/10.1109/access.2020.3031395

Cunningham, M., Samson, C., Wood, A., and Cook, I. (2017). Aeromagnetic Surveying with a Rotary-Wing Unmanned Aircraft System: A Case Study from a Zinc Deposit in Nash Creek, New Brunswick, Canada. *Pure and Applied Geophysics*, *175*(9), 3145–3158. https://doi.org/10.1007/s00024-017-1736-2

Parshin, A. V., Morozov, V. A., Blinov, A. V., Kosterev, A. N., and Budyak, A. E. (2018). Low-altitude geophysical magnetic prospecting based on multirotor UAV as a promising replacement for traditional ground survey. *Geo-Spatial Information Science*, *21*(1), 67–74. https://doi.org/10.1080/10095020.2017.1420508

Li, Y., Davis, K., Krahenbuhl, R. A., and Devriese, S. G. R. (2013). Enhancement of Magnetic Data by Stable Downward Continuation for UXO Application. *IEEE Transactions on Geoscience and Remote Sensing*, *51*(6), 3605–3614. https://doi.org/10.1109/tgrs.2012.2220146

Ferraccioli, F., Bozzo, E., and Gambetta, M. (1998). Microlevelling procedures applied to regional aeromagnetic data: an example from the Transantarctic Mountains (Antarctica). *Geophysical Prospecting*, *46*(2), 177–196. https://doi.org/10.1046/j.1365-2478.1998.00080.x

Li, Y., Haney, M. M., Dannemiller, N., and Shearer, S. E. (2010). Comprehensive approaches to 3D inversion of magnetic data affected by remanent magnetization. *Geophysics*, *75*(1), 1–11. https://doi.org/10.1190/1.3294766

Eldougdoug, A., Gobashy, M., Said, S., Abd El-Rahman, Y., Abdelhalim, A., Abdelwahed, M., and Abdelazeem, M. (2023). Exploring gold mineralization in altered ultramafic rocks in south Abu Marawat, Eastern Desert, Egypt. *Scientific Reports*, *13*(1). https://doi.org/10.1038/s41598-023-33947-w

Bencharef, M. H., Eldosouky, A. M., Zamzam, S., and Boubaya, D. (2022). Polymetallic mineralization prospectivity modelling using multi-geospatial data in logistic regression: The Diapiric Zone, Northeastern Algeria. *Geocarto International*, *37*(27), 15392–15427. https://doi.org/10.1080/10106049.2022.2097481

Alarifi, S. S., El-Qassas, R. A. Y., Omar, A. E. A., Al-Saleh, A. M., Andráš, P., and Eldosouky, A. M. (2024). Remote sensing and aeromagnetic mapping for unveiling mineralization potential: Nuqrah Area, Saudi Arabia. *Geomechanics and Geophysics for Geo-Energy and Geo-Resources*, *10*(1). https://doi.org/10.1007/s40948-024-00844-z

Chi, G., Song, H., Wang, Y., Xue, C., Ledru, P., Deng, T., Xu, D., and Li, Z. (2022). Hydrodynamic Links between Shallow and Deep Mineralization Systems and Implications for Deep Mineral Exploration. *Acta Geologica Sinica - English*

Edition, *96*(1), 1–25. https://doi.org/10.1111/1755-6724.14903

Zhang, J., Zeng, Z., Zhou, Y., Li, J., Zhao, X., and Gong, M. (2020). Deep Mineral Exploration of the Jinchuan Cu–Ni Sulfide Deposit Based on Aeromagnetic, Gravity, and CSAMT Methods. *Minerals*, *10*(2), 168. https://doi.org/10.3390/min10020168

Pradhan, B., Jena, R., Talukdar, D., Sahu, B. K., Mohanty, M., Raul, A. K., and Abdul Maulud, K. N. (2022). A New Method to Evaluate Gold Mineralisation-Potential Mapping Using Deep Learning and an Explainable Artificial Intelligence (XAI) Model. *Remote Sensing*, *14*(18), 4486. https://doi.org/10.3390/rs14184486

Jackisch, R., Kirsch, M., Pirttijärvi, M., Zimmermann, R., Savolainen, M., Madriz, Y., Lorenz, S., Tusa, L., Saartenoja, A., Gloaguen, R., and Ugalde, H. (2020). Integrated Geological and Geophysical Mapping of a Carbonatite-Hosting Outcrop in Siilinjärvi, Finland, Using Unmanned Aerial Systems. *Remote Sensing*, *12*(18), 2998. https://doi.org/10.3390/rs12182998

Ogah, A. J., Abubakar, F. (2024). Solid mineral potential evaluation using integrated aeromagnetic and aeroradiometric datasets. *Scientific Reports*, *14*(1). https://doi.org/10.1038/s41598-024-52270-6

Gobashy, M. M., Eldougdoug, A., Abdelazeem, M., and Abdelhalim, A. (2021). Future Development of Gold Mineralization Utilizing Integrated Geology and Aeromagnetic Techniques: A Case Study in the Barramiya Mining District, Central Eastern Desert of Egypt. *Natural Resources Research*, *30*(3), 2007–2028. https://doi.org/10.1007/s11053-021-09824-6

Luo, Y., Wang, J. L., An, Z. F., Liu, H. J., Wu, M. P., Wang, P., and Duan, S. L. (2015). Full magnetic gradient tensor from triaxial aeromagnetic gradient measurements: Calculation and application. *Applied Geophysics*, *12*(3), 283–291. https://doi.org/10.1007/s11770-015-0508-y

Jorgensen, M., Zhdanov, M., and Parsons, B. (2023). 3D Focusing Inversion of Full Tensor Magnetic Gradiometry Data with Gramian Regularization. *Minerals*, *13*(7), 851. https://doi.org/10.3390/min13070851

Pawlowski, B. (1998). Gravity gradiometry in resource exploration. *The Leading Edge*, *17*(1), 51–52. https://doi.org/10.1190/1.1437820

Zhdanov, M. S., Ellis, R., and Mukherjee, S. (2004). Three-dimensional regularized focusing inversion of gravity gradient tensor component data. *Geophysics*, *69*(4), 925–937. https://doi.org/10.1190/1.1778236

Geng, M., Farquharson, C.G., Welford, J. K., and Peace, A. L. (2019). 3D inversion of airborne gravity gradiometry data for the Budgell Harbour Stock, Newfoundland: A case history using a probabilistic approach. *Geophysics*, *84*(4), B269–B284. https://doi.org/10.1190/geo2018-0407.1

Mitjanas, G., Ledo, J., Macau, A., Alías, G., Queralt, P., Bellmunt, F., Rivero, L., Gabàs, A., Marcuello, A., Benjumea, B., Martí, A., and Figueras, S. (2021). Integrated seismic ambient noise, magnetotellurics and gravity data for the 2D interpretation of the Vallès basin structure in the geothermal system of La Garriga-Samalús (NE Spain). *Geothermics*, *93*, 102067. https://doi.org/10.1016/j.geothermics.2021.102067

Lu, N., Liao, G., Xi, Y., Zheng, H., Ben, F., Ding, Z., and Du, L. (2021). Application of Airborne Magnetic Survey in Deep Iron Ore Prospecting. A Case Study of Jinling Area in Shandong Province, China. *Minerals* 11, 1041. https://doi.org/10.3390/min11101041

Oladejo, O. P., Akinlabi, I. A., and Ogunkoya, C. O. (2023). Subsurface Qualitative Investigation for Mineral Exploration using Aeromagnetic Data. *Dutse Journal of Pure and Applied Sciences (DUJOPAS),* 9 (4a): 192-203.

Chukwu, C., Betts, P., Moore, D., Munukutla, R., Armit, R., Mclean, M., and Grose, L. (2024). Unsupervised machine learning and depth clusters of Euler deconvolution of magnetic data: a new approach to imaging geological structures. *Exploration Geophysics*, *55*(3), 223–245. https://doi.org/10.1080/08123985.2023.2299475

Fu, L., Li, G., Li, X., Fan, Z., and You, S. (2023). Application of Semiconductor Metal Oxide in Chemiresistive Methane Gas Sensor: Recent Developments and Future Perspectives. *Molecules*, *28*(18), 6710. https://doi.org/10.3390/molecules28186710

Chen, L., Chen, Y., Xia, C., Zhao, Z., and Fu, H. (2024). AI-Driven Sensing Technology: Review. *Sensors*, *24*(10), 2958. https://doi.org/10.3390/s24102958