

Exploration of Modern Geological and Mineral Prospecting Methods under the Background of Big Data

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Abstract: In the context of the big data era, geological and mineral exploration and prospecting are encountering new opportunities and challenges. Characterized by massive volume, high variety, and rapid velocity, big data provides abundant information resources for geological and mineral exploration. Modern geological and mineral exploration workflows include regional geological surveys, geophysical and geochemical exploration, and drilling verification. Integrating big data into these processes is essential for improving prospecting efficiency and accuracy. This paper focuses on core big data-driven prospecting methods, including multi-source data integration, the construction of analytical and predictive models, and the development of intelligent decision-support systems. Meanwhile, challenges in the application of big data—such as data security and privacy issues, uneven data quality, and shortages of skilled professionals—are analyzed. Corresponding countermeasures are proposed, including improving data-sharing mechanisms, strengthening technological research and development, enhancing talent cultivation, and introducing supportive policies, in order to promote the development of geological and mineral exploration and prospecting.

Keywords: Big data; geological and mineral exploration; prospecting methods; information integration

Introduction

Geological and mineral exploration and prospecting are of great significance to national resource security and economic development. Traditional prospecting methods rely on limited geological data and experience, resulting in low efficiency and insufficient accuracy. With the rise of big data technologies, their capabilities in massive data processing and analysis have brought new perspectives to geological and mineral exploration. Big data enables

the integration of multi-source geological information, the mining of potential prospecting patterns, and the improvement of prospecting success rates. Studying modern geological and mineral exploration and prospecting methods in the context of big data helps overcome the limitations of traditional approaches, realize intelligent and precise prospecting, meet the growing national demand for mineral resources, promote the transformation and upgrading of the geological exploration industry, and provide technical



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support for the sustainable utilization of resources.

1. Big Data and Fundamental Theories of Geological and Mineral Exploration

1.1 Concept and Characteristics of Big Data

Big data refers to datasets that cannot be captured, managed, or processed by conventional software tools within a certain time frame. It is characterized by large volume, meaning massive data scale; variety, encompassing structured, semi-structured, and unstructured data; high velocity, indicating rapid data generation and processing; value, where individual data points have low value density but collectively contain enormous potential value; and veracity, ensuring data authenticity and reliability. In geological and mineral exploration, big data enables the integration of multi-source data such as geological, geophysical, and geochemical information, mining correlations among datasets and providing comprehensive informational support for mineral prospecting. This helps identify potential mineral resources, transforms traditional prospecting models, and improves exploration efficiency and accuracy.

1.2 Basic Process of Geological and Mineral Exploration

Geological and mineral exploration is a systematic process of searching for and evaluating mineral resources. First, regional geological surveys are conducted to understand basic geological conditions such as regional geological structures and stratigraphic lithology, thereby delineating favorable prospecting areas. Next, geophysical exploration is carried out, using physical methods to detect differences in the physical properties of subsurface geological bodies and to infer the occurrence and distribution of mineral resources. Subsequently, geochemical exploration is implemented by analyzing the elemental content and distribution in media such as soil, rocks, and stream sediments to identify geochemical anomaly zones. After further investigation of these anomaly areas, drilling engineering is conducted to obtain subsurface physical samples and verify prospecting predictions. Finally, various types of data are comprehensively analyzed to evaluate mineral resource potential and determine mineral reserves and development value, providing a basis for subsequent development and utilization^[1].

1.3 Necessity of Integrating Big Data into Geological and Mineral Exploration

Traditional geological and mineral exploration relies on limited data and experience, which constrains prospecting efficiency and accuracy. The integration of big data can bring about transformations in multiple aspects. The integration of massive datasets enables a more comprehensive representation of geological characteristics, mining potential prospecting information and avoiding information omissions. Big data analysis can reveal hidden patterns within complex geological datasets, facilitating the construction of accurate prospecting prediction models and improving prospecting success rates. Intelligent decision-support systems based on big data enable real-time data analysis and provide decision-making recommendations, assisting exploration personnel in making scientific decisions. In addition, big data promotes the sharing and exchange of exploration data, fostering collaborative development within the industry. Integrating big data is an inevitable choice for geological and mineral exploration to adapt to contemporary development trends and enhance competitiveness, and it is of great significance for safeguarding national resource security.

2. Core Methods of Big Data–Driven Modern Geological and Mineral Prospecting

2.1 Multi-Source Data Integration and Feature Extraction Methods

Multi-source data integration is the process of integrating heterogeneous data from multiple sources, including geological, geophysical, geochemical, and remote sensing data. Through techniques such as data cleaning, transformation, and integration, data discrepancies and redundancies are eliminated to form a unified dataset. Feature extraction aims to mine key prospecting information from the integrated data, such as stratigraphic lithology and structural characteristics from geological data, physical property parameters from geophysical data, and elemental anomalies from geochemical data. Methods such as principal component analysis and factor analysis are used to reduce data dimensionality and extract dominant features. Combined with machine learning algorithms, such as support vector machines and neural networks, relevant feature patterns associated with mineral

prospecting can be automatically identified. This provides an accurate data foundation for subsequent prospecting prediction, improving the efficiency and accuracy of prospecting information utilization.

2.2 Big Data Analysis and Construction of Prospecting Prediction Models

Big data analysis employs statistical methods, data mining, and machine learning techniques to uncover prospecting patterns within multi-source datasets. Association analysis is used to identify relationships between different geological factors and mineral distribution, cluster analysis is applied to delineate favorable prospecting zones, and classification analysis is conducted to predict mineral types in unexplored areas. The construction of prospecting prediction models is based on the results of big data analysis in combination with geological theories. Common models include traditional approaches such as logistic regression, decision trees, and random forests, as well as deep learning models. Geological, geophysical, and geochemical data are used as inputs, while mineral occurrence or mineral type serves as the output to train the models^[2]. By continuously optimizing model parameters, prediction accuracy is improved. After model construction, new data are used for validation and updating to ensure adaptability to changing geological conditions, providing reliable predictive support for mineral prospecting.

2.3 Construction of Intelligent Prospecting Decision Support Systems

Intelligent prospecting decision support systems integrate multi-source data, analytical models, and decision rules to provide scientific decision-making recommendations for exploration personnel. The system architecture consists of a data layer, model layer, decision layer, and user layer. The data layer is responsible for storing and managing multi-source geological data; the model layer integrates various prospecting prediction models; the decision layer generates decision recommendations based on model outputs and predefined rules; and the user layer provides an interactive interface for exploration personnel. System functions include data querying, analysis, prediction, and decision-making. When exploration personnel input information about a target exploration area, the system automatically

invokes relevant data and models to perform analysis and prediction, offering recommendations such as prospecting targets and exploration schemes. In addition, the system includes visualization functions to intuitively present data and results. Intelligent prospecting decision support systems enhance the scientific rigor and efficiency of exploration decision-making while reducing decision-related risks.

3. Application Challenges and Countermeasures of Big Data in Geological and Mineral Prospecting

3.1 Major Application Challenges

3.1.1 Data Security and Privacy Issues

Geological and mineral exploration data contain sensitive information such as national resource data and corporate commercial secrets. In a big data environment, data storage and transmission face numerous security risks. Data storage systems may be subject to cyberattacks, leading to data leakage and thereby harming national interests and corporate competitiveness. During data transmission, if effective encryption measures are not adopted, data can be easily intercepted or tampered with. In addition, data sharing and openness increase the difficulty of privacy protection. When data are shared among different departments and institutions, inadequate privacy protection mechanisms may result in the leakage of personal and corporate confidential information. Data security and privacy issues constrain the widespread application of big data in geological and mineral prospecting, making it necessary to strengthen research and application of security protection and privacy-preserving technologies.

3.1.2 Uneven Data Quality

Geological and mineral exploration data originate from diverse sources, including geological surveys, geophysical exploration, geochemical exploration, and drilling, resulting in significant differences in data formats, precision, and reliability. Data collected at different exploration stages and by different organizations vary in quality, and some datasets contain errors, missing values, or inconsistencies. During data acquisition, factors such as instrument precision and operational standards affect data quality; during data processing, inappropriate algorithm selection or

parameter settings can also lead to data distortion. Low-quality data adversely affect the accuracy of big data analysis results and reduce the reliability of prospecting predictions. Improving data quality requires strict control at the data acquisition stage, standardized operational procedures, enhanced research on data processing algorithms, and the establishment of data quality evaluation and monitoring systems.

3.1.3 Shortage of Professional Talent

The application of big data in geological and mineral prospecting requires interdisciplinary professionals who possess both geological and mineral exploration expertise and proficiency in big data technologies. At present, the talent structure in the geological exploration industry is relatively homogeneous. Most professionals focus on traditional geological exploration and have limited understanding of big data technologies, while big data specialists often lack professional knowledge of geological and mineral exploration, making it difficult to effectively apply big data techniques to prospecting practices. The shortage of interdisciplinary talent restricts the promotion and application of big data technologies in geological and mineral exploration. Cultivating such talent requires strengthening relevant academic programs in higher education institutions, optimizing curriculum design, and implementing interdisciplinary training. Enterprises should enhance internal training, encourage employees to acquire cross-disciplinary knowledge, and introduce high-level interdisciplinary professionals to improve the overall technical capacity of their teams^[3].

3.2 Countermeasures and Recommendations

3.2.1 Improving Geological Exploration Data Sharing Mechanisms and Standardization Systems

A unified geological exploration data-sharing platform should be established to break down data barriers among departments and institutions and promote data circulation and sharing. The scope, access permissions, and responsibilities of data sharing should be clearly defined to ensure data security and privacy protection. A standardized system for geological exploration data should be developed to unify data formats, coding rules, and quality standards, thereby enhancing data compatibility and interoperability. Data quality review and supervision should be strengthened to ensure the reliability of shared data. By improving data-sharing

mechanisms and standardization systems, geological exploration data resources can be effectively integrated, providing abundant and high-quality data support for big data applications and promoting the coordinated development of geological and mineral prospecting activities.

3.2.2 Strengthening Core Technology R&D and Algorithm Innovation and Promoting Industry–University–Research Integration

The application of big data in geological and mineral prospecting relies heavily on the support of core technologies. However, significant bottlenecks still exist in key areas such as big data processing, analysis, and mining, which restrict deeper application in the prospecting field. Research institutions possess specialized scientific personnel and advanced experimental facilities, while enterprises have extensive practical experience and market demand insights. By leveraging their complementary advantages, both parties can jointly overcome critical technological challenges. It is essential to develop innovative data analysis algorithms tailored to the characteristics of geological and mineral exploration and to create specialized algorithms suitable for prospecting prediction. Deep integration of industry, universities, and research institutions should be promoted: universities and research institutes should capitalize on their talent and technological strengths to conduct fundamental research and frontier technology exploration, providing theoretical support for industry development; enterprises should offer practical application scenarios and financial support to accelerate the transformation and application of research outcomes. Through collaborative innovation among industry, academia, and research sectors, the application level of big data in geological and mineral prospecting can be enhanced, driving continuous technological progress in the industry.

3.2.3 Intensifying Talent Cultivation and Building Interdisciplinary Exploration Technology Teams

The application of big data in geological and mineral prospecting requires interdisciplinary professionals who are proficient in both geological and mineral exploration and big data technologies; however, such talent is currently in short supply. As the primary institutions for talent cultivation, universities

should optimize the structure of geology, mineral exploration, and big data-related programs by offering interdisciplinary courses that integrate geology, mineral exploration, big data technologies, and artificial intelligence, thereby developing students' comprehensive knowledge systems. Practical teaching should be strengthened through cooperation with enterprises to establish internship bases, enabling students to enhance their practical skills and problem-solving abilities through real-world projects. Enterprises should also formulate talent development plans, conduct internal training and continuing education programs, provide employees with opportunities to learn cross-disciplinary knowledge, and encourage participation in training courses and academic exchanges to improve overall professional competence. In addition, the active recruitment of high-level big data professionals should be encouraged to strengthen exploration technology teams with advanced technologies and innovative concepts^[4]. Through a combination of university education, enterprise-based training, and talent recruitment, an interdisciplinary exploration technology team can be established to meet the application demands of big data in geological and mineral prospecting and to provide solid human resource support for industry development.

3.2.4 Introducing Supportive Policies to Reduce Technology Promotion Costs

The application of big data technologies in geological and mineral prospecting is still at a developmental stage, and high promotion costs have limited their widespread adoption. Relevant authorities should introduce supportive policies to provide strong backing for enterprises and research institutions. Financial support should be granted to big data application projects in geological and mineral prospecting by establishing special funds to encourage enterprises to develop demonstration projects, using these projects as models to promote technology dissemination and application. Preferential tax policies should be implemented to reduce corporate burdens and lower the costs of technological research, development, and promotion. Technical promotion service platforms should be established to integrate industry technological resources and provide enterprises with services such as technical consulting and training, thereby fostering technical exchange and cooperation among enterprises.

In addition, evaluation and reward mechanisms for big data application achievements should be strengthened by establishing dedicated awards to recognize and reward enterprises and research institutions that achieve outstanding results in big data applications, stimulating enthusiasm and creativity. Through policy support, a favorable development environment can be created to accelerate the promotion and application of big data technologies in geological and mineral prospecting and to enhance the overall competitiveness of the industry.

Conclusion

Big data has brought new opportunities and transformations to geological and mineral exploration and prospecting. Through multi-source data integration, the construction of analytical and predictive models, and the development of intelligent decision-support systems, prospecting efficiency and accuracy have been significantly improved. In the future, with the continuous development and refinement of big data technologies, their application in geological and mineral exploration and prospecting will become more in-depth and widespread. Ongoing innovation and exploration, together with the full utilization of the advantages of big data, will promote the geological exploration industry toward greater intelligence and precision, providing solid support for national resource security and economic development.

References

- [1] Song Zhicheng, Kou Zhaojun, Zhang Dongrui, et al. Discussion on Modern Geological and Mineral Exploration and Prospecting Methods under Big Data [J]. *China Science and Technology Panorama*, 2025(10):124–126.
- [2] Liu Wei, Jiang Kai. Discussion on Modern Geological and Mineral Exploration and Prospecting Strategies from a Big Data Perspective [J]. *China Metal Bulletin*, 2025(4):76–78.
- [3] Yang Guangxiang. Reflections on Modern Geological and Mineral Exploration and Prospecting Methods under the Background of Big Data [J]. *China Metal Bulletin*, 2023(22):44–46.
- [4] Ouyang Bin. Reflections on Modern Geological and Mineral Exploration and Prospecting Methods under the Background of Big Data [J]. *China Metal Bulletin*, 2021(10):98–99.