

Review Article

Research on the Achievements and Development Strategies in the Construction of National Mineral Rock and Fossil Specimen Resource Center, China

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Abstract

Scientific and technological resources constitute the indispensable material foundation for a country's scientific and technological innovation and serve as the fundamental safeguard for achieving progress in this field. China has set up a national platform for sharing scientific and technological resources, with a focus on the collection, preservation, and utilization of such resources. This paper summarizes the achievements of the National Science and Technology Resource Sharing Service Platform—National Mineral Rock and Fossil Specimen Resource Center (NMRFC). These achievements span various aspects, including the construction of a specimen resource sharing platform within China's geoscience field, the collection, organization, preservation, and digitization of specimen resources, the establishment of a standardized system, technological innovations, science and technology-enabled sharing services, talent development, international cooperation, and science popularization. Additionally, this paper analyzes the challenges confronting the repository: the quantity of preserved geological specimen resources in China is notably smaller compared to those in Europe and America, and there are substantial discrepancies in the number of specimens held by domestic preservation institutions. Furthermore, it explores future development strategies, suggesting the promotion of the repository's upgrade and the construction of a full-chain science and technology resource sharing service system. This can be achieved by collecting global resources, establishing a multifunctional repository in the Xiong'an New Area, enhancing management and operational capabilities, integrating artificial intelligence technologies, and advancing an international development strategy. These efforts will collectively provide fundamental support for scientific research and technological innovation.

Keywords

Geological Specimen Resource, Mineral Rock and Fossil, National Resource Center, Resource Sharing, Platform Management, Development Strategies, Support for Innovation

1. Introduction

Mineral rock and fossil specimen resources constitute a critical component of scientific and technological resources. These resources encompass physical samples of minerals,

rocks (cores), ores, and fossils, along with their associated metadata. Geological scientists collect, compile, organize, study, test, and preserve these materials during regional geo-

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logical surveys, mineral resource exploration, and Earth science research. Serving as the most direct evidence for advanced Earth science studies, these resources are characterized by their fundamental importance, strategic significance, public benefit, long-term sustainability, and both cumulative and incremental value [1].

To address the challenges of scattered preservation, severe loss, inefficient sharing and utilization, and the substantial gap in geological specimen resources compared to international standards, China has taken proactive measures. Since 1999, with funding and support from the Ministry of Science and Technology (MOST), the Ministry of Education, and other relevant departments, China University of Geosciences (Beijing) has spearheaded a consortium of 49 key specimen preservation institutions across the country. This collaboration established China’s largest earth science specimen resource-sharing platform. In June 2019, the platform received formal accreditation from MOST and the Ministry of Finance as the National Science and Technology Resource Sharing Service Platform—National Mineral Rock and Fossil Specimen Resource Center (NMRFC). The timeline of NMRFC milestones is presented in Table 1. The NMRFC forms an integral component of the National Science and Technology Resource Sharing Service Platform system, which integrates

multiple specialized resource centers. The National Biological Germplasm Resource Center (covering animals, plants, and microorganisms), National Human Genetic Resource Center (encompassing health and disease, stem cells, and human brain tissues), National Specimen Resource Center (including plants, animals, fungi, and rock-mineral-fossil specimens), and National Experimental Material Resource Center (providing experimental animals, experimental cells, reference materials, and research reagents) [2-4].

Since 2019, the NMRFC has accelerated the construction of the national resource repository, significantly enhancing both the development quality and shared services capacity. Remarkable achievements have been made in the development of specimen resource infrastructure, encompassing collection (submission), systematization, digitization processes, thematic database construction, and standardization systems, while concurrently enhancing shared services capabilities. The database has provided over 384,300 specimen resources and has integrated and published more than 300 geoscience thematic datasets spanning 10 major categories. These resources offer crucial support for national strategic initiatives, technological innovation, talent development, and public science education [5]. It has established China’s foremost platform for sharing rock, mineral, and fossil specimen resources.

Table 1. Timeline of NMRFC Milestones (1999–2025).

Years	Development Phase	Number of Members
1999-2002	Northern Rock and Mineral Fossil Specimen Repository: Establishment of the Physical Repository and Basic Framework of the Database	4
2003-2010	National Platform for Sharing Rock, Mineral and Fossil Specimen Resources: Achieving the standardization and normalization of specimen resources.	7
2011-2018	National Infrastructure of Mineral Rock and Fossil Resources for Science and Technology: Achieving Incremental Development of Specimen Resources	22
Since 2019	National Mineral Rock and Fossil Specimen Resource Center (NMRFC): Approved as a national science and technology innovation base, a national science and technology resource sharing service platform, achieving large-scale and effective sharing of specimen resources.	50

2. Achievements in the Construction of the National Rock, Mineral and Fossil Specimen Resource Database

2.1. Establishment of the Largest Rock, Mineral and Fossil Specimen Resource Sharing Platform in China's Geoscience Field

The NMRFC has established a bilingual information service platform, accessible via its portal website

(<http://www.nimrf.net.cn>). This platform is integrated into China’s Science and Technology Resource Sharing Platform and provides open access to 384,300 specimen resources [5]. It systematically organizes and disseminates more than 300 geoscience datasets across 10 thematic categories, including 171 datasets of typical mineral deposits in China, 45 databases of palaeontological fossil assemblages in China, 14 databases covering "Golden Spikes" and geological sections in China. The platform also features a systematic mineralogy database containing 4,101 species [6], alongside 39 datasets on gemstones and jade, a health geology - traditional Chinese medicine mineral database [7], while digital resources comprise 3D model database of type fossils and typical fossil

specimens, and a premium image library. The platform receives millions of annual visits and has achieved a data download volume of 900GB. It has become the largest specimen resources sharing platform in the field of geoscience in China.

The platform has demonstrated sustained user engagement, with annual sessions exceeding one million. Cumulative data transfers have reached 900GB. These metrics collectively establish the platform as China's leading infrastructure for geoscience specimen sharing and interdisciplinary research collaboration.

2.2. Rapid Increase in the Quantity and Quality of Specimen Resource Collection, Organization, Preservation and Digitization

The NMRFC has significantly advanced the large-scale organization and digitization of geological specimen resources in China. It integrates rock and fossil collections from 50 institutions, including China University of Geosciences (Beijing), the Geological Museum of China, the Nanjing Institute of Geology and Palaeontology of the Chinese Academy of Sciences, Jilin University, and Peking University, with a total of 384,372 digitized specimens [1]. The NMRFC's resources originate from 120 countries and 34 provincial administrative regions in China, including 171,378 type fossils and typical fossil assemblages of scientific significance. The collection also consolidates 127,458 rock and meteorite specimens from key geological structural regions and representative geological sections, both domestically and internationally. Additional resources comprise 42,451 mineral specimens, including newly discovered minerals from China, typical Chinese minerals, and foreign mineral specimens. Furthermore, the NMRFC holds 43,085 specimens from China's super-large and large-scale deposits, strategic mineral resources, and representative foreign deposits.

The NMRFC has launched an initiative to integrate geoscience specimen resources from national scientific and technological projects. This effort has consolidated over 50,000 specimens sourced from more than 300 government-funded scientific initiatives. These resources have undergone standardized organization and digitization processes. Furthermore, a significant number of rare specimens at risk of being lost have been successfully preserved.

2.3. Establishment of a Comprehensive Standardized System for Mineral, Rock, and Fossil Specimen Resources

The NMRFC has developed and implemented 55 standards for specimen resource description and 40 technical regulations [8-10], while also publishing the monograph *Standardized Management and Digital Research of Large Specimens from Typical Deposits* [11]. Its effort encompasses five industry standards covering "Description of Ore Specimen

Resource", "Description of Mineral Specimen Resource", "Description of Fern Fossil Specimen Resource", "Description of Fish Fossil Specimen Resource", and "Description of Reptile Fossil Specimen Resource", alongside three group standards addressing "General Rules for Management of Biological Germplasm and Experimental Material Resources Centers", "Description Specification for Rock Specimen Resource", and "Appraisal for Mineral View Stone". These initiatives provide a model and technical assurance for the collection, organization, preservation, and digitization of specimen resources both domestically and internationally.

2.4 Enhanced Capabilities for Innovation in Database Systems and Artificial Intelligence Technologies

The NMRFC platform developed a database and network technology system, along with a specimen digital management system and a portal website. These systems were built using the SpringBoot and Vue frameworks, enabling full-process management of specimen data and supporting multi-dimensional data release and sharing. Additionally, the integration of WebGIS (OpenLayer) and 3D (Three.js) facilitated the creation of a specimen WebGIS visualization system and a 3D display system. These enhancements improved the spatial representation of specimen data and optimized user interaction experiences [12].

The NMRFC also developed an artificial intelligence (AI)-based recognition system for mineral specimens. This platform developed mineral artificial intelligence recognition technology, constructed mineral knowledge graphs, and applied large language model technology. A mineral recognition software was created, capable of identifying 36 common minerals with an accuracy rate of 86% [13, 14], and three national invention patents were obtained. Additionally, a large language model for minerals was developed, enabling rapid and professional queries of mineral knowledge [15].

2.5. Establishing Efficient and Collaborative Shared Service Frameworks for Geoscience Research and Technological Innovation

The NMRFC has established comprehensive quality management and full-process sharing service mechanisms for specimen resources. This platform offers multidisciplinary users, both domestic and international, with access to physical specimen loans, comparative research, testing and analysis, visits, and information services. The platform has supported 320 scientific and technological projects through providing physical resources, information resource sharing, and sample testing and analysis services, covering major national science and technology projects for deep earth exploration, international large-scale scientific projects, national key research and development projects, national natural science foundation projects, and provincial and municipal scientific research

projects. This support has facilitated the publication of over 300 scientific research papers and 35 monographs.

2.6. Significant Achievements in Talent Cultivation

The NMRFC, supported by universities and research institutions in the geoscience field, has cultivated a large number of advanced talents specialized in specimen collection, organization, digitization, scientific issues in-depth exploration, and resource development and utilization. Annually, more than 300 undergraduate, master's, and doctoral students from geoscience-related universities and research institutions participate in field research activities. Their work includes specimen resource collection, organization, description, and digitization, as well as in-depth exploration, comprehensive integration, analysis, and utilization of scientific issues related to specimen resources. After graduation, these students either continue their academic pursuits or join universities, research institutions, and high-quality enterprises, where they assume important roles. This has generated a highly positive social response.

2.7. Fostering International Cooperation and Exchange

The NMRFC aligns with national strategic priorities and adopts a global perspective to provide specimen resource preservation, organization, and international research collaborations. It provides specialized core specimen organization and preservation services for the International Continental Scientific Drilling Program (ICDP), with an established core repository supporting its operations.[16]. To support international collaboration in dinosaur evolution research, it launched specialized services. Within the National Key Research and Development Program's Key Special Project for International Cooperation in Science and Technology Innovation, titled "Key Technologies and Demonstration for Standardized Planetary Geological Mapping", it supplies physical specimen resource services to the China-EU team developing an internationally standardized technology system for planetary surface geological mapping. Additionally, through collaboration with China Exchange Program for Young International (CEP), it invited graduate students from the University of Toronto, Canada for academic seminars, field investigations, and joint research activities in China.

2.8. Public Accessibility and Popular Science Services Achieving Notable Social Benefits

The NMRFC plays a crucial role in disseminating geological knowledge and promoting public science education. It operates 30 specialized bases, including the National Popular Science Education Base accredited by the China Association for Science and Technology, the National Youth Science and

Technology Education Base, the Natural Resources Popular Science Base designated by the Ministry of Natural Resources, and the National Primary and National Research and Practice Education Base for Primary and Secondary School Students endorsed by the Ministry of Culture and Tourism. Annually, it receives hundreds of thousands of visitors, comprising primary and secondary school students as well as the general public. Additionally, the NMRFC has established an open-air geological museum named "Jinshi Ping" along the main campus road of China University of Geosciences (Beijing). The museum displays 32 large-scale specimens representing key mineral deposits across China, including gold ores from famous gold mining regions, copper ores from the Gangdese metallogenic belt on the Qinghai-Tibet Plateau, magmatic copper-nickel sulfide ores from the world's third-largest Jinchuan deposit, molybdenum ores from Luanchuan (the world's molybdenum capital), iron ores from the iron-copper-gold polymetallic metallogenic belt in the middle-lower Yangtze River region, boron ores from Liaodong, and the Fangshan rock mass in Zhoukoudian, Beijing. Equipped with a digital 3D display and interpretation system, these large-scale specimens are highly representative and serve multiple educational purposes, including fostering campus geological culture, supporting professional geological fieldwork training, and enhancing public science education.

3. Challenges in the Development of the NMRFC

3.1. Imbalanced Distribution of Resource Preservation Institutions Across China

An extensive survey of mineral, rock, and fossil specimen resources across nearly 100 geological museums, research institutions, and universities in China reveals distinct disparities in collection sizes. Four institutions—the China Geological Museum, the Institute of Vertebrate Paleontology and Paleoanthropology of the Chinese Academy of Sciences, the Nanjing Institute of Geology and Paleontology of the Chinese Academy of Sciences, and China University of Geosciences (Beijing and Wuhan)—each house collections exceeding 100,000 specimens. In contrast, the majority of institutions maintain between 10,000 and 50,000 specimens, while a significant number possess only several thousand. These findings underscore an urgent need to strengthen specimen preservation through diversified strategies, including systematic collection, standardized submission, institutional exchange, public donation, and targeted acquisition.

3.2. Quantitative Gaps in Specimen Resources Between China and Western Countries

A comprehensive survey of 335 geological preservation institutions across 42 countries estimates the global inventory

of mineral, rock, and fossil specimens at approximately 120 million items. The distribution of these resources is as follows: the United States accounts for 52.0%, followed by the United Kingdom (12.2%), Germany (10.0%), Australia (6.2%), and France (5.5%). China's holdings account for 1.75% of the global total, equivalent to roughly 2.1 million specimens [17]. In terms of preservation institutions, the Smithsonian National Museum of Natural History in the United States and the Natural History Museum in the United Kingdom house the world's largest collections. The Smithsonian National Museum of Natural History contains 40.6 million specimens, including 40 million fossil specimens and 600,000 rock and mineral specimens. Its database contains 743,566 fossil specimen records and 465,278 rock and mineral specimen records [18]. The Natural History Museum in the UK has collected approximately 7.5 million rock, mineral and fossil specimens globally since the 18th century, including 7 million vertebrates, invertebrates and plants fossils. Its database includes 630,296 fossil records and 376,151 rock and mineral specimen records. Participating institutions of the NMRFC collectively preserve roughly 1.2 million specimens. These figures underscore China's significant gap in geological specimen holdings compared to developed nations such as the United States and the United Kingdom [19].

4. Development Strategies

4.1. Enhance The Ability to Collect and Preserve Specimen Resources

(1) To enhance specimen resource integration, establish long-term, stable collaborations with academic institutions, research institutes, museums at all levels, specimen repositories, physical data centers, fossil sites, and mining geoparks in the geological sciences. Clearly define roles and responsibilities to facilitate the consolidation of high-quality, distinctive specimens from diverse stakeholders.

To enhance the NMRFC central repository's specimen resource collection capabilities by deploying expert technical teams to field collect, organize, and preserve specimens from globally renowned fossil sites, world-class typical mineral deposits, and globally significant geological regions. This approach will accelerate the expansion of both the diversity and quantity of specimen resources.

To enhance specimen resource collection and submission from scientific and technological projects by establishing dedicated task forces to keep communication with research teams. Ensure rigorous oversight of nationally funded initiatives, including the National Key R&D Program and the National Basic Research Program, with priority given to national strategic priorities such as deep Earth science and exploration, deep-space exploration, deep-sea development, deep-time digital Earth initiatives, strategic mineral resource security, and new strategic actions for mineral exploration break-

throughs. Develop customized collection plans to guarantee timely and comprehensive acquisition of relevant specimens.

4.2. Strengthen Infrastructure Support Capabilities

A new multi-functional NMRFC resource library will be established in Xiong'an New Area, including an international continental scientific drilling core library, a rock, mineral and fossil specimen resource library, a specimen resource exhibition hall, a specimen resource borrowing room, a specimen resource sorting and digitization room, a specimen resource information center, as well as laboratories and office areas. This integrated national resource library will facilitate comprehensive functions including specimen resource sorting, digitization, preservation, display, borrowing, testing, and analysis.

4.3. Enhance the Management and Operation Capabilities of the NMRFC

(1) To develop and improve strict management systems for national resource libraries, standardizing procedures for data entry, storage, update and backup operation processes. Regular performance evaluations of the database system will be conducted to ensure synchronous growth in specimen data volume and resource increments. This approach will enable dynamic updates of geoscience specimen data while maintaining operational efficiency.

(2) To enhance data verification and quality control by establishing a rigorous data auditing framework with clearly defined standards and standardized procedures. This will include the development of an AI-driven data quality control system that employs machine learning algorithms for automated auditing and validation of sample data, enabling rapid error detection and correction. Additionally, periodic sampling and assessments will be conducted to ensure sustained data accuracy and reliability.

(3) To establish interdisciplinary research teams to systematically develop thematic databases and data products based on specimen resources. These teams can focus on six key themes: Deep Earth, Deep Space, Deep Sea, and Deep Time, as well as Chinese large, super-large, and strategic mineral deposits, globally significant palaeontologist communities, and representative geological sections. Researchers can collect, organize, and analyze relevant data to construct high-quality thematic databases, ensuring alignment with international standards for data interoperability and reproducibility. Concurrently, the project will integrate science communication materials, such as e-books and videos, into a comprehensive knowledge repository, providing researchers and the general public with accessible and valuable knowledge resources.

(4) To advance artificial intelligence (AI) technology development, it can increase investment in this domain and

collaborate with universities and research institutions to establish dedicated AI technology research and development teams. These teams can focus on big data analytics models for visual specimen resources, leveraging deep learning and data mining techniques to enable in-depth analysis and extraction of specimen data. By doing so, the research will provide robust support for scientific decision-making and efficient resource utilization.

4.4. Enhance the Capacity to Support National Scientific and Technological Innovation

The NMRFC prioritizes national strategic research domains, including deep Earth science and exploration, deep-space exploration, deep-sea development, deep-time digital Earth initiatives, strategic mineral resource security, and the new round of strategic actions for mineral exploration breakthroughs, while actively aligning with major national science and technology programs such as the Key National R&D Programs, National Science and Technology Basic Resource Survey Projects, International Science and Technology Cooperation Programs, National Natural Science Foundation Projects, Regional Geological and Earth System Survey Projects, and Strategic Mineral Resource Survey and Evaluation Projects. To ensure comprehensive support, the initiative systematically formulates and optimizes service processes encompassing comparative studies of specimen resources, identification and analysis, organization and preservation, and data sharing. By establishing these integrated mechanisms, rock and fossil specimen resources and associated data will continue to be made accessible to the national scientific community, thereby supporting the generation and dissemination of scientific research outcomes.

4.5. Professional Talent Introduction and Cultivation

(1) The NMRFC will attract professionals from relevant disciplines, including geology, mineralogy, paleontology, information technology, and database management, to join the development team of the National Rock, Mineral, and Fossil Specimen Resource Repository. Through active participation in domestic and international academic conferences and recruitment fairs, the repository actively promotes the strategic objectives and talent needs of the national repository. This approach aims to attract high-caliber professionals with demonstrated expertise and innovative capabilities.

(2) To foster staff professional development, The NMRFC will implement a structured internal training framework and organize regular skill-enhancement programs covering domain-specific knowledge and technical competencies. This initiative includes hosting lectures by leading domestic and international experts who provide methodological guidance and share cutting-edge research advancements. Employees will be encouraged to participate in academic conferences and

pursue formal continuing education opportunities, thereby systematically upgrading their expertise and interdisciplinary capabilities.

4.6. Promote the Internationalization Development Strategies

The NMRFC will strategically integrate into the international Earth system science framework by aligning its development agenda with global priorities. This involves co-establishing international academic consortia and joint research platforms to promote the internationalization of national scientific infrastructure and strengthen global communication networks. International collaboration will be formalized through partnerships with leading global museums, geological research institutions, and international organizations specializing in mineral and fossil specimen resources. These partnerships will facilitate structured agreements for specimen collection, data sharing, and collaborative research initiatives. The NMRFC will actively participate in flagship international programs such as the International Geoscience Programme (IGCP) and the International Continental Scientific Drilling Programme (ICDP), enabling joint resource utilization and co-developed research projects with international counterparts. Sustained engagement in these initiatives will elevate China's visibility and influence on global specimen resource governance. The NMRFC will organize international academic conferences on mineral and fossil specimen resources, inviting global experts and scholars to present cutting-edge research findings and technical advancements. These forums will serve as high-level platforms for academic exchange, promoting harmonization of domestic specimen repository protocols with international standards.

4.7. Enhance Sharing Services for Public-oriented Science Popularization

To comprehensively enhance public awareness of and engagement in geosciences, the NMRFC will implement integrated online-offline science communication strategies. This includes publishing specialized geological science reports while utilizing digital platforms and social media to disseminate specimen resource data, updated data products, and science education content. Through systematic dissemination of geoscientific knowledge, the NMRFC aims to promote public understanding of Earth sciences, support the acquisition of scientific and technological literacy, and advance overall scientific competence.

5. Conclusions

The NMRFC will enhance its infrastructure development and service capabilities to address the evolving demands of scientific innovation, national strategic priorities, and socio-economic growth. As a foundational support platform, it will

serve as the National Science and Technology Resource Sharing Service Platform, ensuring compliance with unified technical specifications and descriptive standards for rock, mineral, and fossil specimens. The repository will integrate geoscience resources from domestic and international sources, adhering to standardized protocols for specimen collection, preservation, and data management. It will establish a comprehensive system for data retrieval and querying, online services, and digital dissemination, enabling the creation of a modern, internationally aligned, and open-access physical and digital repository for geoscience specimens. This integrated platform will provide robust foundational support and technical support for government decision-making, scientific research, talent development, innovative applications, AI-driven research, and geosciences popularization.

Abbreviations

NMRFC National Mineral Rock and Fossil Specimen Resource Center

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Conflicts of Interest

The authors declare no conflicts of interest.

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Research Field

Mei Yang: mineralogy, petrology, geology of deposit, standardization and digitization of specimen resourcess, geological science

popularization.

Mingyue He: mineralogy, petrology, geology of deposit, Gemology, standardization and digitization of specimen resourcess, mineral fesources exploration, geological education.