Geoinformation Supports Responsible Exploration of Natural Resources and Management of the Environment

Current and high-quality geoinformation is a critical asset when addressing global challenges such as climate change, sustainable natural resources management, environmental monitoring, and urban planning. Availability of spatial data and related digital solutions provide a platform that enables data-driven decision making and cost-efficient management practises. The accumulation and use of geological data enriches existing data and creates new information. Here we highlight key priorities for advancing geoinformation to position Finland among global leaders in data-driven geoscience, through innovation and state-of-the-art approaches.

Innovative geoinformation solutions benefit society

Finland has expertise in collecting geodata, advanced technological infrastructure, and digitally available geological data. This positions the country among global geoinformation leaders, especially in mining, but also in water management, land use planning, and environmental monitoring.

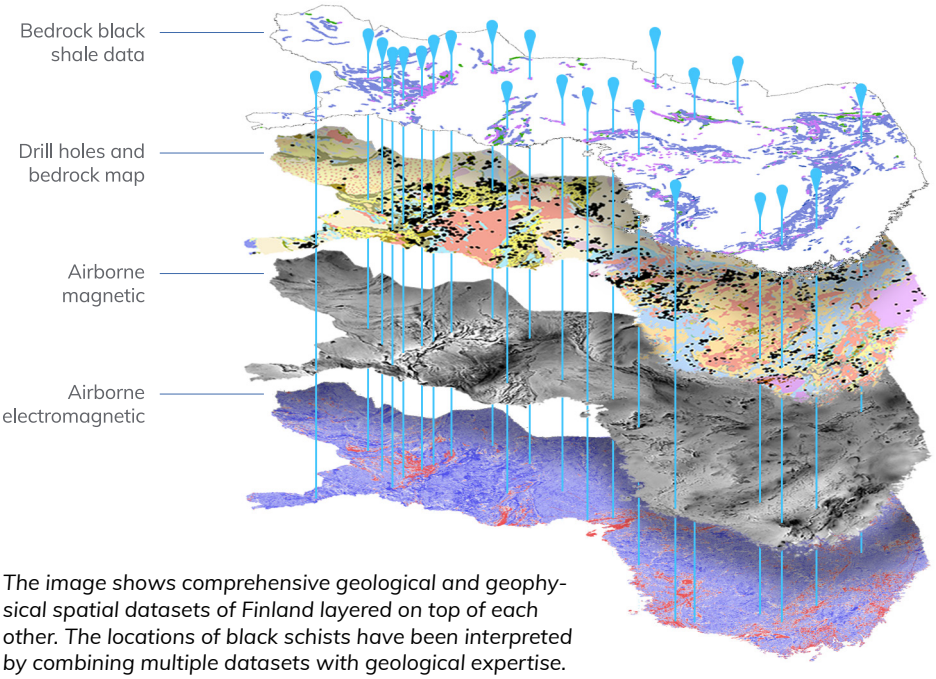
Public geoinformation enables informed decisions for sustainable development, safer infrastructure and economic growth.

Geological Survey of Finland GTK manages extensive, high-quality datasets, including:

- **Geological data**. Information on bedrock and superficial deposits, lithological formations and structures, and mineral deposits.
- **Geophysical data**. For example, seismic, magnetic, and gravimetric surveying data from the Earth's subsurface.
- **Environmental and geochemical data**. Information on chemical composition of rock, soil, peat, and water.
- **Remote sensing, close-range sensing, and monitoring data**. Collection of data using satellites, aerial surveys, drones, and ground-based sensors.

GTK research presented in this Policy Brief contributes to these United Nations Sustainable Development Goals

Data-driven decision making with combining spatial data sets and expertise



The image shows comprehensive geological and geophysical spatial datasets of Finland layered on top of each other. The locations of black schists have been interpreted by combining multiple datasets with geological expertise.

Availability of spatial data, related geological expertise and digital solutions provide a platform that enables data-driven decision making and cost-efficient management practices.

The accumulation and use of geological data enriches existing data and creates new information.

Combining datasets and applying Artificial Intelligence (AI) -based analysis creates new possibilities and fosters innovations and efficiency. GTK's research activities focus on:

- Modern solutions for spatial data collection, management, and distribution.
- Novel data acquisition and interpretation technologies.
- National geological datasets integrating global geostandards and data models.
- Innovative applications for analysing and modelling spatial data.
- Developing and utilising AI-based machine learning applications and methodologies for data analysis.

High-quality research activities depend on strong partnerships, joint efforts and knowledge transfer, efficient and secure systems for data management and distribution, high-performance computing platforms, and people with excellent knowledge. The life cycle of geodata is long, and the long-term preservation, accmulation, and enrichment of these national assets are therefore vital.

Advanced geoscience solutions are needed

Emerging technologies and demands for more accurate spatial data and tightening quality and security standards require constant improvement in existing data collection, management, and analysis methodologies.

With increasing reliance on AI and machine learning for data analysis, there is a pressing need to enhance data infrastructure and adopt cutting-edge technologies, such as Earth observation and close-range systems including hyperspectral imaging (see infobox). These tools allow more precise mapping, better environmental monitoring, and improved mineral exploration.

AI and machine learning. The utilisation of AI-driven data analysis provides the ability to process large-scale geospatial data with greater accuracy and efficiency. These applications assist, for example, geologists, researchers, and exploration companies to analyse geoscientific data in order to identify areas with high mineral potential.

Earth observation and close-range sensing. Advanced sensing technologies such as satellite, drone-based, and laboratory imaging instrumentation enhance our ability to acquire real-time, high-resolution geoinformation across various terrains and scales – critical for sectors such as mining and environmental protection.

Harmonised geological data models. The development of harmonised datasets, combined with global standards, ensures the accuracy, compatibility, and accessibility of geological data. New 3D geological models provide deeper insights into the Earth's crust, essential for applications such as mineral prospecting and land-use planning.

Hyperspectral imaging data

Hyperspectral sensing can be used to gather information about different materials, for instance, minerals and rocks. This information is recorded using spectrometers that range from handheld devices to satellites.

The technology is based on the detection of light that is reflected or emitted from surfaces. This information is recorded in hundreds of contiguous bands, which allows for the detection of materials and their properties.

In geology, hyperspectral technology can be used to identify the mineralogy and mineral chemistry of rocks. Therefore, the technology is particularly useful to support drill core logging. In the best case, the technology makes it possible to identify many commonly occurring minerals.

These data can be interpreted with machine learning algorithms, which provide a fast and cost-efficient method to identify the mineralogy and mineral chemistry of rocks.

Moving, handling and sharing digital data is easier than moving the actual rock samples. GTK has collected hyperspectral data of drill cores in several research projects.

Steps towards state-of-the-art geoscientific information and innovation

Producing geoinformation for the needs of society has been one of GTK's main tasks for decades, and thus GTK has a long tradition in geological data collection and digitalisation. The information reserves GTK manages are unique and valuable, but inadequate for modern needs. Constant development, innovation and research are necessary, and as the availability of human and financial resources is limited, collaboration is essential.

GTK brings a geological perspective and expertise into jointly produced spatial datasets and solutions. Existing geoinformation reserves can be harvested to support the collection and creation of new solutions and thus focus scarce resources. GTK has long experience in developing and maintaining geoinformation infrastructure, interpreting and analysing geological data, and for developing novel data collection methodologies.

The amount of data is increasing rapidly, which challenges traditional data management and analysis practices as well as finance. GTK continues to actively contribute and participate in the development of geoinformation for the needs of society.

Innovative data collection and analysis techniques. It is necessary to expand utilising cutting-edge technologies such as AI, machine learning, and remote sensing for producing accurate, scalable geodata in the application areas of mineral prospectivity mapping, mineral exploration, drill core scanning, mine site monitoring, environmental impacts of mining, and soil mapping for the land use sector, etc. The deployment of drone-based platforms, satellite imagery and, e.g. optical and radar imaging sensors to enhance mapping and monitoring data is vital.

Advanced geoinformation infrastructure. GTK has been developing its geoinformation infrastructure over a long period of time and the good work continues. Further development of web services, harmonised geospatial systems and 2D/3D geological data models to improve data integration and usability, and connecting the external information flow to this infrastructure benefits all users of geological data. Datasets are aligned with the global standards for better interoperability and accessibility across sectors.

AI/machine learning -driven insights. The amount of data is increasing. Therefore, leveraging AI/machine learning and high-performance computing to analyse large-scale geospatial datasets with greater precision and speed is needed. Incorporating machine learning -based predictive models into geoscientific worflows to support real-time decision making creates efficiency. GTK has developed special knowledge regarding AI-based processing and analysing of geological data; this knowledge should be strengthened.

Collaborative ecosystems. Strengthening national and international collaboration to drive innovation and funding opportunities and build partnerships with academia, industry, and government to foster knowledge transfer and co-develop solutions is essential. Joint efforts for new data collection programs as well as focusing and sharing limited resources to create new datasets and solutions is vital.

More accurate analysis with mineral prospectivity mapping (MPM)

The development of geographic information systems (GIS) and spatial data mining techniques as well as the increase in computing power and availability of vast digital datasets facilitate efficient quantitative modelling and mapping of mineral potential, thereby facilitating the targeting of exploration activities.

One of the methodologies developed for GIS-based data analysis is called mineral prospectivity mapping (MPM).

MPM methodology allows combining geological and exploration data from various sources to produce a single heatmap for mineral potential. Also, data related to land use planning, natural protection areas and other restriction areas can be included to further produce a map indicating favorability to do exploration and start mining activities.

This enables even more precise delineation and predictivity for exploration areas and projects, thus providing a timesaving, cost-effective, and environmentally neutral exploration technique.

The application of MPM approach requires geological expertise and understanding of mineral system models, which

- summarises the knowledge regarding which geological processes have been triggering the formation of ore deposits and
- varieties of geological structures that have controlled the processes, as well as
- which commodities are targeted.

Based on the mineral system model, applicable data and parameters for the MPM procedure are selected. The good quality of geodata is critical for modelling: it directly affects the quality of the appraisal.

GTK has a long tradition and strong expertise in the development and application of MPM methodologies and tools. The following tools that have been developed are either publicly available at the GTK website or via GitHub repository, or can be obtained by request:

- **MPM online: online tools for mineral prospectivity mapping using Fuzzy Logic overlay**
- **ArcSDM: desktop GIS tools for mineral prospectivity mapping**
- GisSOM: un-supervised machine learning and clustering using Self-Organizing-Maps technology (not public)
- **EIS toolbox and Plugin: open-source desktop GIS tools for integrating mineral systems modelling with mineral prospectivity mapping**

These spatial data analysis tools have been developed using public funding from the domestic and international funding agencies, together with leading research and academic institutions and industry.

National Geological Framework of Finland (NGFF)

Maintaining and advancing the availability of geological information on bedrock and superficial deposits as well as mineral deposits is one of GTK's basic tasks. GTK maintains national multidimensional (2D/3D/4D) datasets and databases related to regional geology, and harmonises new data into robust and widely accepted international data models. These fundamental national geological datasets and data models form the National Geological Framework of Finland (NGFF).

Robust data models ensure interoperability of data and facilitate the harvesting and incorporating data into international data infrastructures. Managing NGFF data requires special knowledge and expertise accumulated over a period of decades. GTK develops new methods for collecting and interpreting geological data, combining and analysing all existing data from multiple sources, including airborne laser scanning data (LIDAR) and new field data capture. Also, AI-based algorithms are developed for the interpretation processes. The aim is to produce better, up-to-date geoinformation.

In addition to traditional 2D digital map databases, GTK provides expertise for 3D-modelling of the Earth's crust. The 3D model of upper crust was published in 2023, and currently GTK is finalising the 3D model of the whole crust of Finland, forming an integral part of NGFF.

GTK also produces and gathers information on published age determination of lithological units based on analysis of radioactive isotopes. The main evolution stages of the bedrock of Finland date back, for the most part, to between 2800–2700 million and 1900–1800 million years ago. Expertise on regional geology combined with age determinations enable interpretation of belt-scale stratigraphical correlations in addition to the geological processes behind the bedrock evolution and related stratigraphy. The extent of a certain litostratigraphic unit can be detected and followed geographically.

Study of the crustal architecture, basin evolution, and stratigraphy of the Precambrian bedrock, especially in Northern Finland, is important due to the presence of large mineral deposits, and it is a major region of current explorations. National Geological Framework of Finland datasets are available in the **Hakku** service

How can we maximise the benefits of public geodata?

By embracing innovative technologies, strategic collaborations, and robust data management practices, Finland can provide high-quality geodata and geoinformation solutions to stakeholders within the public and private sector, enhancing sustainable development and economic growth. For this purpose, the following actions are recommended:

Adopt AI and machine learning in geoinformation systems. Promote policies encouraging the integration of AI/machine learning for enhanced geoinformation analysis and decision-making.

Harmonise geospatial standards. Establish global data standards to improve consistency and accuracy, making geospatial products more reliable and useful.

Support public geoinformation platforms. Invest in dynamic, real-time geoinformation platforms to provide decision-makers with accessible and applicable data.

Foster cross-sector partnerships. Strengthen collaboration between stakeholders to accelerate innovation in sustainable geoinformation applications.

Promote geoinformation for sustainable development. Encourage the use of advanced geoinformation in policy-making to reduce environmental impacts and optimise resource use.

Sources and additional information

GTK's research areas, policy briefs and research projects

Geoscience Information Solutions – information and research projects

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GTK research news

- **Highlights from Remote sensing and Earth Observation Workshop at the Geological Survey of Finland**
- **First Spatial Dataset on Peatlands Covers Mires and Drained Peatlands Throughout Finland**
- **Management of National Geodata Is One of Basic Tasks of Geological Survey of Finland**
- **Finnish Research Consortium Pioneers AI Breakthrough in Sustainable Mineral Exploration with €5.6 Million Project**
- **Hyperspectral Technology Enhances the Quality and Accuracy in Drill Core Loggings**
- **Developing Remote Sensing and Machine Learning Solutions for Exploration of Critical Raw Materials and Monitoring Environmental Impact of Mining**
- **Exploration Information System – New Tools for Mineral Exploration**
- **GisSOM for Clustering Multivariate Data – GisSOM**
- **European Commission Ranked the Novel and Environmentally Friendly Survey System for Mineral Exploration a Top Innovation Product**
- **GisSOM for Clustering Multivariate Data – Self-organizing Maps**
- **GisSOM for Clustering Multivariate Data – Multivariate Clustering and a Glance to Self-organizing Maps**

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The Geological Survey of Finland (GTK) produces impartial and objective research data and services in support of decision-making in industry, academia, and wider society to accelerate the transition to a sustainable, carbon-neutral world. GTK employs more than 400 experts specializing in the mineral economy, circular economy, solutions related to energy, water and the environment, as well as digital solutions. GTK is a research institution governed by the Finnish Ministry of Employment and the Economy, operating in Finland and globally.