MICA

Minerals Intelligence Capacity Analysis

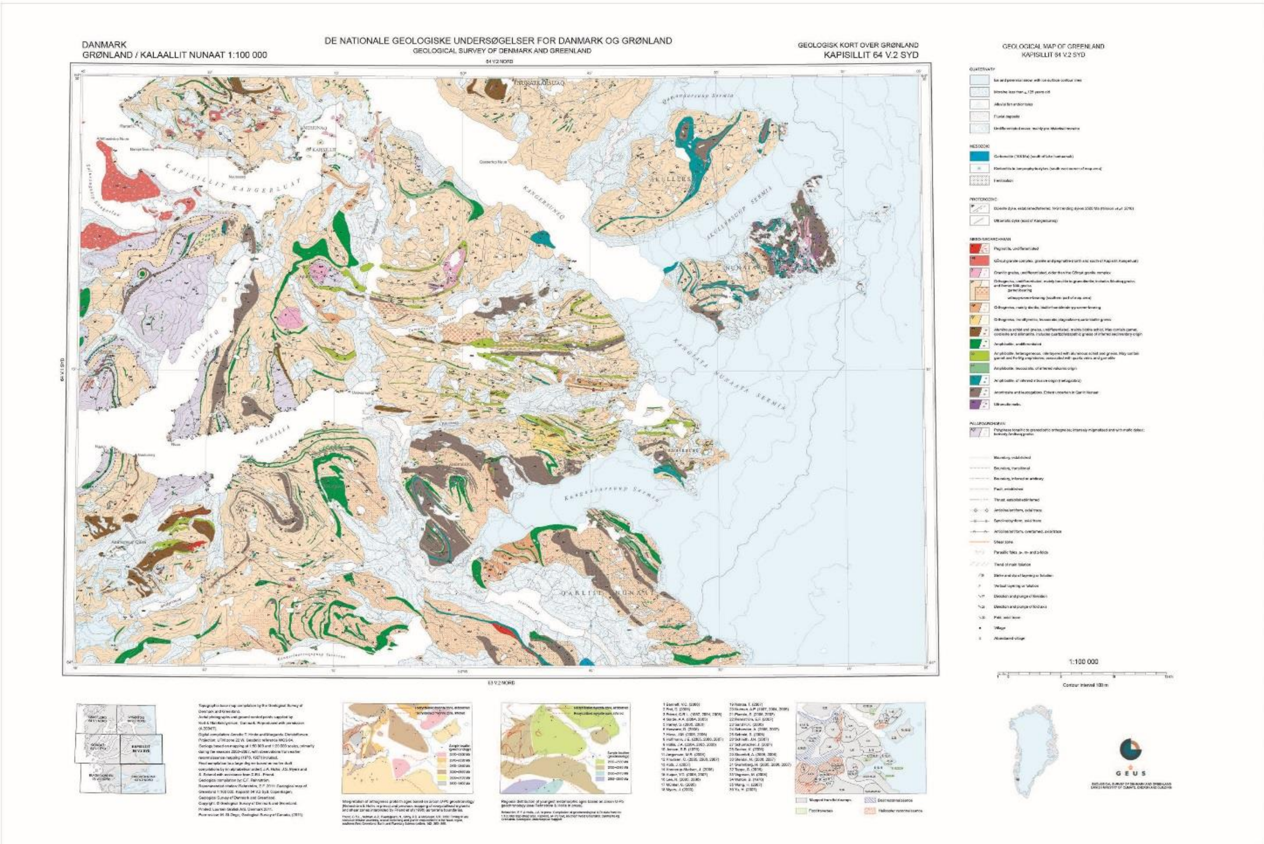
FACTSHEET

2D geological mapping (regional vs. detailed; purely geological vs. mining oriented)

The significance of different scales in geological mapping for different purposes.

Scope (conceptual model & main characteristics)

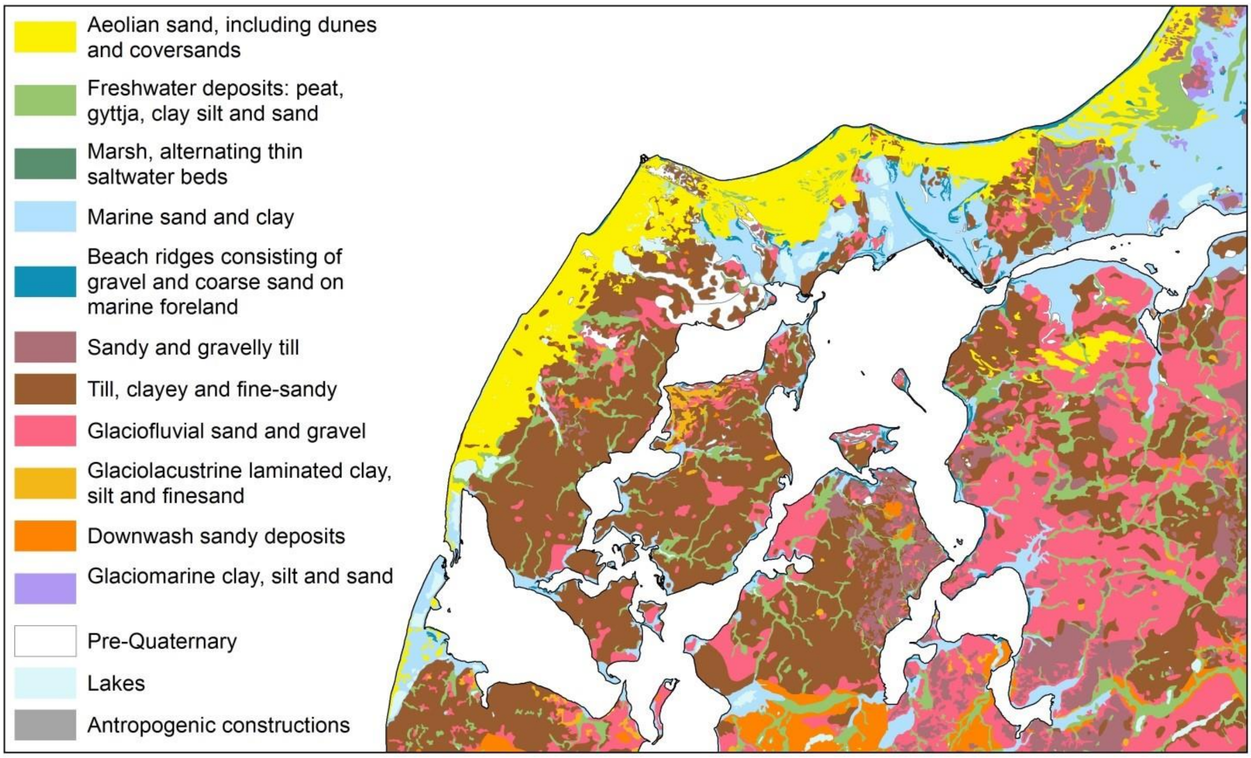
The 2D graphical presentation of geological observations and interpretations is called a geological map. These geological maps are often the first aim when exploring an area for either scientific or exploration purposes. It helps in creating either a basic or a detailed understanding of the area, depending on the objective. Detailed knowledge about specific geological aspects such as ore forming processes require more detailed work. The difference in regional geological mapping and mining oriented mapping is the scale. Geological mapping for obtaining basic information will most often be at a regional scale in the order of 1:10 000-100 000 scale whereas mining oriented mapping needs a much larger scale that will help determine the drill sites: 1:1 000-10 000. This is because small details of the potential orebodies are rarely picked up on the smaller scaled maps, where significantly more interpolation between observations points or outcrops is conducted, whereas larger scale maps (also sometimes called "fact-maps") have less if any interpolation.



Typical regional scale map. 1:100 000 64 V2 Kapisillit. Source: GEUS.

Contexts of use, application fields	-> contexts (e.g., environmental, economic, social assessment) -> which types of stakeholder questions are concerned? -> link to published studies that implement the method

There may be different needs for a specific geological map; scientists might want a broad picture of a region focusing on the bedrock and general geological information, whereas mineral exploration companies are interested in the local extent of a deposit. As a result there are many types of geological maps; maps for geological resources, maps for engineering properties, maps for evaluation of geological hazards (such as flood zones) or maps showing geological structures and basic bedrock which may reveal the geological history of that particular area. This means the maps are used in many fields; engineering, hazard assessment, resource investigation or generally in academic research.



Geological map of the upper most soil in northwestern Denmark. Source: GEUS

Input parameters

-> which parameters are needed to run the method

The basis for any geological map, regional or detailed, is a topographic map, at the same scale of the desired geological map. Each outcrop is marked with its coordinates on the base map. When the position of the locality is in place, it is possible to describe the outcrop as it appears in the field from major inputs such as; rock type, the color, rock textures and structures. Then it is possible to look at the rock or rocks in detail. The objective here is to get as much information as possible, and will typically consist of: Classification of rock type (e.g. metamorphic, magmatic, sedimentary, hydrothermal, etc.); color; metamorphic grade (if any); content of minerals and preferably the volumetric proportions of said minerals; presence of fossils, ore minerals or other special indicators. These descriptions will be accompanied by a representative rock sample, for laboratory classification and chemical analysis and/or microscopic study and photographs as appropriate. Structural readings from the outcrop can be very important to understand the structural history such as folding and faulting.

Type(s) of related (input) data or knowledge needed and their possible source(s)	-> which types of data are needed to run the method, from which sources could they come… -> could be qualitative data or quantitative data, and also tacit knowledge, hybrid, etc.

The increasing availability of data by remote sensing methods such as satellite imagery, aerial photography and digital terrane models and use of Geographic Information System (GIS) technology, have greatly improved the quality of both the topographical maps themselves and facilitated integration with geological, geophysical and remote sensing data.

Model used (if any, geological mathematical, heuristic…)	-> e.g., geological model for mapping -> e.g., mathematical model such as mass balancing, matrix inversion, can be stepwise such as agent -based models, dynamic including time or quasidynamic specifying time series… -> can also be a scenario

Regional mapping takes place by visiting selected outcrops (others may be inaccessible due to topography, vegetation or simply distance), and interpolate observations between these. This means that not all available outcrops are visited and that the resulting geological model is subject to bias, as it is the map compiler, who decides on an informed and experienced basis, how to place the interpolated lines and boundaries, aided by the data obtained from remote sensing methods.

Conversely, detailed mapping relies on visiting and outlining every possible outcrop in the mapping area. As a much smaller area is covered, the need for interpolation is greatly reduced. That is why detailed mapping is also sometimes called observational or 'fact' mapping, as the map shows what is actually present.

It is important to be aware that even the most large scale maps produced (such as 1:1 000), are still subject to bias, as it is not possible to describe and include every minuscule detail found in nature.

System and/or parameters considered	-> **the system can be described by its boundaries**. These can refer to a geographic location, like a country, or a city, the time period involved, products, materials, processes etc. involved, like flows and stocks of copper, or the cradle-to-grave chain of a cell phone, or the car

	fleet, or the construction sector, or the whole economy… -> **parameters** could possibly refer to geographic co-ordinates, scale, commodities considered, genesis of ore deposits and others…

The area covered by a geological map depends very much on the end user, i.e. a regional geological survey or mineral exploration company. Regional surveys cover a larger area and have a larger degree of interpolation, compared to detailed mapping used in the more advanced stages of mineral exploration. For that reason regional geological mapping is often performed in the order of 1:250 000 or 1:50 000 sheets, whereas deposit or mining scale maps are in the order of 1:1 000 or 1:5 000.

Mineral exploration typically starts at the regional scale with small scale mapping and ends with large scale detailed mapping, where the map contains maximum information, including the extent of the mapped mineral deposit and special geological features of interest for that particular deposit.

The geological maps show a spatial reference, which is geographic coordinates that marks the boundaries of the map, often expressed in Latitude/Longitude or by national coordinate systems.

Time / Space / Resolution /Accuracy / Plausibility…	-> to which spatio-temporal domain it applies, with which resolution and/or accuracy (e.g., near future, EU 28, 1 year, country/regional/local level…) -> for foresight methods can also be plausibility, legitimacy and credibility…

The geology of a certain area normally does not vary on the timescale of a human lifespan. However, the interpretation of the geology may change, with new research, with the effect that the mapped area needs to be revisited. A classic example is that of Alfred Wegener's theory of C*ontinental Drift* which became accepted in the 1970's. This meant that many known geological features obtained a new significance and became subject to reinterpretation. For Greenland it is argued that the geological maps should be revised every 50 years or so, because of new understandings and advancement of geological techniques. Regional scale geological maps may also be partially revised if more detailed maps of an area are produced, such as large scale maps for the mining industry, which have greater accuracy.

Indicators / Outputs / Units	-> this refers to what the method is actually meant for. Units are an important part but that is most of the time not sufficient to express the meaning. For example, **the indicators used in LCA express the cradle-to-grave environmental impacts of a product or service**. This can be expressed in kg CO_2-equivalent. But also in €. Or in millipoints. Or in m^2year land use. -> for foresight methods the outputs are products or processes

The inputs are geological observations from the field, regional scale geophysical measurements (e.g. aerogeophysics), chemical analyses of the rocks and minerals, which, combined with the topographical map, creates the output, a geological map at a given scale. Before the digital evolution, such maps were printed, but are now increasingly available online in digital and often interactive versions. The map is accompanied by a legend where different map units and symbols are explained, such as rock types and their classification, structural measurements, mineralization with economically interesting minerals as well as geographical reference points.

Treatment of uncertainty, verification, validation	-> evaluation of the uncertainty related to this method, how it can be calculated/estimated

It is primarily geological experts in the field who perform the geological mapping. This makes errors and natural bias difficult to quantify, as there is seldom a control group mapping the same area. Naturally, areas with dense vegetation (i.e. few outcrops) or high geological variance will generate the greatest amount of uncertainty. Geological boundaries in such areas are often dotted, to represent the uncertainty accompanying the interpretation. For these reasons, geological maps and the accompanying explanatory notes should be peer reviewed by other geologists, who ideally have in depth knowledge of the area and geological mapping techniques, to ensure that a high standard is met. Chemical analysis and microscope studies can be used to verify correct rock identification and classification.

If two adjoining map areas are mapped independently across a timespan of several years, this may result in a mismatch, as classifications or names for the same rock units may have changes in the meantime. This may be particularly evident across national boundaries.

Main publications / references	-> e.g. , ILCD handbook on LCA, standards (e.g. , ISO) -> can include reference to websites/pages -> references to be entered with their DOI

Haldar, S. K. (2013). Mineral Exploration – Principles and Applications. Elsevier Inc. pp 334.

Henriksen, N. (2002). Geologisk kortlægning i Grønland – forudsætninger, metoder og resultater. Geologisk Tidsskrift 2002 (1), pp 1-48.

Marjoribanks, R. (2010). Geological Methods in Mineral Exploration and Mining. Springer-Verlag Berlin Heidelberg, 2nd edition. XV pp 238.

Related methods	-> List of comparable methods, their particularities… -> link to one or several other existing fact sheet(s)

- Not applicable

Some examples of operational tools (CAUTION, this list is not exhaustive)	-> e.g., software… Only give a listing and a reference (publication, website/page…) -> **should be provided only if ALL main actors are properly cited**

Today's geological mapping routinely employs GIS software, where the mapper types in his/her respective observations directly on e.g. a handheld tablet with the base map and coordinates for the observations. This allows information on rock class, mineral content strike and dip of fault planes, etc., to be stored in one place and as appropriate, accompanied by photographs, which together with the mapping software will generate a report useful for the generation of the final map. The pen and paper are in that sense obsolete, but the principles and practices for the observations themselves remain the same, with utilization of hammer, magnifying glass, compass, etc.

Geological mapping and sampling using GIS software on a handheld tablet. Source: GEUS

Key relevant contacts	-> list of relevant **types** of organisations that could provide further expertise and help with the methods described above.

Regional geological maps are often offered by the national surveys for the area of interest. Detailed geological maps at the scale of a mineral deposit are often company property but may be publically accessible dependent on the local legislation. Below is a list of some of the organizations which have geological maps available. They may also help to acquire deposit scale maps.

Country	**Geological map portal**
Croatia	http://www.hgi-cgs.hr/images/geoloska-karta-republike-hrvatske-1-300.jpg
Czech Republic	http://www.geology.cz/extranet-eng/maps/online
Denmark	http://www.geus.dk/UK/data-maps/Pages/default.aspx
Finland	http://en.gtk.fi/informationservices/map_services/index.html

France	http://infoterre.brgm.fr/
Germany	https://geoviewer.bgr.de/
Ireland	https://www.gsi.ie/Mapping.htm
Norway	https://www.ngu.no/en/topic/applications
Poland	http://bazagis.pgi.gov.pl/website/cbdg_en/viewer.htm
Romania	http://81.196.111.132/testgeo2/
Slovakia	http://infoportal.geology.sk/web/guest/mapovy-portal
Spain	http://info.igme.es/visorweb/
Sweden	http://apps.sgu.se/kartvisare/kartvisare-index-en.html
Switzerland	https://map.geo.admin.ch
United Kingdom	http://www.bgs.ac.uk/geoindex/

Glossary of acronyms /abbreviations used	-> Definition
GEUS	Geological Survey of Denmark and Greenland
GIS	Geographical Information System
GPS	Global Positioning System