# GTK MAP DATA ARCHITECTURE: THE CORE OF THE DEVELOPING NATIONAL GEOLOGICAL FRAMEWORK OF FINLAND

*by*

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The ongoing transition from 2D to 3D modelling of geology needs to be supported, both within the Geological Survey of Finland (GTK) and nationally, by efficient infrastructure. As a part of the future-forward national information infrastructure, the key performance of the GTK Map Data Architecture is to provide easy use of geological map data in all forward modelling processes. In practice, this means consistency, standardization and traceability of the available interpreted map data.

The implementation of the GTK Map Data Architecture (MDA) has two major objectives. First, on a practical level, the utilization and re-use of map data will be improved through a systematic, conceptually solid and standard-based national storage system. International standards and vocabularies will be applied in the construction of the MDA, and the NADM-C1 conceptual model and GeoSciML documentation are used as primary references. Second, a deeper-level objective is an information system enabling the management of geological content in full scientific depth, including both the underpinning conceptual framework and the original research behind the interpreted geological map data.

The GTK Map Data Architecture is designed to meet the needs of various use cases, such as 3D-modeling processes and GTK's online map data services. The MDA concept is broader than a map library, and it is founded on three pillars: (1) structured **spatial data**, with the map objects and related attributes arranged as thematic layers; (2) structured non-spatial data, including the **Finstrati** databases with definitions and descriptions of geological units and the **Finstruct** database with descriptions of the major geological structures, and (3) linked documentation, including **key references** with the original descriptions and scientific content.

The GTK Map Data Architecture is planned to be a dynamically developing part of the broader National Geological Framework of Finland. The GTK MDA combines the spatial features and systematic classification of the defined geological units and structures. Structured non-spatial data is the key element of the architecture and will link the regional spatial data to the key scientific references. The GTK MDA aims to enable access to geological information, not only to spatial map objects and their attributes.

Keywords: Geological map, map data architecture, spatial, 3D modelling, data model, Geological Survey, Finland

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# 1 INTRODUCTION

## 1.1 Perspective and rationale

The Geological Survey organizations (GSOs) all over the world have had to develop governance frameworks and structured data management systems to meet their objectives as modern information providers. The fundamental importance of a shared conceptual frame was recognized by the North American surveys and lead to data-model standard NADM-C1 (NADMSC 2004) for the description of geologic features in digital geologic map databases. The next challenge was set by the interoperability and the derived essence of standards. Australia has been the beacon showing the way to implementation of standards to geological information systems.

The Geological Survey of Finland (GTK) has created a vision and a national approach for the production and storage of, as well as services for all primary and interpreted geological information. System development has been ongoing for several years. The present contribution outlines **GTK's Map Data Architecture (MDA)** and the concepts underpinning the system. The fundamental idea is that the GTK MDA will have the capability to develop towards a more advanced geological information architecture with scientific geological content as the main focus, not only the storage of spatial data. GTK MDA forms an essential part of the developing National Geological Framework of Finland (NGFF). As an overall objective, the NGFF shares features of the BRGM RGF program (Urvois et al. 2016) and the systems implemented by Geoscience Australia (https://www.ga.gov.au/about/projects/resources/continental-geology) and many other GSOs.

A geological map compilation is currently not only the final product of an interpretation process, but also provides essential input data for forward modelling processes. Typically, the derived outputs include generalized and thematic maps, GIS-based spatial analyses (e.g. Nykänen & Ojala 2007) and geological 3D models (see Kohonen et al. 2019). Information technology and advances in geological conceptual modelling have opened up new perspectives and approaches in the management of map data:

- National geological compilations at various scales
- Recurrently updated, 'evergreen' map compilations
- Modular map datasets with scientifically sound themes as a basis of the data products
- Evolution from a simplistic 2D map portrayal to more realistic 3D models

Our overall objective is to design and implement a comprehensive system for storing geological descriptions, particularly those related to geological maps (e.g., geological units, lithology and geologic structures), as well as spatial information on map features. The main 2D realization is the national geological map dataset with various derived products and online services.

During the last decade, 3D modelling and mapping has emerged and is now gradually becoming the mainstream in the description and portrayal of geology. In 2017, GTK started to prepare a long-term programme ('**3DSuomi**'; Kohonen et al. 2019), which aims to facilitate the overall transition from the 2D approach to 3D in all activities, from geological data collection and interpretation to the production of digital outputs and services. Easy access to well-organized geological map data is an essential requirement for an efficient 3D modelling process. The main input to 3D modelling systems consists of primary constraints (data) and secondary constraints (interpreted data). **GTK map data** (interpreted 2D data), **2D data models** and **GIS technology lay in practise the foundation for geological 3D modelling.** Explicit geological 3D models are typically directly derived from 2D maps and cross-sections, and the reliability of the implicit 3D models largely depends on the quality of the input data. Improvement of the quality of structured 2D data is a foremost task of the 3DSuomi programme.

This paper provides an overview of GTK's approach to geological information management and describes: (1) the Map Data Architecture (MDA) as a part of the evolving National Geological Framework of Finland (NGFF), (2) the overall structure and functionality of the MDA. Map theme descriptions can be found in the appendices, but technical description, like database structures and feature class relationships diagrams are not included.

## 1.2 GTK mapping tradition and legacy information

GTK has systematically mapped the geology and Earth resources of Finland for well over 100 years. The geology of Finland is characterized by Precambrian crystalline bedrock (Fennoscandian Shield) covered by a thin layer of Late Quaternary superficial deposits. The distinctly two-fold characteristics of Finnish geology are directly reflected in the mapping practices and research traditions in Finland.

The limitations of traditional lithostratigraphic methods in meeting the needs of both Precambrian and Quaternary geology are widely recognized (cf. NACSN 2005), and the strong lithology-based mapping tradition in Finland can be seen as a consequence of this. The Precambrian terrain has traditionally been mapped according to the rock types of different age groups, and the Quaternary unconsolidated deposits have been divided to classes by the sediment type and the grain size class. In 2008, GTK bedrock mapping was directed towards a unit-based (litostratigraphic-lithodemic) approach, and as a result, a seamless 1:200 000 scale bedrock compilation with a linked non-spatial unit database (Finstrati) was established in 2009 (see Luukas et al. 2017). Mapping of superficial deposits by GTK followed this example a couple of years later, and a new database for Quaternary map units has been defined (Palmu et al. 2021; this volume).

The division of geological units is essential in order to understand the geometry and sequence of rock bodies. Such an approach has many advantages regarding both the arrangement of the geological content and technical aspects (such as database structures). The original Finstrati has been reviewed and divided to FinstratiKP for the Precambrian units and FinstratiMP for the Quaternary units.

The stepwise evolution path of the long-term regional mapping programmes of GTK includes some major milestones, for example:

- Since the 1980s, all the bedrock field observations have been stored in a GTK database
- Since the 1990s, the GIS implementation has resulted in fully digital mapping and map production processes
- In 2005, the map sheet-based approach was replaced by seamless map databases
- Since 2008, in (Precambrian) bedrock mapping, the lithology (rock type)-based procedure has been progressively replaced by a geological unit-based method; introduction of the Finstrati concept.
- Since 2016, the superficial (Quaternary) geology mapping process has been completely renewed following the emergence of LiDAR imagery
- In 2018, construction of the Finstruct database and linked structural and tectonic map themes (bedrock) was started

The amount of GTK legacy information is vast, and a major part of this has been digitized and utilized in the production of the current core data, such as the MDA map themes. These data are a major asset for GTK, but consistency, metadata and data access still need improvement. GTK's field mapping activities have considerably declined during the last ten years, but the extensive GTK databases combined with a modern information infrastructure provide an applicable and informative working environment for novel geological interpretations and an excellent starting point for targeted field operations.

## 1.3 GTK Map Data Architecture as part of the National Geological Framework of Finland

Within the overall 3DSuomi frame, the **National Geological Framework of Finland (NGFF)** means the harmonization, 3D extension and consolidation of the GTK information infrastructure (Fig. 1).

The overall objectives of the NGFF cover all aspects of the GTK mission. In short, the NGFF is the conceptual and technical framework for geological research in 2D and 3D. Ideally, the NGFF will be able to:

- Accommodate 2D and 3D models of different extents and scales representing various themes of geology (e.g., tectonics, mineral systems, engineering geology) by applying the National Data Architecture
- Provide a national reference and spatial 3D framework
- Provide a technology architecture, including 3D software and 3D data storage solutions needed for the implementation of 3DSuomi
- Activate innovative new applications, interpretations and 2D and 3D models

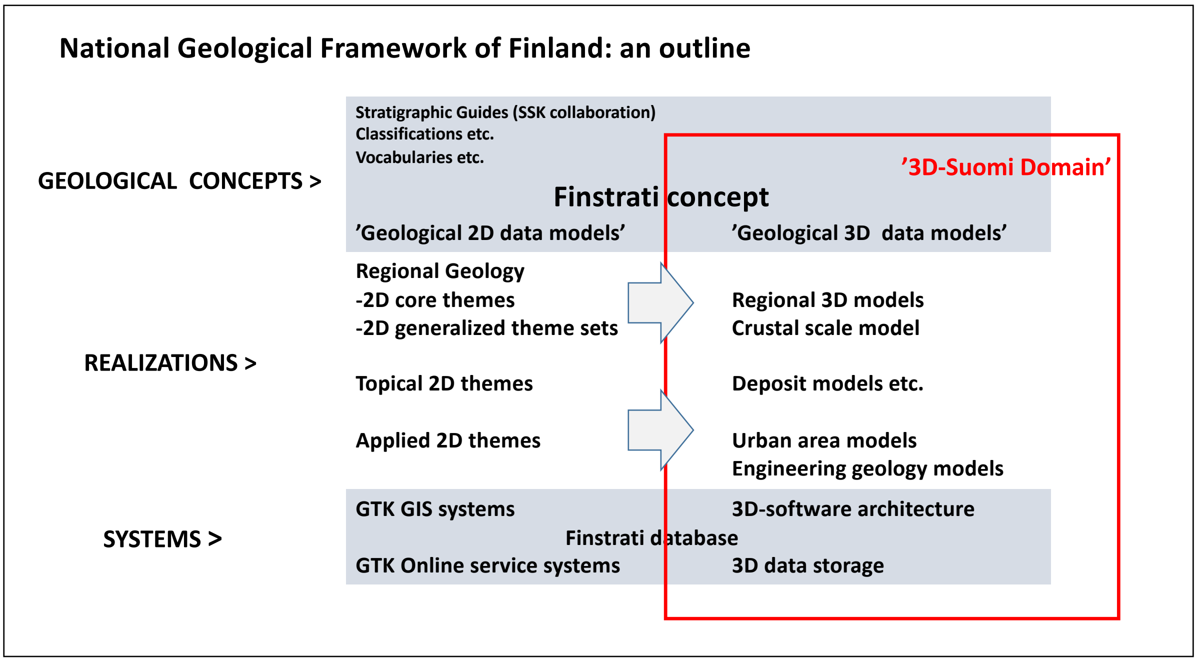


Fig. 1. A schematic diagram of the 2D to 3D transformation at GTK. The 3D realizations (models) build on 2D map data. Solid geological data models with supporting scientific documentation and robust technical systems form the framework for 3D modelling.

The **NGFF Data Architecture** is based on defined concepts, data models, vocabularies and international standards. Such an information system for all corporate data, including primary and interpreted 2D and 3D presentations and models, would ideally increase both the efficiency of processes and the quality of the end products in all activities, including contracted projects and customer solutions, mapping processes and scientific interpretations. At the same time, a well-organized and well-structured database would be a major asset for the long-term relevance of GTK as a science-based agency and an authority holding and maintaining geological data in Finland.

The GTK Business Architecture (processes and services) is in continuous interaction with the Data Architecture, which in turn is supported by Application and Technology Architectures. The NGFF Data Architecture consists of components that are essential for 2D and 3D data production and forms a subset of the entire GTK Data Architecture (Fig. 2). This paper focuses on the GTK Map Data Architecture (see Fig. 3), which currently, by volume at least, forms the core part of the developing NGFF data architecture.

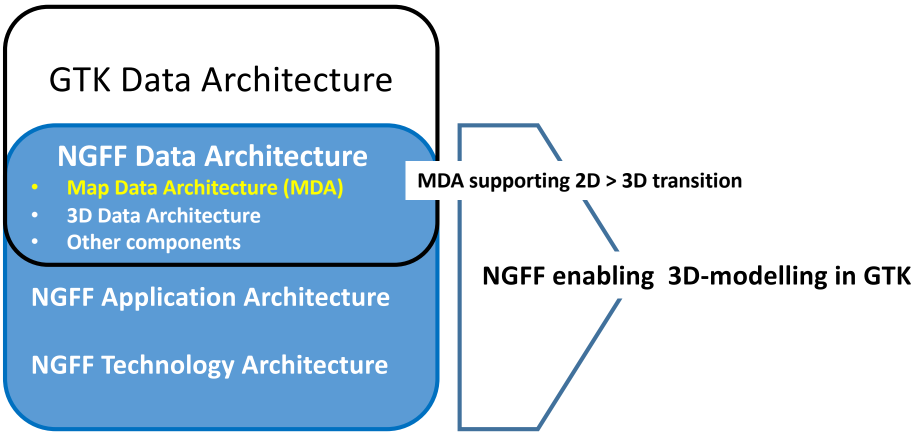


Fig. 2. NGFF domains essential for the implementation of an appropriate corporate-level 3D work process at GTK.

The National Geological Framework of Finland is a long-term objective: a structured information system and technology platform providing tools for efficient access to both primary data and interpretations. The general requirements for the NGFF are condensed to the following points: (1) the data models must be nationally relevant and compatible with international standards, (2) the framework must be capable of accommodating various geological themes, such as tectonic modelling, aquifer modelling and mineral systems modelling, (3) the fundamental, nationwide models must act as an integrated basis for various types of geological interpretation and applications, and (4) the framework should have capabilities to guide future geoscientific research.

The implementation and management of an enterprise-scalable Map Data Architecture requires clear business rules for data security, ownership, and authority for all data that is stored in databases. Integration of data from different sources will require the maintenance of adequate metadata such that the original source for each data object can be determined and traced.

**PHASE 1**

- Conceptual modelling
- Definition of the overall (spatial) data architecture (structure of the information infrastructure)

**PHASE 2**

- Definition of the spatial data themes (main feature classes)
- Linked datasets (e.g. Geological Units)
- Outline of the application architecture (e.g. software and database solutions)
- Implementation of the 2D architecture

**PHASE 3**

- Integration into international data services
- Implementation of the 3D architecture

**IN ALL PHASES**

- Strategic planning
- Project planning
- Application of standards and international guidelines
- Training programmes
- New and updated data products and online services

Fig. 3. A schematic diagram of NGFF implementation.

## 2 GTK MAP DATA ARCHITECTURE

### 2.1 Conceptual framework

All geological information, including geological units, is based on primary data (e.g., observations, measurements) and interpreted spatial features (e.g., geological unit boundaries, structures) with documented scientific descriptions, such as reports and articles. However, all the map features and geological depictions are eventually abstract conceptions managed by conceptual modelling. The maps and models consist of geometric objects representing geological features defined by the specific main descriptor, such as ‘rock type name’, ‘lithostratigraphic unit name’, ‘tectonic province name’ or ‘fault type’ (Fig. 4). It is essential to see the distinction between **map data** and their **cartographic map symbolization**. Map data are geological features in a real-world spatial reference framework whereas cartographic map results in symbolization of those via coloured areas, lines and map symbols.

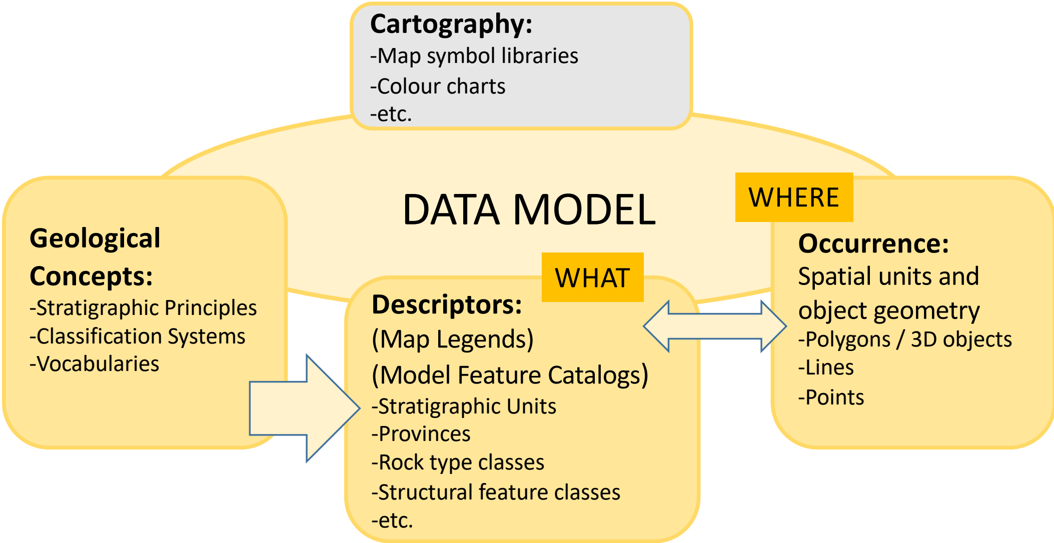


Fig. 4. Simplified representation of the generic data model for geological maps and models. The presence of an object is described by 1) its **spatial features** and 2) its properties with a defined set of **descriptors**. (Diagram modified after Soller et al. 2005)

The conceptual level consistency, concepts associated with defined terms, form the fundamental basement of a sustainable information infrastructure. Whitehead et al. (2010) noted: '*Geoscience data capture is expensive. In order to extract maximum value, the data need to be consistently described, easily found, and then shared among those who need it. While storage and transfer standards are vital, they lack a descriptive element which standardizes the meaning of their contents.*' Without tackling the ontological challenge as such, careful conceptual modelling is one key to long-term functionality and versatility of the architecture.

The vital interaction between the advancing science (new theories and concepts) and information technology now provide unforeseen opportunities to develop completely new insights into geological mapping and modelling. Unfortunately, the systemic advantage of these extensions to traditional geological map content is not automatically accepted by all members of the community (see USGS NCGMP 2020) or gaining funds for long-term information infrastructure programs. A report by NADM-SLTT (2004) elegantly describes the deep-seated tension between 'traditionalistic, legacy oriented' and 'maximum scientific content oriented' philosophies in geological map data management. Thus, one major challenge is to compose data models that are suitable for legacy data management, but also have flexibility for extension with new schemas that allow the map compiler to represent what is actually known about the geological features portrayed on a geological map.

Our intention is to apply the international best practices and standards wherever possible. The major underlying framework is the NADM-C1 conceptual model (NADMSC 2004). The model emphasizes geoscience concepts and relationships related to information presented on geological maps, and the model documentation (https://pubs.usgs.gov/of/2004/1334/) states: '*A key aspect of the model is the notion that representation of the conceptual framework (ontology) that underlies geologic map data must be part of the model, because this framework changes with time and understanding, and varies between information providers. The top level of the model distinguishes geologic concepts, geologic representation concepts, and metadata. The geologic representation part of the model provides a framework for representing the ontology that underlies geologic map data through a controlled vocabulary, and for establishing the relationships between this vocabulary and a geologic map visualization or portrayal.*'

## 2.2 GTK approach

The arrangement of geological map data is not just a practical task. It is based on a long mapping tradition and national conventions developed over decades. Nationwide geological maps are essential components of a geoscientific framework. GTK has a long history of compiling 1:1M scale geological maps (e.g. Simonen 1980, Korsman et al. 1997, Nironen et al. 2016, Niemelä et al. 1993) and their national legends. However, the conceptual frame of a national map information system is no longer a solitary map compilation or a national legend template. Instead, the core of the geological framework is the Map Data Architecture with defined data models, classification systems and linked vocabularies. The NADM-C1 specifies the basic types of geological features, with guidelines for descriptors. It does not specify a database implementation. We apply the NADM-C1 geological concepts hierarchy with related classification systems and vocabularies to define the descriptors, which direct the division of the spatial objects of a map or 3D model.

Another key question in MDA construction is the selection of technology. GTK has experience and a long history of combining relational database and GIS technologies, but the ideal solutions for the future still need to be carefully considered. With geological data, the ultimate relational database implementations may lead to very complex database structures and result in a lack of agility in both database development and applications. In contrast, pure GIS solutions may lead to simplistic data models and poor query performance. The management of different scales of map data without duplication of the attribute data is also found as a challenge.

The GTK Map Data Architecture is planned to be a dynamically developing system of geological information (see Fig. 5), and is basically founded on three pillars:

(1) Structured **spatial data**: map objects and related attributes

(2) Structured non-spatial data: **Finstrati** databases with geological unit definitions and descriptions; the **Finstruct** database with major structure descriptions; related documentation; linked to two other pillars

(3) **Key references** with the original descriptions and scientific content

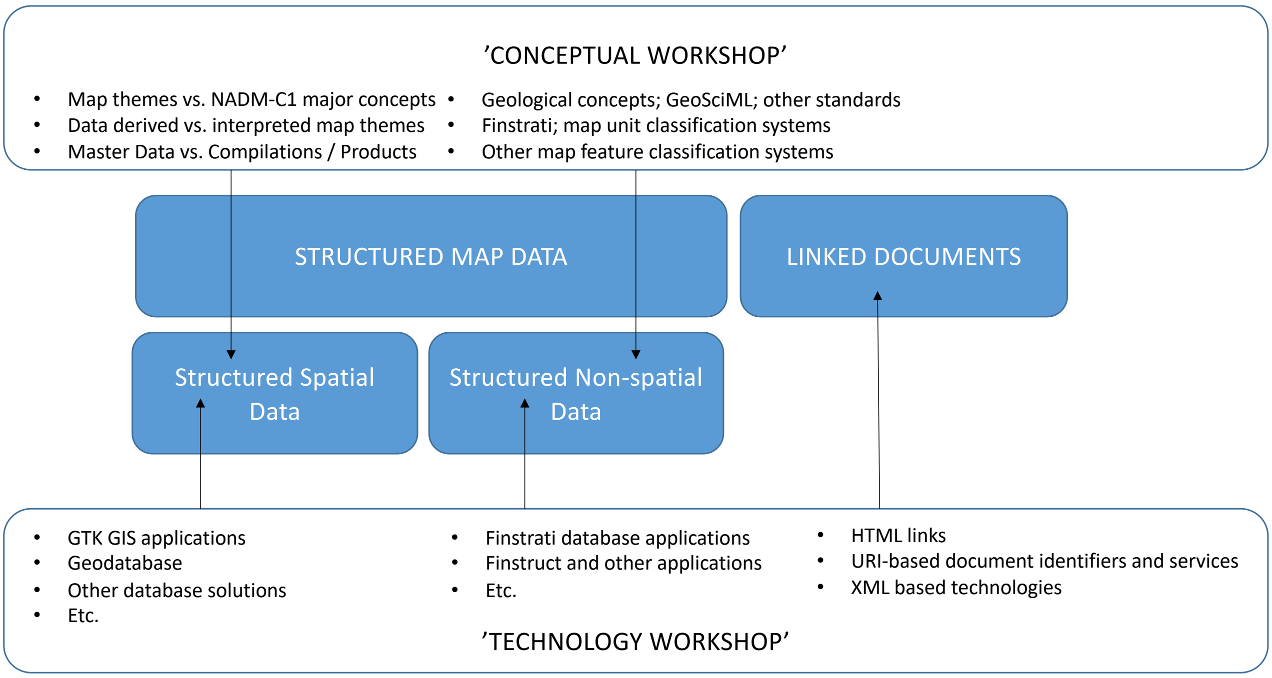


Fig. 5. The main components of the GTK Map Data Architecture (blue boxes). The architecture has been designed according to the selected concepts, definitions and geological data models by the 'Conceptual Workshop'. The functionality relies on applications and technologies selected by the 'Technology Workshop'.

The selected approach aims to combine the spatial features and systematic classification of the defined geological units with the primary description and geological interpretation. The structured non-spatial data form the scientific key element of the architecture. For example, the conceptual division of different geological units, their characteristics and attributes form the backbone of the Finstrati databases. These structured non-spatial data link the spatial master data (spatial objects) to the key references (Fig. 6). Basically, the system allows browsing from the map view to the unit lexicon (Finstrati) and further to the original scientific reference source and, in the future, also vice versa. The architecture enables access to geological information, not only to 'map data'.

The scalability is one of the major challenges in all map data applications. The selected approach described above provides two significant advantages: (1) intelligent linkage of structured non-spatial data (shared attributes between different spatial scales and between 2D and 3D models) and (2) maximal hierarchy of the non-spatial classification systems. The first reduces duplication of attributes for different spatial scale compilations, and the second utilizes the traditional scalable classifications (e.g., group – formation – member – bed). Most importantly, the integrity of the structured non-spatial core data is sustainable compared to data stored in numerous attribute tables. The linked non-spatial databases allow basic queries from GIS-based services.

All the structured map data are quality controlled and maintained by GTK; the appropriate metadata is the most essential component of documentation. Some of the linked documents, such as data models, database descriptions and map theme feature catalogues, are also produced and updated by GTK (see Fig. 6). In addition to maintaining geological information, the GTK Map Data Architecture is an essential component of GTK's ongoing data production processes and services. New map data are generated in research projects or received from external sources (e.g., academia, companies). The project map library is the primary storage for these outputs, and after a harmonization process, the data are incorporated into the structured GTK map database (Fig. 7).

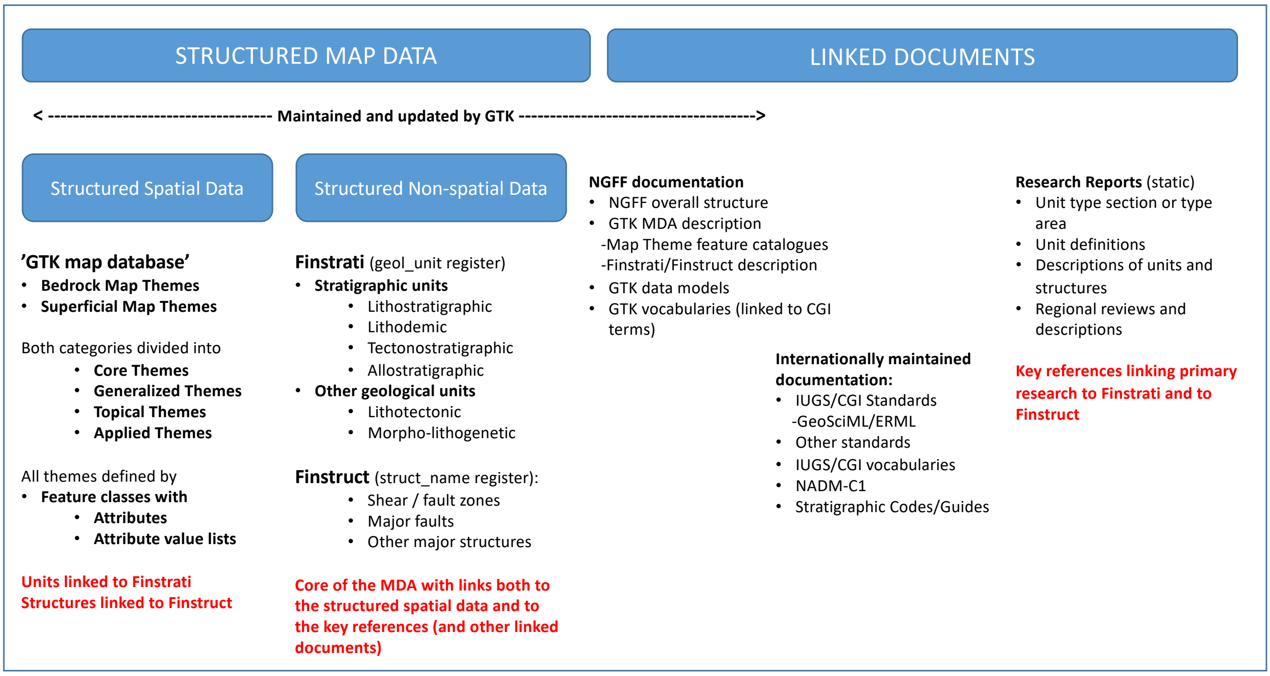


Fig. 6. The overall structure of the GTK Map Data Architecture. Finstrati and Finstruct link the spatial map units to the primary research reports. The consistency of the system is supported by NGFF documentation and international standards. The structure allows extensions from 2D map themes to 3D models without any major modification.

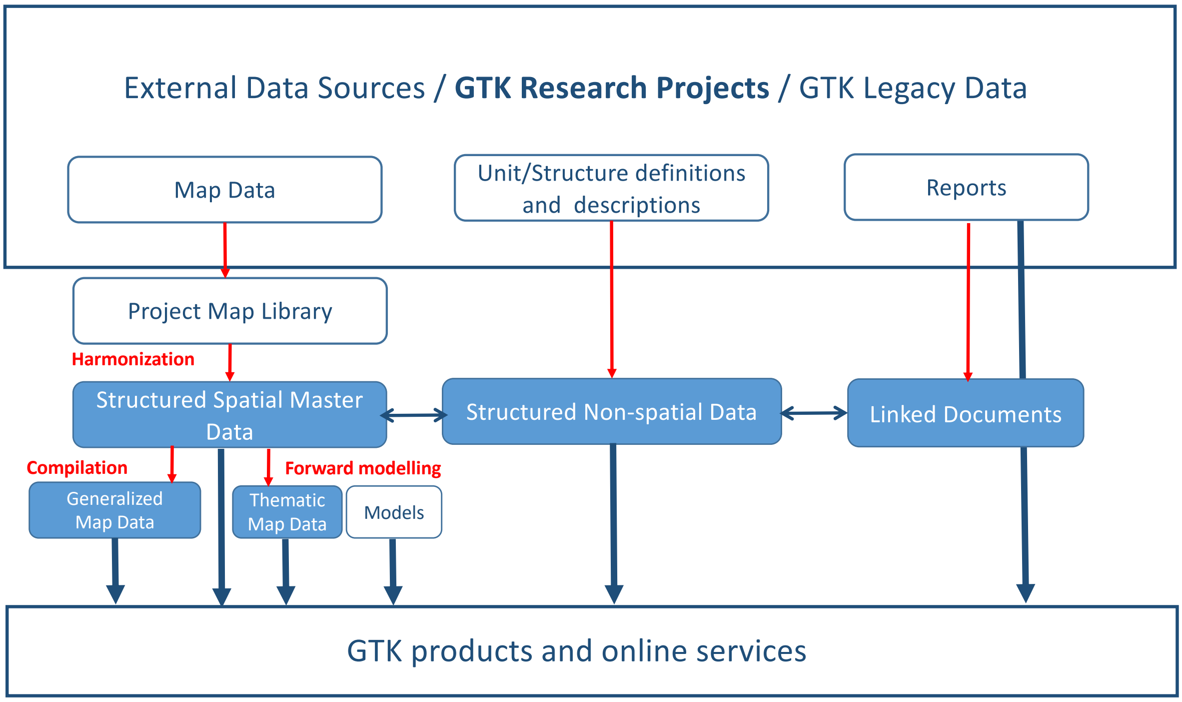


Fig. 7. The GTK Map Data Architecture (blue boxes) is positioned between data input (top) and the GTK customer interface (bottom).

## 3 STRUCTURED MAP DATA

Structured map data refers to thematically and hierarchically arranged datasets with defined features and controlled vocabularies. Structured map data comprise the GTK Map Database (spatial data) and Finstrati and Finstruct databases (non-spatial data). The system supports easy access and the orderly use of map data in any forward modelling process and enables defined update procedures for all parts of the system.

### 3.1 GTK Map Database: structured spatial data

The GTK Map Database is a structured system for the interpreted spatial 2D information. The attribute data are stored in theme-specific GIS attribute tables. All the attribute value lists are composed according to internationally recognized classification systems with some national modifications (e.g. rock name value lists as part of the system documentation). The key attributes link map features (geological units and the major structures) to the Finstrati and Finstruct databases.

Structured spatial master data (Core Themes; see Fig. 6) are the first-generation harmonized, structured map data arranged as thematic layers according to the main feature classes derived from the NADM-C1 conceptual model. The master data are regularly updated by the harmonization of new map data gathered in the project map library (Fig. 7), ensuring and checking that map features are linked to the non-spatial databases. The master data are the primary source for modelling processes and generalized or thematic map compilations. Basically, structured spatial data are not limited to 2D map data. A major part of the interpreted map data is used as input data in 3D modelling and, consequently, the models have close ties to the spatial map data and to the related attributes. In the future, the 3D spatial objects can be incorporated as part of the system by an extension or as a separate system linked to the GTK MDA.

Bedrock geology and superficial geology form the main branches of the GTK Map Database. The map themes of both branches are divided into core themes and other themes. A more detailed description of the GTK Map Database can be found in the Appendices, but the components are summarized as follows:

**Core Themes** (Regional geology master data)
- 'Evergreen' thematic compilations with a regular update procedure by GTK
  - New data from project maps (harmonization)
  - Primary update to the core theme (not to generalized themes or digital products)
- Spatial map data in full resolution (not generalized to any nominal map scale)
- New feature classes and features added with developing science and the conceptual model

**Generalized themes**
- Selected set of core themes generalized for the production of digital or printed map products with lay-out and map symbols
- Generalized regional data are widely used in the creation of research report figures and as the background of thematic map compilations

**Topical themes**
- Themes displaying scientific interpretation (e.g. regional variation of metamorphic grade)
- Data usage with reference to compilers only

**Applied themes**
- Themes related to applied geology (e.g. engineering geology, aggregates)

The NADM-C1 top-level geological classes (Geological Unit, Earth Material and Geological Structure) form the main frame for the conceptual modelling of the GTK master map data. The *core themes* with the underpinning regional geology conceptual model form the cornerstone of the systematic production and storage of the (interpreted) map data by GTK. The objective of the core theme definition was to create a map database with (1) a science-based thematic division, (2) minimum overlap between the themes and (3) appropriate options for extension with a minimum risk of conceptual-level inconsistencies.

*Topical and applied themes* are linked on conceptual level to the GTK regional geology model and the shared features are identical. The geological data model and corresponding feature catalogues are extended by features specific to the topic (Fig. 8). The feature catalogues for solitary maps (e.g., project maps) are also supported by the GTK geological data models and map theme feature catalogues. The use of identical features is recommended to support the incremental update of the core themes. In principle, the configuration of the map theme

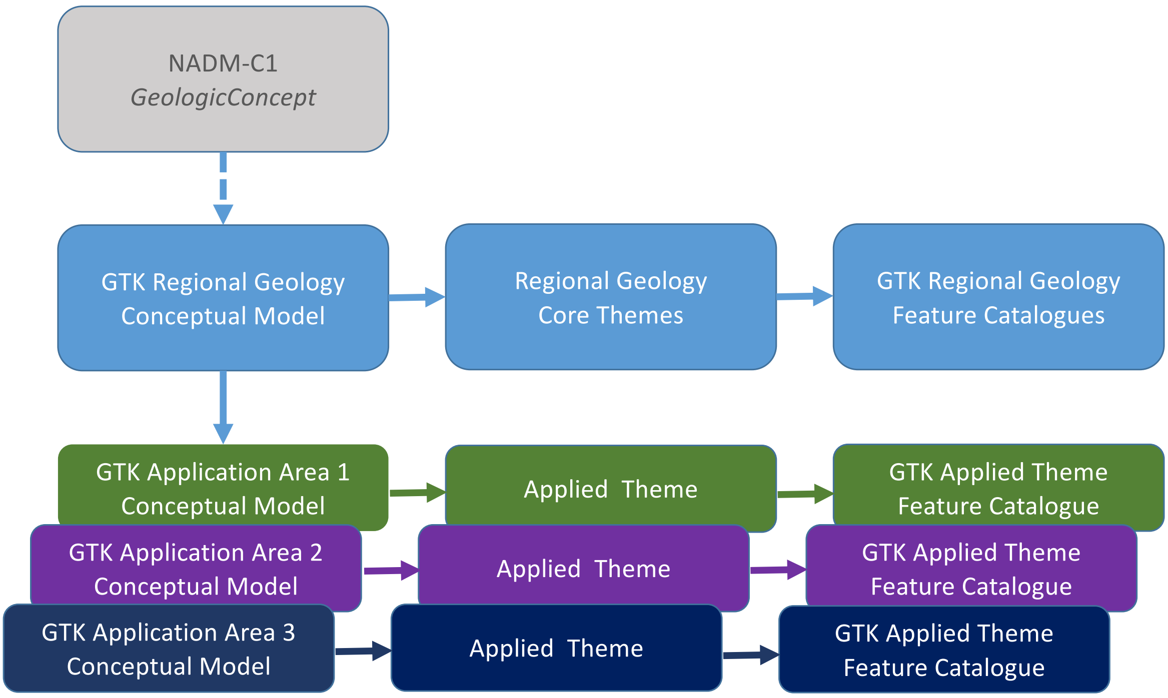


Fig. 8. Conceptual-level consistency is a major requirement for structured spatial data. International compliance is supported by linking the *GTK regional geology conceptual model* to NADM-C1. The consistency of the GTK Map Database is based on a harmonized system of all the conceptual-level models. As a result, the *feature catalogues of the applied and topical themes* (lower right in the diagram) form an extendable system with the basic conceptual framework inherited from the generic conceptual models.

follows the same steps as the process for a solitary map or model:

- Map theme definition with theme-specific features (descriptors derived from the conceptual model)
- Connection of the features to the spatial objects (e.g., polygons, lines).
- Generation of the map theme feature catalogue (main feature classes, features)
- Terminological definition of the features and related attributes (mainly by links to CGI / INSPIRE vocabularies)
- Compilation (or checking) of attribute value lists used by GTK

### 3.2 Finstrati and Finstruct: structured non-spatial data

In a traditional GIS approach, the attributes characterize the spatial geometric objects. In the GTK MDA the non-spatial data together with key references address the geological ideas underpinning the spatial objects. The linked but solitary non-spatial database (see Fig. 6) extends the MDA to a digital lexicon and to management of geological units and structures. These features are defined and named as a result of geological research, and the link to key references is therefore an essential part of their management.

The geological units and structures comprising Finstrati and Finstruct, respectively, may be linked to an unlimited number of spatial objects (2D/3D; surface/subsurface). Nonetheless, the geological features are not only attributes of a polygon or line, but conceptual geological features basically independent of object geometry. Therefore, the Finstrati units (and Finstruct structures) must not have a corresponding map object. For example, a defined lithostratigraphic member or bed may be too minute for any map scale in use, but it forms relevant component of the structured non-spatial data. Spatially it is confined by the parent unit, and the description can be found in the original reference. Currently the MDA structured non-spatial data consist of the following parts:

- Non-spatial unit databases
  - FinstratiKP (Bedrock geology unit database)
    - Stratigraphic units
      - Lithostratigraphic units
      - Lithodemic units
    - Lithotectonic Units
      - Tectonic-scale units
      - Thrust-bounded units
  - FinstratiMP (Superficial geology unit database)
    - Stratigraphic units
      - Lithostratigraphic Units
      - Allostratigraphic Units
    - Morpho-lithogenetic Units
    - Glacial Dynamic Provinces and Regions
  - Finstruct (Bedrock structure database)
    - Major (named) structures

## 4 CONCLUDING REMARKS

Geology, as a science, is fundamentally based on concepts, models and theories. Geology is rich in terminology, and the AGI Glossary (Neuendorf et al. 2005) has nearly 40 000 entries. As research advances, our concepts are improved and modified. This, together with developing information technologies, makes the systematic storage of geological information, including both legacy data and new observations, a highly challenging task.

The fundamental importance of consistency at the conceptual level is widely understood, but as concepts are developing within different branches of geology (e.g., mineral systems, engineering geology), full coherence may not be a realistic objective except for the highest conceptual levels. Nevertheless, many practical reasons call for increased conceptual consistency. The versatility of map data (and all interpreted data) will be improved when the different domains, such as scientific research, regional geology and applied geology, share the same national or international system. The coordinated system of thematic data sets (Data Themes) will ideally support this development at GTK and in Finland. The MDA improves the interoperability of GTK data regarding both international data infrastructures, such as INSPIRE (Cetl et al.

2019), EGDI (www.europe-geology.eu) and more science-oriented Macrostrat (Peters et al. 2018).

Structured geological data, with definitions, hierarchies and sufficient metadata, improve the quality of any forward modelling process, either in 2D or 3D. Geological 3D modelling at various scales, and especially implicit modelling, sets high requirements for the input data, including the interpreted geological map data. The concrete benefits of the MDA for 3D modelling include: (1) improved quality control of 2D input data, (2) shared names and attributes in the MDA in 3D models, (3) scalability provided by the unit hierarchies and (4) the linkage of the regional and applied models by conceptual-level consistency partly of the data models.

The trend is from qualitative description to quantitative (or semi-quantitative) data sets. These types of attributes, such as rock density and modal composition, are of growing importance. Structural geology and structural data are developing together with the modelling, and the systematic classification of spatial structural features will support both geological 3D modelling and the regional mapping of different structural domains.

The geological map has dominated the landscape for more than 200 hundred years. The traditional printed map, or geological 2D model of the region, obviously has a very limited capacity to depict all the geological detail or the phenomena related to geological evolution. Furthermore, the technical limitations of the map (such as the defined scale and use of symbols) have unfortunately reflected mapping specifications and regional geological data models; in many cases, we have literally been 'mapping', not collecting data for geological research in all its richness. New technologies have fundamentally changed the situation, and our task is to utilize this opportunity. The GTK Map Data Architecture is one step from the map-dominated (spatial, GIS technology) approach towards content-oriented (conceptual, information systems) geology.

## ACKNOWLEDGEMENTS

The numerous discussions with our international and GTK colleagues are greatly appreciated. We are grateful to C. Loiselet and J. Virtasalo for their careful reviews.

## LIST OF APPENDICES

The appendices are part of MDA documentation and will be updated on a regular basis.

**Appendix 1** Structured spatial map data; **Bedrock**; map themes and main feature classes

**Appendix 2** Structured spatial map data; **Superficial deposits**; map themes and main feature classes

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# APPENDIX 1

15.9. 2020

# STRUCTURED SPATIAL MAP DATA; BEDROCK; MAP THEMES AND MAIN FEATURE CLASSES

*J. Kohonen & J. Luukas*

## 1 GENERAL DESCRIPTION OF SPATIAL MASTER DATA ('GTK Bedrock Map database')

GTK Bedrock map database is part of the GTK Map Data Architecture (see Ahtonen et al. 2021; this volume). This document describes the current structure of the spatial bedrock map data (interpreted data): (1) the underpinning conceptual model, (2) the map features arranged according to Geologic Concept hierarchy and (3) the division to map themes.

Key part of the system are the Core Themes. Core themes contain the map data structured according to defined classification systems. The Core Themes (spatial master data) and the linked non-spatial databases (FinstratiKP, Finstruct) constitute Regional Master Data (bedrock), which is maintained and updated on regular basis by GTK. Regional Master Data form the source for both generalized data sets and thematic data sets (Fig. 1).

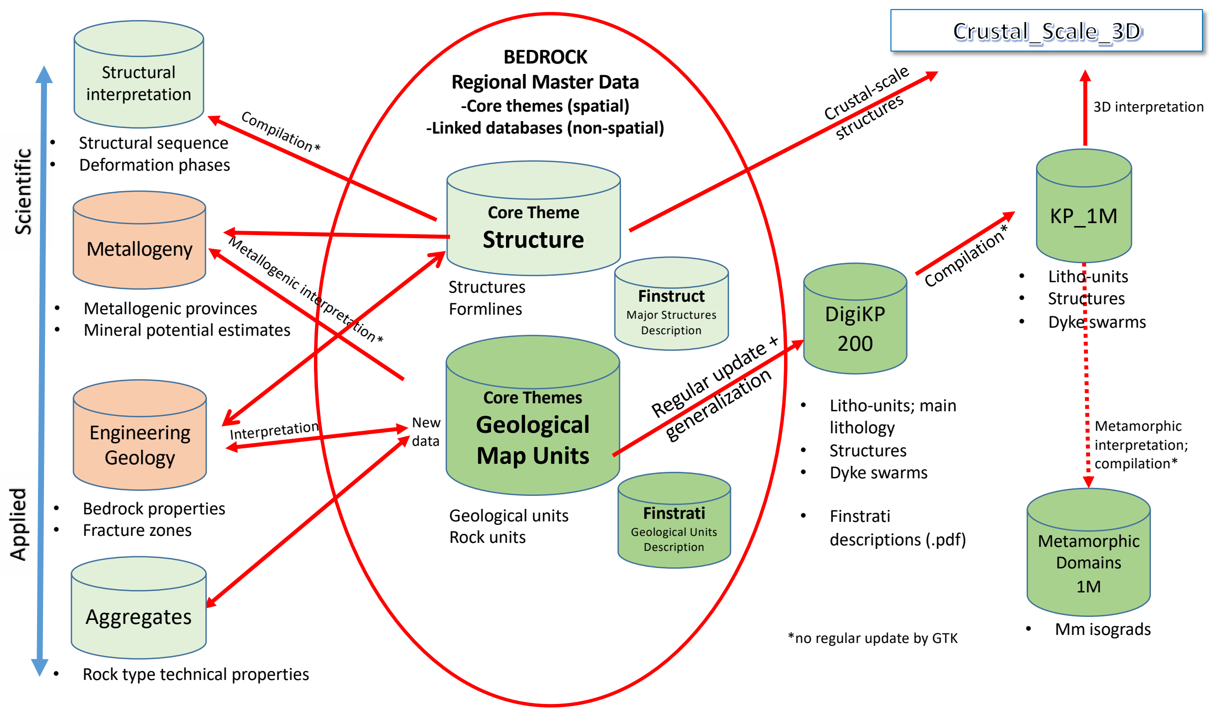


Fig. 1. Diagram illustrating the vision for the functionality of the GTK Map Data Architecture (bedrock). The core of the system are Regional Master Data (spatial and non-spatial) regularly updated by GTK. Generalized theme sets (upper right) and the Topical / Applied themes (left and lower right) are also shown. (Green components are implemented, light green are progressing and red are in planning stage).

## 2 CONCEPTUAL FRAMEWORK OF REGIONAL GEOLOGICAL DATA (bedrock)

The main feature classes are arranged according to NADM-C1 top-level Geologic Concept hierarchy (Fig. 1 and Table 1). The basic idea is to support the further arrangement of map features into thematic layers called as 'Map Themes'.

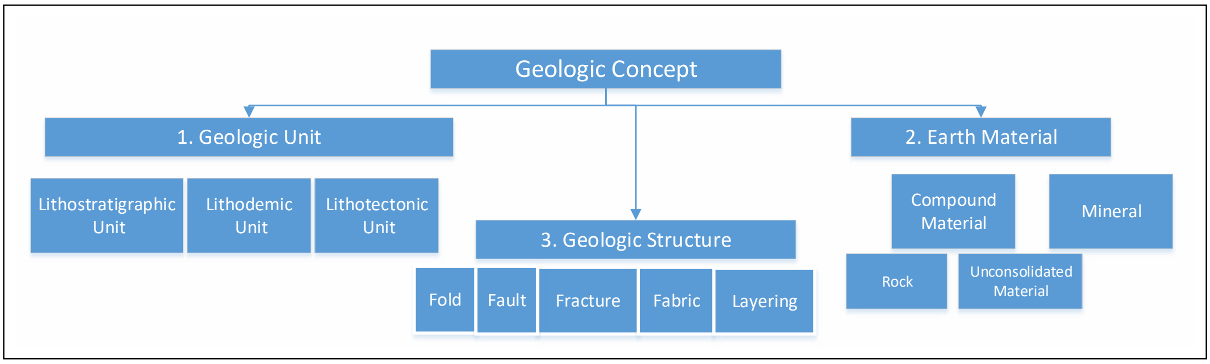


Fig. 2. Diagram displaying the NADM-C1 top-level Geologic Concept hierarchy.

Table 1. The main feature classes used in GTK regional bedrock mapping arranged according to the NADM-C1 top level Geologic Concepts. Terms directly corresponding to NADM-C1 are indicated in grey.

| **1 Geologic Unit** | **2 Earth Material** | **3 Geologic Structure** |
|---|---|---|
| 1.1 Litostratigraphic unit | 2.1 Compound material<br>2.1.1. Rock (rock type)<br>2.1.1.1 Weathered rock<br>2.1.1.1.1 Regolith/paleosol<br>2.1.1.1.2 Hydrothermally altered rock | 3.1 Fold |
| 1.2 Lithodemic unit | 2.2 Mineral<br>2.2.1 Metamorphic (index) mineral<br>2.2.2 Ore mineral | 3.2 Displacement structure<br>3.2.1 Fault<br>3.2.2 Fault zone<br>3.2.3 Shear zone |
| 1.3 Thrust-bounded unit ('tectonostratigrahic unit') | | 3.3 Fracture |
| 1.4 Lithotectonic unit<br>1.4.1 Crustal Province<br>1.4.2 Tectonic Province<br>1.4.3 Structural Province<br>1.4.4 Geologic Region | | 3.4 Fabric<br>3.4.1 Foliation<br>3.4.2 Gneissic banding/ migmatite veining<br>3.4.3 Lineation |
| | | 3.5 Layering |
| | | 3.6 Sedimentary structure |

# 3 SPATIAL OBJECTS TYPES (polygons, lines, points) AND MAIN FEATURE CLASSES

The main objective here is to connect the geological features (or feature classes) used in portrayal of regional geology to spatial object types. Basically the object type (polygon / line) is dependent on the map scale and all features can be linked to any spatial object type. Table 2 describes the linking in map scales currently used at GTK. The point data, features linked only to points, form a special case. All point data sets can be displayed in any scale and those data do not have a direct connection to the division of the thematic layers (Map Themes). These map features (e.g. observation locations, structural strike/dip symbols) are omitted from Table 2. In some cases map-unit polygons are too small to show at scale and are presented as point symbols (e.g. kimberlites, impact rocks) and these cases are included to Table 2.

Table 2. The linked to Table 1 (numbers) and spatial objects (Polygon / Line) corresponding to those in GTK Regional Geology Maps. Features occurring only as points are omitted (see text). X = in use; (X) possible but not in use with core data

| | Polygon | Line | (Point) |
|---|---|---|---|
| **1 Geologic Unit** | | | |
| 1.1 Litostratigraphic unit | X | (X) | |
| 1.2 Lithodemic unit | X | (X) | |
| 1.3 Thrust-bounded ('tectonostratigrahic') unit | X | | |
| 1.4 Lithotectonic unit | X | | |
| **2 Earth Material** | | | |
| 2.1.1 Rock (type)* | X | X | (X) symbol |
| 2.1.1.1.1 Regolith/Paleosol | (X) | | |
| 2.1.1.1.2 Hydrothermally altered rock | | (X) | |
| **3 Geologic Structure** | | | |
| 3.1. Fold (axial plane trace) | | X | |
| 3.2.1 Fault | | X | |
| 3.2.2 Fault zone** | | (X) (1M-10M scale) | |
| 3.2.3 Shear zone** | | (X) (1M-10M scale) | |
| 3.3 Fracture | | X | |
| 3.4.1 Foliation (trend) | | X | |
| 0.0 Undefined structural trend / formline | | X | |
| 3.4.2 Migmatite veining / Gneissic banding (trend) | | | |
| 3.5.1 Layering (trend) ('bedding') | | X | |

*rock type not only material property; partly depends on texture; e.g. gneisses, pyroclastic rocks
**zones will be presented spatially as collection of other features (e.g. faults, fractures)

# 4 DIVISION OF BEDROCK MAP THEMES

Thematic division of the map data is building on the work done over the years with GTK. Main reasons for the current restructuring are: (1) to improve the documentation; (2) to provide clear concepts and definitions in all levels; (3) to refine the terminology between the (digital) map data and the (digital) map products and (4) to clarify update responsibilities and procedures.

- Core Themes
  - Regional Master Data (spatial); map features arranged and attributed according to the best available classification systems / standards
  - Core part of GTK Corporate Data (internal GTK system; access: all in GTK)
  - Regular update by GTK (standard procedure and responsibilities defined)
- Generalized Themes
  - Data sets corresponding to products (generalized/modified from Regional Master Data)
  - Theme: DigiKP200
    - IPR: GTK corporate; Access: All in GTK; License: see product 'Kallioperä 1:200 000 / Bedrock of Finland 1:200 000'
    - Regular update by GTK
  - All other themes:
    - IPR: reference to compilers recommended; Access: All in GTK; Open License (see the corresponding products)
    - Static (no regular update)
- Topical Themes
  - Metamorphic Domains
  - Other themes currently mostly data sets corresponding to products
  - IPR: reference to compiler(s) required; Access: All in GTK; License: mostly Open License (see the corresponding products) or defined in data set metadata
  - Update: Static (no regular update; possible update by compilers)
- Applied Themes (currently no themes defined)

The more detailed description and documentation, like attribute and value lists, database structures and feature class relationships diagrams are developed and maintained as part of the GTK MDA documentation. Also MDA documentation structure, Finstrati / Finstruct descriptions and the glossary of key terms will be presented in separate documents.

DigiKP themes (Core Themes 'Lithological Unit' and 'Structure') are the main source data for the generalized theme DigiKP200, which is the most frequently used compilation in various online product and services. The other Core Themes are indicated by CT in the theme name. In the following: P=polygon, L=line, Pt=point.

### A) Core Themes; Bedrock

**1 DigiKP_Lithological_Unit** (Linked to FinstratiKP)
Main feature classes (FIN: pääkohdeluokat):

- Lithostratigraphic/Lithodemic unit P
- Dyke L (Lithodemes; P/L depends on resolution)

NOTE:

- For description of the units – see **FinstratiKP**
- 'Main rock type' is here an attribute of the map the geological unit
- Dyke / dyke swarm is defined in **FinstratiKP** as lithodeme (suite)
- For 'Dyke swarms' – see 'topical themes'

**2 CT_KP_Rock Type**
Main feature classes (FIN: pääkohdeluokat):

- Rock type P
- Rock type L
  - Vein (e.g. large Q-veins)
  - Dyke rock (e.g. diabase, lamprophyre)
  - Interbed (e.g. black shale, carbonate rock, conglomerate)
- (Minerals Pt)*
- Hydrothermally altered rock (alteration zone)

NOTE:

- 'Rock type' is here the main descriptor of the map feature defining the P/L
- Rock type L features are spatial lithological features (located) – not structural pattern lines (see CT_KP Structure)
- Dykes are mainly defined as lithodeme (see DigiKP Lithological Unit); the dyke rock here is a rock type; not a lithodemic unit
- *Metamorphic index minerals and ore minerals may be presented as point symbols

**3 CT_KP_Thrust-bounded Unit**
(Linked to FinstratiKP)
Main feature classes (FIN: pääkohdeluokat):

- Tectonostratgraphic unit* P
- Allochthon P
- Thrust block P
- Thrust stack P
- Thrust sheet P

NOTE:
- See Luukas & Kohonen (2021; this volume) for details of the classification
- *Tectonostratigrahic unit is here a subclass of thrust-bounded unit

**4 CT_KP_Lithotectonic Unit** (Linked to FinstratiKP)
Main feature classes (FIN: pääkohdeluokat):
- Crustal Province P
- Tectonic Province P
- Structural Province P
- Geologic Region P
- Suture zone boundary* L

NOTE:
- See Kohonen et al. (2019) for details of the classification
- *Suture zone (or Cryptic suture zone) is the area between the Tectonic Provinces; spatially defined by Tectonic Province boundaries

**5 DigiKP_Structure** (The named structures linked to Finstruct)
Main feature classes (FIN: pääkohdeluokat):
- Fault L
- Fracture L
- (Fault zone)*
- (Shear zone)*
- Fold axial plane trace L
- Form line L
  - Layering trend (primary)
  - Foliation trend
  - Gneissic banding trend
  - Migmatite veining trend
    - Neosome
    - Paleosome
  - Other formlines
    - Magnetic trace trendline
    - EM trace trendline
    - Undefined structural trend (muotoviiva) esim. vanhat muotoviivat, joiden tuotantotapaa ei tunneta

NOTE:
- Characterization of the features mainly in attribute table (description partly in **Finstruct)**
- *No spatial feature in this theme; all defined and named in **Finstruct**
- Any spatial features (faults, fractures) may be linked to a zone (defined in **Finstruct**)
  - Fault, fracture (fold) are the basic units (like Fm)
  - Basic units may be arranged under fault zone, shear zone (like Group)
- **Fault zone** corresponds to 'brittle/semiductile shear zone'
  - system of faults
  - set of faults related to the same major structure (e.g. Suhmura thrust zone)
- **Shear zone** refers to a zone with **ductile / semiductile zone of strain partitioning**
  - system of faults and/or smaller high strain elements
  - set of faults within a regional high strain zone (e.g. Kynsikangas shear zone)
- The difference between Fault zone and Shear zone is indistinct

**6 CT_KP_Subaereal_weathering / Phanerozoic sedimentary cover remnants / Bedrock relief** (Proposed; waiting for specification)

## B) Generalized themes (data sets); Bedrock

**1 DigiKP200** (corresponding map product: Kallioperä 1:200 000 / Bedrock of Finland 1:200 000)
Feature classes (FIN pääkohdeluokat):
- Litostrat/Lithodem 200 P
- Structural lines 200 L

NOTE: Feature classes refer to generalized (200) version of the corresponding core theme

**2 DigiKP1M** (corresponding map product: Kallioperä 1:1 000 000 / Bedrock of Finland 1:1 000 000; see Nironen et al. 2016)
Feature classes (FIN: pääkohdeluokat):
- Units1M P
- Dykes1M L
- Kimberlites1M Pt
- Meteorite_impacts1M pt
- Structural line 1M L
- Tectonic Province P

**3 KP1M_yleistetty** (corresponding map product: Yleistetty kallioperä 1:1 000 000 / Generaliserad berggrund 1:1 000 000 / Generalized Bedrock of Finland 1:1 000 000)
- Feature classes (FIN: pääkohdeluokat):
- Units1My P
- Dykes1My L

- Kimberlites1M Point
- Meteorite_impacts1M point
- Structural line 1My L

**4 DigiKP5M** (corresponding map product: Kallioperä 1:5 000 000/1:10 000 000 / Bedrock of Finland 1:5 000 000/1:10 000 000; Mikkola 2017)
- Units5M P
- Structural line 5M L

**5 DigiKP10M** (corresponding map product: Mikkola 2017)
- Units10M P
- Structural line 10M L

**6 KP_2M_2001** (corresponding printed map product: Koistinen et al. 2001)
- Units2M P
- Dykes2M L
- Structural line 2M L
- etc.

**7 KP_1M_1997** (corresponding printed map product: Korsman et al. 1997)
- Units1M P ***
- Dykes1M L ***
- Kimberlites1M Point ***
- etc.

### C) 2D Topical themes (Bedrock)

**1 Metamorphic Domains** (see Hölttä & Heilimo 2017; Metamorphic map of Finland)
- Isograd pre-peak 1M
- Isograd peak 1M
- Isograd overprint 1M
- Isograd overprint2 1M

**2 Regional structural sequence (interpretation)**

2.1 Structural sequences in Central and Northern Finland (Luukas 202X; specification and compilation in progress)
- Fold hinge trace (Dn to Dn+x)
- etc.

2.2. Structural sequence interpretation (xxxxxx, 20XX; just an example – there can be several versions by different compilers)

**X. Metallogenic Provinces** (Proposed; preliminary planning in progress)

**X. Mineral Systems** (Topical theme or Core theme??) (Proposed; waiting for specification)

**X. Dyke swarms** (Proposed; waiting for revision / checking)

**X. Black Shales** (Proposed; waiting for revision / checking)

### D) Applied themes; Bedrock

**1 Aggregates** (Proposed; waiting for specification)

**2 Engineering geology** (Proposed; waiting for specification)

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# APPENDIX 2

2.2. 2021

# STRUCTURED SPATIAL MAP DATA; SUPERFICIAL DEPOSITS; MAP THEMES AND MAIN FEATURE CLASSES

*J.-P. Palmu, A. E. K. Ojala & J. Kohonen*

## 1 GENERAL DESCRIPTION OF SPATIAL MASTER DATA (‘GTK Superficial deposits map database’)

The GTK superficial deposits map database is part of the GTK Map Data Architecture (see Ahtonen et al. 2021; this volume). This document describes the current structure of the spatial superficial deposits map data (interpreted data): (1) the underpinning conceptual model, (2) the map features arranged according to the Geological Concept hierarchy and (3) the division into map themes.

A key part of the system is the Core Themes. Core themes contain the map data structured according to defined classification systems. The Core Themes (spatial master data) and the linked non-spatial database (FinstratiMP) constitute the Regional Master Data (Superficial deposits), which are maintained and updated on a regular basis by GTK. Regional Master Data form the source for both generalized datasets and thematic datasets (Fig. 1).

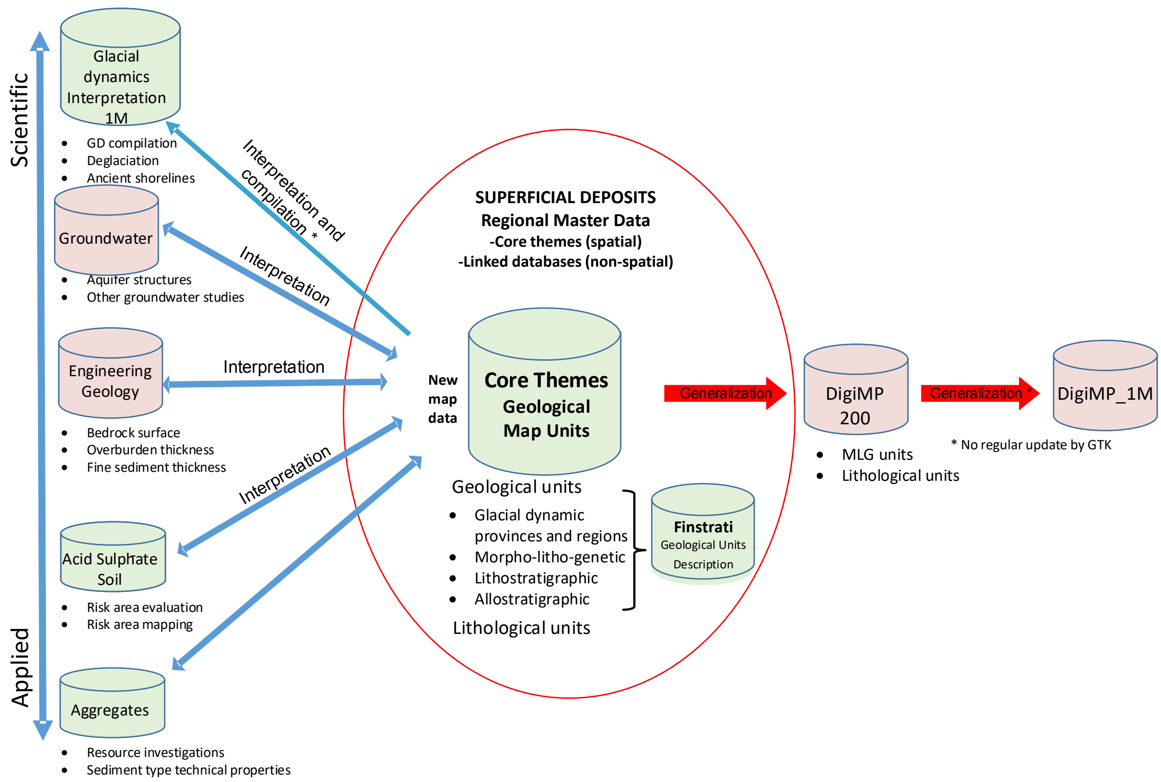


Fig. 1. The vision and functionality of the GTK Map Data Architecture for superficial deposits. The Regional Master Data (spatial and non-spatial) forms the core, which is regularly updated by GTK. The generalized theme set of DigiMP 200 is updated regularly, while DigiMP 1M is not. (The scientific and applied themes on the left are either ongoing (light green) or planned components (red) of the system.)

# 2 CONCEPTUAL FRAMEWORK FOR REGIONAL GEOLOGICAL DATA (superficial deposits)

The main feature classes are arranged according to the NADM-C1 top-level Geologic Concept hierarchy (Fig. 1 and Table 1). The basic idea is to support the further arrangement of map features into thematic layers known as 'Map Themes'.

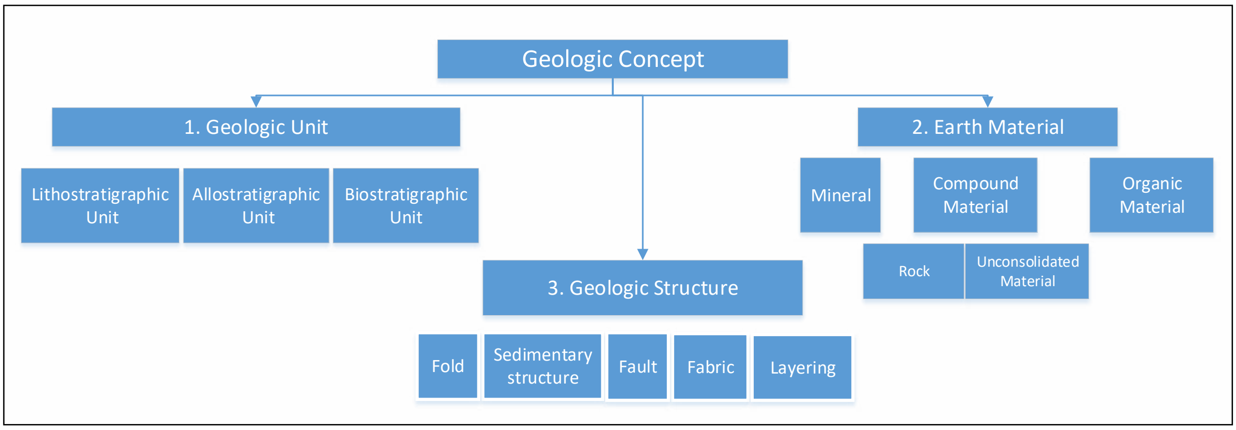


Fig. 2. Diagram displaying the NADM-C1 top-level Geologic Concept hierarchy.

Table 1. The main feature classes used in GTK superficial mapping arranged according to the NADM-C1 top-level Geologic Concepts. Terms directly corresponding to NADM-C1 are indicated in grey.

| 1 Geological Unit | 2 Earth Material | 3 Geological Structure |
|---|---|---|
| 1.1 Lithostratigraphic unit | 2.1 Compound material<br>2.1.1 Unconsolidated material<br>2.1.1.1 Gravel<br>2.1.1.2 Diamicton<br>2.1.1.3 Sand<br>2.1.1.4 Mud<br>2.1.2 Rock Material<br>2.1.2.1 Weathered rock (Regolith/Paleosol) | 3.1 Fold<br>3.1.1 Glacial deformation fold |
| 1.2 Allostratigraphic unit | 2.3 Organic material<br>2.3.1 Peat<br>2.3.2 Organic-rich sediment | 3.2 Sedimentary external structure<br>3.2.1 Depositional structure<br>3.2.2 Erosional structure<br>3.2.3 Dep./eros. structure<br>3.2.4 Synsedimentary def. structure<br>3.2.4.1 (Drumlin) lineation |
| 1.3 Morpho-lithogenetic unit | 2.4 Dumped material | 3.3 Fault<br>3.3.1 Postglacial fault |
| 1.4 Glacial dynamic unit | | |

# 3 SPATIAL OBJECT TYPES (POLYGONS, LINES, POINTS) AND MAIN FEATURE CLASSES

The main objective here is to connect the geological features (or feature classes) used in the portrayal of regional geology to spatial object types. Basically, the object type (polygon / line) is dependent on the map scale and all features can be linked to any spatial object type. Table 2 describes the linking at map scales currently used by GTK. The point data, features linked only to points, form a special case. All point data sets can be displayed at any scale, and these data do not have a direct connection to the division of the thematic layers (Map Themes). These map features (e.g. observation locations) are omitted from Table 2.

Table 2. The link to Table 1 (numbers) and spatial objects (Polygon / Line) corresponding to those in GTK Regional Geology Maps. Features only occurring as points are omitted (see text). X = in use; (X) possible but not in use with core data

| | Polygon | Line | (Point) |
|---|---|---|---|
| **1 Geological Unit** | | | |
| 1.1 Lithostratigraphic unit | (X) | (X) | |
| 1.2 Allostratigraphic unit | (X) | (X) | |
| 1.3 Morpho-lithogenetic unit | X | X | |
| 1.4 Glacial dynamic unit | X | | |
| 1.5 Biostratigraphic unit | (X) | | |
| **2 Earth Material** | | | |
| 2.1.1.1 Gravel | X | | |
| 2.1.1.1 Diamicton | X | | |
| 2.1.1.1 Sand | X | | |
| 2.1.1.1 Mud | X | | |
| 2.1.2.1 Regolith/Paleosol | (X) | | |
| 2.3.1 Peat | X | | |
| 2.3.2 Organic-rich sediment | X | | |
| 0.0. Bedrock outcrop / thin overburden | | | |
| **3 Geological Structure** | | | |
| 3.3.1 Postglacial fault | | (X) | |
| 3.2.4.1 (Drumlin) lineation | | X | |

# 4 DIVISION OF SUPERFICIAL DEPOSIT MAP THEMES

The thematic division of the map data builds on the work done over the years at GTK. The main reasons for the current restructuring are to: (1) improve the documentation; (2) provide clear concepts and definitions at all levels; (3) harmonise the terminology between the (digital) map data and the (digital) map products and (4) clarify the responsibilities and procedures for updating.

- Core Themes
  - Regional Master Data (spatial); map features arranged and attributed according to the best available classification systems/standards
  - Core part of GTK Corporate Data (internal GTK system; access: all at GTK)
  - Regular update by GTK (standard procedure and responsibilities defined)

- Generalized Themes
  - Data sets corresponding to products (generalized/modified from Regional Master Data)
  - Theme: DigiMP200 (not finalized)
    - IPR / Access / License
    - Regular update by GTK
  - All other themes:
    - IPR: reference to compilers recommended; access: all at GTK; Open License (see the corresponding products)
    - Static (no regular update)
- Topical Themes (currently no themes defined)
- Applied Themes (currently no themes defined)

The more detailed descriptions and documentation, such as attribute and value lists, database structures and feature class relationship diagrams, are developed and maintained as part of the GTK MDA documentation. The MDA documentation structure, Finstrati descriptions and glossary of key terms will also be presented in separate documents.

DigiMP themes (Core Themes 'MLG Unit' and 'Sediment Type') are the main source data for the generalized theme DigiMP200, which will be the most frequently used compilation in various online products and services. The Core Themes are indicated by 'CT' in the theme name. In the following: P = polygon, L = line, Pt = point.

### A) Core Themes (Superficial deposits)

**1 CT_MP_MLG_Unit** (Linked to FinstratiMP) (Will be finalized in 2020)
Main feature classes (FIN: pääkohdeluokat):
- Glacial dynamic unit P
- Morpho-lithogenetic unit P
- Genetic deposit type P
- *Drumlin lineation L

NOTE:
- For feature classes, see Palmu et al. (2021; this volume)
- Structure included in the unit theme due to the lack of a theme devoted to structures

**2 CT_MP_Sediment Type (Lithological map units)**
Main feature classes (FIN: pääkohdeluokat):
- Sediment type P
  - Gravel
  - Diamicton
  - Sand
  - Mud
  - Peat
  - Organic-rich sediment

NOTE:
- Compiled from 1:20k, 1:50k, 1:100k and 1:200k map sheet data; resolution variable
- An upgrade proposed

### B) Generalized themes (datasets (Superficial deposits)

**1 DigiMP200** (Proposed; waiting for specification)
Feature classes (FIN: pääkohdeluokat):
- MLG 200 P
- Sediment Type 200 P

NOTE: Feature classes refer to the generalized (200) version of the corresponding core theme

**2 DigiMP1M** (Proposed; waiting for specification)

**3 MP_1M_1993** (Corresponding printed map product: Niemelä et al. 1993)

### C) Topical themes (Superficial deposits)

**1 Ancient shorelines**
**2 Acid sulphate soils**

### D) Applied themes (Superficial deposits)

**1 Aggregates (gravel, sand)** (Proposed; waiting for specification)
- Areas suitable for aggregate production

**2 Engineering geology** (Proposed; waiting for specification)

**3 Groundwater**
- Interpolated bedrock surface
- Interpolated groundwater table

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