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GUIDELINES AND PROCEDURES FOR NAMING BEDROCK UNITS IN FINLAND : (Fully revised 2nd edition)

Kohonen, Jarmo; Köykkä, Juha; Strand, Kari

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Stratigraphic framework in Finland – formal classification and practical guidance
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GUIDELINES AND PROCEDURES FOR NAMING BEDROCK UNITS IN FINLAND

(Fully revised 2nd edition)

by

Jarmo Kohonen[1)], Juha Köykkä[2)], Kari Strand[3)] and Stratigraphic Commission of Finland (Precambrian Subcommission)*

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The Stratigraphic Commission of Finland (SCF) was established in 2006 and the first edition of *Guidelines and Procedures for Naming Precambrian Geological Units in Finland* was published in 2010. The Precambrian Subcommission of the SCF and the Geological Survey of Finland (GTK) have jointly developed the bedrock geological nomenclature in Finland, and this revised edition provides a summary of the current practices and recommendations. This guide presents the principles of the classification of geological units, the procedure for the naming of formal and informal units and advice for the application of the different classifications. Special emphasis has been placed on: (1) the combined use of lithostratigraphic and lithodemic units and (2) the classification of tectonic/structural bedrock units of Finland.

Effective communication in geosciences requires accurate and internationally consistent terminology and nomenclature. The emergence of networked and interoperable data systems and information services has underlined the need for hierarchical classification systems and globally harmonized vocabularies. On the national level, the best practices can be obeyed by creating internationally compliant information infrastructures and by enforcing appropriate scientific procedures. The principles and recommendations presented in this guide provide one practical step towards structured geological data and unambiguous nomenclature of geological units.

Keywords: bedrock, lithostratigraphy, stratigraphic units, lithodemic units, tectonostratigraphic units, sequence stratigraphy, chronostratigraphy, nomenclature, guidelines, Finland

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PREFACE TO THE REVISED 2024 EDITION

The first edition of this guide appeared more than ten years ago in 2010, resulting from collaboration between the Stratigraphic Commission of Finland (SCF) and the Geological Survey of Finland (GTK). The background information and the contributors can be found in the preface of the first edition. Since the 2010 edition, there have been significant developments in the management of geological map data in Finland. This revised 2nd edition has largely benefitted from the experience gained at GTK regarding the compilation of the seamless, national map database. One lesson learned is the need to clarify the relationship between the formal stratigraphy and the practical management of different geological map units. In 2019, the SCF formulated a procedure for the approval of formal stratigraphic units in Finland. GTK is currently maintaining a digital lexicon (FinstratiKP) for the management of all the bedrock units in Finland.

Globally, a significant change is that the different classification systems and derived nomenclature are increasingly forming a part of our information infrastructure. International initiatives, such as the European infrastructure for spatial information (INSPIRE) and the global data transfer standard for geological data (GeoSciML), are transforming our working environment and provide unseen opportunities for shared geological information. The related vocabularies are developing to international standards, and the national agencies responsible for geological information need to adapt to this change, including globally interoperable systems and compliance with the INSPIRE directive and related national legislation.

This guide, produced by the Precambrian Subcommission of the SCF, is intended to be both authoritative and helpful in explaining the stratigraphic method for practicing geologists. The main emphasis is still on the application of different classification categories and recommendations in naming the bedrock units in Finland. Compared to the first edition, the guide is more concise and practical, and attempts to provide pragmatic advice on the designation and naming of geological units. To fulfil the purpose of supporting the harmonization of the geological nomenclature and related practices, the guide would ideally be widely applied by the Finnish geological community. One of the notable changes is that this guide is now applicable to all bedrock units in Finland, without any specific emphasis on "Precambrian" geology. By design, this guide is meant to be an evolving document. Both the evolution of stratigraphy and changing means of information management may cause a need for revisions in the future.

In 2022, during the compilation of the guide, the members of the Precambrian Subcommission were: Prof. Kari Strand (chair; University of Oulu), Dr Jaana Halla (University of Helsinki), Prof. Juha Karhu (University of Helsinki), Dr Jarmo Kohonen (GTK), Dr Juha Köykkä (GTK), Dr Raimo Lahtinen (GTK) and Dr Markku Väisänen (University of Turku). The editors appreciate the collaboration within the Subcommission and are grateful for all the contributions to the manuscript. L. Wickström and E. Lehtonen are thanked for reviews of the manuscript and their constructive comments and improvements.

Espoo 01.02.2024

Jarmo Kohonen, Juha Köykkä and Kari Strand
Editors of the revised 2024 edition

1 INTRODUCTION

1.1 Background

Geological knowledge, such as scientific articles, reports, maps and models, builds on common concepts expressed by the language of geoscience. The spectrum of geological units has developed with the tradition of geological mapping, and the description and definition of different units still forms the basis for the field-based research process. To support a common understanding and consistency, geological units need to be named and classified according to the accepted international and national guidelines and stratigraphic codes. An increasingly important application area is the design of geological information systems and related data models. The search for information with modern information technology tools can be highly improved by consistent classification systems and shared vocabularies.

The Stratigraphic Commission of Finland (SCF) was founded in a constitutive meeting held on 27 February 2006 under the Finnish National Committee for Geology. The role of the SCF is to provide guidance on stratigraphic nomenclature and procedures in Finland. The development of stratigraphic procedures and management of the geological units is elaborated in close collaboration between the Geological Survey of Finland (GTK) and the SCF (Fig. 1). The increasing importance of stratigraphy, and geological classification systems in general, is due to the following reasons:

- National and international efforts to harmonize geological information;
- The establishment of geological databases requires defined, hierarchical classification systems;

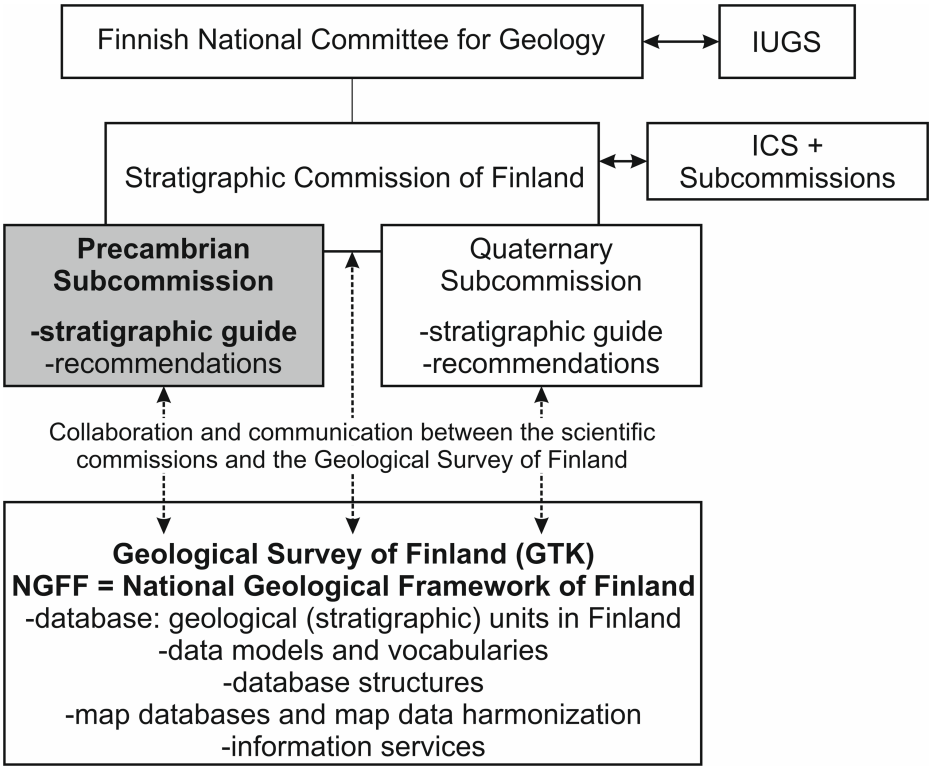


Fig. 1. The roles of the Stratigraphic Commission of Finland and the Geological Survey of Finland in the development of stratigraphic procedures and databases.

- In the global working environment, data exchange and interoperability are no longer only necessary for leading scientists, but for everybody working in the broad field of geology.

The established stratigraphic classification systems (e.g., International Stratigraphic Guide, Salvador 1994) evidently have limitations when applied to bedrock terrains (see Hattin 1991, NASC 2005, Easton 2009). Especially challenging are the intensely and multiply deformed complexes consisting of metamorphic and plutonic rock assemblages. As a result, a formal lithostratigraphic approach has not been applied in most parts of the rock record in Finland. Nevertheless, novel stratigraphic concepts developed by the international stratigraphic organizations and documented by the International Union of Geosciences (IUGS), the International Commission of Stratigraphy (ICS) and the North American Commission on Stratigraphic Nomenclature (NACSN) have opened new insights into the application of stratigraphy.

1.2 Purpose of the guide

'*Guidelines and Procedures for Naming Bedrock Units in Finland*' communicates how modern stratigraphy is best applied in Finland and forms the backbone for the work of the Precambrian Subcommission of the SCF. This guide was compiled to: (1) support consistent geological unit nomenclature in Finland, (2) assist regional geologists and other geoscientists in practical stratigraphic problems related to complex, metamorphic terrains and (3) facilitate the development of the national geological unit database (digital lexicon). This guide provides practices and standard procedures for defining and naming the bedrock units. It is not a formalized stratigraphic code but attempts to meet the practical needs of geologists studying the bedrock of Finland. The guide also serves as a proxy to more formal and advanced stratigraphic information. Several stratigraphic guides or codes are available for international (e.g., Hedberg 1976, Salvador 1994, Murphy & Salvador 1999, NASC 2005) and regional (e.g., NCS 1989, Kumpulainen 2016) usage. These editions, together with the IUGS CGI (GeoSciML) vocabularies, have been used as the principal references. For conciseness, the key references are presented in the text as abbreviations: **ISG 1994** (International Stratigraphic Guide; Salvador 1994); **NASC 2005** (North American Stratigraphic Code; North American Commission on Stratigraphic Nomenclature 2005); **NCS 1989** (Rules and recommendations for naming geological units in Norway; Norwegian Committee on Stratigraphy, Nystuen, J. P. (ed.) 1989); and **CGI** (IUGS CGI GeoSciML vocabulary https://cgi.vocabs.ga.gov.au/vocab/). To avoid unnecessary overlap with the established international editions, the technical procedures and general rules are not included in full detail.

The key terms are presented in *italics*. When a definition is not provided in the text, the ISG 1994 glossary (pp. 106–142), the main reference for each classification category (see Table 1), the IUGS CGI (GeoSciML) vocabulary and the Glossary of Geology (5th revised edition; Neuendorf et al. 2011) are the suggested terminological sources. It is noted that following the principal references (ISG 1994, NASC 2005) and the 'standard' vocabulary by the CGI, the short spelling 'stratigraphic' (instead of stratigraphical) is used, whereas the long spelling for the more general words (geological, lithological) is retained.

1.3 Stratigraphic procedure and management of geological units in Finland

The management of geological units in Finland incorporates three fundamental roles: (1) the provision of stratigraphic advice and a knowledge base, (2) ownership of the digital lexicon, maintenance of the defined units and the development of related systems and services and (3) ownership of the formal process (see Fig. 1). The first role, handled by the SCF, includes the monitoring of international development, participation in the ICS subcommissions and national communication on stratigraphy. The second role is played by GTK, the national authority responsible for geological information and databases. GTK develops and maintains the digital lexicon of bedrock units (FinstratiKP database) and is thus authorized to insert units and manage the system. In practice, GTK gathers nomenclature from published scientific articles, reports and maps. The third role, final approval of the formal stratigraphic units, is again the responsibility of the SCF.

2 CLASSIFICATION OF GEOLOGICAL UNITS

2.1 Geological unit and stratigraphic unit

In the most traditional form, stratigraphy is essentially an organized description of stratified rocks (the stratum). However, the stratigraphic method has evolved towards the systematic arrangement of all the rock bodies of the Earth's crust. Nowadays, stratigraphy is the science of the rock record, concerning the characteristics, boundaries (2D and 3D) and attributes of rock bodies (e.g., distribution, form, geochemical properties, age, lithological composition) and, in some cases, also involving the interpretation of geological units.

The term *geological unit* (or *geologic unit*) denotes a volume of rock that has defined boundaries, characteristic features and, generally, a name as an identifier. There is no universally recognized definition for a geological unit, and the following is adapted from NADM-C1 (North American Geologic Map Data Model Steering Committee 2004): *A body of earth material distinguished from adjoining material on the basis of content (lithologic or fossil), inherent attributes, physical limits, geologic age, or some other property or properties. Commonly used properties include composition, texture, included fossils, magnetic signature, radioactivity, seismic velocity, and age. Sufficient care is required in defining the boundaries of a unit to enable others to distinguish the material body from those adjoining it [NACSN 1983]. A geologic unit is a part of the solid Earth that is identified by its geologic characteristics, has definable, locatable boundaries, and is persistent in time. Excludes non-material, temporal units.*

The denotation of and difference between the terms 'geological unit' and 'stratigraphic unit' is not distinct. Some key references (e.g., NASC 2005) use stratigraphic unit synonymously with geological unit. The INSPIRE vocabulary (INSPIRE 2013) defines a geological unit as follows: *A volume of rock with distinct characteristics. Includes both formal units (i.e. formally adopted and named in an official lexicon) and informal units (i.e. named but not promoted to the lexicon) and unnamed units (i.e. recognisable and described and delineable in the field but not otherwise formalised).* The CGI vocabulary (http://cgi.vocabs.ga.gov.au) currently recognizes 19 types of geological units (Fig. 2). Some of these units do not have a direct connection to the rock record (such as some lithotectonic units) or are independent of the unit relationships (e.g., lithological units), and these units are not comprehended as stratigraphic units (*sensu stricto*). In this guide, 'geological unit' is a broader concept than 'stratigraphic unit'. Only the classification categories recognized by stratigraphic guides and codes are considered here as stratigraphic *sensu stricto* (see Fig. 3 and Table 1).

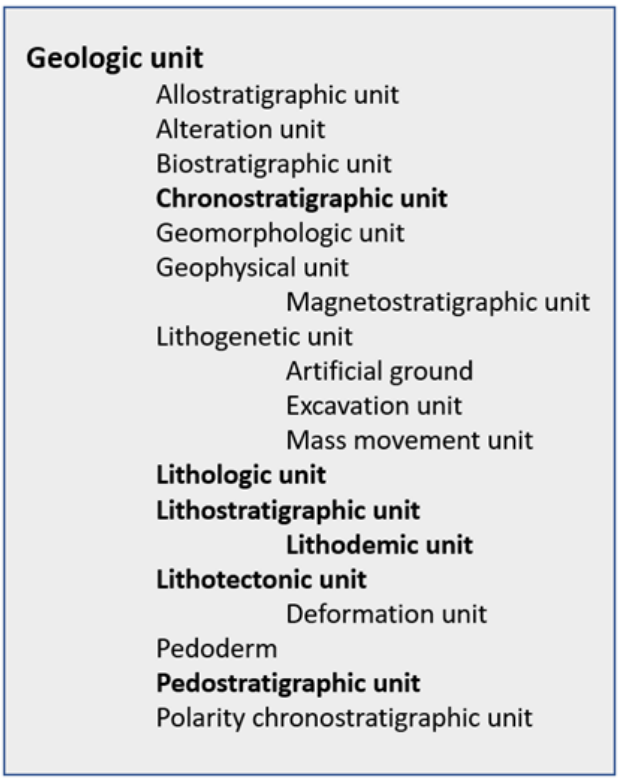


Fig. 2. Geological unit categories, as defined by the IUGS Commission for Geoscience Information (CGI) Geoscience Terminology Working Group (status 1/2022). Unit types are differentiated based on their defining lithological, stratigraphic or other physical properties. The classifications considered in this guide are in bold.

A *stratigraphic unit* is a geological unit that is recognized by applying a stratigraphic classification scheme (stratigraphic category). Stratigraphic units based on one property (according to the selected category) will not necessarily coincide with those based on another. Therefore, it is essential that different terms are used for each named unit so that the units can be distinguished from each other. A clear definition of a stratigraphic unit is of paramount importance.

The identification, characterization and definition of geological units is part of the geological research process. Geological units are generated in the description of stratigraphic columns (stratotypes of a succession), in geological mapping (map units) or as a result of interpretation based conceptual modelling (e.g., lithotectonic units). Geological units form a basic component of most geological maps or models, and the map area or model volume is most typically composed of geological units. Therefore, a meaningful unit is mappable, has defined boundaries and is geologically significant. In this guide, good practices in application of the established classification categories are encouraged, but new innovative ways to define and classify are not excluded. However, the new systems need to be documented, comprehensible and sufficiently explicit to enable users to distinguish rock bodies that are included in a class from those that are not.

2.2 Categories of unit classification

Rock bodies may be classified according to many different inherent properties. Each classification needs its own distinctive nomenclature. The categories of unit classification are of two principal types: (1) material categories defined on the basis of physical properties and (2) categories expressing or related to geological age, which can be divided into material units that formed within a specific time span.

The classification of geological units supports the description of both successions (type sections, stratotypes) and geometries (e.g., map units, volume units of a 3D model) of rock bodies. The parallel use of various classification categories opens views to the different aspects of stratigraphy and improves the effective communication of geological information. The fundamental objective of the classification schemes is to promote the unambiguous characterization of observed rock bodies. Ideally, a code with classification categories improves the distinction between observable features (reproducible data, such as stratotypes) and inferences or interpretations.

2.2.1 Stratigraphic classification categories

The **material categories** (e.g., lithostratigraphic, lithodemic, tectonostratigraphic and sequence stratigraphic) are based on the content or physical limits of rock bodies. The composition and related characteristics (e.g., texture, structure) or different physical, chemical or biological contents or properties of rock serve as the basis for distinguishing and defining the fundamental formal units. The material-based, tangible units are distinguished either by their lithological characteristics or by the nature of their bounding surfaces.

- *Lithostratigraphic units* are based on the lithological properties and stratigraphic relationships of rock bodies conforming to the Law of Superposition.
- *Lithodemic units* are based on the lithological properties of rock bodies (typically non-stratified).
- *Biostratigraphic units* are based on the fossil content of rock bodies.
- *Tectonostratigraphic units* are bodies of rocks bounded above and below by tectonic detachment *surfaces.*
- *Sequence stratigraphic units* are based on interpreted depositional stacking patterns and their bounding surfaces controlled by cyclic base-level changes (mainly relative or eustatic sea-level changes).
- *Unconformity-bounded stratigraphic units* are bodies of rocks bounded above and below by *surfaces* representing significant discontinuities in the stratigraphic succession.
- *Allostratigraphic units* are bodies of rocks bounded above and below by *surfaces* representing significant geological discontinuities. This category of the NASC 2005 largely corresponds to the unconformity-bounded category of the ISC 1994, but is more generic by definition.
- *Magnetostratigraphic units* are based on the specified remanent magnetic properties of rock bodies. The upper and lower limits of a *magnetopolarity unit* are defined by boundaries marking a change in polarity.
- *Pedostratigraphic units* (geosols) are bodies of rocks that consist of one or more buried pedological horizons developed by weathering in one or more lithostratigraphic, lithodemic or allostratigraphic units.

The **categories based on geological age** express material units that formed within a specific time span. For these types of units, characterizing collective names are given, such as the Siderian

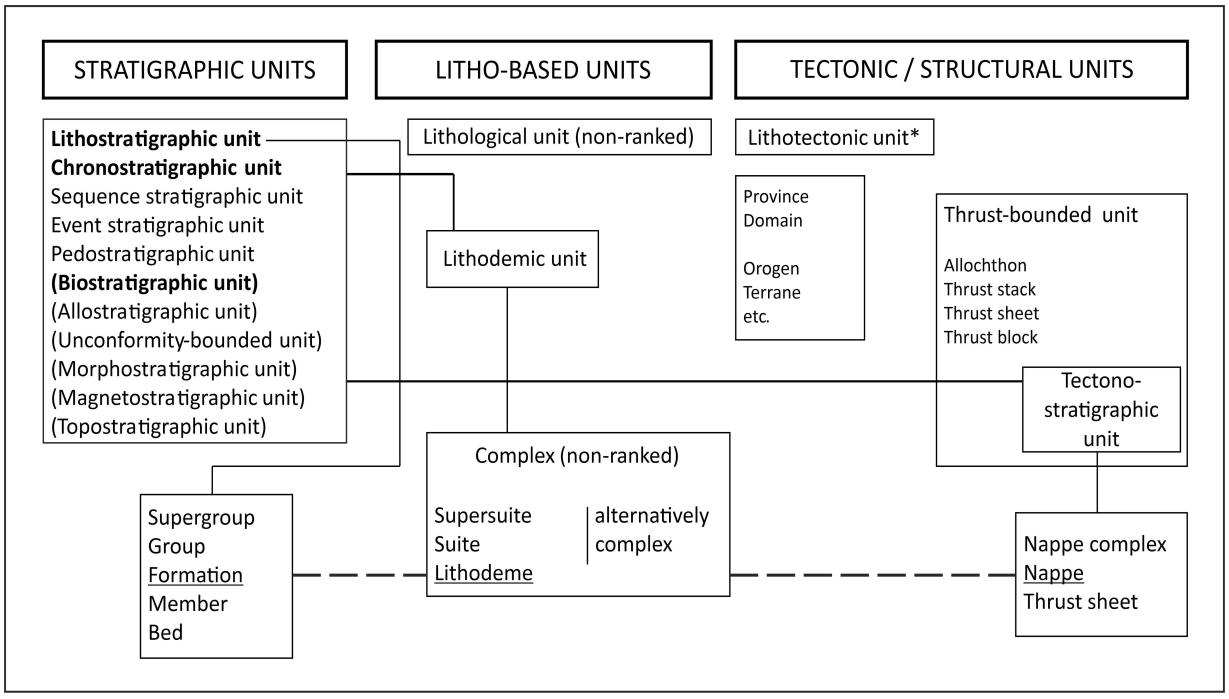
System (chronostratigraphic unit) corresponding to the Siderian Period (geochronological unit).

- *Chronostratigraphic (time-stratigraphic) units* are based rock bodies deposited in the same period of time.

Geological time plays a vital role in stratigraphy, and geochronological units correspond to the time spans of chronostratigraphic units. However, geochronological units divide geological time and not bodies of rocks. Therefore, geochronological units are excluded from this guide (for the International Geologic Time Scale and the International Chronostratigraphic Chart, see the ICS website: http://www.stratigraphy.org).

The concept of *event stratigraphy* was first proposed by Ager (1973) for the recognition, study and correlation of the effects of significant physical events (e.g., marine transgressions, volcanic eruptions, geomagnetic polarity reversals, climatic changes) or biological events (e.g., extinctions) on the stratigraphic record of whole continents or even of the entire globe. In bedrock geology, boundaries placed at "key events" in the stratigraphic record have been suggested as a new basis for chronostratigraphic division (e.g., Bleeker 2004, Altermann et al. 2012).

Geological units can be arranged (Fig. 3) in three main groups: (1) stratigraphic *(sensu stricto)*, (2) litho-based and (3) tectonic/structural. Lithostratigraphy represents a litho-based stratigraphic classification. Following the Swedish example (Kumpulainen 2016, Andersson et al. 2023), lithodemic units are primarily related to the litho-based group. However, the category has close ties to lithostratigraphy, and can also be understood as a stratigraphic category (see NASC 2005). Despite the name of the category, tectonostratigraphy is not recognized by ISG 1994 or NASC 2005, and here, the category is considered as a tectonic/structural classification scheme. In Figure 3, the tectonostratigraphic units are loosely coupled with the proper stratigraphic categories, however.



*Before any application of lithotectonic units, the corresponding categories, their ranks and classification rules shall be defined.

Fig. 3. Summary of geological units. The most formal stratigraphic categories are in **bold**; the categories and units not considered in this guide are in parentheses; the principal ranks of a category are underlined (modified from Kumpulainen 2016).

2.2.2 Geological unit classification in Finland

Each country and geological region has a unique research tradition and heritage concerning the geological units and their usage. The emphasis of this guide is on classification categories, which are widely used in bedrock geology and also applied in Finland (Table 1). The less relevant categories, such as biostratigraphy and magnetostratigraphy, have either been omitted or are only briefly mentioned.

For information on optional categories, detailed procedures and international examples, the reader can turn to ISC 1994, NASC 2005 and, regarding tectonostratigraphy, NCS 1989.

Table 1. Geological unit classifications included to this guide (X; most significant in bold) and their recognition in the international references. The main reference for each category is also indicated (color cells).

Classification	**Unit definition based on**	**Recognized (X) or mentioned (+) in**						
		This guide	IUGS*		Regional/national stratigraphic guides/codes**			
		SCF	ISSC	CGI	NACSN	UK	NCS	Sweden
Lithostratigraphic	Lithology, stratigraphic relationships	**X**	X	X	X	X	X	X
Lithodemic	Lithology	**X**	+	X	X	X	X	X
(Lithological, non-ranked)	Lithology	+		+				
Sequence stratigraphic	Stacking pattern, bounding surfaces	X	+	+		X		+
Unconformity-bounded	Bounding unconformity surface	+	X	+		+		
Chronostratigraphic	Geological age	**X**	X	X	X	X	X	X
Pedostratigraphic	Pedological horizon (paleosol)	X		X	X		X	
Event-stratigraphic	Rare, identifiable geological events	+	+			+		+
Magnetostratigraphic	Magnetic characteristics	+	X	X	X	X	X	+
Isotope stratigraphic	Isotope characteristics	+	+			X		
Tectonostratigraphic	Bounding detachment surfaces	X				+	X	X
Lithotectonic***	Variable; specified in classification rules	X		X				+

*International Union of Geological Sciences; ISSC (International Subcommission on Stratigraphic Classification; ISG 1994); CGI (Commission for the Management and Application of Geoscience Information; GeoSciML vocabularies; status 01/2022)

** NACSN (North American Commission on Stratigraphic Nomenclature; NASC 2005); UK (United Kingdom; Rawson et al. 2002. Stratigraphic Procedure. Geological Society, London, Professional Handbook); NCS (Norwegian Committee on Stratigraphy, Nystuen, J. P. (ed.) 1989); Sweden (Kumpulainen 2016, Andersson et al. 2023).

***Before the application of lithotectonic units, the corresponding categories, their ranks and classification rules should be defined

In this guide, four principal categories of geological units are presented to support the classification of the bedrock of Finland (Table 1). The conventional classification schemes are divided into groups (the principal categories are in **bold**):

1. Geological units based on material content
- (Lithological)
- **Lithostratigraphic**
- **Lithodemic**
- Pedostratigraphic (paleosols)

2. Geological units based on the physical limits of the material unit
- **Tectonostratigraphic**
- Sequence stratigraphic

3. Categories based on various specified tectonic and/or structural properties of the material unit
- Lithotectonic

4. Categories based on geological age
- **Chronostratigraphic** (or time-stratigraphic)

The *lithostratigraphic and lithodemic units* are fundamental and the most important in the division of bedrock bodies. Thus, the related principles have priority when approaching the definition and management of geological units of the Finnish bedrock. Lithodemic classification can be seen as a complementary system for classic lithostratigraphy, and these principally different classifications are mostly not applied independently (see Chapter 4.1).

In highly metamorphic and complex folded terrains, like most of the bedrock of Finland, *lithological (lithologic) classification* is usually the first approach in geological mapping. After defining the type section or type areas, *lithostratigraphic and/or lithodemic units* are established and named. However, in detailed and applied studies, when the genetic relationships of the rock units are not the main focus, typically only lithological units have been used. The CGI vocabulary defines a *lithologic unit* (a subclass of a geologic unit) as: "*Geologic unit defined by lithology independent of relationships to other units. Denotes a 'kind' of rock body characterized by lithology, e.g. basaltic rocks".* Lithological units are not named, ranked and designated, and are not therefore part of the nomenclature of geological units. Thus, lithological units are not considered any further in this guide and are presented in parentheses in the list above and in Table 1.

Tectonostratigraphic principles are applicable in areas where thrusting has resulted in prominent and mappable detachment surfaces. *Sequence stratigraphy* focuses on the relationships between the architecture of the depositional units and cyclic changes in a base level, where the different depositional trends can be studied and analysed at variable scales. Sequence stratigraphy is essentially a basin analysis method, and it has been applied in some studies on the bedrock of Finland (see Chapter 6.1). *Unconformity-bounded units* are briefly considered in Chapter 6.2. *Lithotectonic units* have emerged as a response to the problematic management of conceptual tectonic-scale units and boundaries. The units are specified on the basis of structural or deformation features, mutual relations, origin or historical evolution. The challenges of bedrock *chronostratigraphy* are presented and considered in Chapter 7.3.

Furthermore, some less conventional methods may also have potential in stratigraphic studies in Finland. *Magnetostratigraphy* covers all aspects of stratigraphy based on remanent magnetism (paleomagnetic signatures). Four basic paleomagnetic phenomena can be determined or inferred from remanent magnetism: polarity, the dipole-field-pole position (including apparent polar wander), the non-dipole component (secular variation) and field intensity. The apparent polar-wander paths provide supporting information for the inter-regional, and even global, correlation of bedrock units (e.g., Mertanen & Pesonen 2005, Pesonen et al. 2012, 2021, Salminen et al. 2021). However, it is not a principal method for the identification and naming of geological units in Finland. The use of carbon, oxygen or strontium isotopes (*isotope stratigraphy*) in correlating strata has been a promising method, especially in Cenozoic deposits. In bedrock research, isotope methods provide a potential tool when used with other stratigraphic information or for correlation (e.g., Karhu 1993, 2005). Nevertheless, these categories and approaches are not considered any further in this guide.

3 GENERAL PRINCIPLES AND PROCEDURES FOR DEFINING AND NAMING GEOLOGICAL UNITS

3.1 Definition of geological units

Stratigraphy is a global subject, and conformity with internationally established terms and practices is therefore important. ISG 1994 provides detailed procedures for the establishment of formal stratigraphic units and a glossary of stratigraphic terms. Naming specifies an individual geological unit having a spatially defined location, boundaries and associated geological properties and attributes. Therefore, the name preferably contains both a geographical and a geological component. The unit name is the fundamental identifier, which shall be unique for a formal unit and ideally so for all the named geological units. The applied unit classification system (and possible rank) needs to be specified. Preferably, the source of the geographical name is explained (e.g., National Land Survey of Finland base map or topographic map; sheet and year), if not self-evident. The use of the

same geographical name for two or more different units, even of different categories or ranks, is not recommended, but exceptions regarding established names are acceptable.

Different stratigraphic categories can be applied in the same area, but the terminology of the categories must never be mixed. For example, the combined use of the lithostratigraphic and lithodemic categories is conventional, but a lithodeme cannot be placed within a group. Similarly, a formation can be described within a nappe, but the formations cannot be included in the subdivision of a nappe or nappe complex.

The establishment of a formal geological unit requires the publication of adequate characterization in a recognized scientific medium, and publication is suggested for all new stratigraphic units. In naming a unit, the priority in the publication of a properly proposed, named and defined unit should be respected (see ISC 1994, p. 23). Names in long traditional use will thus have preference over other suggested names if there is no justified reason for discarding the principle of priority. The procedures for the establishment and naming of stratigraphic units of different categories are provided in Chapters 4–7.

The name is the unique unit identifier, and the unit nomenclature needs to be nationally maintained. The stratigraphic lexicon of Finnish bedrock units (FinstratiKP database of GTK) is in practice the tool for the management of geological units, where the names, characteristic features and, most importantly, references to original research can be accessed. New units, changes in the name or rank of a unit and unit abandonment may be proposed in writing to GTK (see Appendix 1 for the procedure).

3.2 Formal and informal units

The international guides (ISC 1994, NASC 2005) recommend the usage of formal units. The importance of formal geological units is in forming a stable, well-documented collection of the most significant rock records. Only geological units having a stratigraphic rank (Fig. 3) can be accepted as formal units.

A new formal unit must be described and defined appropriately, and the intent to establish or designate it must be specific. *Formal stratigraphic units* shall sufficiently correspond to the requirements of the category of classification (see Chapters 4 and 5). Formal units are proposed, named and defined according to the guidelines presented in Chapters 4.4 and 5.2. In practice, a formal unit is established when the research with appropriate characterization is published or via the formalization of an informal unit. The status and record of all formations can be accessed via the digital national lexicon (GTK FinstratiKP). The formally defined stratigraphic units are essentially persistent and protected against change without a new formal procedure. Thus, an injudicious or premature establishment of a formal unit may turn out as inexpedient. The procedure for the final approval of formal names is presented in Appendix 1.

A named geological unit not fulfilling the requirements of a formal stratigraphic unit or pending approval is always *informal*. Informal nomenclature is found useful in bedrock stratigraphic work, when the applicability of formal lithostratigraphy is restricted (e.g., Easton 2009 and references therein) and the age constraints are limited. Even though the usage of formal nomenclature is encouraged, it is emphasized that the appropriate characterization of geological units, whether informal or formal, is important for cumulative geological knowledge. Nevertheless, no geological unit should be established unless the new unit serves a clear purpose.

Informal units form a major part of the bedrock stratigraphic nomenclature in Finland. There are different kinds of informal units. Some units of geological significance may, for various reasons, be difficult to characterize according to the formal requirements. An informal status is advisable where the unit is only known in an area having a very limited extent. In practice, an informal unit is created when it is designated, founded when its study, including the description of the named unit, is published and, finally, established when incorporated into the (digital) national lexicon (see Figs. 4 and 7). Informal names are, in principle, not protected against change by the stability provided by proper formalization, but the priority of the name also applies to informal nomenclature. Obviously, there cannot be any formal procedures for informal units. However, it is recommended that the description, characterization and definition of informal units should follow the suggestions of this guide when possible and appropriate.

3.3 Redefinition, revision and abandonment

Redescription means the correction of an improper description, whereas *redefinition* may include major changes to a description and a change in the lithological designation (see NASC 2005). For example, igneous rocks originally defined as quartz monzonites can be re-classified as granites, or the descriptive part of the unit name (e.g., shale) can be replaced by another descriptive term (e.g., marl) without changing the original proper geographical term in the unit name. Minor *revision* is defined here to include changes in map unit boundaries and minor hierarchical changes (formation/member ranks; suite/lithodeme ranks). The hierarchical rank of a geological unit can be changed without any changes to the definition or geographical part of the name.

Major *revision* involves (1) all justifications of the stratotype or the definition of the unit, (2) changes in the category or (3) major changes in the unit's rank or boundaries. Where the unit is divided (i) into two units of different ranks, the original name cannot be used for both units as a whole and for a part of it, and where it is divided (ii) into two or more units having the same hierarchical rank, the original names should not be used for any of the new units. Any formally approved names should not be modified without strong and well-documented reasons. An established geological unit can be abandoned or rejected when it is (i) improperly defined, (ii) equivalent to a previously formally defined unit or (iii) defined in the wrong category, or does not otherwise fulfil the requirements of the nomenclature or definition rules. A unit may also be abandoned if it proves inappropriate (e.g., very small or not recognizable or mappable beyond the type area). The abandoned names are retained in the lexicon.

For practical reasons, GTK has a mandate to manage informal units, as well as the re-description, re-definition and minor revision of formal units in the digital lexicon (GTK FinstratiKP) and in spatial map databases. Major revision and abandonment of a formal unit follows the procedure described for the approval of a new formal unit (see Appendix 1).

3.4 Correlation

Correlation, the demonstrated correspondence of separated parts of a geological unit in some defined property or relative stratigraphic position, is one fundamental objective of stratigraphy. A suggested correlation, and information on which it is based, is an essential part of an ideal unit description. *Lithocorrelation* links together units with a similar lithology and stratigraphic position, or the sequential or geometric relations of lithodemic units. In geological mapping, the distinction of individual formations (as mappable units), geological units with a regional extent and major stratigraphic divisions is all based on correlation at different scales: between the sections and rocks (formations), between the key areas (regional map) and, finally, between the regions (e.g., nation-scale map). Under the Finnish conditions of limited bedrock exposure, a mappable unit seldom forms one observable entity but is represented by geographically separated outcrops, and correlation is typically aided by geophysical maps. *Chronocorrelation* refers to a correspondence between the age and chronostratigraphic position of a geological unit. Once the lithostratigraphic, lithodemic and tectonostratigraphic units have been established, there is a need to correlate them by age with one another and with the global chronostratigraphic scale. The different methods of calibration and correlation, such as biostratigraphy, sequence stratigraphy, event stratigraphy and isotope stratigraphy, are described and discussed in Rawson et al. (2002). In the bedrock geology of Finland, isotope geological geochronometry is by far the most important method of chronocorrelation. The results typically indicate age estimates for the crystallization of igneous rock or the minimum/maximum depositional age of a supracrustal succession.

4 LITHOSTRATIGRAPHY

4.1 Combined use of lithostratigraphic and lithodemic units

The establishment of adequately characterized lithological units and their correlation at all scales forms the core of the lithostratigraphic method. According to the international guides (ISC 1994, NASC 2005), the establishment of formal units should be the primary target in stratigraphic work (see Chapter 3.2). The lithostratigraphic challenges of bedrock terrains have been tackled with lithodemic classification, which can be understood as an extension of the lithostratigraphic approach (e.g., Easton 2009, CGI classification scheme in Fig. 2). The combined application of lithostratigraphic, lithodemic and paleosol units in Finland is described and discussed in Kohonen et al. (2024, this volume). In practice, the use of the categories is complementary and exclusive: all the fundamental units are formations, lithodemes or paleosols. This type of combined approach has been called 'lithostratigraphic (*sensu lato*) nomenclature for bedrock units' (Easton 2009).

Naming the mapped lithological unit as a lithostratigraphic or lithodemic fundamental unit (formation/lithodeme) after the type locality is always the first step in unit designation (Fig. 4). In the combined lithostratigraphic–lithodemic method, it is essential to ensure that each lithology-based unit (distinct body of rock) can be classified as either lithostratigraphic or lithodemic. Where the body of rock lacks primary stratiform features or understanding of the superposition of units is missing, the use of lithodemic units is justified (see Chapter 4.6). The application of lithodemic classification is simple and convenient. However, lithostratigraphic classification should always be considered as the first choice for supracrustal rocks.

The primary objective should be the foundation of formal stratigraphic units, and the description and characterization of all units should therefore obey the formal lithostratigraphic/lithodemic procedure when applicable and appropriate. The semipersistent nature of informal units, both lithostratigraphic and especially lithodemic, is acceptable and practical when there are not conditions or rational reasons to establish formal units.

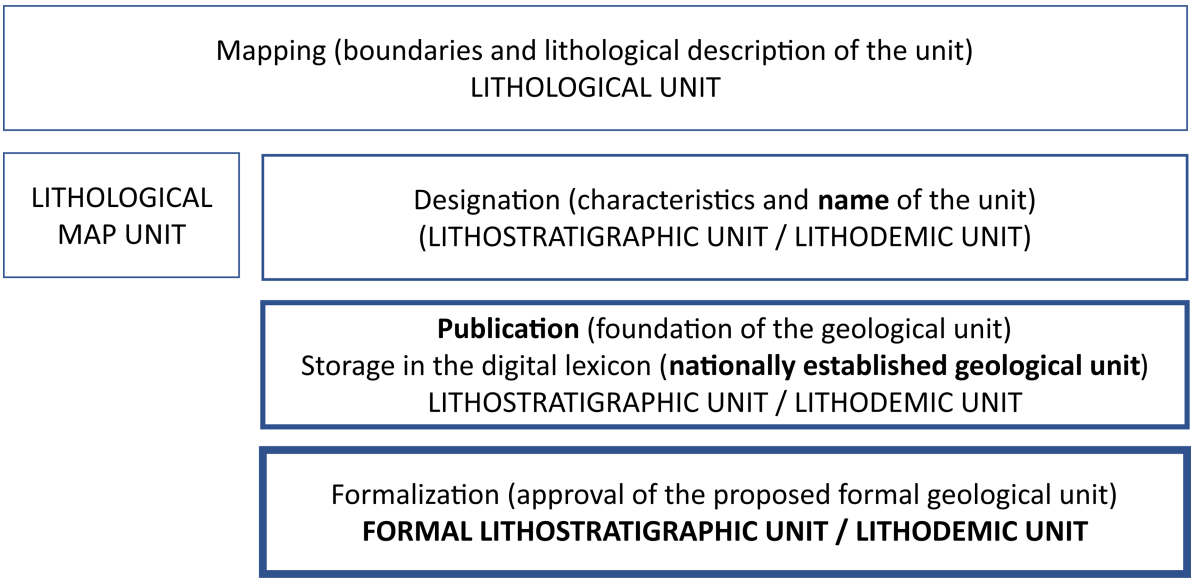


Fig. 4. The evolution of a geological unit from a map unit (top) towards a formal stratigraphic unit (bottom). Key steps of the process shown in bold.

4.2 Lithostratigraphic units

4.2.1 General properties, rules and boundaries

Lithostratigraphic units are defined and distinguished on the basis of lithological characteristics and stratigraphic position (Fig. 3). The distinctive lithological characteristics may include features such as composition, texture, primary structures and colour. The units are commonly stratified and tabular in form.

A lithostratigraphic unit generally conforms to the Law of Superposition, and the application requires that even a deformed supracrustal succession has retained an observable time sequence of the beds and units. A high grade of deformation and metamorphism limits but does not necessarily restrain the use of lithostratigraphic units.

A *lithostratigraphic unit* has been defined as:

- A body of rocks that is defined and recognized on the basis of its observable and distinctive lithologic properties or a combination of lithologic properties and its stratigraphic relations (ISC 1994);
- A body of sedimentary, extrusive igneous, metasedimentary or metavolcanic strata that can be delimited by its stratigraphic position;
- A stratum or body of strata, comprising stratified rocks and superficial deposits (conforming to the Law of Superposition, i.e., sedimentary layers are deposited in a time sequence, with the oldest on the bottom and the youngest on the top), which are distinguished and defined based on lithological properties and stratigraphic boundary relations;
- A geological unit defined on the basis of observable and distinctive lithological properties or a combination of lithological properties and stratigraphic relationships. Denotes a particular body of rock. (CGI definition as a subclass of *geologic unit*).

Lithostratigraphic units are defined independently of the inferred geological history or the mode of genesis, and the all the units are diachronous in nature. The ranks are, in decreasing order, supergroup, group, formation, member and bed/flow, where formation is the fundamental unit. The guidelines for the characterization and naming of formations and other lithostratigraphic units are presented in Chapter 4.4.

The boundaries of lithostratigraphic units are placed at positions of lithological change, at distinct, sharp contacts or, at some selected arbitrary level, within zones of gradation. Both vertical and lateral boundaries are based on the lithological criteria that provide the greatest unity and utility. Unconformities, where objectively recognizable based on lithological criteria, are ideal boundaries for lithostratigraphic units.

Stratotypes (type sections) form the stratigraphic foundation by providing a link from the detailed description to a specified site in the field.

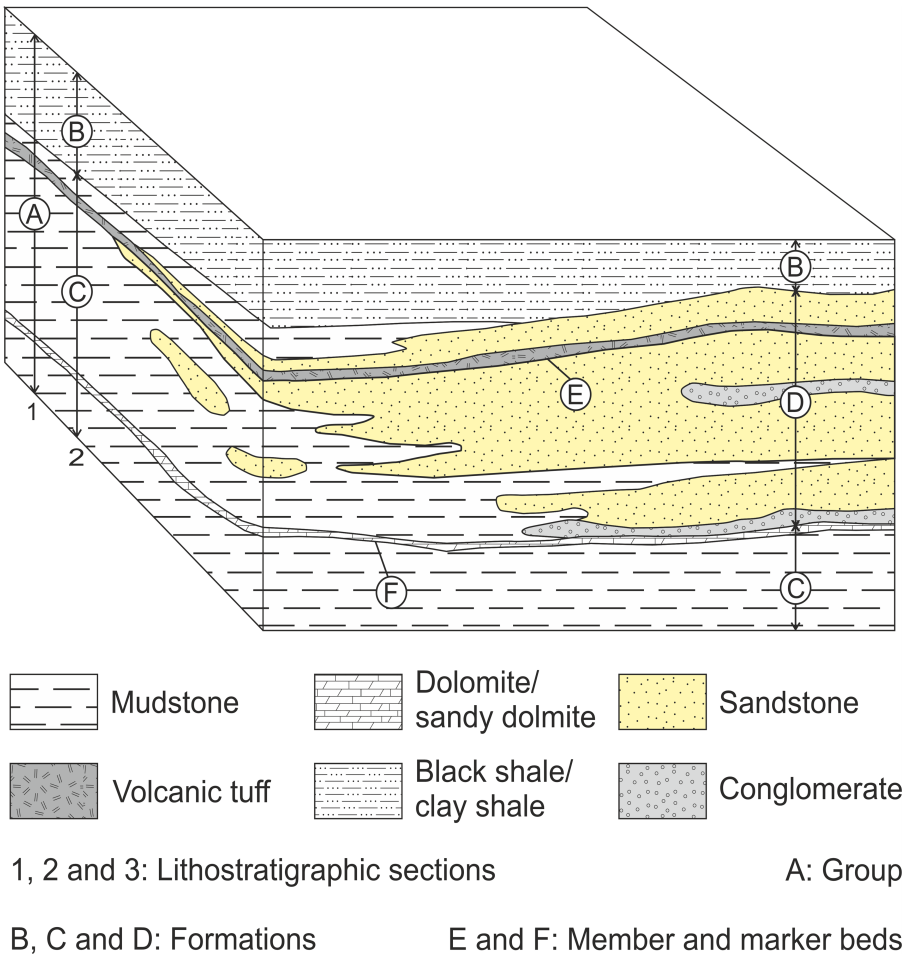


Fig. 5. Schematic illustration of the lithology-based designation of lithostratigraphic units (modified after NCS 1989).

4.2.2 Formation

A *formation* (*Formation*) is the fundamental unit in lithostratigraphic classification. Like all the lithostratigraphic units, a formation is identified by the lithological characteristics and the stratigraphic position. As the fundamental unit, a formation is the first unit to be designated, and the selected dimensions largely define the scale of the units within the area. Basically, the division into formations makes a distinction between the adjacent mappable units. Very large formations do not discriminate and, consequently, lead to a poor resolution of mapping. A formation must be mappable (or traceable in the subsurface) at a relevant, regional scale. In practice, this sets the lower limit for the dimensions of a formation. Therefore, the division into formations needs to be carefully considered and, before designation, comparisons with the formations of adjacent areas may provide examples of their dimensions. According to the general practice in Finland, a formation should be mappable at scales from 1:10 000 to 1:50 000, and the resulting map unit should be readable at a 1:100 000 map scale.

The stratigraphic relations, boundaries and position are part of the definition. Accordingly, when feasible, the formation boundaries preferably correspond to significant depositional change within the succession. The boundaries of a formation are set by lithological changes, however, and not by the depositional model.

Stratified volcanic rocks are comparable to sedimentary rocks and should be treated equally in the designation of a formation. An interbedded succession (e.g., sedimentary and volcanic rocks) and volcanic rock may be assembled into one formation, and the lower ranks can be used for further designation. The properties of a formation may change laterally. The changes in thickness, composition or metamorphic grade must be considered case by case. Suitable tools for these situations include, for

example, presenting several sections through the formation, a change in the rank or category and the naming of a new unit. Laterally discontinuous bodies of similar rock, occurring at the same stratigraphic level, may be considered as the same formation.

4.2.3 The lower ranks: Member and Bed

A *member* (*Member*) is the unit ranked below a formation and is always a part of a formation. It is recognized as a named unit within a formation and it must show characteristics different from the adjacent parts of the formation. A formation does not need to be divided into members unless a useful purpose is served by doing so. Some formations may be completely divided into members, while others may have only certain parts designated as members, and still others may have no members. A member may extend laterally from one formation to another. The establishment of members is advantageous in the description of heterogeneous formations, and especially in cases when a rather thin unit bears specific value for the correlation or interpretation. A member, whether formally or informally designated, does not need to be mappable at the scale required for formations.

The lower rank of a member is a *bed* (*Bed*), except for volcanic flow rocks, for which the lowest rank is a *flow*. Members may contain beds and flows, but never other members. A bed, or beds, is the smallest formal lithostratigraphic unit of sedimentary rocks. A bed usually represents a single depositional event in a sedimentary succession. The designation of a bed or a unit of beds as a named lithostratigraphic unit should generally be limited to distinctive beds whose recognition is particularly useful. A key or *marker bed* is a thin bed of distinctive rock that is widely distributed. Individual marker beds may be traced beyond the lateral limits of a particular unit. A *flow* is a discrete, extrusive volcanic rock body distinguishable by texture, composition, the order of superposition, paleomagnetism or other objective criteria. A flow is usually a volcanic extrusive rock formed during a single eruption. Beds and flows are usually considered as informal units.

4.2.4 The upper ranks: Group and Supergroup

A *group* (*Group*) is a lithostratigraphic unit next higher in rank to a formation, always consisting of two or more associated formations of the same class of rocks. Groups are defined to express the natural relations of associated formations. They are useful in the compilation of regional-scale map legends and in wide regional correlations. In practice, groups typically represent major depositional units. A *supergroup* (*Supergroup*) is the highest lithostratigraphic rank, comprising two or more groups, having a natural vertical or lateral relationship with one another. Such units have proved useful in regional and provincial syntheses. Supergroups should only be named where their recognition serves a clear purpose. The upper rank units are named according to the general rules of naming (see Chapter 3.1) and the name combines a geographical name and the term "group" or "supergroup".

Examples of application

Northern Finland: Orakoski, Palokivalo, Petäjäskoski, Matarakoski, Sattasvaara and Kumpu formations/ Formations; Salla, Kuusamo, Kivalo, Sodankylä, Savukosksi and Kumpu groups/Groups (e.g., Lehtonen et al. 1998, Kyläkoski et al. 2012, Köykkä et al. 2019, Köykkä & Luukas 2021, Köykkä et al. 2022).

Eastern Finland: (1) Kainuu belt: Laanhongikko, Matinvaara, Paljakkavaara and Siikavaara Formations; Kurkikylä, Korvuanjoki and East Puolanka Groups of the (e.g., Laajoki 1991, Strand & Köykkä 2012); (2) Höytiäinen belt: Urkkavaara, Koli and Jero Formations; Kyykkä and Herajärvi Groups (e.g., Kohonen & Marmo 1992).

4.3 Lithodemic units

4.3.1 General properties, rules and boundaries

Lithodemic units are recognized and defined by their observable lithological characteristics. Basically, this denotes a mappable lithological unit with an attached identifier (the name), which allows lithocorrelation and attributes typical for a lithostratigraphic unit. Examples of such attributes are geochronological data, the estimated age and relationships with other rock units. The application of lithodemic classification supports regional description in areas where the relations between supracrustal and intrusive rocks are complex or where the supracrustal rocks have not retained primary unambiguous stratification. A unit may consist of several rock types; typical examples are

different co-magmatic intrusions and migmatite complexes. The guidelines for the characterization and naming of lithodemic units are presented in Chapter 4.4.

A *lithodemic unit* has been defined as follows:

- A non-stratified body of intrusive, volcanic or highly metamorphosed and/or completely deformed rock (not conforming to the Law of Superposition) that mostly lacks primary depositional structures.
- A geological unit consisting of one or additional bodies of predominantly intrusive, plutonic or extrusive rocks and/or highly metamorphosed and deformed rocks, which are defined and distinguished on the basis of lithological characteristics. A lithodemic unit does not generally obey the fundamental principle of the Law of Superposition.

The contacts with other geological units may be sedimentary, extrusive, intrusive, tectonic or metamorphic (Fig. 5). The boundaries, vertical or lateral, of a lithodemic unit should be placed at the location of an observable lithological change. The boundary may be represented by a visible contact but also by a zone of gradation or interfingering. In practice, arbitrary and inferred boundaries cannot always be avoided.

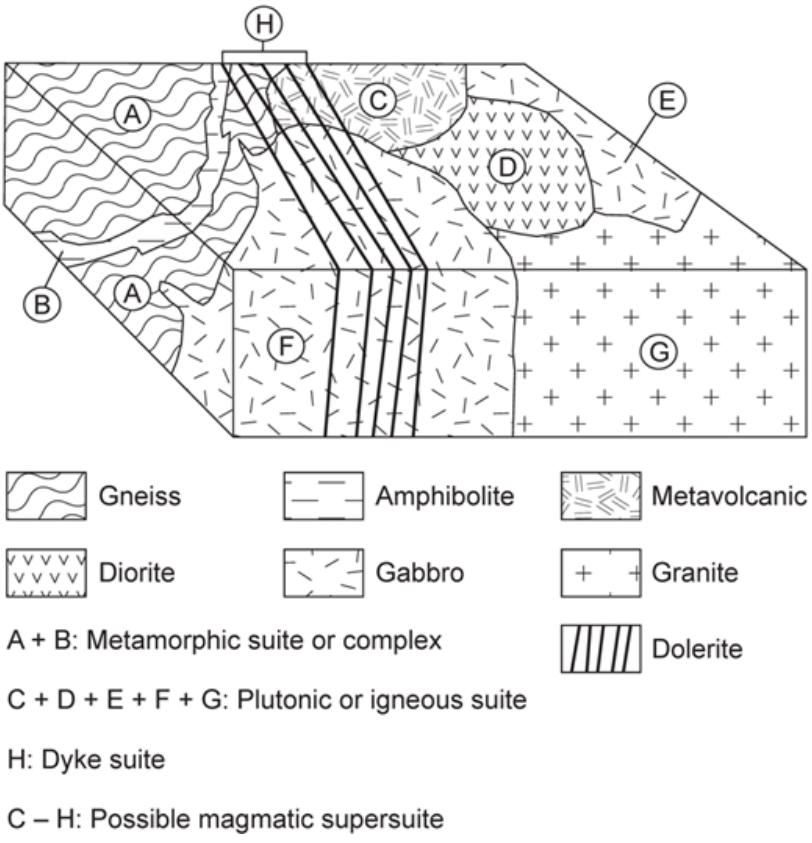


Fig. 6. Schematic illustration of the lithology-based designation of lithodemic units (modified after NSC 1989). Deformed and metamorphosed lithodemes form a suite or complex. The intrusive lithodemes comprise a plutonic suite or a dyke suite. Genetically related plutonic and dyke rocks can be grouped as a magmatic supersuite. (Modified from NCS 1989).

The lithodemic units are, in order of decreasing rank, *supersuite*, *suite* and *lithodeme*. A *complex* is a non-ranked lithodemic unit comparable to a suite or supersuite. The definition of a formal lithodemic unit (*Lithodeme, Suite, Supersuite*) should be based on an appropriate lithological description of the type area (see Chapter 4.4) and observations of the lateral and vertical variations and its contact relations with other rock units. The type locality (and possible reference localities) of a formal lithodemic unit should always be clearly defined. In Finland, formal lithodemic units should only be defined where the named unit is well established or another practical purpose for the formalization is presented.

4.3.2 Lithodeme

A lithodeme is a fundamental unit in lithodemic classification and nomenclature, and it is comparable to a formation (see Fig. 3). A lithodeme is mappable at the Earth's surface or traceable into the subsurface by using geological and/or geophysical methods. There are no lower ranks of a lithodeme. As a map unit, a lithodeme may enclose unnamed lithological units (see Kohonen et al. 2024, this volume).

A lithodeme may consist of (i) a single rock type, (ii) a mixture of two or more different rock types or (iii) a heterogeneous lithology, which in itself constitutes a separated unit that is distinct from adjoining or surrounding rock units. The different distinctive lithological characteristics may include mineralogy, textural features (e.g., grain size) and structural features (e.g., gneissic), and a lithodeme may change its character regionally. It may also be characterized by chemical, electromagnetic/magnetic, radiometric, seismic or some other physical properties derived from its lithological properties.

4.3.3 The upper ranks: Suite and Supersuite

A *suite* is the next higher in rank to a lithodeme. Formally, a suite consists of two or more associated lithodemes of the same class of rocks (e.g., metamorphic or igneous). In the map unit hierarchy, a suite is comparable to a group. A *supersuite* is the highest unit rank of the lithodemic category and is, as a map unit, comparable to a supergroup. A supersuite is always comprised of two or more suites.

4.3.4 Complex

An assemblage or mixture of two or more genetic classes (sedimentary, igneous and metamorphic) of rocks may be named as a *complex*. A complex is not a ranked lithodemic unit. As a map unit, a complex is commonly comparable to a suite or supersuite. A complex may be identified as an assemblage of diverse rock units and is typically used in bedrock areas where the mapping of each separate lithological component is impractical, difficult at ordinary mapping scales or provisional in nature. A complex may consist of two or more named lithodemes, lithostratigraphic units and/or unnamed lithological units. Where a named map unit consists of an assemblage of diverse types of a single class of rock, such as granitoids of an Archean terrane, terms such as metamorphic suite or plutonic suite should be considered as the first choice. NASC (2021) recognises three types of complexes (volcanic, intrusive, structural) but does not exclude use of other types of complexes. Tectonostratigraphic nappe complexes (Chapter 5.2) must not be confused with lithodemic complexes.

4.3.4.1 Volcanic complex

A *volcanic complex* refers to a site of persistent volcanic activity characterized by a diverse assemblage of different kinds of volcanic or metavolcanic rocks and related intrusions and their weathering products.

4.3.4.2 Intrusive complex

An "intrusive complex" differs from a "volcanic complex" in that it consists largely or entirely of intrusive rocks.

4.3.4.3 Structural complex

Tectonic processes may result in heterogeneous mixtures or disrupted bodies of rock in which some individual components are not mappable. Where the mixing or disruption is, without any doubt, due to tectonic processes, such a unit may be designated as a *structural complex*. Usually, a structural complex refers to an assemblage of two or more different kinds of rocks intermixed by tectonic processes, but may also consist of only a single class of rock.

Examples of application

Laajoki and Luukas (1988) applied, for the first time, the principles of lithodemic classification to the bedrock of Finland in the Salahmi-Pyhäntä area. For example, their Rapisevankangas gneiss suite consists of highly metamorphosed and deformed banded gneisses and mica schists divided into seven different lithodemes (e.g., Teerimäki biotite-plagioclase gneiss and Leppiperä quartz-feldspar gneiss).

In northern Finland, the supracrustal Mellajoki, Räväsjärvi, Haisujupukka and Sieppijärvi and Olostunturi suites comprise large areas in northern Finland of migmatitic arkose/mica schist, quartzite, paragneiss and amphibolite (Köykkä et al. 2019). The Kittilä suite covers an area of more than 2600 km² in central Lapland and comprises several different volcanic-sedimentary lithodemes (e.g., Vesmajärvi mafic volcanic rock, Jänisvaara BIF, Uurrekarkia boninite, Nuttio serpentinite and Kivipurnuvaara conglomerate; see Köykkä et al. 2019, Bedrock of Finland 1:200 000).

Examples of intrusive lithodemic units: Forssa gabbro (Hakkarainen 1994, Peltonen 2005), Koli sill suite (e.g., Vuollo & Piirainen 1992, Vuollo & Fedotov 2005, Vuollo & Huhma 2005), Penikat intrusion in the Tornio-Näränkävaara belt (see Alapieti & Lahtinen 1986, Iljina & Hanski 2005). A more complex example is the Akanvaara layered intrusion (see Mutanen 1997, Hanski & Huhma 2005).

One example of the 'full lithodemic hierarchy' is proposed for the rapakivi granites in SE Finland: Southern Finland rapakivi supersuite>Kymi rapakivi suite>Wiborg granite>wiborgite phase, and several informal supersuites are included in the GTK map database (Bedrock of Finland 1:200 000). However, in Finland, the term "complex" has commonly been used instead of "supersuite" for the large units consisting of two or more assemblages (suites or complexes) and having an assumed linkage to one another. Hölttä et al. (2012) classified the Finnish part of the Archean Province into nine different complexes: Ilomantsi, Lentua, Kuopio, Iisalmi, Rautavaara, Manamansalo, Kalpio, Siurua and Ranua. Other examples of application include the Nurmes gneiss complex (Kontinen 1991, Sorjonen-Ward & Luukkonen 2005), Suomujärvi complex (Evins et al. 2002, Sorjonen-Ward & Luukkonen 2005, Lapland granulite complex (Tuisku & Huhma 2006, Tuisku et al. 2006, Lahtinen & Huhma 2019), Central Lapland granitoid complex (Lahtinen et al. 2018) and Kemihaara and Naruska complexes (Tepsell et al. 2020). Informal names such as 'Tohmajärvi volcanic complex' and 'Pyhäsalmi volcanic complex' have been used in general descriptions without any detailed description of the rocks included. In Lapland, 'Vuotso complex' corresponds to parts of the structurally complex area formerly known as the Tana Belt. However, these units correspond rather well to the definition of a volcanic/structural complex (see 4.3.4.1 and 4.3.4.2 above).

4.4 Definition of lithostratigraphic and lithodemic units

4.4.1 Characterization

A designated new lithostratigraphic/lithodemic unit is characterized by information such as:

1. ***Name, category and rank;***
2. ***Location*** (with coordinates) of the type section (stratotype) or type area (if suitable);
3. Description of the unit, including: (i) ***a detailed description of the type section or type area***, (ii) characteristic features, (iii) ***nature of the unit boundaries***, including contacts, unit dimensions and shape (if possible);
4. The geological age, stratigraphic correlation and genesis (if possible);
5. ***Key references*** and historical background (if available).

There are several mandatory requirements for the formal units (shown above in ***bolded italics***). Furthermore, the definition, naming and establishment of new formal units, as well as their major revision or abandonment, requires publication in a recognized scientific medium.

4.4.1.1 Name, category and rank

The name of a unit consists of a geographical name referring to type section or type area (for the requirements of a geographical name, see Chapter 3.1) and a rank term and/or a descriptive term (for naming details and examples, see Chapter 4.4.2 below). The category and rank of a new or revised unit must be specific and follow the hierarchy presented in Table 2.

Table 2. Lithostratigraphic and lithodemic unit rank terms.

Lithostratigraphic Unit terms	Lithodemic Unit terms
Supergroup Group Formation Member (Lens, Tongue) Bed (Flow)	Supersuite Suite Lithodeme

4.4.1.2 Type section, type area and description of the unit

The description and definition should be so good that other geologists or scientists will also be able to recognize the geological unit and its characteristic features in the field. A type section (stratotype) or type area is a geological standard for a stratigraphic unit or boundary, and these should be sufficiently described, both geographically and geologically.

A *type section* is the specific geographical location of a unit stratotype or unit boundary where the unit was first defined and named. There are two kinds of lithostratigraphic stratotypes: (i) a unit stratotype and (ii) a boundary stratotype. These refer, respectively, to a type section for a stratified

geological deposit and to a specific point of a stratigraphic boundary. A type section may consist of several reference sections to demonstrate the areal extent or dimensions of the unit. A *type area* is the geographical area that encompasses the type locality of a stratigraphic unit. A detailed description of the type area, including the characteristic features of the named unit, is the main procedure in the definition of a lithodemic unit. The type area is ideally the place where the characteristic features of the unit are best observed. However, in the case of the well-established names of non-layered igneous rock bodies, the locality where the unit was originally defined and named may be preferred. The exact locality of the type area(s) and section(s) and the possible reference area(s) or section(s) of the units, e.g., formations and members, should be given in coordinates. These requirements also apply to named subsurface units, when the coordinates and other relevant information on the borehole are given.

In a unit description, the characteristic lithological features and nature of the unit boundaries should be emphasized. *Unit characterization* specifies the unique or specific features and attributes of the unit and serves as a key for both future recognition and correlation. The *unit boundaries* should be carefully recognized (see boundary stratotype above) and described. The boundary may be represented by a distinct contact between two different rock units or by a gradational or interfingered change between clearly different rock bodies. When the upper or lower boundaries of the unit have variable features, a covering description is essential. However, arbitrary and poorly defined boundaries are unavoidable in the bedrock geology of Finland. Where the unit boundaries are not exposed, their interpreted position may rely on other measured properties (such as magnetic, electromagnetic, seismic). In all cases, the nature of boundaries (observed, interpreted, inferred) should be indicated. The lateral dimensions, thickness variation and shape of the unit should be described or estimated (if possible). Finally, it is recommended that all different data on and samples of a formal unit should be stored in appropriate places for later examination.

4.4.1.3 Age, correlation and genesis

Lithostratigraphic and lithodemic units are not defined by inferred geological age or genesis. However, the age is an attribute of paramount importance, especially in bedrock geology. Therefore, all the available geochronometric age determinations or the interpreted/inferred chronostratigraphic information should be attributed to the lithostratigraphic and lithodemic units. The relations with the adjacent units, and the suggested stratigraphic correlation (litho- and chronocorrelation), should be included in the unit description. A correlation can be presented by referring to previous studies or in the form of attached tables, diagrams or any other relevant means. The presumed origin of a unit is preferably presented mainly by references, and long genetic speculations should not be included in the description.

4.4.1.4 Key references and historical background

Stratigraphic units are a result of geological research, and the full list of references is consequently essential. References to the articles defining, characterizing or describing a unit or its boundaries are mandatory. References to the history of the unit name or dissenting views concerning the position of the unit can be included. Extensive historical or regional reviews should not be included in unit descriptions.

4.4.2 Naming of formal and informal units

A new lithostratigraphic and lithodemic unit can be proposed as an informal or formal unit. A proposed formal unit should be characterized according to the requirements presented above (Chapter 4.4.1). Nevertheless, all units are, legitimately, informal before the formal approval process is completed. The formal status of a unit is indicated in name by capitalizing all words forming the name. Fulfilling all the requirements (ISG 1994) of a formal unit (e.g., lithostratigraphy: stratotype, unambiguity of unit boundaries) is mostly not realistic in the bedrock of Finland, and some tolerance and flexibility in application is needed. If the proposed formal unit serves a clear stratigraphic purpose and is characterized and defined appropriately, minor technical insufficiencies should not automatically exclude the formal status.

In all unit names (both lithostratigraphic and lithodemic), the lithological component should be a common and well-known rock name, such as gneiss or gabbro. A lithostratigraphic unit name consists of a geographical name and the appropriate rank term. In the informal names of formations and their lower ranks, a descriptive lithological term can be included between the two mandatory

components. Examples of informal names include the Ukkola formation, Ukkola quartzite formation, Muijala dolomite member and Äijälä group. The corresponding formal names are the Ukkola Formation, Muijala Member and Äijälä Group. A formal group can be established where all the incorporated formations are formal units. The epithets lower/middle/upper are not allowed as part of a formal unit name (e.g., lower Tiksanoja Member vs. upper Tiksanoja Member). All the unit names include a lithostratigraphic rank term.

A lithodemic name principally combines a geographical name with a lithological and/or descriptive term and/or the appropriate rank term. The naming convention is less formal compared to lithostratigraphic units. Informal lithodeme name typically consists of (1) a geographical name with a lithological and/or descriptive term (e.g., Haukila quartzite, Särkilä gneiss, Lahnala gabbro sill) or simply (2) a geographical name with the rank term 'lithodeme' (e.g., Kalala lithodeme). The latter may be useful for very heterogeneous lithodemes or for lithodemes that are largely identified by geophysical features. Terms implying the rock genesis should always be avoided. The formalization of lithodemes needs to be considered with caution, particularly in cases where the supracrustal unit has the potential to be redefined later as a lithostratigraphic unit. Examples of formal names are such as Haukila Quartzite and Lahnala Gabbro Sill. The term 'formation' (or any other lithostratigraphic rank) should never be used in lithodemic nomenclature.

The name of a suite combines a geographical name and the rank term 'suite', with or without an adjective denoting the fundamental character of the suite. Examples of informal names include the Verkkola suite, Rysälä metamorphic suite, Koukkula intrusive suite and Siimala sill suite. The corresponding formal names are the Verkkola Suite, Rysälä Metamorphic Suite, Koukkula Intrusive Suite and Siimala Sill Suite. The name of a supersuite combines a geographical name with the term 'supersuite' (or 'Supersuite'). Only informal names are used for complexes, and the naming convention follows that of a suite (e.g., Venelä metamorphic complex, Airola migmatite complex). Finally, it is noted that the formalization of lithodemic units does not generate, as such, any major benefits, but in the case of well established names (e.g., Laitila Granite, Hyvinkää Gabbro) it is justified.

4.5 Paleosol as a stratigraphic unit

Indications of paleoweathering, or more formally, pedological horizons (see NASC 2005) represent products of soil development, which occurred subsequently to the formation of the underlying units. These horizons cannot be considered as lithostratigraphic or lithodemic units, but the involvement of pedostratigraphy is required. A *geosol*, the only pedostratigraphic unit, is defined as a buried, traceable, three-dimensional body of rock that consists of one or more differentiated pedological horizons. A geosol is a laterally traceable, mappable, geologic weathering profile that has a consistent stratigraphic position (NASC 2005).

Geosols are an important part of the stratigraphic record and have significance in correlation and even in paleoatmospheric studies. Marmo (1992) introduced the term *paleosol*, meaning a metamorphosed geosol, into the stratigraphic nomenclature of Finland. The description of a geosol (and a paleosol) should include a sufficient description of the material, based on features such as the colour, structure, chemical composition and mineralogy, and the nature of the unit boundaries. The lower boundary of a geosol (and a paleosol) is the lowest definite physical boundary of the horizon formed by pedogenesis, and the upper boundary is the top of a buried soil profile. Paleosols are named informally according to the type locality (e.g., Hokkalampi paleosol).

5 TECTONIC / STRUCTURAL GEOLOGICAL UNITS

5.1 Practice for establishing tectonic / structural units

Tectonic and structural units are not part of the classical stratigraphic portfolio (see Table 1 and Fig. 3). The classifications are variable and lack the stability of proper stratigraphic classification categories. However, the (semi)formal, 'Caledonian-style' tectonostratigraphy has a long tradition in Norway and Sweden. The term 'tectonostratigraphic unit' is used with two meanings in this guide: (1) tectonostratigraphic units (*sensu stricto*) corresponding to the NCS1989 classification and (2) tectonostratigraphic units (*sensu lato*) covering all kinds of thrust-bounded geological units in Finland. Tectonostratigraphic classification, as defined by NCS 1989 in Norway, is well defined and enables formal nomenclature.

Various lithotectonic divisions and classifications have gradually emerged (e.g., Sweden: Stephens 2020, Finland: Kohonen et al. 2021, Slovakia: Nemeth 2021), and these need to be considered as geological units. Luukas & Kohonen (2021) proposed a division for informal thrust-bounded units in Finland. Currently, internationally well-established lithotectonic classification schemes are not available. The description and characterization of all tectonic/structural units should correspond to the requirements presented in the classification scheme. Where lithotectonic units are used, the corresponding classification needs to be specified or defined (Fig. 7).

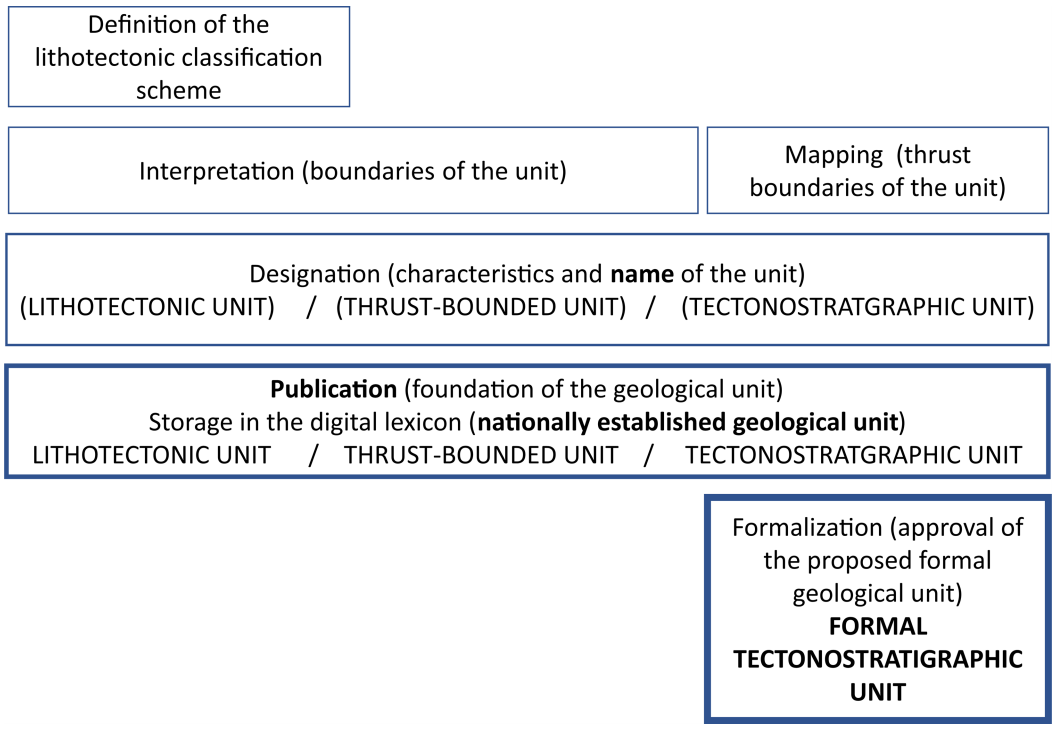


Fig. 7. Evolution of mapped (right) and interpreted (centre and left) structural / tectonic units from a map unit (top) towards a nationally established unit and further to a formal tectonostratigraphic unit (bottom right). For lithotectonic units, a classification scheme must be specified before the designation of new units (top left). The essential steps of the process are shown in bold.

5.2 Tectonostratigraphic units

5.2.1 General properties, rules and boundaries

Tectonostratigraphy is concerned with the stratigraphic division of geological units that are tectonically piled (Fig. 8) on top of each other (NCS 1989). The units are defined by their thrust boundaries and not by the lithology of the unit. The lower boundary is the floor thrust (sole thrust, basal detachment)

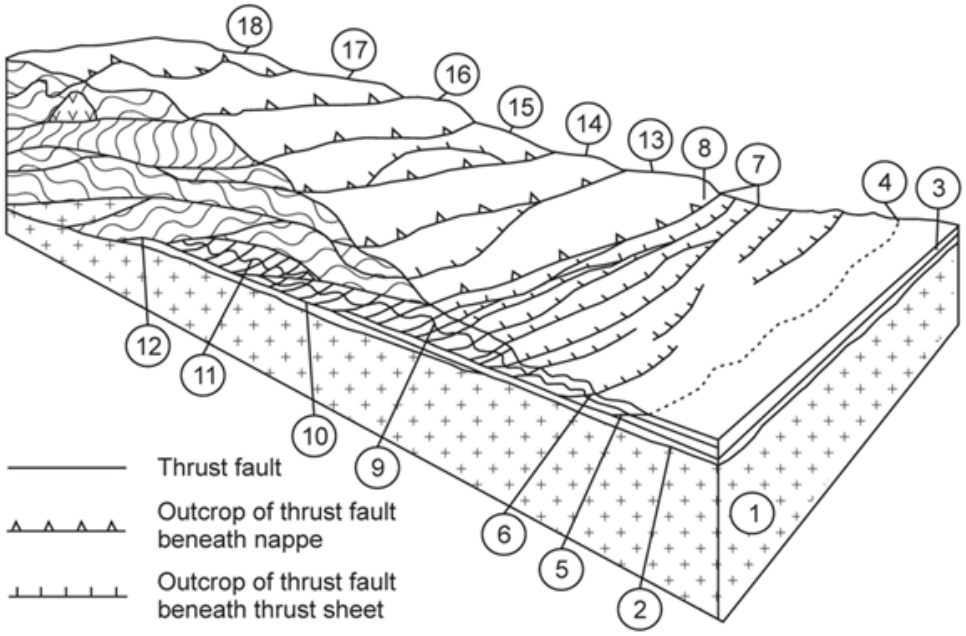
and the upper boundary may be delimited either by the roof thrust or by an erosion surface. Thus, tectonostratigraphic classification fundamentally differs from lithostratigraphic and lithodemic classifications.

A *tectonostratigraphic unit* has been defined as follows:

A tectonostratigraphic unit represents a body of rock that (1) has been shifted or displaced along a thrust fault and (2) is located above or between the thrusts defining the boundaries of the unit.

A tectonostratigraphic unit may contain one or more lithostratigraphic or lithodemic units, but these should never be used as lower ranks of a tectonostratigraphic unit. It is important to make a distinction between the structures (e.g., fault, thrust) and the units defining the bounding structures. Not all thrusts bound a geological unit. The establishment of a thrust-bounded ('tectonostratigraphic') map unit is only justified when it simplifies the geological description and substantially aids the representation of the regional geology.

Tectonostratigraphy is not an internationally recognized stratigraphic category, and it is not included in ISG 1994 or NASC 2005. Tectonostratigraphic units (*sensu stricto*) are widely used in Scandinavia and recognized in the national stratigraphic guides (Norway: NCS 1989; Finland: Strand et al. 2010; Sweden: Kumpulainen 2016). In this guide, the nomenclature and procedures suggested by NCS (1989) are followed in the formal classification of tectonostratigraphic units.



1: Ancient autochthonous basement (e.g. gneisses)
2: Nonconfromity surface
3: Autochthonous foreland succession
4: Thrust front
5: Front of the sole thrust
6: Splay thrust
7: Exposed imbricate thrust sheet
8: Nappe front
9: Imbricate nappe developed as a duplex (bounded by floor and roof thrusts)
10: Flat
11: Duplex with thrust sheets
12: Ramp
13: Nappe
13–19: Nappes that have been moved and displaces relative to the underlying tectonostratigraphical units
13–15: Nappes with a common history of thrusting (nappe system)
16–18: Nappes with a uncertain and/or unknown history of thrusting (nappe complex)
1–18: A tectonostratigraphical units bounded by a different surfaces and contacts

Fig. 8. Simplified schematic illustration of a foreland fold-and-thrust belt from the foreland (right) to the nappe region (left). (Modified from NCS 1989).

The designation of a new tectonostratigraphic unit should be supported by reference sections covering the bounding thrusts. The detailed description of the bounding faults is of paramount importance.

The description of a new tectonostratigraphic unit (nappe, thrust sheet) should include all necessary information, and for formal units, some items (indicated below in ***bolded italics***) are mandatory. An established new unit is characterized by information such as:

1. ***Name*****,** including the unit rank (or descriptive unit type for the informal units).
2. ***Location*** (with coordinates) of the type section or type area (if suitable).
3. Description of the unit, including: (i) ***a detailed description and names of the bounding thrusts***, (ii) other characteristic features, (iii) unit dimensions and shape (if possible).
4. Geological age, correlation and genesis (if possible).
5. ***Key references*** and historical background (if available).

The formal classification of tectonostratigraphic units (NCS 1989) would be applied when the thrust system is well established with published information, and where the major thrusts form the one primary basis for the rock unit division (e.g., Scandinavian Caledonides). In cases where the allochthonous nature of the unit is inferred, or the location and nature of the bounding thrust is poorly defined, the application of informal, descriptive *thrust-bounded units* is suggested.

5.2.2 Ranks of formal tectonostratigraphic units

The tectonostratigraphic units are, in decreasing order of the rank, *nappe system* and *nappe complex, nappe*, and *thrust sheet*, where nappe is the fundamental unit (NCS 1989). A nappe complex and nappe system have equal rank in a hierarchical classification (see Chapter 5.2.2.3 below).

5.2.2.1 Nappe

A *nappe* (*Nappe*) is the fundamental unit in tectonostratigraphic classification and nomenclature, and it is as a rank comparable to a formation or lithodeme (see Fig. 3). A nappe is a sheet-, slice-, wedge- or lens-shaped body of rock that has been moved and displaced, due to thrust faulting and/or sliding, a large distance in a horizontal or near subhorizontal (gently dipping) direction over the plane of separation along a thrust fault. A nappe is mappable at the Earth's surface and sometimes traceable into the subsurface by using geological and/or geophysical methods.

A nappe is defined and recognized by a tectonic thrust fault (floor thrust). The floor thrust and the nappe may, especially in multiply folded bedrock, be refolded or otherwise tectonically complicated. Therefore, the identification, systematic mapping and spatial representation of the early thrusts and related nappes may be difficult. Furthermore, in the deep levels of a thrust belt, the internal structure of a nappe is often complex and includes duplexes, other anastomosing shear zones, recumbent or overturned folds and thrust sheets of various dimensions and geometries.

5.2.2.2 *The lower rank: Thrust sheet*

A *thrust sheet* is the only lower rank of a nappe and comparable to a member of the lithostratigraphic classification system (see Fig. 2) representing a mappable unit within a defined nappe. The shape of a thrust sheet may vary (sheet, slice, wedge or lens), and there are no limitations for the size or the length of transport of a thrust sheet.

5.2.2.3 *The upper ranks: Nappe system and nappe complex*

A *nappe system* is a tectonostratigraphic unit next higher in rank to a nappe, and equivalent in rank to a nappe complex. It comprises two or more nappes, having a geometrical relation to one another. The movements and displacements of the distinct and individual nappes have taken place during the same deformation event. A nappe system may consist of several individual and distinct nappes and/or thrust sheets, which can be distinguished from one another by their content of lithostratigraphic, lithodemic and biostratigraphic units. The term nappe system should only be used when the movements and displacements of the individual nappes belong to the same deformation event and are well documented.

A *nappe complex* is a tectonostratigraphic unit next higher in rank to a nappe. Compared to 'nappe system', 'nappe complex' a less distinct term indicating that the displacements of the individual nappes represent different deformation phases or orogenies or that their relative ages are unresolved. A nappe complex may be comprised of two or more distinct nappes, but the term can also be used for complicated systems of inferred nappes or thrust

sheets. Before naming a unit as a 'nappe complex', the options provided by the 'thrust-bounded units' (Chapter 5.2.3) need to be considered.

5.2.3 Informal thrust-bounded units

A thrust-bounded unit is a body of rock that has been displaced along a floor thrust and may be delimited uppermost by a roof thrust or the erosion surface. All thrust-bounded units may contain one or more lithostratigraphic or lithodemic units. The proposed terminology of thrust-bounded units (Luukas & Kohonen 2021) basically consolidated the common practice used in Finland.

5.2.3.1 *Allochthon, thrust sheet (klippe, window)*

An *allochthon* is a thrust-bounded unit underlain by an inferred decollement. The inferred amount of tectonic transport must be substantial (several kilometres, at least). A *thrust sheet* is the lower rank of a nappe but is also used as a descriptive term for any mappable volume of rock underlain by a thrust. A thrust sheet may form a part of a nappe, allochthon, thrust stack, imbricate fan or duplex. A *klippe* is an outlier (erosional remnant) of an allochthon (or nappe) and a *window* is an inlier surrounded by an overlying decollement at the present erosional level. Both of the terms are defined by the current land surface representing the extent of a map unit rather than a proper geological unit. 'Klippe' and 'window' are standard terms but should not be used in the nomenclature of geological units.

5.2.3.2 *Thrust stack, duplex, thrust block*

Not all thrusts are low-angle detachment zones, and the steeper fault zones may also delineate map units useful in regional description. *Thrust stack* refers to imbricated thrust sheet systems when the decollement is not identified, or the sole thrust is not a low-angle detachment; a typical example is a basement-involved foreland thrust system. A *duplex* is a thrust stack or a thrust sheet consisting of sigmoidal, smaller thrust sheets ('horses') between two larger-scale thrusts (e.g., Boyer & Elliott 1982). A *thrust block* is a special type of a thrust sheet, which is a relatively rigid, voluminous thrust-bounded body of rock. These are especially useful in the description of large-scale crustal features (for examples, see Luukas & Kohonen 2021). Finally, it is important to ensure that reverse faults, thrust faults and shear zones are geological structures, which do not automatically bound any geological unit. The Finnish bedrock is occupied by minor thrusts and reverse faults, and not all of these are meaningful in the sense of thrust-bounded unit boundaries.

5.2.4 Naming of formal and informal units

The formal and informal names for the tectonostratigraphic units are formed, according the general rules of naming (see Chapter 3), by the combination of a geographical name and a rank term or a descriptive term.

According to the procedure in NCS (1989), a proper tectonostratigraphic unit is defined and named according to the lower bounding thrust. The name combines a geographical term attached to the floor thrust (nappe, thrust sheet) or to the type area (nappe system and nappe complex) with the rank term. A thrust sheet must not be given the same geographical name as the nappe or the lithostratigraphic/lithodemic units within the nappe or thrust sheet. A nappe system or a nappe complex must not be given the same geographical name as a component nappe, or as any of the lithostratigraphic/lithodemic units in it.

A formal unit name is indicated by capitalized initial letters (e.g., Vaddas Nappe). In Finland, no formal names for nappe complexes have been suggested. The formal status requires the procedure described in Chapter 3.2. As an exception, where the unit names are adopted from an established formal nomenclature of the neighbouring countries (e.g., Finnish Caledonides), no re-approval by the SCF is needed. The informal thrust-bounded units are named by the combination of the geographical name of the type area and the descriptive term (such as 'thrust block' or 'thrust stack'; see Luukas & Kohonen 2021).

Examples of application

Lehtovaara (1986, 1989, 1995) and Lehtovaara & Sipilä (1987) applied the NCS 1989 tectonostratigraphic scheme to the Finnish Caledonides (e.g., Nalganas, Nabar and Vaddas Nappes) in the northwestern part of Finnish Lapland. In the Finnish bedrock, the repetition of strata by thrusts is probably much more common than currently recognized, and this is reflected by several examples of the tentative use of the term 'nappe', even without a sufficient description of the boundaries (e.g., Koistinen 1981, Laajoki 1991). Luukas & Kohonen (2021) provide both suggestions for the management of structural units and several examples of their practical usage. Another recent example is the Ylitornio nappe complex proposed by Lahtinen et al. (2019).

5.3 Lithotectonic units

5.3.1 General properties

A lithotectonic unit has been defined as follows*:*

- A body of rock distinguished and defined based on the specified tectonic or structural features and attributes;
- A geological unit defined on the basis of structural or deformation features, mutual relations, origin or historical evolution. Contained material may be igneous, sedimentary or metamorphic (CGI definition as a subclass of *geologic unit*).

Tectonic terms and related nomenclature are closely linked to the concepts and interpretations applied in their designation. Therefore, the harmonization of the nomenclature is challenging, and well-established classifications (or categories) with an internationally recognized status are not available. However, the published tectonic models, regional maps and general overviews include a plethora of 'crustal blocks', orogenic-crustal-structural 'domains', different kinds of 'provinces', 'terranes' and 'mobile belts', typically without any definition or other explanation. The nomenclature of these, typically extensive, geological units is needed, but systematic approaches are currently still in their infancy.

5.3.2 Classifications and subdivisions

The CGI vocabulary (v2016.01) recognizes only one subclass of a lithotectonic unit. A *deformation unit* is a lithotectonic unit defined by the deformation style or characteristic geological structure observable in outcrop. In Finland, Kohonen et al. (2021) proposed a classification scheme for three classes of lithotectonic units: *crustal province*, *tectonic province* and *structural province*. The provinces are characterized by a defined set of features and subdivided into subprovinces, domains and subdomains.

5.3.3 Obsolete terms: terrane, province and block

A *terrane* (or 'tectonic terrane'; 'suspect terrane'; 'exotic terrane') is an informal descriptive term for a fault-bounded body of rock characterized by a geological history different from that of the adjacent areas. The term was introduced by Irwin (1972) and finally established by Coney et al. (1980). The term has been used for (i) continental blocks bounded by suture zones and newly formed oceanic crust, (ii) nappes bounded by thrust faults, (iii) blocks bounded by regional transform faults, and (iv) pieces of the Earth's crust having complex and structurally composite fault surfaces. The key feature is that the terrane is found 'exotic' in comparison to the surrounding units. Presently, the term is ambiguous and partly overlaps with other terms such as allochthon, province, structural complex and tectonic block. *Terrane* must not be confused with the term "terrain", which is a general term relating to the physical features of the region or area.

International examples of the systematic classification of *provinces* are few, and the terminology is not well established. The Glossary of Geology (Neuendorf et al. 2011) provides the two following broad definitions: (1) A *province* is a large region with similar features or a history significantly different from the adjacent areas; (2) A *geological province* is an extensive region with a similar geological history throughout or similar structural, petrographic or physiographic features. A *block* (or fault block) is a fault-bounded unit that has been displaced as a single unit. Without a detailed description, or a reference to a definition, the use of the general terms 'terrane', 'province' and 'block' is not suggested in the unit nomenclature of Finland, and even in these cases, other naming options (such as structural province, crustal domain) are worth considering.

6 OTHER MATERIAL-BASED CLASSIFICATIONS

6.1 Sequence stratigraphy

6.1.1 General principles and unit boundaries

The lithostratigraphic classification of the sedimentary record remains the basic descriptive process for stratigraphic documentation because the extensive body of documentation is based on lithostratigraphy. However, the ultimate future goal is to develop stratigraphic frameworks based

on sequence stratigraphy (Catuneanu et al. 2011). The method combines the insights of stratigraphic classifications and disciplines such as sedimentology, geomorphology, geophysics and basin analysis (cf. Catuneanu et al. 2009). The deductive sequence stratigraphic approach (see Embry & Johannessen 2017) defines the surfaces in terms of theoretical events on a base-level curve and builds a bridge between the identified boundaries and basin modelling techniques. Sequence stratigraphy is concerned with the large-scale arrangement of sedimentary strata, and the major factors that influence the unit geometries, such as sea-level change, contemporaneous fault movements, basin subsidence and sediment supply (see Rawson et al. 2002). Fundamentally, sequence stratigraphy deals with the sedimentary response to changes in the base level, and the depositional trends that emerge from the interplay of sedimentation (clastic input) and the accommodation space (available for sediments to fill).

Sequence stratigraphy is an approach to integrated stratigraphic analysis, dealing with the sedimentary response to changes in the base level, and the depositional trends that emerge from the interplay of sedimentation and accommodation space. Changes in the base level depend on the interplay of allogenic controls such as eustasy, tectonism and climate. The base level is therefore the link that synchronizes depositional processes across a sedimentary basin, bringing necessary coherence to the sequence stratigraphic model. This, in turn, means that sequence stratigraphy is an effective tool for correlation on a regional basis.

Sequence stratigraphy is not currently recognized as a stratigraphic category by any of the references given in Table 1. The units are defined by their boundaries, and the method shares some features of allostratigraphy (see NASC 2005), the definition of unconformity-bounded units of ISG 1994 and seismostratigraphy (cf. NCS 1989). The generic definition of a sequence corresponds to a full cycle of base-level changes (Fig. 9), and four main events are generally recognized:

I. Onset of forced regression (onset of a base-level fall in the shoreline)
II. End of forced regression (end of a base-level fall in the shoreline)
III. End of regression (during a base-level rise in the shoreline)
IV. End of transgression (during a base-level rise in the shoreline)

These four events control the timing of the formation of all sequence stratigraphic surfaces and systems tracts. Sequence stratigraphic surfaces (Fig. 9) define the unconformities due to the response to the main events. These serve in both the recognition of events and the division of the corresponding units. The process-based understanding of the origin of all genetic types of deposits and their bounding surfaces is fundamental to the success of the sequence stratigraphic approach. The integration of outcrop, core, well-log and seismic data affords the most effective application of the sequence stratigraphic method.

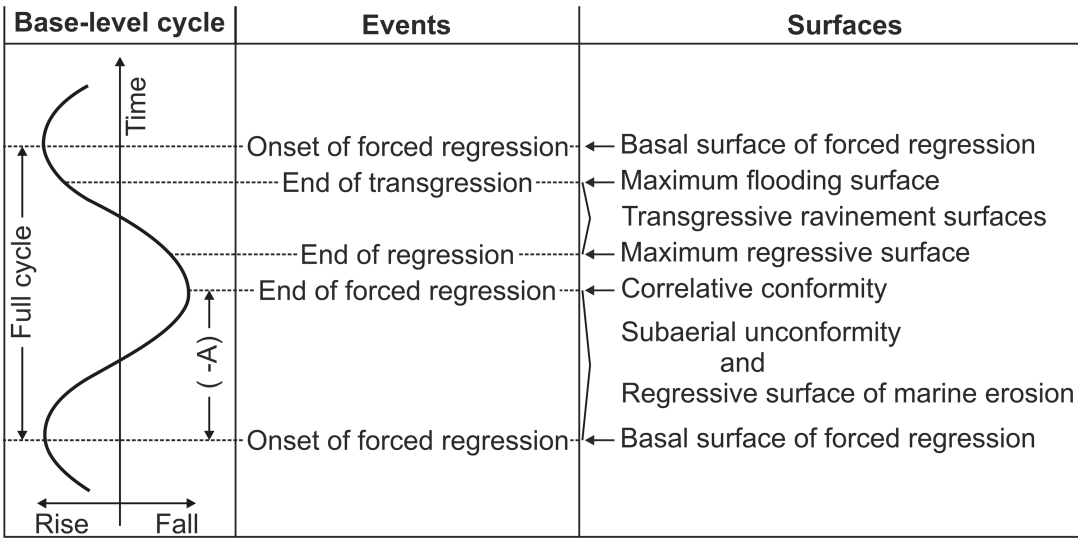


Fig. 9. Timing of the seven sequence stratigraphic surfaces relative to the four main events of the base-level cycle (modified from Catuneanu 2006). (Abbreviation: (–A) stands for negative accommodation)

The cyclicity of Proterozoic sedimentary rocks is still a rather crude concept, and the application of sequence stratigraphy to the Proterozoic rock record typically encounters difficulties due to poor preservation, tectono-metamorphic overprint and a lack of age determinations (Catuneanu 2006, Catuneanu et al. 2009). Nonetheless, the studies by Christie-Blick et al. (1988, 1995), Harris & Eriksson (1990), Jackson et al. (1990) and Catuneanu & Eriksson (1999) have demonstrated that the sequence stratigraphic approach can in principle be applied to the analysis of Proterozoic successions.

6.1.2 Units in sequence stratigraphy

The key concepts of sequence stratigraphic unit division are 'sequence' and 'systems tract' (Fig. 10). A full stratigraphic cycle, which starts and ends with the same type of sequence stratigraphic surface, delineates a 'sequence' (Catuneanu & Zecchin 2013), which typically includes two or more systems tracts. A *sequence* is a relatively conformable succession of genetically related strata bounded by unconformities or their correlative conformities (Mitchum 1977). A sequence corresponds to a full cycle of base-level changes. It includes two stages of sediment-driven regression forming low-stand and high-stand systems tracts, an intervening stage of forced regression driven by a base-level fall generating a falling stage systems tract, and a stage of shoreline transgression, which relates to a transgressive systems tract. Each of these stages results in the formation of a particular genetic type of deposit, with characteristic stratal stacking patterns and sediment distribution within the basin. The definition of a sequence is independent of temporal and spatial scales. The relative importance of sequences is resolved via the concept of hierarchy. Higher-rank sequences may consist of two or more lower-rank sequences. A *parasequence* is a relatively conformable succession of genetically related beds or bedsets bounded by flooding surfaces or their correlative surfaces (Van Wagoner et al. 1988, 1990, Arnott 1995). Depending on the circumstances, these may be represented by transgressive ravinement surfaces, maximum flooding surfaces, maximum regressive surfaces, or facies contacts within the transgressive systems tract. Parasequences are commonly used to describe individual prograding lobes in coastal to shallow water systems, where evidence of flooding surfaces is easiest to demonstrate.

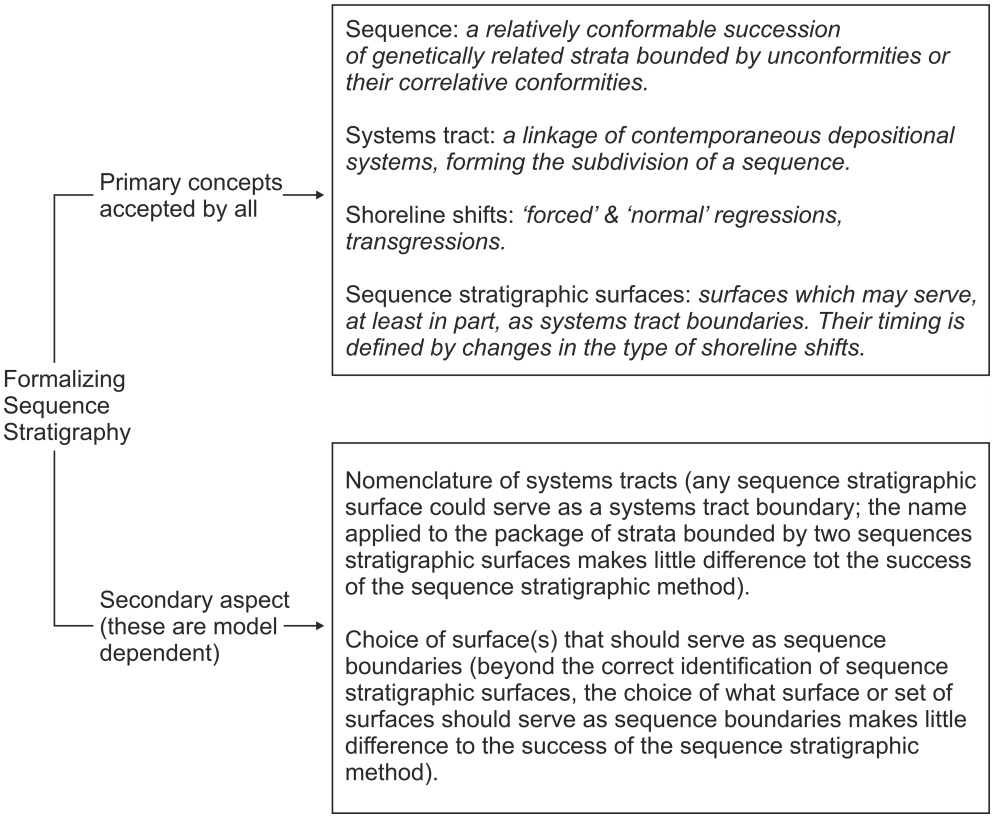


Fig. 10. Primary and secondary aspects in sequence stratigraphy (modified from Catuneanu 2006). Primary aspects are validated and generally accepted ('generic'). Secondary aspects are dependent on the model selected. The generic concept is the first step towards more formalized sequence stratigraphic units.

The mappability of the sequences, systems tracts and the bounding surfaces depends on the depositional setting and the types of data available for analysis (Catuneanu et al. 2009). In practice, the main methods of sequence stratigraphy in modern environments include the analysis of seismic reflectors and well-log signatures. In the study of ancient deposits (including bedrock successions), the facies analysis of outcrops, cores and interpretation of the unconformities are generally the only tools available. The achievement of time control via relative or absolute age determination is important in both cases. Conclusively, the application of sequence stratigraphic units may be useful in detailed studies with a genetic approach (e.g., paleosedimentology, basin analysis). However, the definition of any new geological unit must serve a clear purpose in stratigraphic work in Finland.

Examples of application

The basin analysis of the Kainuu belt (see Strand & Laajoki 1999, Strand 2005, 2012) provides examples of sequence stratigraphy applied to the Proterozoic rocks in Finland,

6.2 Tectofacies classification in Finland

Laajoki (1990, 1991) introduced the informal stratigraphic concept of *tectofacies* for "all the formations formed during a specific broad tectonic phase of the depositional-volcanic history of a basin or nearby basins." In fact, all the different tectofacies (Sumi, Sariola, Kainuu, Jatuli, Lower Kaleva and Upper Kaleva; Laajoki 1990) in the Kainuu belt are separated by major unconformities. Therefore, the concept of tectofacies shares features of a synthem, a diachronous, unconformity-bounded stratigraphic unit (see ISG 1994). However, without regionally identified unconformity surfaces, the unit (synthem) boundaries remain elusive.

Laajoki (2005) widened the perspective by stating that "in terms of sequence stratigraphy the tectofacies are related to Hubbard's (1988) megasequences." Even so, tectofacies cannot be considered as sequence stratigraphic units. In fact, the tectofacies concept appears to be primarily linked to the depositional megacycles derived from the basin evolution model of Kainuu (Laajoki 1991, 2005), and this has restricted the inter-regional application of the scheme.

7 CLASSIFICATIONS RELATED TO GEOLOGICAL AGE

7.1 Chronostratigraphic units

7.1.1 General properties, rules and boundaries

A chronostratigraphic unit has been defined as follows:

- A body of rocks that includes all rocks formed during a specific interval of geological time and only those rocks formed during that time span. Chronostratigraphic units are bounded by synchronous horizons. The rank and relative magnitude of the units in the chronostratigraphic hierarchy are a function of the length of the time interval that their rocks subtend, rather than of their physical thickness (ISG 1994);
- A body of rocks that includes all rocks representative of a specific interval of geological time, and only this time span. Chronostratigraphic units are bounded by isochronous horizons that mark specific moments of geological time (https://stratigraphy.org/guide/ 25.1.2022);
- A body of stratified rock that forms a material reference for all rocks formed during the same period of time;
- A geological unit that includes all rocks formed during a specific interval of geological time. CGI definition (a subclass of a *geologic unit*).

Chronostratigraphic units are based on the time of formation of the rock bodies and not on the material properties of the observed rock bodies. A unit includes all rocks formed during a specific interval of geological time and it comprises rocks with isochronous (time-parallel) lower and upper boundaries.

Chronostratigraphic classification provides a means of establishing the temporally sequential order of rock bodies. The principal purpose is to provide a framework for (1) the temporal correlation of the rocks in one area with those in another,

(2) placing the rocks of the Earth's crust in a systematic sequence and indicating their relative position and age with respect to the Earth's history as a whole, and (3) constructing an internationally recognized Standard Global Chronostratigraphic Scale (e.g., Grandstein et al. 2004).

The boundaries of the Phanerozoic stages, the lower boundary of the Ediacaran System and the corresponding geochronological units (age, period; see Table 3), are based on the recognition of a Global Boundary Stratotype Section and Point (GSSP; see Cohen et al. 2013; https://stratigraphy.org/ICSchart/ChronostratChart2023-09.pdf). In contrast, most Proterozoic (all Precryogenian) system/period boundaries, and all the Archean Erathem/Era boundaries are based on the geochronometric subdivision of geological time, and the boundaries defined by the Global Standard Stratigraphic Ages (GSSA) have no corresponding rock sequences. Therefore, the conceptual difference between the chronostratigraphic and geochronological nomenclature is easily dissolved in the bedrock geology.

Geochronological units are divisions of time, not tangible material units. A geochronological unit is not a stratigraphic unit but represents the time span of the corresponding chronostratigraphic unit. The difference is underlined by the subdivision of the units: chronostratigraphic units may be formally divided into Lower, (Middle) and Upper, whereas the corresponding geochronological units are divided into Early, (Middle) and Late. The names and boundaries of the all the chronostratigraphic, and corresponding geochronological, units are defined internationally by ICS (https://stratigraphy.org).

7.1.2 Ranking and nomenclature of chronostratigraphic units

The hierarchy of chronostratigraphic units, in order of decreasing rank, is eonothem, erathem, system, series and stage. In Proterozoic and Archean chronostratigraphy, system and erathem are the primary ranks. At any level in the hierarchy, an initial capital letter is used for each formal component of the name (e.g., Paleoproterozoic Erathem; Orosirian System). The use of lowercase initial letters implies an informal usage (e.g., 'lower Orosirian succession'; for details, see Grandstein et al. 2004).

Table 3. Rank terms of the chronostratigraphic category and the correspondence of the geochronological units (modified after ISC 1994).

Division of rock record (strata) into units based on their age	**Division of time** based on GSSP age or GSSA.
Chronostratigraphic Unit terms	**Geochronological Units**
Eonothem Erathem System Series Stage (Chronozone)	Eon Era Period Epoch Age (Chron)

7.1.2.1 Eonothem and Erathem

The highest unit rank is the *eonothem* and the next lower rank is *erathem*. The Phanerozoic Eonothem encompasses the Paleozoic, Mesozoic and Cenozoic Erathems. The Proterozoic Eonothem covers the Paleoproterozoic (2500– 1600 Ma), Mesoproterozoic (1600–1000 Ma) and Neoproterozoic (1000–542 Ma) Erathems. The Archean Eonothem is presently subdivided into Eoarchean (4031–3600 Ma), Paleoarchean (3600–3200 Ma), Mesoarchean (3200–2800 Ma) and Neoarchean (2800–2500 Ma) Erathems.

7.1.2.2 System

The unit of rank next lower to erathem is *system*. Rocks encompassed by a system represent a time span and an episode of the Earth's history sufficiently great to serve as a worldwide chronostratigraphic reference unit. The temporal equivalent of a system is a period. Presently, the Archean is not divided into systems. The Paleoproterozoic erathem encompasses the Siderian (2500–2300 Ma), Rhyacian (2300–2050 Ma), Orosirian (2050–1800 Ma) and Statherian (1800–1600 Ma) systems. The Mesoproterozoic erathem encompasses the

Calymmian (1600–1400 Ma), Ectasian (1400–1200 Ma) and Stenian (1200–1000 Ma) erathems, and the Neoproterozoic erathem encompasses the Tonian (1000–850 Ma), Cryogenian (850–630 Ma) and Ediacaran (630–542 Ma) systems. The Proterozoic–Cambrian boundary has been defined at 542 Ma by Amthor et al. (2003).

7.1.2.3 Series and Stage

A *series* is a chronostratigraphic rank below a system and is always a division of a system. A series commonly constitutes a major unit of chronostratigraphic correlation within a province, between provinces or between continents. Although many European series are increasingly being adopted for dividing systems on other continents, provincial series of regional scope continue to be useful. The temporal equivalent of a series is an epoch. A *stage* is a chronostratigraphic unit of smaller scope and rank than a series. It is most commonly of greatest use in intra-continental classification and correlation, although it has the potential for worldwide recognition. The geochronological equivalent of a stage is an age. For the nomenclature and boundaries of the Phanerozoic systems, stages and series, the International Chronostratigraphic Chart is referred to (https://stratigraphy.org/ICSchart/ChronostratChart2023-09.pdf).

7.1.2.4 Chronozone

A *chronozone* is a nonhierarchical, but commonly small, formal chronostratigraphic unit, and its boundaries may be independent of those ranked chronostratigraphic units such as system or stage. Although a chronozone is an isochronous unit, it may be based on a biostratigraphic unit (e.g., Cardioceras cordatum Biochronozone), a lithostratigraphic unit (Woodbend Lithochronozone) or a magnetopolarity unit (Gilbert Reversed-Polarity Chronozone). Chronozones may be of widely different time spans and, in theory, the extent of a chronozone is worldwide (for details of application, see ISG 1994).

7.2 Event stratigraphy

The term '*event stratigraphy*' was proposed by Ager (1973) for the recognition, study and correlation of the effects of significant physical events (e.g., marine transgressions, volcanic eruptions, geomagnetic polarity reversals, climatic changes) or biological events (e.g., extinctions) on the stratigraphic record of whole continents or even of the entire globe. Event stratigraphy can be defined as the organization and correlation of rocks on the basis of short-term, extraordinary phenomena, such as explosive volcanism, abrupt sea-level changes, climatic anomalies and meteorite impacts. The fundamental idea comes rather close to chronozones, marker beds and even to sequence stratigraphy (rapid eustatic changes).

Nevertheless, the effects of major events in the rock record may define truly synchronous horizons, and their correlation thus potentially leads to greater resolution and a more accurate chronostratigraphic scale, especially in the bedrock geology. The developments in Precambrian chronostratigraphy and the potential of various 'events' in the progressing definition of GSSPs has been reviewed by Altermann et al. (2012).

7.3 Application of chronostratigraphy and geochronology to the bedrock units of Finland

The Eonothem (Eon) and Erathem (Era) nomenclature is widely used in Finland. The application of the formally defined Proterozoic periods (e.g., Rhyacian, Orosirian) is not common in the literature, but the map data of GTK have been attributed accordingly. Furthermore, to improve the resolution of the map data of the Fennoscandian Shield, an informal subdivision to epoch level has been proposed (Asch et al. 2007, Luukas et al. 2017). The challenge with the Proterozoic period/system nomenclature is related to the globally defined boundaries not ideally corresponding to the observed age pattern and derived nomenclature used in Fennoscandia and in Finland. According to ISG 1994, the regional scales are acceptable: "*It is better to refer strata with accuracy to local or regional units than to strain beyond the current limits of time-correlation in assigning these strata to units of a global scale. Local or regional chronostratigraphic units should adhere to the same rules established for the units of the Standard Global Chronostratigraphic Scale*."

In Finland, the regional classifications related to geological age are referred to as '*time-stratigraphic*' in order to avoid any confusion and to underline the global nature of the proper chronostratigraphic units. Regionally defined geochronological and corresponding time-stratigraphic (or 'event-stratigraphic') units are found appropriate when based on an established (scientifically published) scale. c All such time-stratigraphic units are informal and should not been mixed with the formal, internationally defined chronostratigraphic nomenclature. Finally, it is essential to note that in the bedrock of Finland, the chronostratigraphic (time-stratigraphic) boundaries are not possible to define in the field. Consequently, the application is limited to the correlation of the tangible material-based unit and the presumably corresponding time-based unit.

Examples of application

Event-stratigraphy basically attempts to identify natural events as a basis for time-based boundaries. Following this, Hanski & Meletzhik (2012) proposed an 'event-stratigraphic' (essentially time-stratigraphic) scheme for the (2505–1900 Ma) eastern and northern parts of the Fennoscandian Shield. Furthermore, the authors converted some legacy names (such as Jatulian, Kalevian) to the nomenclature of the proposed scale. Kohonen et al. (2024, this volume) developed the idea further and complemented the scale by including the Svecofennian evolution (2000-1800 Ma) in western and southern parts of Finland.

8 TERMINOLOGICAL COMMENTS

Misuse of the terms 'group' and 'supergroup'

Even the informal use of the lithostratigraphic rank terms 'group' and 'supergroup' for units not consisting of lower rank lithostratigraphic units is inappropriate.

Use of the term 'complex'

The word 'complex' is a component of various geological terms (e.g., intrusive complex, core complex, metamorphic complex). Regarding geological units, the definition of a lithodemic complex is presented in Chapter 4.3.4. Other uses of 'complex' are common and useful in general descriptive text (e.g., Archean basement complex). When the meaning is unambiguous and when not mixed with the defined nomenclature of geological units, this type of usage is part of conventional terminology and thus acceptable.

Misuse of the term 'series'

The term 'series' has sometimes been used or applied to lithodemic and lithostratigraphical units, or to a sequence of rocks resulting from a succession of eruptions or intrusions. 'Series' is a formally defined chronostratigraphic term, corresponding to the geochronological term 'epoch', and should not be used for any other geological unit. In the informal Precambrian chronostratigraphy, '*system*' is the lowest rank, and no Precambrian geological unit name should not include the word 'series'. However, the words 'series', 'stage' and 'system' have been found useful in the description (e.g., layered series in the Narkaus intrusion; the early basin stages during the Jatulian) and, when confusion with chronostratigraphy is implausible, this usage is acceptable.

Names with ending '-ian'

According to the common usage, the names with the ending '-ian' (e.g., Devonian, Orosirian, Jatulian) are preferably used for chronostratigraphic (time-stratigraphic) or geochronological units. To support consistency and to avoid digressions, the ending is not suggested for any unit without a reference to a defined classification related to geological age.

Geographical geological names

Names referring to a geographical area or region in Finland (such as the Outokumpu area, the Kainuu belt and Central Finland granitoid area) and other geological geographical names (such as Fennoscandian Shield, the Russian platform, the Caledonian orogenic belt) are not part of the geological unit nomenclature. These region names are useful for many practical purposes, such as generalized maps and regional descriptions. The current region nomenclature, and its relationships with the lithotectonic terminology, has been summarized in Kohonen et al. (2021).

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APPENDIX 1

PROCEDURE FOR ESTABLISHING AND REVISING FORMAL STRATIGRAPHIC UNITS IN FINLAND

Accepted as a practice in the SCF (SSK *in Finnish*) meeting on 4.12.2019

Rationale:

- **The Geological Survey of Finland (GTK) maintains and develops the National Stratigraphic Database of Finland** (Finstrati). As the owner, GTK is authorized to develop the structure of Finstrati, guided by the operational needs of GTK and the development of GTK customer services.
- The charter of the Stratigraphic Commission of Finland (approved in the National Geological Committee of Finland meeting in 2006) states that **establishing and revising formal stratigraphic units is one key task of the SCF**.

Procedure for establishing formal units:

- GTK presents proposals for a formal unit status to the SCF. The original statement of intent may be presented by GTK or by a third party. The final GTK proposal must contain a due and clear description of the unit(s) in question and according to the requirements of the classification category.
- After submission to the SCF
  - The SCF asks the opinion of the Precambrian or Quaternary Subcommission; if needed, the Subcommission may request further information or a supplementary description of the unit.
  - The proposal seconded by the Subcommission is handed over to the SCF secretary.
  - The final decision is made in a meeting of the SCF.
- After SCF approval
  - GTK executes the required changes in the database.
  - GTK saves adequate documentation about the approval procedure in the information attributed to the unit.

ORIGINAL TEXT (IN FINNISH):

Formaalisten stratigrafisten yksiköiden muodostaminen ja hyväksyminen Suomessa

Hyväksytty käytännöksi SSK:n kokouksessa 4.12.2019

Lähtökohdat:

- *Geologian tutkimuskeskus (GTK) ylläpitää ja kehittää Suomen kansallista stratigrafian tietokantaa (Finstrati).*
- *GTK:lla on omistajan oikeus kehittää Finstratin rakennetta oman toimintansa ja asiakastarpeiden ohjaamana.*
- *Suomen Stratigrafian Komitean (SSK) perustamiskirjassa (hyväksytty Suomen Kansallisen Geologian Komitean vuoden 2006 kokouksessa) todetaan SSK yhtenä tehtävänä olevan muodollisten stratigrafisten yksiköiden hyväksyminen Suomessa.*

Menettelytapa formaalisten yksiköiden hyväksymisessä:

- *GTK tekee omasta aloitteestaan tai jonkin muun tahon aloitteen hyväksyttyään perustellun esityksen formaalin statuksen antamisesta. Perustelun tulee sisältää yksikölle / yksiköille riittävä kuvaus, joka täyttää kyseisen stratigrafisen luokittelun vaatimukset koskien yksikön määrittelyä.*
- *Esitys toimitetaan lausunnolle kvartäärin tai prekambrin työryhmään. Työryhmä voi tarvittaessa pyytää lisätietoja ja/tai edellyttää esityksen täydentämistä perustelluista syistä.*
- *Puollettu esitys toimitetaan SSK:n sihteerille ja esitys käsitellään SSK:n kokouksessa.*
- *GTK tekee SSK:n hyväksymisen jälkeen tarvittavat muutokset tietokantaan ja tallentaa yksikön tietoihin riittävän dokumentaation hyväksymismenettelystä.*

APPENDIX 2

LIST OF SUPPLEMENTARY INFORMATION IN THE WORLD WIDE WEB

CGI Vocabularies Register
https://cgi.vocabs.ga.gov.au/vocab/

GTK Map service – MDaE (Mineral Deposits and Exploration)
https://gtkdata.gtk.fi/mdae/index.html

North American Commission on Stratigraphic Nomenclature:
https://nacsn.americangeosciences.org/
http://www.agiweb.org/nacsn/code2.html

The Helsinki Term Bank for the Arts and Sciences (Tieteen Termipankki)
https://tieteentermipankki.fi/wiki/Geologia

The International Commission on Stratigraphy (ICS)
https://stratigraphy.org/
https://stratigraphy.org/guide/
https://stratigraphy.org/timescale/

The Stratigraphic Commission of Finland (SCF)
https://www.geologia.fi/2020/07/12/Suomen-stratigrafian-komitea-ssk/