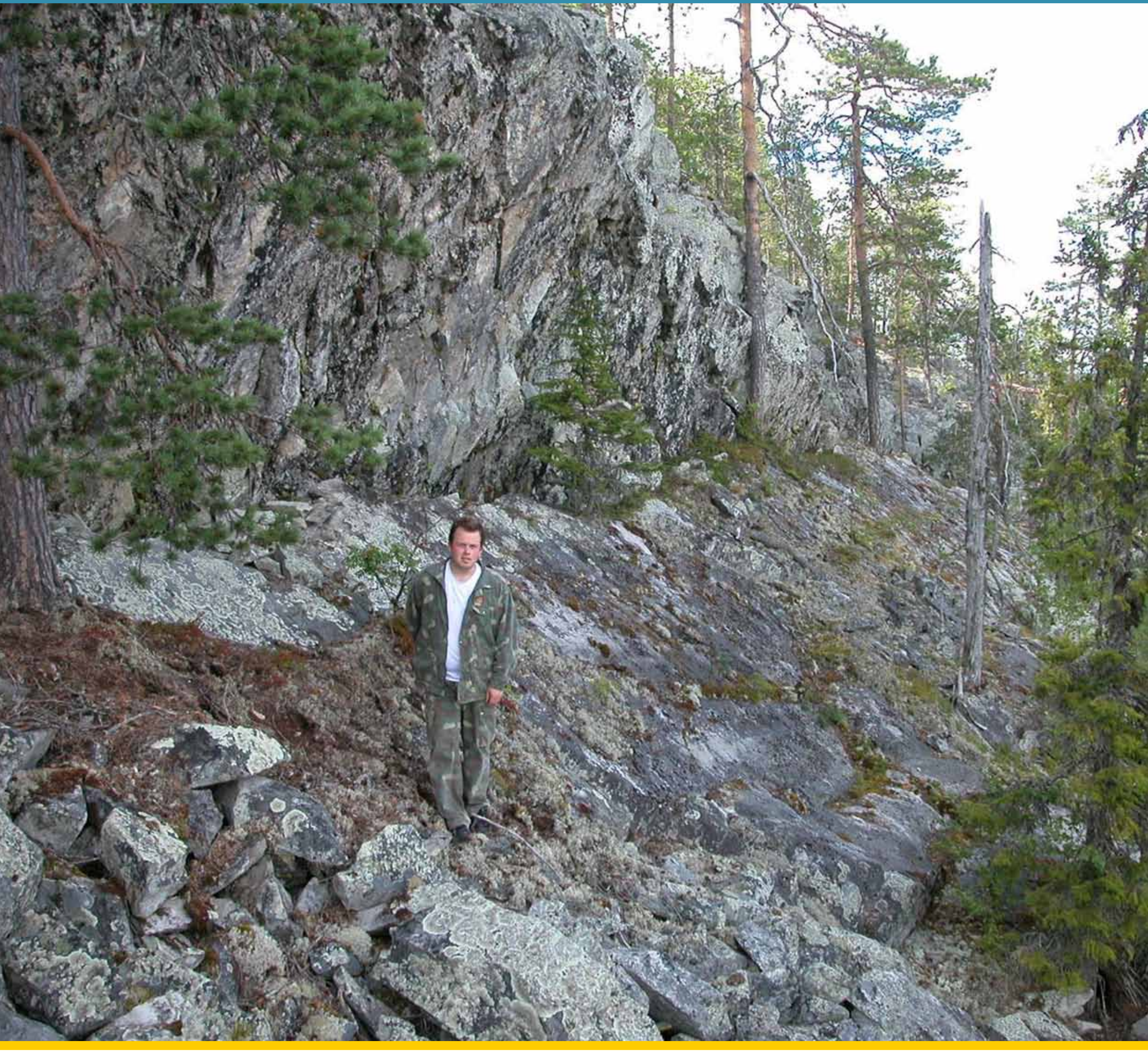
GEOLOGICAL SURVEY OF FINLAND
Guide 55
2010



Guidelines and Procedures for Naming Precambrian Geological Units in Finland

2010 Edition Stratigraphic Commission of Finland: Precambrian Sub-Commission

Kari Strand, Juha Köykkä and Jarmo Kohonen (eds.)

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GEOLOGIAN TUTKIMUSKESKUS **GEOLOGICAL SURVEY OF FINLAND**

Opas 55 Guide 55

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GUIDELINES AND PROCEDURES FOR NAMING PRECAMBRIAN GEOLOGICAL UNITS IN FINLAND

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Espoo 2010

Cover photo: Bedforms in quartzites of the Kometto Formation in Siikavaara, northern Finland. Photo: Kari Strand.

Strand, K., Köykkä, J. & Kohonen, J. (eds.) 2010. Guidelines and Procedures for Naming Precambrian Geological Units in Finland. 2010 Edition Stratigraphic Commission of Finland: Precambrian Sub-Commission. *Geological Survey of Finland, Guide 55*, 41 pages, 6 figures and 1 table.

This guide and procedure for naming Precambrian geological units in Finland was produced under the supervision of the Stratigraphic Commission of Finland. The role of the commission is to provide guidance for stratigraphic procedures, terminology and the revision of geological units in Finland. An increasing need for advice on the use of stratigraphic terminology and for rules for establishing geological units has clearly been apparent in recent years, both nationally and internationally. Effective communication in geosciences requires accurate and precise internationally acceptable terminology and procedures. In this guide, the principal types of stratigraphy related to Precambrian geology are outlined and guidelines and recommendations are provided on the procedure for recognizing and formalizing geological units and terminological usage. A significant development in principles has included recognition of the meaning of correlative unconformities in the rock record as a part of stratigraphy, and their application in sequence stratigraphy. The definition and description of geological units and their possible stratigraphic order forms an essential part of every country's geological vocabulary. To avoid misunderstanding and confusion and to help in transferring knowledge of geoscience information and systems, geological units need to be named and classified according to accepted guidelines and stratigraphic codes.

This guide seeks to be taken as an essential tool for geoscientists, students and information professionals in defining and naming geological units in Finland. The adopted procedures will then also provide valid information for the stratigraphic databases used in the country. The Geological Survey of Finland is maintaining the stratigraphic database under its map services (http://www.geo.fi) in collaboration with the Stratigraphic Commission of Finland. With significant new international recommendations, online updates of this guide will appear under the guidance of the Stratigraphic Commission of Finland. The use of the guide in everyday work is the best way to ensure best practices in naming the Precambrian geological units in Finland.

Keywords (GeoRef Thesaurus, AGI): lithostratigraphy, stratigraphic units, lithodemic units, tectonostratigraphic units, sequence stratigraphy, chronostratigraphy, Precambrian, nomenclature, guidelines, Finland

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ISBN 978-952-217-140-5 (PDF)
ISSN 0781-643X

Strand, K., Köykkä, J. & Kohonen, J. (toim.) 2010. Guidelines and Procedures for Naming Precambrian Geological Units in Finland. 2010 Edition Stratigraphic Commission of Finland: Precambrian Sub-Commission. *Geologian tutkimuskeskus, Opas 55*, 41 sivua, 6 kuvaa ja 1 taulukko.

Tämä Suomen prekambristen geologisten yksiköiden nimeämisohjeet ja käytännöt kokoava opas valmisteltiin Suomen stratigrafisen komitean johdolla. Komitean tehtävänä on ohjeistaa, uudistaa ja valvoa Suomen stratigrafisen luokittelun ja nimistön käyttöä. Viime aikoina kansainvälisesti ja kansallisesti on tullut esille selkeä tarve saada ohjeet ja käytänteet stratigrafisen terminologian käytöstä ja siitä, miten nimetä geologisia yksiköitä. Johdonmukainen geologinen keskustelu vaatii käyttämään kansainvälisesti hyväksyttyä ja tarkkaa terminologiaa ja käytäntöjä. Tässä oppaassa on koottuna prekambrisen geologian kannalta keskeisimmät stratigrafiset menetelmät ja annetaan ohjeet ja suositukset käytänteistä ja keskeisen terminologian käytöstä. Merkittävä kehitys stratigrafisissa periaatteissa on ollut korreloitavien epäjatkuvuuksien merkityksen ymmärtäminen kiviseurannoissa ja näiden soveltaminen sekvenssistratigrafiassa. Geologisten yksiköiden kuvaus ja systemaattinen nimeäminen sekä mahdollisen stratigrafisen järjestyksen määrittäminen ovat keskeisiä jokaisen maan kannalta. Väärinkäsitysten välttämiseksi ja geotieteellisen tiedonsiirron ja -hallinnan kannalta on tärkeää, että geologiset yksiköt nimetään ja luokitellaan hyväksyttyjen ohjeiden ja stratigrafisen käytänteiden mukaisesti.

Tämä opas halutaan geotieteiden tekijöiden, opiskelijoiden ja tietoammattilaisten keskeiseksi työvälineeksi nimettäessä ja kirjattaessa Suomen prekambrisia geologisia yksiköitä. Opas antaa ohjeita myös Suomen stratigrafisten tietokantojen kokoamiseen. Geologian tutkimuskeskus ylläpitää stratigrafista tietokantaa karttapalvelunsa kautta (http://www.geo.fi) yhteistyössä Suomen stratigrafisen komitean kanssa. Jos merkittäviä uusia kansainvälisiä suosituksia ilmaantuu, tämä opas tullaan päivittämään Suomen stratigrafisen komitean ohjauksessa. Oppaan mukaanotto käytännön työhön takaa parhaiten sen, että Suomen prekambriset yksiköt tulee nimettyä parhaiden käytäntöjen mukaisesti.

Asiasanat (Geosanasto, GTK): litostratigrafia, stratigrafiset yksiköt, litodeemiset yksiköt, tektonostratigrafiset yksiköt, sekvenssistratigrafia, kronostratigrafia, prekambri, terminologia, ohjeet, Suomi

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PREFACE

This guide was produced under the supervision of the Stratigraphic Commission of Finland (SCF), working under the Finnish National Committee of Geology and with the support of the Geological Survey of Finland. The financial support by the Geological Survey of Finland is gratefully acknowleged by the Stratigraphic Commission of Finland. All the members of the Precambrian sub-commission, including Prof. Juha Karhu, Docent Jarmo Kohonen, Prof. Raimo Lahtinen, Docent Jouni Vuollo and Prof. Kari Strand (chair), and Juha Köykkä M.Sc. as the sub-commission secretary, have contributed to the compilation of the guide. The materials and guidance provided by the sub-commission's invited experts, Docent Mikko Nironen, Jouni Luukas Ph.Lic. and Tuomo Manninen M.Sc. from the Geological Survey of Finland, are very much appreciated. The preparation of the guide was coordinated by the editors Kari Strand (University of Oulu, Thule Institute), Juha Köykkä (University of Oulu, Department of Geology) and Jarmo Kohonen (Geological Survey of Finland). The sub-commission held its first meeting in October 2006, after the SCF had established two sub-commissions to respectively prepare guides for naming the Precambrian and the Quaternary geological units in Finland. Since then, the Precambrian sub-commission has organized several working meetings related to the preparation of this guide. The main responsibility for the writing and revision of the sections of the guide was assigned to the following members or invited experts: Kari Strand, Jarmo Kohonen and Juha Köykkä – lithostratigraphic units; Kari Strand, Juha Köykkä, Jouni Vuollo and Jouni Luukas – lithodemic units and the usage of lithostratigraphic vs. lithodemic units; Juha Köykkä, Raimo Lahtinen and Mikko Nironen – tectonostratigraphic units; Kari Strand and Jarmo Kohonen – sequence stratigraphy; Kari Strand and Juha Karhu – chronostratigraphy; Jarmo Kohonen and Kari Strand – the usage of traditional geological terms for the Precambrian of Finland.

An increasing need for advice on the use of stratigraphic terminology and for rules for establishing geological units has been clearly apparent in recent years. With evolving concepts in Earth Sciences and with new international recommendations, however, future needs for revision will appear. The SCF will consider the need for new editions of the guide and the editors of the guide encourage the guide users to present ideas and suggestions for future modifications or additions to the SCF. The use of the guide in everyday work is the best way to ensure best practices in naming the Precambrian geological units in Finland.

Prof. Kari Strand
Chair of the Precambrian sub-commission

1 INTRODUCTION

1.1 Background

The geological knowledge disseminated and exchanged through geological maps, scientific publications and various reports is built on common geological concepts and expressed by the language of earth sciences. The definition and description of geological units and their order is termed stratigraphy, and it forms an essential part of the geological vocabulary. To avoid misunderstanding and confusion, geological units need to be named and classified according to accepted international or national guidelines and stratigraphic codes.

The traditional stratigraphic classification systems and codes have evidently had limitations when applied to Precambrian geology (see NASC 2005). Especially challenging are the intensely deformed Precambrian terrains with complex metamorphic and plutonic rock assemblages. Consequently, the stratigraphic classification and procedures have not yet been formalized in all parts of the Precambrian of Finland. Nevertheless, the new stratigraphic concepts developed by the international stratigraphic organizations and documented in publications 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.

In 2005, the Stratigraphic Commission of Finland (SCF) was founded by the Finnish National Committee of Geology. The role of the SCF is to provide guidance for stratigraphic procedure, terminology and revision of the geological units in Finland. The increasing importance of stratigraphy, and geological classification systems in general, is due to the following reasons:

- The creation of geological databases requires solid and uniform classification systems.
- National and international efforts to harmonize geological information call for internationally compatible terminology.
- The global working environment and the need for global communication, data exchange and interoperability is no longer only for leading scientists, but for everybody in the broad field of geology.
- The search for information, especially with modern information technology tools, can be highly improved by consistent terminology and hierarchical classification systems.

1.2 Purpose of the guide

Although several stratigraphic guides or codes are already available for local and international usage (e.g. Hedberg 1976, NCS 1989, Salvador 1994, NACSN 2005), the purpose of this guide is to provide a primary national standard for defining and naming the Precambrian geological units in Finland, and to improve the efficiency and effectiveness of communication of geological unit information. The objective was to meet the practical needs of Finnish geologists working with the Precambrian geology of the Fennoscandian Shield.

The guide is a formulation of current views on stratigraphic principles and procedures designed to promote standardized classification and formal to informal nomenclature of rock units. It provides the basis for formalization of the language used to denote rock units and their spatial and temporal relations. To be effective, the suggested guidelines and procedures must be widely accepted and used; geological organizations and journals may adopt its recommendations for stratigraphic procedures.

The guide was compiled to: (1) help mapping geologists and researchers to overcome stratigraphic problems characteristic for complex, high-grade metamorphic terrains, (2) establish the backbone for the further work of the Precambrian sub-commission of the SCF, (3) support the compilation of a database for the Precambrian geological units in Finland, seamless map databases of Finland and other national efforts by the Geological Survey of Finland, (4) assist university lecturers and students in studying the stratigraphic code in Finland and (5) improve the efficiency and effectiveness of communication of geological unit information.

This guide has its emphasis in the international stratigraphic classifications, which are widely used in Precambrian geology. Therefore, some categories, e.g. biostratigraphy and magnetostratigraphy, have been omitted from this guide. When there is a need for practical examples for the formalization of the geological units, the reader can turn to the *International Stratigraphic Guide* (Salvador 1994), the *North American Stratigraphic Code* (NACSN 2005) or, for instance, the *Rules and recommendations for naming geological units in Norway* (NCS 1989).

Every country and geological region has a unique research tradition and heritage related to geological units and their usage. The geological literature of Finland and the Fennoscandian Shield has a long history, and contributors represent various nationalities and conceptual schools. As a result, the legacy of information is characterized by a rich flora of stratigraphic terms reflecting tradition more than formal scientific language with defined terminology. Many of the traditional terms are still in use, and in many cases the usage and content has transformed beyond the original definition. As a result, there are misleading terms, and in particular there has been overlapping cross-usage of formal and informal terms for the same geological unit in the Finnish geological literature, which has caused confusion. This guide has been seen as necessary to encourage a common approach to stratigraphical practice by offering proper guidelines for geologists working in Finland. One chapter of this guide is devoted to discussion on the appropriate usage of traditional terminology.

To be effective, the suggested guidelines and procedures must be widely accepted and used; geological organizations and journals may adopt its recommendations for nomenclatural procedure. 'Guidelines and Procedures for Naming Precambrian Geological Units in Finland' seeks to be taken as an essential tool for geoscientists, students and information professionals in defining and naming geological units in Finland. The adopted procedures will then also provide valid information to the stratigraphic databases used in the country.

2 GENERAL RULES FOR NAMING AND DEFINING GEOLOGICAL UNITS

2.1 Categories and ranking of geological units

The term *geological unit*(s) stands for a volume of rock or other superficial deposits, some geological structure, or geological time unit, which has a recognizable name (e.g. for maps and scientific articles), and usually has mappable and recognizable characteristic features (e.g. lithology or petrography), and the origin and the age of the unit are sometimes identifiable. The term *category* comprises one or more geological unit(s), having one or more common feature(s). In addition, *stratigraphy* is a science of rock strata, concerning different characters, boundaries and attributes of rock strata (e.g. distribution, form, geochemical properties, age, lithological composition), and the interpretation of rock strata in terms of their environment, origin and geological history. Thus, all different classes of rocks and superficial deposits are defined, described and classified stratigraphically (formally or informally). Stratigraphic classification and the distinguishing of different geological units is based on (i) material categories of units and units defined on the basis of physical properties, and (ii) categories expressing or related to geological age, which can be divided into time or material units that formed within a specific time span. Different stratigraphic categories can be applied in the same area, but terminology of the categories must never be mixed. For example, a formation can be described within a nappe, but the formations can not be included to the subdivision of a nappe or a nappe complex.

In this guide, six major and principal categories of geological units are presented to serve the stratigraphic classification of the deformed and metamorphosed Precambrian bedrock in Finland (Table 1).

- Categories of material units and units defined on the basis of physical properties and content:
  1) A *lithostratigraphic unit* is a stratum or body of strata, comprising stratified rocks and su-

perficial 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 (Chapter 3).

2) A *lithodemic unit* is 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 (Chapter 4).

- Categories of material units and units defined on the basis of bounding unconformities and physical limits:

3) A *tectonostratigraphic unit* is a body of rock that has been shifted or displaced along a thrust fault, i.e. is located above or between thrusts (Chapter 6).

4) Sequence stratigraphy studies the relationships between the architecture of the stratigraphic record and cyclic changes in a base level, where the different depositional trends can be studied and analyzed from variable scales (Chapter 7).

- Categories expressing or related to geological age, which can be divided into time or material units that formed within a specific time span:

5) A *chronostratigraphic unit* is a synchronous (i.e. simultaneous) bounded body of stratified rock that forms a material reference for all the rocks formed during the same period of time (Chapter 8).

6) A *geochronological unit* is a division of time defined on the basis of boundaries of chronostratigraphical units (Chapter 8).

2.1.1 Material categories

The material categories (lithostratigraphic, lithodemic, tectonostratigraphic and sequence stratigraphic units) are based on the content or physical limits of rock bodies. The composition and related lithostratigraphical characteristics (e.g. texture, structure etc.) or different physical, chemical or biological contents or properties of rock serve as the basis for distinguishing and defining the fundamental formal units. *Lithocorrelation* can be used when linking different geological units of a similar lithology and stratigraphic position, or sequential or geometric relations of lithodemic units. The lithostratigraphic and lithodemic units are the fundamental and the most important geological units in the Precambrian stratigraphic framework of Finland when establishing rock successions (Table 1). Thus, the principles of lithostratigraphy and lithodemy should be the priority methods when approaching and defining the geological units of the Precambrian bedrock in Finland. The tectonostratigraphic units and sequence stratigraphy (Table 1) can be used for more detailed studies, e.g. basin analysis, and if they serve a clear purpose in Precambrian stratigraphic work with a genetic approach. While lithostratigraphic, lithodemic and tectonostratigraphic units are necessary for defining the rock successions and sequence stratigraphy, bio-, magneto- and isotope stratigraphy are the most useful procedures for calibrating and correlating successions (Dawson et al. 2002).

2.1.2 Categories based on geological time or age

The categories based on geological time or age (chronostratigraphic and geochronological units) represent the period of time during which a sequence of rock layers, or a chronostratigraphic unit, was deposited. For these types of units, characterizing collective names are given such as the Siderian System (chronostratigraphic unit) and Siderian Period (geochronological unit). C*hronocorrelation* is a term that refers to a correspondence between the age and chronostratigraphic position of a geological unit.

2.1.3 Other categories

Another useful property in stratigraphic work is the magnetic property of rocks, which is the change in the direction of the remanent magnetization of the rocks caused by reversals in the polarity of the Earth's magnetic field. *Magnetostratigraphy* is generally defined as 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. A magnetostratigraphic unit is a body of rock unified by specified remanent-magnetic properties and is distinct from underlying and overlying magnetostratigraphic units having different magnetic properties. The upper and lower limits of a magnetopolarity unit are defined by boundaries marking a change of polarity. Such boundaries may represent either a depositional discontinuity or a magnetic-field transition. The boundaries are either polarity-reversal horizons or polarity transition zones, respectively. The international codes or guides generally only consider polarity reversals, which now are widely recognized as a stratigraphic tool. However, apparent polar-wander paths offer increasing promise for correlations within Precambrian rocks (Mertanen & Pesonen 2005). Thus, it is only a correlative, not a fundamental method for defining and naming the Precambrian geological units in Finland, and thus is not treated in this guide.

The use of carbon, oxygen, or strontium *isotope stratigraphy* in correlating strata has been promising and quite useful, especially for the Cenozoic deposits, but is also used for some older deposits, if the outcrops have been poorly exposed. Although the importance of geochemistry in geological work cannot be disputed, the use of isotope stratigraphy for correlating data is an effective tool if it is used together with other stratigraphical information, e.g. lithostratigraphy (Karhu 2005). The proportions of some critical isotopes when incorporated in biogenic minerals (calcite, aragonite, phosphate) change through time in response to fluctuating palaeoenvironmental and geological conditions. This primary signal, however, is often masked by later diagenetic or metamorphic alteration of the sediments, especially in older deposits. The use of carboniferous or strontium stratigraphy for the Precambrian bedrock of Finland is quite limited, because both methods are generally limited to carbonate samples, and the strontium seawater curve is only well defined for the Cenozoic age. Although some other isotopes, e.g. uranium-lead, are quite useful for the Precambrian bedrock of Finland, isotope stratigraphy is nevertheless only a correlative tool in the stratigraphic framework and does not alone provide the necessary information or tools for defining and naming geological units according to the hierarchical classification, as presented in Table 1. Thus, it is only a correlative, not a fundamental method for defining and naming Precambrian geological units in Finland, and is consequently not treated in this guide. In addition, biostratigraphic, pedostratigraphic and allostratigraphic units are not used or presented in this guide, because they do not serve practical needs in the Precambrian geology of Finland or the stratigraphic framework, and are more pronounced for the Quaternary deposits in Finland.

2.2 Formal and informal units

The Code, followed here, distinguishes between *formal* and *informal geological units*. Formal units are named and defined with an established scheme of classification, by capitalizing the initial letter of the rank or unit term (e.g. the Paljakkavaara Formation). Informal names and definitions are given to geological units that have not been established in accordance with rules given in this guide for the definition of formal units (Chapter 2.1), and which have not been approved as formal names by the Stratigraphic Commission of Finland.

Informal names are not protected by the stability provided by proper formalization, and they are usually only descriptive terms. Although the informal nomenclature is very useful in Precambrian stratigraphic work, the usage of formal nomenclature for the geological units should be emphasized. The following chapters describe how to define and name formal and informal geological units in Finland.

2.2.1 Definition of formal units

The importance of formal geological units is that they serve a function for a long time, retaining a stable, unambiguous geological significance

Table 1. Categories and ranks of different geological units followed in this guide (modified after NCS 1989, NACSN 2005). The lithostratigraphic and lithodemic units are the most important material categories of geological units, and the most applicable to the Finnish Precambrian bedrock (bold framed). Fundamental units in the hierarchical classification are underlined.

<table>
<tr><td colspan="5">MATERIAL CATEGORIES BASED ON PHYSICAL PROPERTIES, CONTENT OR LIMITS</td></tr>
<tr><td>Lithostratigraphic Units</td><td colspan="2">Lithodemic Units</td><td>Tectonostratigraphic Units</td><td>Sequence Stratigraphy[*]</td></tr>
<tr><td>Supergroup</td><td>Supersuite</td><td rowspan="2">Complex</td><td>Nappe system[+]</td><td></td></tr>
<tr><td>Group</td><td>Suite</td><td>Nappe complex[+]</td><td></td></tr>
<tr><td><u>Formation</u></td><td colspan="2"><u>Lithodeme</u></td><td><u>Nappe</u></td><td><u>Sequence</u>[#]</td></tr>
<tr><td>Member</td><td colspan="2">Phase (or Zone)*</td><td>Thrust sheet (including small thrust sheet)</td><td>Systems tract[#]</td></tr>
<tr><td>(or Lens, or Tongue)</td><td colspan="2"></td><td></td><td>Parasequence[#]</td></tr>
<tr><td>Bed(s) or Flow(s)</td><td colspan="2"></td><td></td><td></td></tr>
<tr><td colspan="3">MATERIAL CATEGORIES USED TO DEFINE TEMPORAL SPANS</td><td colspan="2">NON-MATERIAL CATEGORIES RELATED TO GEOLOGICAL AGE</td></tr>
<tr><td colspan="3">Chronostratigraphic Units</td><td colspan="2">Geochronological Units</td></tr>
<tr><td colspan="3">Eonothem</td><td colspan="2">Eon</td></tr>
<tr><td colspan="3">Erathem</td><td colspan="2">Era</td></tr>
<tr><td colspan="3"><u>System</u></td><td colspan="2"><u>Period</u></td></tr>
<tr><td colspan="3">Series</td><td colspan="2">Epoch</td></tr>
<tr><td colspan="3">Stage</td><td colspan="2">Age</td></tr>
<tr><td colspan="3">Chronozone[+]</td><td colspan="2">Chron[+]</td></tr>
</table>

[*] Not yet formalized and standardized in the international stratigraphic guidebook.
[+] Units without hierarchical rank or ranking equally within the category.
[#] Hierarchical classification is not comparable to other units.
[*] Internal category under lithodeme.
(NCS 1989, NACSN 2005).

in geological maps, scientific works, and other documents. There are several requirements for the formally named geological units. Defining, naming and establishing, as well as revising, redefining or abandoning a new formal geologic unit(s), requires a publication in a recognized scientific medium, which should include fundamental information such as:

1. A detailed description of the unit;
2. The naming of the unit (see Chapter 2.2.1.1);
3. A proposal for category and rank (subdivision mentioned if possible);
4. Historical background (if available);
5. The stratotype (type area or type section) of the unit (if suitable);
6. A definition of the unit boundaries, including contacts, dimensions and shape (if possible);
7. The geological age, correlations and genesis (if possible).

In addition, 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. These requirements also apply to offshore and subsurface units, where the unit can be named after the borehole or mine, which represents the stratotype, or after a nearby geographical feature. If a new unit is mentioned in a map legend, abstract, figure caption, or mentioned at a scientific meeting, presented in a thesis or dissertation, or distributed by an author over the Internet, it does not meet the requirements of a recognized scientific medium, i.e. it is mentioned in an improper publication. Guidebooks with a limited distribution to the participants of a field excursion are also somewhat unfavourable publications, and thus other media are more preferable. In these days, electronic media are acceptable publications, if published and/or recognized by some scientific community or academic institution.

A new formal unit must serve a clear stratigraphical purpose, be described and defined appropriately and in detail, and the intent to establish or designate it must be specific. The description and definition should be so good that other geologists or scientists should also be able to recognize and find the geological unit and its characteristic features in the field. In the case of the Precambrian units of Finland, the category and rank of a new or revised unit must be specific, and follow the proposed hierarchy that has been presented in this guide (see Table 1). In addition, it is also recommended that different data and samples of a formal unit should be stored in appropriate places for later examination. The Stratigraphic Commission of Finland can on request approve formally defined units when these are established according to the rules presented in this guide.

2.2.1.1 Naming

The compound name of a formal geological unit should consist of a geographical name (e.g. Puolankajärvi), combined with a rank (e.g. Formation) or descriptive term (e.g. Gneiss), and the first letters of all words used in the names of formal geological units are capitalized. The three-part names should not be used, or should be avoided whenever possible. Geographical terms are derived from the permanent areas or near where the geological unit is present, and it is recommended that these names are shown on official maps (e.g. topographic maps of the National Land Survey of Finland). It is preferable to give geographical names to established units, so that the location or the areal extent of the unit in question can easily be comprehended, and to make scientific discussion clearer. Two different names should not be derived from one and the same geographical feature, and units should not be named after the source of their components. A historical nomenclatorial background for the proposed geological unit should be included with a description and definition, e.g. references to the previous treatment of the unit.

Already formally established names should not be modified without a proper need, and if necessary, redefinition, revision or abandonment of a unit must be done properly, as explained in this guide (see Chapter 2.2.3). The geographical part of a formally named and established stratigraphical unit is retained, although the geographical feature(s) may change. All the chronostratigraphical units belong to already well-known and established, and accepted names with diverse origins.

2.2.1.2 Stratotypes

A stratotype (type section or location) is a geological standard for a named geological unit or boundary, including the basis for the definition or recognition of that unit, and it is thus a fundamental "element" for all formal units. Stratotypes should be described in detail, both geographically and geologically, by using coordinates and maps etc. In other words, the description should be so good that other geologists or scientists should also be able to recognize and find this stratotype and its characteristic features in the field.

There are two kinds of stratotypes for Precambrian stratigraphic work: (i) the unit stratotype and (ii) the boundary stratotype. The former refers to a type area or section for a stratified or non-stratified geological deposit that represents a standard for the definition and recognition of a formal geological unit. The latter is the type locality for the boundary reference point for a stratigraphic unit, i.e. the upper and lower limits of the unit. A type section or location is the specific geographical location of a formal unit stratotype or unit boundary, where the unit was first defined and named. A stratotype may also consist of several reference sections to demonstrate the areal extent or totality of a stratigraphic unit.

2.2.1.3 Boundaries, dimensions and age

Different boundaries between geological units have great importance in the Precambrian stratigraphic framework, and a unit and its boundaries should thus be carefully recognized and described. The boundaries may be placed at clearly visible and distinguished contacts between two different rock units, or a unit may change through gradation into, or intertongue with, a rock body with clearly different characteristics. In Precambrian deposits and bedrock, it may be necessary or unavoidable to draw an arbitrary boundary within the zone of gradation.

The dimensions and regional relations of a geological unit, such as the thickness, tectonostratigraphical thickness, composition, relations, and possible stratigraphic correlation with other units, should be included in the description and definition. The origin of a geological unit is also an interesting and important feature to describe, although it may play no proper role in the definition of the unit. An informal designation is always advisable if the unit is known only in an area of limited extent.

For the material-based geological units, geological age plays no proper role in the definition, except in the case of chronostratigraphical units (see Table 1). The age is an important feature of a unit, and should be mentioned whenever possible. In the case of lithodemic units, a distinction should be made between the age of the unmetamorphosed protolith (i.e. parent rock) and the metamorphism or deformation. It is recommended to use the term *numerical age* for all ages determined from isotopic ratios, fission tracks, and other quantifiable age-related phenomena. The age of a geological event or a stratigraphic unit may be expressed in years before the present (e.g. ka, Ma or Ga), and abbreviations for the number of years, without reference to the present, are informal (e.g. y for years or my for millions of years, etc.).

2.2.2 Definition of informal units

Informal units form also an important part of the Precambrian stratigraphic framework, and they can be used temporarily during ongoing scientific investigations or geological mapping, when preliminary research results are being published, or when writing reports and theses that are not going to be published. Informal units can also be used in a long-lasting sense if there is no practical reason to establish formal units. Most of the rules for informal units are the same as for establishing formal units, but the main differences are the publication, documentation, naming and designation. Informal units can be documented and published without fulfilling the requirements of a recognized scientific medium and also be used in the database of the Geological Survey of Finland.

2.2.2.1 Naming and designation

Informal geological units can be designated in many ways by using a lithological or other descriptive term alone (e.g. laminated sandstone), or by using the rank or unit designations from the formal terminology, or combined with a lithological or other descriptive designation (e.g. a sandstone sequence). In addition, a number and/or letter code combined with formal or informal rank or unit designations can be used (e.g. formation A), and position designations such as lower, middle and upper are also acceptable (e.g. lower sandstone unit). Sometimes, designations can also come from economic mining geology, or from geographical names in conjunction with lithology or some characterizing features (e.g. Forssa gabbro).

The most important point to remember when naming informal geological units is that the names of informal units are not to be combined with a geographical name in conjunction with a fundamental, more highly ranking unit in hierarchical classification systems (see Table 1). For example, Forssa gabbro is an informal name, but the Forssa Formation or the Forssa Gabbro are the formal names of the units. (NCS 1989, NACSN 2005).

2.2.3 Revision and abandonment of formal units

All formally named and defined geological units may be redefined, revised, or abandoned, whenever necessary, but the procedure for revision or abandonment requires as much justification as the establishment of a new geological unit. *Redefinition* includes changing the view or emphasis on the content of the geological unit without changing the boundaries, rank, or category, whereas *revision* involves minor changes to the definition of boundaries and/or rank, and/or the category of the geological unit.

2.2.3.1 Redefinition and revision

The redefinition of a Precambrian geological unit can be carried out if there is (i) a change in the lithological designation, or (ii) the original lithological designation is inappropriate. For example, igneous rocks originally described and defined as quartz monzonites can be modernized and appropriately termed as granites. In addition, the formal compound formation name, e.g. shale, can be replaced by the term limestone without changing the original proper geographical term, if the chemical and mineralogical composition is appropriate for that. If the revision only modifies a minor part of the content of a previously established geological unit, the original name can be retained.

The hierarchical rank of a geological unit can be changed without redefining the unit boundaries or changing the geographic part of its name (e.g. a lithodeme may become a suite, or vice versa). In addition, the original type locality or type section is retained for the newly ranked geological unit, but the same name of the unit cannot be used both for the unit as a whole and for a part of it. However, when a geological unit is changed to a different category, the proper geographical name also has to be changed, unless the unit is redefined to a closely related category (e.g. from a metamorphic lithodemic unit to a metamorphic lithostratigraphical unit). If a geological unit is divided into two or more units having the same hierarchical rank as the original one, the original defined proper names should not be used for any of the new divisions. The original proper name of the established unit can be retained if the rank of that unit is raised following the new division.

2.2.3.2 Abandonment

A formally established geological unit can be abandoned or rejected if it is improperly defined, is equivalent to a previously formally defined unit, is defined to the wrong category, or if it does not qualify under some other previously mentioned nomenclature or definition rules. A unit may also be abandoned if it proves impracticable, being neither recognizable nor mappable elsewhere. A previously established and abandoned unit name becomes available and can be used for some other unit if a long period has passed since the name was used in its original meaning, but explanation of the history of the name should be part of the designation. Previously abandoned unit(s) can also be reinstalled, whenever it is necessarily (e.g. abandonment is found to be erroneous).

Abandonment, additions, or changes to this Code may be proposed in writing to the Stratigraphic Commission of Finland by any geoscientist, at any time. The Commission will evaluate whether the proposed abandonment, addition or change to a unit is necessary or reasonable, and whether it fulfils all the previously mentioned requirements. (NCS 1989, NACSN 2005).

2.2.4 Procedure in Finland

On a practical level, the national authority responsible for geological information and databases is the Geological Survey of Finland. The maintenance and further development of the newly established database for the Precambrian geological units in Finland demands defined procedures and hierarchical stratigraphic classification systems. The database will be maintained by the Geological Survey of Finland in collaboration with the Precambrian sub-commission of the Stratigraphic Commission of Finland (SCF), where new suggestions for the naming of Precambrian geological units in Finland can be submitted, preferably in electronic form by using the designed web portal (Figure 1). The SCF also approve the new formally defined units to be added to the map database.

The guidelines and procedures for naming Precambrian geological units in Finland have been formulated under the supervision of the SCF and

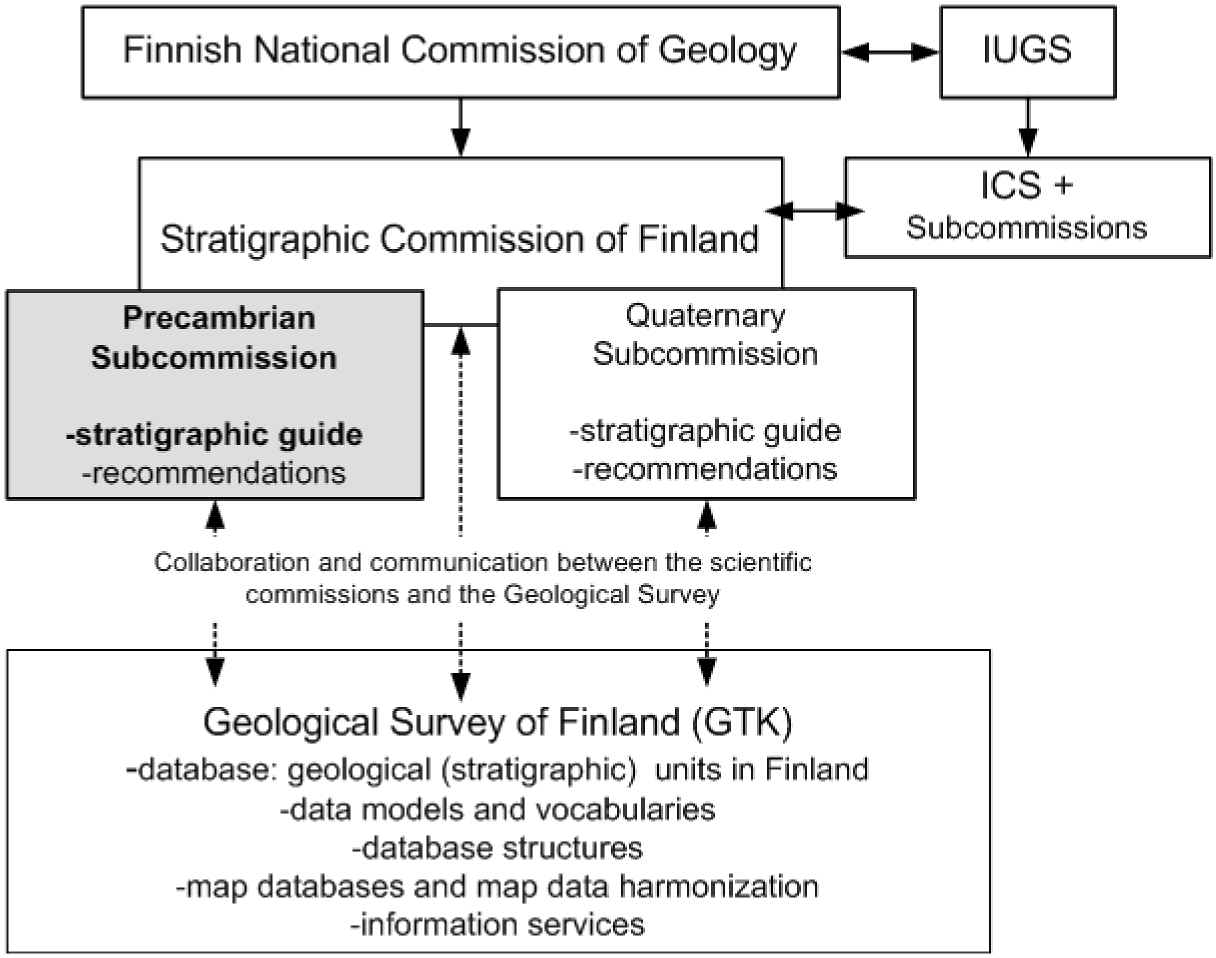

Figure 1. The roles of the Stratigraphic Commission of Finland and the Geological Survey of Finland in the development of stratigraphic procedures and databases.

with the support of the Geological Survey of Finland. The SCF will consider the needs for updating the guidelines or procedures and for possible future modifications or additions to this guide.

3 LITHOSTRATIGRAPHIC UNITS

3.1 General properties, rules and boundaries

Lithostratigraphic units consist of the organization of rock strata, which are defined and distinguished on the basis of lithological characteristics (Figure 2). A lithostratigraphic unit can be a defined body of sedimentary, extrusive igneous, metasedimentary, or metavolcanic strata and can be delimited by its stratigraphic position. A lithostratigraphic unit generally conforms 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, and it is commonly stratified and tabular in form. Lithostratigraphical units are defined independently of inferred geological history or the mode of genesis, and the units are, in decreasing order of rank, *supergroup*, *group*, *formation, member and bed/flown*, where the *formation* is the fundamental unit. Overall, lithostratigraphic units are the basic units of general geological work and serve as the foundation for delineating strata, local and regional structures, economic resources, and geological history in regions of stratified rocks.

In Finland, the formal lithostratigraphic units should be defined and used if they serve a practical purpose, and for the purposes of nomenclatural stability; a type locality and reference localities of lithostratigraphic units should be always designated, whenever possible. A high grade of deformation and metamorphism does not necessarily inhibit the use of lithostratigraphic units.

The application of principles of lithostratigraphy for the deformed and metamorphosed Precambrian sedimentary rocks in Finland has been useful, and is encouraged, when mapping these rock bodies. For example, Laajoki et al. (1989) established a formal lithostratigraphy for the northern part of the Kainuu Belt, and Laajoki (1991) extended it to also include the associated gneiss complex. Marmo et al. (1988) and Kohonen & Marmo (1992) successfully established a formal lithostratigraphy for the Palaeoproterozoic deposits in the Nunnanlahti-Koli-Kaltimo area of eastern Finland. In the Höytiäinen area, however, the turbiditic arenites and greywackes have been difficult to formally divide into lithostratigraphic units (Kohonen 1995).

The boundaries of lithostratigraphic units are placed at positions of lithological change, at distinct contacts or, at some selected arbitrary level, within zones of gradation. Both vertical and lateral boundaries are based on the lithic criteria that provide the greatest unity and utility. Unconformities, where objectively recognizable based on lithic criteria, are ideal boundaries for lithostratigraphic units. If no lithological distinction can be adequately defined, a widely recognizable boundary can be made, and only one unit should be recognized, even though it may include rock that accumulated in different epochs, periods, or eras. The boundaries of lithostratigraphic units should be chosen on the basis of lithological changes, and when feasible should also correspond with the boundaries of genetic units, so that subsequent studies of genesis will not have to deal with units that straddle formal boundaries.

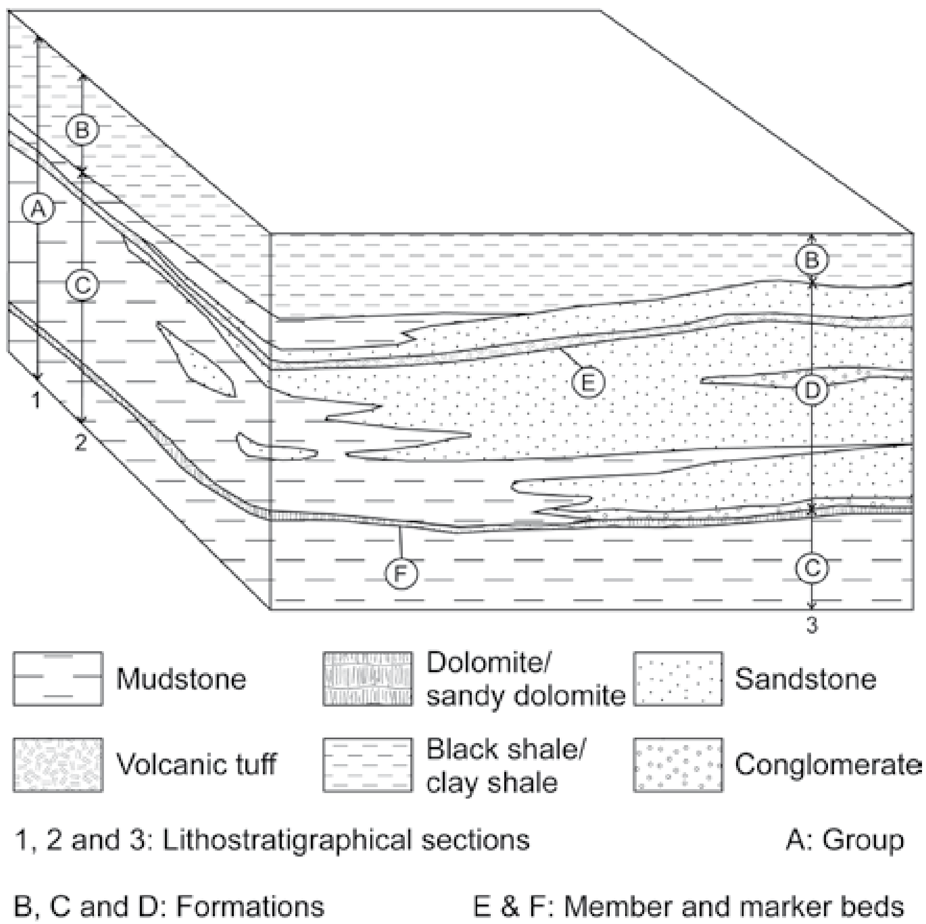

Figure 2. Schematic illustration of the Precambrian bedrock and its lithostratigraphic units (A–H), and their possible classification (Modified from NSC 1989). (NCS 1989, NACSN 2005).

3.2 Classification and ranking of lithostratigraphic units

3.2.1 Formation

A formation is the fundamental unit in lithostratigraphic classification. It is a body of rock identified by lithological characteristics and stratigraphic position; it is prevailingly but not necessarily completely tabular and is mappable at the Earth's surface or traceable in the subsurface. Mappable is, however, a loose criterion and it depends on the scale of mapping. In general practice, a formation should be mappable at 1:50 000 scale and readily represented at 1:100 000 map scale. The distinctive lithological characteristics include chemical and mineralogical composition, texture, and such supplementary features as colour, primary sedimentary or volcanic structures, fossils (viewed as rock-forming particles), or other organic content (coal, oil shale).

Sedimentary rock and volcanic rock that are interbedded may be assembled into a formation under one name that should indicate the predominant or distinguishing lithology. The mappable distinguishable sequences of stratified volcanic rock should be treated as formations or lithostratigraphic units of higher or lower rank. Formations composed of low-grade metamorphic rock (defined for this purpose as rock in which primary structures are clearly recognizable) are, like sedimentary formations, mainly distinguished by lithological characteristics. The mineral facies may differ from place to place, but these variations do not require the definition of a new formation. High-grade metamorphic rocks whose relation to established formations is uncertain are treated as lithodemic units.

3.2.1.1 Formation nomenclature

A formation can be given a formal or informal name, depending on the purpose and/or general rules of naming (see Chapter 2). The name of a formal lithostratigraphic unit is a compound. For most categories, the name of a unit should consist of a geographic name combined with an appropriate rank (the Paljakkavaara Formation) or descriptive term (Ruka Quartzite). The first letters of all words used in the names of formal geologic units are capitalized.

An example of usage of lithostratigraphic formation nomenclature in Finland comes from the northern parts of the Kainuu Belt. A general fragmentation of the Late Archean basement corresponded to the deposition of three interfingering formations in its type area at Kurkikylä: (1) the coarse-clastic Laanhongikko Formation, (2) the volcanic Matinvaara Formation and (3) the coarse volcaniclastic Ahven-Kivilampi Formation (Strand 1988, Laajoki 1991). The Nunnanlahti-Koli-Kaltimo area in North Karelia is another area where formal formation names have been established, including the glaciogenic Urkkavaara Formation and the quartzose Koli and Jero Formations (Marmo et al. 1988). The Archean Hattu greenstone belt in the Ilomantsi area consists of the volcanic Pampalo, the metapelitic Tittalanvaara, and the conglomeratic to arenitic Sivakkavaara Formations (e.g. Sorjonen-Ward 1993, Sorjonen-Ward & Luukkonen 2005). (NCS 1989, NACSN 2005).

3.2.2 Member

A member is the formal lithostratigraphic unit next in rank below a formation and is always a part of some formation. It is recognized as a named entity within a formation because it possesses characteristics distinguishing it from adjacent parts of the formation. A formation need not be divided into members unless a useful purpose is served by doing so. Some formations may be completely divided into members; others may have only certain parts designated as members; still others may have no members. A member may extend laterally from one formation to another.

3.2.2.1 Member nomenclature

A member is established when it is advantageous to recognize a particular part of a heterogeneous formation. A member, whether formally or informally designated, need not be mappable at the scale required for formations.

An example usage of a formal member name, in Finland, is a thin metaconglomerate – metaquartzite unit called the Himmerkinlahti Member, in the southeastern part of the Palaeoproterozoic Kuusamo Belt, northern Finland. The lithostratigraphic position of the Himmerkinlahti Member has been problematic. It was originally defined by Laajoki (2000), who included it in the middle part of the Karelian supracrustal rocks of the belt, ca. 2.1–2.4 Ga (Hanski et al. 2001), and correlated it to the Siltstone Formation or Greenstone Formation III (see Silvennoinen 1972), but it was more recently interpreted to be related to the post-1.88 Ga molasses-like development in northern Fennoscandia (Laajoki & Huhma 2006).

Other examples: the Early Proterozoic Nuottilampi Member, the Pentinsuo Member and the Pikku-Äikkä Member in the Kainuu Belt (see Laajoki et al. 1989, Laajoki 1991).

3.2.3 Bed

A formally or informally recognized division of a member is called a bed or beds, except for volcanic flow rocks, for which the smallest formal unit is a flow. Members may contain beds or flows, but may never contain 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. A flow is usually a volcanic extrusive rock formed during a single eruption.

3.2.3.1 Bed nomenclature

The designation of a bed or a unit of beds as a formally named lithostratigraphic unit should generally be limited to certain distinctive beds whose recognition is particularly useful. A key or marker bed is a thin bed of distinctive rock that is widely distributed. Such beds may be named, but are usually considered as informal units. Individual key beds may be traced beyond the lateral limits of a particular formal unit.

A flow is a discrete, extrusive volcanic rock body distinguishable by texture, composition, order of superposition, paleomagnetism, or other objective criteria. It is part of a member and is thus equivalent in rank to a bed or beds of sedimentary-rock classification. Many flows are informal units. The designation and naming of flows as formal rock-stratigraphic units should be limited to those that are distinctive and widespread.

Formally named beds are rare in the Finnish geological literature, but one example usage is the Kuvajavaara Bed, which is located inside the Kalhamajärvi Complex, in the Kainuu Belt (see Laajoki 1991). The Kuvajavaara Bed is an at least 30 m thick quartzite bed among feldspar gneisses with amphibolite layers, dipping vertically with conformable contact with the gneisses (op. cit.). The whole bed is mainly composed of a distinctly bedded, light-brown quartzite with bluish or greenish ortho-quartzitic parts. Laajoki (1991) also described and informally named the Kuivikkovaara bed from the same area, which forms an almost horizontal, tightly folded quartzite bed about 2–10 m thick, underlain by mica gneisses and overlain by amphibolite.

3.2.4 Group

A 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 small-scale mapping and regional stratigraphic analysis. Groups are frequently separated from each other by major unconformities.

3.2.4.1 Group nomenclature

Groups are only given formal names, in accordance with general rules of naming (see Chapter 2). The name combines a geographical name and the term "group".

Formal example usages of groups in Finland are those at the eastern margin of the Kainuu Belt consisting of the (1) Kurkikylä Group and (2) Honkajärvi Group, which occupy approximately the same stratigraphic position. These groups form relics of continental rift sequences with glacially influenced rocks in the upper parts (Strand & Laajoki 1993). The overlying units are (3) the Korvuanjoki Group, which represents the first quartz arenitic (Kainuan) sequence over the Kurkikylä Group, and (4) the

East Puolanka Group, which consists of successions of relatively mature (Jatulian) sandstones of the proximal cratonic margin.

Other examples: The Kyykkä Group and the overlying Herajärvi Group in the Nunnanlahti-Koli-Kaltimo area, eastern Finland representing the lowermost part of the Paleoproterozic sedimentary sequences deposited nonconformably upon the Archean basement complex (Kohonen & Marmo 1992); the Forssa Group and the Häme Group in the Häme belt (see Hakkarainen 1994, Lahtinen 1996, Kähkönen 2005). (NCS 1989, NACSN 2005).

3.2.5 Supergroup

A supergroup is a lithostratigraphic unit next higher in rank to a group, comprising two or more groups, having a natural vertical or lateral relationship to one another.

3.2.5.1 Supergroup nomenclature

A supergroup is a formal assemblage of related or superposed groups, or of groups and formations. Such units have proved useful in regional and provincial syntheses. Supergroups should be named only where their recognition serves a clear purpose. Supergroups are given formal names, in accordance with the general rules of naming (see Chapter 2), that combine a geographical term with the term "supergroup".

The term supergroup is rare in the Finnish geological literature. It has mainly been used for the Paleoproterozoic Karelian and Svecofennian Supergroups (see e.g. Ojakangas et al. 2001, Vuollo & Huhma 2005), which refers to a formal usage of the term supergroup, but the same term has also been used in an informal and collective sense for the same area, such as the Karelian formations and the Karelian supergroup (e.g. Laajoki 2005 and references therein). This kind of overlapping cross-usage of formal and informal terms for the same geological unit is rather confusing, and a clear distinction between the formal and informal units should therefore be made. The Kuhmo Supergroup (Archean) and the Karelia Supergroup (Proterozoic) are used in a formal way in the map database of the Geological Survey of Finland. (NCS 1989, NACSN 2005).

3.3 Misuse of the term "series" for group or supergroup

Although "series" is a useful general term, it is applied formally only to a chronostratigraphic unit and should not be used for a lithostratigraphic unit. The term "series" should no longer be employed for an assemblage of formations or an assemblage of formations and groups, as it has been, especially in studies on the Precambrian. These assemblages are groups or supergroups.

3.4 Use of the terms "belt" and "domain"

A belt is a zone or band of a particular kind of rock strata exposed on the surface. A schist belt, however, is an old traditional term that refers to rock strata that are predominantly elongated and metamorphosed. A belt is also a regional surface zone along which mines and prospects occur. A belt can additionally be understood as an elongated area of mineralization. In Finland, term *belt* has mainly been used in defining an area with a linear shape and internal structures, e.g. Lapland granulite Belt, Kainuu (Schist) Belt and Peräpohja Belt (see Nironen et al. 2002, Vaasjoki et al. 2005).

Domain usually refers to the areal extent of rock assemblages with similar lithology and tectonic or depositional history (see also chapter 6.3.2). The domain of a facies of sedimentation, however, refers to an area where a given set of physical controls have combined to produce a distinctive deposit. A magnetic domain is a region within a grain of magnetically ordered mineral, within which the spontaneous magnetization has a constant value characteristic for the mineral composition and temperature. Sometimes, the domain is understand as a macroscopically recognizable part of an altered rock, frequently of a mafic volcanic or plutonic igneous rock, that can be regarded as having a distinctive lithological or bulk chemical composition. Domain is also mentioned in relation to structural terms in petroleum geology. (NCS 1989, NACSN 2005).

4 LITHODEMIC UNITS

4.1 General properties, rules and boundaries

A lithodemic unit consists of one or more 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 (Figure 3). A lithodemic unit does not generally follow the fundamental principle of the Law of Superposition, where the oldest rocks are on the bottom and the youngest on the top, unless some later processes disturb this arrangement. Its contacts with other geological units may be sedimentary, extrusive, intrusive, tectonic or metamorphic (Figure 3). The lithodemic units are, in decreasing order of rank, *supersuite*, *suite* and *lithodeme*, where the *lithodeme* is the fundamental unit and comparable to a formation. A *complex* is also a lithodemic unit and comparable to a suite or supersuite, but it is not ranked.

In general, lithodemic units can be defined and recognized by observable rock characteristics. They are the practical units of general geological work in terranes in which the bedrock lacks primary unambiguous stratification. The definition of a lithodemic unit from the bedrock should be based on as complete knowledge and observations as possible of its lateral and vertical variations and its contact relations with other rock units. In Finland, formal lithodemic units should only be defined and used if they serve a practical purpose, and for the purposes of nomenclatural stability, a type locality and reference localities of lithodemic units should be always designated, whenever possible. The usage of principles of lithodemic stratigraphy or lithodemic units for the deformed and metamorphosed Precambrian bedrock in Finland has not been very customary, but should be encouraged when mapping these rock bodies. Laajoki and Luukas (1998) studied the stratigraphy of the Salahmi-Pyhäntä area and applied, presumably for the first time, the principles of lithodemic stratigraphy to the Precambrian bedrock of Finland. However, many formally or informally named, unstratified rock bodies still predate lithodemic nomenclature.

The boundaries, vertical or lateral, of lithodemic units are based on and should be placed at positions of lithological change. They may be placed at clearly visible and distinguished contacts in two different rock units or within zones of gradation, where a lithodemic unit changes through gradation into, or intertongues with, a rock body with clearly different characteristics. In Precambrian deposits and bedrock, it may be necessary or unavoidable to draw an arbitrary boundary within the zone of gradation.

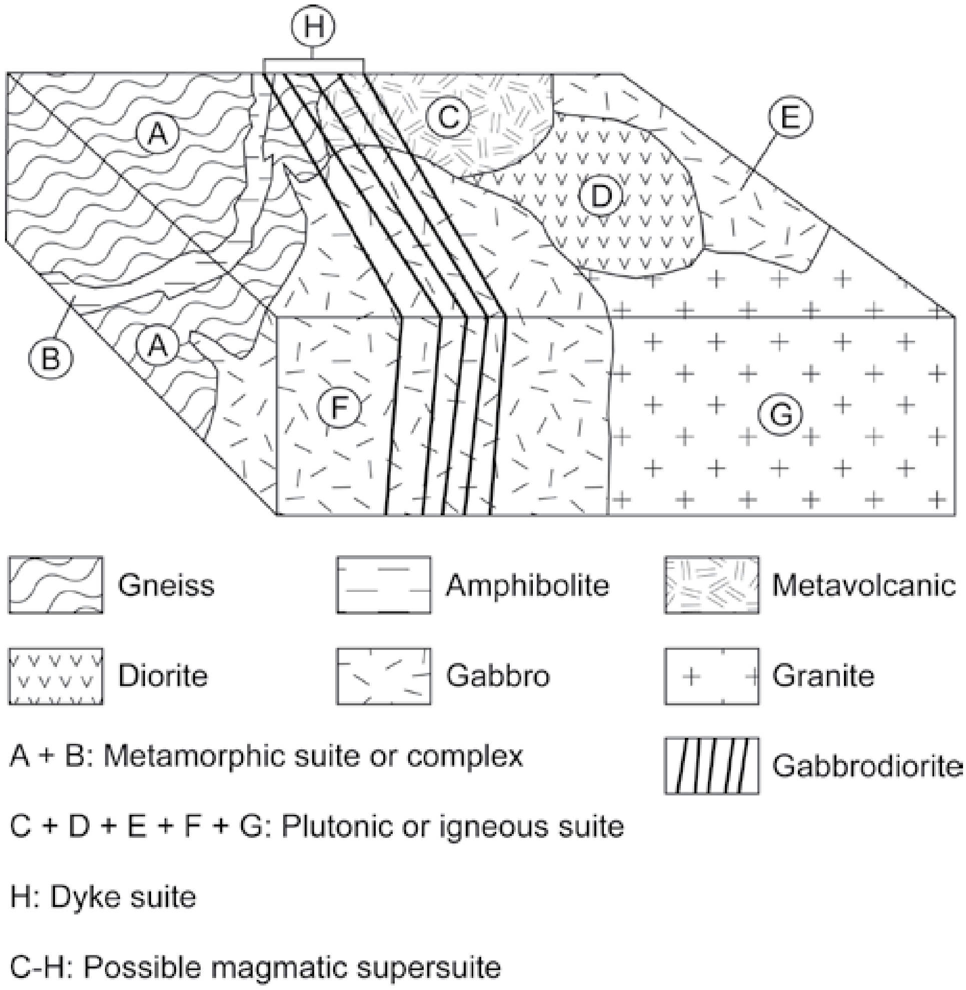

Figure 3. Schematic illustration of the Precambrian bedrock and its lithodemic units (A–H), and their possible classification. Deformed and metamorphosed lithodemes may form a suite, supersuite or complex, which is at a higher rank level than a lithodeme, and the plutonic lithodemes or the dyke lithodemes may form a plutonic suite or dyke suite, respectively. Genetically related plutonic and dyke rocks can be grouped as a magmatic supersuite. (Modified from NSC 1989). (NCS 1989, NACSN 2005).

4.2 Classification and ranking of lithodemic units

4.2.1 Lithodeme

A lithodeme is a body if intrusive, volcanic or metamorphosed and/or deformed rock that lacks primary depositional structures, and it can be distinguished from other adjacent geological units by its lithological properties. It is a fundamental unit in lithodemic classification and nomenclature, and it is comparable to a formation (see Table 1). A lithodeme is mappable at the Earth's surface and sometimes traceable into the subsurface by using geological and/or geophysical methods. Units below the rank of lithodeme have not been formally defined and are thus informal. Such informal terms include zone or phase, which is used in the map database of the Geological Survey of Finland.

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, electrical, thermic, magnetic, radiometric, hydraulic and seismic or some other physical properties derived from its lithological properties. The unit is usually informal, if it is distinguished from its adjoining rock unit(s) only by means of some preceding characteristics.

4.2.1.1 Lithodeme nomenclature

A lithodeme can be given a formal or an informal name, depending on purpose and/or general rules of naming (see Chapter 2). The name of a lithodeme is a compound, consisting of a geographical name, combined with a lithological name or descriptive term. The lithological term should always be common and well known, like gneiss or gabbro. In Precambrian bedrock, some of the intrusive rock bodies are difficult to characterize with a single lithological term and some of the plutonic rocks may not be intrusions. Therefore, the descriptive term should preferably be compositional (e.g. gabbro), but may also denote form (e.g. sill), or be neutral (e.g. intrusion). Terms implying to rock genesis should be always avoided. The informal term phase or zone is also acceptable and can be applied to the designation of lithodemic units (e.g. mineralized zone or pegmatitic zone in lithodemic boundaries).

An example usage of lithodeme nomenclature in Finland is the Akanvaara intrusion, which was described in detail and defined by Mutanen (1997) (see also Hanski & Huhma 2005), and it gives a good example of how to define and classify igneous stratigraphy. The Akanvaara intrusion stratigraphy is here summarized and modified after Mutanen (1977) and Hanski & Huhma (2005). It contains different lithological units, in which the layered succession above the lower chilled margin was formally divided into three major zones or units: (i) the Lower Zone, consisting of a lower orthopyroxene unit and an upper gabbroic unit, and several chromitite layers; (ii) the Main Zone, which begins with a chromitite unit (the Uppermost Lower Chromitite) and is followed by a peridotite unit and a thicker sequence of noritic gabbro cumulates with minor anorthositic interlayers; and (iii) the Upper Zone, also consisting of chromitite (the Upper Chromitite) overlain by noritic gabbros and anorthositic unit. Units below the rank of lithodeme are not formally defined and are thus informal terms, such as phase or zone in use in the map database of the Geological Survey of Finland e.g. phases in the Akanvaara layered intrusion.

Other examples: Forssa gabbro in the volcanic dominated Häme belt, in southern Finland (see Hakkarainen 1994, Peltonen 2005); Koli sill in North Karelia (see Vuollo & Piirainen 1992, Vuollo 2005, Vuollo & Huhma 2005); the Penikat intrusion in the Tornio-Näränkävaara belt (see Alapieti & Lahtinen 1986, Iljina & Hanski 2005). (NCS 1989, NACSN 2005).

4.2.2 Suite

A suite is a lithodemic unit next higher in rank to a lithodeme, typically consisting of two or more associated lithodemes of the same class of rocks (e.g. metamorphic or igneous). Like a lithodeme, a suite is also mappable at the Earth's surface and sometimes traceable into the subsurface by using geological and/or geophysical methods. It usually has some regional extent, or consists of two or more distinct units that together have a regional extent.

Suites can be defined and should be used for the purpose of expressing and clarifying the natural relations of associated formal and/or informal, or unnamed lithodemes, which have one or more lithological features in common. Depending on the geological history and/or mode of origin, a suite may change or lose all of its lithological character(s) regionally to some extent, making it more practical and clearer to designate the unit as a lithodeme in areas beyond its type area, and retain the same originally defined name. However, as long as the original sense of the natural relations and common lithological features of units are not violated or disrupted, it may be treated as a suite.

4.2.2.1 Suite nomenclature

Suites are only given formal names, in accordance with the general rules of naming (see Chapter 2). The name combines a geographical name, the term suite, and sometimes a descriptive term. The geographical name of a suite may not necessarily be the same as the lithodeme component, but intrusive assemblages usually share the same geographical name if an intrusive lithodeme is representative of the suite. If it is necessary to change the rank of two or more mappable lithodemes to a suite, the original geographic component of the name can be retained, but the original name should not be retained for one of the divisions of the original unit.

A formal example usage of the term suite in Finland is the Rapisevankangas Gneiss Suite, which was described in detail, defined and classified by Luukas (1987) and Laajoki & Luukas (1988). The Rapisevangas Gneiss Suite mainly consists highly metamorphosed and deformed banded gneisses and mica schists, including seven different lithodemes in a relatively small area (Luukas 1987, Laajoki & Luukas 1988), which gives a good example of how the highly metamorphosed and deformed Precambrian rock assemblage should classified by using the lithodemic stratigraphic nomenclature. The name Rapisevankangas Gneiss Suite also contains the descriptive term "Gneiss", which has not been very customary in Finland.

Other examples: the Köyry Suite (see Hanski 2002), the Mellajoki Suite (see Perttunen 2002, Perttunen & Hanski 2003) and the Tankajoki Suite (see Lehtonen et al. 1998), which are all located in Finnish Lapland. (NCS 1989, NACSN 2005).

4.2.3 Supersuite

A supersuite is a lithodemic unit next higher in rank to a suite, comprising two or more suites or complexes, having a natural vertical or lateral relationship to one another. A supersuite is comparable to a supergroup and it is mappable at the Earth's surface and sometimes traceable into the subsurface by using geological and/or geophysical methods.

A supersuite has some regional extent and it consists of lithodemic units belonging to the same and/or a different class or classes of rocks. A supersuite can be defined and should be used after detailed mapping and scientific documentation, and only if it has any practical value.

4.2.3.1 Supersuite nomenclature

Supersuites are only given formal names, in accordance with the general rules of naming (Chapter 2). The name combines a geographical term with the term "supersuite".

So far, no formally (or informally) named supersuites has been defined from the bedrock of Finland, although, for example, some of the Finnish terrains or areas consist of two or more assemblage of suites or complexes, which have some natural relationship to one another, and could be formally defined as a supersuite. In Finland, the term "supersuite" is usually substituted by a term "complex" (see the next chapter). In the map data of Finland, the Karelia layered intrusion supersuite is used. Other examples include the Western Finland supersuite, the Southern Finland supersuite and the Southern Finland rapakivi supersuite. (NCS 1989, NACSN 2005).

4.2.4 Complex

A complex is not a ranked lithodemic unit, and consists of an assemblage or mixture of two or all classes of sedimentary, igneous and metamorphic rocks. It is commonly comparable to a suite or supersuite, although it is unranked. A complex is mappable at the Earth's surface and sometimes traceable into the subsurface by using geological and/or geophysical methods, and generally has some regional extent.

Complexes can be identified as an assemblage of diverse rock units, and should be used in bedrock areas where the mapping of each separate lithological component is impractical or difficult at ordinary mapping scales. Therefore, a complex may consist of two or more formally named lithodemes, lithostratigraphical units, and/or informal and unnamed lithological units, which have usually been more or less deformed together in the Finnish Precambrian bedrock.

Bedrock consisting of an assemblage of diverse types of a single class of rock, as in some Precambrian terranes, should not be designated or defined as a complex, but terms such as metamorphic suite or plutonic suite, for example, should rather be used. However, exceptions to this rule include the terms volcanic complex (Chapter 4.2.4.1) and structural complex (Chapter 4.2.4.2) The term "complex" is also sometimes connected with tectonostratigraphical classification (see Chapter 6).

4.2.4.1 Volcanic complex

A volcanic complex refers to a diverse assemblage of different kinds of volcanic or metavolcanic rocks and associated intrusive and weathering products (e.g. Pyhäsalmi volcanic complex). If volcanic complexes are included in a thick sequence of sedimentary rocks, they can be defined together with it as a supergroup.

4.2.4.2 Structural complex

Usually, a structural complex refers to an assemblage of two or more different kinds of rocks intermixed by tectonic processes, in which some individual components are not mappable (e.g. Vuotso Complex as the former Tana Belt). A structural complex may also consist of only a single class of rock if the mixing or disruption is clearly due to tectonic processes.

4.2.4.3 Misuse of the term "series"

Especially in some studies on the Precambrian bedrock, the term "series" has sometimes been used or applied for lithodemic and lithostratigraphical units, or to a sequence of rocks resulting from a succession of eruptions or intrusions. This practice is improper and the term "series" should not be used in formal names or any geological units of this sort, or for any tectonostratigraphical units. Term "series" should be replaced by the terms "suite", "complex" or "supersuite", and in addition the term "group" should be used for volcanic and low-grade metamorphic rocks, and "intrusive suite" for intrusive rocks of the group rank, instead of "series".

4.2.4.4 Complex nomenclature

Complexes are given a formal or an informal name, in accordance with general rules of naming (see Chapter 2). A geographical term in the name should only be used for formally defined complexes.

In the Finnish geological literature, the term "complex" has been widely used, mostly informally, for many fault-bounded parts of the bedrock, or for an igneous complex. According to the general rules for naming and defining geological units, the term "complex" should be capitalized (Complex) if it is formal, which is not very common in the Finnish geological literature. An example usage of the term "complex" in Finland is the Iisalmi complex, mainly consisting of 3.2–2.6 Ga old strongly deformed and/or metamorphosed tonalitic gneisses and amphibolitic migmamatites, and some younger granites and diabase dikes, which have intruded the gneisses (Nironen et al. 2002, Vaasjoki et al. 2005). The Iisalmi complex also contains some Archean paragneisses and a smaller Archean carbonatite complex.

Other examples: the Koillismaa (layered igneous) complex in the Tornio-Näränkävaara belt (see Alapieti 1982, Iljina & Hanski 2005); the Nurmes gneiss complex in the Kianta terrain (see Kontinen 1991, Sorjonen-Ward & Luukkonen 2005); and the Suomujärvi Complex in the Koillismaa terrain (see Evins et al. 2002, Sorjonen-Ward & Luukkonen 2005). Many of these complexes may presently also be defined according to stratigraphic guidelines and procedures, e.g. the Nurmes suite and the Koillismaa layered intrusion suite. (NCS 1989, NACSN 2005).

5 USAGE OF LITHOSTRATIGRAPHIC VS. LITHODEMIC UNITS IN FINLAND

The usage and the boundaries of lithostratigraphic vs. lithodemic units in Finland is sometimes a complicated task, and there have been difficulties in some studies in formally dividing bedrock into lithostratigraphic units (e.g. Kohonen 1995), especially if the body of rock is not highly metamorphosed and/or completely deformed. The main problems arise when mapping, defining, and establishing the rock unit in the field and the lithological characteristics are not clearly visible. A sequence of rocks may sometimes conform to the Law of Superposition in one area, whereas this property may be lacking in another area. This can lead to lithostratigraphic and lithodemic units that are nevertheless correlative (e.g. rock sequences containing quartzite in southern Finland).

In general, the principles of lithostratigraphic units (Chapter 3) for the Precambrian bedrock should only be used if the primary sedimentary structures are somewhat clearly visible, and the boundaries can placed at distinct contacts or may be selected at some arbitrary level within zones of gradation. Those boundaries are placed at positions of lithological change. However, if the body of rock lacks primary sedimentary or volcanic structures, or the bedrock consists of one or more bodies of intrusive, plutonic or extrusive rocks, the use of the principles of lithodemic units should not be avoided (Chapter 4). The boundaries of lithodemic units may be placed at clearly visible and distinguished contacts in two different rock units or within zones of gradation.

Thus, it is important to note that the boundary dividing the use of lithostratigraphic or lithodemic units is not the degree of metamorphism or deformation, but rather the mappable lithological properties. This implies that geologists in the field, with careful consideration, must ultimately make conclusions and decisions about the rock unit(s) and the hierarchical model to use, which will later be evaluated by the Stratigraphic Commission of Finland.

6 TECTONOSTRATIGRAPHIC UNITS

6.1 General properties, rules and boundaries

Tectonostratigraphic classification and division may be used for rock units that are stacked on top of each other by compressional forces (Figure 4). A tectonostratigraphic unit is a body of rock that has been shifted or displaced along a thrust fault (floor thrust), and may be delimited either by a roof thrust or by the erosion surface. It may consist of one or more lithostratigraphic and/or lithodemic units. Thus, tectonostratigraphic classification differs fundamentally from lithostratigraphic and lithodemic classifications.

The tectonostratigraphical units are, in decreasing order of rank, *nappe system and nappe complex, nappe,* and *thrust sheet,* where the *nappe* is the fundamental unit and comparable in hierarchy to a formation or lithodeme. A *nappe complex* and *nappe system* have equal rank in a hierarchical classification, but they can be distinguished from each other by knowledge of the displacement and relative age of individual nappes. The term *thrust sheet* may also be used as a general unit term without the hierarchical rank.

Essentially, tectonostratigraphical units can be defined and recognized from the underlying older or younger rocks by a tectonic thrust(s), and in addition, the packets of stacked rock bodies may be bounded by other vertical or lateral tectonic surfaces, intrusive contacts and later depositional surfaces or by the erosion surface. In Finland, it is sometimes unavoidable or advisable to use a tectonostratigraphical and/or tectonic approach to the Finnish deformed and faulted Precambrian bedrock (e.g. see Laajoki 1990, 1991, 2005) or, for instance, to the faulted Pre-Quaternary rocks in Finnish Lapland (see Lehtovaara 1986, 1988, 1989, 1994, 1995, Lehtovaara & Sipilä 1986). A repetition of strata by thrusts is probably much more common than yet recognized in Finnish bedrock that has

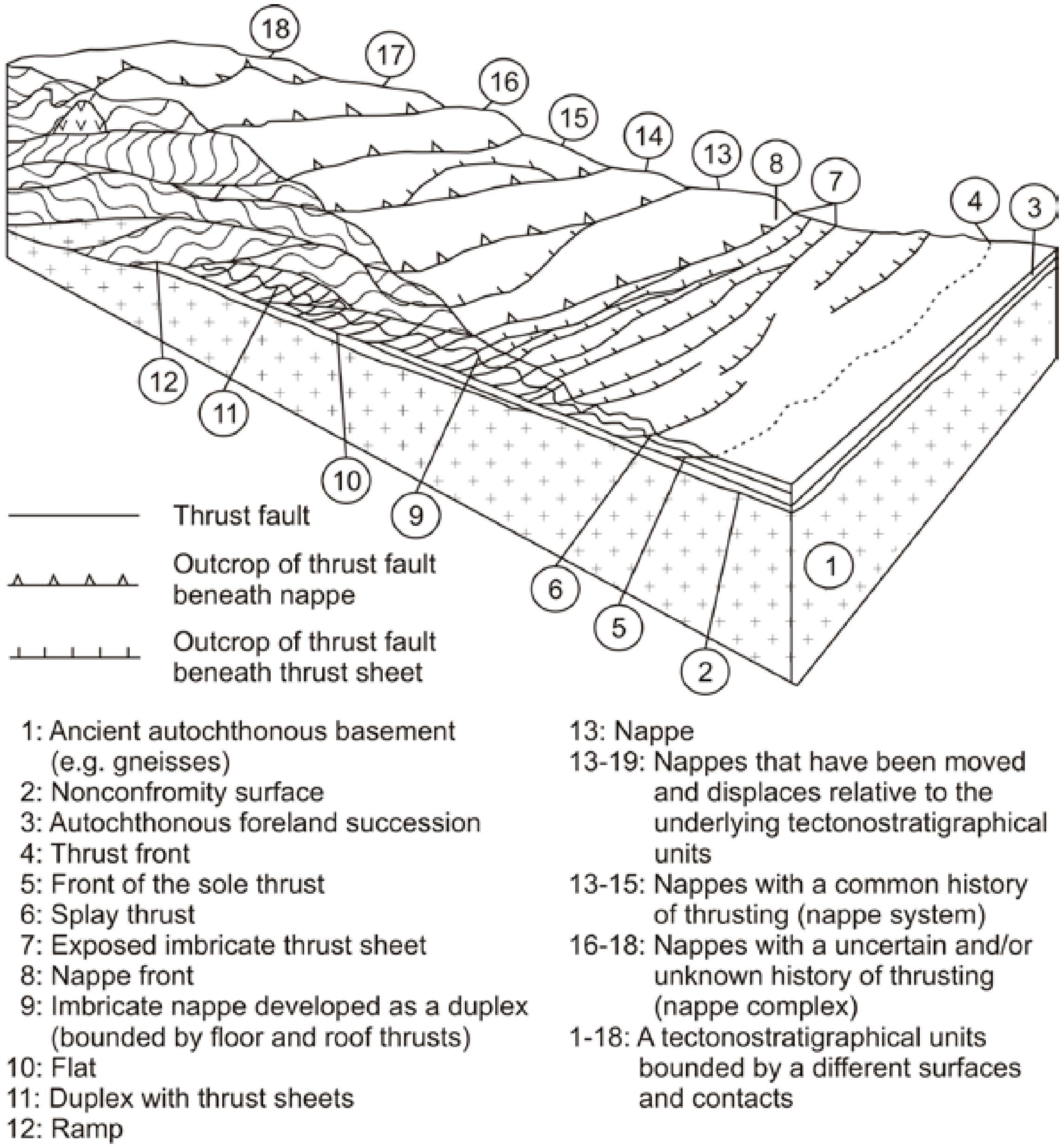

Figure 4. Simplified schematic illustration of the Precambrian mountain chain, from the right foreland to the left nappe region, and its tectonostratigraphic units. (Modified from NSC 1989).

been subjected to contractional deformation during orogeny. Although the generally flat topography of the Finnish bedrock is challenging, the identification of tectonostratigraphic units helps to reveal the repetition of strata and collisional history; it is particularly important that the floor thrust is defined. Overprinting by subsequent extensional structures may complicate the system (cf. Caledonides).

6.2 Classification and ranking of tectonostratigraphic units

6.2.1 Nappe

A *nappe* is a sheet-, slice-, wedge- or lens-shaped slab of bedrock 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. It is a fundamental formal unit in tectonostratigraphic classification and nomenclature, and it is comparable to a formation or lithodeme (see Table 1). A nappe is mappable at the Earth's surface and sometimes traceable into the subsurface by the use of geological and/or geophysical methods. No limitations are placed on the size of a nappe.

A nappe consists of one or more nappe sheets or thrust sheets that are assumed to have undergone displacement together on the floor thrust of the nappe. In addition to the floor thrust, a nappe may be bounded by later depositional surfaces, other tectonic surfaces, intrusive contacts, and the erosion surface.

A nappe may consist of one or more rock types, allochthonous or parautochthonous, with the same or a different origin, age, composition, facies or degree of metamorphism and deformation, which have originated from the tectonic environment(s) (e.g. a foreland basin on the continental crust). Thus, it is possible to distinguish and define different lower rank lithostratigraphical, lithodemic and biostratigraphical units within the nappe. A nappe can be defined and recognized from the underlying older or younger rocks by a tectonic thrust fault (*floor thrust)*, and in addition, it may be bounded by other vertical or lateral tectonic surfaces, intrusive contacts and later depositional surfaces or by the erosion surface. In the Precambrian bedrock, a nappe may be somewhat tectonically complicated, consisting for instance of *duplexes* or different fold structures such as *fold nappes*.

A nappe may consist of imbricate fans and duplexes in which the stratal sequence remains in its original way-up orientation or the sequence may have been overturned in fold nappes. Because of deformation and erosion, a nappe may be found as detached nappe remnants (klippen) and may envelop one or more windows. The tectonostratigraphic units underlying the nappe are exposed in the window.

6.2.1.1 Nappe nomenclature

A nappe is a non-genetic term, which can be given a formal or an informal name, depending on the purpose and/or general rules of naming (see Chapter 2). If a nappe is given a name, it must consist of the same geographical name as that of the floor thrust of the nappe. It must not be given the same geographical name as is used for the lithological units within the nappe. The type locality of a nappe should be within the area in which the thrust sheets forming the nappe are located.

Good examples of the use of the tectonostratigraphic scheme and formal nappe nomenclature in Finland are the allochthonous Jerta Nappe, the Nalganas Nappe, the Nabar Nappe and the Vaddas Nappe in the northwest part of Finnish Lapland (see Lehtovaara 1986, 1988, 1989, 1994, 1995, Lehtovaara & Sipilä 1986). According to Lehtovaara (op. cit.), the Caledonian tectonostratigraphic sequence consists of the Archaean basement gneisses, overlain by the autochthonous Proterozoic/Early Cambrian sedimentary rocks, which are overthrusted by a thick sequence of allochthonous schistose and strongly lineated nappes of Cambrian-Ordovician emplacement. These are overlain by an ultrabasic magmatic thrust complex, which completes the Caledonian tectonostratigraphic sequence in Finland.

Other examples: the Väyrynkylä Nappe, the Tupala Nappe and the Tulijoki Nappe in the Kainuu Belt (see Havola & Kontinen 1991, Laajoki 1991). (NCS 1989).

6.2.2 Thrust sheet

A *thrust sheet* is a sheet-, slice-, wedge- or lens-shaped slab of bedrock above a thrust fault that has been displaced along a horizontal, near subhorizontal (gently dipping) or listric (concave upwards) thrust fault. A thrust sheet is next lower in rank to a nappe and comparable to a member in a lithostratigraphical classification system, but thrust sheet can also be used as a non-ranking tectonostratigraphical term. A thrust sheet that forms a part of nappe can be called a *nappe sheet*. A thrust sheet is mappable at the Earth's surface and sometimes traceable into the subsurface by using geological and/or geophysical methods. There are no limitations for the size or the length of transport of a thrust sheet. Like a nappe, a thrust sheet may be eroded and divided into *klippen*, and it may surround one or more *windows.*

A thrust sheet may consist of one or more rock types, with a common or different origin, age, composition, facies or degree of metamorphism and deformation. Thus, it is possible to distinguish and define different lithostratigraphical, lithodemic and biostratigraphical units within a thrust sheet. A thrust sheet is distinguished from the underlying older or younger rocks by a leading thrust or floor thrust, or from an overlying thrust sheet by a trailing thrust or roof thrust. In addition, a thrust sheet may be bounded by later depositional surfaces, other tectonic surfaces, intrusive contacts and the erosion surface.

6.2.2.1 Thrust sheet nomenclature

A thrust sheet can be given a formal or an informal name, depending on the purpose and/or general rules of naming (see Chapter 2). When using the term "thrust sheet" formally for a tectonostratigraphical unit that has already been defined as a nappe, the geographical name of the nappe must be always used together with the term thrust sheet. In addition, if the floor thrust under the thrust sheet has already been formally or informally named, the same name must be used for the sheet. A thrust sheet must not be given the same geographical name as was used for the lithological units in the nappe or thrust sheet. A thrust sheet that has been defined and given a formal name can have its status changed to a nappe sheet or nappe if investigations show this to be desirable.

Examples of the rarely used term thrust sheet in Finland are the Oratunturi thrust sheet, the Martinvaara thrust sheet, the Ellitsa thrust sheet and the Leviäaapa thrust sheet, located in the Sodankylä area in the central part of the Lapland Greenstone belt, which represents a complex thrust duplex within a nappe overlying the Belomorian Archaean basement and autochthonous Luirojoki calc-silicate Proterozoic cover rocks (Evins & Laajoki 2002). According to Evins & Laajoki (2002), the whole Sodankylä area can be divided into seven different domains, which are bounded by faults, displaying unique lithologies, metamorphic conditions, structural patterns and/or aeromagnetic anomalies. In Finland, the term thrust sheet has sometimes also been used as a general descriptive unit term by ignoring the hierarchical rank. This usage is not recommended. In addition, the term nappe sheet has been used in Finland. An example is the Mattila Nappe Sheet, which is a narrow wedge-like slab of bedrock within a nappe complex, forming part of a nappe (see Laajoki 1991). Since the term nappe sheet is equivalent to thrust sheet, it is not recommended. (Boyer & Elliot 1982, NCS 1989).

6.2.3 Nappe System

A *nappe system* is a tectonostratigraphical unit next higher in rank to a nappe, and equivalent to a nappe complex. It comprises two or more nappes, having a geometrical relationship to one another. The movements and displacements of distinct and individual nappes, due to thrust faulting and/or sliding, have taken place during the same deformation event (cf. Chapter 6.2.3). A nappe system is mappable at the Earth's surface and sometimes traceable into the subsurface by using geological and/or geophysical methods. It usually has some regional extent, although not all the individual and distinct nappes in the system need to be present whenever a nappe system is found.

A nappe system may consist of several individual and distinct nappes and/or thrust sheets, and it is possible to distinguish them from one another by their content of lithostratigraphical, lithodemic and biostratigraphical units. In Finland, the term nappe system should only be used if the movements and displacements of the individual nappes are well known and documented, and they belong to the same deformation event.

6.2.3.1 Nappe System nomenclature

A nappe system can be given a formal or an informal name, depending on the purpose and/or general rules of naming (see Chapter 2). A nappe system must not be given the same geographical name as a component nappe, or as any of the lithostratigraphical, lithodemic or biostratigraphical units in it. The original name of the nappe system is retained, although in some areas it may become thinner, and even if it is attenuated and may be visible and represented by only one of its component nappes. The formal name combines a geographical name with term "Nappe System". Informally, the geographical name can be used together with the term "the nappes".

So far, no clearly formally or informally defined and/or described nappe systems have been published in the Finnish geological literature. In some articles, the term nappe system is confused with term term nappe complex (e.g. the Outokumpu nappe system vs. the Outokumpu nappe complex), which should be avoid in all circumstances to clarify the tectonostratigraphic nomenclature. (NCS 1989).

6.2.4 Nappe Complex

A *nappe complex* is a tectonostratigraphical unit equal or next higher in rank to a nappe. In the latter case it may then be comprised of two or more nappes, having a geometrical relationship to one another. The movements and displacements of distinct and individual nappes, due to thrust faulting and/or sliding, have taken place during different deformation phases or orogenies, or the movements and displacements are unknown, or they have uncertain relative ages (cf. Chapter 6.2.4). A nappe complex is mappable at the Earth's surface and sometimes traceable into the subsurface by using geological and/or geophysical methods. It usually has some regional extent, although not all the individual and distinct nappes in the complex need to be present whenever a nappe complex is found

A nappe complex may consist of several individual and distinct nappes and/or thrust sheets, characterized by an earlier and different deformation type and metamorphic grade, but may have undergone later and common deformational and metamorphic event(s). It is possible to distinguish individual and distinct nappes and/or thrust sheets from one another by their content of lithostratigraphical, lithodemic and biostratigraphical units.

6.2.4.1 Nappe Complex nomenclature

A nappe complex can be given a formal or an informal name, depending on the purpose and/or general rules of naming (see Chapter 2). A nappe complex must not be given the same geographical name as a component nappe, or any of the lithostratigraphical, lithodemic or biostratigraphical units within it. The original name of the nappe complex is retained, although in some areas it may become thinner, and even if it is attenuated and may be visible and represented by only one of its component nappes. The formal name combines a geographical name with term "Nappe Complex", and in an informal context, the geographical name can be used together with the term "the nappes".

Formally or informally named nappe complexes are rare in the Finnish geological literature. Probably the best definitions and example usages of formally named nappe complexes can be found from the Kainuu Belt area, which is characterized by thrusting and nappe tectonics (see Havola & Kontinen 1991, Laajoki 1991). The main tectonostratigraphic units within the Kainuu Belt area include, for example, the Korhololanmäki Nappe Complex, comprising mainly ca. 2000–1960 Ma riftogenic turbidites and black schist, and the allochthonous Törmänmäki Nappe Complex, comprising distinct nappes and thrust sheets (see op. cit.). Another example of usage of the term nappe complex is the Outokumpu nappe complex, which is structurally complex, consisting of several distinct nappes of both Paleoproterozoic cover and Archean basement slices (see e.g. Laajoki 2005). (NCS 1989).

6.3 Tectonostratigraphic terrane

A *tectonostratigraphic terrane or terrane* is a fault-bounded body of rock of regional extent, characterized by a geological history different from that of contiguous terranes or bounding continents. Terranes may be (i) large or small continental blocks, bounded by suture zones and newly formed ocean-floor crust, (ii) nappes bounded by thrust faults, (iii) blocks bounded by regional transform faults, or (iv) pieces of the Earth's crust having complex and structurally composite fault surfaces.

Tectonostratigraphic terranes can be defined and recognized by their observable and characteristic geological structure and evolution, age, fauna and flora, paleomagnetic history and bounding faults.

Sometimes, terms like a *suspect terrane, exotic terrane, metamorphic terrane, composite terrane or disrupted terrane* can be used to emphasize the origin, history, spatial and genetic relations, or some characteristic features of the terrane. It is important that the term "terrane" is not confused with the term "terrain", which is a general term for the region or area, the third or vertical dimension of the Earth's land surface.

6.3.1 Terrane nomenclature

Tectonostratigraphical terranes or terranes can be given informal names by using their assumed plate tectonic origin (e.g. rift basin terrane), combined with a geographical name from the type area. If a tectonostratigraphical terrane combines with a previously defined and named tectonostratigraphical unit, then the properly defined name of that unit should be used in the name of the terrane in formal nomenclature. However, if the recognized terrane has different boundaries from the previously defined and named tectonostratigraphical units, then it should be defined and named by using the general rules of naming (see Chapter 2).

Tectonostratigraphical terranes can be any size and shape, having varying degrees of compositional complexity, and thus Antarctica or India, for example, are single great terranes (see Howell 1985). Some smaller tectonostratigraphic terrane examples can be found, for instance, from the Caledonian mountain chain, which coincide with nappe units. The geometry and the shape of a tectonostratigraphic terrane is the product of its history of movements and tectonic interactions.

6.3.2 Use of the terms "province" and "block"

A province refers to any large area or region which is characterized by similar features and history. A more specific term, geological province, is defined as any large areas or extensive regions characterized by a similar geological history, or by similar structural, petrographic or physiogeographic features. The boundaries with adjacent areas are those of collided continental units or a continental unit and an accreted arc complex; an oceanic basin is considered to have existed between different provinces. Nowadays, the term geological province usually refers to sections or regions of a craton recognized within a given time-stratigraphic period. The term domain has also be used in a meaning very close to that of the geological province (e.g. Korsman et al. 1997).

Blocks and fault blocks are defined as completely or partly fault-bounded bodies within terranes. They behave as a crustal units during block faulting and tectonic activity (Howell 1985, NCS 1989).

6.4 Tectofacies

In Finland, the terms *tectofacies* and *tectofacies classification* have mainly been used for the major units of the North Karelia and Kainuu belts, which are bounded by unconformities (e.g. see Laajoki 1990, 2005). Laajoki (op. cit.) defined tectofacies to include all the formations formed during a specific broad tectonic phase of the depositional or volcanic history of a basin or nearby basins. Thus, the use of tectofacies nomenclature may add a broad tectonic setting or framework to the stratigraphical classification, although it is not included in the hierarchical tectonostratigraphic classification or units that are proposed here.

7 SEQUENCE STRATIGRAPHY

7.1 General properties, rules and boundaries

Sequence stratigraphy is currently utilized as a modern approach to integrated stratigraphic analysis, which combines insights from all other types of stratigraphy and several non-stratigraphic disciplines such as sedimentology, geomorphology, geophysics and basin analysis. Although sequence stratigraphy is a modern approach to integrated stratigraphic analysis, it is the only type of stratigraphy that is not yet standardized in international stratigraphic codes. The key to the formal inclusion of sequence stratigraphy within the array of stratigraphic disciplines is the recognition of what are thecore aspects versus those of lesser significance, and an appreciation that the approach to standardization has to be entirely unbiased. The general approach to standardization is to promote those concepts that can be accepted by all, and thus retain flexibility in the application of the sequence stratigraphic method. 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 and accommodation, i.e. the space available for sediments to fill.

A sequence stratigraphic framework includes genetic units that result from the interplay of accommodation and sedimentation (i.e., forced regressive, lowstand and highstand normal regressive, and transgressive), which are bounded by sequence stratigraphic surfaces. Each genetic unit is defined by specific strata stacking patterns and bounding surfaces, and consists of a tract of correlatable depositional systems (i.e., a systems tract). Stratal stacking patterns respond to the interplay of changes in rates of sedimentation and the base level, and reflect combinations of depositional trends that include progradation, retrogradation, aggradation and downcutting. The mappability of systems, tracts and sequence stratigraphic surfaces depends on the depositional setting and the types of data available for analysis (Catuneanu et al. 2009). Sequence stratigraphy is concerned with the large-scale arrangement of sedimentary strata, and the major factors that influence their geometries are sea-level change, contemporaneous fault movements, basin subsidence and sediment supply. Sequence stratigraphy has revolutionized the thinking on and methods of stratigraphic analysis, and, in contrast to most other types of stratigraphy, it places strong emphasis on processes of facies formation and preservation, and on the nature and timing of the contacts that separate various stratigraphic units.

The predictable association of depositional systems into sequences and component systems tracts is made possible by the fact that processes in all depositional environments respond to a common control: the base level. In turn, changes in the base level depend on the interplay of allogenic controls such as sea-level change (eustasy), tectonism and climate. The base level is therefore the link that ‘synchronizes’ depositional processes in all environments across a sedimentary basin, bringing coherence to the sequence stratigraphic mode (Figure 5). This in turn means that sequence stratigraphy is an effective tool for correlation on a regional basis. The method is now commonly utilized as a modern approach to integrated stratigraphic analysis, combining insights from all other types of stratigraphic as well as several non-stratigraphic disciplines (Catuneanu et al. 2009).

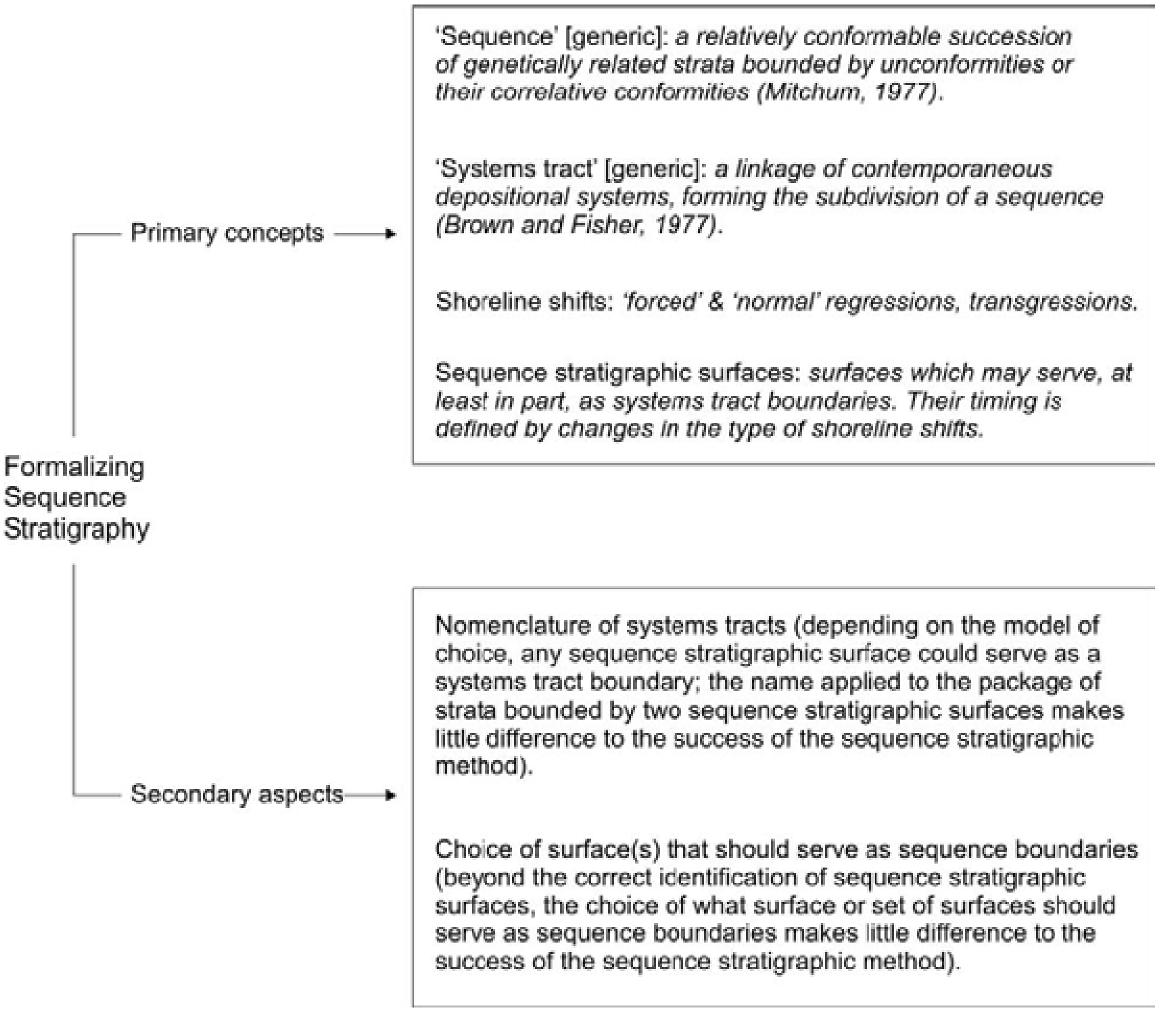

Figure 5. Primary vs. secondary aspects in sequence stratigraphy after Catuneanu (2006). Primary aspects are validated and generally accepted. Secondary aspects are model-dependent. Once the sequence is formalized as a generic concept, one can take a step further and list the various types of sequences, by defining what surfaces are selected as sequence boundaries in each case.

7.2 Classification and order of sequence stratigraphic units

The main methods that need to be integrated into a sequence stratigraphic analysis include facies analysis of ancient deposits (outcrops, cores) and modern environments, analysis of well-log signatures or analysis of seismic data and the achievement of time control via relative or absolute age determination.

Four main events are recognized during a full cycle of base-level changes:

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

These four events control the timing of formation of all sequence stratigraphic surfaces and systems tracts. A generic definition of a sequence leaves the selection of sequence boundaries to the discretion of the individual, thus providing the necessary flexibility that allows one to adapt to the particularities of each case study, and the freedom to experiment with new concepts and ideas. Once the 'sequence' is formalized as a generic concept, one can take a

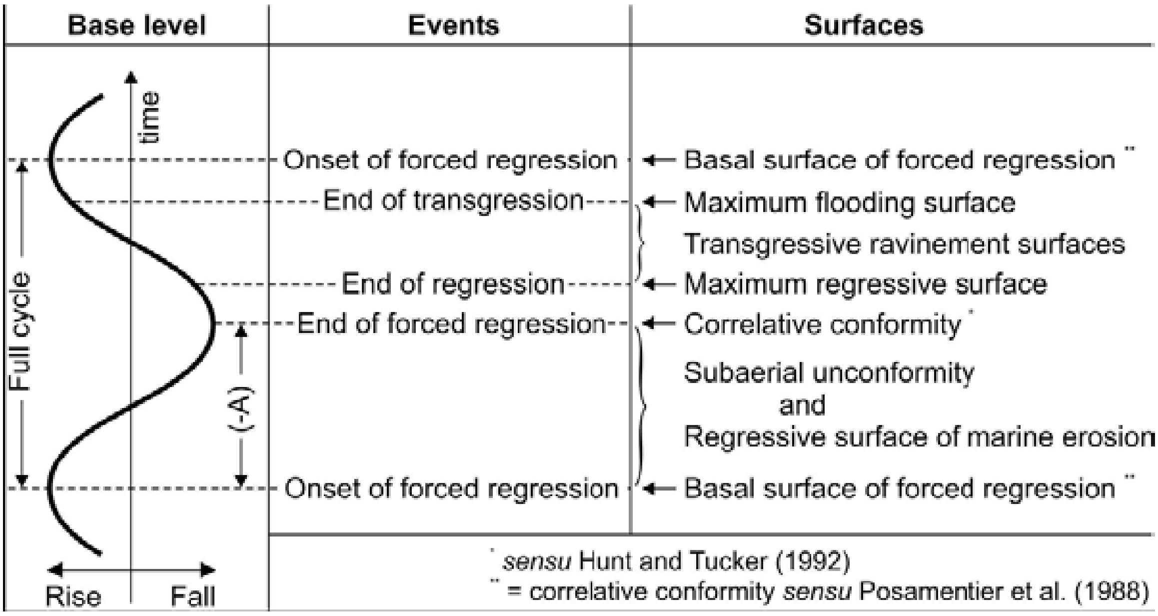

Figure 6. Timing of the seven sequence stratigraphic surfaces relative to the four main events of the base-level cycle (from Catuneanu 2006). Abbreviation: (–A) – negative accommodation.

step further and list the various types of sequences, by defining what surfaces are selected as sequence boundaries in each case. In this, 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.

Sequence stratigraphic surfaces are surfaces that can serve, at least in part, as systems tract boundaries. Seven sequence stratigraphic surfaces are defined relative to the four main events of the base-level cycle (Figure 6). The recognition of sequence stratigraphic surfaces in the rock record is data-dependent.

Sequence: 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. 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.

Parasequence: 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). Parasequences are commonly used to describe individual prograding lobes in coastal to shallow water systems, where evidence of abrupt water deepening (i.e., documentation of flooding surfaces) is easiest to demonstrate. Parasequences are commonly used to describe individual prograding sediment bodies in coastal to shallow-water systems, and confusion regarding the meaning of parasequences has arisen with the application of the term to fully fluvial as well as deep-water systems, where the concept of 'flooding surface' becomes meaningless (Catuneanu et al. 2009).

Systems tract: a sequence may be subdivided into component systems tracts, which consist of packages of strata that are genetically distinct (e.g. forced regressive, normal regressive, transgressive). Systems tracts are interpreted based on stratal stacking patterns, the position within the sequence, and types of bounding surfaces.

7.3 Application and limitations for the Precambrian record

The genetic facies level approach, when applied to the Precambrian sedimentary record, can make it possible to constitute depositional systems, which are generally bounded by unconformities or unrelated facies transitions. The possible causes and effects of the relative changes in sea-level and connections with the tectonic history of the cratonic margin can then be evaluated from the depositional systems tracts and the main sequences distinguished. The sequence stratigraphy of coastal and shallow shelf deposits is very complex because of the interplay of such factors as the rate of sea-level change, the rate of sediment supply, the rate of subsidence, the frequency and amount of wave erosion, and the nature of the local palaeogeography (Miall 1997).

The cyclicity of Proterozoic sedimentary rocks is still a rather crude concept, but studies by Christie-Blick et al. (1988, 1995), Harris and Eriksson (1990), Jackson et al. (1990), Catuneanu and Eriksson (1999), Strand and Laajoki (1999) and Strand (2005), among others, prove that Proterozoic nonfossiliferous strata are applicable to a sequence stratigraphy approach and provide, for instance, evaluation of what were the major factors controlling Precambrian sea-level changes. The application of sequence stratigraphy to the Proterozoic rock record, however, often encounters difficulties because of poor preservation, some tectonic or metarmophic overprint and a lack of age determinations. (Catuneanu 2006, Catuneanu et al. 2009).

8 CHRONOSTRATIGRAPHY

8.1 General properties, rules and boundaries

Chronostratigraphic classification provides a means of establishing the temporally sequential order of rock bodies. The principal purposes are 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 (see Grandstein et al. 2004).

The boundaries of chronostratigraphic units should be defined in a designated stratotype on the basis of observable palaeontological or physical features of the rocks. The boundaries of chronostratigraphic units can be extended only within the limits of resolution of available means of chronocorrelation, which currently include palaeontology, numerical dating, remanent magnetism, thermoluminescence, relative-age criteria and such indirect and inferential physical criteria as climatic changes, the degree of weathering, and relations to unconformities. Traditionally, the Precambrian stratigraphy is classified chronometrically by absolute age, i.e. the base of each Precambrian eon, era and period is assigned an arbitrary numerical age. However, continual improvements in data coverage and methodology could also lead to standardization of the chronostratigraphic units for the Precambrian rock record.

8.2 Ranking and nomenclature of chronostratigraphic units

A chronostratigraphic unit is a body of rock established to serve as the material reference for all constituent rocks formed during the same span of time. A chronostratigraphic unit may be based upon the time span of a biostratigraphic unit, a lithic unit, a magnetopolarity unit, or any other feature of the rock record that has a time range. It may be any arbitrary but specified sequence of rocks, provided it has properties allowing chronocorrelation with rock sequences elsewhere.

The hierarchy of chronostratigraphic units, in order of decreasing rank, is eonothem, erathem, system, series, and stage. Of these, system is the primary unit of world-wide major rank; its primacy derives from the history of development of stratigraphic classification. At any level in the chronostratigraphical hierarcy, an initial capital letter is used for each formal component of the name, e.g. Paleoproterozoic Erathem or Orosirian System. Chronostratigraphical units may be formally divided into Lower, (Middle) and Upper, and the corresponding geochronological units into Early, (Middle) and Late. The use of lower case initial letters implies an informal usage (see Grandstein et al. 2004).

8.2.1 Eonothem

The unit highest in rank is the eonothem. The Phanerozoic Eonothem encompasses the Paleozoic, Mesozoic, and Cenozoic Erathems. Although older rocks have to date been assigned to the Precambrian Eonothem, they have also recently been assigned to the Archean (2850–2500) and Proterozoic (2500–542 Ma) eonothems by the IUGS Precambrian Subcommission. The Hadean eonothem refers to the possibly older than 3850 Ma record and events on the Earth, where the age has been derived from the oldest preserved supracrustals so far found. The span of time corresponding to an eonothem is an *eon*.

8.2.2 Erathem

An erathem is the formal chronostratigraphic unit of rank next lower to eonothem and consists of several adjacent systems. The span of time corresponding to an erathem is an *era*. Presently, the Archean eonothem encompasses the Eoarchean (3850–3600 Ma), Paleoarchean (3600–3200 Ma), Mesoarchean (3200–2800 Ma), and Neoarchean (2800–2500 Ma) erathems. The Proterozoic eonothem encompasses the Paleoproterozoic (2500–1600 Ma), Mesoproterozoic (1600–1000 Ma) and Neoproterozoic (1000–542 Ma) erathems (see Grandstein et al. 2004).

8.2.3 System

The unit of rank next lower to erathem is the system. Rocks encompassed by a system represent a time span and an episode of Earth 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), Cryocenian (850–630 Ma) and Ediacaran (630–542 Ma) systems (see Grandstein et al. 2004). The Precambrian-Cambrian boundary is defined to 542 Ma by Amthor et al. 2003).

8.2.4 Series

A series is a conventional chronostratigraphic unit that ranks 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*

8.2.5 Stage

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*.

8.2.6 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 stage or series. 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).

8.3 Use of chronostratigraphy for the Precambrian record

Precambrian stratigraphy is presently formally classified only chronometrically, i.e. the base of each Precambrian eon, era and period is assigned an arbitrary numerical age (Plumb & James 1986, Plumb 1991, Granstein et al. 2004). In the definition of the earlier Precambrian chronological divisions, a different geochronology is applied. For example, the Proterozoic-Archaean boundary is commonly defined as being at 2500 Ma. The geological time scale for the Precambrian is still incomplete and now defined in terms of strictly chronometric, i.e. absolute age boundaries that are divorced from the primary, sometimes objective record of planetary evolution. In the future, the Precambrian time scale should also be defined in terms of extant rock record, but presently the formal stratotypes are not defined. Boundaries should be placed at key events or transitions in the stratigraphic record. An ideal stratotype for a chronostratigraphic unit is a completely exposed unbroken and continuous sequence of fossiliferous or non-fossiliferous stratified rocks extending from a well-defined lower boundary to the base of the next higher unit. Unfortunately, only few available sequences are sufficiently complete to define stages and units of higher rank, which are therefore best defined by boundary stratotypes. The bedrock of Finland may provide some prominent Archean and Paleoprotorezoic stratotypes if sufficiently studied and recorded in the above-mentioned way.

8.4 Misuse of the term “series”

The term “series” has sometimes been used as a lithostratigraphical designation, or as a designation for groups of magmatic rocks (e.g. layered series in Narkaus intrusion). Series is not recommended to be used in such connections, and can only be used formally in a chronostratigraphic sense.

8.5 Corresponding geological time division (geochronology)

Geochronological units are divisions of time traditionally distinguished on the basis of the rock record as expressed by chronostratigraphic units. A geochronological unit is not a stratigraphic unit (i.e., it is not a material unit), but it corresponds to the time span of an established chronostratigraphic unit, and its beginning and ending corresponds to the base and top of the referent.

The hierarchy of geochronological units in order of decreasing rank is *eon*, *era*, *period*, *epoch*, and *age*. Chron is a non-hierarchical, but commonly brief, geochronological unit. Ages in sum do not necessarily equal epochs and need not form a continuum. An eon is the time represented by the rocks constituting an eonothem; an era by an erathem; a period by a system; an epoch by a series; an age by a stage; and a chron by a chronozone.

The names for periods and units of lower rank are identical to those of the corresponding chronostratigraphic units; the names of some eras and eons are independently formed. Rules of capitalization apply to geochronological units. The adjectives Early, Middle, and Late are used for the geochronological epochs. (NCS 1989, NACSN 2005).

9 USE OF TRADITIONAL GEOLOGICAL TERMS IN THE PRECAMBRIAN OF FINLAND

The Fennoscandian Shield in Finland has been a focus of long-term geological interest and targeted variable geological nomenclature since the advent of modern geology in the 19th century (see Ramsay 1902, Sederholm 1932, Eskola 1925, Simonen 1980, Laajoki 1986, 1990, 1991, Hanski 2001). The Fennoscandian Shield consists of the Precambrian crystalline rocks that crop out among younger sedimentary rocks and the Caledonian mountain chain in Northwest Europe. The Precambrian crust of Finland forms the central part of the Fennoscandian Shield. A synonymous term is the Baltic Shield (see Gaál & Gorbatschev 1987), which can be abandoned to prevent confusion. The Fennoscandian Shield, however, is only related to an uplifted and excumated geographical area, and is not related to the division of Precambrian rocks. However, this relatively well-documented Precambrian terrain has long lacked a systematic naming of geological units. The existing traditional names have been used for many purposes and sometimes out of their original context. The Finnish geological literature is rich in multiple regional or informal unit names, often assigned conflicting meanings. Recently, however, attempts have been made to avoid confusion in lithological-geographical naming (Vaasjoki et al. 2005).

The poorly defined traditional terms such as Sariola, Sumi-Sariola, Lapponi, Kainuu, Jatuli, Ladoga, Kaleva and Jotuni have variously been used to name sedimentary facies, chronostratigraphic units or lithostratigraphic groups (see Sederholm 1897, 1932, Meriläinen 1980a,b, Simonen 1980, Laajoki 1986, Hanski et al. 2001, Ojakangas et al. 2001). For example, the terms Jatuli and the Jatulian include meta-arenites, and associated metavolcanics, metapelites and dolomites overlying the Kainuu-type rocks in Karelia have been named as the Kaleva, while the Kalevian is a metapelite-dominated unit in northern Karelia, deposited unconformbaly on the Jatuli rocks (see Eskola 1925). How these terms are used is not always clear. Adjectival form endings with the –an or –ian, however, refer to "the chronostratigraphical units". In a chronostratigraphical sense, the Jatulian stage is from the ca. 2.3 to 2.15 Ga (Melezhik et al. 1997, Ojankangas et al. 2001), and it overlaps with the Rhyacian period, which is endorsed by the International Commission of Stratigraphy.

In order to avoid further confusion, the use of these traditional terms should be restricted to broad, informal discussion. In lithostratigraphical sense, such traditional terms can only be used informally, as these are not defined as stratotypes in any specific area. These are, however, useful terms in defining specific Paleoproterozoic successions or types of sedimentary rocks deposited over the Archaean basement complex in the Fennoscandian Shield. These rocks are commonly categorized as the Karelian formations of a certain age, which includes all the rocks deposited or extruded on the Archean basement in eastern and northern Finland (see Eskola 1925, Simonen 1980, 1986). A term such as Karelides only refers to an orogenic area that consists of these so-called Karelian formations. This term should not be confused with stratigraphic units. Similarly, the term Svecofennides only refers to an orogenic area that consists of the so-called Svecofennian formations, and should also not be confused with stratigraphic units.

The use of these terms in a geochronological sense, however, should be avoided and used only informally. In practice, these terms may have a clear tectonic meaning in characterizing certain basin stages during Precambrian margin development. Nowadays, many useful examples exist of the use of formal geological units in these successions.

The Svecofennian formations are, however, discriminated by the Paleoproterozoic convergent margin successions aggregated against the Archaean basement complex, sometimes with the Karelian formations between. Examples of the formal naming of these formations are only few, and in the Svecofennian Domain the current tendency is also to try to take into use the formalized geological units (e.g. Ehlers et al. 1986, Kähkönen 1991, 2005, Korsman et al. 1997, Strand 2002).

The rocks of the Precambrian terrains can be considered as variably deformed and metamorphosed, but their preservation is often good enough to permit the establishment of formal stratigraphic or geologic units. To avoid misunderstanding and confusion, the geological units need to be classified and given names and content in accordance with generally agreed guidelines. This guide aims to provide consistency in this respect.

Supplementary information on the web:

International Commission on Stratigraphy of the International Union of Geological Sciences

http://www.stratigraphy.org/

http://www.stratigraphy.org/column.php?id=Stratigraphic%20Guide

North American Comission on Stratigraphic Nomenclature

http://www.agiweb.org/nacsn/

http://www.agiweb.org/nacsn/code2.html

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This guide for naming the Precambrian geological units in Finland was produced under the supervision of the Stratigraphic Commission of Finland under the Finnish National Committee of Geology, and with the support of the Geological Survey of Finland. The rocks of the Precambrian terrains can be considered as variably deformed and metamorphosed, but their preservation is often good enough to permit the establishment of formal stratigraphic or geological units. To avoid misunderstanding and confusion, the geological units need to be classified and given names and content in accordance with generally agreed guidelines. The Geological Survey of Finland is maintaining the stratigraphic database under its map services in collaboration with the Stratigraphic Commission of Finland. This guide aims to provide consistency in this respect. The use of the guide in everyday work is the best way to ensure best practices in naming the Precambrian geological units in Finland.

ISBN 978-952-217-140-5 (PDF)
ISSN 0781-643X