Developments in map data management and geological unit nomenclature in Finland
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CLASSIFICATION SYSTEM FOR SUPERFICIAL (QUATERNARY) GEOLOGICAL UNITS IN FINLAND

by

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The emergence of digital map processing and interpretation environments, including advanced tools for 3D modelling and forward modelling, has created a demand for easy access to well-organized geological map data. At the same time, the interpretation of LiDAR DEM imagery with high spatial resolution has revolutionized the production of new Quaternary mapping in greater detail than hitherto. As a consequence, the need for an improved arrangement and coherent terminology for the superficial geological units is apparent. Here, we present an upgraded classification system for Quaternary superficial geological units in Finland. The main emphasis is on the management of regional-scale map units and their connection to local lithostratigraphic type sections and units.

The present document outlines the new digital lexicon (FinstratiMP) in Finland. We divide the superficial units according to four parallel classification systems: (1) *glacial dynamic province/region* classification, (2) *morpho-lithogenetic (MLG)* classification, (3) *lithostratigraphic* classification, and (4) *allostratigraphic* classification. The four parallel systems cover the needs of regional to local scale mapping, as well as detailed research describing the genetic relationships of geological units in vertical sections.

This document also updates the division of major glacial dynamic Quaternary map units in Finland and defines the use and mapping procedures of morpho-lithogenetic units and classification. The *glacial dynamic units (provinces and regions)* are geological map units based on their interpreted glacial dynamic settings in Finland. The glacial dynamic *ice lobe provinces* reflect the movements of ancient ice sheets, the most significant agents of glacial erosion, transportation and deposition. The *glacial dynamic regions* correspond to passive ice areas that are located in between relatively fast ice flow areas. The *glacial dynamic units* are defined *as major geological map features (units) with glacial dynamic characteristics different from the adjacent units.* The units are identified based on the characteristics of morpho-lithogenetic (MLG) assemblages.

The glacial dynamic unit-based approach creates the overall framework for depositional models, whereas the morpho-lithogenetic classification is useful in the production of new interpreted map data from LiDAR DEM imageries. Lithostratigraphy and allostratigraphy are standard methods in type section-based mapping and classification categories based on lithological characteristics and stratal discontinuities. The combined use of the different classifications provides a powerful toolbox for the management of the Quaternary superficial geological units in Finland.

Keywords: glacial features, Quaternary, stratigraphic units, surficial geology maps, databases, superficial deposits, superficial geological units

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CONTENTS

1 INTRODUCTION

Superficial Quaternary deposits in Finland are dominated by tills and different types of moraines and glaciofluvial deposits, which were later partly covered by postglacial fine-grained sediments and peat. The challenges in the classification of the Quaternary deposits in Finland are manifold. The classification scheme should serve, for example, the practical needs for regional-scale geological mapping, the requirements of more detailed mapping and 3D modelling, and science-oriented research approaches. Formal stratigraphic categories and procedures (Salvador 1994, McMillan et al. 2011) have been found insufficient as the only system in the definition of Quaternary map units (see Chapter 3.2 and references therein).

In this document, we present principles for the classification and division of the superficial geological units in Finland. The main emphasis is on the management of regional-scale map units and in their connection to local lithostratigraphic type sections and formations within. The need for an upgraded classification system of superficial deposits in Finland arises from three progress areas: (1) the systematic survey and classification of map units interpreted from LiDAR DEM imagery, (2) the management of different spatial data sets in the 3D forward modelling process and (3) the development of the national geological unit lexicon (*Finstrati*).

With the emergence of LiDAR DEM imagery, the mapping process for superficial geology at the Geological Survey of Finland (GTK) was completely renewed (see Putkinen et al. 2017). The traditional, superficial deposits, partly lithology-based mapping method (1:20 000 map sheets, Haavisto-Hyvärinen & Kutvonen 2007) was replaced by glacial terrain mapping, including the dynamics of the Fennoscandian Ice Sheet (FIS), also known as the Scandinavian Ice Sheet, during the Weichselian. Consequently, the map units of the superficial deposits need to be consistent with the dynamics and evolution of the FIS.

The renewed interpretation process for superficial deposits maps is complemented by the development of modelling (2.5D and 3D) activities (cf. Ojala et al. 2018a, Kohonen et al. 2019). 3D modelling is gradually becoming mainstream in the depiction and conceptualization of geology. The modelling process incorporates different spatial datasets (e.g. geological maps, vertical sections, underground surfaces) with various terminologies and classifications. The merging of data would greatly benefit from harmonized classification rules, procedures and vocabularies for the geological units.

Finstrati was originally designed as the stratigraphic database for lithostratigraphic/lithodemic bedrock units (see Luukas et al. 2017). Gradually, the scope was enlarged towards a lexicon and national key reference to all geological units and the linked vocabularies. Currently, Finstrati consists of two domains: *FinstratiKP* for the bedrock units and *FinstratiMP* for the superficial deposits. The main aim of the present document is to define and construct the FinstratiMP but at the same time also defining the concepts and classifications for the geological unit categories (see Chapter 3 and 4) for morpho-lithogenic, glacial dynamic, lithostratigraphic and allostratigraphic units. This document provides tools for the practical management of superficial geological units in Finland, including the interpreted (conceptual) units and the mappable lithology-based or surface-bounded units. The envisaged application areas that will benefit from the FinstratiMP include regional and nationwide geological map compilations, stratigraphic interpretations and correlations, data modelling/database design, 3D modelling and Quaternary research. The classification principles, terminology and nomenclature presented in this document are a part of the Finstrati documentation, which will be updated with the developing concepts of superficial deposits mapping in Finland.

2 THE QUATERNARY OF FINLAND: DEPOSITIONAL FRAMEWORK

The relatively thin, unconsolidated sedimentary cover overlying the Precambrian bedrock is generally termed *superficial deposits* or, when especially regarding the time, *Quaternary deposits* in Finland. The Quaternary period represents the last 2.7 million years (Gibbard & Cohen 2008, Cohen & Gibbard 2011); most of these deposits in Finland are Late Weichselian to Holocene in age. The term *superficial* is used here to emphasize features immediately at the land surface (cf. surface geology vs. subsurface geology; Neuendorf et al. 2005 (Glossary of Geology 2005)).

The superficial deposits in Fennoscandia were deposited by various glacial and postglacial processes during the Late Quaternary glacial-interglacial cycles (Fig. 1) and especially during and after the last (Weichselian) glaciation (e.g. Johansson et al. 2011). The Late Weichselian to Holocene deposits are the most abundant superficial deposits in Finland, whereas the pre-Weichselian sediments are only preserved locally as remnants, most commonly in northern Finland (Fig. 1). Since the last deglaciation, postglacial clastic deposition in aeolian, lacustrine, shoreline and fluvial environments has continued, and thick organic sediments (peat) have accumulated in bogs (see Table 1).

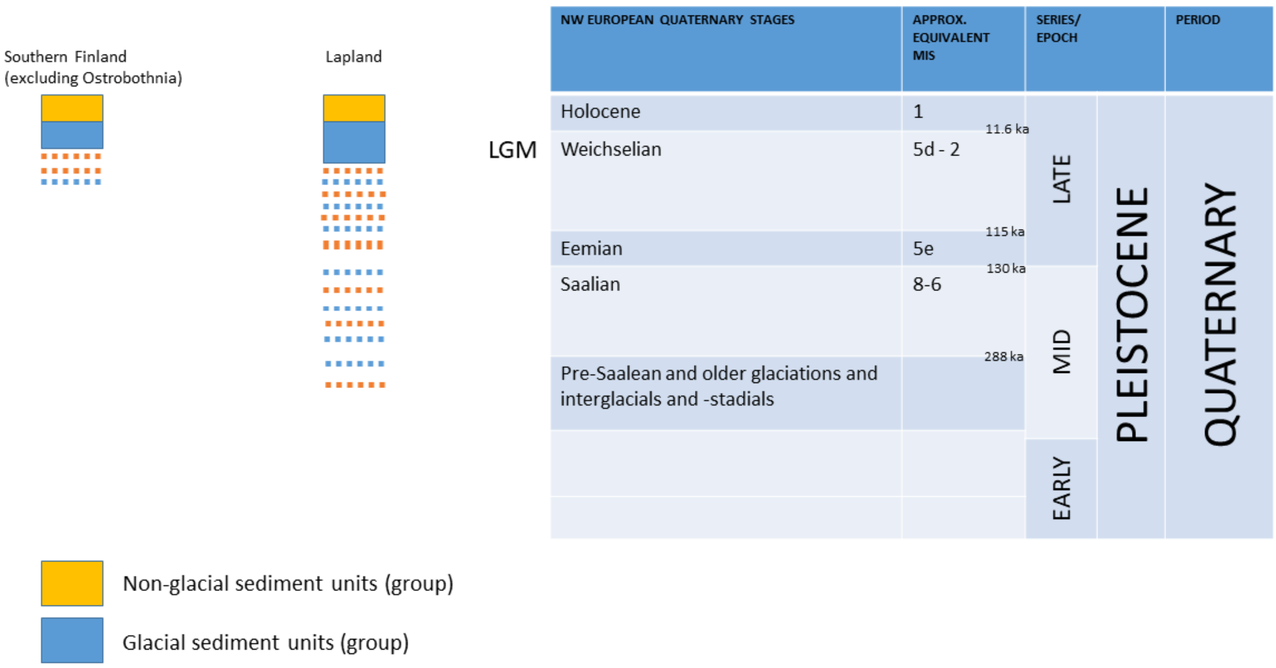

Fig. 1. A schematic illustration of Quaternary superficial deposit occurrences in Finland and their relation to geological time. In southernmost Finland the superficial deposits are mostly form Late Weichselian and Holocene, whereas in parts of Lapland are relatively much older Quaternary deposits. See also Cohen & Gibbard 2020: https://stratigraphy.org/ICSchart/QuaternaryChart1.jpg.

Glacial deposits comprise the primary glacial and glaciofluvial sediments of the Weichselian and earlier glaciations. Earlier interglacial and interstadial sediments are not considered as glacial deposits.

Glacial deposits are composed of different types of tills (sediments) and moraines (formations), partially superimposed by glaciofluvial deposits with diagnostic geomorphological features: eskers, deltas, extensive ice-marginal deposits and hummocky moraines. The locations of subglacial drainage systems are composed of washed and sorted gravel, sand and silt, and often constitute the thickest accumulations of superficial deposits in Finland (e.g. Salpausselkä I, II and III ice-marginal systems; also known as end-moraine systems).

The composition, structure, and occurrence of subglacial tills varies spatially due to differences in topography, the subglacial deformable material type and bedrock lithology, and the distribution of Late Weichselian ice lobes. They are occasionally covered by hummocky moraines, formed either subglacially or less frequently on melting ice-marginal zones.

Glaciofluvial deposits and moraines usually have complex depositional architectures and relatively low lateral connectivity; in contrast, some till beds show rather extensive lateral continuity and extent and can be used for stratigraphical purposes.

The fine-grained **basinal deposits** represent the distal deposition during the glaciation (glaciolacustrine and glaciomarine), intermittent interglacial and interstadial basin stages and the several post-glacial stages of the Baltic Sea basin (i.a. Björck 1995, Virtasalo et al. 2014). Silt and clay deposits cover large areas of the present Baltic Sea basin and coastal areas in Finland. Basinal deposits are normally laterally extensive and, and both lithostratigraphic and allostratigraphic approaches have been applied to study these type of sedimentary sequences (Virtasalo et al. 2005, Virtasalo et al. 2014; see Chapter 4.3 and 4.4).

The most common **postglacial sediments**, representing the last 10 000 years, include fluvial river sediments, coastal and aeolian sands, and lacustrine sediments, such as organic-rich sediments and silts. At present, almost one-third of Finland is covered by peatlands. The minor, but stratigraphically important, **interglacial and interstadial sediments** have a scattered spatial occurrence with very restricted lateral continuity (Tornivaara & Salonen 2007). Most typically, these consists of sand, silt, clay, peat and other organic-rich sediments.

Table 1. Features typical for the glacial and other superficial deposits in Finland.

Features	**Glacial deposits**	**Basinal deposits**	**Other non-glacial deposits (mainly postglacial deposits)**
Typical lithology	Diamicton, till, boulders, gravel, sand, silt	Silt, clay (minor organic-rich clay / clayey organic-rich sediment)	(Boulders), gravel, sand, silt, clay, also peat
Lower contact on:	Diamicton, till, boulders, gravel, sand, silt, or over Precambrian bedrock	Variable, over or in-between glacial sediments or over Precambrian bedrock	Variable, over glacial sediments or over Precambrian bedrock
Typical deposits and the inferred depositional processes	Varied, dominantly various types of glacigenic and glaciofluvial environment sediments and deposits	Varied, different types of sediments deposited in lake and marine environments	Varied, different types of sediments deposited in littoral, fluvial, aeolian environments, organic sediments and mass movement sediments
Distribution and coverage	– The whole of Finland – Pre-Weichselian glacial units occur especially in South Ostrobothnia, Middle Ostrobothnia, Northern Ostrobothnia, Central Lapland and Eastern Finland	– Baltic Sea – Finland – Post-glacial fine sediments, especially in southern Finland	Finland
Thickness	0–150 m, typically 0–3–>10 m for till-dominated and 10–30–>100 m in regions with glaciofluvial sediments	0–100 m, typically 0–10 m	0–100 m, typically 0–5–>10 m
Age	Pleistocene to Early Holocene (ca. 10 000 – 2.6 million years)	Late Pleistocene to present	Holocene to present

3 CLASSIFICATION OF SUPERFICIAL DEPOSITS IN FINLAND

3.1 Geological unit – the fundamental building block in geological description

Geological unit is a generic term used in variety of meanings in different geological contexts. However, by definition (Fig. 2) a geological unit has boundaries, spatial properties (e.g. stratotype location, map unit boundary coordinates) and geological characteristics.

A geological unit can be, for example, a *map unit*, a *stratigraphic unit* in a vertical log/section or a sediment body between the recognized bounding surfaces. The classification system is based on classification rules in order to keep the system of units consistent and to enable the controlled use of parallel unit classifications. Good scientific practice is supported by defining all the new geological units using an appropriate classification scheme.

It is essential to recognize that different work processes use and produce different geological unit information. For example, the compilation of a national map legend progresses from the definition of the major map units reflecting the general geological setting (or context) stepwise to smaller, more detailed geological units. An opposite, bottom-up approach is the observation-based research process proceeding from detail observations to their interpretation and finally to the definition of the geological units.

GeologicUnit	A body of earth material distinguished from adjoining material on the basis of content (lithologic or fossil), inherent attributes, physical limits, geologic age, or some other property or properties [adapted from NACSN, 1983, p.22; http://www.agiweb.org/nacsn/code2.html]. Corresponds to 'stratigraphic unit' in the North American Stratigraphic Code. Commonly used properties include composition, texture, included fossils, magnetic signature, radioactivity, seismic velocity, and age. Sufficient care is required in defining the boundaries of a unit to enable others to distinguish the material body from those adjoining it [NACSN, 1983]. A geologic unit is a part of the solid Earth that is identified by its geologic characteristics, has definable, locatable boundaries, and is persistent in time. Excludes non-material, temporal units. `GeologicUnit` instances are related using the general `GeologicRelation` structure in NADM-C1.

Fig. 2. The definition of a geological unit in NADM-C1 documentation (North American Geologic Map Data Model Steering Committee 2004).

FinstratiMP, the GTK database of superficial deposits (see Ahtonen et al. 2021; this volume), will in the future be the major source for information on Quaternary geological units in Finland. Other important sources of information are the STRATO database (Tornivaara & Salonen 2007) (see chapter 4.3.2) and the GTK online information services. Regarding the superficial deposits in Finland, abundant information is available:

- Quaternary geological mapping data at different scales including, for example:
  - glacial dynamic mapping data (Putkinen et al. 2017)
  - various types of primary geological observational data (quarry sections and test pits, data from drillings and borings)
  - analysis data (including ground geophysics)

(Geologian tutkimuskeskuksen verkkopalvelu: Karttapalvelut https://www.gtk.fi/palvelut/aineistot-ja-verkkopalvelut/karttapalvelut/)

(Geologian tutkimuskeskuksen verkkopalvelu: Aineistot ja verkkopalvelut - geo.fi https://www.gtk.fi/palvelut/aineistot-ja-verkkopalvelut/)

- Published or accessible data from web services is available, for example, for:
  - lake sediments (i.a. Itkonen et al. 1999, Pajunen 2004, Ojala & Alenius 2005)
  - peat deposits (i.a. Geologian tutkimuskeskuksen verkkopalvelu: Suot ja turvemaat http://gtkdata.gtk.fi/Turvevarojen_tilinpito/index.html, Mäkilä 1997, Mäkilä et al. 2001)
  - fine (basinal) sediments (i.a. Gardemeister 1975, Sahala 1987, Ojala et al. 2007, Geologian tutkimuskeskuksen verkkopalvelu: Happamat sulfaattimaat http://gtkdata.gtk.fi/hasu/index.html).

3.2 Applicability of geological unit classification systems in Finland; an overview

In Finland, a systematic national approach to the management of superficial geological units has been lacking. Several case studies (e.g. Hirvas 1991, Sutinen 1992, Nenonen 1995, Bouchard et al. 1990, Sarala 2005, Lunkka et al. 2016) have applied stratigraphic classificatioahokan. However, due to the general lack of meaningful, mappable glacial units with reasonable lateral continuity and connectivity, the use of standard lithostratigraphical practices have had a little value in regional Quaternary mapping. As a consequence, until the last ten years, regional superficial mapping practices were dominated by a surface lithology-based approach, before the LiDAR data revolution (see chapter 1). The past 1:20 000 map-sheet programme classified the superficial sediments according to grain-size, sediment types and geomorphological features (cf. Haavisto-Hyvärinen & Kutvonen 2007). The resulting map units (polygons) were not defined, characterized and named as geological units. Instead, we are using the new glacial deposits mapping data as the basis for superficial deposits map unit management.

INSPIRE classification has been proposed to be used as the basis for superficial deposits geological unit classification, but it is so general that it cannot be applied to here presented glacigenic deposit classification. In the INSPIRE classification for Natural Geomorphologic Feature Types the glacial, glaciofluvial, glaciolacustrine and glaciomarine features are all combined to one group (code list value).

The superficial deposits in Finland are considered as (formal) stratigraphic units and map units (Fig. 3). The four parallel systems (categories) form the framework of the FinstratiMP geological unit database. The descriptive classifications include: (1) *lithostratigraphic* classification (cf. Salvador 1994, North American Stratigraphic Code; NACSN 2005) and (2) *allostratigraphic* classification (North American Stratigraphic Code; NACSN 2005). The proposed interpretative classification categories are: (3) *morpho-lithogenetic* classification (McMillan 2005, McMillan et al. 2005, 2011; this report) and (4) *glacial dynamic* division (Putkinen et al. 2017; this report).

The classification of geological units based on different characteristics, boundaries and attributes (e.g. lithology, fossil content, geochemical characteristics, distribution and age) of rock strata still form the scientific and practical foundation of the Finnish Quaternary stratigraphy. The *stratigraphic classification systems* are based on internationally accepted, standard rules and procedures. Stratigraphic units have a recognizable name (formal or informal), and the unit is defined by mappable characteristic features. The most commonly used stratigraphic categories in Quaternary geology are lithostratigraphy, biostratigraphy, chronostratigraphy and allostratigraphy; the procedures and respective unit terms for all these can be found in Salvador (1994), Murphy & Salvador (1998) and the North American Stratigraphic Code (NACSN 2005).

A common stratigraphical practice is to divide vertical sediment successions in exposures and/or bore-holes into stratigraphical units. The detailed bottom-up description of vertical sections typically begins with the identification of lithofacies

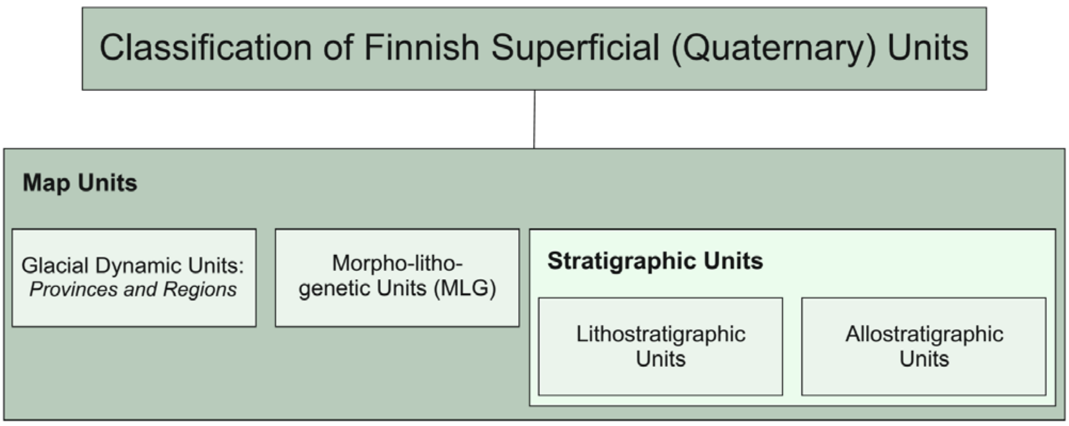

Fig. 3. Geological unit categories defined for the construction of the GTK FinstratiMP unit database.

and lithofacies associations, which form the basis for the architectural elements and depositional models. Finally, the type sections (stratotypes) are documented and the stratigraphic units defined. Seismic, seismoacoustic, ground-penetrating radar and electrical resistivity tomography are most typical data in the interpretation of surfaces applicable for allostratigraphic classification. In some cases, allostratigraphy is also a useful method in the division of till beds (Räsänen et al. 2009 and Fig. 4).

The applicability and usefulness of the stratigraphic tradition and classification systems in Quaternary mapping has long been debated (e.g. McMillan & Merritt 2012, Boulton 2012 and references therein), and both international (e.g. McMillan et al. 2005) and domestic (Räsänen et al. 2009) alternative approaches have been suggested. *Morpho-lithogenetic classification* (MLG) is an informal approach developed by the British Geological Survey (cf. McMillan 2005) to meet the practical needs of Quaternary mapping in the British Isles. McMillan et al. (2011) provide the following definition: "***Morpho-lithogenetic units*** *are locally mappable sediment-landform assemblages which should be considered without regard to time (Schenk & Muller 1941, Salvador 1994). Some morpho-lithogenetic units are not readily amenable to lithostratigraphic classification because their stratigraphical relationships are poorly known.*" The rationale and principles of the MLG system can be found in McMillan et al. (2011), McMillan et al. (2005) and McMillan (2005). In this article, we introduce the GTK application of the original BGS approach (see Chapter 3.2. and Appendix 2).

We also introduce a new category of geological map units based on their interpreted glacial dynamic setting. The fundamental unit, *ice-lobe province*, signifies the regional extent of the ancient active ice sheet. A ***glacial dynamic unit (province and region)*** *is here defined as a major geological map feature (unit) with glacial dynamic characteristics that differ from the adjacent units.* The movement of the ancient ice sheets (ice lobes) played a major role in shaping the landscape and was the most significant agent of erosion, transportation and glacial deposition. The underpinning geological foundation is the history of the Fennoscandian Ice Sheet (e.g. Punkari 1980, Donner 1995, Hughes et al. 2015, Stroeven et al. 2016, Putkinen et al. 2017). The glacial dynamic map units correspond to glacigenic deposits of a certain glacial dynamic domain and are identified by characteristic morpho-lithogenetic (MLG) assemblages. Thus, the morpho-lithogenetic units with their genetic depositional interpretation form a basis for glacial dynamic reconstructions with the major ice lobes and the new glacial dynamic map unit division. The principles and procedures of *glacial dynamic classification* are introduced in the Chapter 4.1.

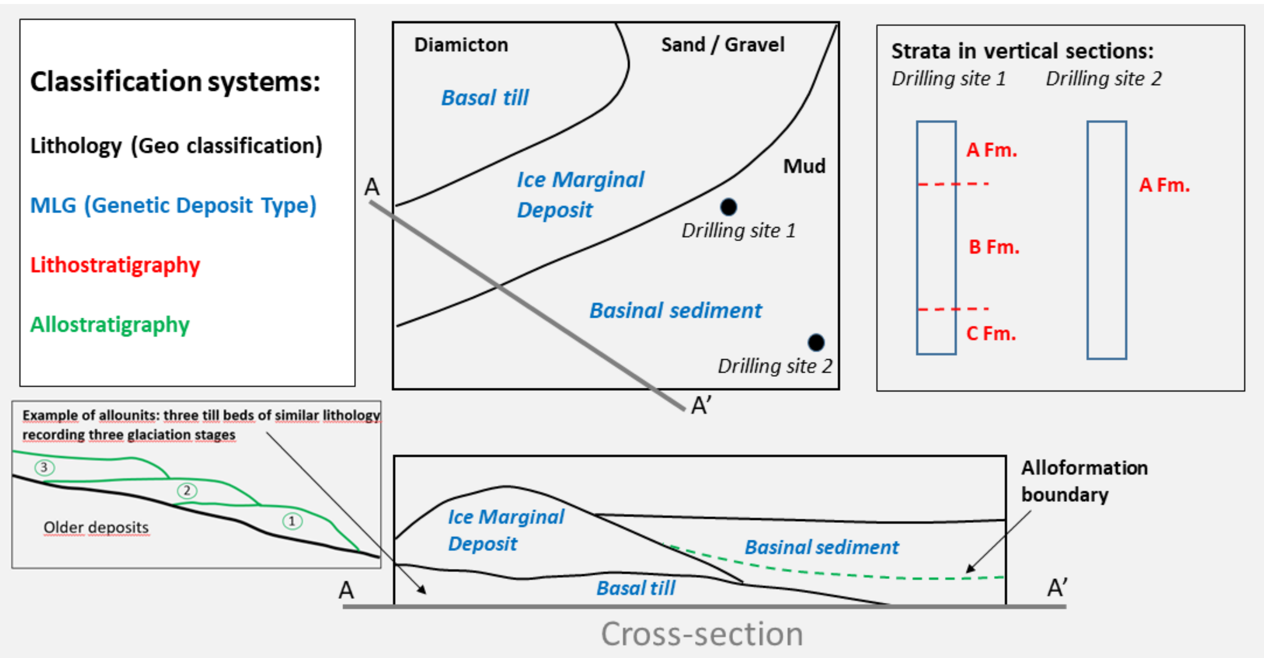

Fig. 4. Schematic illustration addressing the connections of the different classification systems applied to map view (top centre), vertical strata (top right) and geological cross-section (bottom centre). Note the colour coding (top left) for the classification systems.

Parallel classification categories are needed to cover the variable practical needs, such as regional mapping (feature catalogues, legends), the development of a lexicon database (Finstrati data model) and the various aspects of Quaternary research projects. Through the flexible combination of different classifications, the Finnish superficial geology can be described in both a comprehensive and systematic way; the overall idea is summarized in Figure 4.

4 SUPERFICIAL GEOLOGICAL UNITS IN FINLAND

In the following, the superficial geological units in Finland are presented, starting from the glacial dynamic regions and provinces, followed by morpho-lithogenetic and stratigraphic units. The glacial dynamic map units (regions and provinces) reflect the regimes where the morpho-lithogenetic units, such as the Late Weichselian and Early Holocene ice-marginal deposits, main esker systems, drumlins and hummocky moraine fields, were formed. Furthermore, the morpho-lithogenetic map units can, when appropriate, be complemented and combined with stratigraphic units (see Lee & Booth 2006). For the local allostratigraphic and lithostratigraphic units, the MLG units provide a depositional framework and a link to the overall depositional system (Fig. 4).

4.1 Glacial dynamic map units: provinces and regions

4.1.1 General

Changes in ice flow systems at the ice sheet scale represent readjustments to a changing glacier mass balance driven by climate, sea-level changes and ice sheet internal dynamics. As a whole, the glacial dynamic map units are a collection and synthesis of ice flow (stream) areas (ice-lobe provinces) and the interlobate areas (regions) in between (Fig. 5). In addition, a spatially imprecise ice-divide zone in Lapland has been outlined. Currently, 19 distinct glacial dynamic map units (Fig. 5 and Appendix 1) have been identified in Finland. We note, however, that there are other earlier ice-lobe provinces related to Middle, Early and pre-Weichselian glaciations that have not yet been mapped in detail. These provinces commonly occur in the Ranua interlobate region, Kuusamo ice-lobe province and in central Lapland (Kolari-Kittilä-Sodankylä). These older glacial dynamic map units are planned to be defined later.

4.1.2 Definition of glacial dynamic provinces and regions (GD units)

Glacial dynamic (GD) provinces and regions constitute the largest Quaternary map units in Finland (Fig. 5) and form the overall conceptual, spatial and temporal framework for the superficial deposits in Finland. The division was developed to meet the needs of both (1) nationwide superficial deposits mapping and (2) Quaternary scientific communication in Finland. It is essential to note that *GD provinces and regions* represent conceptual, second-order map units based on features interpreted according to the MLG interpretation process. The MLG features (e.g. drumlin fields and lineations, interlobate eskers, and ice-marginal complexes) relate to a glacial dynamic set-up at a certain geological time and that the definition of time constraints is part of the GD unit description.

The glacial dynamic province or region (map unit) definition shall contain information related to all items described below and the description of their boundaries shall follow the guidelines given in Appendix 1, Table 1. The definition of a new lower-class unit of sub-province (domain) must include the name of the parent unit. The glacial dynamic map units are defined and characterized by the following features and attributes:

Glacial dynamic province/region geological map unit attributes
The definition of the attributes list focuses on the managing of the specific features of the individual units. There is no need to repeat in the attribute fields the same information already incorporated in the unit classification (glacial dynamic setting, characteristic structural features).

Geological age of the Glacial dynamic provinces and regions is Late Weichselian and/or Holocene. In the future, the aim is to add older (pre-Late

Weichselian) GD spatial units; for these, the age is an essential attribute.

Boundaries description includes their type, nature and characteristics, for outer, lateral and inner boundaries. Description of the status/nature of the province/region as part of ice sheet-scale ice-flow dynamics and deglaciation are important.

Description of the GD-unit-specific structural trends and patterns for ice-lobes includes the zone of ice-marginal deposits and the ice lobe inner structure: drumlin fields (lineations), hummocky moraine fields, meltwater routes and eskers. These consist of lineation and transport directions and lengths in the active phase(s) and deglaciation stage development as interpreted from the MLG units: esker system directions, hummocky moraine field locations and characteristics, and the De Geer moraine and other recessional moraines fields and their characteristics. Older deposits (pre-late Weichselian) are also concisely described for the GD spatial units. Former names for the approximately corresponding map unit are given and key references are included.

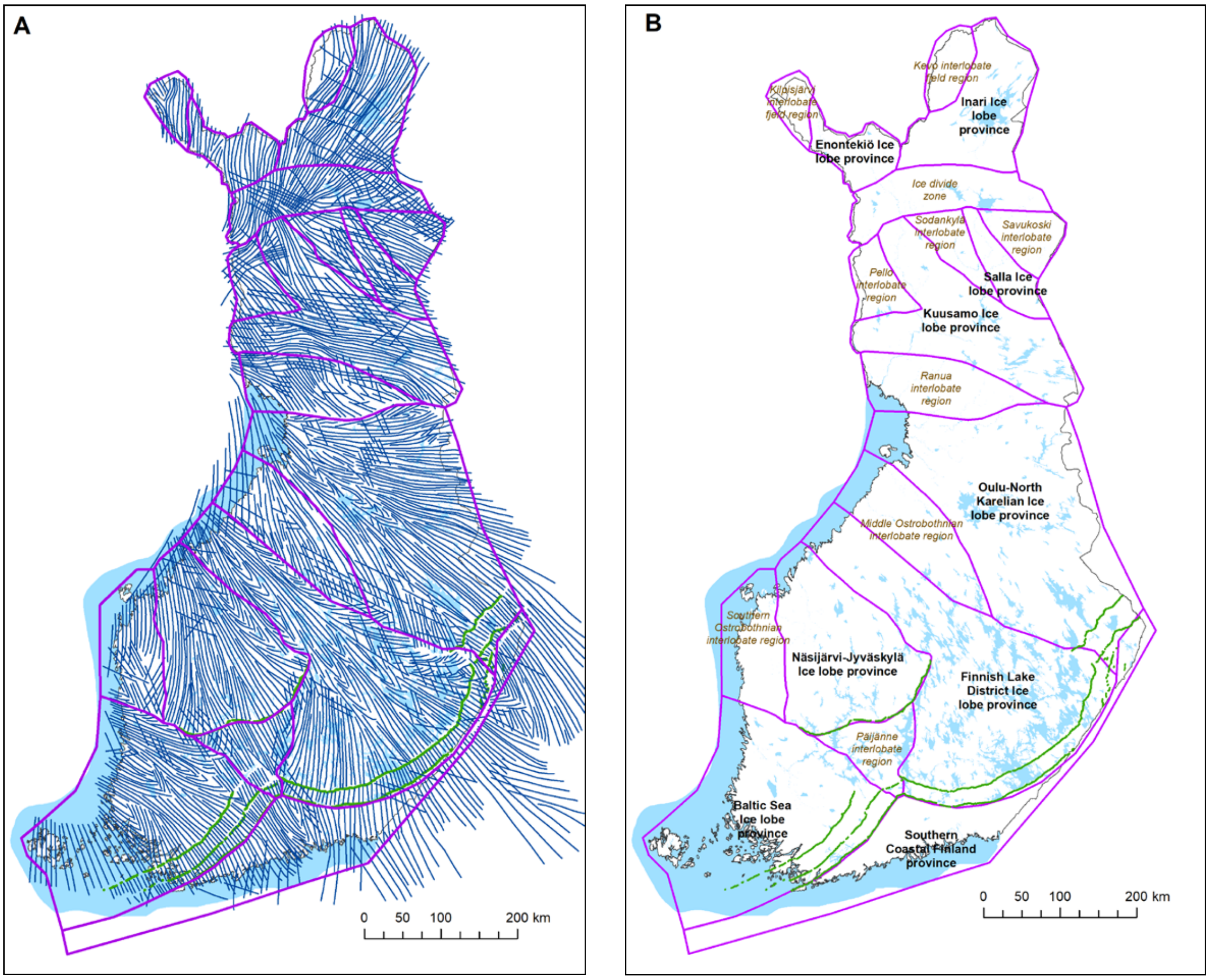

Fig. 5. (A) The general ice-flow directions of various ages (blue lines; interpreted by Salonen 1986) and major ice-marginal positions (green lines) of the last deglaciation; province and region boundaries are shown as purple lines. (B) Glacial dynamic provinces and regions in Finland (modified from Putkinen et al. 2017); the Salpausselkäs and other major ice-marginal systems are shown as dark grey lines. Basemap © National Land Survey of Finland.

4.1.3 Ice-lobe provinces

The ice-lobe provinces form the backbone of the glacial dynamic division in Finland, and all the other GD unit types are defined by their relation to these. The scientific context and background of the ice-lobe provinces have developed from the pioneering work of Punkari (1980, 1997) through work by Salonen (1986), Lunkka et al. (2004), Johansson & Kujansuu (2005), Johansson et al. (2011) to the latest summary by Putkinen et al. (2017).

Ice lobe provinces correspond to an areas of intense motion (flow) of a continental ice sheet. The pattern of the predominant ice-flow direction is consistent in the entire ice lobe region. An ice-lobe province is frequently laterally bordered by large interlobate deposits (interlobate eskers and moraines) on both sides, and it often terminates distally in well-developed ice-marginal complexes that are composed of glaciofluvial sandurs, deltas and ice-marginal (both glaciofluvial and diamictic material) deposits.

Timewise, the major ice lobes existed and the dominant landscape-forming components of drumlins, megalineations, ice marginal deposits, eskers and hummocky moraines were built mainly during the latest phase of the last deglaciation, in the Late Weichselian, and the Early Holocene, c. 13 000 to 10 000 cal. BP (see Fig. 1).

Pre-Younger Dryas ice-lobe province
Southern coastal Finland province (SCF)

The main glacial dynamic ice-lobe provinces can in some cases be divided into sub-provinces. There are also areas than have been overridden by ice flow of younger ice lobes. These sub-provinces and areas constitute mappable geological entities.

The main ice-lobe provinces of the Younger Dryas and early Holocene
Baltic Sea ice-lobe province (BSIL)
- *Loimaa sub-province (BSIL-L)*

Finnish Lake District ice-lobe province (FLDIL)
- *FLDL sub-province* (overridden by Näsijärvi–Jyväskylä lobe ice flow) (FLDIL-OR)

Oulu–North Karelian ice-lobe province (ONKIL)
Kuusamo ice-lobe province (KIL)
Salla ice-lobe province (SIL)
Inari ice-lobe province (IIL)
Enontekiö ice-lobe province (EIL)

Ice-lobe province of the early Holocene:
Näsijärvi–Jyväskylä ice-lobe province (NJIL)

4.1.4 Interlobate regions, fell regions and the ice-divide zone

Interlobate regions corresponds to a passive ice area that is located between relatively fast ice-flow areas (i.e. ice-lobe provinces). An interlobate region is typically characterized by highly variable and complex landforms. Older glacial and glaciofluvial deposits and lineations have often been preserved from earlier glaciations. Weak young lineations may occur in some locations. Fell regions (highland interlobate region) correspond to higher-altitude areas that are located above and between the significant ice-flow areas (i.e. ice-lobe provinces)

The main interlobate regions:
Päijänne interlobate region (PIN)
Southern Ostrobothnian interlobate region (SOIN)
Middle Ostrobothnian interlobate region (MOIN)
Ranua interlobate region (RIN)

Less extensive interlobate regions in Lapland; located between areas where ice was still flowing relatively fast, the ice lobes of Kuusamo and Salla:
Pello interlobate region (PEIN)
Sodankylä interlobate region (SODIN)
Savukoski interlobate region (SAIN)

Fell regions in northernmost Lapland
Kevo interlobate fell region (KEINF)
Kilpisjärvi interlobate fell region (KIINF)

Ice-divide zone *Ice-divide zone (ID)*
Ice-divide zone corresponds to the central zone of the ice sheet characterized by exceptionally low ice-flow activity and low glacial erosion during the last glaciations; the area includes the remains of intense pre-glacial weathering (Hall et al. 2015, Nenonen et al. 2018). A region in central Lapland located between the onset areas of ice lobes (Kuusamo, Inari, Enontekiö and Salla).

4.2 Morpho-lithogenetic units (MLG units)

4.2.1 General

The basic idea of the MLG approach is not new in Finland (see GTK superficial mapping guide; Virkkala 1972). The combination of geomorphological, lithological (grain-size) and genetic aspects also formed an underlying context for the past 1:20 000 Quaternary mapping programme (1972–2007), but grain-size classes were still used as the main descriptors for sediments, while geomorphology was added for landform classification criteria. Currently, *morpho-lithogenetic (MLG) classification* (e.g. McMillan 2005) is the principal method in the division of Quaternary map units at GTK.

High-resolution LiDAR DEM data bring out the detailed geomorphology and landforms in the FIS area (e.g. Johnson et al. 2015, Ojala & Sarala 2017). In recent years, the interpretation of these data has become the main method in Quaternary mapping (i.a. Sarala et al. 2015, Putkinen et al. 2017, Sarala & Räisänen 2017). The MLG interpretation process allows a flexible combination, utilization and process flow for mapping and modelling, using different datasets such as previous maps (surface lithology and deposit type), other mapping data and vertical sections deduced from temporary cuttings, natural sections and subsurface datasets such as borehole logs, excavation exposures, well records, test pits and various geophysical interpretative data types (e.g. GPR, refraction and reflection seismics, gravimetric profiling).

All MLG units are formed in an interpretative process. According to Lee & Booth (2006), "The combination of landform morphology, lithology and formation process leads to interpreted morpho-lithogenetic units, which are mappable units that provide the basis for establishing a local stratigraphy." The **key components** of the approach are the **MLG map units** defined by the interpreted genetic deposit type and the named **MLG geological units** characterized by a set of attributes. The combination of all MLG units will spatially provide full coverage in Finland.

The MLG interpretation may be complemented by a lithostratigraphic approach. With sufficient data, the next step forward would be to incorporate the local MLG model into the wider regional stratigraphic context involving geochronology and lithostratigraphy (Figs. 4, 6). These elements contribute to the evolution of the conceptual model towards a completed map or 3D model.

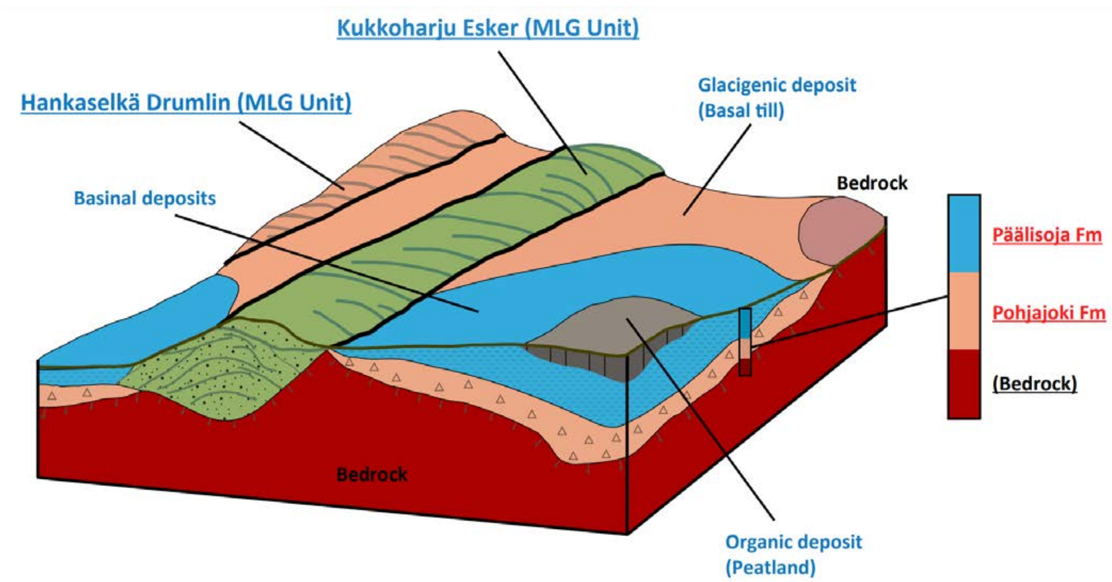

Fig. 6. Map units (top surface) classified by 'genetic deposit type' (blue text; see also Table 2) and their relationships with lithostratigraphic units (red text). All the underlined geological units (see Table 3) will be included in the FinstratiMP lexicon database.

4.2.2 Morpho-lithogenetic map units; definition of genetic deposit type

Using the landform and lithology elements – process (the mode of origin) – may be interpreted. In practice, the MLG units are identified and formed in geological analysis based on the overall depositional context, landforms, existing mapping knowledge on lithology and, finally, on assumed depositional process (Fig. 7). The resulting **map unit** is classified according to the genetic deposit type, and the classification used at GTK is shown in Table 2.

Obviously, the final step of the process, the definition of the genetic deposit type, is sensitive to the underpinning evolutionary model and to the presumed depositional environments as a part of the model. A well-established and communicated depositional context is a critical requirement for the attempted uniform 'mapping result'. Glacial dynamic mapping with defined GD provinces and regions strongly supports the development of such a shared context.

The current GTK system for genetic deposit types incorporates *basinal fine sediment deposits* in only one class (glaciolacustrine deposits and other basin fill deposits combined), *beach deposits* in only one class, and coarse fluvial deposits as one map-unit type (mainly in northern Finland). *Organic deposits* include peatlands but also other organic-rich sediments. A*eolian deposits* are displayed in maps as dune crest polylines.

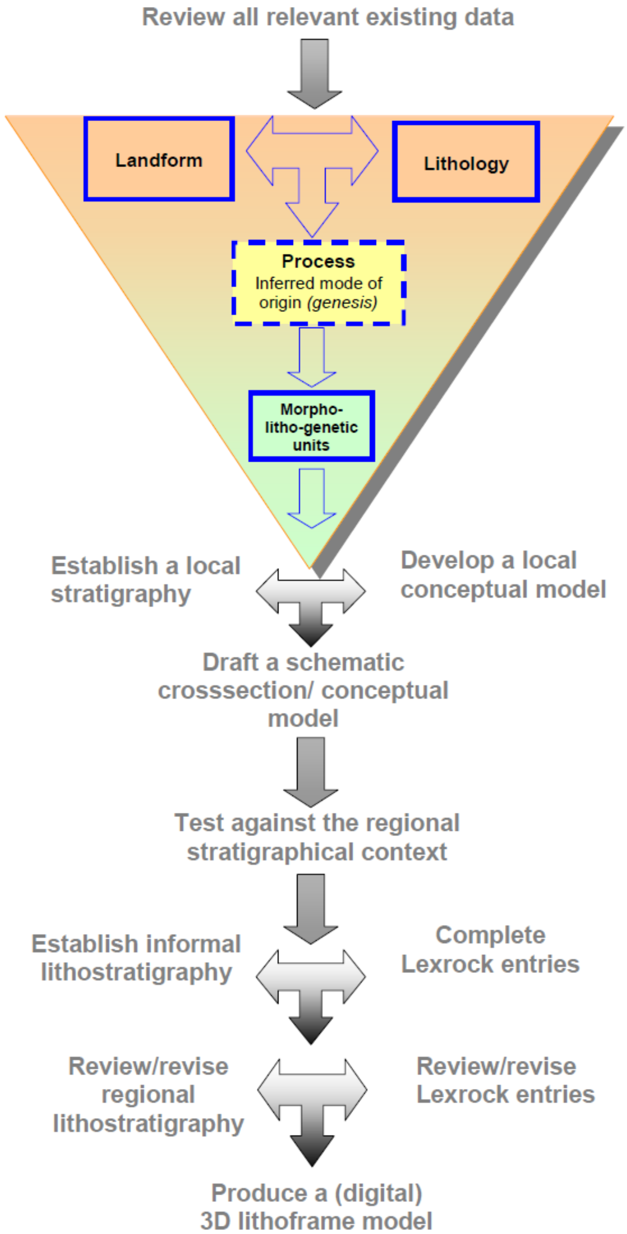

Fig. 7. The basic rationale for mapping Quaternary (superficial) deposits, showing the progression through landform and lithological observations to the interpretation of process and genesis. The MLG interpretation is complemented by the establishment of a local stratigraphy and finally utilized in the development of a regional 3D model (adopted from Lee & Booth 2006). Note that 'morpho-lithogenetic unit' in the diagram corresponds to the 'morpho-lithogenetic map unit' of this work.

Table 2. Genetic deposit types used in GTK MLG map unit classification.

GTK classification Level 1	Level 2	Level 3
Glacigenic deposits, G	**Glacial deposits, GT**	**Till, basal** – includes lineations (drumlins etc.), **GTb**
		Hummocky moraines (with various subtypes), **GTh**
		Diamicton-dominated ice-marginal deposits, De Geer and other recessional moraines (also in groups of ridges) **GTim**
	Glaciofluvial deposits, GF	**Eskers GFe**
		Ice-marginal glaciofluvial deposits (sandurs, deltas, subaqueous fan deposits), **GFim**
		Other glaciofluvial deposits, (extramarginal, kames, kame and kettle) **GFex**
Basinal deposits, B	Marine sediments **BM** Lacustrine sediments **BL**	
	Glaciolacustrine and -marine sediments, BG	
Beach (littoral) **deposits, L**	Beach deposits on the higher hillslopes, berms, bars, spits Beach deposits covering lower hillslopes and valleys	
Fluvial deposits, F	Coarse-grained fluvial deposits **Fc** Fluvial deposits of variable grain size **Fv**	Deltas **Fvd**
Aeolian deposits, E		
Organic deposits (peatlands), **P**	Minerotrophic peatlands, fens **PCt** Ombrotrophic peatlands, bogs **PSt**	
Mass movement deposits M	Mass movement deposits of fine-grained sediments Mass movement deposits produced by seismic activity Solifluction deposits Talus	
Frost action deposits **FR**		
Anthropogenic deposits **A**		

4.2.3 Establishment of morpho-lithogenetic geological units

The concluding step of the MLG process is the establishment of morpho-lithogenetic geological units. The boundaries of the prominent geomorphological features/properties are relatively easy to identify, and the resulting geological units are locally mappable entities based on landforms with an interpreted (or inferred) depositional process. In most cases, some supporting lithological information is available to support the interpretation. The units are given by their characteristics using attributes and classified according to the MLG type (see Table 3). Finally, the geological unit is named by combining the locality name with the MLG unit type.

The key attribute of a MLG unit is the genetic deposit type, which is directly reflected in MLG unit types (Table 3). The morpho-lithogenetic unit types can also be seen as a subdivision or incremental component of the genetic deposit types. In FinstratiMP, the characterization of a morpho-lithogenetic unit shall include the following features (i–iii) and corresponding attributes:

Table 3. Morpho-lithogenetic unit types for FinstratiMP.

MLG geological unit type	Genetic Deposit Type	Main Lithology*	Typical Landform characteristics
Ice-marginal system	GFim	S, G, (D)	An ice-marginal system of delta complexes and other related deposits, with delta plateaus, ice-marginal ridges
>Delta complex	GFim	S, G, (D)	Plateaus, often with the below-mentioned parts
>>Delta (Sandur Delta)	GFimd	G, S, mS, fS	Plateaus
>>Sandur	GFims	G, S	Plateaus, with meltwater channels
>>Proximal ice contact zone unit	GFimpic	G, S, (D)	See below, often overridden, kettle holes
>>Ice-marginal ridge	GFimpm	G, S, (D)	Ridge on top of the plateau (delineates the proximal part)
>Ice-marginal ridge	GFimr	S, G, (D)	A separate ridge
Esker system	GFe	S, G	The complete “train”
>Esker	GFeb	S, G	Esker main and linked branches
>>Esker ridge	GFer	G, S	Ridge, also a ridge delineated by kettle holes, with lateral depositional elements (see below)
>>Esker sand (splay)	GFes	S (G)	Esker lateral (and distal) depositional elements
>>Esker delta	GFed	G, cS, mS, fS	Delta component of an esker system (code GFimd)
>>Kame area	GFek	S	
>Interlobate esker	GFeil	S, G	Eskers at the boundaries of ice-lobe provinces and/or interlobate regions
Other glaciofluvial deposit, incl. extramarginal deposits	GFex	G, cS, mS, fS	
Till system	GTb	D	
>Basal till	GTbb	D	Veneer or blanket
>Drumlin (lineation**) field	GTblf	D	Lineation fields
>>Drumlin/lineation**	GTbl	D	Linear ridges (now polylines), normally not used as a unit
Hummocky moraine	GTh	D	Hummocky terrains and fields
>Subglacial hummocky moraine	GThb		“
>>Ribbed moraines	GThbr	D, (S, G)	“, Ribbed moraine geomorphology
>>Murtoo moraines	GThbm	D, G, S	“, Murtoo moraine geomorphology
>Ice contact (passive, partly supraglacial) unit	GThp	D, S, (G)	“
End moraines (diamicton-dominated)	GTim	D, (S)	
>End-moraine ridge (Reunamoreeni-muodostuma) (can be part of an ice-marginal delta complex) (Notice the material difference compared to GFimr and GFimpm)	GTimr	D, (S)	Ridge form, may be multiple combined ridges, mainly in conjunction with the ice marginal systems
>Recessional moraines, small ridges (field)	GTimsr	D, (S)	
>>De Geer moraine field	GTim-srDG	D (S)	De Geer ridges in fields
>> Minor recessional moraine field	GTimsrr	D, (S)	Usually supra-aquatic or shallow water deposition
Dune field	E	fS	Dune ridge field

* GEO classification, in English, typical examples: S = Sand, fS = Fine sand, mS = medium sand, cS = coarse Sand, G = Gravel, D = Diamicton,

** For drumlin/lineation: See text

(i) Landform (morphology, geomorphology) (Observed)
(ii) Genetic deposit type (Interpreted)
(iii) Lithology (material of the deposit) (Observed / Interpreted / Inferred / Not known)

The number of attributes has not been limited to these, but additional features and descriptions, such as age, stratigraphy or lithofacies (Miall 1985), or the more detailed depositional environment or process, may be included. Key references to original research papers are important.

It is pointed out that morpho-lithogenetic geological units are currently only used for the glaciofluvial and moraine deposit types, which have distinctive positive geomorphological form. It is suggested that the definition and naming of units (and their storage in FinstratiMP) would be restricted to prominent, well-known and studied cases; the establishment of a new geological unit is only appropriate in cases where it substantially aids in the overall data usefulness.

It is noted that the map features corresponding to MLG units can be either a polygons or polylines. For example, the *Pieksämäki drumlin field*, and the corresponding information in FinstratiMP, may refer to all the drumlins of the Pieksämäki region mapped as polygons or polylines if these symbolize the drumlins. However, if the drumlin polylines are lineations indicating the transposition (reorientation) structure of the sedimentary material, it must be conceptually classified as a geological structure (not a geological unit) and attributed accordingly.

The FinstratiMP MLG unit name is formed by the combination of the locality name (e.g. 'Pielisjärvi') or landform name (e.g. 'Salpausselkä') with the unit type given in Table 3. Here are some examples:

- Second Salpausselkä (FLDIL part) Ice-marginal System
  - Vesivehmaankangas Delta Complex
- Pielisjärvi Ice-marginal System
- Hämeenkoski-Kangasala-Pyynikki-Ylöjärvi Esker System
- Asikkala-Joutsa Esker System
- Pieksämäki Drumlin Field
  - Paltamäki Drumlin
- Kalvola-Renko Hummocky Moraine Field
  - Karhulammi-Tähilammi Hummocky Moraine

4.2.4 Major MLG units in Finland

The major MLG units are:

- Large glaciofluvial systems (Fig. 8), which consist of:
  - Large ice-marginal deposit systems (”formations”), also called end-moraine systems (of mainly sorted glaciofluvial material)
  - Large interlobate deposits (esker systems)
  - Major ice-lobe provinces (intralobate) esker systems
- Large moraine fields, which consist of:
  - Hummocky moraine terrains (Fig. 2 in Appendix 2)
  - Recessional (De Geer) moraine fields
- Large drumlin fields, which are also related to the main till deposit units (Fig. 2 in Appendix 2)

Morpho-lithogenetic units have a hierarchy ranging from smaller into larger, from depositional complexes to systems (Figs. 9, 10, 11). For example, Vesivehmaankangas sandur delta (Fig. 10), a complex consisting of sandur, delta, proximal ice-contact parts and a push moraine ridge element, form a deposit complex in the system of ice-marginal deposits of the Second Salpausselkä of the Finnish Lake District ice-lobe province. Likewise, a major esker forms a system whose elements are the esker ridges, adjoining glaciofluvial sediment deposits and, if practical, esker deltas have also been delineated (Fig. 11).

Similarly, esker systems and hummocky moraine areas in the central area of the Finnish Lake District ice-lobe province (FLDIL) are shown in Figure 11. The esker systems consist of the morpho-lithogenetically mapped smaller areas (the ridges, sometimes esker deltas, and adjacent areas of glaciofluvial deposition). In Figure 11, the various types of glacial lineations (e.g. drumlins, megaflutings, flutings) are also shown, as are

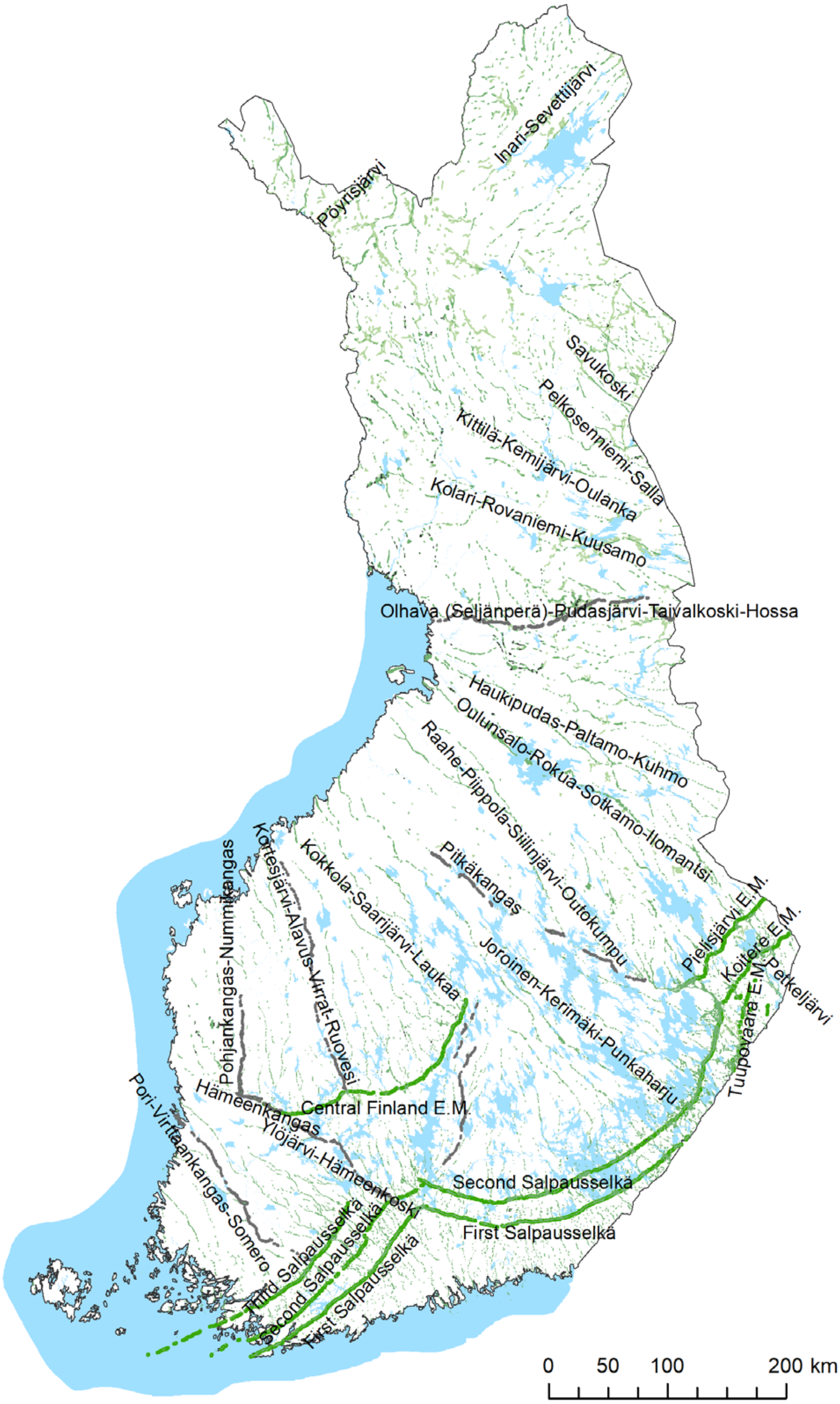

Fig. 8. Examples of significant glaciofluvial morpho-lithogenetic units in Finland: ice-marginal systems, major interlobate and intralobate esker systems. E.M = end moraine, aka ice marginal systems; names along the grey lines correspond to major esker systems e.g- Joroinen-Kerimäki-Punkaharju. Basemap © National Land Survey of Finland.

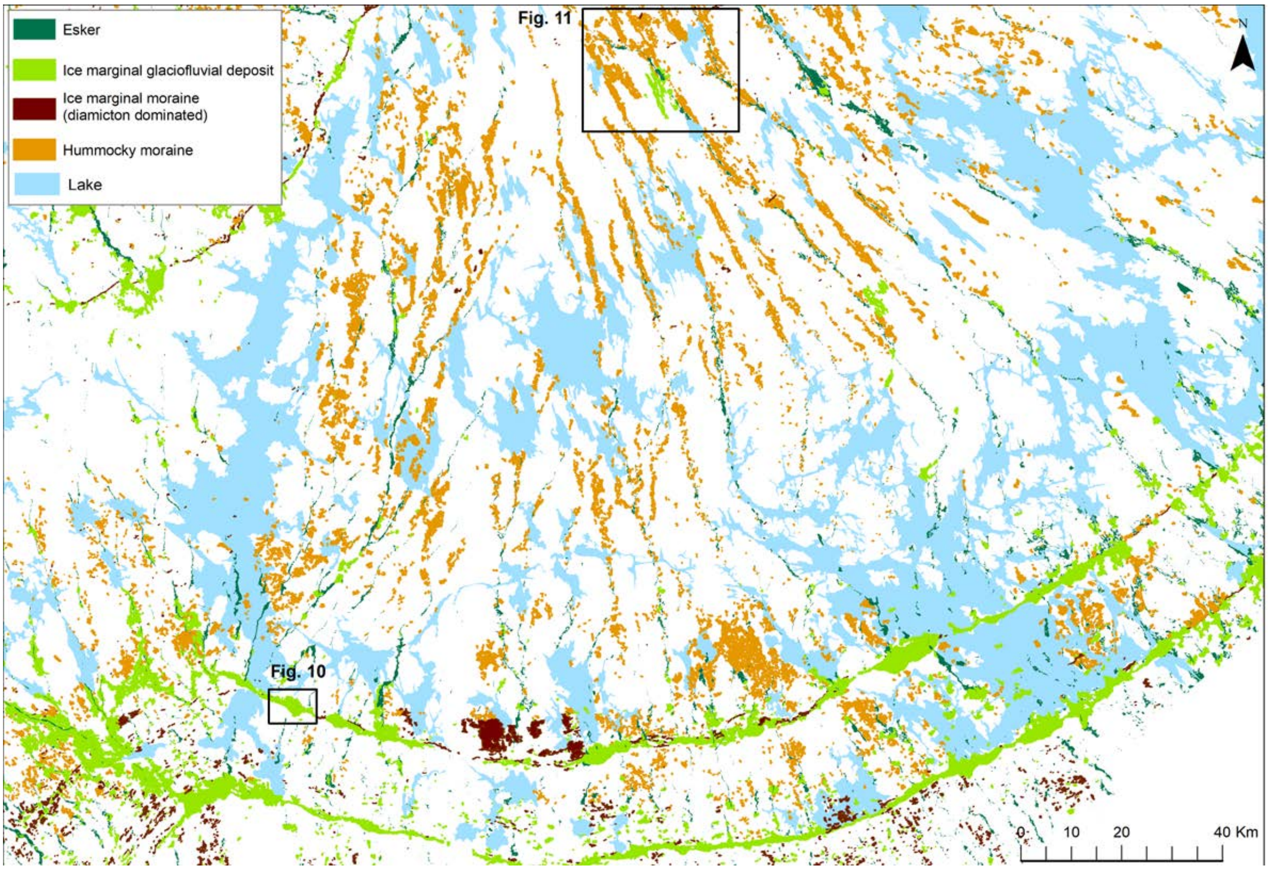

Fig. 9. Morpho-lithogenetic units of the southern part of the Finnish Lake District ice-lobe province. On the map are shown the glaciofluvial deposits (eskers and Salpausselkä ice-marginal deposits (also referred as end moraines) (sandurdelta/delta complexes, green; also diamiction-dominated ridges, dark brown)) and various types of hummocky moraines and other glacial deposits (browns). The two Salpausselkä ice-marginal systems, with their ice-marginal sandur deltas, form distinct and fairly continuous chains across the map area, from the Lahti region in the west to Imatra in the east. Esker systems radiate from the ice-marginal deposit (also called end moraine) zone towards the north. Hummocky moraines form regions and discontinuous chains. Basemap © National Land Survey of Finland.

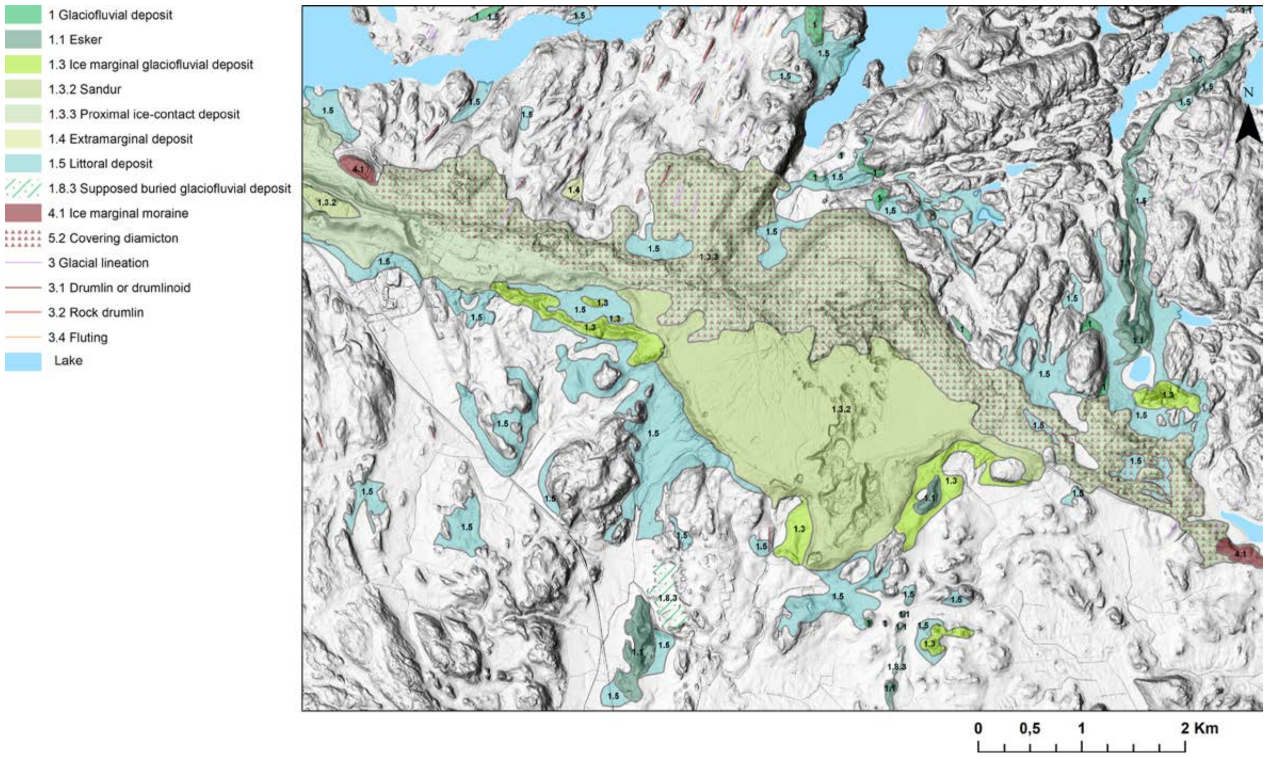

Fig. 10. Vesivehmaankangas delta complex and its surroundings. The mapping classification includes also covering diamicton in the proximal part of the complex. Basemap and LiDAR data © National Land Survey of Finland.

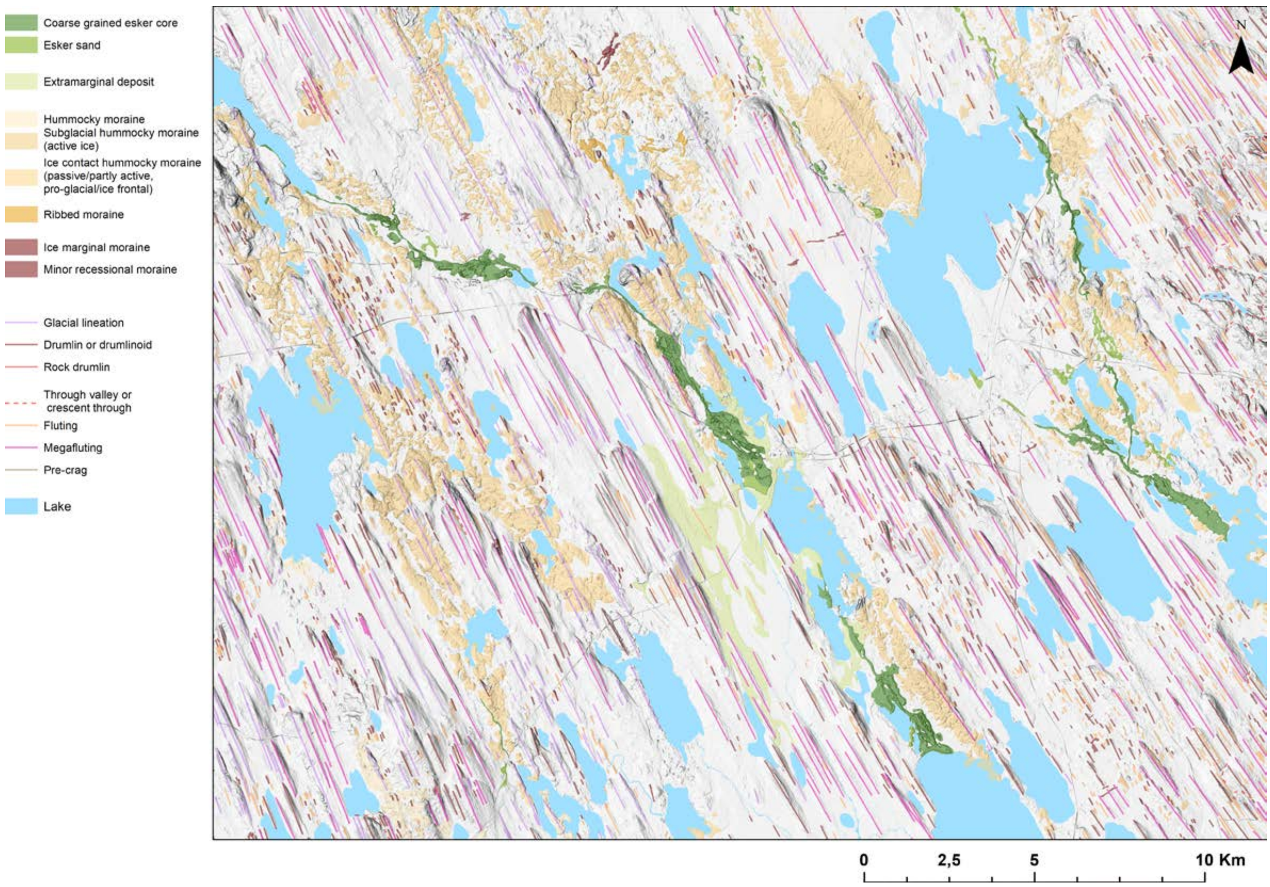

Fig. 11. Pieksämäki area in the central area of the Finnish Lake District ice-lobe province. Esker systems are shown with green, hummocky moraine fields with light brown and glacial lineations with purples. Blue areas are lakes. Basemap and LiDAR data © National Land Survey of Finland.

4.3 Lithostratigraphic units

4.3.1 General

A *lithostratigraphic unit* consists of an organization of rock strata, which are defined and distinguished on the basis of their lithological characteristics. Lithostratigraphic units are defined independently of the inferred geological history, mode of genesis or biological development. A *formation* is the fundamental unit (Fig. 12), defined as a type section (stratotype). A formation shall have lateral continuity, but it is not tied to age, so it can occur as a diachronic unit. Lithostratigraphic units should be defined by practical purpose, and for terminological stability, a type locality should always be presented. For the procedures related to lithostratigraphy, Salvador (1994) and McMillan et al. (2011) are referred to.

The challenges of a standard lithostratigraphic method with glacial deposits were discussed in Chapter 3.1. In Finland, Quaternary lithostratigraphic units (LS) have been defined when there is adequately vertical log and profile data on representative superficial deposits. Type section localities (observations points) include natural escarpments (e.g. erosional riverbanks) and, more typically, man-made excavations such as quarries, roadside sections and geological test pits. Morpho-lithogenetic units can be complemented by lithostratigraphic units (formation, member, bed) only after the type section (stratotype) has been described and named.

Formal stratigraphic description may not be the most suitable method to report investigations in most applied (e.g. groundwater, engineering) and research projects. However, when combined with facies analysis, the definition of architectural elements (e.g. Miall 1985), the stratotypes will provide a valuable addition to the national information base. Well defined, and formally documented lithostratigraphic units form a cumulative, uniform, observation-based dataset and one fundamental foundation of geological information in Finland.

Lithology: Structured description of rocks (both consolidated and unconsolidated) on the basis of such characteristics as colour, mineral composition, grain size, texture and structures (cf. GoG 2005).

UPPER RANKS:

- **Supergroup:** *A supergroup may be used for several associated groups or associated formations and groups with significant lithological properties in common.*
- **Group:** *A group is the formal lithostratigraphic unit next in rank above a formation and is commonly applied to a sequence of contiguous formations with significant diagnostic lithological characteristics.*
- **Subgroup:** *A group may be divided into subgroups, although it is not in the formal hierarchy but has been usefully employed for subdividing certain groups.*

PRIMARY UNIT:

- **Formation**: *A formation is* ***the primary formal unit of lithostratigraphic classification*** *used to map, describe and interpret the geology of a region. A formation is generally defined as the smallest mappable unit and has lithological characteristics that distinguish in from adjacent formations. However, component members and beds may be mappable in maps and 3D models, depending on the resolution. A formation is defined by a type section (stratotype) or type area.*

LOWER RANKS:

- **Member:** *A member is the formal lithostratigraphic unit next in rank below a formation and is always part of a formation. Formations need not to be divided either wholly or partially into members. Member may extend from one formation to another.*
- **Bed**: *A bed is the smallest formal unit in the hierarchy of sediment lithostratigraphic units. Bed names are commonly applied to distinctive units that may be thin and laterally restricted or known only from a borehole or single exposure. Some beds may be fossiliferous or yield dateable material (e.g. a soil, peat or bone bed). A bed status tends to be assigned for units with some palaeogeographical, geochronological or specific lithological significance.*

Fig. 12. Summary of the key concepts and terms of lithostratigraphic classification (Salvador 1994, McMillan et al. 2011).

4.3.2 Lithostratigraphic units in Finland

The number of formally defined lithostratigraphic units of Finnish superficial sediments is relatively low. The use of sedimentological techniques and facies analysis to study superficial sediment sections during the past 30 years have increased has generated a number of site-specific studies with detailed section descriptions. Formations, members and beds that have been described according to the principles of formal lithostratigraphic classification (e.g. Bouchard et al. 1990, Pitkäranta et al. 2014, Salonen et al. 2014, Lunkka et al. 2015). In addition, numerous precise descriptions of sediment vertical sections are available (e.g. Hirvas & Nenonen 1987, Hirvas 1991, Sutinen 1992, Nenonen 1995, Sarala 2005, Sarala et al. 2016, Ojala et al. 2018a, Putkinen et al. 2020), which can be considered and classified as lithostratigraphic units.

The current state of the Quaternary lithostratigraphic units can be found in FinstratMP. Representative examples of lithostratigraphic studies in Finland include (Fig. 13):

- Bouchard et al. (1990); *Kela Formation* (western Uusimaa); *Members*: Espoo Till, Pickala Sands and Siuntio Till.
- Nenonen (1995) described several Pleistocene till stratigraphies from eastern, southern and western Finland; Sallila (Vampula) and Horonkylä (Teuva) till stratigraphy.
- Pitkäranta (2005, 2013) and Pitkäranta et al. (2014): formal lithostratigraphy of the Suupohja region in western Finland (Ostrobothnia).
- Salonen et al. (2008), Salonen et al. (2014) and Lunkka et al. (2015): lithostratigraphy of Hitura, Hannukainen and Rautuvaara in northern Ostrobothnia and western Lapland.
- Sarala (2005) Peräpohjola lithostratigraphy (Table 4) with type sections.

Table 4. An example of lithostratigraphic unit division from the Peräpohja area (from Sarala 2005).

Formation	Member	Depth	Description	Interpretation	Chrono-stratigraphy	Type section
Suolijoki Formation		0.5 - 2 m	Stratified sand and gravel	Shore deposit	Holocene	N7345.5 I2561.5 M118, Vammavaara
Tervola Till Formation	Korttelivaara Till Member	0.1 - 1.5 m	Brownish grey sandy diamict	Melt-out, flow or waterlain till	Late Weichselian	N7334.0 I3444.6 M90, Korttelivaara
	Petäjävaara Till Member	1 - 3 m	Brownish grey or grey gravelly diamict	Lodgement or basal melt-out till		N7358.5 I2564.1 M1, Petäjävaara
	Vammavaara Till Member	1 - 4 m	Grey sandy diamict	Lodgement till		N7346.2 I2561.2 M25, Vammavaara
Sihtuuna Sands		1 - 2.5 m	Horizontally or cross bedded sand	Subaquatic fan	?	N7344.6 I2529.6 M124, Sihtuuna
Kemijoki Till Formation		1 - 2 m	Bluish grey, compact sandy/silty diamict	Lodgement till	Early or Middle Weichselian	N7345.9 I2562.2 M21, Vammavaara
Saarenkylä Gytja		2 - 3 m	Organic gytja, silt and sand	Lacustrine or marine deposit	Eem Interglacial or Early Weichselian	N7382.5 I4447.6 Saarenkylä (Sutinen 1992)
Saarenkylä Till Formation		> 1 m	Grey, compact sandy diamict	Lodgement till	Saalian	N7382.5 I3447.6 Saarenkylä (Sutinen 1992)

The interglacial and interstadial deposits are important marker horizons in studies on glacial history in Finland. Tornivaara & Salonen (2007) collected and systematically classified (STRATO database) a large number of investigations that present stratigraphic units from continuous successions of the Saalian, Eemian, Weichselian and some Weichselian interstadial stages. The data collected (STRATO final report; Tornivaara & Salonen 2007) enable the definition of lithostratigraphic units based on regional type sections. Pre-Weichselian geological (lithostratigraphical) units, typically covered by Weichselian and post-Weichselian sediments, have been described in examples from Sokli in eastern Lapland (Helmens et al. 2015, Kylander et al. 2017), the Suupohja region in Ostrobothnia (Pitkäranta et al. 2014), Tepsankumpu, Kittilä (Saarnisto et al. 1999), and Äältövittikot, Sodankylä (Putkinen et al. 2020) in Lapland, Vesiperä in Middle Ostrobothnia (Nenonen 1995), Harrinkangas (Gibbard et al. 1989, Räsänen et al. 2015), Hitura (Salonen et al. 2008) and Mertuanoja (Eriksson et al. 1999, Nenonen 1995).

Fig. 13. Key locations of the stratigraphic record of superficial deposits in Finland. Locations: Kela and Lommila (Bouchard et al. 1990); Vuosaari (Hirvas et al. 1995); Sallila, Horonkylä, Haapalankangas, Eteläkylä, Kaasila, Pampalo, Ruotanen, Vesiperä, Mertuanoja, Vuojalankangas (Nenonen 1995); Risåsen, Penttilänkangas, Karhukangas, Harrinkangas (Pitkäranta 2013); Hitura (Salonen et al. 2008); Ruunaa (Lunkka et al. 2008); Vammavaara, Petäjävaara, Sihtuuna, Korttelivaara, (Sarala 2005); Saarenkylä (Sutinen 1992); Rautuvaara (Lunkka et al. 2015); Hannukainen (Salonen et al. 2014); Sokli (Helmens et al. 2015); Koivusaarenneva (Lunkka et al. 2016); Kaarreoja (Sarala et al. 2016) and Äältövittikot (Putkinen et al. 2020). Basemap data © National Land Survey of Finland.

4.4 Allostratigraphic units

4.4.1 General

The International Stratigraphic Guide (Salvador 1994) recognizes a classification category based on stratal discontinuities (unconformity-bounded unit), but the corresponding unit type, synthem, has not been widely used. In many countries (including Finland; Virtasalo et al. 2005, 2007, 2014), a similar system of *allostratigraphic* classification (North American Stratigraphic Code, NACSN 2005) and terminology has, in practice, replaced the convention suggested by the IUGS Guide (Salvador 1994).

An allostratigraphic unit is a mappable body of rock that is defined and identified on the basis of its bounding discontinuities (NACSN 2005). The fundamental unit is an *alloformation* with a lower rank of *allomember* and a higher rank of *allogroup*. For terminology, procedures and examples of formal *allostratigraphy*, the North American Stratigraphic Code (NACSN 2005) is referred to.

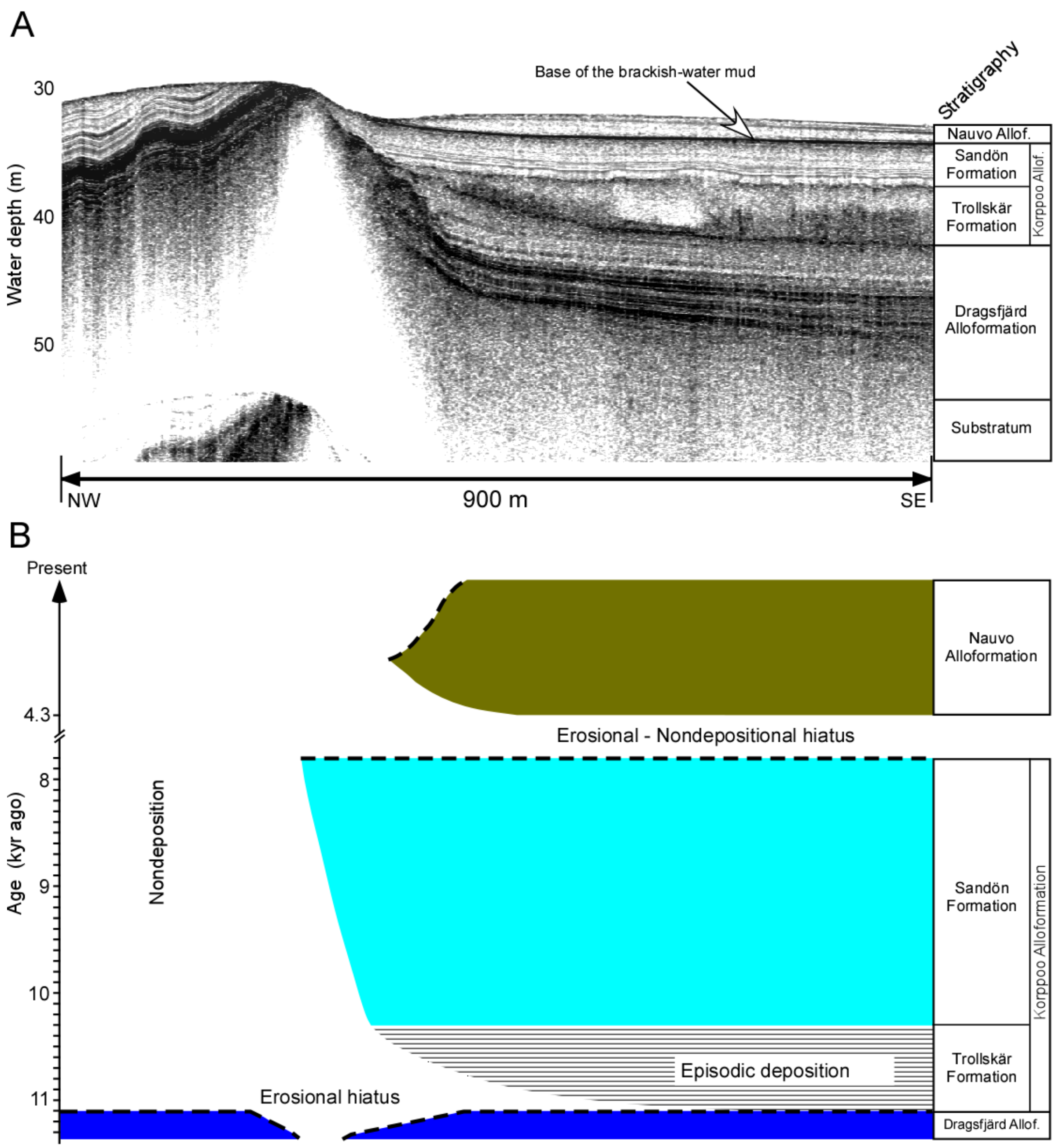

Fig. 14. (A) Seismoacoustic sub-bottom profile (12 kHz pinger) and allostratigraphic units from the Archipelago Sea. (B) Corresponding Wheeler diagram with time on the vertical axis. Modified from Virtasalo et al. (2007). Stratigraphic units after Virtasalo et al. (2010).

It is emphasized that the system is fundamentally based on bounding surfaces (discontinuities, unconformities) between the units – not on the lithology or other properties of the units themselves. Many of the discontinuities originally represent either erosional surfaces or periods of non-deposition ('hiatus') (see Virtasalo 2017). Based on their observation that substantial lithological heterogeneity typically complicates the lithostratigraphic classification of glacial deposits, Räsänen et al. (2009) proposed a procedure involving the combined use of allostratigraphy and lithostratigraphy (CUAL) as a classification basis for (Quaternary) glacial deposits.

4.4.2 Allostratigraphic units in Finland

Allostratigraphy has proven particularly useful in marine geological surveys, where significant unconformities can readily be identified and traced over distances in high-resolution seismoacoustic sub-bottom profiles that are routinely collected (Virtasalo et al. 2005, 2007, 2010, 2014). For example, *the base of the brackish-water mud* is traceable in sub-bottom profiles over the whole Baltic Sea (Virtasalo et al. 2016). Allostratigraphic units identified in offshore seismoacoustic profiles can be correlated with those on land on the basis of significant unconformities identified, for example, by ground-penetrating radar surveys and electrical resistivity tomography (Ojala et al. 2018b, Virtasalo et al. 2019). Allostratigraphic units are the preferred means of stratigraphic classification instead of conventional practice of classifying sediments according to the so-called Baltic Sea Stages (Baltic Ice Lake, Yoldia Sea, Ancylus Lake, Littorina Sea, etc.). Conventional practice lacks clear and consistent definitions and are incompatible with international stratigraphic approaches (cf. Virtasalo et al. 2014, Virtasalo 2017).

Even though the classification principles of lithostratigraphy and allostratigraphy differ, in practice they are based on the same information: the visual characteristics of sediment units. Therefore, Räsänen et al. (2009) developed a combined allo- and lithostratigraphic approach (CUAL) where sediments are classified on the basis of significant unconformities into allostratigraphic units, which can be further subdivided into lithostratigraphic units by lithological criteria. Virtasalo et al. (2005, 2007, 2010) used the CUAL approach for subdividing late- and postglacial sediments in the Archipelago Sea into Dragsfjärd, Korppoo and Nauvo Alloformations, and the Korppoo Alloformation further into the lithostratigraphic Trollskär and Sandön Formations (Fig. 14). In the neighbouring sea area, Virtasalo et al. (2014) subdivided brackish-water muds corresponding to the Nauvo Alloformation into local allomembers. All the defined allostratigraphic units will be stored in the FinstratiMP database.

5 SUMMARY AND IMPLICATIONS

As a national Geological Survey, GTK maintains, gathers, refines and distributes geological data in Finland. The definition and development of national procedures, the geological unit framework, map compilations and maintenance of the geological unit database (digital Lexicon) are essential components of these activities. This document defines these issues from the viewpoints of geological unit description and map data management.

Lithostratigraphy and allostratigraphy are well established classification systems with defined terms and procedures (Salvador 1994, McMillan et al. 2011). In this work the main emphasis has been to define and explain the use of the morpholithogenetic (MLG) units. The use of MLG units in LiDAR DEM-based mapping and classification of Quaternary superficial deposits in Finland is fundamentally important. The use of MLGs has been described by Lee and Booth (2006, p. 21) as (edited):

"…geological interpretations of morphological features will be based upon geological hypotheses developed by the geologist for an individual mapping area. It is critical therefore that these hypotheses and geological interpretations can evolve and are testable based upon field observations. As a consequence of this need for testing and re-evaluation, pure morphological mapping is perhaps best suited to areas where the relief and geology is not complex – for instance lowland areas. Geomorphological mapping enhances the purely morphological approach, as it also involves determining the genesis of the observed landforms, taking into account lithologies and their spatial geometry (including stratigraphy). As sound interpretation is the key to the success of this method, it requires a good understanding of

landform assemblages and their genesis, together with an appreciation of other appropriate field and laboratory techniques that might assist in interpretation. Whatever other methods are brought into the geomorphological survey (e.g. if remotely sensed data are available, they can serve to increase the rate of ground coverage and reduce field time), groundtruthing remains an essential element (e.g. to confirm remotely sensed interpretations, to observe sections and to record lithologies).”

It is noted, however, that morpho-lithogenetic classification does not achieve the accuracy and formality of the traditional schemes of stratigraphic classification (Salvador 1994). Furthermore, both the fundamental definition of MLG units and the interpretation process leading to the actual MLG map units can easily be criticized as ‘inexplicit’ or ‘ambiguous’. The definition and mapping of MLG units is obviously dependent on the experience and the ‘mind set’ of the interpreting person – to some degree, at least.

Experiences gained in the regional LiDAR-based mapping of glacial deposits in Finland have proven the usefulness of the informal MLG approach as a frame for practical map data production (e.g. Putkinen et al. 2017). The mapped MLG units also provide a framework and a starting point for both the lithostratigraphy and Quaternary 3D geology. Glacial sediments have been mapped in Finland with the morpho-lithogenetic deposit approach using a classification of glacigenic and glaciofluvial deposit types. The MLG system is an important part of the larger system, as the glacial dynamic provinces and regions are largely based on the spatial distribution and characteristics of the MLG units; as an example, the ice-marginal systems and other first-order datasets, such as drumlin fields and esker systems, together form a glacial dynamic province when combined. Subdivision of the deposits into their textural, morphological and genetic components is theoretically possible but seldom practically possible (Fulton 1993, McMillan & Powell 1999).

The glacial dynamic provinces and regions correspond to the past ice (stream) lobe provinces and the interlobate regions. Thus, the map unit term ‘ice lobe’ (e.g. Finnish Lake District ice lobe) used by Putkinen et al. (2017) has been replaced by the term ‘ice-lobe province’ – the current region and map unit corresponding to the palaeoterm ‘ice lobe’.

The concept of glacial dynamic provinces has now been applied to deposits corresponding to a relatively short, albeit the most important stage of glacial dynamical activity during the latest Weichselian deglaciation. However, we note that the time-dependent dynamic evolution of the ice sheet resulted in overlapping glacial dynamic characteristics, which are not yet included in the GD unit division. They will be supplemented later based on the available fragmentary information on the various ice-flow systems and ice-marginal deposits. This information has for the most part been discovered from interlobate GD regions of the last deglaciation and the ice-divide zone, but partly also from the ice-lobe GD provinces, especially the Kuusamo ice-lobe province of the last deglaciation (Sutinen 1992, Kleman et al. 1997, Lunkka et al. 2004, Sarala 2005, Johansson et al. 2011).

The renewed LiDAR DEM-based interpretation process is complemented at GTK by the development of modelling (2.5D and 3D) activities (cf. Ojala et al. 2018a, Kohonen et al. 2019). MLG units constitute a Quaternary 2D-map theme. MLG units and lithological units with defined boundaries (surfaces), together with (depositional) architectural elements, are the main constituents of a regional 3D framework. At a detailed scale, the recognition and application of architectural elements, packages of genetically related strata recording aggradation during the successive depositional events, are of growing importance. Architectural elements can therefore be regarded as the basic building blocks of any (stratigraphic) succession, and their management as geological units needs to be resolved.

Geological maps, 3D models and map features, such as glacial dynamic regions or MLG units, are interpretations, and interpretations are vulnerable to changes. In contrast, well-defined stratigraphic units are based on observation at a documented site, and stratigraphic units form a cumulative foundation of geological information. FinstratiMP will be the digital national lexicon for all the defined Quaternary units in Finland. Due to the lack of a comprehensive chronostratigraphic scheme, the depositional age (determined or inferred) will be included in FinstratiMP as a unit attribute, when possible and appropriate.

The residual units (palaeosols of unknown age) are to be included in the FinstratiKP (digital lexicon for the bedrock units) together with sporadic pre-Quaternary sedimentary units (e.g. some marine clays, diatomites) and unmetamorphic sedimentary rocks of Finland.

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LIST OF APPENDICES

Appendix 1 Glacial dynamic (GD) provinces and regions (map units) in Finland: definition, identification, characterization and description

Appendix 2 Morpho-Lithogenetic (MLG) geological units in Finland: identification and characterization

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APPENDIX 1

15.4.2021

GLACIAL DYNAMIC (GD) PROVINCES AND REGIONS (MAP UNITS) IN FINLAND: DEFINITION, IDENTIFICATION, CHARACTERIZATION AND DESCRIPTION

J.-P. Palmu, A. E. K. Ojala, J. Virtasalo, N. Putkinen, J. Kohonen & P. Sarala

CONTENTS

1 GD PROVINCE AND REGION IDENTIFICATION

Glacial dynamic provinces and regions are identified and defined by their ice-flow characteristics or lack of them in terrain surface morphology. The ice-flow intensity is indicated by the lineation length and axial dimensions of the various types of drumlins, mega-scale lineations, crag and tails, etc. The ice-flow direction indicators, such as lineations and other flow-indicating features, constitute a continuum and form an independent flow set system for each glacial dynamic ice-flow province. In addition, other morpho-lithogenetic units and landforms, such as glaciofluvial eskers and fields of hummocky moraines, are used in the identification and delineation of glacial dynamic provinces and regions

2 GD PROVINCE BOUNDARY DEFINITION AND BOUNDARY TYPE CLASSIFICATION

2.1 Outer margins

Ice-lobe GD provinces have outer margins that constitute ice-marginal deposit (also called end moraine) zones (see Figs. 8 and 9 in the main article).

a. Salpausselkä ice-marginal deposits of the Finnish Lake District ice-lobe province (FLDIL) and the Baltic Sea ice-lobe province (BSIL).
b. In Northern Karelia, for the Oulu–Northern Karelia ice-lobe (ONKIL) glacial dynamic province, ice-marginal glaciofluvial deposits and diamicton-dominated ice-marginal ridges corresponding to the Salpausselkäs are, from southeast to northwest: the Värtsilä–Tohmajärvi ice-marginal system, continuing northeast towards Tuupovaara, the Kiihtelysvaara ice-marginal system, which continues northeast, south of Lake Koitere, and the Pielisjärvi ice-marginal system, which continues northeast, north of Patvinsuo national park.
c. For the Näsijärvi–Jyväskylä ice-lobe (NJIL) GD province, the Central Finland ice-marginal deposit zone is its outer margin. Towards the west is Hämeenkangas, which is also an interlobate deposit, and on the southern side of Hämeenkangas is the Baltic Sea ice-lobe GD province.
d. For many ice-lobe GD provinces in Finland, the outer margins are ice-marginal positions, often ice-marginal glaciofluvial deposit zones outside Finland, in Russia and Norway. In Norway, the Younger Dryas stage ice-marginal positions are in northernmost Norway for the Inari and Enontekiö ice-lobe provinces. In Russia, ice-marginal positions are in northwestern Russia for most of the Oulu–Northern Karelia ice-lobe GD province and for the whole of the Kuusamo ice-lobe province.
e. The southern coastal Finland GD province (SCF) (south/southeast of the Salpausselkäs and Northern Karelian ice-marginal deposit zone). The outer (distal) boundary of this province is outside Finland, towards the south and southeast in Estonia and Russia. GD province ice flow was towards the Pandivere–Neva ice-marginal position (Donner 1995). The glacial geological development of this province dates from an earlier period (before 13 cal. ka) compared to the other glacial dynamic provinces.

2.2 Lateral margins of the GD provinces

Lateral margins of the GD provinces are variable and can be characterized as follows:

f. The margins between ice-flow lobes have been dynamic zones, with changes in flow intensity and direction. In some cases, one ice-flow system (lobe) has finally prevailed over the adjacent flow system. An example of this is the border between the Oulu–Northern Karelia ice-lobe province (ONKIL) and the Finnish Lake District ice-lobe province (FLDIL) at Outokumpu. In that area, an interlobate deposit was formed, as in the final stage the ONKIL GD province prevailed, but at an earlier stage, FLDIL GD province ice flow was dominant further northeast of the later-formed interlobate deposit. A similar development occurred in the Jyväskylä region, where the Näsijärvi–Jyväskylä ice-lobe (NJIL) GD province area now overlaps the ice-flow system of the FLDIL GD province area, as the NJIL ice margin readvanced east- and southeastwards.

g. Some of the margins between GD provinces are gradational and/or diffused. There is often, but not always, an interlobate deposit: a smaller interlobate glaciofluvial "esker" or a large interlobate formation between the ice-lobe provinces and the interlobate regions. The latter clearly separates provinces and regions of distinct glacial dynamic activity. An example of interlobate deposits is the system of deposits running from Hossa via Taivalkoski in the east towards the west via Pudasjärvi and further on to the shores of the northern Bothnian Bay. The system of deposits delineates the boundary between the Oulu–Northern Karelia ice-lobe (ONKIL) GD province and the Ranua interlobate (RIL) GD region.

h. Indistinct lateral borders are typical for GD provinces and regions of Northern Finland. An example of this is the Pello interlobate GD region, located between the flow sectors of the Kuusamo ice-lobe GD province. The southern margin of the Kuusamo ice-lobe GD province is also indefinite and indistinct, and to a large extent can only be inferred from the flow indications. In Northern Finland, confusion is also caused by indications of ice-flow systems of earlier (pre-Last Glacial Maximum, LGM) glacial stages. For example, in the Ranua interlobate GD region, in the Kemi–Tornio area, there is a drumlin field of presumably the Middle Weichselian stage.

2.3 Inner margins of the GD provinces

GD ice-lobe provinces mostly have inner margins that are onset zones of their ice-flow systems. For the GD ice-lobe provinces of the Baltic Sea (BSIL), the Finnish Lake District (FLDIL), Oulu–Northern Karelia (ONKIL) and the relatively younger Näsijärvi–Jyväskylä (NJIL), the onset zones are in the sea areas west of Finland, in the Bothnian Bay. For the Kuusamo, Salla, Inari and Enontekiö ice-flow areas (lobes), the onset zones are diffuse areas towards the ice-divide zone.

Table 1. Generic descriptions for the boundaries within the glacial dynamic province (GDP) classification in Finland.

UNIT BOUNDARY; MAIN DESCRIPTORS	**Boundary type (Geological Relation) Glacial dynamic (Descriptive**	**Boundary type (Geological Relation) Deposit (D) Bed (B)**	**Boundary type (Geological Relation) Spatial**	**Boundarytype (Geological Relation) Spatial**	**Boundary type (Geological Relation) Spatial**
GLACIAL DYNAMIC CLASS / RANK					
	Nature	Contact	Location	Nature	Width
Glacial dynamic Unit (Province/ Region)	Outer limit – Readvance – Passive Ice (stream) lobe distal ice-marginal deposits, moraine zone Lateral boundary – Lobe/Lobe – Lobe/Interlobate Inner boundaries – For ice (stream) flow, onset zones	Geological province contact – Interlobate deposit (D), either glaciofluvial or diamicton-dominated Lithogenetic contact – Basal till beds (B) Overlapping areas at the lateral margins of the provinces (in cases) Flow indications – Lineations – Striations – Other	>Inferred >Poorly defined >Defined >Well defined	>Undefined >Sharp >Gradational >Diffuse	>Line >Narrow zone >Wide zone >Undefined
Glacial dynamic Sub-unit (Sub-province)	Intralobate – GF – Hummocky moraine Mixed	Geological sub-province contact	>Inferred >Poorly defined >Defined >Well defined	>Undefined >Sharp >Gradational >Diffuse	>Line >Narrow zone >Wide zone >Undefined

3 GLACIAL DYNAMIC PROVINCE/REGION GEOLOGICAL MAP UNIT ATTRIBUTES

The definition of the attributes list focuses on the categorising the specific features of the individual units. There is no need to repeat in the attribute fields the same information already incorporated in the unit classification (glacial dynamic setting, characteristic structural features).

- Geological age: Late Weichselian and/or Holocene. In the future, the aim is to add older (pre-Late Weichselian) GD spatial units, as for these, the age is an essential attribute
- Boundaries (o/i)
  - 1) outer boundary
  - 2) lateral boundaries
  - 3) inner boundary
- Description:
  - Genesis (i): GD-unit-specific history and features. The description format is separate for ice-lobe provinces (and sub-provinces) and interlobate regions:
    - Lineation and transport directions in the active phase(s)
    - Deglaciation stage development as interpreted from the MLG units: esker system directions, hummocky moraine field locations and characteristics, and also the De Geer moraine fields and their characteristics
  - Physical and compositional characteristics of major MLG features; basal till and related drumlin fields, ice-marginal deposits (systems), main esker systems, hummocky moraine terrains, de Geer moraine fields, other recessional moraines. Older deposits (pre-late Weichselian) are also concisely described
- Former names for the approximately corresponding map unit:
- Key references:

4 GD PROVINCE AND REGION CHARACTERIZATION

Southern coastal Finland province (SCF)
(Salpausselkien eteläpuoleiset alueet)
The glacial geological development of this province dates from an earlier period (before 13 cal. ka) compared to the other glacial dynamic provinces. The outer (distal) boundary of this province is outside Finland, towards the south and southeast in Estonia and Russia. Ice flow was towards the Pandivere–Neva and Palivere ice-marginal positions (Donner 1995, Kalm 2006, Rosentau et al. 2009, Kalm 2012). The proximal boundaries of this province are the intensive ice-flow lobe provinces of the Baltic Sea, Finnish Lake District and Oulu–Northern Karelia GD provinces.

The ice-lobe provinces of the Younger Dryas and early Holocene in the Finnish area of the Fennoscandian Ice Sheet are as follows:

The Baltic Sea ice-lobe province (BSIL)
(Itämeren kielekevirtausalue)
For the Baltic Sea ice-flow GD province, the outer boundary zone includes the Younger Dryas stage First and Second Salpausselkäs and the early Holocene Third Salpausselkä ice-marginal deposits. This ice-flow system also operated in Sweden, towards the Central Sweden ice-marginal zone. Thus, the lateral boundary of the province is located west of Finland. The lateral boundary towards the northeast is against the Päijänne interlobate province and further northwest against the Näsijärvi–Jyväskylä ice-lobe province, and still further west-northwest against the Southern Ostrobothnian interlobate region. There are flow indications of the onset zone in the sea region between Finland and Sweden, in the Bothnian Bay area (Greenwood et al. 2017).

The Finnish Lake District ice-lobe province (FLDIL)
(Järvi-Suomen kielekevirtausalue)
For the Finnish Lake District ice-flow GD province, the outer boundary zone includes the Younger Dryas stage First and Second Salpausselkäs. There is evidence from till-covered glaciofluvial deposits of ice-margin readvance from an inner position to the zone of the Salpausselkäs. The lateral boundary towards the southwest is against the Päijänne interlobate region and the border is diffuse. The boundary against the Näsijärvi–Jyväskylä ice-lobe province is overriding; the NJIL ice-lobe overrode part of the former flow area of the FLDIL province, north of Jyväskylä. The northwestern part of the FLDIL, the so-called “trunk” of the ice flow area,

has sometimes been seen as a separate flow area (for example, Lunkka et al. 2004). For this area, FLDIL and NJIL ice-flow systems were competing, so the boundary is indistinct (Ahokangas & Mäkinen 2013).

The Oulu–Northern Karelia ice-lobe province (ONKIL)
(Oulun-Pohjois-Karjalan kielekevirtausalue)
For this ice flow province, the flow was towards ice-marginal positions in Northern Karelia and the ice-marginal positions in Soviet Karelia (Rainio 1996, Putkinen & Lunkka 2008). The lateral boundary towards the southwest was in the Outokumpu area against the FLDIL. The ONKIL flow strength was stronger in the latest parts of the deglaciation, as can be seen in the overprinting flow indications. In the northern boundary of the province, the Ranua interlobate (RIN) region is the main neighbouring region. However, there is also a zone, where the boundary is against the Kuusamo ice-lobe province.

Kuusamo ice-lobe province (KIL)
(Kuusamon kielekevirtausalue)
For the Kuusamo ice-lobe province, the ice flow was towards ice-marginal positions in Russian Karelia (Putkinen & Lunkka 2008). The lateral boundary towards the south was against the Ranua interlobate GD region. This boundary consists of an interlobate esker from Hossa towards the west to Taivalkoski, Pudasjärvi and the northern Bothnian Bay. The western and northern neighbouring provinces are the Pello and Sodankylä interlobate regions and the ice-divide zone. The northeastern margin of the GD province is against the Salla ice-lobe GD province. There is also a small area where the boundary is against the Oulu–Northern Karelia ice-lobe GD province.

The Salla ice-lobe province (SIL)
(Sallan kielekevirtausalue)
The Salla ice-lobe GD province is a relatively small flow system. The province joins the Kuusamo ice-lobe GD province flow system with a gradational common margin. On the lateral margins, the Salla GD province is bordered by the Sodankylä and Savukoski interlobate GD regions.

The Inari ice-lobe province (IIL)
(Inarin kielekevirtausalue)
Inari ice-lobe GD province differs from the ice-lobe GD provinces in the ice flow direction, which was towards the northeast, whereas in all other ice-lobe GD provinces the flow direction varied from southeast to south and east. The outer margin of this GD province is mainly in Norway (in the Tana bru – Kirkenes area) and partly in Russia. The Kevo interlobate fell GD region is located on the western side of the Inari ice-lobe GD province, with a diffuse, undefined border. The onset zone against the ice-divide zone is also diffuse and indistinct.

The Enontekiö ice-lobe province (EIL)
(Enontekiön kielekevirtausalue)
The Enontekiö ice-lobe GD province flow was roughly towards the north, towards the ice-marginal positions in the Finnmark area of Norway, of the Younger Dryas stage. On the western margin of this ice-lobe GD flow system province is located the Käsivarsi fell interlobate GD region. On the eastern margin, the neighbouring GD province is the Inari ice-lobe GD province. This margin is diffuse. The onset area margin towards the ice-divide zone is diffuse and gradational.

The Näsijärvi–Jyväskylä ice-lobe province (NJIL)
(Näsijärven-Jyväskylän kielekevirtausalue)
The outer margin of the Näsijärvi–Jyväskylä ice-lobe GD province is the ice-marginal deposit zone of the Central Finland ice-marginal system. There is evidence of a readvance of several tens of kilometres to this zone. In the southwestern corner of the GD province, at Hämeenkangas, the margin against the Baltic Sea ice-lobe GD province is a specific type of system: NJIL ice flow roughly towards the south and almost west-to-east ice movement on the southern side of the Hämeenkangas interlobate deposit. On the western lateral margin of the GD province, against the Southern Ostrobothnia interlobate GD region, the Pohjankangas interlobate deposit has also been interpreted as an ice marginal deposit with ice flow from the west (Lunkka & Gibbard 1996). Northwards on the western GD province margin, the nature of the common border is diffuse. Usually, the margin has been interpreted to be positioned along the esker running via Nummijärvi. The margin between the FLDIL GD province trunk and the NJIL GD province is complicated and partly diffuse. According to Ahokangas and Mäkinen (2013), there is an interstream zone northwest of Kivijärvi and the Kivijärvi-Lohtaja esker should not be considered as a true interlobate esker, but as an ice-lobe margin esker, and the Laukaa-Kokkola esker also gains a possible status as an ice-lobe margin esker.

The interlobate regions in the Finnish area of the Fennoscandian Ice Sheet are:

The Päijänne interlobate region (PIN)
(Päijänteen kielekevirtausten välinen alue)
An interlobate GD region between the Baltic Sea and the Finnish Lake District ice-lobe GD provinces has its outer margin in the confluence region of the BSIL and FLDIL, where the massive ice-marginal system of Salpausselkä I was deposited. The eastern lateral margin of this province with the Finnish Lake District ice-lobe province is diffuse, running through the basin of Lake Päijänne. The western margin of this region is the interlobate esker, which runs from Hämeenkoski via Tampere towards the northwest. The northern, inner margin of this region is the boundary with the Näsijärvi–Jyväskylä ice-lobe province and its Central Finland ice-marginal system, which was deposited after a readvance to the ice-marginal position.

The Southern Ostrobothnian interlobate region (SOIN)
(Etelä-Pohjanmaan kielekevirtausten välinen alue)
The SOIN GD region is one of the most complex GD regions in Finland. There are grounds to divide the region into smaller subregions of Vaasa and Suupohja, but to do this we need more information. The eastern margin of the region is partly sharp, with the Pohjankangas interlobate or ice marginal glaciofluvial deposit the probable deposit delineating the margin. Further towards the north along the eastern margin, the nature of the margin becomes diffuse and undefined. In the western coastal area (Kristiinankaupunki area), an ice-flow system of north–south movement has been recognized. The southern margin of the region is against the Baltic Sea ice-lobe GD province, and the nature of the border is diffuse and gradual. In this GD region, there are numerous locations with pre-Late Weichselian stratigraphic units.

The Middle Ostrobothnian interlobate region (MOIN)
(Keski-Pohjanmaan kielekevirtausten välinen alue)
This interlobate GD region has its southwestern margin against the FLDIL GD province in the interlobate esker running from Siilinjärvi via the south of Pyhäjärvi towards the northwest through Nivala. This interlobate esker disappears before reaching the coastal area, indicating the cessation of meltwater discharge (Ahokangas & Mäkinen 2013). The northeastern margin of this GD region is more diffuse and there are two interpretations of where the margin is located. In the southeast of the GD region, the boundary against the Oulu–Northern Karelia ice-lobe GD province has usually been interpreted to be the interlobate esker running from Siilinjärvi through the Iisalmi area towards Pyhäntä. From Pyhäntä, the GD region border has been interpreted to go either southwest of Piippola, northwest towards Raahe or to have a more extensive areal northeastern extent, with the boundary going through Kestilä and northwestwards to Siikajoki. In this interlobate region, there are numerous locations with pre-Late Weichselian stratigraphic units.

The Ranua interlobate region (RIN)
(Ranuan kielekevirtausten välinen alue)
The northern margin of this GD region is against the Kuusamo GD province. The margin is diffuse and poorly defined. The southern margin against the ONKIL GD area is an interlobate esker, running east to west from Hossa via Taivalkoski and Pudasjärvi to the shores of the northern Gulf of Bothnia. There are many locations with pre-Late Weichselian stratigraphic units.

Pello interlobate region
(Pellon kielekevirtausten välinen alue)
The Pello GD region is located between the bifurcated ice-flow subregions of the Kuusamo ice-lobe GD province. The margins of this GD region are diffuse and poorly described. There are many locations with pre-Late Weichselian deposits and stratigraphic units.

Sodankylä interlobate region
(Sodankylän kielekevirtausten välinen alue)
The Sodankylä interlobate GD region is located between the northwest-southeast flow system of the Kuusamo ice lobe GD province and the Salla small ice-lobe GD province. This province has a diffuse northern margin with the ice-divide zone. In this region, there are well-preserved deposits (for example, well-preserved eskers and drumlin fields) of pre-LGM glaciations, from Middle and Early Weichselian stages. Consequently, there are numerous locations with pre-Late Weichselian stratigraphic units in this GD region.

Savukoski interlobate region
(Savukosken kielekevirtausten välinen alue)
The Savukoski GD region is bounded towards the

southwest against the Salla ice-lobe GD province. This area could also be considered as part of a larger ice-divide region (compared with the current spatial delineation of the ice-divide zone), which also includes the Sodankylä GD region. The northern neighbour for this region is the ice-divide zone, with a undefined and diffuse margin between these regions.

Other regions that can be delineated based on ice-lobe patters and morpho-lithogenetic characteristics in the Finnish area of the Fennoscandian Ice Sheet are:

The Kevo (interlobate) fell region
(Kevon tunturialue)
The Kevo fell interlobate region is a relatively high fell area west of the Inari ice-lobe GD province. The boundary between these regions is gradational and diffuse.

The Kilpisjärvi (interlobate) fell region
(Kilpisjärven tunturialue)
The Kilpisjärvi fell interlobate region is a high fell area west of the Enontekiö ice-lobe GD province. The boundary between these regions is gradational and diffuse.

The ice-divide zone (ID)
(Jäänjakajavyöhyke)
The ice-divide zone in central Lapland is surrounded by both provinces of ice lobes (Kuusamo, Salla, Enontekiö and Inari) and the interlobate regions of Sodankylä and Savukoski. For this region, the margins against almost all surrounding provinces are gradational and diffuse. In this zone are numerous locations with pre-Late Weichselian stratigraphic units.

Glacial dynamic ice-lobe provinces are in some cases divided into distinct and independent or semi-independent sub-lobe provinces. This division can also include subregions or sub-provinces of the presently described glacial dynamic provinces and regions that were overridden by subsequent (younger) ice flow. These sub-provinces and subregions constitute mappable geological entities. Concurrently, well-defined and distinct subprovinces are the following (to be complemented as work progresses):

- The Baltic Sea ice-lobe province (BSIL)
  - Loimaa sub-province (BSIL-L)
- The Finnish Lake District ice lobe (FLDL)
  - FLDL province sub-region overridden by Näsijärvi-Jyväskylä lobe ice flow (FLDIL-OR)

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APPENDIX 2

14.4.2021

MORPHO-LITHOGENETIC (MLG) GEOLOGICAL UNITS IN FINLAND: IDENTIFICATION AND CHARACTERIZATION

J.-P. Palmu, A. E. K. Ojala, J. Virtasalo, N. Putkinen, J. Kohonen & P. Sarala

CONTENTS

1 IDENTIFICATION OF GENETIC DEPOSIT TYPE AND MLG UNITS

The MLG procedure applied in Finland is presented in Figure 1. Landform (morphology) relates to the shape of the land surface features (slopes, slope breaks, landform patterns), whilst lithology refers to the composition (grain size, mineral composition) of a deposit. Using the landform and lithology elements, a third element – process (the mode of origin) – may be interpreted. The resulting map unit is classified according to the Genetic Deposit Type (Table 2) and the MLG unit may be defined and named.

An understanding of the process by which a geological unit was formed is the most *essential* element of superficial mapping. If geological processes are known and understood, this insight enables geologists to establish the spatial and temporal associations and complexities between individual deposits and their respective morphological elements. In the early stages of mapping, the emphasis will be placed on observation. Nonetheless, the final step of the process (Fig. 1) is sensitive to the overall geological evolution model and to the presumed depositional environments as a part of the model. A shared geological context is a critical requirement for the attempted uniform 'mapping result'. Glaciodynamic modelling with GD provinces and regions strongly supports the development of such a shared context.

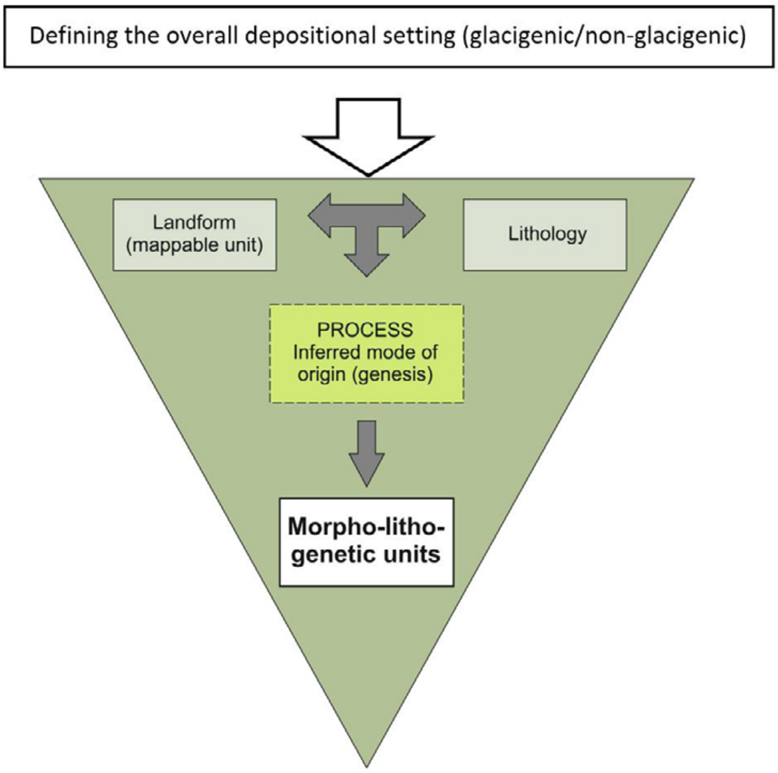

Fig 1. Simplified interpretation process chart for the morpho-lithogenetic units (modified from Lee & Booth 2006). The genetic interpretation is a 'two-stage' process, involving evaluation of the overall depositional context (first step) and interpretation of the genetic deposit type (last step).

2 NAMING OF MLG UNITS, EXAMPLES

The naming of MLG map units comprises a locality/landform name and an MLG map unit class for FinstratiMP (Table 3).

Second Salpausselkä Ice-Marginal System
>Vesivehmaankangas Delta Complex

Pieksämäki Drumlin Field
>Paltamäki Drumlin

3 ATTRIBUTES OF MLG UNITS IN FINLAND

MLG units in FinstratiMP are characterized and described by the following attributes. The definition of the attributes list focuses on the handling of specific features of the individual morpho-lithogenetic map units. The genetic deposit type is incorporated in the unit classification and thus not repeated in the attributes.

- Boundaries (observed/interpreted): criteria for observation/interpretation
- Description:
  - Genesis (i): MLG-unit-specific history and features:
    - GD setting for all MLG units
    - Depositional setting (environment), including ice margin water depth etc.
    - Genetic deposit type (Tables 3, 4)
    - Landform characteristics
    - Brief description
- Compositional characteristics (o/i): lithology and structures, also including information on deposit thickness, if known
- Geological age: Late Weichselian and/or Holocene. In the future, the aim is to add older (pre-Late Weichselian) GD spatial units, as for these, the age is an essential attribute
- Former names for the same or approximately corresponding map unit:
- Key references:

an example:

MLG UNIT: Pulkkilanharju Esker

- Boundaries
  Bounded by Lake Päijänne, on dry land with fairly sharp borders
- GD setting
  Ice-lobe province flow area of the FLDIL province
- Depositional setting (environment)
  Subglacial setting, glaciolacustrine setting
- MLG Deposit Type
  GFer (Table 3 is also included in the main document)
- Landform characteristics
  Ridge, straight to curved
- Brief description:
  One of the main eskers of the FLDIL province SW part...
- Compositional characteristics
  S, G
- Age group:
  Late Pleistocene, (Late Weichselian), Early Holocene
- Former names of the corresp. unit:
  Part of the Asikkala–Joutsa Esker System
- Key references:
  Fogelberg, Palmu, etc. (see SS II-ice marginal system and..)

The table of all morpho-lithogenetic units in Finland includes the name and the type of unit, and the attributes ready to be transferred to FinstratMP (see above). A separate table is created in Excel, with tables for the MLG unit types (common table structure)

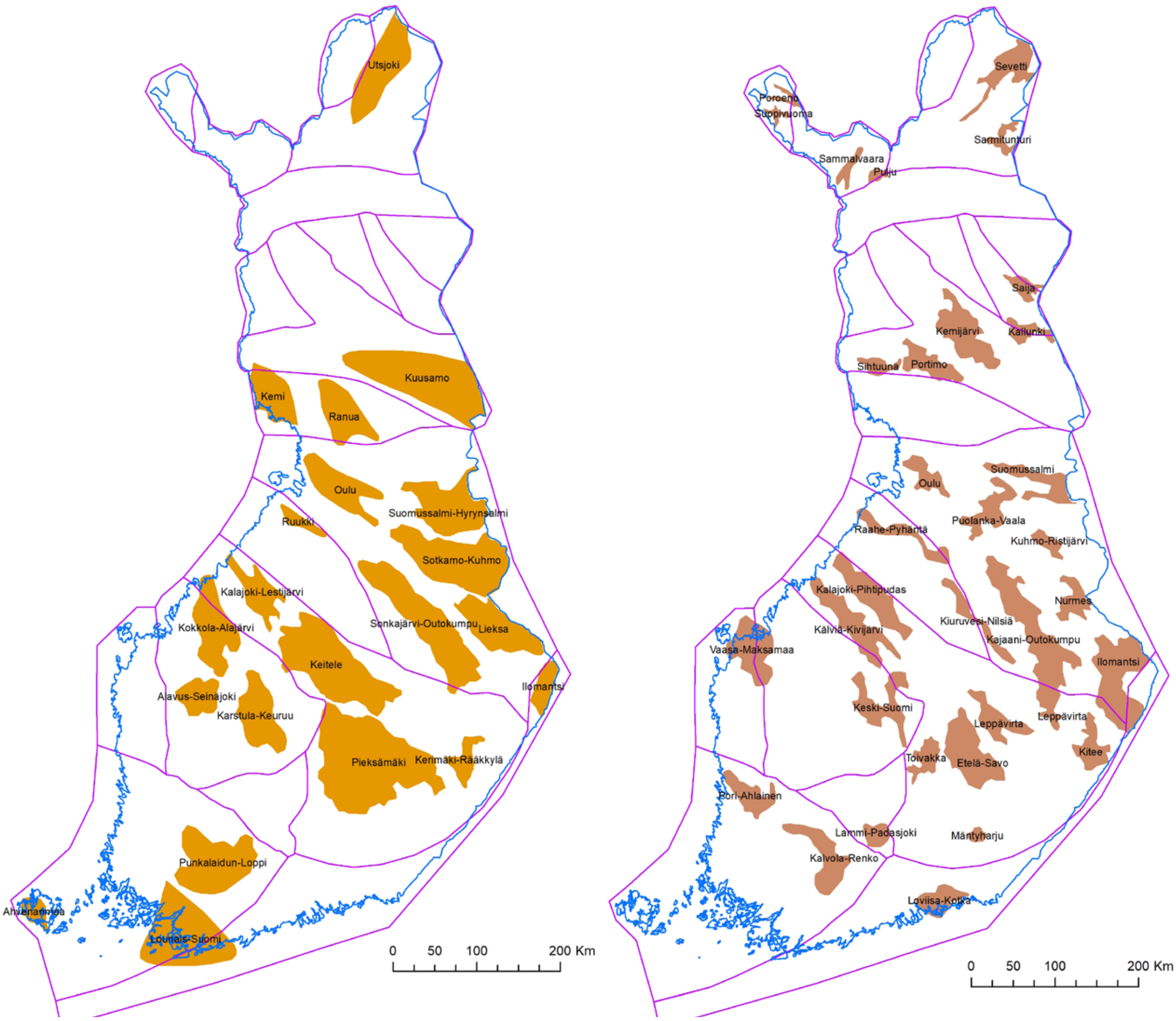

Fig. 2. Major drumlin fields on the left and major hummocky moraine fields on the right (Mäkinen et al. 2007, MORMI project 2007). The violet lines are the GD ice lobe provinces and interlobate regions (see the main article).

4 FINSTRATI MLG UNIT ATTRIBUTE DOMAIN LIST TABLES

Table 1. Glaciodynamic setting, linked to a defined glacial dynamic ice-lobe province or interlobate region.

Ice-lobe province outer marginal zone
Ice-lobe province flow area
Ice-lobe province lateral margin
Ice-lobe province, internal route
Ice-lobe province onset zone
Interlobate region
Interlobate region, fjeld area
Ice-divide zone

Table 2A. Hierarchical depositional setting attribute domain list: A subset from the Event Environment Vocabulary of the IUGS Commission for Geoscience Information (CGI) Geoscience Terminology Working Group.

Earth surface setting			
	Glacier-related setting		
		Englacial setting	
		Glacial outwash plain setting (links to the glaciofluvial deltaic system setting)	
		Proglacial setting	
			Glacier terminus setting
		Subglacial setting	
		Supraglacial setting	
		Glaciolacustrine (and glaciomarine) setting (missing from CGI)	
	Deltaic system setting (glaciofluvial ice-contact deltas here)		
		Delta front setting	
		Delta plain setting	
		Lacustrine delta setting	
	River plain system setting (extramarginal glaciofluvial deposits here)		
		River channel setting	
			Braided river channel setting

Table 2B. Suffix classification extracts from BGS mapping of superficial deposits (additional depositional setting (environment) information).

Ice Contact
Ice Marginal
Ice Thrust
Lodgement
Melt-out
Subglacial
Sheet or Tabular
Fan or Delta

Table 3. Morpho-lithogenetic unit types for FinstratiMP.

MLG geological unit type	Genetic deposit type	Main lithology*	Typical landform characteristics
Ice-marginal system	GFim	S, G, (D)	An ice-marginal system of delta complexes and other related deposits, with delta plateaus, ice-marginal ridges
>Delta complex	GFim	S, G, (D)	Plateaus, often with the below-mentioned parts
>>Delta (Sandur Delta)	GFimd	G, S, mS, fS	Plateaus
>>Sandur	GFims	G, S	Plateaus, with meltwater channels
>>Proximal ice contact zone unit	GFimpic	G, S, (D)	See below, often overridden, kettleholes
>>Ice-marginal ridge	GFimpm	G, S,(D)	Ridge on top of the plateau (delineates proximal part)
>Ice-marginal ridge	GFimr	S, G, (D)	A separate ridge
Esker system	GFe	S, G	The complete "train"
>Esker	GFeb	S, G	Esker main and linked branches
>>Esker ridge	GFer	G, S	Ridge, also a ridge delineated by kettle holes, with lateral depositional elements (see below)
>>Esker sand (splay)	GFes	S (G)	Esker lateral (and distal) depositional elements
>>Esker delta	GFed	G, cS, mS, fS	Delta component of an esker system

* GEO classification, in English, typical examples: S = Sand, fS = Fine sand, mS = medium sand, cS = coarse Sand, G = Gravel,
D = Diamicton,

** For drumlin/lineation: See text

Table 3. Cont.

MLG geological unit type	Genetic deposit type	Main lithology*	Typical landform characteristics
>>Kame area	GFek	S	
>Interlobate esker	GFeil	S, G	Eskers at the boundaries of ice-lobe provinces and/or interlobate regions
Other glaciofluvial deposit, incl. extramarginal deposits	GFex	G, cS, mS, fS	
Till system	GTb	D	
>Basal till	GTbb	D	Veneer or blanket
>Drumlin (lineation**) field	GTblf	D	Lineation fields
>>Drumlin/lineation**	GTbl	D	Linear ridges (now polylines), normally not used as a unit
Hummocky moraine	GTh	D	Hummocky terrains and fields
>Subglacial hummocky moraine	GThb		"
>>Ribbed moraines	GThbr	D, (S, G)	", Ribbed moraine geomorphology
>>Murtoo moraines	GThbm	D, G, S	", Murtoo moraine geomorphology
>Ice contact (passive, partly supraglacial) unit	GThp	D, S, (G)	"
End moraines (diamicton-dominated)	GTim	D, (S)	
>End moraine ridge (Reunamoreeni-muodostuma) (can be part of an ice-marginal delta complex)(Notice the material difference to GFimr and GFimpm)	GTimr	D, (S)	Ridge form, may be multiple combined ridges, mainly in conjunction with ice-marginal systems
>Recessional moraines, small ridges (field)	GTimsr	D, (S)	
>>De Geer moraine field	GTimsrDG	D (S)	De Geer ridges in fields
>> Minor recessional moraine field	GTimsrr	D, (S)	Usually supra-aquatic or shallow water deposition
Dune field	E	fS	Dune ridge field

* GEO classification, in English, typical examples: S = Sand, fS = Fine sand, mS = medium sand, cS = coarse Sand, G = Gravel,
D = Diamicton,

** For drumlin/lineation: See text

Table 4. MLG unit-type classification for glacigenic (glacial and glaciofluvial) deposits compared with the classification of the GD map database (15.9.2020).

Code	Feature	Description	MLG unit type for FinstratiMP (see Tables 2 and 3) (genetic deposit type)
1	Glaciofluvial deposit	Main class of superficial deposits formed in ice-contact or closely related environments and deposited in fluvial processes by glacial meltwaters. The sediments of the deposits are generally coarse-grained sands and gravels, with minor components of diamictons and fine-grained sediments.	Not applicable = N/A
1.1	Esker	Eskers are the dominant general type of glaciofluvial deposit, usually deposited in an ice-contact environment by glacial meltwaters. Typical deposits are long, continuous ridges with the related lateral and distal depositional elements. The depositional sub-environments are mainly subglacial tunnels, large crevasses and ice margins.	Esker (GFe)
1.1.1	Coarse-grained esker core	The dominantly gravelly or coarse sand core element of an esker (deposit)	Esker (GFe)
1.1.2	Esker sand	Typically the main element of an esker: deposited on top and to the lateral and distal sides of an esker core (deposit)	Esker (GFe)
1.2	Interlobate esker	An interlobate esker is a ridge type of superficial deposit that has been deposited by two major ice lobes at their common edge-to-edge contact. These bedforms are typically larger in scale and also coarser grained than eskers.	Interlobate esker (GFeil)
1.3	Ice-marginal glaciofluvial deposit	An ice-marginal deposit is a major glaciofluvial deposit type in Finland and, as the name implies, has been deposited by glacial meltwaters at the ice margin. The material of the deposit is usually sand and gravel, with a minor part formed by diamicton. In large systems, silty sand and silt is also prominent in the deeper distal parts of the deposits.	Delta complex (GFim)
1.3.1	Delta	A glaciofluvial delta is an ice-marginal deposit, in which the deposition has continued until the contemporaneous ice lake water level has been reached, i.e. the surface of the deposit is related to the water level during the deposition.	Delta (Sandur delta) (GFimd)
1.3.2	Sandur	A sandur is an ice-marginal glaciofluvial deposit (part), where the surface has grown above the depositional stage lake water level. On the surface are typically channels, showing meltwater flow routes towards the deltaic part of the deposit (see above)	Sandur (GFims)
1.3.3	Proximal ice-contact deposit	A proximal ice-contact deposit is a proximal ice-marginal deposit part of a large deposit complex, which is mainly composed of sorted coarse-grained material and a minor compositional component of diamictons. The deposit is typically a ridge and can be depositionally described as a push moraine complex, with glaciotectonic structures. This deposit subtype is related to deposit type 4.1.1, which has the same depositional spatial location, but, due to a different depositional environment and processes, has diamicton-dominated materials.	Proximal ice-contact zone unit (GFimpic)
1.4	Extramarginal deposit	A superficial deposit with the sedimentation processes dominated by glacial meltwaters, but in a non-ice-marginal, more distal location, for example in a valley further away from the ice margin.	Other glaciofluvial deposit, incl. extramarginal deposits (GFex)
1.5	Littoral deposit	Various types of mappable littoral deposits, often related to glaciofluvial deposits.	N/A (L)

Table 4. Cont.

Code	**Feature**	**Description**	**MLG unit type for FinstratiMP** (see Tables 2 and 3) (genetic deposit type)
1.8	Buried glaciofluvial deposit	These deposits are buried sand and gravel deposits that are not recognizable in DEM or shallow geophysical surveys. They are typically overlain by marine or till deposits representing pre-Late Weichselian deposition. Therefore, their identification is based on drilling, reflection seismic and borehole seismic methods. The most typical formation in these classes is an esker.	Esker (GFe)
1.8.1	Buried coarse-grained esker core	The main element of a buried esker deposit. Gravel or coarse sand are core elements of an esker.	Esker (GFe)
1.8.2	Buried esker sand	The second element of a buried esker deposit. Sand deposits cover the esker core.	Esker (GFe)
1.8.3	Supposed buried glaciofluvial deposit	Typically a continuation of the 1.8 deposit, but not verified by drilling. Drilling is an essential method to ensure the lithology of the deposit lying at 10–100 metres depth below the ground surface.	N/A
2	Glacially lineated terrain	Glacially lineated terrains were exposed to the subglacial deformation processes. Most commonly, they are till beds modified during the last deglaciation. This main class is not in general mapping use. It is planned to be used for mega-scale glacial lineation (MSGL) generalizations from drumlin 3.1 and megafluting 3.5 datasets in map production.	N/A
2.1	Fluted terrain	The fluted terrain class is determined for the thoroughly fluted (see 3.4 for fluting description) surface of the bed, where large numbers of ridges are present and it is not practical to draw every single ridge crestline. Large concentrations of small fluting ridges are typically located on the thin till surfaces of relatively thin cover till, on the lee sides of bedrock hills. Example sites are indexed in Rukavaara and Inari.	Drumlin (lineation) field (GTblf)
2.2	Drumlin upland	Drumlin upland is a theoretical class to delineate the shield-shaped upland areas that typically have thick Quaternary sediment cover, perhaps related to older ice-marginal glaciofluvial deposits. They are relict forms of a shield-shaped (cf. Gluckert 1973) earlier landscape smoothened by a glacier (cf. Möller & Dowling 2015, Eyles et al. 2016). Flutings, drumlins, megaflutings and rarely pre-crags are mapped as polylines on drumlin upland polygons (see 3.1, 3.4 and 3.5 for mapping and bedforms principles). The upland itself is delineated by the morphology of the hill.	Drumlin (lineation) field (GTblf)
3	Glacial lineation	Glacially lineated terrain is a main class for mapping glacially lineated beds. In the glaciological sense, the bedforms highlight the glacial erosion of substrates at the base of a deforming subglacial debris layer. Typical features mapped under head class 3 are drumlins and megaflutings (for a review, see 3.1 and 3.5), which are not possible to classify into classes 3.1 and 3.5 due to uncertainties such as urban activities or more natural reasons such as shoreline, fluvial or aeolian processes cutting or masking the start or end point. Sometimes, mega lineations are mapped in this class, because their shape is too vague to be mapped under specific classes below. Palimpsest beds belong to this class, and their relative age is given in the remarks field in the attribute table.	Drumlin/lineation (GTbl)

Table 4. Cont.

Code	**Feature**	**Description**	**MLG unit type for FinstratiMP** (see Tables 2 and 3) (genetic deposit type)
3.1	Drumlin or drumlinoid	Drumlins have a "classical shape" consisting of smooth oval-shaped elongated hills or hillocks with a steeper, often wider and blunter end, the stoss side, pointing in the up-ice direction and a gently narrowing, sloping pointed end, the lee side, facing in the down-ice direction (Fig. 3). This class has a wide variety of forms, not only the classical cigar or cylinder-shaped drumlin, but also less matured and developed drumlinoids, and bedrock plays its own role in the internal structure. They are landforms formed by erosion of the substrates at the base of a deforming subglacial debris layer. Under the (<1metre-thick) deformation till carapace, there are typically remnant sediment bodies with autochthonous cores (Eyles et al. 2016). Drumlins also often exist in swarms or fields of tens or even thousands of drumlins and drumlinoids, representing fast ice flow work in the region. Their elongation ratios used in this process are between 2:1 and 7:1.	Drumlin/lineation (GTbl)
3.2	Rock drumlin	Rock drumlins on the Fennoscandian shield are always formed when the glacier flowed up and over a bedrock hill, resulting in the steering of the ice side of the rock. They are presumably much older and long-lived bedforms that have been cut and reshaped during successive glaciations. The topography of glacially megalineated bedrock surfaces, once established, may control ice-flow directions during subsequent glaciations. Their size varies from between a few metres to tens of kilometres in scale (cf. Krabbendam et al. 2016). (E. Appendix. Hankasalmi etc.)	Drumlin/lineation (GTbl)
3.3	Trough valley or crescent trough	Trough valleys are formed in shear zones or other large bedrock valleys that are extensively eroded by crystalline rock boulders present in basal debris. Krabbendam & Bradwell 2014 proposed that trough valleys are formed in old bedrock valleys that have been exposed to long-term erosion and subsequently "rotten rock" has been easily removed by the glacier. Sometimes, tightly spaced trough valleys have bullet noses facing up-glacier. They have resulted from the steering of ice movement by escarpments are presumably much older and long-lived bedforms cut and reshaped during successive glaciations. Crescent troughs belong to the same family of mega-scale bedrock erosional features. They are formed during glacier flow over bedrock hills. Their blunt revolver bullet shape is always eroded down to the crystalline bedrock and they are typically the starting points for megaflutings.	N/A
3.4	Fluting	Flutings are elongated streamlined ridges of sediment aligned parallel to former fast ice flow (elongation ratio < 7:1). They are usually only a few dozens of centimetres to a few metres high and wide (Fig. 3). Flutings tend to occur in sub-parallel groupings and consist of deformation till (Eyles et al. 2015). Flutings are usually straight or slightly curving, although they may bend and cut the direction around the boulders and then resume a straightforward course. Flutings are often formed downglacier from small bedrock knobs or boulders. Flutings may be hundreds of metres, even kilometres long, but many times smaller in scale compared to drumlins and megaflutings, representing exposure to much lower glacier-based pressures during their formation.	Drumlin/lineation (GTbl)

Table 4. Cont.

Code	Feature	Description	MLG unit type for FinstratiMP (see Tables 2 and 3) (genetic deposit type)
3.5	Megafluting	Megaflutings (Megaridges: in Eyles et al. 2016) are elongated glacial bedforms that form an erosional continuum with drumlins, representing faster ice flow (Eyles et al. 2016). Their lengths are the longest in our inventory, also representing the fastest ice flow under high glacier-based pressures (elongation ratio < 7:1). Their shape is typically highly variable due to bedrock topography changes and these sediment ridges are naturally more symmetrical than bedforms that exist on the "rough" bedrock region (see Fig. 3). Sediment dominant ridges typically have a (<1-m-thick) deformation till carapace overlying remnant sediment bodies with autochthonous cores (Eyles et al. 2016).	Drumlin/lineation (GTbl)
3.6	Pre-crag	The so-called 'pre-crags' are common features in southwestern Finland. A typical feature is flutings (3.4) extending on their upstream side. They are composed of remnant older sediments and record the divergent flow of the erodent layer around an emerging bedrock high (Haavisto-Hyvärinen et al. 1989).	Drumlin/lineation (GTbl)
4	Moraine	This main class consists of diamicton-dominated superficial deposits with a positive geomorphological landform, i.e. the features are hummocks, ridges, hillocks.	N/A
4.1	Ice-marginal moraine	Ice-marginal moraines have been deposited at the glacier margin. This is the hierarchically the highest-level class of the diamicton-dominated, ice-marginally formed superficial deposits.	End moraines (diamicton-dominated) (GTim)
4.1.1	Large diamicton-dominated dump moraine in end-moraine complexes	A large diamicton-dominated moraine ridge area, often in end moraine complexes, produced by material being dumped or thrusted.	End moraines (diamicton-dominated) (GTim)
4.1.2	De Geer moraine	De Geer moraines (DGM) are small moraine ridges formed at the grounding line or deformation during a calving event of the retreating ice sheet (e.g. De Geer 1940, Aartolahti 1972, Lindén & Möller 2005, Bouvier et al. 2015, Ojala et al. 2015). Bouvier et al. (2015) and later (Ojala 2016) argued that DGMs are equifinal landforms with various mechanisms of formation, but when characterized by regular and evenly spaced ridges, they are probably formed annually, or at least very closely represent the local rate of ice-margin retreat. Furthermore, most studies agree that their geomorphology represents ice sheet dynamics by indicating the direction of deglaciation and the curvature of the ice margin during the retreat (e.g. Boulton et al. 2001, Lindén & Möller 2005, Ojala et al. 2015).	De Geer moraine field (GTimsrDG)
4.1.3	Minor recessional moraine	Minor recessional moraines are supra-aquatic relatives of De Geer moraines. Their thrusted and sheared character together with smaller amounts of glacial melt stream deposits propose their formation at the supra-aquatic glacier margin. These diamicton-dominated ridges have been deposited by glacier bulldozing. Their shape seems to follow the ice margin shape with a height of some tens of centimetres to some metres. They typically form fields indicating glacier retreat in the area. See 4.1.3 for a review; this is the single form of the type class, mapped earlier as a polyline, which could now be delineated as a polygon.	Minor recessional moraine field (GTimsrr)

Table 4. Cont.

Code	**Feature**	**Description**	**MLG unit type for FinstratiMP** (see Tables 2 and 3) (genetic deposit type)
4.3	Hummocky moraine	Hummocky moraine areas of the highest hierarchical classification level, either the subglacial active ice type or passive type, including hummocky moraine areas of the supraglacial environment. This class is used for ambiguous deposits that are problematic to delineate.	Hummocky moraine (GTh)
4.3.1	Subglacial hummocky moraine (active ice)	A large zone of hummocky moraines deposited under the active ice. Often related to the transition of ribbed moraine fields to the cold bed region. The typical glaciological location is in marginal areas of flow corridors and onset zones or other regions of sluggish ice flow.	Subglacial hummocky moraine (GThb)
4.3.2	Ice-contact hummocky moraine (passive/partly active, pro-glacial/ice frontal)	Hummocky moraine areas that have at least a proportion of the hummocks consisting of coarse-grained material (sands and other meltwater-related sediments), and mass movement sediments ("flow till"), sometimes also relatively fine-grained sediments (silts), deposited in a supraglacial environment, with topographic reversal as one of the key components during the time of deposition (cf. Boulton 1968). This hummocky moraine type has been deposited in the relatively passive (stagnant) environment inside the ice margin, in a zone probably a few kilometres wide. Also to be noted is that this type of a deposit has had a sedimentation environment that is either supra-aquatic or with a maximum water depth of 20-30 metres at the adjacent ice margin.	Ice contact (passive, partly supraglacial) unit (GThp)
4.4	Ribbed moraine	The transversal, active-ice moraine-ridge morphology type has been classified as ribbed moraine (Kleman & Hättestrand 1999, Hättestrand 1997, Sarala 2003, 2005). As generalised, the ribbed moraine morphology consists of till ridges transverse to the ice-flow direction. However, there is considerable variation between areas and ribbed moraine types. Furthermore, ribbed moraine ridges typical have a bouldery surface or boulder-rich upper till where the lithology of the boulders represents very local bedrock, indicating an extremely short glacial transport distance. The formation of ribbed moraine occurred in the central parts of last Fennoscandian Ice Sheet (FIS), in the transitional zone between the cold-bed and the thawed-bed glacier during the early phase of deglaciation. Conditions for the formation of ribbed moraines were favourable in the zone between 200–300 km from the latest ice-divide zone, i.e. in southern Finnish Lapland and in Ostrobothnia, in western coast areas. In the GD database, the ribbed moraines are described as areas. They are divided into three main subtypes, hummocky ribbed moraine, Rogen moraine and minor ribbed moraine, following the classification presented by Sarala (2003). Furthermore, it is occasionally possible to recognise a fourth type, namely crescent ribbed moraine. A crescent ribbed moraine, also described also as a Blattnick moraine in Sweden (e.g. Hättestrand 1997), is a rare ribbed moraine type in Finland, indicating certain subglacial reworking conditions after the formation of transversal ridge cores. The shape of a crescent ridge is more like a half circle, resembling dome-/barchan-shaped dunes. Ribbed moraines form a transitional series with streamlined features in those areas where glacier slid over the transversal ridge topography. In several places, a transitional series can be recognized from hummocky ribbed moraines to Rogen moraines and finally to drumlins and flutings (cf. Aario 1977a, b)	Ribbed moraines (GThbr)

Table 4. Cont.

Code	Feature	Description	MLG unit type for FinstratiMP (see Tables 2 and 3) (genetic deposit type)
4.4.1	Hummocky ribbed moraine	The hummocky ribbed moraine type (4.4.1) is the most common type in Finland (Sarala 2006). It consists of different sizes of hummocks oriented transversally to the ice-flow direction but not having direct signs of the flow direction.	Ribbed moraines (GThbr)
4.4.2	Rogen moraine	The Rogen moraine type is a classical ridge type (cf. Lundqvist 1969), which includes a distinct transversal ridge body with heads that bend in the down-ice direction. Sometimes, flutings on the surface of ridges are also found. The signs of the ice-flow direction are an indication of short glacier movement after the formation of the transversal ridge.	Ribbed moraines (GThbr)
4.4.3	Minor ribbed moraine	Minor ribbed moraines (4.4.3) only occur in the Sihtuuna area in Tervola, southwestern Finnish Lapland. The dimensions are somewhat smaller than of those of the other ribbed moraine types. This moraine type is called a Sihtuuna moraine and was first described by Aario et al. (1997).	Ribbed moraines (GThbr)
5	Covering deposit	This main class (5) is used for deposits covering glacier moraines or glaciofluvial deposits. Covering deposits are especially significant in relation to glaciofluvial deposits, because their original dimensions are often difficult to verify underneath the overlapping sediment cover that is actually part of the larger hydrogeological system. However, in the Ostrobothnian area of the Finnish west coast, these deposits can form zones several times wider compared to the completely reworked esker ridge, for which the original area is unmappable with remote sensing techniques.	N/A
5.1	Covering littoral deposit	Sea currents or shoreline wave action reworked shallow coastal sediments to form sand or gravel deposits. These deposits are often related to glaciofluvial deposits, but fascinating beach ridges and related deposits are also found, which are linked to regions with till and moraine deposits.	N/A (L)
5.2	Covering diamicton	A thin sheet of till resting on the older sediments describes this glacier deposit type the best. The till, which is <4 m thick, is typically massive deformation till with a fluted surface and stands out from the sometimes similar but more variable surface of the large end moraine complexes (4.1.1). There is a thin till cover over the glaciofluvial delta and a small end moraine ridge marking the end of the short period of glacier surge. These deposits relate to glacier re-advance and therefore appear in large end moraine zones.	N/A (GTb)
5.3	Littoral deposit on covering diamicton	A special case of a diamicton-covered glaciofluvial deposit overlain by littoral sediments.	N/A
7	Ice-marginal system	This is a main class for large ice-marginal deposits (different components) combined into a single deposit complex polygon.	Ice-marginal system (GFim)
8	Unclassified feature (distinctive feature, but there is not yet any information to classify)	This feature class consists of distinctive features for which there is not yet information to classify them into a specific deposit type.	N/A

Table 5A. Landform characteristics (CGI Geologic Unit Morphology, geological body, subset of relevant classes) (IUGS Commission for Geoscience Information (CGI) Geoscience Terminology Working Group).

Arch morphology
Basin shape
Blanket shape
(Boudin shape)
Channel shape
(Column shape)
Fan
Layer shape
Mound
Pipe
Rock body geometry irregular
Trough shape

Table 5B. Landform characteristics, BGS landform classification, could be partly more suitable.

Fan
Plain
Hummocky/moundy terrain
Ridges
Terraces
Blanket
Veneer
Complex

Table 6. Main lithology (grain size).

Main lithology (grain size), Code	GEO	GEO in English
S	Hiekka	Sand
>fS	Hieno Hiekka	Fine Sand
>mS	Keskikarkea Hiekka	Medium Sand
>cS	Karkea Hiekka	Coarse Sand
G	Sora	Gravel
D	Moreeni	Diamicton (Till)
F	Siltti ja Savi	Fine sediments (Silt and Clay)
>FC	Savi	Clay
>FSi	Siltti (Hiesu ja hieno hieta)	Silt

Table 7. Age group attribute: geological timescale classification from the IUGS Commission for Geoscience Information (CGI) Geoscience Terminology Working Group.

Eonothem / Eon	Erathem / Era	System / Period	Series / Epoch	Stage / Age	North West European Stages
Phanerozoic					
	Cenozoic				
		Quaternary			
			Holocene		
				Meghalayan	
				Northgrippian	
				Greenlandian	
			Pleistocene		
				Late Pleistocene	
				Chibanian	
				Calabrian	
				Gelasian	
GTK internal proposition					
		Quaternary			
			Holocene		
				Late Holocene	
				Middle Holocene	
				Early Holocene	
			Pleistocene		
				Late Pleistocene	
					Late Weichselian
					Middle Weichselian
					Early Weichselian
					Eemian
					Saalian

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Additional table. Genetic deposit types used in the GTK MLG map unit classification. An abridged comparison with BGS genetic subdivisions (classes) of natural superficial deposits (McMillan and Powell 1999) is also provided.

GTK classification Level 1 >Level 2 >>Level 3	**BGS classification** Level 1 >Level 2 >>Level 3
Glacigenic deposits, G	
>Glacial deposits, GT	
>>Till, basal – includes lineations (drumlins etc.), **GTb**	Glacigenic deposits: >Till (glacial diamicton)
>>**Hummocky moraines** (with various subtypes), **GTh**	Glacigenicdeposits:>Morainicdeposits>>Hummocky moraine*
>>Diamicton-dominated end moraines, De Geer and other recessional moraines (also in groups of ridges) **GTim**	Glacigenic deposits: >Morainic deposits >>Push moraine
>Glaciofluvial deposits, **GF**	
>>Eskers GFe	Glacigenic deposits: >Ice-contact glaciofluvial deposits >>Esker deposits*
>>**Ice marginal glaciofluvial deposits** (sandurs, deltas, subaqueous fan deposits), **GFim**	Proglacial deposits: >Glaciofluvial sheet and channel deposits >>Outwash (sandur) deposits* >>Terrace deposits; >Glaciolacustrine deposits >>Lacustrine deltaic deposits >>Beach deposits >>Subaqueous fan deposits*
>>**Other glaciofluvial deposits** (extramarginal, kames, kame and kettle), **GFex**	Glacigenic deposits: >Ice-contact glaciofluvial deposits >>Kame and kettle deposits*
Basinal deposits, B **>Marine sediments BM** **>Lacustrine sediments BL**	Includes gyttja
>Glaciolacustrine and glaciomarine sediments, BG	Proglacial deposits: >Glaciomarine deposits >>Sea-bed deposits Lacustrine deposits: >Glaciolacustrine deposits
Beach (littoral) deposits, L >Beach deposits on the higher hillslopes, berms, bars, spits >Beach deposits covering lower hillslopes and valleys	Coastal zone deposits: >Intertidal deposits >>Beach deposits; >Supratidal deposits >>Storm beach deposits Lacustrine deposits: >Beach deposits >Lacustrine shore face deposits
Fluvial deposits, F >Coarse grained fluvial deposits **Fc** >Fluvial deposits of variable grain size **Fv** >>Deltas **Fvd**	Alluvial deposits: >Fluvial deposits >Alluvial fan deposits >>Fluvial terrace deposits Lacustrine deposits: >Lacustrine deltaic deposits
Aeolian deposits, E	Aeolian deposits
Organic deposits (peatlands), **P** >Minerotrophic peatlands, fens **PCt** >Ombrotrophic peatlands, bogs **PSt**	Organic deposits>Peat>>Blanket bog peat>> Hill, Raised bog peat*>>Basin peat>>Fen peat*>>Peat flow
Mass movement deposits **M** >Mass movement deposits of fine-grained sediments >Mass movement deposits produced by seismic activity >Solifluction deposits >Talus	Mass movement deposits: >Landslip >Talus >Head
Frost action deposits **FR**	
Anthropogenic deposits **A**	Artificial (man-made) ground (no exact correspondence)