




Revised classification of glaciofluvial landforms in the Finnish sector of the Fennoscandian Ice Sheet

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Effective and sustainable land use, conservation, and the use of geological resources (incl. raw materials, aggregates and groundwater) require a clear classification system of sedimentary units, with well-defined vocabulary and unified mapping practices. To ensure harmonization of the GTK's (Geological Survey of Finland) map database of Finnish Quaternary surficial features, classification criteria for glaciofluvial landforms have been updated. The work is based on earlier geological field mapping of surficial Quaternary deposits as well as previous and ongoing LiDAR DEM-based mapping of glaciofluvial landforms in Finland. In this paper, we present the updated classification and terminology, discuss the defining criteria of glaciofluvial map unit types and show their representative examples. Inherent challenges and limitations of this remote sensing-based mapping approach are also discussed.

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Glaciofluvial sediments deposited by the Late Weichselian Fennoscandian Ice Sheet (FIS) form much of the surficial sediment cover in Finland and are crucial for Finnish society in various ways. Most importantly, they host Finland's main aquifer systems for municipal water extraction (e.g. Mälkki 1999), and they also serve as key sources of construction aggregates (e.g. Niemelä 1979). Due to their varied and often distinct lithological and morphological characteristics, glaciofluvial landforms such as eskers also guide and contribute to habitat diversity (e.g. Finnish Environment Institute 1984; Airaksinen & Karttunen 2001). Academically, glaciofluvial strata in the FIS area include an outstanding sedimentary archive of the Younger Dryas—Holocene (e.g. Donner 2010; Stroeven *et al.* 2016; Mangerud *et al.* 2023), recording changing glacial hydrology and dynamics during times of abrupt climate changes and climate warming, in part analogous to today. Finally, the ice-marginal glaciofluvial systems, such as the Salpausselkä ice-marginal systems, are globally remarkable and represent some of the most important geological formations in Finland's geological heritage and national scenery.

Effective land-use planning, sustainable land use and environmental protection of surficial sediment-based systems require accurate geological mapping data (e.g. Haavisto 1983) and a well-established classification scheme for sedimentary units. The map data, classification systems and vocabulary need to be easily available, unified and well-defined to enable efficient communication and cooperation among various stakeholders, including communities, the private sector, government

agencies and academia. Recently, the Geological Survey of Finland (GTK) has adopted a morpho-lithogenetic (MLG) approach to classify and map surficial glacial features in the Finnish sector of FIS (Putkinen *et al.* 2017; Palmu *et al.* 2021; Lunkka *et al.* 2024). This approach, originally developed by the British Geological Survey (McMillan 2005; Lee & Booth 2006), integrates the lithology, genesis and morphology of a depositional unit. Although the concept has been in use in some form since the 1970s in Finland, the advent of high-resolution Light Detection And Ranging (LiDAR) technology has revolutionized the mapping of Quaternary geomorphology across the country (Johnson *et al.* 2015; Ojala & Sarala 2017). As formal stratigraphic approaches are notoriously challenging to apply to Quaternary deposits in the FIS area due to their scattered and often thin appearance, MLG mapping has turned out to be the most practical approach to classify the Finnish Quaternary landforms (Putkinen *et al.* 2017; Palmu *et al.* 2021; Lunkka *et al.* 2024).

The previous MLG mapping aimed to provide the first version of a surficial glacial features map covering all of Finland, including both moraine and glaciofluvial features (Putkinen *et al.* 2017). Altogether, almost 200 000 map unit polygons were digitized and published in the Maankamara webportal (GTK 2025). In addition, palaeo ice-stream corridors were mapped (Palmu *et al.* 2021). Although the project was successfully completed, the substantial workload and stringent time constraints posed challenges, particularly in maintaining consistency in mapping criteria. Recently, the previously

defined map units have been reviewed using LiDAR-derived hillshaded 2 m grid digital elevation models (DEMs) (NLS 2025), in combination with lithological mapping data at scales of 1:20 000/50 000, 1:100 000 and/or 1:200 000. The revised map will be published in the Maankamara webportal in 2026. This paper aims to present an updated classification of glaciofluvial landforms and to clarify the criteria used in the classification. Representative examples of map units are provided to illustrate their typical characteristics and support visual interpretation. Additionally, the challenges and limitations of this remote sensing-based MLG mapping approach are discussed.

Earlier versions of the classification

The earlier version of the classification (Putkinen *et al.* 2017; updated in Palmu *et al.* 2021) used the following classes: 1. Glaciofluvial deposits; 1.1. Esker; 1.1.1. Coarse-grained esker; 1.1.2. Esker sand; 1.2. Interlobate esker; 1.3. Ice-marginal glaciofluvial deposit; 1.3.1. Delta; 1.3.2. Sandur; 1.3.3. Proximal ice-contact deposit; 1.4. Extramarginal deposit; 1.8. Buried glaciofluvial deposit; 1.8.1. Buried coarse-grained esker core; 1.8.2. Buried esker sand; 1.8.3. Supposed buried glaciofluvial deposit. Additionally, classes 1.5. Littoral deposit; 1.6. Glaciofluvial erosional area; and 1.7. Empty holes were included in the database structure. In the text below, the refined classes and their mapping criteria are presented.

Updated classification

Glaciofluvial landforms (Class 1)

Glaciofluvial landforms (Class 1) are the main overall category for landforms formed by meltwater flow processes in glacial environments (Table 1). These landforms contain deposits that are generally coarse-grained, comprising sand and gravel, with minor components of diamictons and fine-grained sediments. In GTK's classification, the class glaciofluvial is broad and extends from subglacial meltwater flow-dominated settings (e.g. esker) to interlinked subaquatic glaciolacustrine environments directly sourced by glaciofluvial processes (e.g. deltas). The class includes several sub-classes, primarily eskers (Class 1.1), ice-marginal glaciofluvial landforms (Class 1.3), extramarginal landforms (Class 1.4) and buried glaciofluvial landforms or deposits (Classes 1.8 and 1.9). In mapping, the generic and undifferentiated Class 1 is used for predominantly sorted sandy to gravelly deposits where glaciofluvial affinity can be inferred from the depositional context, but which are poorly exposed or preserved and cannot be assigned to any sub-category with certainty due to the lack of a clearly interpretable geomorphological form (Fig. 2).

Esker (Class 1.1). – Class 1.1 is a general category for coarse-grained, steep-sided gravelly ridges often oriented perpendicularly towards the ice-margin. Morphologies can vary from sharp-crested to round-crested or flat-crested. The word esker comes from the Irish word *eisceir*, which means 'a ridge or an elevation separating two plains or depressed surfaces' (eDIL 2019). Eskers are usually formed in subglacial and englacial tunnels (Röthlisberger channels) but are also thought to include deposition in large crevasses (cf. crevasse fill deposits) and ice-contact channels at the ice-margin (e.g. Banerjee & McDonald 1975; Brennand 2000; Hooke 2005; Burke *et al.* 2008). Their development is typically time-transgressive, enhancing their polygenetic nature (Mäkinen 2003). This means that the depositional environments of ridge sequences are often varied and may include elements produced in multiple sub-environments (Warren & Ashley 1994).

Esker development and resulting morphology are influenced by numerous factors, including bedrock topography, fracture zones and the lithology of the substratum (e.g. hard bed vs. soft bed; Frydrych *et al.* 2025). The location within ice sheets, subglacial pressure (affecting esker orientation), sediment availability and meltwater input also play significant roles (e.g. Burke *et al.* 2015; Ahokangas 2019). For instance, a large-scale variant of eskers, known as interlobate eskers, forms in the contact zone between two major Late Weichselian ice lobes and can reach thicknesses of up to 100 metres and widths of several kilometres (Mäkinen 2004; Ahokangas 2019; Palmu *et al.* 2021; Fig. 3C). Additionally, the rate of ice-margin retreat (e.g. beading, segmentation vs. continuation) and whether the ice-margin is subaerial or subaquatic can significantly influence their morphology and architecture (e.g. tunnel roof collapse and esker bifurcation when ice-margin terminates on dry land; Dewald *et al.* 2021).

In the updated classification, Class 1.1 forms the main category for eskers and contains two sub-categories: Esker core (Class 1.1.1) and Esker splay (Class 1.1.2) (Fig. 3A–C). In mapping, the general Class 1.1 is used for esker occurrences with widths less than approximately 100 m or indistinct esker occurrences, where the core and adjacent sediments cannot be clearly separated (Fig. 3A). In addition, in contrast to the previous classification (Putkinen *et al.* 2017; Palmu *et al.* 2021), interlobate eskers (previously Class 1.2; Fig. 1) are now treated with the same criteria as other eskers and are incorporated in other esker classes. However, the interlobate affinity is kept as an attribute in the database. The present classification does not deeply explore esker genesis or their lithological diversity and should therefore be considered only as an initial framework for esker-related research.

- Esker core (Class 1.1.1). Esker cores are usually long, elongate, straight or sinuous, steep-sided ridges that typically consist of gravel and/or coarse sand

Table 1. Classification and short descriptions of glaciofluvial MLG units in the Finnish sector of the FIS after the present revision. For class numbers, see also the legend in Fig. 1.

Class	Unit type	Short description	Number of occurrences
1	Glaciofluvial landforms	A general and undifferentiated class of varied landforms dominantly composed of sorted coarse-grained sediments, such as sand and gravel, with minor amounts of diamicton and fine-grained sediments, eroded and/or deposited by glacial meltwaters. The class extends from subglacial glaciofluvial systems to ice-marginal deltas.	12 305
1.1	Esker	Coarse-grained, steep-sided ridges that may be flanked by finer-grained, gently sloping landforms. The general Class 1.1 is used for small- to medium-sized eskers (width approximately <100), indistinct occurrences and cases where the core and splay cannot be separated.	26 284
1.1.1	Esker core	Dominantly gravelly and sharp-crested ridge that forms the core of an esker.	4334
1.1.2	Esker splay	Gently sloped, often sand-dominated landform flanking the esker core.	7875
1.3	Ice-marginal glaciofluvial landforms	A general class of ice-marginal landforms consisting of sand and gravel, with minor amounts of diamicton in the proximal zone and layers of silty sand and silt in the distal zone. The general Class 1.3 is used for indistinct, poorly developed or preserved ice-marginal landforms.	6575
1.3.1	Ice-marginal proximal zone	Dominantly sorted, coarse-grained landform with minor diamicton content, typically expressed as an asymmetric ridge parallel to the ice margin. It often shows a steep ice-contact slope and glaciotectionic structures.	1013
1.3.2	Sandur and delta plain	Gravelly to sandy glaciofluvial landforms characterized by braided meltwater channels, forming on gently sloping plains in proglacial or ice-contact environments. Class 1.3.2 includes inland features, such as outwash plains, and coastal features representing the subaerial parts of deltas.	940
1.3.3	Delta front	A sand- or gravel-dominated, variably sloping subaqueous landform occurring below and distal to Class 1.3.2. Class 1.3.3 refers to the delta front and includes features such as wave-cut terraces.	1516
1.3.4	Ice-marginal distal zone	Finer-grained, sand-to-silt-dominated, gently sloping landform occurring at the toe of 1.3.3. Interpreted to represent prodelta and associated sediments reworked by littoral processes.	251
1.4	Extramarginal landforms	Erosional and depositional, sandy to gravelly landforms formed by glacial meltwater usually in valleys beyond the ice-margin, commonly linked with the drainage of upstream ice-dammed lakes.	6890
1.8	Buried glaciofluvial landforms or deposits	Buried sandy and gravelly ridges and their gently sloping lateral extensions, whose geomorphology is not, or is only faintly, recognizable in DEM. These landforms/deposits are typically overlain by post-glacial fine-grained sediments, and their presence is verified by drilling or other methods.	67
1.9	Buried glaciofluvial landforms (inferred)	Typically a continuation of Class 1.8, but not verified by drilling or other methods.	300

(Fig. 3A–E). Class 1.1.1 is used when the core is morphologically well-defined, and its width with the related lateral sediments exceeds approximately 100 m. The sub-class covers both single trunk eskers as well as esker enlargements (Dewald *et al.* 2021), which comprises multi-ridged esker sections that converge both in downflow and upflow directions (Fig. 3C; Lindström 1993; Dewald *et al.* 2021). The class is typically used in conjunction with esker splay (Class 1.1.2). At ice-marginal positions, however, the sub-class can be associated with an ice-marginal glaciofluvial deposit (Class 1.3).

- Esker splay (Class 1.1.2). Esker ridges are commonly bordered by often finer-grained, sand-rich, gently sloping landforms that typically dip away from the central esker core. These landforms, referred to as esker splay (Class 1.1.2), are characteristically wider, lower-lying and thinner than the main ridge (Lewington *et al.* 2020; e.g. Fig. 3A, B). In planform, esker

spreads run parallel to the ridges and display relatively straight margins.

Their depositional environment and internal architectural diversity are known to a limited extent, and according to current knowledge, they may form subglacially in a linked cavity environment surrounding a tunnel within the meltwater route (Gorrell & Shaw 1991; Brennan 1994; Lewington *et al.* 2020). Additionally, esker spays may form in proglacial environments as subaqueous outwash fans (Powell 1990).

In GTK's classification, Class 1.1.2 covers mostly lateral occurrences of esker splay deposits and is used in conjunction with Class 1.1.1. The deposits of esker spays may grade into and/or merge with ice-marginal deposits (Class 1.3), and intergradational occurrences exist locally complicating their classification. Distinguishing characteristics include their relatively uniform width and contrasting orientation: esker spays are ori-

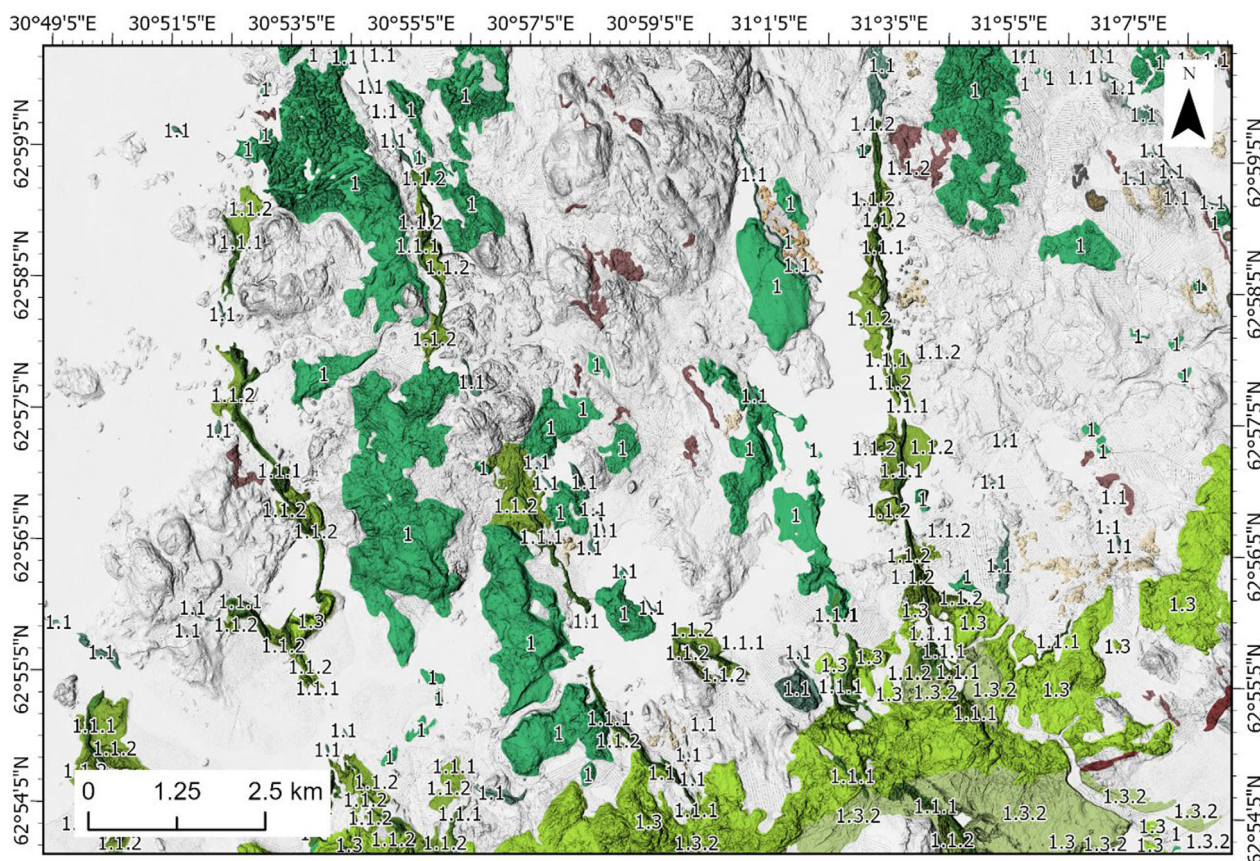


Fig. 2. Examples of map units assigned to the generic Class 1. Till-covered glaciofluvial deposits (Class 1) lacking a clear geomorphological form. Lapinniemi, north side of Koitere ice-marginal system.

ented parallel to the esker ridge, whereas ice-marginal deposits form ice-margin-parallel expansions (Fig. 3B).

Ice-marginal glaciofluvial landforms (Class 1.3)

Class 1.3 encompasses a wide variety of predominantly glaciofluvial landforms formed at or near the ice margin. Ice-marginal landforms formed by meltwater flow are varied, often forming complexes, consisting of a predictable set of features in proximal–distal transects. These landforms are typically composed of sand and gravel, with a minor diamicton component. Additionally, in large depositional systems, silty sand and silt are common in the subaqueous distal parts of the system. The prevailing landform and deposit types were particularly influenced by the water depth of the receiving basin (deep, shallow, dry land), the topography and structure of the bedrock affecting the feeder type and the re-advance or oscillation of the ice-margin. Sediment volumes vary substantially according to the locations of feeder systems and bedrock fracture zones, and locally, the deposits form some of the largest Quaternary sediment accumulations in Finland (Palmu *et al.* 2026). Post-depositional sedimentation and erosion processes,

such as wave action, have also significantly shaped the morphological expression of the Salpausselkäs, especially in southern and southwestern Finland.

In the updated classification, Class 1.3 forms the main category for ice-marginal glaciofluvial deposits, and contains four sub-categories: Ice-marginal proximal zone (Class 1.3.1), Sandur—Delta plain (Class 1.3.2), Delta front (Class 1.3.3) and Ice-marginal distal zone (Class 1.3.4) (Figs 5–7). The classes are redefined and reordered to reflect the proximal–distal gradient.

In mapping, the generic Class 1.3 is used to classify dominantly sorted ice-marginal supra- or subaqueous glaciofluvial–glaciolacustrine deposits where features such as lobate delta-morphology or sediment point source are not developed or preserved (Fig. 4). Its morphology may also include various knobs, mounds and ridges formed as a result of irregular melting of stagnant ice and complex sedimentation from sub-, en- or supra-glacial sources in ice-marginal settings.

Finally, it is also noteworthy that ice-contact subaqueous fans, that is, fans formed where subglacial or englacial meltwater tunnels discharge into glaciomarine or glaciolacustrine basins, constitute a common depositional element of many ice-marginal systems (e.g. in

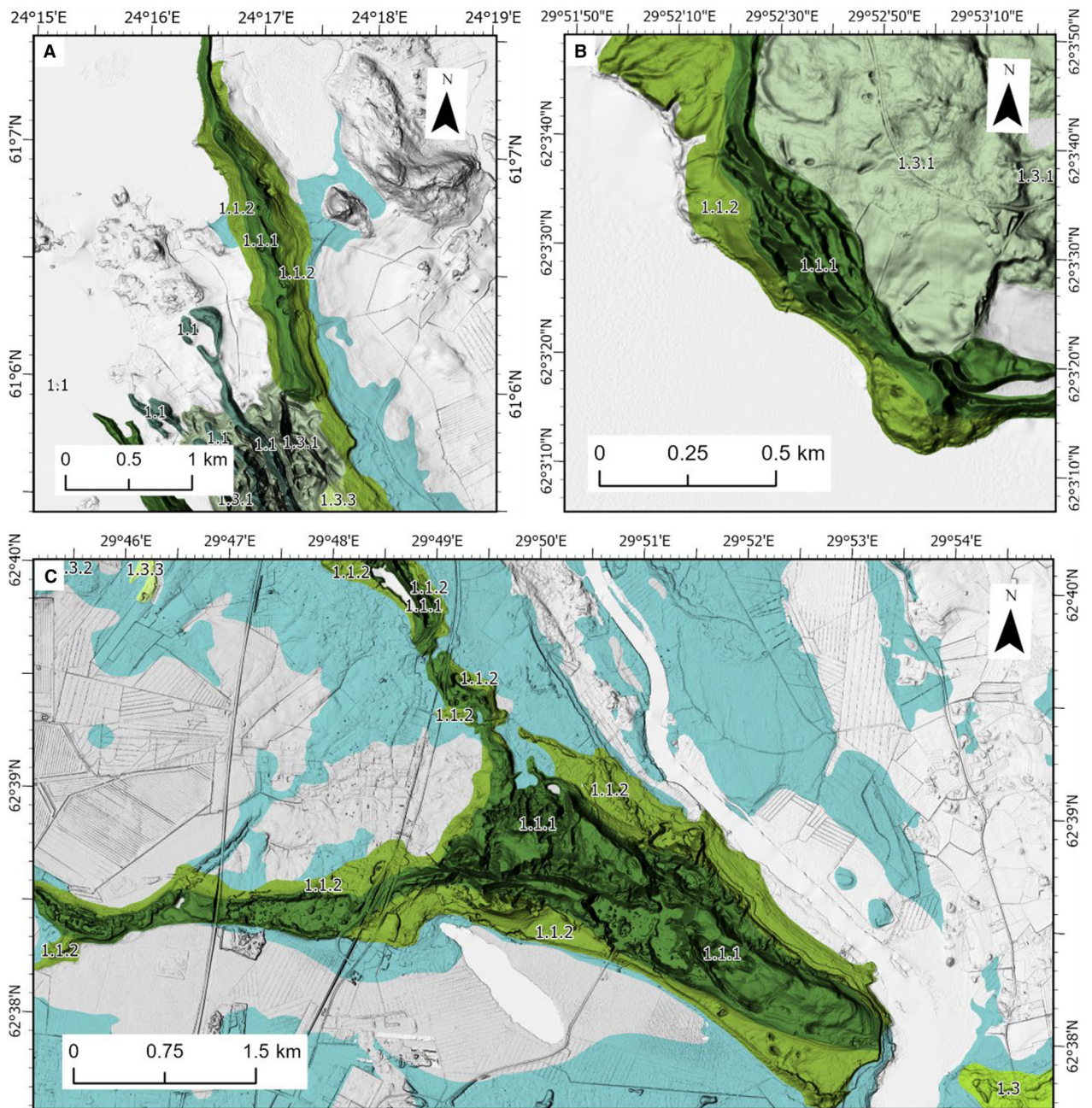


Fig. 3. Examples of esker core (Class 1.1.1) and flanking esker splay (Class 1.1.2) landforms. Note also the esker examples assigned to the generic esker Class 1.1, due to their small size and lack of separable core and splay units. Light blue—littoral deposits. A. South side of lake Vanajavesi, III Salpausselkä. B. Esker enlargement, Puhos, II Salpausselkä. C. Interlobate esker. Joensuu, south side of Pielisjärvi ice-marginal system.

the Salpausselkä zone) in Finland. However, these fans commonly lack preserved geomorphological expression due to subsequent reworking by littoral processes or are found buried beneath delta deposits (Fyfe 1990). Thus, they do not have their own classification but are included in either Class 1.3 or 1.3.1.

- Ice-marginal proximal zone (Class 1.3.1). Class 1.3.1 refers to the proximal ice-contact part of a glacioflu-

vial complex. It is mainly composed of sorted coarse-grained material and a minor component of ice-dumped and/or ice-squeezed diamictons (e.g. Kujansuu *et al.* 1993; Palmu 1999). The element typically forms irregular glaciotectionized ridges or zones that are oriented parallel to the ice-margin, and are characterized by deformation, faults and occasional push moraine slabs (Figs 5A, B, 7A). This element is particularly well-developed in the Finnish Lake

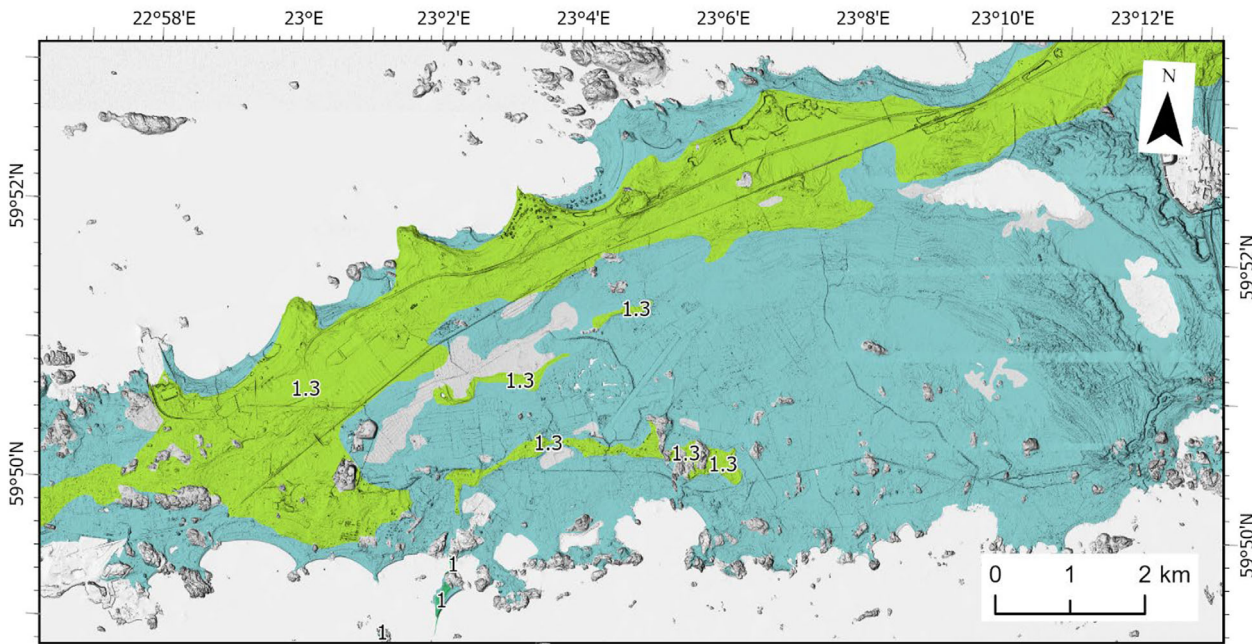


Fig. 4. Example of deposits assigned to the generic ice-marginal glaciofluvial Class 1.3 forming the first Salpausselkä ice-marginal complex at Hankoniemi, SW Finland. The deposits are strongly reworked by post-depositional littoral processes, which have obliterated their original geomorphological form. Light blue—littoral deposits.

District Ice Lobe, where it can form deformation zones several tens of metres high (Fig. 5B). Class 1.3.1 is related to ice-marginal moraines, which also form at an ice-contact environment but are dominantly composed of diamictons and not included in this classification.

- Sandur and delta plain (Class 1.3.2). A sandur is a glaciofluvial sedimentary body typically formed by braided meltwater streams flowing away from the ice margin (e.g. Zielinski & Van Loon 2003). The term is derived from the Icelandic language, meaning a ‘sandy-gravelly area formed by proglacial streams’ (Zielinski & Van Loon 2003). In addition to channelized braided stream deposits, sandurs can contain deposits of shallow sheet floods and kettle holes. In the present classification, Class 1.3.2 covers both the coarse-grained, subaerial delta plain deposits characterized by braided streams (e.g. Kurjański *et al.* 2021; Luncka 2023) and the more extensive, up to several kilometres long outwash plains, the development of which can be unrelated to delta formation (Figs 6, 7). Their sediment thickness can be significantly smaller than in delta deposits (Niemelä 1979).
- Delta front (Class 1.3.3). Ice-contact and proglacial deltas are formed by the deposition of sediments carried by meltwater streams flowing into a standing proglacial body of water (sea or lake) that is in contact with glaciers (e.g. Benn & Evans 2010). Deltas are typically lobate or fan-shaped units in planview, whereas

in cross-section they tend to be wedge-shaped (Fig. 7). The uppermost part of glaciogenic deltas comprises a sub-horizontal delta plain environment, deposited at lake level and subaerial settings being mostly characterized by braided river or stream deposits in Finland (Class 1.3.2; e.g. Kurjański *et al.* 2021; Luncka 2023). Subaquatic portions of deltas consist of delta front and prodelta sediments (covered by Classes 1.3.3 and 1.3.4; Fig. 7A–C; Gilbert 1885). The subaquatic portions of deltas are influenced by basal processes such as waves and underwater currents, and can be regarded as glaciolacustrine or glaciomarine deposits (e.g. British Geological Survey 2020). However, here, all delta sub-environments are categorized under the class ‘glaciofluvial landforms’ for the sake of hierarchical simplicity and due to the interconnected nature of meltwater-sourced depositional environments. The architecture and morphology of deltas are generally influenced by several factors, including sediment grain size, the depth of the depositional basin, flow processes and water density (e.g. Bhattacharya 2006; Zavala *et al.* 2024). Significant variations in the architecture of the Salpausselkä deltas were caused by fluctuations in the water depth of the proglacial depositional basin. Two distinct delta-type end-members can be recognized; Gilbert-type deltas, formed in relatively deep water (over 30 m), are characterized by steep, well-developed foreset beds with angles up to 35° (Kurjański *et al.* 2021) and limited basinward progradation (Fig. 7A, B). In contrast,

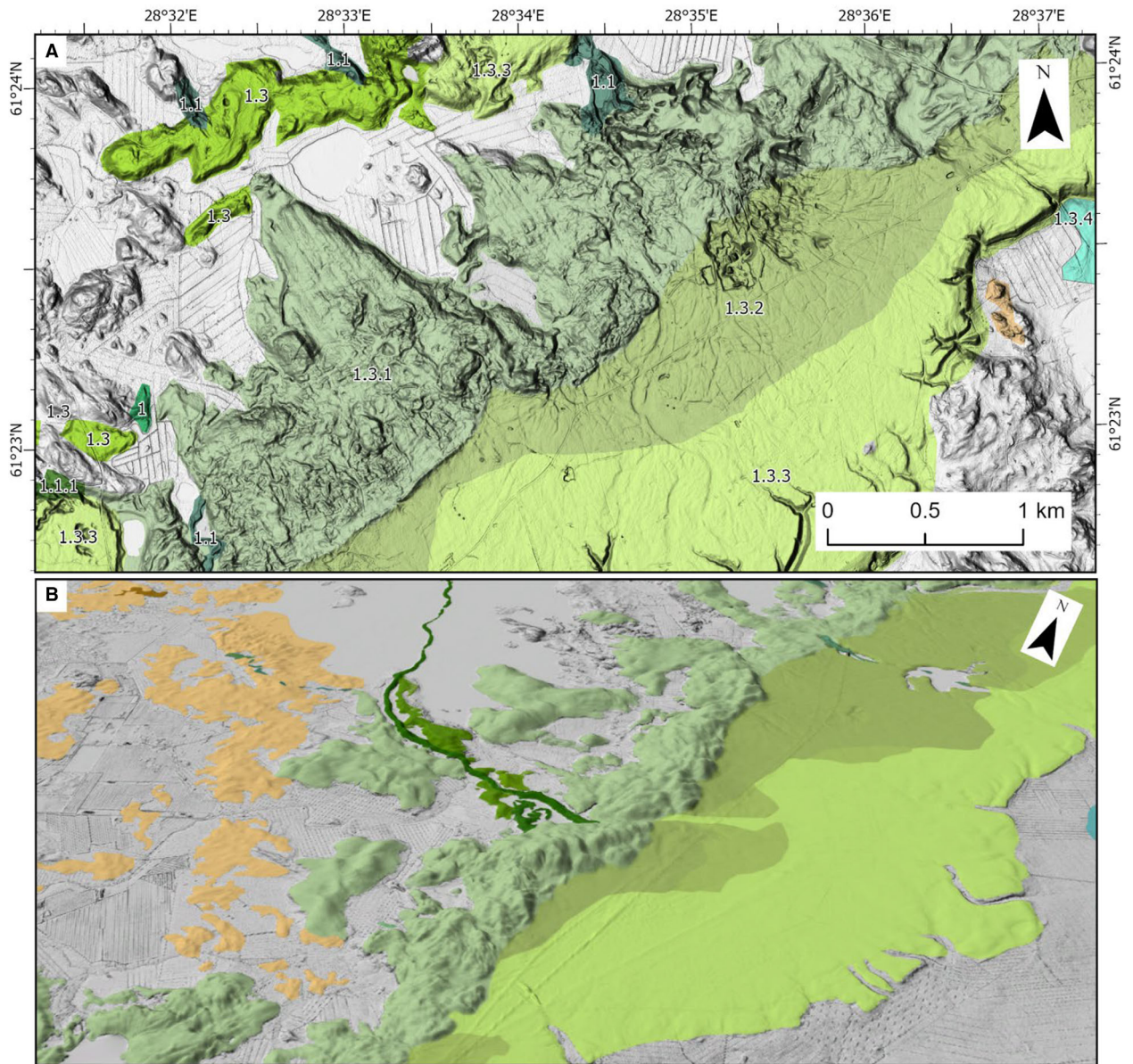


Fig. 5. Examples of the ice-marginal proximal zone (Class 1.3.1). A. East side of Utula, II Salpausselkä. B. A 3D scene image, illustrating the contrasting topography between the ice-contact zone and relatively more distal parts of the ice-marginal complex. Onkamo, II Salpausselkä. Field of view >10 km.

Hjulström-type deltas, formed in shallower water, typically have gently dipping foresets that extend further into the lake basin (Fig. 7C). Unlike Gilbert-type deltas, the gradients of the foresets and the delta plain in Hjulström-type deltas are similar (Kereszturi *et al.* 2014).

Due to significant morphological variability of ice-marginal deltas, the class *delta front* (Class 1.3.3) is broad, covering the subaqueous coarse-grained portion of deltas with various morphologies. These include variably inclined delta front deposits and locally occurring gently sloping wave-cut terraces. Potentially, such shal-

low water terraces may also include lake-ice generated plateaus (cf. Reimnitz 2000). In low-gradient deltas, the boundary between the delta front and delta plain may form a diffuse transition zone due to shoreline migration; therefore, the mapped boundary should be regarded as an approximate location.

The revised classification reduces the previous ambiguity where deltas were treated as comprising only subaqueous components. In particular, the revised definitions of Classes 1.3.2 and 1.3.3 now allow steep-faced Gilbert-type deltas to be classified as deltas rather than sandurs, which in plan view are dominated by the subaerial delta plain.

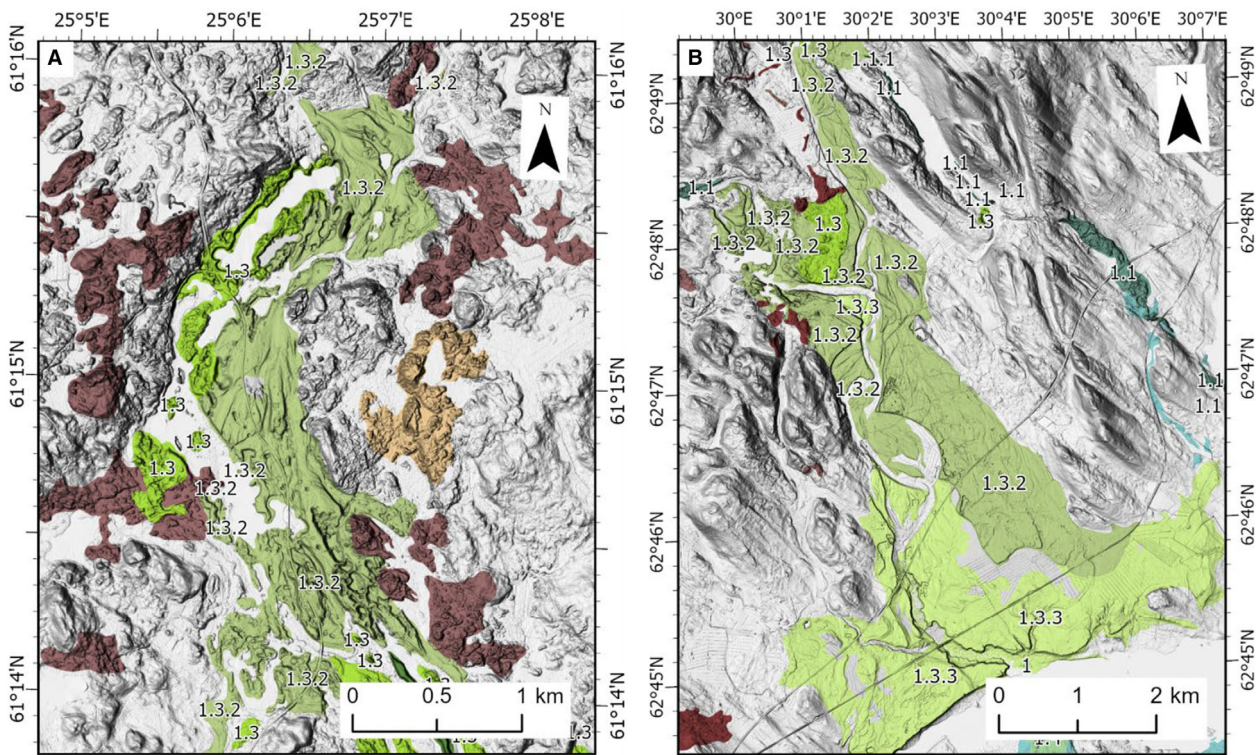


Fig. 6. Examples of sandurs (outwash plains). A. Upper reaches of a sandur system (Class 1.3.2), extending approximately 8 km. Evo, Päijänne interlobate region. Brown—diamicton-dominated ice-marginal deposits; Light orange—hummocky moraines. B. Sandur grading into a low-gradient delta in its distal end. Light blue—littoral deposits; Pieltisjärvi end-moraine.

- Ice-marginal distal zone (Class 1.3.4). Class 1.3.4 refers to subaqueous, relatively fine-grained, sand-dominated, gently sloping deposits that form the distal-most part of ice-marginal systems (Fig. 7A, B). The sediments are mainly deposited basinward from the sloping delta front region (Class 1.3.3), forming the low-relief portion of ice-marginal deposits (e.g. prodelta; Kurjański *et al.* 2021) and related fine-grained, sand-dominated deposits, often reworked by littoral processes. Thus, their distinction from the otherwise similar fine-grained littoral deposits is based on their location at the toe of deltaic deposits. As the density of the meltwater and the water in the depositional basin has been similar (homopycnal) during the Late Weichselian deglaciation in Finland, the formation of prodelta deposits has probably been limited (cf. Zavala *et al.* 2024). Moreover, littoral processes, such as longshore current, have influenced the distribution of fine-grained delta-derived sediments, particularly along the Salpausselkä.

Extramarginal landforms (Class 1.4)

Class 1.4 includes varied gravelly-sandy landform types, whose sedimentation processes are dominated by glacial meltwaters further away from the ice margin (e.g. Johans-

son 1995; Johansson *et al.* 2005). The extramarginal class is currently defined broadly, covering a range of subaerial-subaqueous landforms including channel-levees, sandurs and deltas, which are typically isolated, may show contrasting elevation and orientation from the nearby ice-margin, and can often be traced to a former ice lake upstream via an erosional channel or gorge (Fig. 8A, B). In the downstream end, the class can terminate in another glacial lake or dryland at a lower altitude. The resulting landform system can thus show diverse landforms and extend for tens of kilometres (Johansson 1995; Johansson *et al.* 2005) (Fig. 8A, B). Thus, typical settings of extramarginal deposition are outburst floods of ice-dammed glacial lakes, when large volumes of water and sediment are released abruptly. Challenges arise in ice-marginal settings when subsequent extramarginal deposition cannot be linked to a clearly identifiable meltwater route; such occurrences must therefore be regarded as tentative.

Buried glaciofluvial landforms or deposits (Classes 1.8 and 1.9)

Classes 1.8 and 1.9 cover buried sand and gravel deposits, the morphology of which is not or is only faintly recognizable in DEM (Fig. 8C, D). They are

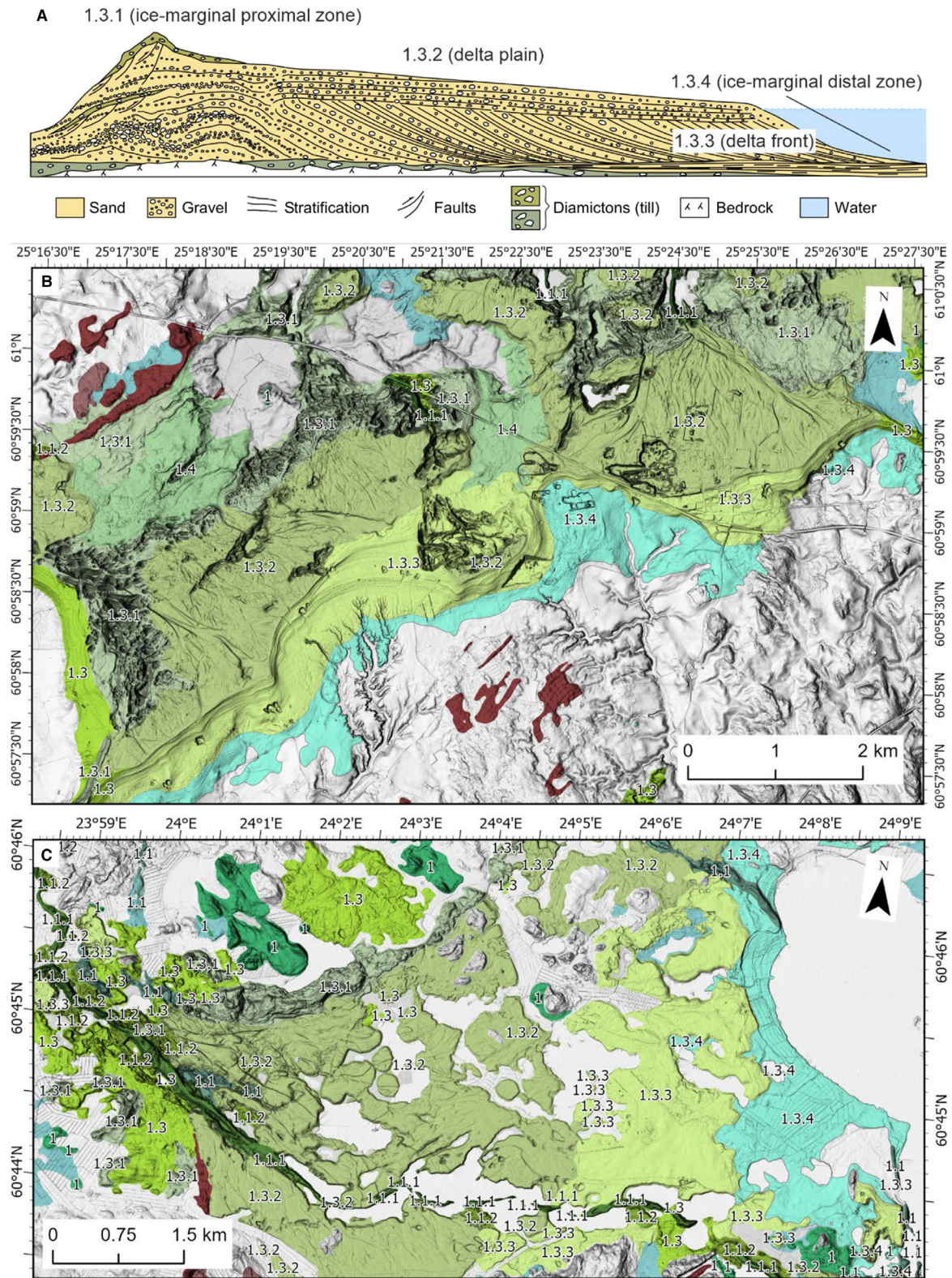


Fig. 7. A. Schematic cross-section of an ice-contact Gilbert-type delta illustrating the typical depositional elements (ice-contact zone, topset, foreset and bottomset) and the corresponding MLG classes (1.3.1–1.3.4, respectively). These classes also cover low-gradient deltas. B. and C. Examples of deltas showing delta plain (Class 1.3.2), delta front (Class 1.3.3) and Ice-marginal distal zone (Class 1.3.4), which includes prodeltaic and related fine-grained deposits often reworked by littoral processes. Light blue—littoral deposits; Brown—diamicton-dominated ice-marginal deposits; Light orange—hummocky moraines. A. Gilbert-type deltas, Sairakkala region, I Salpausselkä. B. Hjulström-type delta, Pernunnummi, III Salpausselkä.

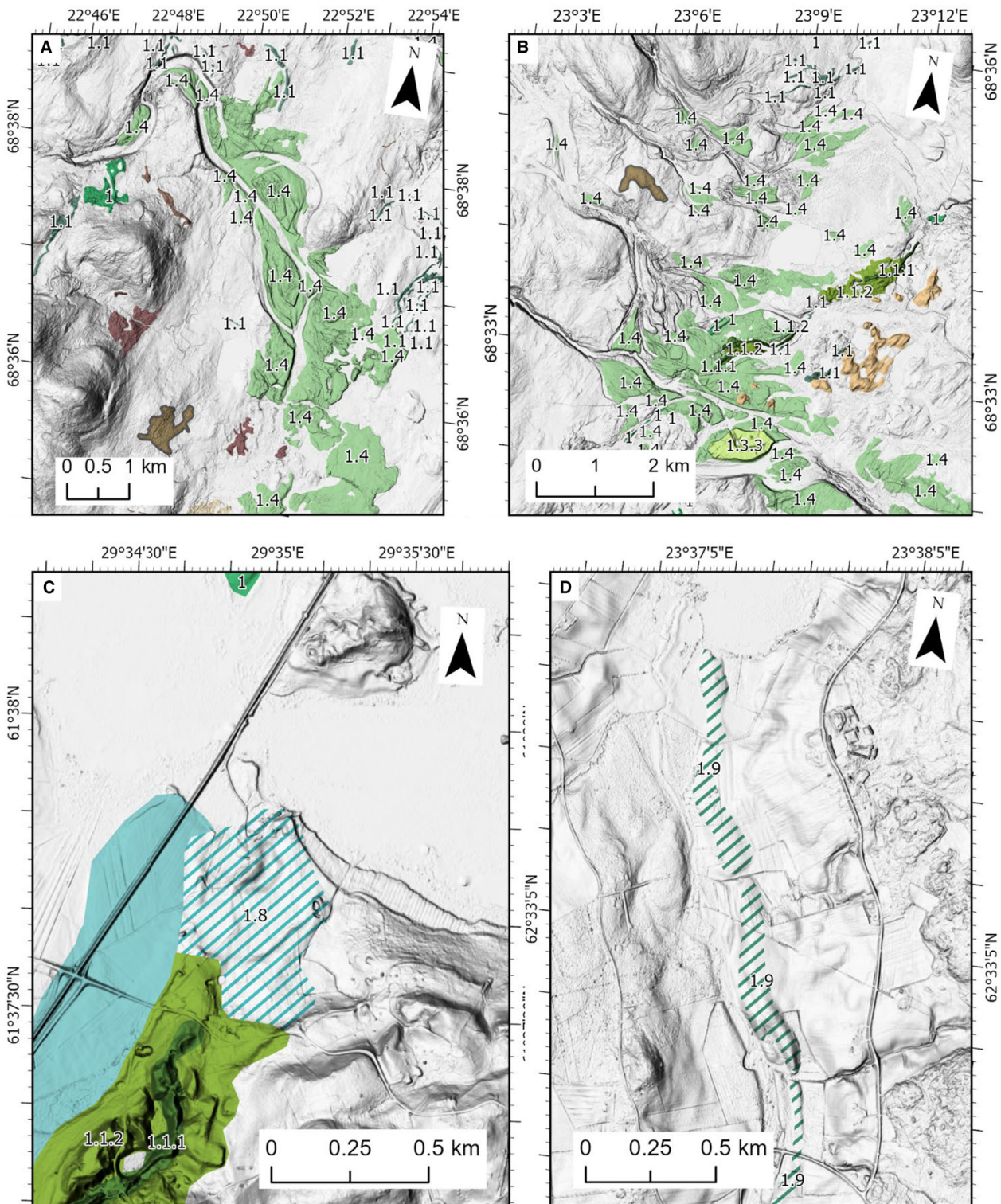


Fig. 8. A. and B. Examples of extramarginal landforms (Class 1.4). Depth of the erosional channels is up to 20 m. Note the contrasting orientation between the extramarginal landforms and an esker in (B). A. Northeast of Tarvantovaara, Enontekiö. B. Palojärvi, Enontekiö. C. An example of a buried glaciofluvial deposit (Class 1.8). Several metres of esker deposits overlain by fine-grained sediments interpreted as basal sediments. Verified by drilling. Parikkala, between I and II Salpausselkä. D. An example of inferred buried glaciofluvial deposit (Class 1.9). Sinuous N–S oriented ridges in a gently sloping valley, aligned in the general direction of eskers in the area overlain by fine-grained sediments interpreted as basal sediments. Not verified by drilling. Alavus, south of lake Alavudenjärvi.

typically overlain by fine-grained basinal deposits of various thicknesses. In the previous classification, the class of buried glaciofluvial deposits was subdivided into four classes (Putkinen *et al.* 2017). Due to their rarity, however, the subdivision is now simplified, and deposits are divided into two classes: Class 1.8 covers occurrences the identification of which is supported by drillings, geophysical data, test pits and/or partial exposures. Class 1.9 covers inferred occurrences that have not been verified by other methods, and their tentative identification is based on faintly observable morphology.

The most typical landform in these classes is an esker ridge, but also other types of glaciofluvial deposits have been identified, including esker splays. When no positive morphology is identifiable, and the presence of sands and gravels is verified by other means only, the shape and extent of buried glaciofluvial deposits mapped in the database are a rough approximation.

Discussion

Surficial glaciofluvial MLG map data in Finland have been reviewed to harmonize mapping styles and clarify their classification criteria. With almost 40 000 map unit occurrences, the updated classification maintains eskers

(Classes 1.1, 1.1.1 and 1.1.2) as the most common glaciofluvial landform types. In addition, the buried glaciofluvial landform/deposit classes (Classes 1.8 and 1.9) enable the classification of eskers overlain by basinal sediments. At ice-marginal positions, however, eskers can continue beneath ice-marginal landform systems (Classes 1.3.1–1.3.3), in which case they cannot be assigned to MLG classes.

Ice-marginal landforms (Classes 1.3 and 1.3.1–1.3.4), with more than 10 000 polygons, represent volumetrically most significant sediment accumulation complexes in Finland. These include the major ice-marginal systems developed during the Younger Dryas and Early Holocene, including the Salpausselkä, Tuupovaara, Koitere, Pielisjärvi and Central Finland ice-marginal systems (Fig. 1; e.g. Fyfe 1990; Rainio 1996; Palmu 1999; Kurjański *et al.* 2021; Lunkka *et al.* 2021; Lunkka 2023; Palmu *et al.* 2026). Additionally, smaller-scale glaciofluvial ice-marginal deposition occurred, particularly in front of esker systems, during the accelerated ice-margin retreat of the Holocene.

The extramarginal class forms the third most common category. Currently, over 6000 map unit polygons are assigned to this class, with occurrences concentrated primarily in the provinces of Lapland, Northern Ostrobothnia and Kainuu, Finland. Finally, 10 000 glaciofluvial

Table 2. Comparison of classifications for glaciofluvial and related landforms in Finland, Sweden (Peterson & Smith 2013) and Norway (NGU 2020). The listed classes are extracted from broader geomorphic and genetic classification schemes.

Finland					
Environment	1. Glaciofluvial				
Landform	1.1 Esker	1.3 Ice-marginal glaciofluvial landforms	1.4 Extramarginal landforms	1.8 Buried glaciofluvial landforms	
	1.1.1 Esker core	1.3.1 Ice-marginal proximal zone		1.9 Buried glaciofluvial landforms (inferred)	
	1.1.2 Esker splay	1.3.2 Sandur and delta plain			
		1.3.3 Delta front 1.3.4 Ice-marginal distal zone			
Planned classes/themes (under work): Glacial meltwater channel/gorge; Lateral channels; Meltwater routes					
Sweden					
Environment	Glaciofluvial				
Landform	Channels Lateral Proglacial	Eskers	Glaciofluvial deltas	Ice-contact slopes	Kettle holes
Norway					
Environment	Environments related to glaciofluvial sedimentation				
Landform/Genetic deposit type	20 Glaciofluvial deposit	31 Glaciofluvial and glaciolacustrine/subglacial lake deposit	53 Deposit from glacier-lake outburst flood (unspecified)	203 Ice-contact deposit	
	21 Glaciofluvial and fluvial deposit		54 Deposit from glacier-lake outburst flood, continuous	205 Glaciofluvial delta deposit (marine)	
	22 Esker		55 Deposit from glacier-lake outburst flood, discontinuous/thin		
	23 Kame				

map units lack sufficient morphological details and are assigned to the undifferentiated Class 1.

Table 2 compares the revised classification with analogous systems for glaciofluvial landforms used in Sweden (SGU) and Norway (NGU). The Finnish classification differs from these systems particularly in its subdivision of both the esker and ice-marginal classes. As described earlier, Finnish eskers typically consist of a generally coarser-grained core (Class 1.1.1) and finer-grained esker splay (Class 1.1.2). Because these units often exhibit contrasting lithologies, this subdivision provides a useful generalized basis both for land-use planning and for interpreting their polygenetic development.

Another key difference is that the GTK's classification further divides ice-marginal landforms into several classes. This reflects the regional geological context in Finland, where ice-marginal systems are particularly extensive and voluminous, and are dominated by sorted glaciofluvial sediments rather than diamictons. Class 1.3.1 (polygon) corresponds broadly to the Swedish 'ice-contact slope' (line) and the Norwegian 'ice-contact deposit' (Peterson & Smith 2013; NGU 2020).

The Swedish classification system distinguishes meltwater channels and divides them into lateral and proglacial sub-units. This approach is similar to that of Clark *et al.* (2004, 2018) focusing on the British Isles, who classify meltwater channels as subglacial, lateral, proglacial or tunnel-valley types. Such landforms are currently absent from the GTK's classification, but glacial meltwater channels/gorges (planned Class 6), lateral channels and subglacial meltwater routes are currently under development.

The Norwegian system includes the class Kame (see also the classification by BGS; McMillan & Powell 1999). In Finland, classes kame and kame terraces have been considered but not adopted, owing to difficulties in establishing unambiguous mapping criteria and geomorphological similarities with hummocky moraines. Under the current definitions of the map units, kame-like terrain occurs locally within Classes 1, 1.1 and 1.3. Finally, the Norwegian classes with codes 53–55, 'Deposit from glacier-lake outburst flood', are closely related to the Finnish Class 1.4 'Extramarginal landforms'. Although Finnish extramarginal landforms are commonly associated with glacier-lake outburst floods, this association is not considered a requirement for their development.

Conclusions

We have updated the surficial glaciofluvial MLG data for Finland to harmonize mapping practices and clarify classification criteria. The revised map will be published on the Maankamara webportal during 2026.

The updated MLG-classification is aimed to offer a general framework and starting point for Quaternary map data, communication, land use planning and scien-

tific studies. As the approach only allows for tentative estimates of the main lithology, genesis and spatial distribution of geological units, it is only intended to serve as a guide for planning more focused field reconnaissance and data collection, such as geophysical profiling, sedimentological studies and groundwater reserve (aquifers) research.

The need for field data is especially critical for ice-marginal glaciofluvial systems. Geomorphology-based mapping tends to highlight the most recent depositional and erosional conditions, while earlier stages of depositional evolution may not be observable from geomorphology. Additionally, post-depositional erosional processes have extensively modified the external architecture of the Salpausselkä ice-marginal systems in Southwest Finland, obliterating much of their original form. Thus, to understand properties such as depositional evolution, internal architecture and aquifer properties of ice-marginal systems, sedimentological and geophysical data are needed. To complement MLG-based mapping, especially for ice-marginal complexes and till-covered deposits formed prior to the last deglaciation, GTK will explore and test additional approaches, including allostratigraphic and lithostratigraphic methods in the coming years.

While the updated classification provides an important step towards harmonized mapping practices of the glaciofluvial MLG units in Finland, it remains incomplete and will continue to be refined with further updates, additions and corrections in the coming years. Notably, as mentioned above, the present classification does not yet incorporate subglacial meltwater routes with murtoos (although murtoos themselves have been mapped) and hummocky tracts that are often collectively referred to as subglacial meltwater corridors (SMC) or subglacial meltwater routes (SMR) (e.g. Peterson *et al.* 2018; Lewington *et al.* 2020; Dewald *et al.* 2022; see Ahokangas *et al.* 2021 for locations of meltwater routes). In the previous version of MLG mapping (Putkinen *et al.* 2017), some of these were already taken into account as glaciofluvial erosional areas, however, SMC classification requires harmonization and applicable classification criteria, which is one of the future tasks in the FIS area. Continued mapping of these meltwater pathways will provide valuable insights into glacial dynamics and subglacial hydrology, including aspects such as water volume, flow types and the evolution of meltwater networks during deglaciation. This, in turn, will enhance our understanding of changes in depositional environments, sediment volumes and the regional distribution of various glaciofluvial landform classes.

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Data availability statement. – The classification generated in this study is included in this article. The Lidar data on which the classification is based is available at: [Laser scanning data—National Land Survey of Finland](#). The revised map will be published in the Maankamara web-portal in spring 2026.

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