Quaternary glacial, interglacial and interstadial deposits of Norway and adjacent onshore and offshore areas

Lars Olsen[1], Harald Sveian[1], Dag Ottesen[1, 2] and Leif Rise[1]

[1]Geological Survey of Norway, Postboks 6315 Sluppen, 7491 Trondheim, Norway.
[2]Present address: Exploro AS, Stiklestadveien 1a, 7041 Trondheim, Norway.
E-mail (corresponding author): lars.olsen@ngu.no

The late Pliocene and Pleistocene sediment distribution, thickness and stratigraphy of Norway and the adjacent continental shelf are reviewed in this paper.
A generalised map of Quaternary[1] sediments in Norway in scale 1:1 million or larger (available from www.ngu.no), compiled from Quaternary maps in various scales, and a simplified map with distribution of an overburden of >1 m-thick loose deposits are used for this regional overview. In addition, the sediment distribution and thickness of the Quaternary sediments from selected parts of the adjacent shelf areas are presented, and the geological implications (with erosion and deposition) of all these data are discussed.

The Quaternary stratigraphy from the land areas in Norway is also presented, with examples from northern, central and southern parts of the country. Correlations with adjacent areas, mainly from central and northern Fennoscandia, are suggested, and the regional implications are indicated, particularly for the Weichselian glaciation, and further dealt with in the accompanying paper focused on Quaternary glaciations (this issue).

It is now known that a major part of the present, remaining, onshore glacial deposits in Norway derive from the last glaciation (Weichselian) and that more than 90% (>100,000–150,000 km^3) of the Quaternary glacial erosional products from Norway have been transported and deposited offshore. These sediments are mainly deposited in large depocentres at the Mid-Norwegian shelf and in trough-mouth fans at the mouths of the Norwegian Channel and the Bjørnøyrenna Trench.

Olsen, L., Sveian, H., Ottesen, D. and Rise, L. (2013) Quaternary glacial, interglacial and interstadial deposits of Norway and adjacent onshore and offshore areas. *In* Olsen, L., Fredin, O. and Olesen, O. (eds.) *Quaternary Geology of Norway*, Geological Survey of Norway Special Publication, **13**, pp. 79–144.

[1] Quaternary is here used as described by Olsen et al. (this issue).

Introduction

A general map of Quaternary sediments in Norway in scale 1:1 million or larger (available as 'best of' version on the internet: http://www.ngu.no/kart/losmasse/) and a simplified map of an overburden with thick sediments are compiled from Quaternary geological maps in various scales (Figure 1). In addition, the sediment distribution and thickness of the Quaternary sediments on the adjacent shelf areas (Figures 2 and 3a, b, c) and the Quaternary stratigraphy from the land areas are presented (extended background data are included in Appendix A), and the geological implications of these data are considered and used in reconstructions shown on maps and in glacial curves (i.e., time–distance diagrams). The pattern of Quaternary ice-sheet erosion and deposition is recently considered theoretically for all of Fennoscandia (Kleman et al. 2007). This is acknowledged by the present authors and the background data for this pattern in Norway is considered and documented with some examples here. The geographical position of most places and sites, which are referred to in the text is shown in Figure 4, with more locations and names presented in Figure B1 and Table B1 (Appendix B).

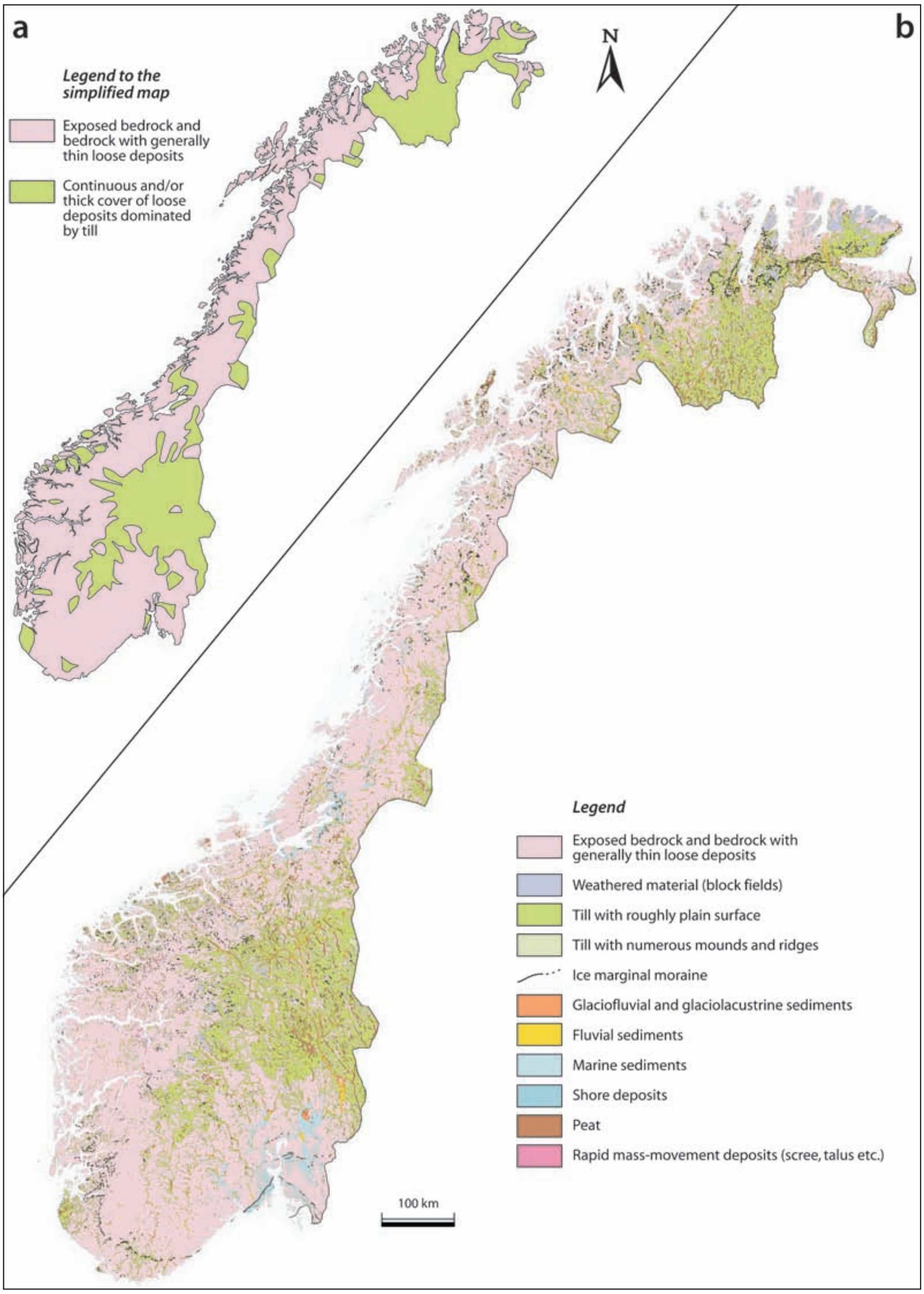


Figure 1. Quaternary geological maps of the mainland of Norway (between c. 58°-71°N and c. 5°-30°E), based on data from the NGU map database, Quaternary map of Norway. (a) Simplified map with exposed bedrock and overburden generally >1 m thickness; and (b) distribution of various sediments from Quaternary map in scale 1:1 million. The legend is simplified from the 1990-version of the map (Thoresen 1990). Some of the areas with exposed bedrock (pink) *may have a thin cover of loose deposits, but in most of these areas the overburden is assumed to be less than 1 m thick. The average thickness of the till deposits* (green)*, which cover about 25% of the mainland of Norway is estimated to* c. *6 m. For more map information, see www.ngu.no, and for further information of the sediment thicknesses, see the main text.*

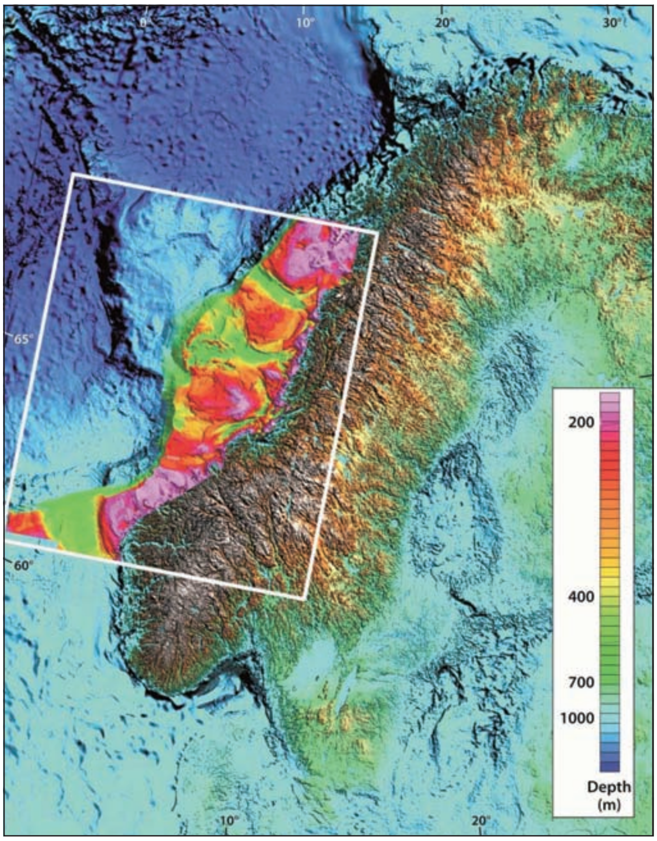


Figure 2. Topographic/bathymetric map of Norway and adjacent land and seabed areas. Position of Figure 3b is indicated. For references, see the main text.

^{14}C ages are calibrated or converted to calendar years according to Olsen et al. (2013), and the abbreviation ka BP, meaning a thousand years before present, is generally referred to as ka throughout this paper.

Shelf areas

Regional mapping programs of the Quaternary sediments on the North Sea and Norwegian shelf areas have taken place during the 1970–1980s (e.g., Rise et al. 1984, King et al. 1987).

In the last few years, during several joint industrial projects, extensive studies of the Late Pliocene/Pleistocene development (Naust Formation) of the Norwegian shelf and margin between 61°N and 68°N have been carried out. In the Ormen Lange project, the shelf and margin stratigraphy were studied by Rise et al. (2002, 2005a) on the basis of a large seismic data base. These data have given a new understanding of the environment/processes during deposition of the Naust Formation, especially the older parts. The Naust Formation has been given a unified stratigraphy across the whole area, and is subdivided into five sequences (N, A, U, S, T from bottom to top) (Figure 3c, d), each comprising several units (Rise et al. 2006, Ottesen et al. 2007). The mapping of these five sequences has made it possible

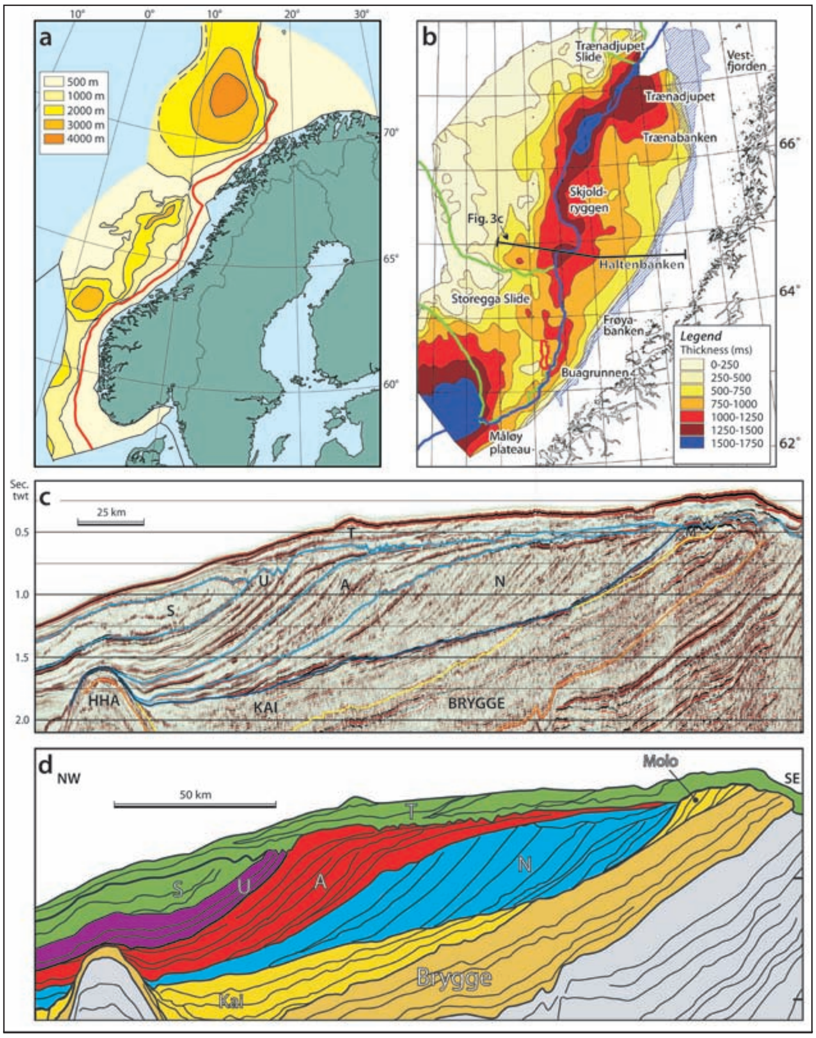


Figure 3. Distribution and thickness of the Quaternary (late Pliocene and Pleistocene) sediments along the Norwegian continental margin of Norway. (a) Seabed areas from the North Sea to the SW Barents Sea, modified from Riis (1996) and Vorren and Mangerud (2008), (b) the Mid-Norwegian shelf, modified from Rise et al. (2005), (c) seismic cross section from the Mid-Norwegian shelf, after Ottesen et al. (2007), and (d) interpretation of the profile in (c) with letters/names of formations/units. After Ottesen et al. (2007). Position of profile is indicated in (b).

to outline the development of the whole Mid-Norwegian shelf during the last 3 million years. For more details, we refer to the recent paper by Ottesen et al. (2009).

Land areas

The Quaternary stratigraphy of northern and central Norway has previously been compiled and presented as simplified logs on small-scale maps resulting from the so-called ‘Nordkalott’ and ‘Mid-Norden’ projects in northern and central Fennoscandia (Hirvas et al. 1988, Bargel et al. 1999). A modified version of selected parts of these data, with additional stratigraphical logs both from northern, central and southern Norway based on various sources, is presented here. The geological implications of these data are further considered in the accompanying paper by Olsen et al. (2013).

The distribution of various Holocene sedimentary deposits and formations that are mainly of nonglacial origin (deposits from rockfalls, landslides, fluvial deposits, weathering, shorelines etc.), is described by Fredin et al. (2013).

Overview of maps of Quaternary deposits onshore in Norway

Mapping of Quaternary sediments in Norway has been carried out during many decades, mostly in scales between 1:10,000 and 1:100,000 (see review by Bargel 2003). The surficial deposits are classified according to genesis. The legend and standard colour coding of the NGU Quaternary geological maps reflect various sediment types. However, it was not until the last three

Figure 4. Geographical position of most sites and areas mentioned in the text. For more details, see Appendix B, Figure B1 and Table B1, and for sites and areas not included here, see Figures 16, 17 and 33, and Appendix B (Figures B2–B5).

to four decades that mapping programs were initiated to produce detailed map sheets covering large areas. The maps were produced for many purposes, among others to locate building material for road construction, etc. The distribution of Quaternary sediments is important for many kinds of human activity, especially agricultural purposes and areal planning, but also for recreation (landscape development and geological history), education and research (ice-sheet modelling) purposes. Another important field of use of such maps is geological hazard or risk analysis for landslides, where, e.g., the distribution and thickness of marine clays are of vital importance.

Generalised maps of different regions have been produced at varying scales (Figure 5). These maps have been compiled into one generalised map covering all of Norway (http://www.ngu.no/kart/losmasse/), which has been simplified to represent merely sediment thickness and shown in reduced scale in Figure 1a. The original map scales were 1:500,000 for Finnmark county (Olsen et al. 1996b), 1:250,000 for Troms (Sveian et al. 2005), 1:400,000 for Nordland (Bargel 2001), and 1:250,000 for Sør-Trøndelag (Reite 1990), Møre & Romsdal (Follestad 1995), Sogn & Fjordane (Klakegg et al. 1989), Hordaland (Thoresen et al. 1995), Rogaland (Bergstrøm et al. 2010) and Aust-Agder (Riiber and Bergstrøm 1990). Furthermore, for Oslo and Akershus (Bargel 1997) and Østfold (preliminary version, Olsen et al. 2005) the generalised scales were 1:125,000, and for Jotunheimen 1:250,000 (Holmsen 1982) (for location, see Figures 4 and 5) and 1:1 million for the remaining parts of Norway (Thoresen 1990, Bargel et al. 1999). The different maps have been digitised, and the lines were imported into a Geographic Information System (GIS). Polygons were built from these lines, and each polygon was given a signature to the sediment type.

Our purpose in this paper is to give an overview of the Quaternary deposits by drawing and describing a simple, small-scale map (Figure 1a) based on a more complex Quaternary map (Figure 1b), where we clearly separate areas with exposed bedrock and bedrock with a discontinuous and thin (commonly <1 m) sediment cover from areas with a thick sediment cover. Therefore, the legend has been simplified to comprise only a few sediment types, all included in one category, which is dominated by till (Figure 1a). Exposed bedrock is pink and continuous cover of till (or sediments dominated by till) is green in both maps (Figure 1a, b). Certain areas have a relative continuous cover of organic deposits. However, these areas are not shown on the simplified map, but are instead given the colour of the underlying material (e.g., bedrock, till, etc.).

Sediment distribution and thickness in the different land areas

Generally, Norway has large areas of exposed bedrock or bedrock with a thin cover of Quaternary sediments. However, the southeastern parts of Norway (the lowland east and northeast of Oslo), areas adjacent to and under the former ice divide in southern Norway (Figure 6), the Jæren area in southwest Norway and Finnmarksvidda in northern Norway (Figures 1 and 4) have large areas with a generally continuous cover of sediments. The sediments are dominated by tills in most areas, but in the main valleys and basins waterlain sediments, including glaciofluvial, fluvial and marine deposits often represent the dominant sediment types. Based on natural sections, excavations, drillings and some seismic profiles, the average sediment thickness in areas with continuous cover of sediments (e.g., at Finnmarksvidda) is estimated to *c.* 6 m, similar to northern and central Finland and Sweden (The Nordkalott Project 1986, The Mid-Norden Project 1999). However, in some valleys and basin areas dominated by marine deposits the sediment thickness is much thicker, commonly more than 10 m, and occasionally the sediment thickness is more than one hundred metres, e.g., up to 400 m sediment thickness in the northernmost, outer part of Gauldalen near Trondheim.

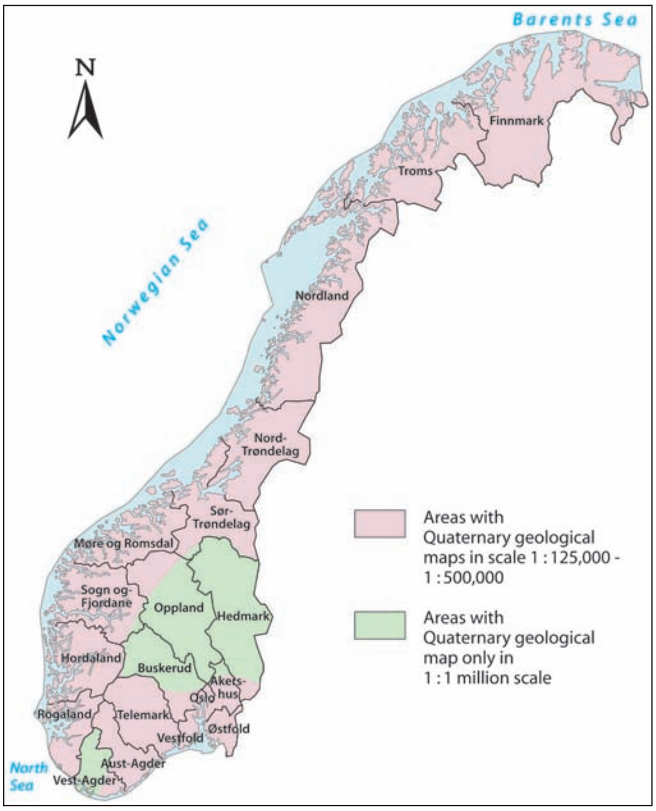


Figure 5. Counties in Norway, most of them mentioned in the main text. Counties with existing Quaternary geological maps in various scales are indicated.

The lowland east and northeast of Oslo (Østlandet)

The fields with continuous sediment cover east and northeast of Oslo are all dominated by marine deposits within the nearest 50 km. These areas are therefore situated mainly below the postglacial marine limit (*c.* 200 m a.s.l.) and have a long history of Holocene fluvial erosion and clay slides. This has changed the topography of the landscape rapidly and dramatically within minutes or hours at certain times in the landscape evolution history. The largest deposits of sand and gravel in Norway, which is mainly of glaciofluvial origin, are located in the northeastern lowland (e.g., Gardermoen airport and surrounding areas).

The sediment thickness in this area may locally reach more than 100 m, e.g., in the Hauerseter area where seismic measurements indicate up to 120–125 m sediment thickness (Østmo 1976, Longva 1987).

The central inland of SE Norway—the ice divide and surrounding areas

During initial phases of glaciations ice growth expanded from core areas along the regional water divide in the Scandinavian mountains, and during phases of maximum glaciations the ice divide migrated to a more easterly and southeasterly position (Figure 6). During the last glaciation, the most extreme easterly and southeasterly position of the ice divide was at, or south of Vinstra in Gudbransdalen (Figures 4 and 6), but all recorded field data suggest that the E–W-trending ice divide maintained a position north of Lillehammer at the southern end of Gudbrandsdalen also during the Last Glaciation Maximum (LGM) (Olsen 1983, 1985a, b). It is clear from the map (Figure 1), that large areas in central southeast Norway (along the former ice divides) are characterised by a continuous sediment cover. This zone extends some 50–80 km beyond the LGM ice-divide zone both in the north and south, which indicates that the glacial erosion, which is generally strong closer to the glacier margins, has been significantly reduced already at a relatively long distance from the ice divide zone.

The sediment thickness in these central inland areas is often more than 5 m on the plains and more than 10 m in the small valleys. In larger valleys, such as Gudbrandsdalen and lower parts of Østre Gausdal the sediment thickness (mainly till) may reach more than 100 m (e.g., Olsen 1985a).

The Jæren area

The Jæren area (Figure 4) (Appendix B, Figure B1: 107, *c.* 25x50 km^2) in southwestern Norway has generally a continuous sediment cover. In the southern coastal part a sediment thickness of more than 100 m is recorded, e.g., at Grødeland (Janocko et al. 1998). The main part of these sediments is till, with some intercalated marine or glaciomarine sediments. At higher elevations (up to more than 200 m a.s.l.) and some 6–10 km from the coast in the southern parts of Jæren (Høgjæren), several-metre thick marine sediments of Middle Weichselian age are recorded at many sites (e.g., Andersen et al. 1987, Larsen et al. 2000). This is considerably higher than the late-/postglacial marine limit, which rises from 0 to 30 m (a.s.l.) northwards in the Jæren area (Andersen et al. 1987).

Finnmarksvidda

Finnmark County in northern Norway has together with Hedmark County in the southeast (Figure 5), the largest fields with continuous sediment cover in Norway. The main part of Finnmarksvidda is located south of the fjord heads. It is a lowland plateau, *c.* 300–500 m a.s.l. and more than 10,000 km^2, with some mountain peaks reaching at least 1000 m a.s.l. in the north. The sediment thickness, which is dominated by tills in this area is estimated to *c.* 6 m in average (Olsen 1988), but may in some cases reach more than 50 m (Olsen et al. 1996a). In the delta areas along the major rivers, e.g., at the Tana River delta the sediment thickness is up to at least 100 m (Mauring and Rønning 1993, Mauring et al. 1995).

Other parts of Norway

Continuous and/or thick Quaternary deposits in areas of size at least tens of square kilometres occur also at Lierne in Nord-Trøndelag. In all other parts not mentioned separately the Quaternary sediments are scarce or only present as thin or discontinuous 'blankets' on bedrock.

Sediment distribution and thickness on the shelf

The North Sea Plateau

The North Sea Plateau is a shallow shelf area south and west of the Norwegian Channel (Figures 4 and 6) that has generally been outside or at the margins of the Fennoscandian/ Scandinavian ice sheet. The ice-sheet configuration in these shelf areas is generally poorly known, with large uncertainties during the most extensive glaciations that occurred during the last 0.5 million years and also during older glaciations in Scandinavia. Studies of seismic profiles show a complicated history with extensive erosion over large areas. This is especially in the eastern areas, in a zone where the westward-expanding Scandinavian ice sheet has reached during several glaciations. In these areas sediment-filled, deep erosional channels are abundant in the Pleistocene sediments, and the channels have been interpreted as subglacial formations (e.g., Sejrup et al. 1991). In the central parts of the North Sea Basin thick sequences (adding to *c.* 1 km thickness) of Late Pliocene–Pleistocene sediments, thickening from the east towards the central area in the west exist (Eidvin et al. 1999). These are mainly deposited through glaciofluvial and glaciomarine processes during the last three million years. However, the age control for these sediments is poor, implying a big uncertainty in the volume estimates.

The Mid-Norwegian shelf

Two major depocentres exist on the Mid-Norwegian shelf. In the north (65°–67°N), large areas along the present shelf edge have more than 1000 m of glacial sediments, whereas at the mouth of the Norwegian Channel outside Stad (62°N) a large trough-mouth fan (TMF) has been deposited. The sediment thickness of the fan may exceed 1500 m. The deltaic Molo Formation that has recently been redated to a Mid/Late Miocene to Early Pliocene age (Eidvin et al. 2007), is located parallel to the Norwegian coastline (Figure 3b, c), generally 60–80 km west of it. The prograding Pliocene/Pleistocene wedges start outside the Molo Formation (Figure 3c, d). Seismic profiles show that the Mid-Norwegian shelf has prograded up to 150 km towards the west, and more than 1000 m of glacially derived sediments have been deposited during the

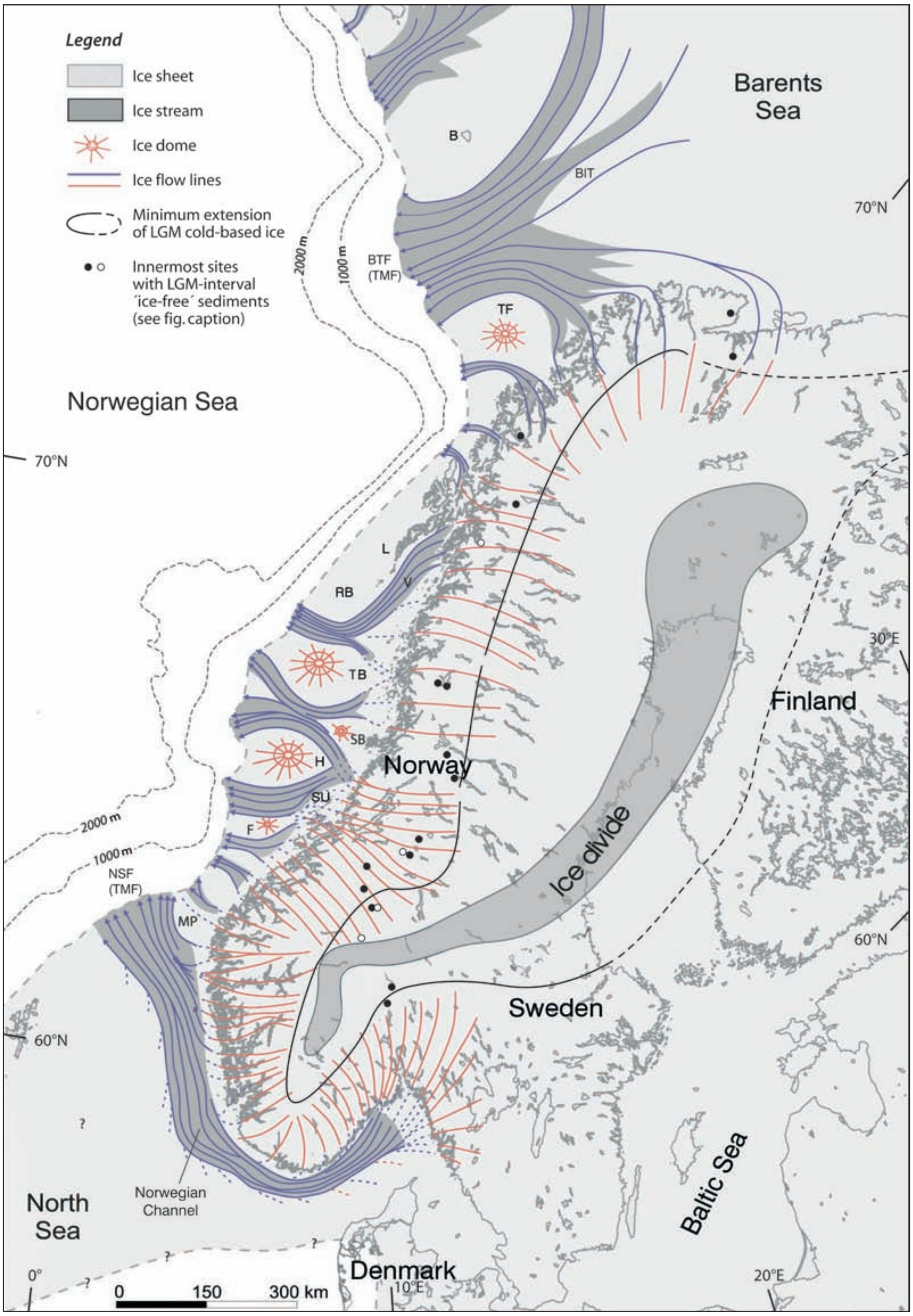


Figure 6. Large-scale ice-flow model of the western part of Scandinavia during the last glacial maximum, modified from Ottesen et al. (2005a). Minimum areas (partly discontinuous and stippled line). with ice frozen to the underground (after Kleman et al. 1997) and innermost locations of sites with sediments deposited during ice-free conditions or proglacially during ice-marginal retreat in the LGM interval are marked (after Olsen et al. 2002). Type of material and dating method are indicated (dot indicates ^{14}C-dated bulk plant remains, and open ring indicates ^{14}C-dated animal bones, U/Th-dated calcareous concretions or OSL-dated sand). B= Bjørnøya (Bear Island), BIT= Bear Island Trough, BTF= Bear Island Trough Fan, TMF= Trough-Mouth Fan, TF= Tromsøflaket, V= Vesterålen, L= Lofoten, RB= Røstbanken, VF= Vestfjorden, TB= Trænabanken, H= Haltenbanken, SU= Sularevet, F= Frøyabanken, MP= Måløyplatået, NSF= North Sea Fan.

last 3 million years on the shelf. For more details about the Mid-Norwegian shelf, see, e.g., Ottesen et al. (2009).

The Vestfjorden/Lofoten/Vesterålen areas

The Lofoten/Vesterålen shelf (67º–69ºN) is generally narrow (Figures 2 and 4) with a thin cover of Quaternary sediments (generally less than 20 m). The largest sediment thickness (>100 m) is found along the shelf edge and in the upper slope. Due to the steep slope with marked valleys and slide scars, a good estimate of the total volume of Pliocene/Pleistocene sediments is difficult to elaborate. The sediment volume may be difficult to estimate also in the Vestfjorden–Trænadjupet area (Figure 7), but many megascale lineations and large grounding-line moraines indicate fast-flowing glaciers as an effective erosion and transport agent. The lineations are several kilometres long ridges, up to 10 m high and 200–500 m wide, and are separated by 300–700 m-wide trenches, whereas the grounding-line moraines are up to several tens of metres thick (Ottesen et al. 2005b).

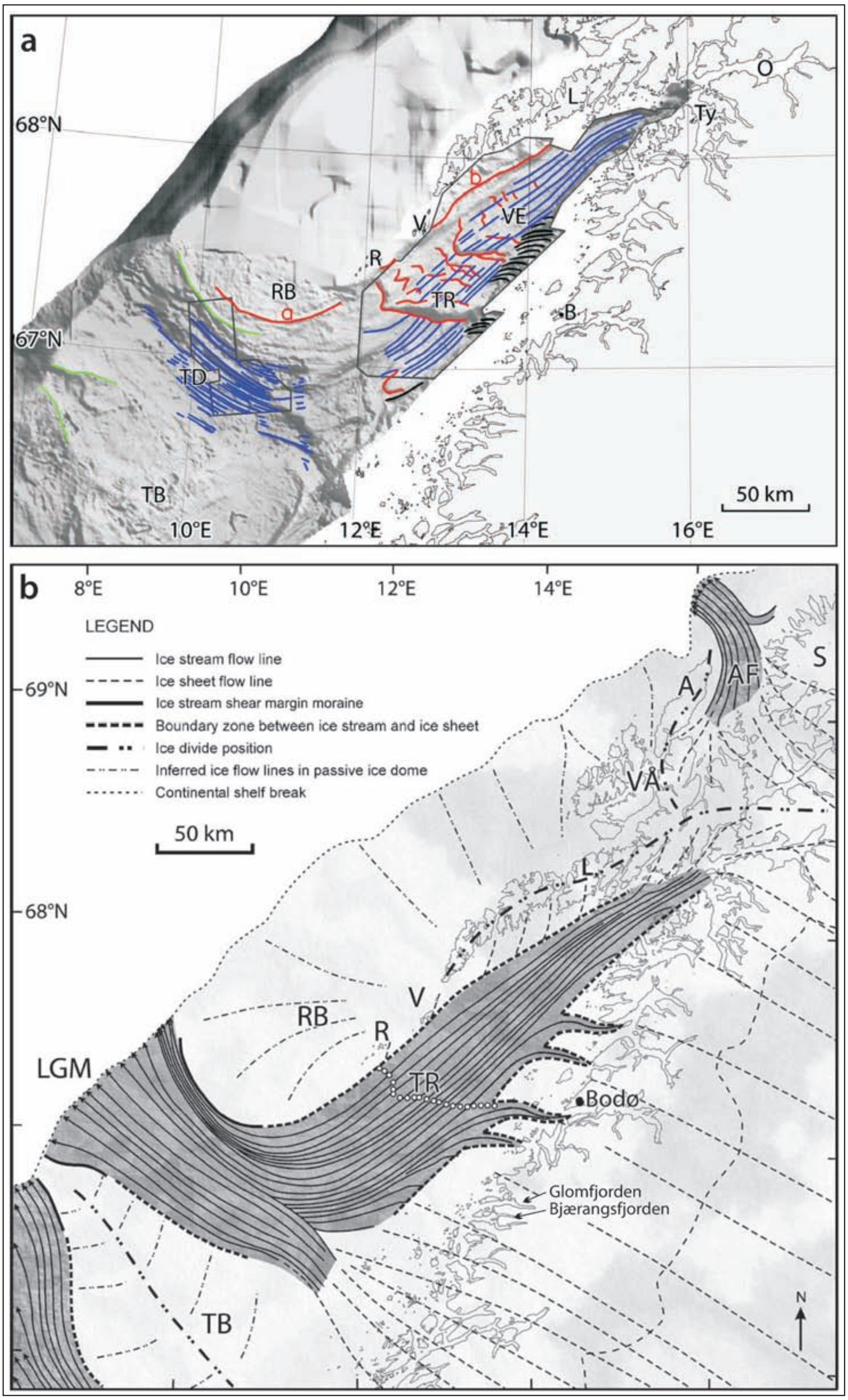


Figure 7. (a) Sea-floor morphology of the Vestfjorden/Trænadjupet with ice-stream marginal and grounding-line moraines (red lines) and megascale glacial lineations (MSGL, blue lines) indicating fast ice flow, and (b) ice-flow model of the Lofoten/Vesterålen area and adjacent shelf. Modified from Ottesen et al. (2005b). Legend of letters: O= Ofotfjorden, Ty= Tysfjorden, L= Lofoten, VE= Vestfjorden, V= Værøy, R= Røst, TR= Tennholmen Ridge, B= Bodø, RB= Røstbanken, TD= Trænadjupet, and TB= Trænabanken. Additional legend for b: S= Senja, AF= Andfjorden, A= Andøya, and VÅ= Vesterålen.

The northern shelf areas off Troms and in the southwest Barents Sea

The Troms shelf is narrow (35 km wide) in the south (69°30'N) outside Senja (Figure 4), but widens towards the north into the Barents Sea. The shelf comprises shallow bank areas with intermediate cross-shelf troughs. The main transport of glacial debris probably followed these depressions, which have hosted the palaeo ice streams whereas the shallow bank areas were covered by passive ice (domes) (Figure 6). Due to the steep slope (up to 10°) outside the shelf break off Troms, it is difficult to estimate the volumes of the glacial debris being transported into the deep sea. Generally, there is a sparse cover of Quaternary sediments on the banks, highly variable but mostly less than 25 m, and certain areas may completely lack Quaternary sediments (Rokoengen et al. 1979).

Tromsøflaket (20,000 km²) is a large, shallow bank area (water depth 150–350 m) on the northern Troms shelf at the transition to the Barents Sea. This large area was probably in some intervals covered by a passive ice dome, which directed ice flow south and north of the area. Most of the ice from Finnmark was drained out the fjords, then being deflected towards the west, and farther northwards into the Bear Island Trough were it coalesced with the main trunk of the Bear Island Trough ice stream. The Bear Island Fan is a huge trough-mouth fan at the shelf edge outside the Bear Island Trough (125,000 km²) with a sediment thickness of up to 4 km (Figure 3a, Riis 1996, Vorren and Laberg 1997).

During the Cenozoic, strong glacial erosion of the floor of the Barents Sea has developed a very marked angular unconformity over large areas. Up to 300 m of glaciogenic sediments overlie this unconformity (Sættem et al. 1992, Vorren et al. 1998, Lebesbye 2000). These sediments can be separated into seismic units separated by smooth or irregular surfaces. Each of the sequences can be up to 150 m in thickness (Lebesbye 2000). Lebesbye mapped a complex sequence of glaciogenic sediments with up to 250 m in thickness in the areas outside the Finnmark coast, revealing alternating phases of deposition and erosion. He also identified several glacial phases and related most of the seismic units to Weichselian or Saalian age. The depocentre developed in a buried wide glacial trough running parallel to the coastline (Lebesbye 2000).

Zones of major erosion and accumulation during the Quaternary

The surface-near sediments of Norway and adjacent Nordic countries comprise mainly sediments from the last glaciation, the Weichselian. However, these young sediments in large areas in the inland of southeast Norway, the Jæren area in southwest Norway, and parts of Finnmark in northern Norway are commonly underlain by deposits from preceding glacials or interglacial/interstadial periods. This is also the case for even larger areas in Sweden and Finland (Hirvas et al. 1988, Bargel et al. 2006).

It has been compiled a till stratigraphy of Finnmark, outlining up to five superimposed till beds with interlayered interglacial/interstadial sediments (Olsen 1988, 1993a, b, Olsen et al. 1996a). Similar compilations are carried out for northern and central Finland and Sweden (The Nordkalott Project 1986, The Mid-Norden Project 1999).

On the basis of the stratigraphical studies in Finnmark it has been mapped certain areas with weathered bedrock in situ, indicating only minor or moderate glacial erosion (Figure 8, Olsen 1998). In Finnish Lapland large areas with preglacial weathered bedrock have been recorded (Hirvas 1991). The same is also registered in northern Sweden (The Nordkalott Project 1986) and in several parts of Norway where also blockfields occur frequently (Figure 8, Thoresen 1990).

The areas under the central parts of the Fennoscandian palaeo ice sheet have generally a continuous sediment cover (Hirvas et al. 1988, Thoresen 1990, Bargel et al. 1999). In these areas ice probably was frozen to the ground during a substantial part of each major glacial cycle, in contrast to the areas closer to the ice margin (e.g., Kleman et al. 1997, Boulton et al. 2001). This is indicated for the last glaciation by the occurrence of numerous multiphase deglaciation features, e.g., crossing patterns of lateral and sublateral drainage channels, all represented in the same area and with a diversity that could not derive from only one deglaciation phase (Figure 9) (Kleman 1990, Sollid and Sørbel 1994, Follestad 2005c, Follestad and Fredin 2007).

The western part of the Fennoscandian ice sheet was efficiently drained through a number of palaeo ice streams (Figure 6). The erosion of the Norwegian land areas was extensive, and during the glacial periods most fjords were eroded and emptied for all sediments (e.g., Aarseth et al. 1997), that generally had been deposited during the retreat of the previous glacial and the subsequent ice-free period. A large amount of the glacially derived sediments were transported onto the shelf and beyond the shelf edge at peak glaciations.

Recently, Kleman et al. (2007) have described and classified patterns of Quaternary ice-sheet erosion and deposition in Fennoscandia, and they have suggested a simple, logical, and quite useful theoretical framework for explanation. The Scandinavian mountain-centred ice sheets and the full-sized Fennoscandian ice sheets, which here and in the accompanying paper

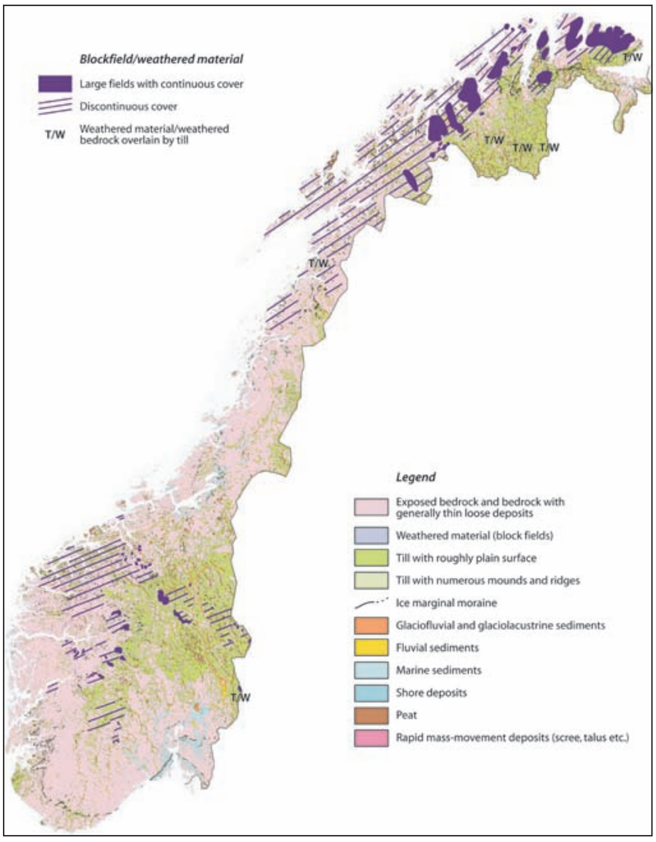


Figure 8. Sites and areas characterised by weathered material (mainly blockfields) and/or weathered bedrock, with or without a Quaternary sedimentary cover, modified from Thoresen (1990).

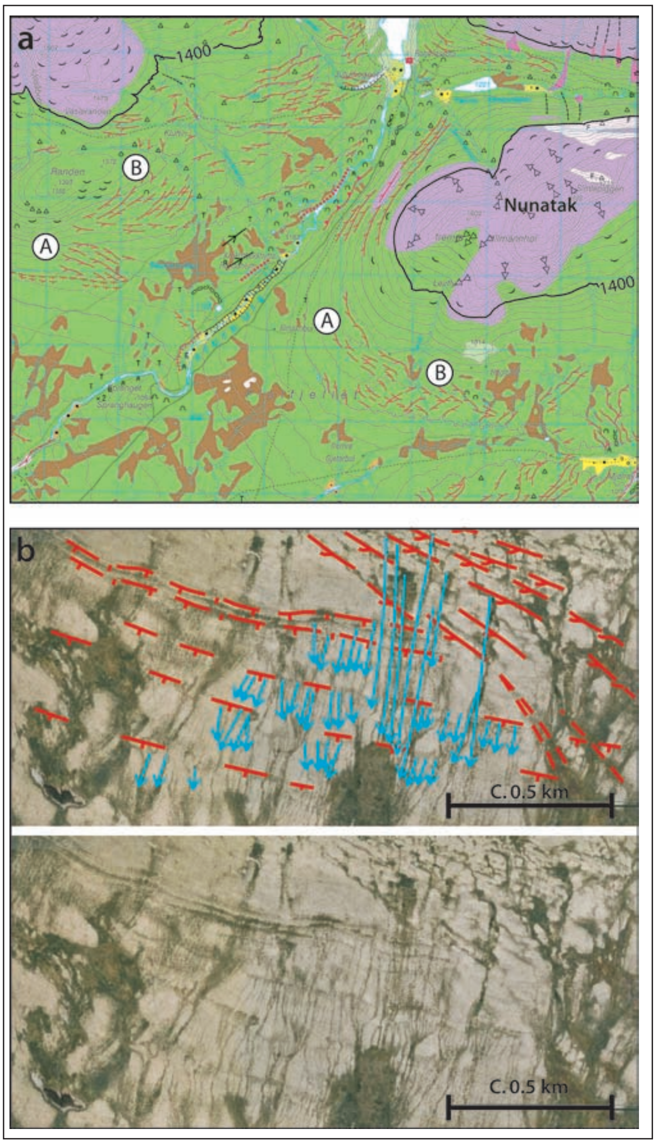


Figure 9. (a) Part of Quaternary geological map Rondane 1718 I (scale 1:50,000) with two sets (A, drainage towards east-southeast, B, drainage towards southwest) of crossing lateral drainage channels, from two different deglaciation phases separated by at least one phase with a cold-based ice cover, after Follestad (2006). Areas higher than 1400 m a.s.l. (indicated) may have been nunataks during the last deglaciation after mid Younger Dryas. North is up and each coordinate net square (light blue lines) on the map represent 1x1 km² in the terrain. (b) Air-photo of an area adjacent to the letter A, to the left in a. Example of several sets of lateral meltwater channels, from central southeast Norway. The drainage shifted between a NE-trending to a SW-trending direction several times during the represented deglaciation history. Several downslope directed meltwater channels (blue colour), many of these thought to derive from subglacial groundwater flow (cf., Gjessing 1960), are represented and are grouped in sets starting in lateral positions at different elevations. These features indicate multiple phases with transitions from cold-based to warm-based ice. Photograph copied from internet (www.norgeibilder.no).

by Olsen et al. (this issue) are described as ice sheets of S (or SIS) and F (or FIS) configurations, respectively, are denoted as MIS[2]-style and FIS-style ice sheets by Kleman et al. (2007). They concluded, for example that the western (fjord) zone of deep glacial erosion (Figure 10) formed underneath both SIS- and FIS-style ice sheets during the entire Quaternary, whereas the eastern (lake) zone of deep glacial erosion is exclusively a product of SIS style ice sheets, and formed mainly during the early and middle Quaternary. They also found that the eastern zones of scouring misfit with respect to SIS configuration, whereas the thick (mainly central and northern Sweden) drift zone (Figure 10) is interpreted to be a result of more than 1.1 million years of SIS-style ice sheet eastern margin locations and drift deposition on the Scandinavian peninsula, and of a subsequent survival of these drift deposits underneath central low-velocity and cold-based parts of FIS-style ice sheets during the last 1 million years.

Quaternary stratigraphical data from Norway and adjacent land/seabed areas

In contrast to the abundance of information which is available from the last glaciation (Weichselian) in Fennoscandia, terrestrial data from previous glaciations in this area are sparse and rely on very few sources of information. The interpretation and correlation of data from pre-Weichselian glaciations follow the same principles as those from the last glaciation and rely to a large extent on the validity of these. Tills from the Elsterian (MIS 12, i.e., marine isotope stage 12) (see e.g., Olsen et al., 2013, fig. 5) (Šibrava 1986, Lowe and Walker 1997) or previous glaciations have not so far been reported or confirmed from onshore positions in Fennoscandia, although data from the North Sea, the Norwegian Sea, the Netherlands, Germany and Eastern Europe suggest very strongly that the ice cover must have included, and in fact been initiated from the mountainous regions of Fennoscandia/ Scandinavia several times during the pre-Saalian (sensu stricto). In this compilation, only the glaciations directly traced in Fennoscandia are included, except to some old glacial deposits occurring on the adjoining shelf in the west, which are also mentioned briefly.

It is necessary to comment on the widely used term Saalian as the name for the penultimate glaciation in Northern Europe. Traditionally this term was used for the whole period between the Holsteinian and Eemian interglacials, but only the last part of the period, probably correlating with the marine isotope stage (MIS) 6, was fully glaciated (the Drenthe and Warthe stades). The long initial part of the Saalian (sensu lato), which alternated between cold and temperate intervals in Germany and the Netherlands, is now known to include glacial intervals, as well as interglacials and interstadials in northern Europe as a whole (Appendix A, Table A1, see also Appendix B, Tables B2 and B3, and Olsen et al., 2013, fig. 2).

Both terms Saalian (sensu stricto) and Late Saalian (sensu

[2] We prefer not to use the abbreviation MIS with respect to ice-sheet configuration since it is presently more often used as an abbreviation for marine isotope stage (Šibrava 1986, Lowe and Walker 1997) which is referred to several times in this and the accompanying papers (this issue).

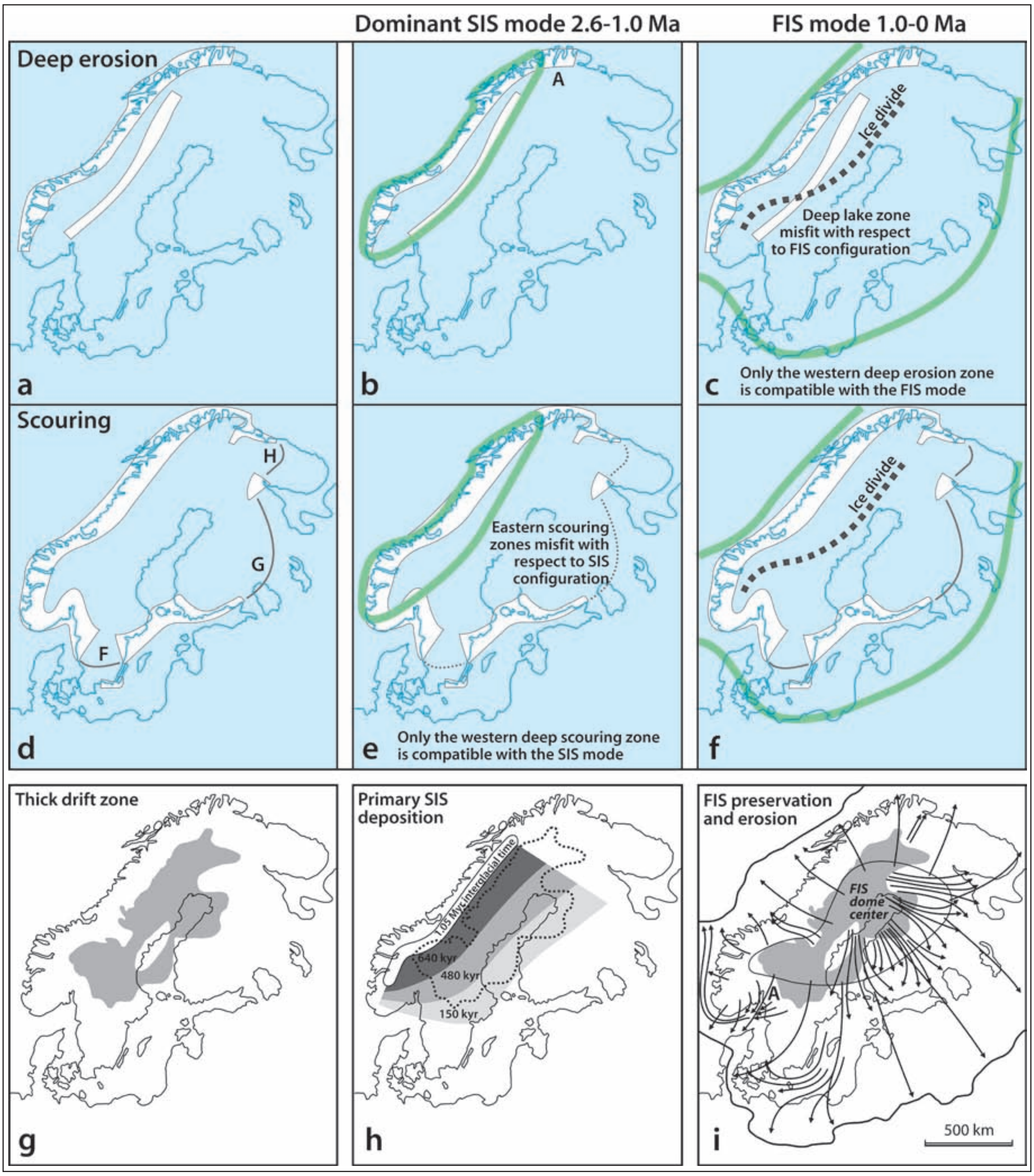


Figure 10. Combined Figures 10 and 11 from Kleman et al. (2007), slightly modified. The maps show patterns of Quaternary ice-sheet erosion and deposition in Fennoscandia. Published with permission from Elsevier and Copyright Clearance Center's Rightslink service, license number: 2075350071489, Nov. 24, 2008.

lato) are here maintained as the name for the penultimate glaciation, of MIS 6 age, whereas the previous long complex period, which followed the Holsteinian interglacial is subdivided in a Saalian Complex, including Early and Middle Saalian cold intervals (stadials) separated by a warmer interval (interglacial or interstadial) of MIS 9 age, and a proper interglacial correlating with MIS 7.

The represented ages and geographical distribution of all Quaternary stratigraphical sites used here, showing that all main regions are represented, are listed in Table B4 (Appendix B).

Principles for stratigraphical correlation used in northern and central Fennoscandia

The principles of correlation in central and northern Norway follow those presented and used in the Nordkalott- and the Mid-Norden projects, which were based on collaboration between the Geological Surveys of the Nordic countries during the 1980s and 1990s (e.g., Hirvas et al. 1988, Bargel et al. 1999). The clast fabric, provenance and lithology, and thereby the associated ice-flow direction associated with each till bed, are used as the main tools for correlation from site to site (Olsen 1988, 1993b, Olsen et al. 1996a). The age assignments are

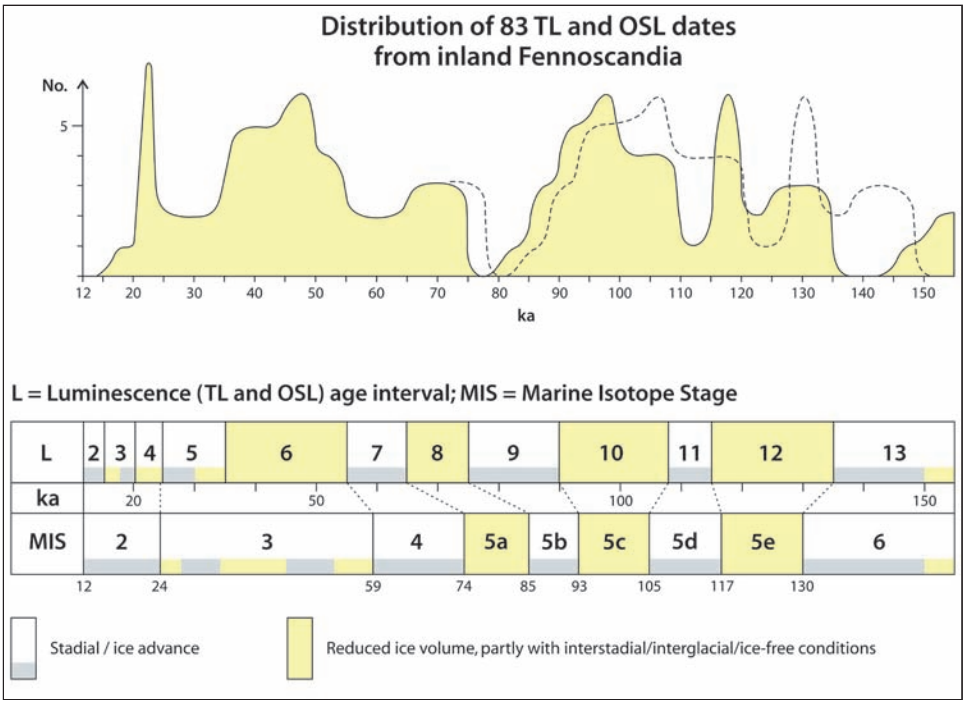


Figure 11. Frequency distribution of 83 luminescence dates of sediments from the inland of Fennoscandia. Most of these dates are from Olsen et al. (1996a), but are here used without correction for shallow traps since the argument for such traps was based on data from Greenland and Denmark and is not (shown to be) valid for Fennoscandia (Olsen, in Lokrantz and Sohlenius 2006). An alternative curve is indicated (stippled) for the possibility of a general underestimation of c. 10% of older ages, >75–100 ka. Seven recently reported OSL dates from subtill glaciofluvial/fluvial sediments from the inland of Trøndelag are also included (after Johnsen et al. 2012).

mainly based on dates from the individual sites, correlations to other dated stratigraphies, and comparison with a general age model (Figure 11) defined by the distribution of luminescence dates (TL and OSL) of sediments from intercalated interstadials/ice retreats from the central inland areas of Fennoscandia. For further details on correlations and correlation principles we refer to Appendix A.

Quaternary stratigraphies and correlations during major (F style) glaciations

Deposits from major pre-Eemian substages, interstades and interglacials

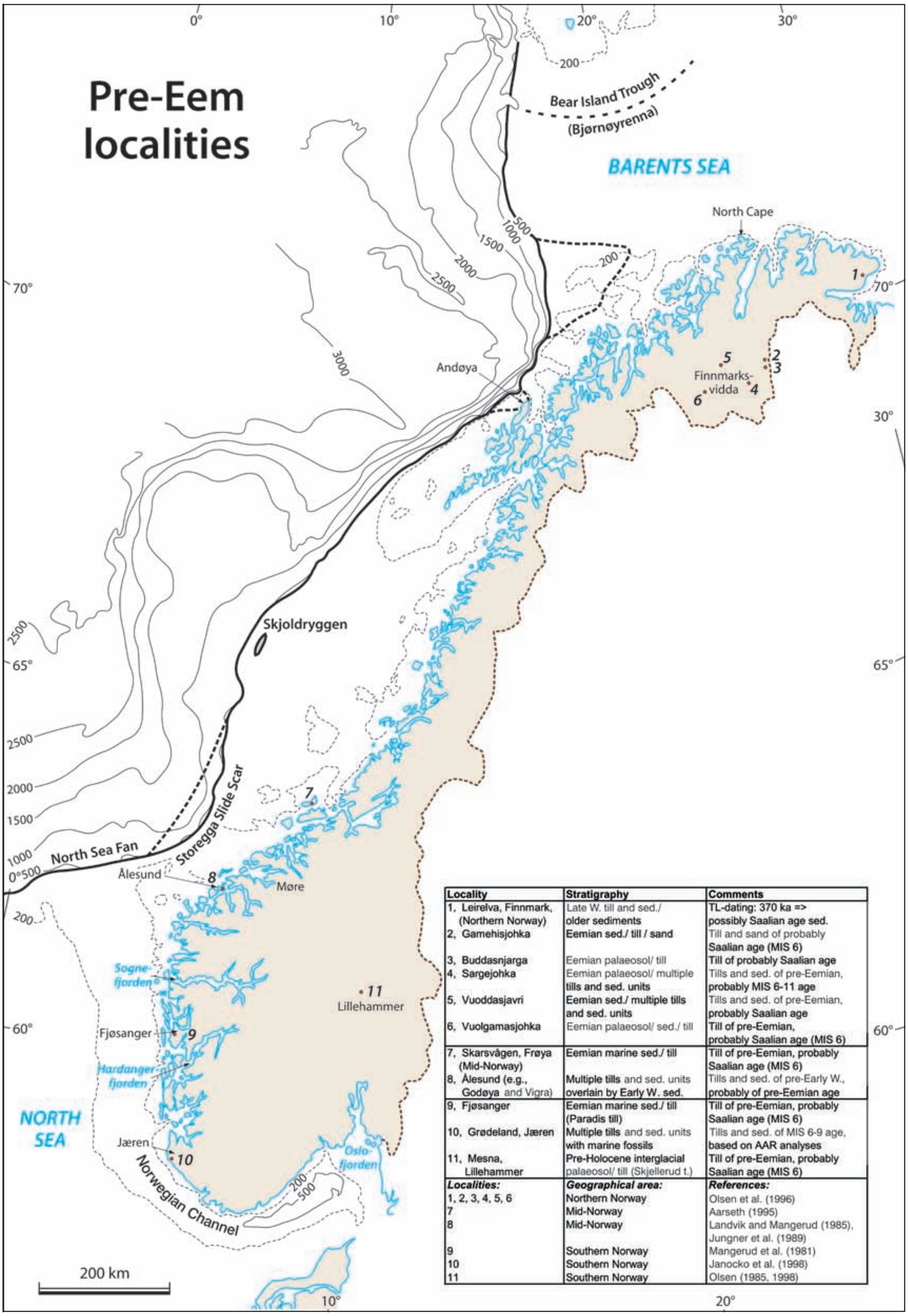
A record of 11 onshore Norwegian sites (Figure 12) with pre-Eemian deposits of glacial, interglacial and interstadial origin is compiled in Table B5 (Appendix B). These and many similar sites from adjacent onshore and offshore areas are briefly described in the following text.

Northern to central Norway and adjacent shelf and land areas
In northern Fennoscandia a record of 17 Finnish, 18 Swedish and 5 Norwegian localities with pre-Weichselian till beds have been reported (The Nordkalott Project 1986: Map of Quaternary geology, sheet 4, Olsen 1993b). Farther south, in central Fennoscandia, 21 Finnish localities, no Swedish and several offshore Norwegian localities are recorded (The Mid-Norden Project 1999: Map of Quaternary stratigraphy, Dahlgren 2002). Examples with stratigraphical information from some of these localities are briefly described in the following text.

Northern and central Norway. In Finnmark, northern Norway two localities with pre-Saalian (sensu stricto) tills and five with Saalian tills have been described (Figure 13 and Appendix B, Figure B2) (Olsen et al. 1996a). Most of these localities are located on eastern Finnmarksvidda, and according to (one of) the used criterions (Appendix A) this implies associated glacier extensions reaching at least to the coastal areas of northern Fennoscandia.

The relatively long and complex stratigraphy of tills and intercalated waterlain glacial and/or nonglacial sediments at Vuoddasjavri and Sargejohka, located at central and eastern Finnmarksvidda, respectively, comprise two of the most important datasets for reconstructing the pre-Weichselian glacier fluctuations in the northern Fennoscandia (Olsen 1993b, 1998, Olsen et al. 1996a).

The oldest sediment unit, Sargejohka unit K (Figure 14) is inferred to be of glaciofluvial origin, and simply based on the location of Sargejohka it derives most likely from the deglaciation of an ice sheet that had a maximum extension reaching at least to a position similar to the early Preboreal–late Younger Dryas glacier margins in the inner fjord areas in the north. Based on counting from the top, stratigraphical relationship to other recorded regional events (e.g., Appendix B, Table B2) and luminescence dates from younger units, the palaeosol (p6) that is developed in unit K is suggested to correlate with the Holstein interglacial (MIS 11), although faunal and vegetational evidence of warm conditions are so far not reported (Olsen 1998). This implies that unit K may represent the retreat of an ice sheet of MIS 12 age (or older). The overlying tills representing Glaciations 7–4 include ice-directional indications that imply S or F ice-sheet (SIS or FIS) configurations (Figure 15, see also Olsen



Locality	Stratigraphy	Comments
1, Leirelva, Finnmark, (Northern Norway)	Late W. till and sed./ older sediments	TL-dating: 370 ka => possibly Saalian age sed.
2, Gamehisjohka	Eemian sed./ till / sand	Till and sand of probably Saalian age (MIS 6)
3, Buddasnjarga	Eemian palaeosol/ till	Till of probably Saalian age
4, Sargejohka	Eemian palaeosol/ multiple tills and sed. units	Tills and sed. of pre-Eemian, probably MIS 6-11 age
5, Vuoddasjavri	Eemian sed./ multiple tills and sed. units	Tills and sed. of pre-Eemian, probably Saalian age
6, Vuolgamasjohka	Eemian palaeosol/ sed./ till	Till of pre-Eemian, probably Saalian age (MIS 6)
7, Skarsvågen, Frøya (Mid-Norway)	Eemian marine sed./ till	Till of pre-Eemian, probably Saalian age (MIS 6)
8, Ålesund (e.g., Godøya and Vigra)	Multiple tills and sed. units overlain by Early W. sed.	Tills and sed. of pre-Early W., probably of pre-Eemian age
9, Fjøsanger	Eemian marine sed./ till (Paradis till)	Till of pre-Eemian, probably Saalian age (MIS 6)
10, Grødeland, Jæren	Multiple tills and sed. units with marine fossils	Tills and sed. of MIS 6-9 age, based on AAR analyses
11, Mesna, Lillehammer	Pre-Holocene interglacial palaeosol/ till (Skjellerud t.)	Till of pre-Eemian, probably Saalian age (MIS 6)
Localities:	***Geographical area:***	***References:***
1, 2, 3, 4, 5, 6	Northern Norway	Olsen et al. (1996)
7	Mid-Norway	Aarseth (1995)
8	Mid-Norway	Landvik and Mangerud (1985), Jungner et al. (1989)
9	Southern Norway	Mangerud et al. (1981)
10	Southern Norway	Janocko et al. (1998)
11	Southern Norway	Olsen (1985, 1998)

Figure 12. Pre-Eemian sites (MIS 6 – MIS 11, i.e., about 140–400 ka).

et al., this issue) with associated ice extensions reaching to the coast, the shelf or even to the shelf edge.

Stratigraphical information from the pre-Weichselian glacial deposits from Vuoddasjavri and Sargejohka, which is correlated with other sites from Finnmarksvidda (Figures 12 and 13) and synthesised with regard to glacier extension is presented in Appendix B, Table B3 (see Substages 9–13, with comments in the north–column of maximum ice extension).

In central Norway very few Quaternary deposits of pre-Weichselian age are reported. Resedimented spruce pollen and

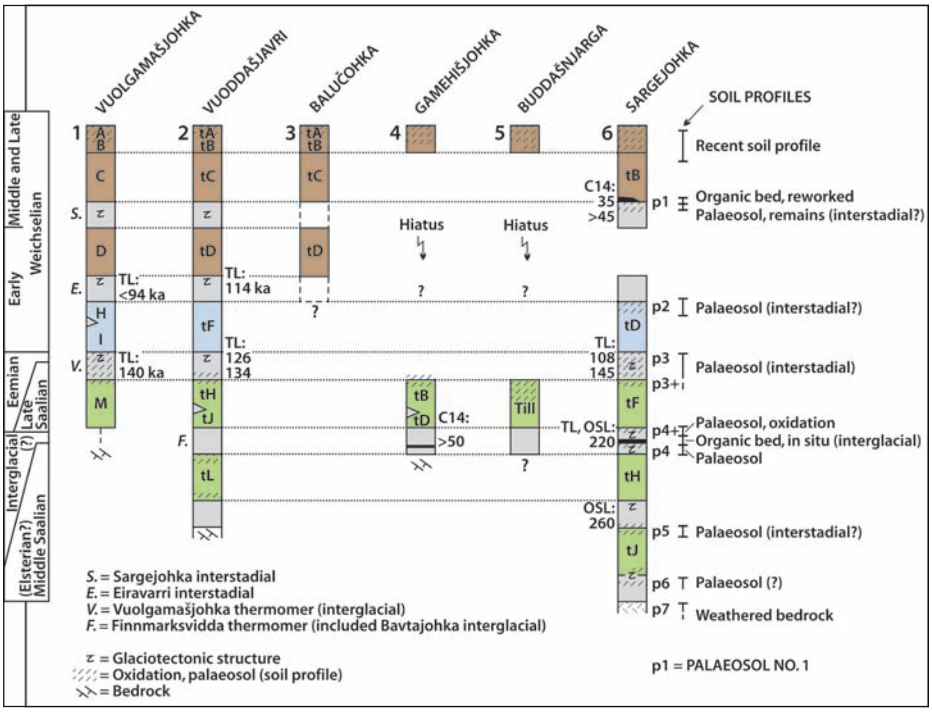


Figure 13. Six correlated Quaternary stratigraphies from Finnmarksvidda, modified from Olsen et al. (1996a). Localities 1–6 are shown in Figure B1 (Appendix B), as localities 15, 16, 12, 10, 11 and 13, respectively. The location of five of these are also included in Figure 12 (with other locality numbers, 1= 6, 2= 5, 3= not represented, 4= 2, 5= 3, and 6= 4).

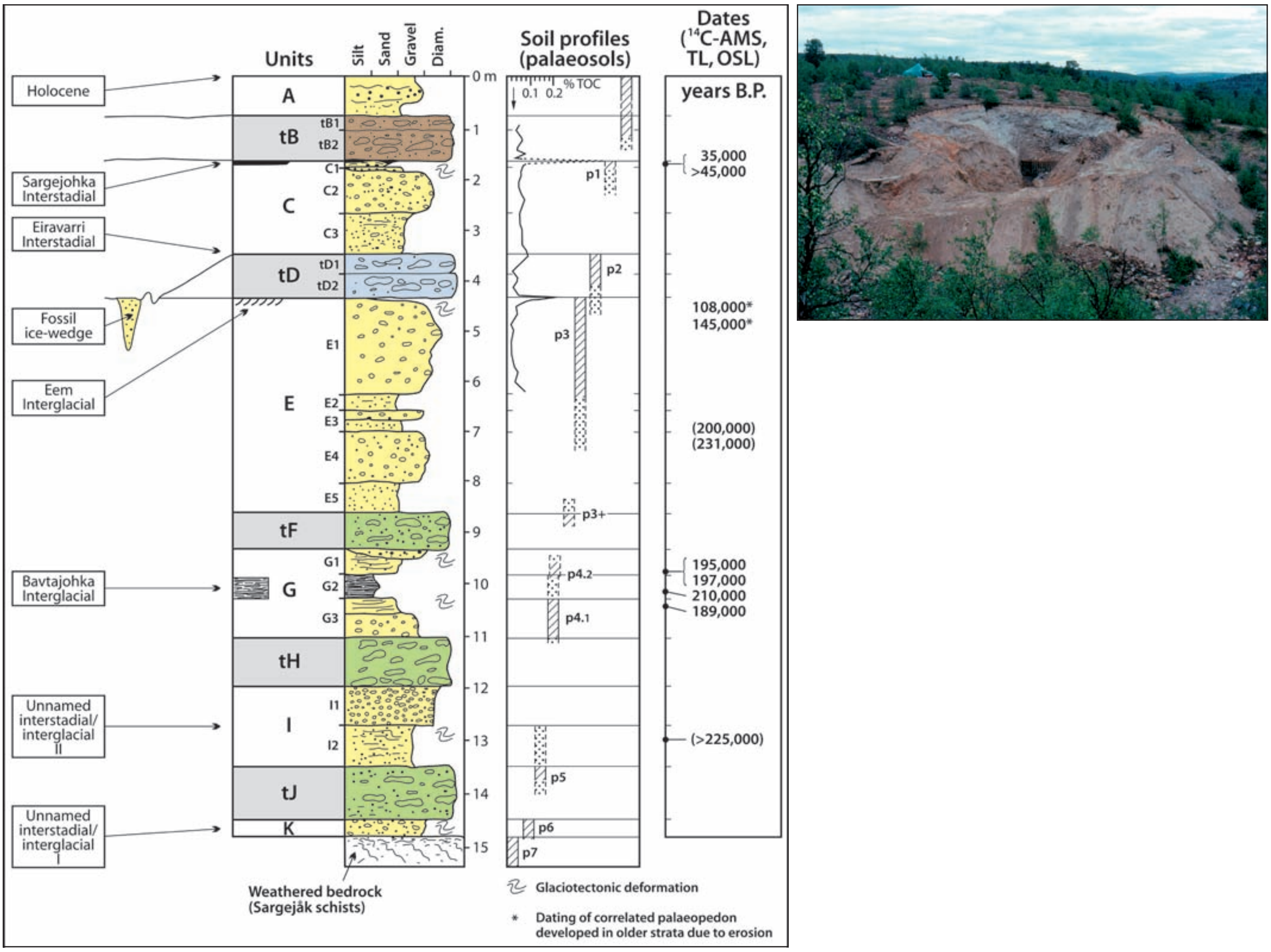


Figure 14. Stratigraphical data from Sargejohka, eastern Finnmarksvidda, modified from Olsen et al. (1996a) and Olsen (1998). (a) Left panel - *stratigraphical column, and (b)* Right panel - *Photograph from excavation at Sargejohka 1989. Dark sediment layers from Bavtajohka interglacial are exposed at c. 10 m depth in the middle of the photo.*

'warm' foraminifera of probably last interglacial (Eemian) age are recorded at some sites in Trøndelag (e.g., Olsen et al. 2001a, 2002), but the only reported in situ sediments of this age is at Skarsvågen on Frøya island, Sør-Trøndelag (Figure 4). This site includes, in addition to Weichselian sediments, both a pre-Eemian, probably Saalian till and marine Eemian beds (Aarseth 1990, 1995).

The Mid-Norwegian shelf. From the Mid-Norwegian shelf a sediment core from the Draugen field includes in its lower part a pre-Weichselian, 70 m–thick succession of till and fine-grained sediments deposited from suspension (Rise et al. 2002, 2005a, The Mid-Norden Project 1999: Map of Quaternary stratigraphy, locality no.104) (Figure 16). At Trænabanken, thick till beds recorded as the Middle and Lower tills, based on data from sediment cores, are assigned Saalian and pre-Saalian ages, respectively (e.g., Dahlgren 2002). Tills and glaciomarine diamictons from the Mid-Norwegian shelf have been correlated with the Naust Formation (glacial debris flows) on the North Sea Fan (e.g., Nygård 2003), and the associated glacier extensions of these units are included in Appendix B, Table B3 (see Substages 9–13, with comments in the west column of maximum ice extension). For more details about the glacial drift on the Mid-Norwegian shelf, we refer to the recent paper by Ottesen et al. (2009).

Northern and central Sweden. Of the 18 reported localities with pre-Weichselian tills in northern and central Sweden only two include more than one such till bed. These are Åkåskielas (no.55) and Lainikvare (no.140) from positions halfway and ¾ distance from the Norwegian–Swedish national border to the Bothnian Bay (The Nordkalott Project 1986: Map of Quaternary geology, sheet 4, The Mid-Norden Project 1999: Map of Quaternary stratigraphy) (Appendix B, Figure B3). The

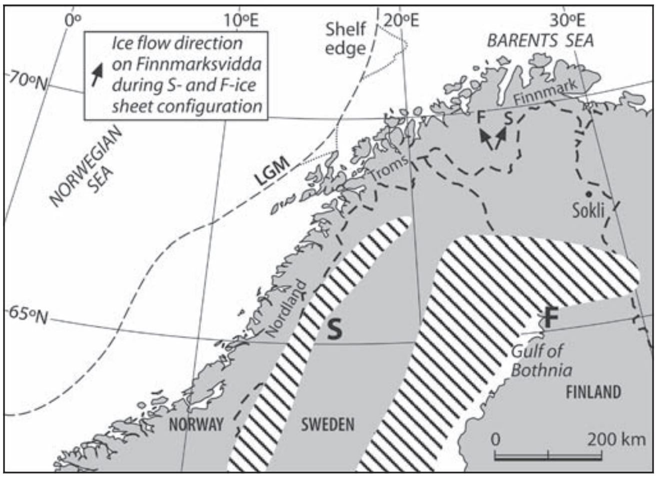


Figure 15. Map of northern Fennsoscandia, with locations of ice-divide zones (shaded) and associated ice movements (arrows) on Finnmarksvidda, modified from Olsen et al. (1996a). F= Fennoscandian ice-sheet configuration, which occurred during maximum glaciations and ice flow towards north-northwest in Finnmark. S= Scandinavian ice-sheet configuration with ice divide along the highest mountains, moderate ice extensions and ice flow towards north-northeast in Finnmark.

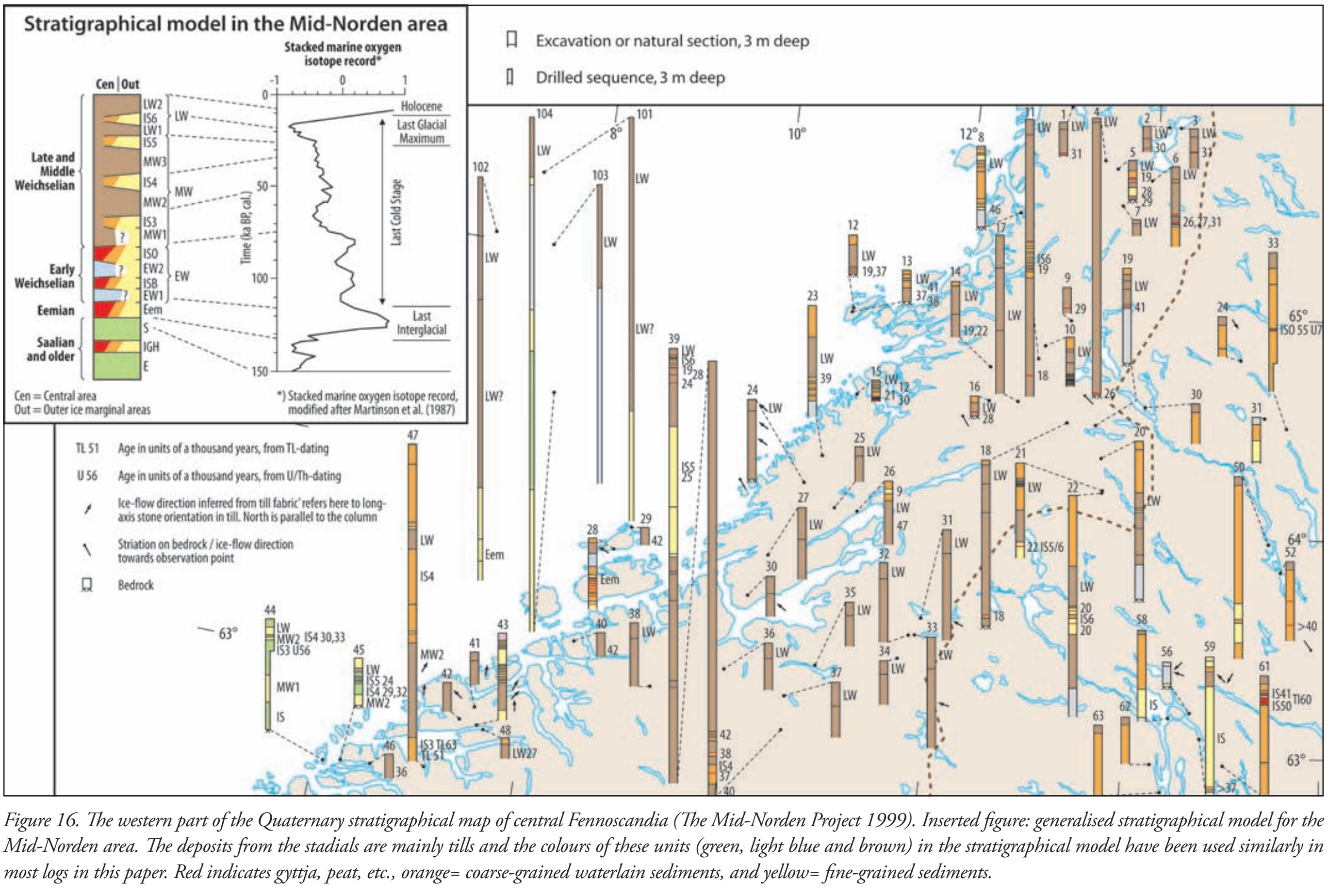


Figure 16. The western part of the Quaternary stratigraphical map of central Fennoscandia (The Mid-Norden Project 1999). Inserted figure: generalised stratigraphical model for the Mid-Norden area. The deposits from the stadials are mainly tills and the colours of these units (green, light blue and brown) in the stratigraphical model have been used similarly in most logs in this paper. Red indicates gyttja, peat, etc., orange= coarse-grained waterlain sediments, and yellow= fine-grained sediments.

occurrence of the oldest till units at these sites implies a glacier extension of at least moderate size of a mountain-centred glacier. Clast fabrics from seven localities with Saalian tills from northern Sweden (The Nordkalott Project 1986: Map of Quaternary geology, sheet 4, nos. 12, 23, 55, 57, 126, 130 and 150) (Appendix B, Figure B3) indicate deposition from a glacier of F-configuration (Figure 15) if all the till beds are from one substage, or more likely deposition both from glaciers of S- and F-configurations if the tills are from more than one substage.

Northern and central Finland. Of the 38 reported localities with pre-Weichselian tills from northern and central Finland only four include more than one such till bed, and only one of these is located in northern Finland (The Nordkalott Project 1986: Map of Quaternary geology, sheet 4, no. 39 Rautuvaara) (Appendix B, Figure B3). The three other of these sites are located less than 140 km from the Gulf of Bothnia in central Finland (The Mid-Norden Project 1999: Map of Quaternary stratigraphy, nos. 16, 36 and 43) (Appendix B, Figure B4). In addition, three sites with glacial striation from pre-Saalian ice flows are reported from the middle and eastern parts of central Finland (nos. 17, 27 and 38) (Appendix B, Figure B4).

The most important site for reconstructing the pre-Weichselian glacier fluctuations and ice flow directions in Fin-

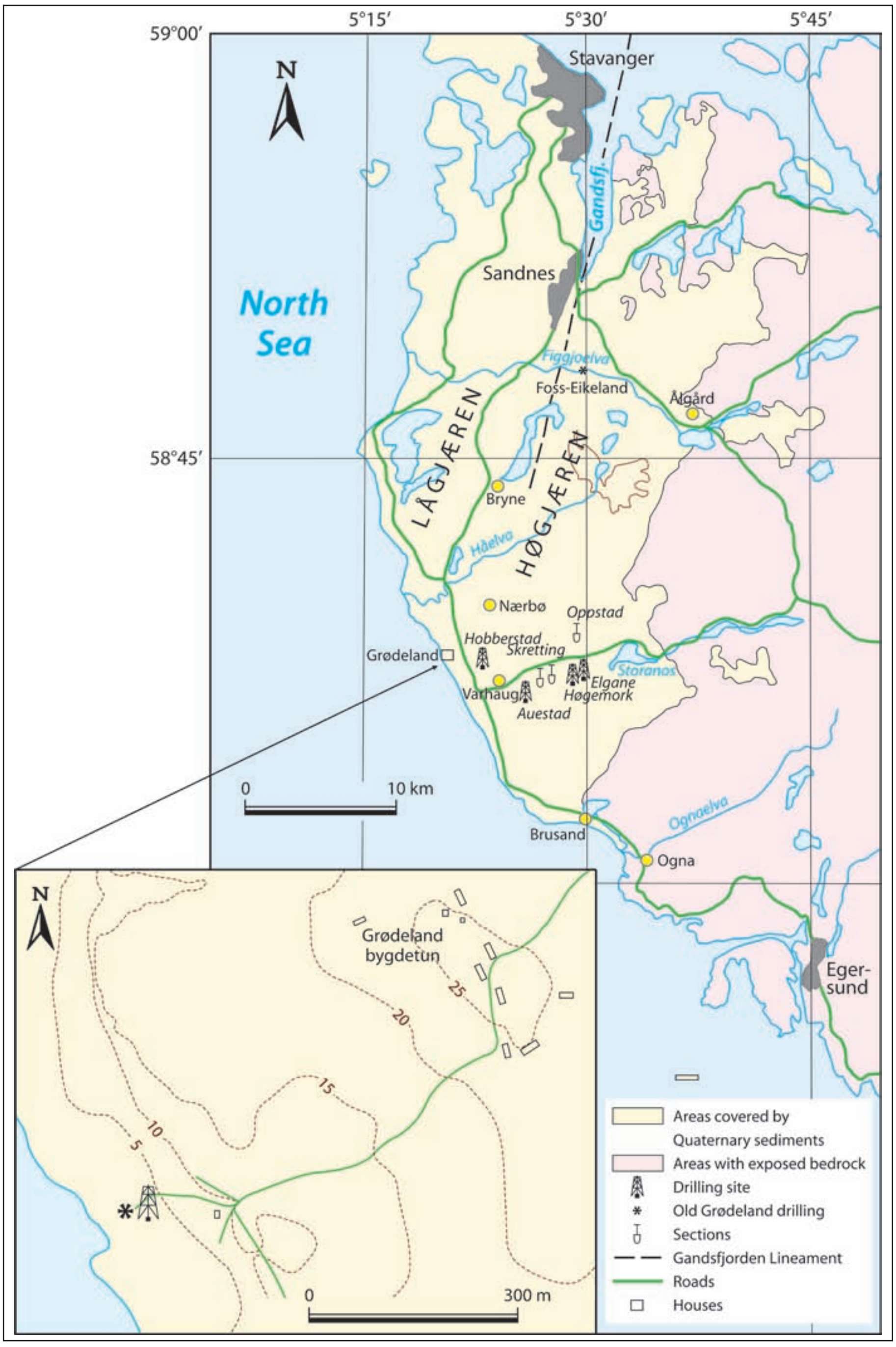


Figure 17. Map of the Jæren area showing the locations of stratigraphical sites (boreholes, sections) referred to in Figures 18, 29 and 31.

land is the Rautuvaara locality (no. 39, Appendix B, Figure B3), near Kolari in northern Finland. It includes five superimposed till beds, three of which are of pre-Weichselian age (Tills 6–4), and this site is a 22 m-high sediment succession that is supposed to be a nice parallel to the Norwegian Sargejohka site mentioned above.

Based on 19 clast fabric analyses, the associated ice-flow directions are inferred to be towards the east to east-southeast for the oldest unit, till bed 6, towards the southeast for till bed 5, and towards the north-northeast (lower part), the east-northeast (middle part) and the south-southeast (upper part) for till bed 4 (Hirvas 1991). Although solifluction may have influenced some of the fabrics, the results altogether suggest associated ice sheets with S-configuration (Figure 15) for till bed 6, F-configuration for till bed 5 (pre-Saalian tills), and both F- (lower and upper parts) and S- (middle part) configurations for till bed 4 (Saalian till).

All the relevant stratigraphical ice-flow directional information from the Rautuvaara locality and the other reported Finnish, Swedish and Norwegian localities with pre-Weichselian tills from northern and central Fennoscandia is compiled in Appendix B (Figure B1) in the accompanying paper by Olsen et al. (2013).

Southern Norway—with additional comments to the North Sea

The oldest reported Quaternary sediments on land in southern Norway are from the Jæren lowland in the southwest, where glacial, interstadial and interglacial deposits with marine fossils, from MIS 10 and upwards are described in boreholes (Janocko et al. 1998, Sejrup et al. 1998, 1999) (Figures 17 and 18). From the coastal area at Fjøsanger, southwest of Bergen (Figure 4), a Saalian till, the Paradis till (MIS 6) is underlying Eemian interglacial marine (MIS 5e) and younger sediments (Mangerud et al. 1981b). Furthermore, at Lillehammer in the inland of southeast Norway a thick till (the Skjellerud till) of pre-Middle Weichselian, probably Saalian age underlies deposits of Middle to Late Weichselian age (Olsen 1985b, 1998).

Data from the Troll core 8903 (Figure 19) (Sejrup et al. 1995) and seismostratigraphical information, also from the Norwegian Channel (Figure 20) (Sejrup et al. 2000, Rise et al. 2004) indicate tills from at least one Saalian (sensu stricto) and four pre-Saalian major ice advances. There seems to be a long nonglacial interval with deposition of a thick marine sediment unit (unit C) between the till bed at *c.* 1.1 million yr BP and the subsequent till that may have a MIS 12 age (Sejrup et al. 1995, Nygård 2003). Recently it has been reported that several glacial erosional horizons occur underneath the base of the previously published Troll core 8903, and the oldest of these may have an age of *c.* 2.7 million years (A. Nygård, pers. comm. 2007). This supports the earlier data from IRD in deep-sea sediments, e.g., from the Vøring Plateau (Bleil 1989, Jansen and Sjøholm 1991), with the implication that glaciers have indeed reached beyond the coastline as early as this.

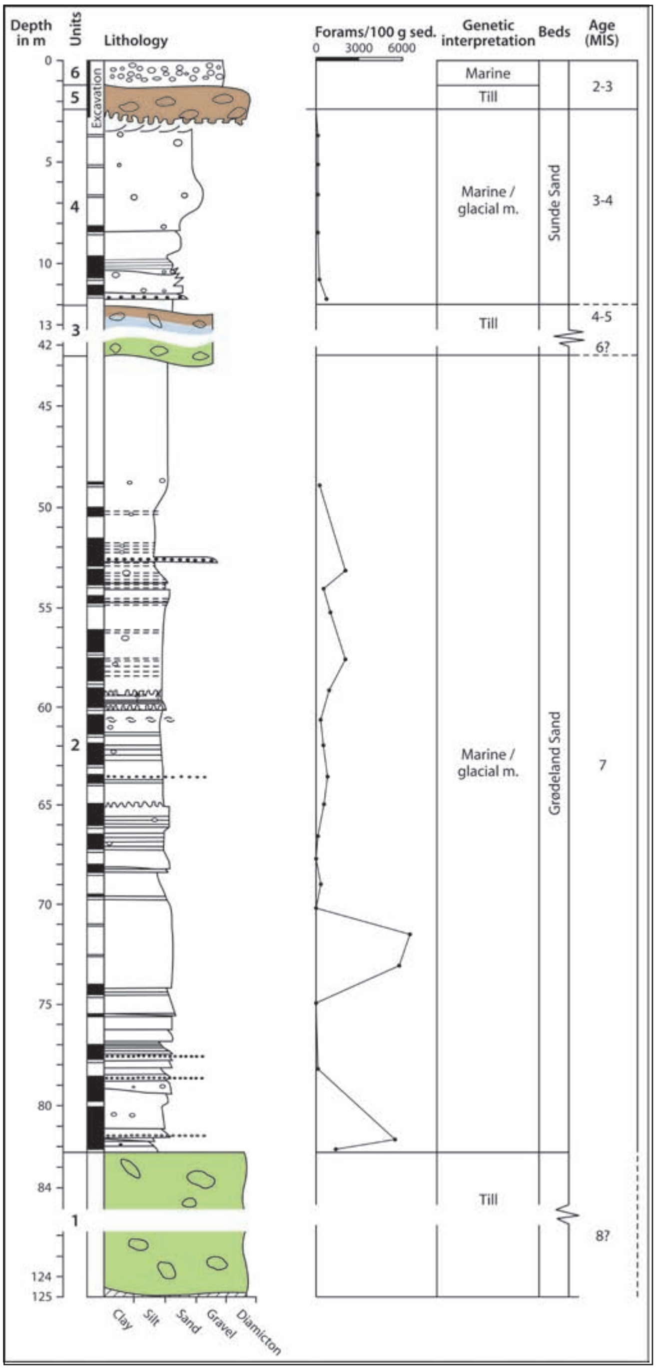


Figure 18. The lithostratigraphy of the Grødeland core, modified from Janocko et al. (1998) and Sejrup et al. (1999). Location of site indicated in Figure 17. Based on amino acid racemisation of marine shells from units 2 (the Grødeland Sand) and 1 (the lowermost till) are supposed to have an age corresponding to MIS 7 and possibly MIS 8, respectively.

Adjacent land areas in the south, southeast and east

Most of the relevant information from the areas considered here are from the compilation of pre-Weichselian glaciations given by Ehlers (1996). During the maximum phases of the Scandinavian Ice Sheet the ice margin reached southwards to the West-European lowlands in the area of the Netherlands–Germany–

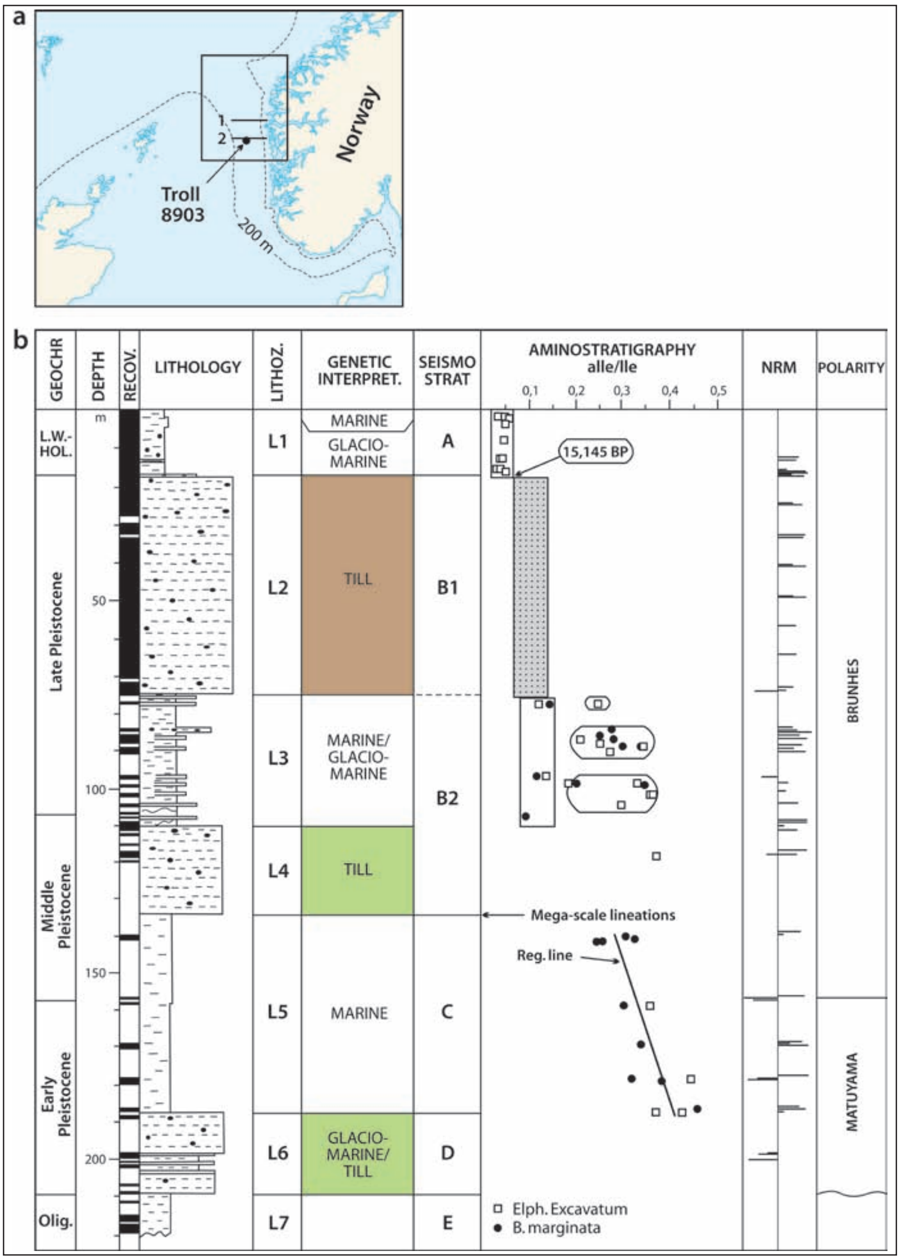


Figure 19. (a) Location map for the Troll core 8903 and the sparker profile lines 1 and 2 referred to in Figures 20a and b, and (b) litho- and chronostratigraphy of the Troll core 8903, and correlation to seismic units indicated in Figure 20. Modified from Sejrup et al. (1995), mainly after Rise et al. (2004).

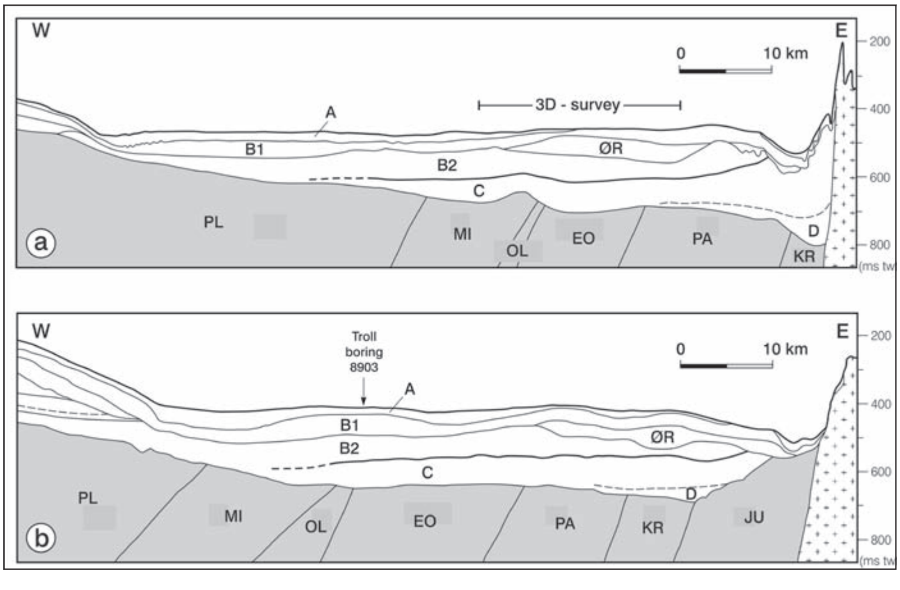


Figure 20. Interpretation of seismostratigraphical cross-section of the Norwegian Channel, (a) along sparker line, profile 1: A77–117, and (b) profile 2: A77–123. After Rise et al. (2004). For location of profiles, see Figure 19a (1= A77–117, and 2= A77–123).

Poland. The glacial deposits from these phases are indirectly dated and correlation to the marine isotope stratigraphy based on the age assignments to the interglacial beds that occur stratigraphically overlying, underlying and/or between these beds (Appendix B, Table B2). Although old glacial deposits have been searched for a long time only the three last glaciations, the Weichselian (MIS 2–5d), the Saalian (MIS 6) and the Elsterian (most likely MIS 12) are documented by glacial deposits/tills in Germany (Ehlers 1996). However, Scandinavian rocks (erratics) that indicate glacial transport are found in older sediments in the Netherlands (Zagwijn 1992).

In the southeast and east (including Russia and Belarussia) the glacial stratigraphical record encompasses tills that are correlated with the Saalian and the Elsterian, and it reaches further back in time and includes also tills from the major Don glaciation (possibly of MIS 16 age, Ehlers 1996) that also had its core area in Scandinavia.

An overview of deposits from the last interglacial (the Eemian)

The Norwegian record of deposits from the Eemian is not large, but still very important as it deals with an important chronostratigraphical marker both on land and offshore (e.g., Mangerud et al. 1981b, Sejrup and Knudsen 1993, Olsen 1998, Hjelstuen et al. 2004, Nygård et al. 2007).

The record includes only some 24 sites on land (Figure 21a and Appendix B, Table B6), but it comprises different formations, such as waterlain sediments (organic and inorganic, marine and terrestrial), palaeosols and speleothems. Several of these formations include palaeoclimatic signatures (as warm as, or warmer than the present) that make them useful for regional correlations. The recorded Eemian sites include six localities from Finnmark, with fluvial/glaciofluvial sediments and/or palaeosols (Olsen et al. 1996a), one from Mid-Norway with gyttja and lacustrine sediments overlain by marine transgression sediments (Skarsvågen, Frøya; Aarseth 1990, 1995), two localities with Eemian marine sediments from southwest Norway (Fjøsanger and Bø; Mangerud et al. 1981b, Andersen et al. 1983), one locality in the inland of southwest Norway with a thin Eemian peat overlain by a Weichselian till (Vinjedalen at Vossestrand; Sindre 1979, Eide and Sindre 1987), at least one locality from Hardangervidda with Eemian lacustrine clay (Hovden; Vorren and Roaldset 1977), and one locality with an Eemian palaeosol developed in a supposed Saalian till at Lillehammer, southeast Norway (Mesna; Olsen 1985b, 1998). In addition, speleothems deposited during the Eemian are reported from caves in Nordland (e.g., Lauritzen 1991, Linge et al. 2001), and several sites with resedimented Eemian organics (e.g., shells and pollen) in Weichselian sediments are reported from different parts of Norway (e.g., Vorren 1972, Vorren et al. 1981, Bergstrøm et al. 1994, Olsen et al. 2001c, Olsen 2002).

The three most cited offshore Eemian sites from the Norwegian shelf are also included in Appendix B (Table B6).

Deposits from major Weichselian substages and intervening ice-retreat phases

An overview of the distribution of Norwegian sites with dated Weichselian-aged sediments (from ice-free intervals) that are intercalated between tills, which have been used as age constrains for the tills, are presented in a series of maps and listed in tables in Appendix B. These include sites from the early Middle Weichselian to Early Weichselian (MIS 4–5d) (Figure 21b and Appendix B, Table B7), the early Middle Weichselian (MIS 3, 44–59 cal ka) (Figure 21c and Appendix B, Table 8), the late Middle Weichselian (MIS 3, 29–44 cal ka) (Figure 21d and Appendix B, Table B9), and the LGM interval (MIS 3/2 and 2, 17–29 cal ka) (Figure 21e and Appendix B, Table B10). The average number of till units that overlie the 'ice-free' sediment units from a particular age interval varies proportionally with age, so that older sediments are overlain by more till units than younger sediments. The average numbers are, listed chronologically (4–3–2–1) from older to younger intervals, 2.65, 1.72, 1.39, and 1.16 (or 1.00, for the LGM) (Appendix B, Tables 7–10). This demonstrates that the *'counting from the top'* principle as described in Appendix A, can be applied and may generally work well for the Weichselian glacial stratigraphy of Norway.

The oldest post-LGM onshore sites with glacial oscillation sediments (till–waterlain sediment–till successions) are listed in Table B11 (Appendix B).

Northern and central Norway—with additional comments to northern and central Sweden and Finland

In northern Fennoscandia, among a total of *c.* 3000 stratigraphical localities more than 175 Finnish, 150 Swedish and 50 Norwegian localities with Early and/or Middle Weichselian till beds have been compiled from various maps (e.g., the Nordkalott Project 1986: Map of Quaternary geology, sheet 4; Olsen 1993). Farther south, in central Fennoscandia, among a total of *c.* 2300 stratigraphical localities more than 47 Finnish localities, 63 Swedish and 48 onshore and several offshore Norwegian localities with Middle Weichselian or older till beds are compiled (e.g., the Mid-Norden Project 1999: Map of Quaternary geology, sheet 3; Dahlgren 2002). Examples with stratigraphical information from some of these and other selected localities are briefly described in the following text.

Northern and central Norway. The Sargejohka, Vuoddasjavri and Vuolgamasjohka sites from Finnmarksvidda, northern Norway (Olsen 1988, 1993b, 1998, Olsen et al. 1996a), include till beds (Gardejohka till) from at least one stadial, and waterlain sediments from at least one interstadial (Eiravarri) during the Early Weichselian. The lower boundary of the Weichselian sediment succession is defined by the subjacent Eemian palaeosol, which is developed as a spectacular podzol at Sargejohka (Figure 22a). Glaciotectonic deformation trending east in the waterlain sediments from the last interglacial (Eemian) at Vuolgamasjohka suggests that the first Weichselian ice

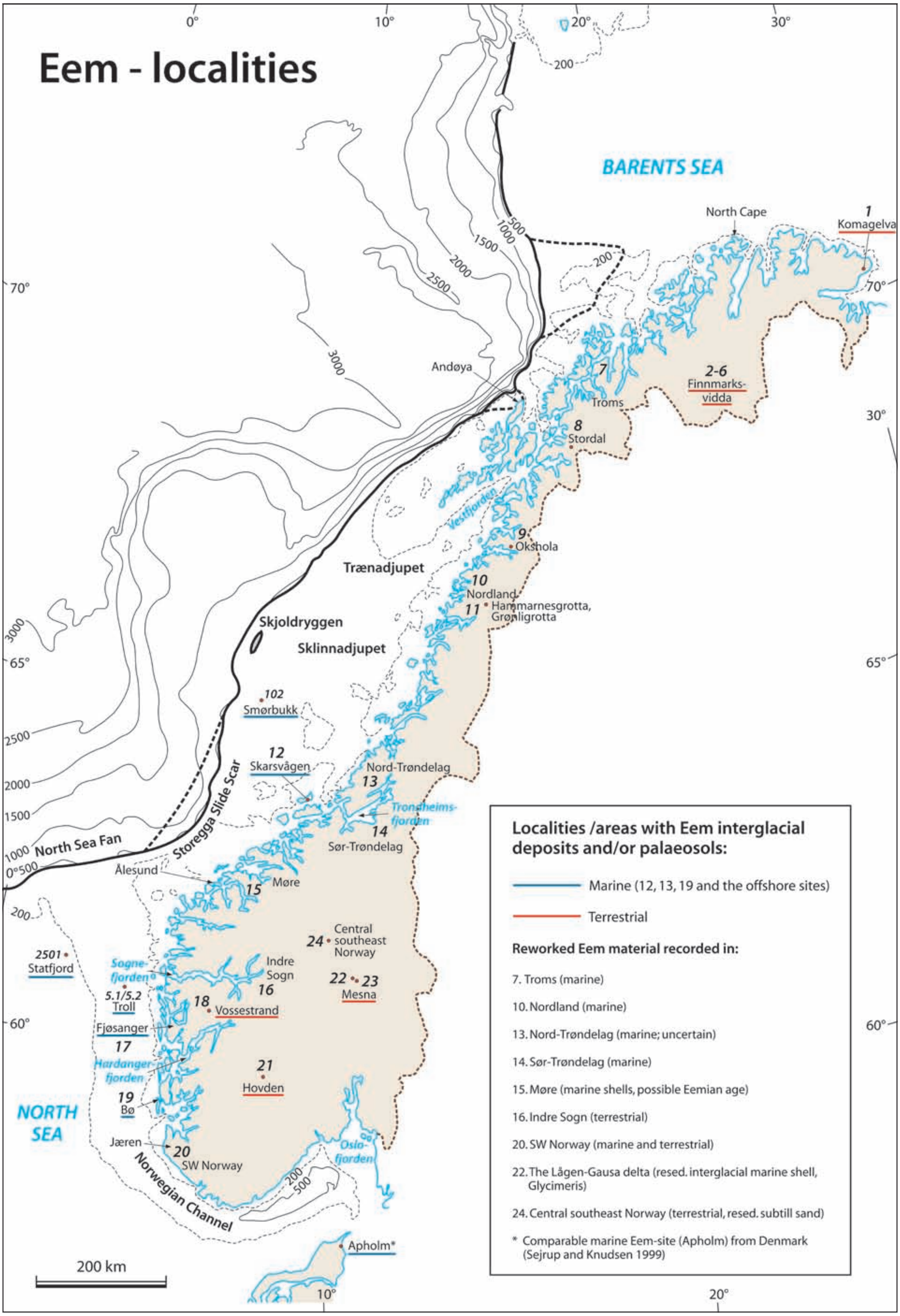


Figure 21. (a) Eem sites (same as Olsen et al., 2013, fig. 6). (b) Early Middle Weichselian to Early Weichselian sites (MIS 4–5d). (c) Early Middle Weichselian sites (MIS 3, 44–59 cal ka). (d) Late Middle Weichselian sites (MIS 3, 29–44 cal ka). (e) LGM interval sites (MIS 3/2 and 2, 17–29 cal ka).

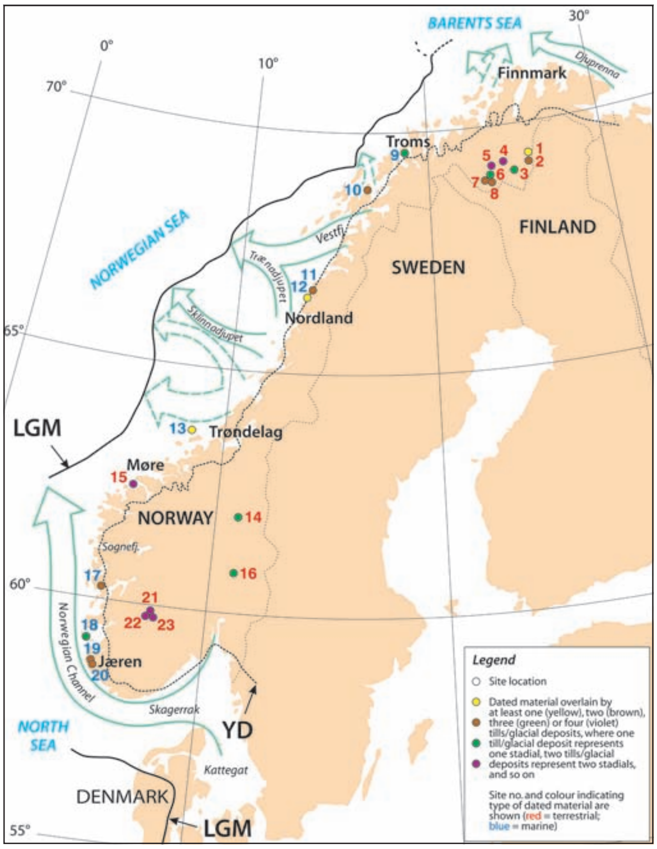


Figure 21b: Early Middle Weichselian to Early Weichselian (MIS 4–5d) (60–115 ka).

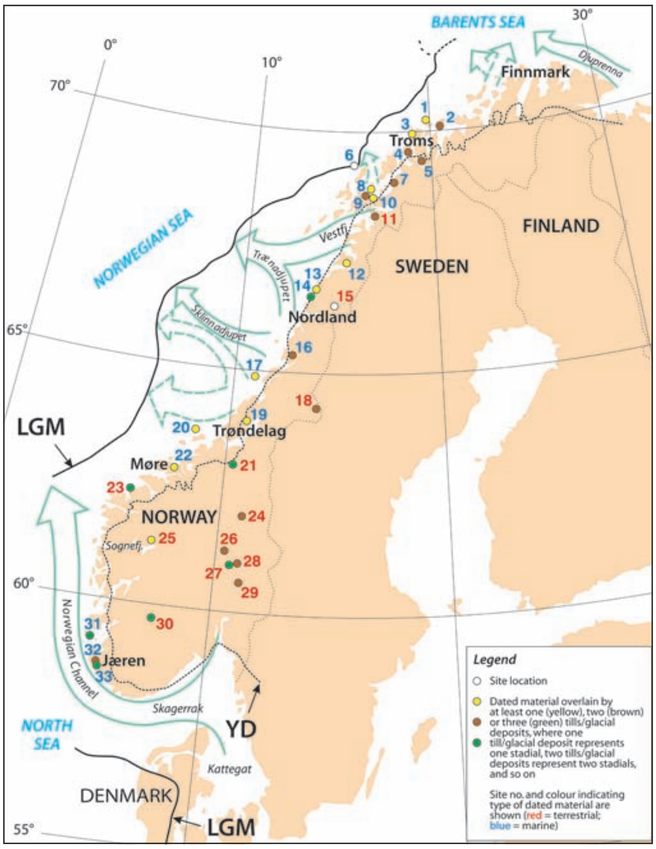


Figure 21c: Early Middle Weichselian (MIS 3) (44–59 cal ka).

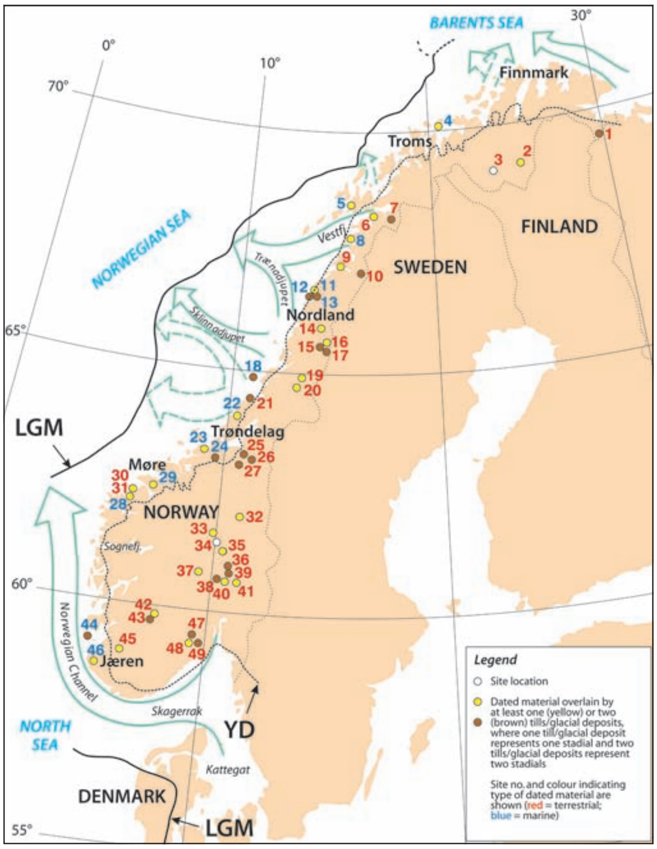


Figure 21d: Late Middle Weichselian (MIS 3) (29–44 cal ka).

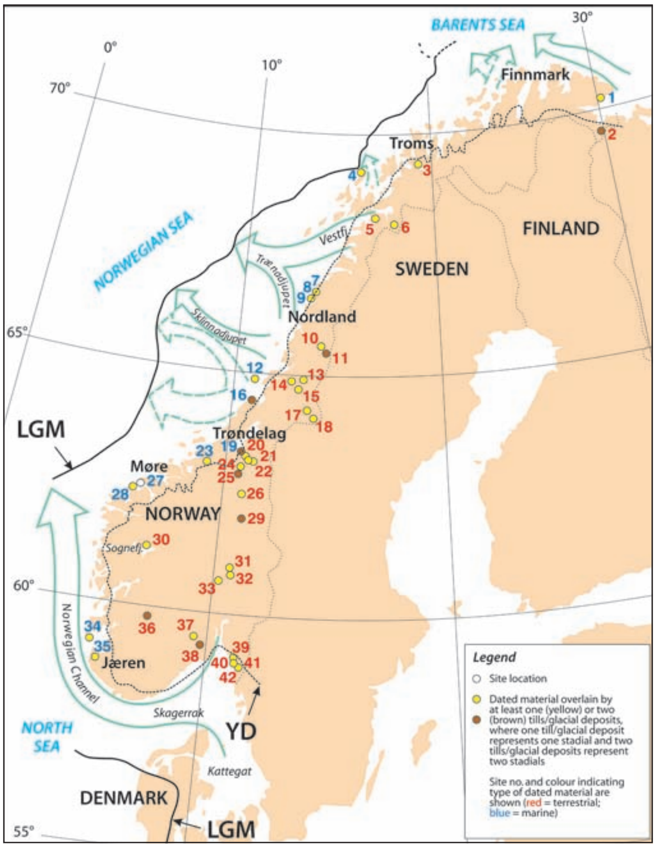


Figure 21e: Late Weichselian (MIS 2), LGM interval c. 15–25 ^{14}C ka (i.e., 17–29 cal ka).

flow came from the mountains in the west. No recorded till is associated with this ice flow, which indicates that the initial Weichselian glaciation may have occurred without deposition of till on Finnmarksvidda (Olsen et al. 1996a). Alternatively, the associated till was eroded during subsequent ice flow(s). All three sites also include tills (Vuoddasjavri till) from at least one stadial, and waterlain sediments from at least one interstadial (Sargejohka) of Middle Weichselian age.

At Leirelva and Komagelva in northeastern Finnmark (Figure 22b), inferred Eemian and older well-sorted sand is overlain by glaciofluvial sediments and till from the Late Weichselian (Olsen et al. 1996b).

At Leirhola, Arnøya, northern Troms, till-covered glaciomarine deposits up to *c.* 8 m a.s.l. indicate that the glacier margin was close to the site a short time before 34–41 cal ka (i.e., around 44 cal ka), advanced beyond the site with deposition of a till bed shortly after *c.* 34 cal ka, retreated and readvanced over the site with additional till deposition shortly after 31 cal ka (Andreassen et al. 1985). A new excavation in the year 2000, *c.* 40 m from the former site revealed a sediment succession including shore deposits and marine-transgression sediments overlain by till indicating that the sea level fluctuated around 14 m a.s.l. in a period sometime between 34 cal ka and the last major LGM advance (Figure 23, Olsen 2010). Due to the considerable glacioisostatic depression, and despite the existence of a globally very low sea level (120–130 m b.s.l.) at that time, a relative sea level as low as this is not likely to represent a phase with rapid ice retreat *c.* 24 cal ka, i.e., during the Andøya–Trofors interstadial between the LGM I and II advances. A comparison with the last deglaciation history suggests that the relative sea level during such conditions would be expected to be at least 20–30 m a.s.l., considered the near maximum glacioisostatic depression at this time. It is much more likely that the 14 m sea level occurred around 31 cal ka, a time when the global sea level was *c.* 50 m lower than the present (e.g., Shackleton 1987) and with the local glacioisostatic depression of moderate size, at the end of an interstadial or after the retreat of a medium-sized glacier expansion and ice-volume event.

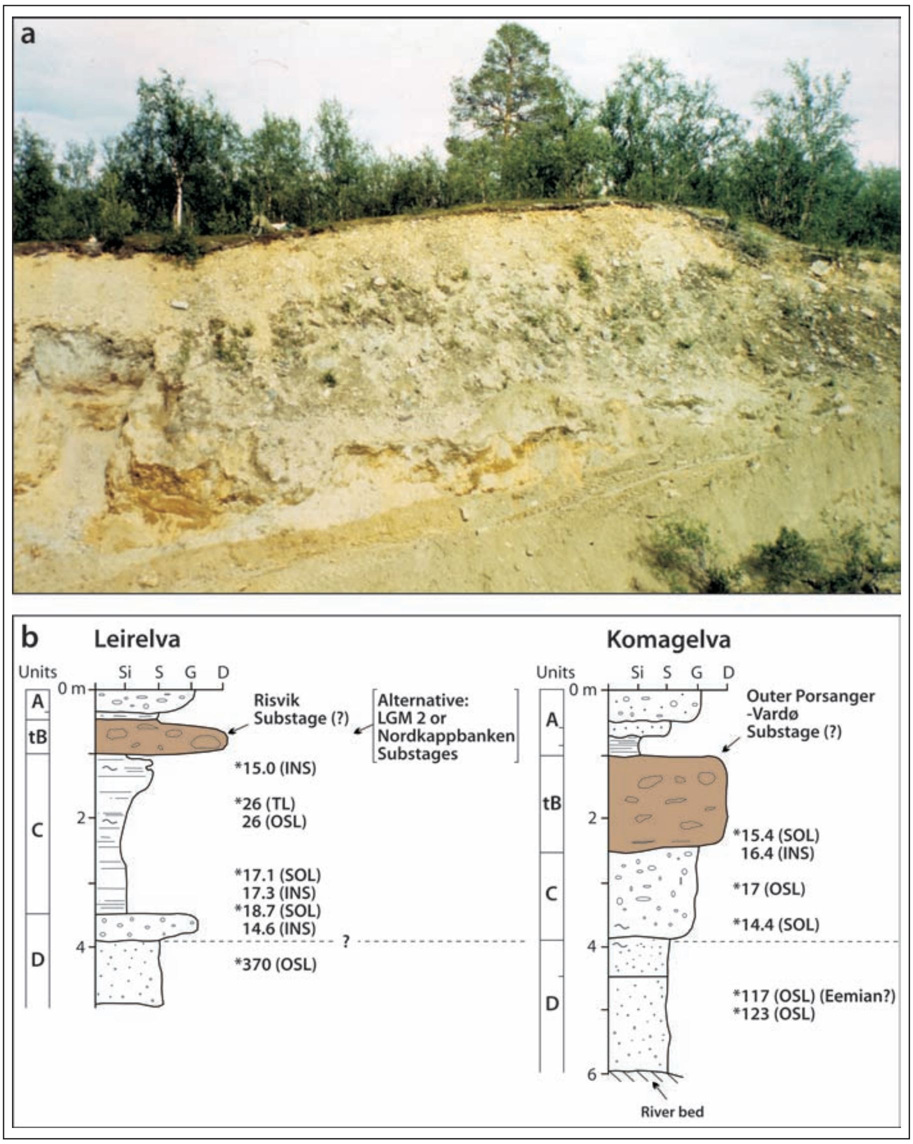
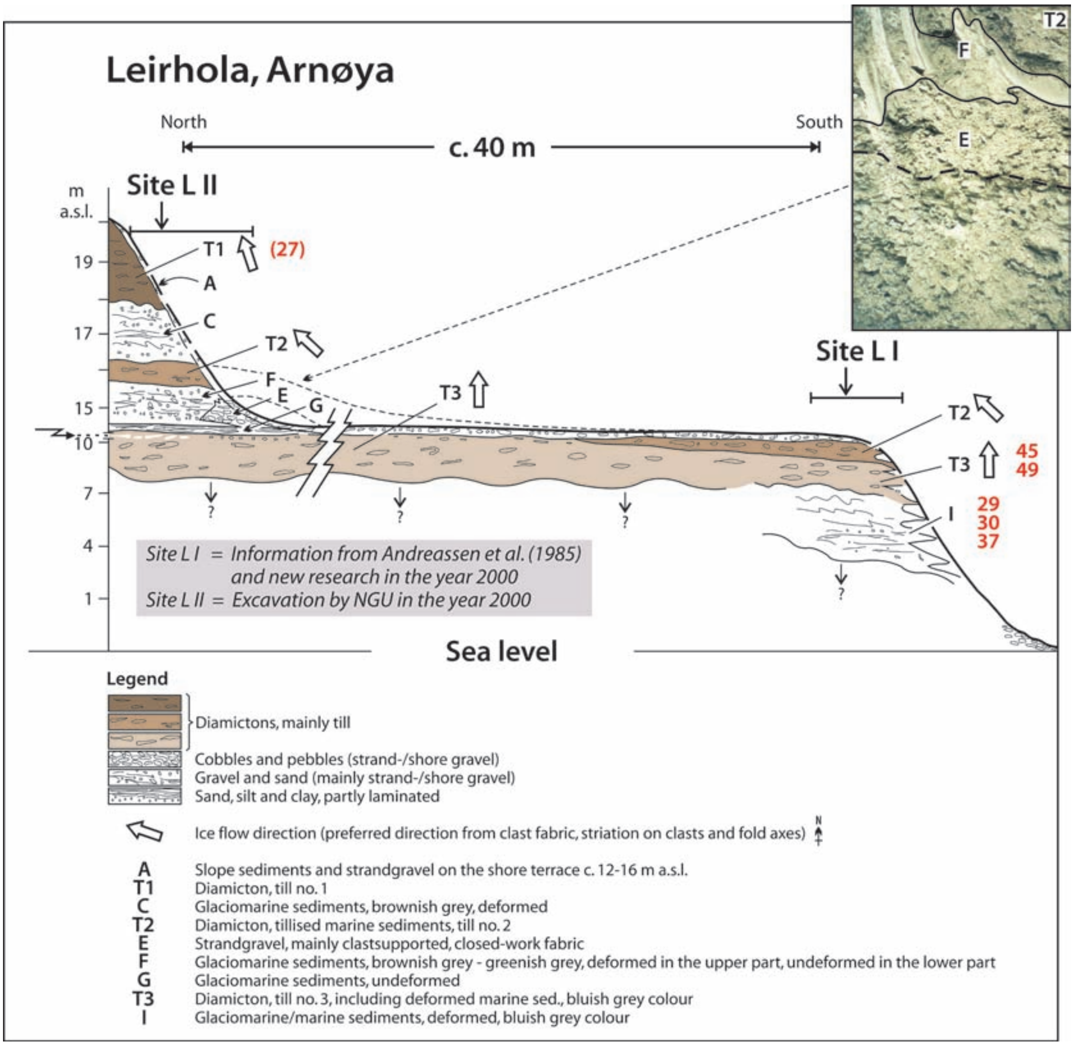


Figure 22: (a) Upper panel – *The strongly cryoturbated Eemian palaeosol, in subtill position and 3–5 m below ground surface at Sargejohka on eastern Finnmarksvidda, North Norway. After Olsen et al. (1996a). (b)* Lower panel – *Correlation of the lithostratigraphies from the inferred Eemian and Weichselian sites Leirelva and Komagelva, Varanger Peninsula, northeast Finnmark, North Norway. Mainly after Olsen et al. (1996a). For location of sites, see Figure 4.*

Figure 23. Generalised section connecting the Middle and Late Weichselian sites LI and LII from Leirhola, at Arnøya (island), North Norway. For location of Arnøya, see Figure 4. Inset photograph: Strandgravel (unit E), between glaciomarine sediments (units F and G), which indicates a distinct lowstand between higher relative sea-levels.



^{14}C dates, from younger to older stratigraphical position, age in ka (red numbers) in Figure 23:

^{14}C - dating (T-3507, 27400 $\pm^{1500}_{1200}$ yr BP, Astarte sp. / Mya truncata) from adjacent loc. (Lauksundet), after Andreassen et al. (1985)

^{14}C - dating (TUa-3624, 44755 $\pm^{1745}_{1435}$, Arctica islandica / Mya truncata) from T3, Site II

^{14}C - dating (TUa-3626, 48635 $\pm^{2595}_{1960}$, Arctica islandica / Mya truncata) from T3, Site I

^{14}C - dating (T-4020, 29000 $\pm^{4200}_{2700}$, Chlamys and Portlandia arctica / lenticula; T-4021, 30200 $\pm^{4100}_{2700}$, div. Shell sp.; T-3509, c. 37500 yr BP, Mya / Astarte / Arctica islandica)

Shell fragments of age around 44 cal ka in tills are recorded from a number of the islands along the coast of Troms and Nordland. Examples of these are Arnøya, Vanna, Kvaløya, Grytøya, Hinnøya, Langøya and Åmøya, but also localities on the mainland show such finds, e.g., in Balsfjorden, Salangen, Sagfjorden, Salten, Skogreina, Glomfjorden, Bjærangsfjorden and Velfjorden. All these data together indicate an ice advance, possibly around 44 cal ka, that reached beyond the coastline in the west. Some of these and other relevant localities will be briefly described below.

At Slettaelva on Kvaløya, northern Troms, the sediment succession starting at the base on bedrock includes a till from a local glacier trending eastwards, i.e., in the opposite direction compared to the subsequent Fennoscandian ice sheet (Vorren et al. 1981). The till is overlain by laminated lacustrine sediments, which were deposited in a tundra environment and in a pond caused by local damming conditions or dammed by a moraine produced during the advance of the Fennoscandian ice sheet, possibly sometime before 46 cal ka, and perhaps during MIS 4 (Figure 24). On top of these sediments lies a till which is divided in three subunits that each may represent an ice advance over the area. The lower two of these contain shell fragments that are dated to *c.* 46 cal ka and estimated, based on amino acid diagenesis, to represent shells from three different intervals, *c.* 44, 77 and 136 ka (cal), respectively (Vorren et al. 1981). Consequently, three regional glacier advances of which the oldest possibly is *c.* 44 cal ka, may have reached beyond this site, and one earlier regional advance, probably also of Weichselian age, may have reached to the site.

At Løksebotn in Salangen, southern Troms (Figure 25) (Bergstrøm et al. 2005b) four till beds separated and underlain with sand and gravel are recorded. Most units are shell bearing, and most shells are resedimented fragments of *Mya truncata* and *Arctica islandica*, except for those from the sediments representing the last deglaciation, which are whole, small shells of *Portlandia arctica* that is a subsurface sediment feeder and should therefore, if possible, be avoided as a precise dating object (e.g., Mangerud et al. 2006). The two oldest tills (T4 and T3) are from the LGM interval or older. The ice movements in this area suggest that the resedimented shells from the lowermost sand and gravel (which itself is located up to 22 m a.s.l.) derive from higher ground along the fjord, which indicate original sedimentation during glacioisostatic depression. The

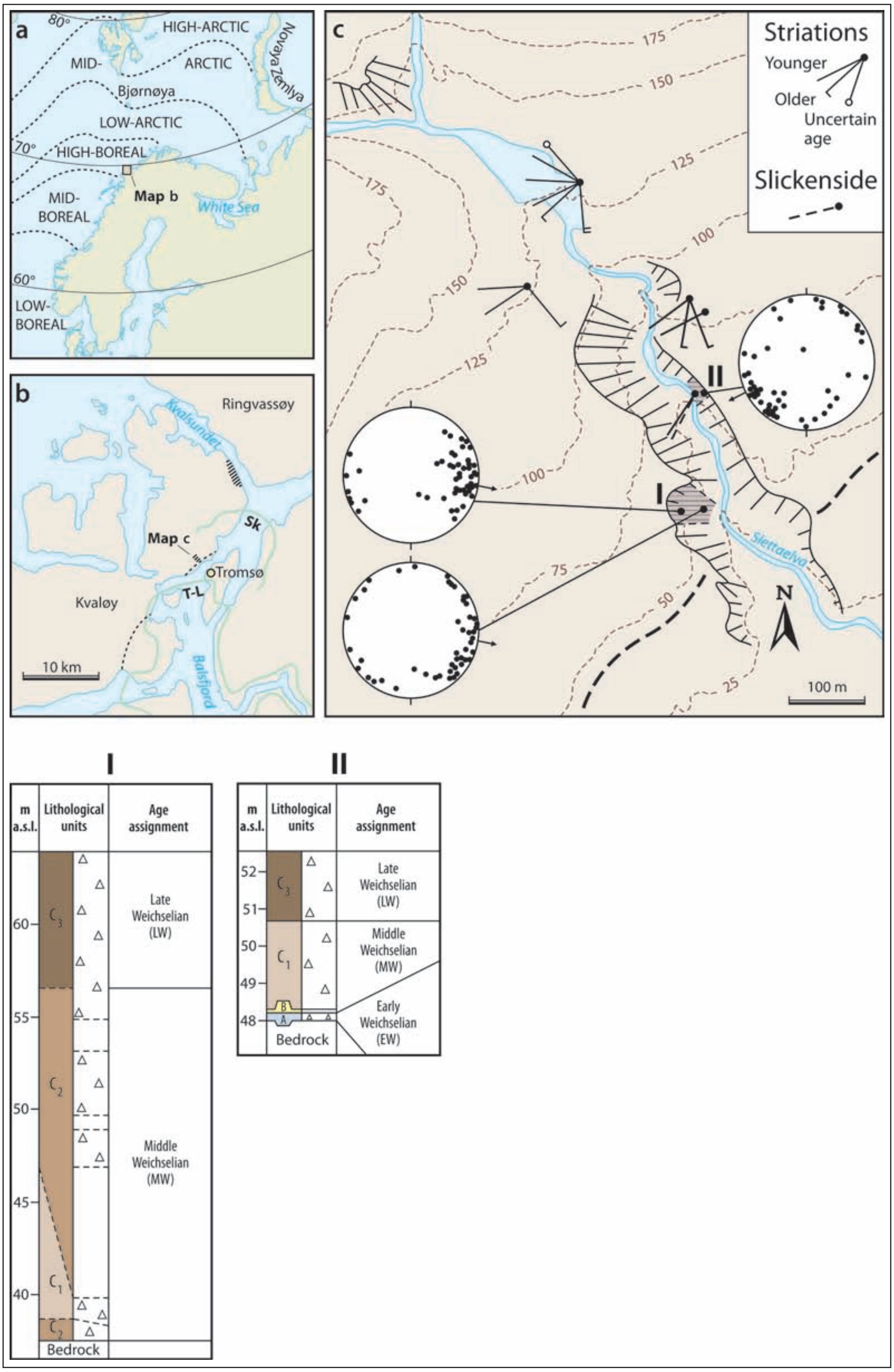


Figure 24. Location maps (a, b, c) of the Middle and Late Weichselian site Slettaelva, North Norway, of which the lithostratigraphy is indicated in logs in the lower panel. Modified from Vorren et al. (1981).

resedimented shells from this locality (Figure 25) are dated to at least a Middle Weichselian age, which indicate that a thick ice covered the ground in the vicinity at, or just before this time, probably around 60 or 44–49 cal ka (the closest known relevant ice-growth phases).

At Storelva, on Grytøya (Figure 4), southern Troms, shallow-marine sediments between till beds *c.* 125 m a.s.l., with shells dated to around 44 cal ka, indicate that the ice was in the vicinity and may have reached beyond Grytøya shortly after this time. It is possible that the lower till also derives from the Weichselian, e.g., MIS 4 (Olsen and Grøsfjeld 1999, Olsen et al. 2001c).

A glacier has probably reached Bleik on Andøya around 44 cal ka, because shells from glaciomarine sediments on the low

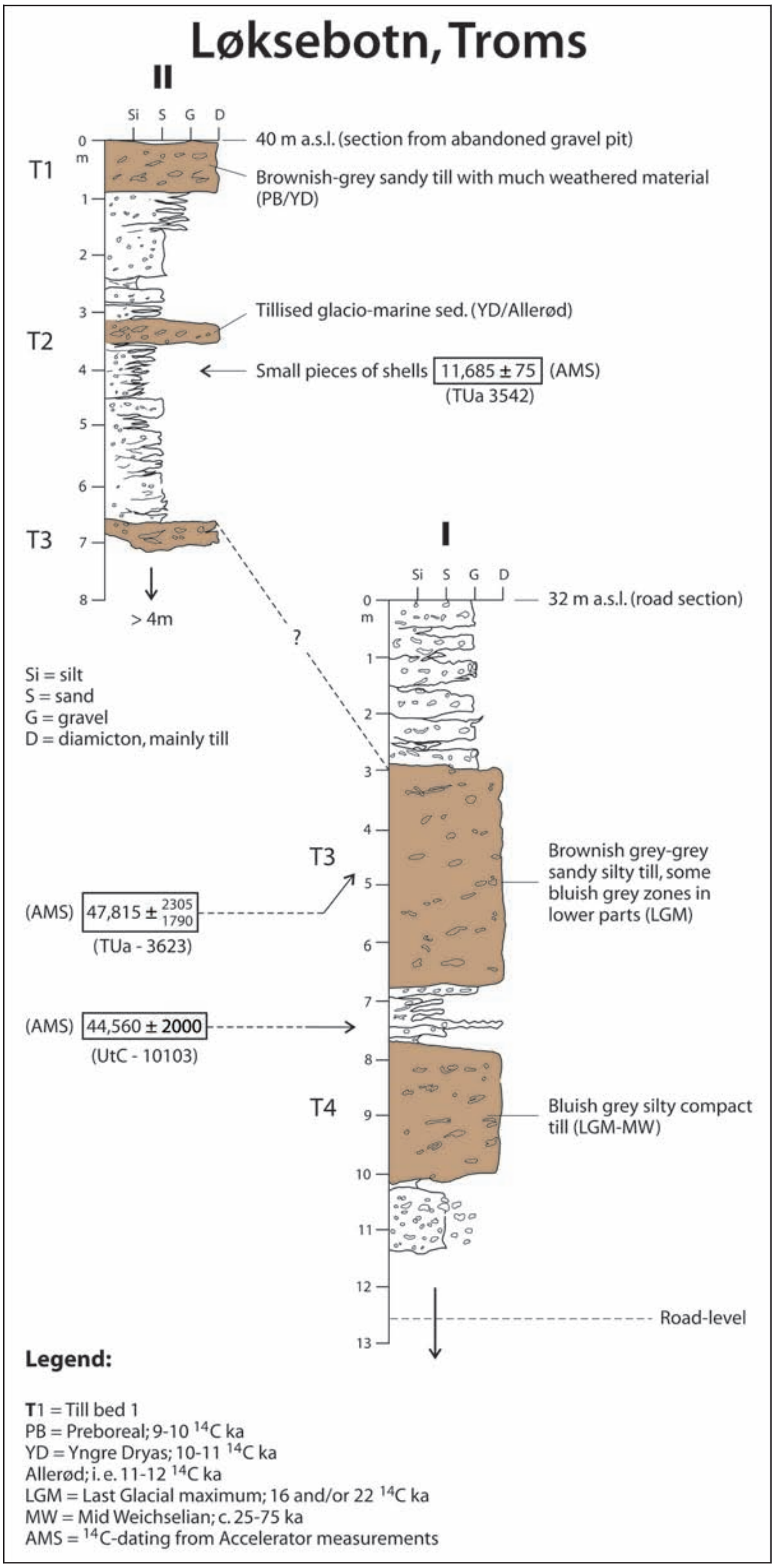


Figure 25. Lithostratigraphy of Middle and Late Weichselian deposits from Løksebotn, Troms, North Norway. Modified from Bergstrøm et al. (2005b). For location of site, see Figure 4.

ground distally to the Bleik area are dated to this age (Møller et al. 1992). At Trenyken, one of the outermost small islands in the Lofoten area, Nordland, a ^{14}C-dating of shell fragments from sediments washed over a moraine into a cave *c.* 19 m a.s.l., gave an age of 33,560 +/- 1100 ^{14}C yr (*c.* 37.5 cal ka) (Ua–2016, Møller et al. 1992). The moraine was deposited at the mouth of the cave, possibly around 44 cal ka. However, redeposition from older strata is an alternative hypothesis, which suggests that the moraine may by younger than 37.5 cal ka. In any case, with a 44 cal ka or LGM age of the moraine, the high relative sea level (more than 19 m a.s.l.) during marine inwash of the shell-bearing sediments is a clear indication of a phase with a considerable glacioisostatic depression far offshore in this western shelf area.

Shell dates from a complex ice-marginal formation at Skogreina, central Nordland, suggest that the ice front may have been there around 44 cal ka (Olsen et al. 2001c, Olsen 2002). At Hundkjerka, a sediment-filled cave in coastal southern Nordland, a ^{14}C-dating of a resedimented shell fragment from marine silt and sand overlying a diamicton with many weathered clasts and underlying diamict material, till and marine sediments from the last deglaciation gave an age of *c.* 50 cal ka (Figure 26) (Olsen et al. 2001c). The level of the cave mouth, *c.* 40 m a.s.l., indicates clearly that the marine sedimentation occurred during a phase of considerable glacioisostatic depression, similar to the first 1000–2000 years of the Holocene. This could have happened just after the retreat of the 44 cal ka ice advance, which consequently must have been considerable in this area. However, the data from this site do not rule out the possibility of an older age (dating close to the upper limit/range of the method) or a younger age (resedimentation) of this ice phase, for example *c.* 34 cal ka.

Plant fragments from sediments redeposited in till at Lierne, in the inland of Nord-Trøndelag, and shells in till at Vikna, on the outer coast of Nord-Trøndelag are both dated to *c.* 44 cal ka, which give a maximum age for the subsequent regional ice advance (Olsen et al. 2001c).

Glacial stratigraphies with intercalated waterlain sediments at Selbu, in the inland of Sør-Trøndelag, represent a highly dynamic late Middle Weichselian to LGM interval ice sheet (Figure 27a). OSL dates at 21–22 cal ka from waterlain sediments correlated with the Trofors interstadial (from the middle of the LGM interval) have recently been reported from the Langsmoen site and support the earlier published ^{14}C-ages of plant remains from subtill sediments at the neighbouring Flora site (Olsen et al. 2001a, Johnsen et al. 2012).

At Grytdal, in Gauldalen south of Trondheim, Sør-Trøndelag, ^{14}C-dated plant remains in tills and intercalated waterlain sediments indicate several Middle to Late Weichselian ice-margin fluctuations in that area, and that the oldest of these ice advances occurred *c.* 44 cal ka (Figure 27b, Olsen et al. 2001c).

At Svellingen, on Frøya (Figure 4), Sør-Trøndelag, shells in till are dated to *c.* 46 cal ka, which may indicate an ice advance *c.* 44 cal ka reaching beyond the Frøya Island (Aarseth 1990). At Skarsvågen, also on Frøya, Sør-Trøndelag, Eemian marine shell-rich sediments and terrestrial sediments (gyttja) are overlain by Early Weichselian marine-transgression sediments followed by regression sediments and till, which is covered by a Middle to Late Weichselian till on top (Aarseth 1990, 1995). The marine sediments overlying the Eemian gyttja derive from a deglaciation, which may either follow a MIS 5d, 5b or a MIS 4 glaciation, perhaps with the latter as the most likely alternative. In that case the overlying till is likely to be of MIS 3 (*c.* 44 cal ka) age, whereas the younger till bed may be either of MIS 3 (*c.* 34 cal ka) or MIS 2 age. However, the age problem for these deposits is not yet solved (I. Aarseth, pers. comm. 2004).

Ice-dammed sediments in the caves Skjonghelleren and Hamnsundhelleren at Møre (Figure 4) indicate that glacier advances reached beyond the coastline of western Norway at least four times, separated by ice-free conditions/interstadials during the Weichselian (Larsen et al. 1987, Valen et al. 1996). The first ice advance crossed these caves at *c.* 60 ka, the next *c.* 44 cal ka, the following *c.* 32 cal ka, and the last after 28.5 cal ka. Geomagnetic excursions (Laschamp at *c.* 44 cal ka and Lake Mungo/Mono Lake at *c.* 32 cal ka) that are recorded in the sediments confirm the age model for the two ice advances in the middle, and therefore indirectly also the other advances (see also review by Mangerud et al. 2003).

Luminescence dates around 100 ka of glaciogenic sandur sediments at Godøya, near Ålesund, Møre, indicate the ice-margin position, or retreat of a relatively large glacier, possibly of MIS 5d age (Jungner et al. 1989, Mangerud 1991a, b, c). However, a younger age, e.g., MIS 5b, or even a Middle Weichselian age of this event, as originally suggested by Land-

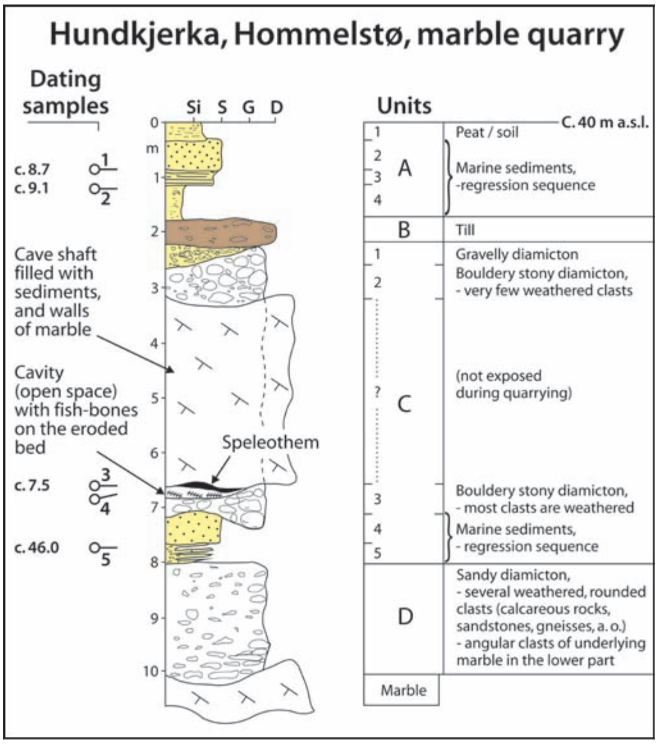


Figure 26. Lithostratigraphy of the sediment succession in the Hundkjerka cave, Nordland, North Norway. Ages in ^{14}C ka BP. After Olsen et al. (2001c). For location of site, see Figure 4.

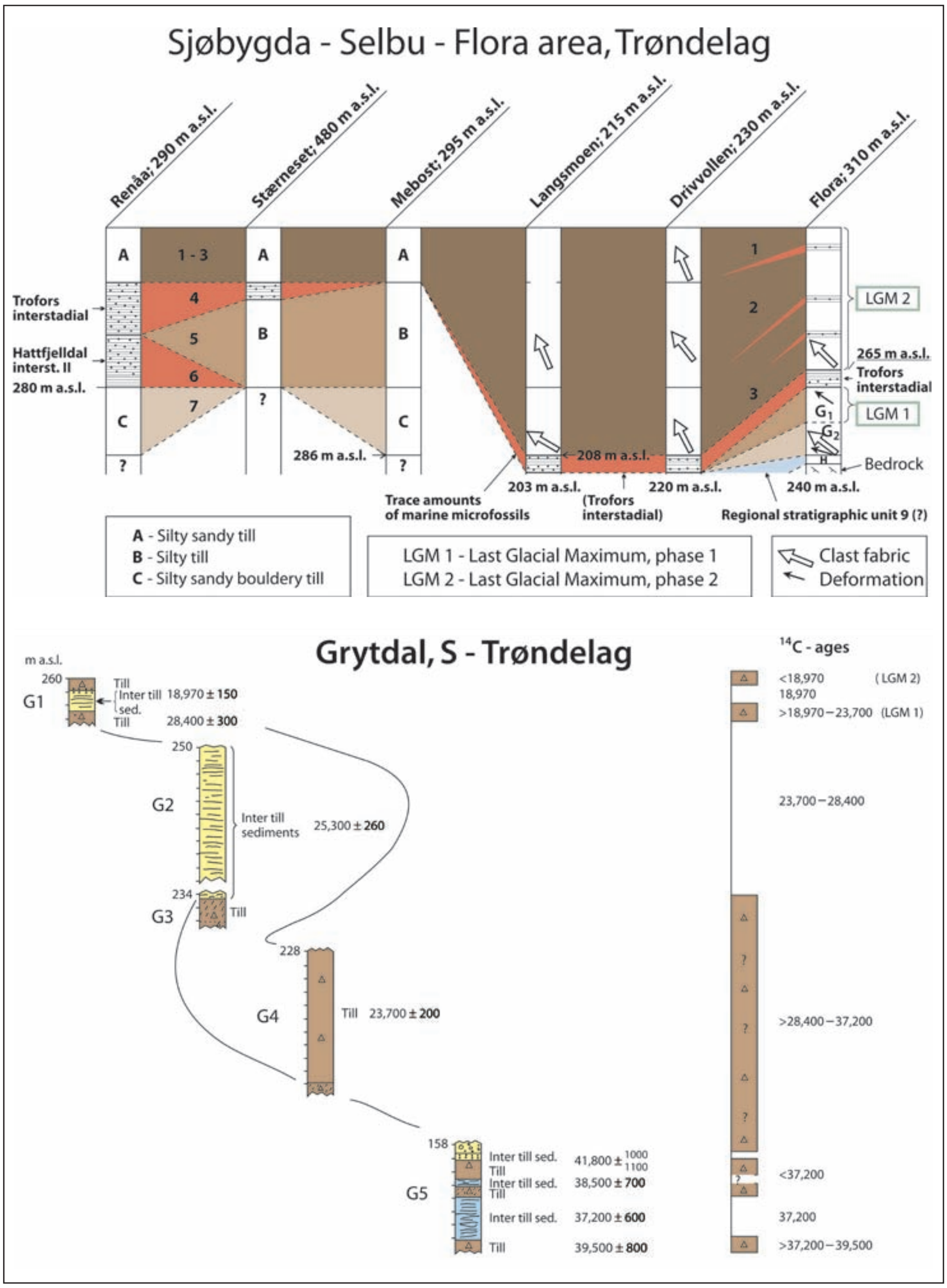


Figure 27. (a) Upper panel - *Glacial stratigraphies from the inland of central Norway, east of Trondheim. Modified from Olsen et al. (2002). OSL dates at 21–22 cal ka from Trofors interstadial-correlative sediments at the Langsmoen site have been reported by Johnsen et al. (2012).*

(b) Lower panel - *Correlation of lithostratigraphies from sections G1–G5 in Middle and Late Weichselian sediments along a steep local road in Grytdal (main valley: Gauldalen), central Norway. Modified from Olsen et al. (2001a). For location of sites, see Appendix B, Table B1–B, and Figure B1.*

vik and Mangerud (1985) and Landvik and Hamborg (1987), should still be considered.

Northern and central Sweden. Till beds correlated with the Finnish Early Weichselian Till 3 are recorded at many sites in northeastern Sweden (The Nordkalott Project 1986: Map of Quaternary geology, sheet 4), and are so far assumed to be present at two sites in central Sweden (The Mid-Norden Project 1999: Map of Quaternary geology, sheet 3, sites no. 43 Stornipan and 47 Hoting). Till 3 or other Early Weichselian tills may well be represented at other sites in this region as the first till unit overlying sediments from the Jämland interstadial (Lundqvist 1969), but this is not properly demonstrated yet. However, tills from the Middle Weichselian (e.g., correlated with the Finnish Till 2) are commonly represented at many sites, both in the northern and central Sweden.

Northern and central Finland. All sites where Till 3 is recorded are located proximal to the Pudasjärvi moraine in northern/central Finland (Figure 4, Sutinen 1984), and consequently, no sites with till from the Early Weichselian is recorded in central Finland (The Mid-Norden Project 1999). The age of Till 3 is uncertain, but the Nordkalott project data (Hirvas et al. 1988) combined with the new information from the Sokli area (Helmens et al. 2000, 2007) suggest that the till may be subdivided in an older unit (which may correlate with MIS 5d), not represented at Sokli, and a younger unit from a more extensive advance, correlated with MIS 5b.

Another important glacial boundary in northern Finland is represented with the Lapland moraines, which are thought to derive from an Early or Middle Weichselian advance or retreat phase.

The Middle Weichselian Till 2, which followed the Peräpohjola interstadial (Hirvas et al. 1988, Hirvas 1991), is more commonly represented at many sites, both in the northern and central Finland (The Nordkalott Project 1986, The Mid-Norden Project 1999).

Southern Norway—including some data from adjacent areas in the south, southeast and east

Southern Norway. In southern Norway, coastal sites as Fjøsanger, Bø on Karmøy and several sites at Jæren are important sources of information with regard to glacial deposition during the Early to Middle Weichselian (e.g., compilation by Mangerud 1991a, b, c, 2004) (Figures 4 and 28a, b). It has been shown that Early Weichselian stratigraphies including glacial deposits exist in the coastal areas, which indicate glacial advance at least once, followed by an ice-retreat/interstadial phase and another ice advance that crossed the coastline, deposited a till (Bønes till) in southwestern Norway and reached the Norwegian Channel at least once during the Early Weichselian. Middle Weichselian marine sediments, which are located at highly elevated sites at Jæren (>200 m a.s.l.) (e.g., Andersen et al. 1987, Larsen et al. 2000, Raunholm et al. 2004), indicate deposition during a state of considerable glacioisostatic depression and therefore indirectly that a big ice must have existed there and/or in the Norwegian Channel shortly before. Consequently, a Middle Weichselian glacier extension has reached the coast at Jæren (Figure 29), and probably also the Norwegian Channel (where an ice stream may have existed) at least once (Sejrup et al. 1998, 2000, Larsen et al. 2000). The Bø site on Karmøy and the Foss–Eikeland site at Jæren include also important Late Weichselian stratigraphies (Figures 30–31), that imply considerable fluctuations of the LGM-interval ice sheet in southwestern Norway.

In the inland areas of southwest Norway, in Vinjedalen at

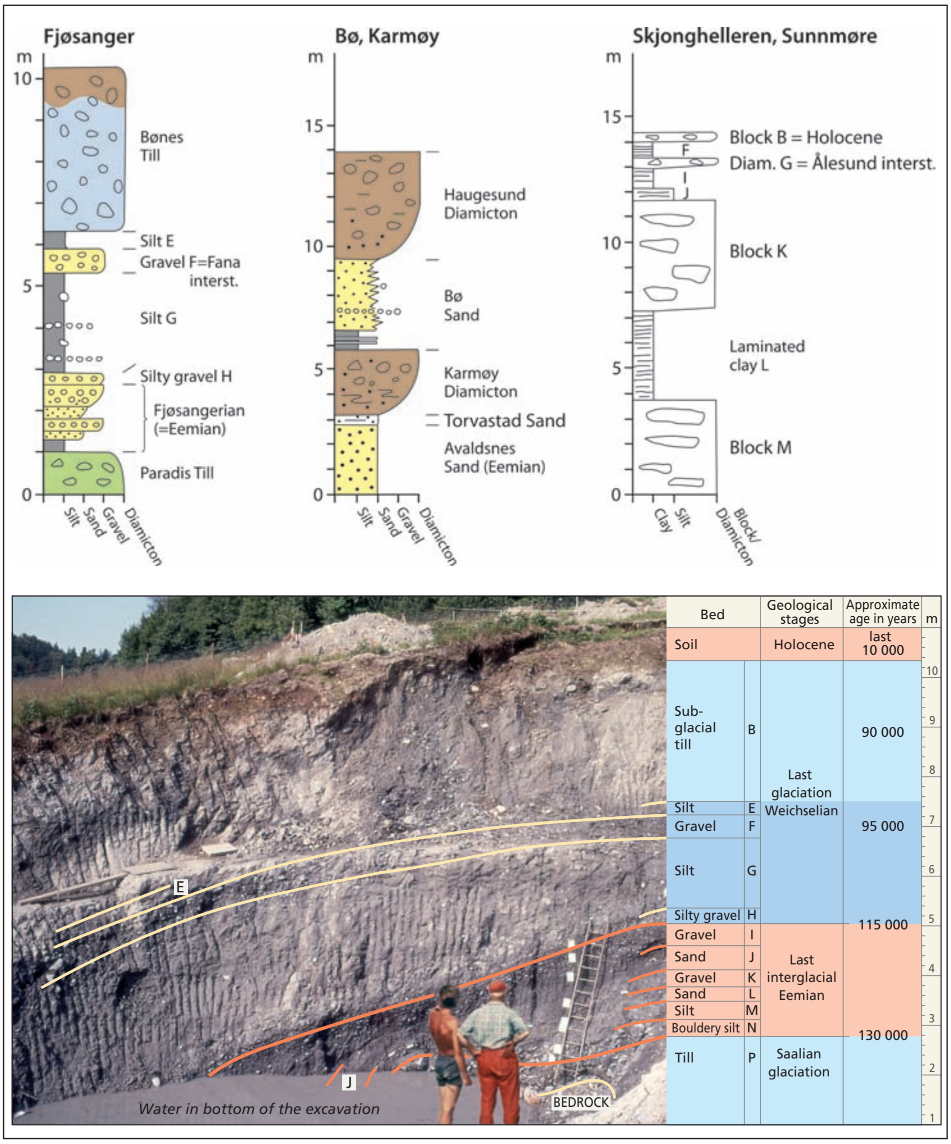


Figure 28. (a) Upper panel – *Eemian and Weichselian sediments in the three stratigraphical sites Fjøsanger, Bø and Skjonghelleren (cave). After Mangerud (1991). (b)* Lower panel – *Photograph from the Fjøsanger site. Note that the colours in (b) of the units are not standardised as they are in the other illustrations in this paper. Modified from Vorren and Mangerud (2006). For location of sites, see Figure 4.*

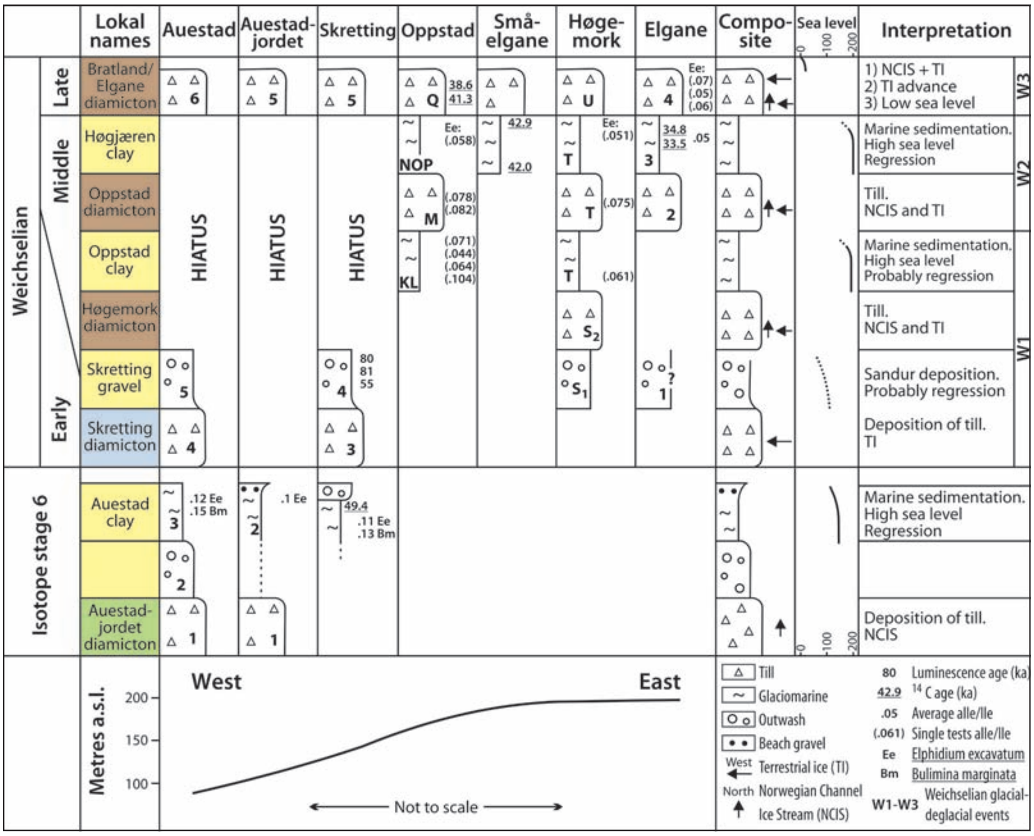


Figure 29. Saalian and Weichselian stratigraphies from sediments at sites from Jæren, southwest Norway. After Larsen et al. (2000). For location of sites, see Figure 17.

Vossestrand (Figure 4) a 2 cm-thick highly compressed Eemian peat is overlain by a Weichselian till (Sindre 1979). In Brumunddalen, southeast Norway till beds (units K, L, P and Q) from the Early Weichselian are recorded underlying the Brumunddalen interstadial beds at Dalseng (Helle 1978, Helle et al. 1981) (Figure 32a), and the interstadial peat was highly compressed at 59 cal ka, possibly by an ice advance, as indicated by a U/Th-dating of this age (S.-E. Lauritzen, pers. comm. 1991). At Mesna, Lillehammer,

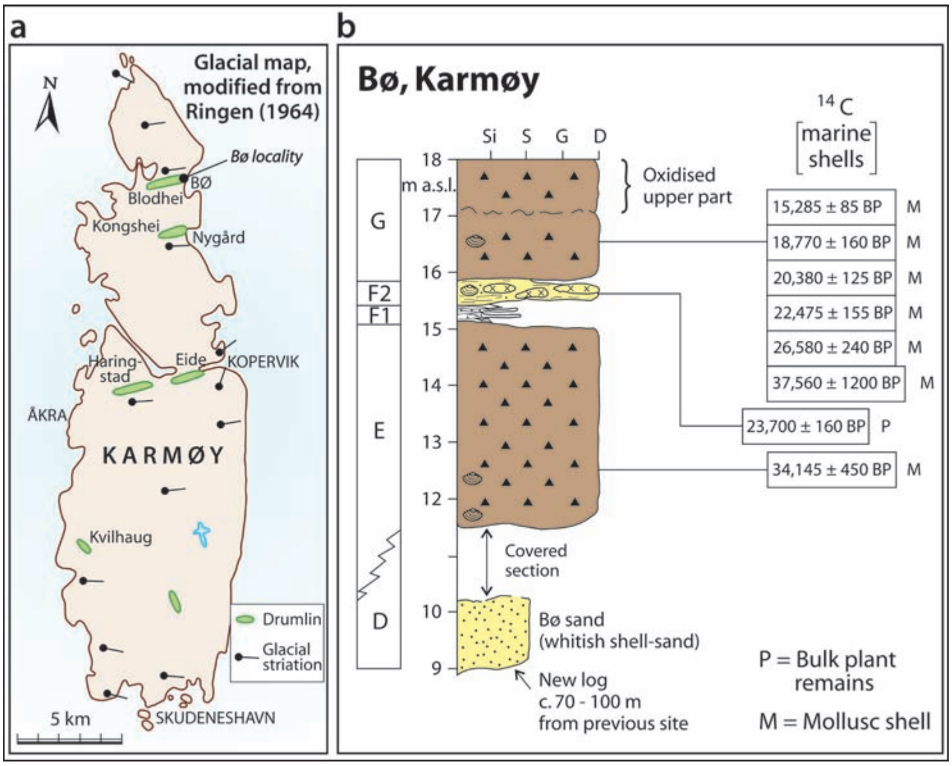


Figure 30. (a) Location map, and (b) lithostratigraphy of the upper part of the sediments in the drumlin at Bø, Karmøy. After Olsen and Bergstrøm (2007). The deeper parts of the sediments at this site (Bø, in Figure 28a) have been studied by Andersen et al. (1983) and Sejrup (1987). The new units E, F1, F2 and G indicated here, represent a subdivision of the previously described uppermost unit, the Haugesund diamicton.

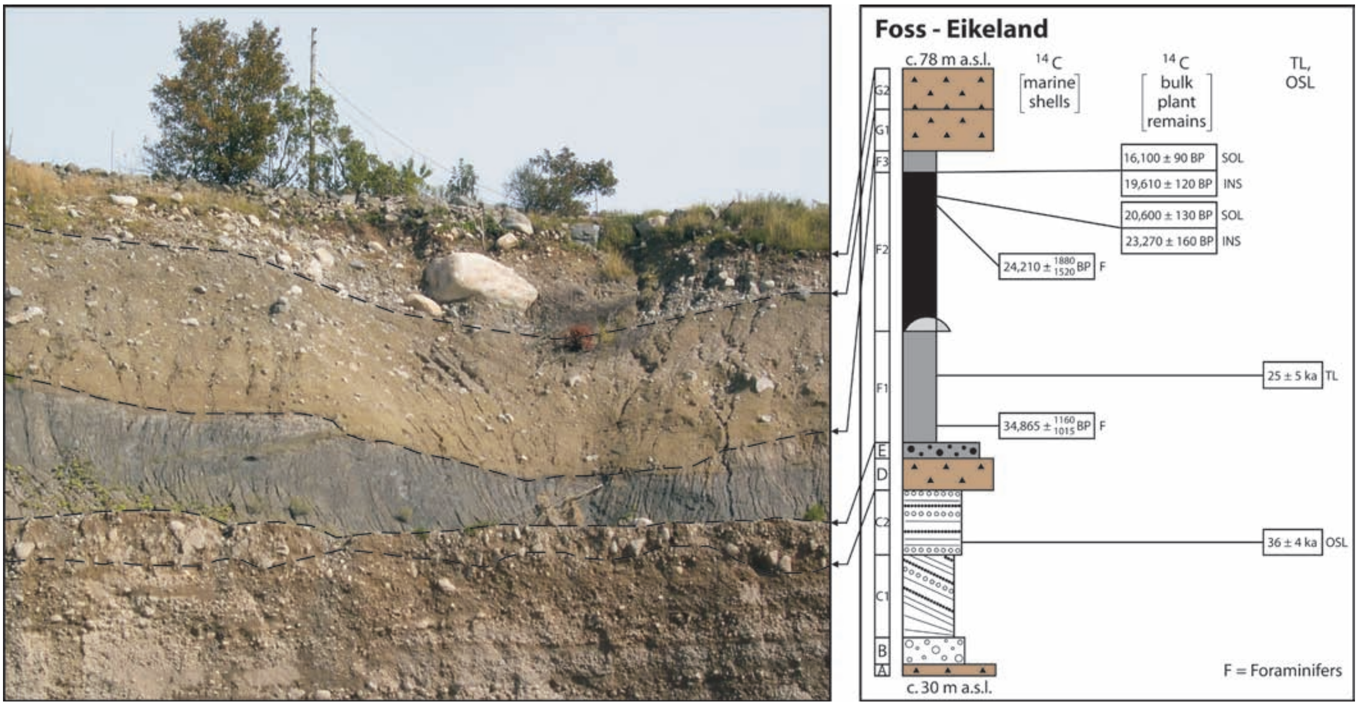


Figure 31. Photograph and lithostratigraphy from the gravel pit in the Middle and Late Weichselian sediments at Foss-Eikeland, Jæren. Lithostratigraphy modified from Raunholm et al. (2003). For location of site, see Figure 17. Photograph by B. Bergstrøm 2002.

southeastern Norway, a till bed (the Mesna till) of age framed between 40 and 44–48 cal ka is recorded (Figures 32a, b and 33b, unit A), and at Rokoberget farther southeast, highly elevated Middle Weichselian sediments with marine microfossils indicate a considerable glacioisostatic depression around 44 cal ka, similar to that recorded for the Jæren area (Rokoengen et al. 1993a, Olsen and Grøsfjeld 1999, Olsen et al. 2001c, Larsen et al. 2000).

At Hardangervidda (Figures 33 and 34), glacial stratigraphies from nine localities reveal a history that according to Vorren and Roaldset (1977) and Vorren (1979) includes deposits from the Eemian (Hovden thermomer), from one stadial (Hovden kryomer) and one interstadial (Førnes thermomer) supposedly from the Early Weichselian, and from two Middle to Late Weichselian stadials separated by one interstadial (all representing the complex Førnes kryomer). Correlations to other areas were made on the basis of pollen content and inferred palaeovegetation and palaeoclimate, but with no absolute dates available. Recently, OSL dates of subtill sediments from Hovden (at Møsvatn), which is one of the sites described by Vorren and Roaldset (1977), and from Grytkilvika (at Mårvatn), previously described by Vorren (1979), and from two additional sites in this area have been reported by Haug (2005). He found that these dates indicate a Middle to Late Weichselian age of all the studied subtill interstadial sediments, including the Hovden sand that Vorren and Roaldset (1977) and Vorren (1979) correlated with the Førnes thermomer, which they assumed was of Early Weichselian age. Based on the OSL dates from Hardangervidda, Haug (2005) suggests a correlation with the three or four Middle to Late Weichselian interstadials, pre-Hattfjelldal (*c.* 50 cal ka), Hattfjelldal 1 (*c.* 37 cal ka), and Hattfjelldal 2 (*c.* 30 cal ka) or Trofors (*c.* 22.5 cal ka), that have been described and reviewed from Norwegian inland areas by Olsen (1997) and Olsen et al. (2001b).

Southern Sweden–Denmark–Poland. At Dösebacka–Ellesbo (Figure 4) in the vicinity of Gothenburg, southwestern Sweden, three Weichselian tills are separated with intercalated pollen-bearing interstadial sediments (Hillefors 1974). The oldest interstadial is probably from the Early Weichselian and the younger one from the Middle Weichselian. The oldest till is therefore possibly of either MIS 5d or 5b age, most likely the latter, whereas the middle till is likely to derive from MIS 4, or possibly MIS 3, since glaciers during both these stages are supposed to have reached southwards beyond the Gothenburg area. The youngest till bed is from the LGM interval (MIS 2).

At Sjötorp, a few km southwest of Skara (Figure 4) in southwestern Sweden, glaciotectonised waterlain sediments have been TL and OSL dated to 43–45 cal ka (Ronnert et al. 1992). The deformation movement was directed from the W–WNW, which indicates that an ice movement from the west may have reached this area and tectonised the sediments around *c.* 44 cal ka, or possibly during a younger ice advance, e.g., *c.* 34 or 25 cal ka. Houmark-Nielsen and Kjær (2003) discussed in their palaeogeographic reconstructions an E-trending ice movement in this area and favoured a 27–29 cal ka age of this.

As reviewed by, e.g., Lundqvist (1992), only till beds from the Late Weichselian have been found overlying the Eemian interglacial sediments at the classical site Stenberget, in the

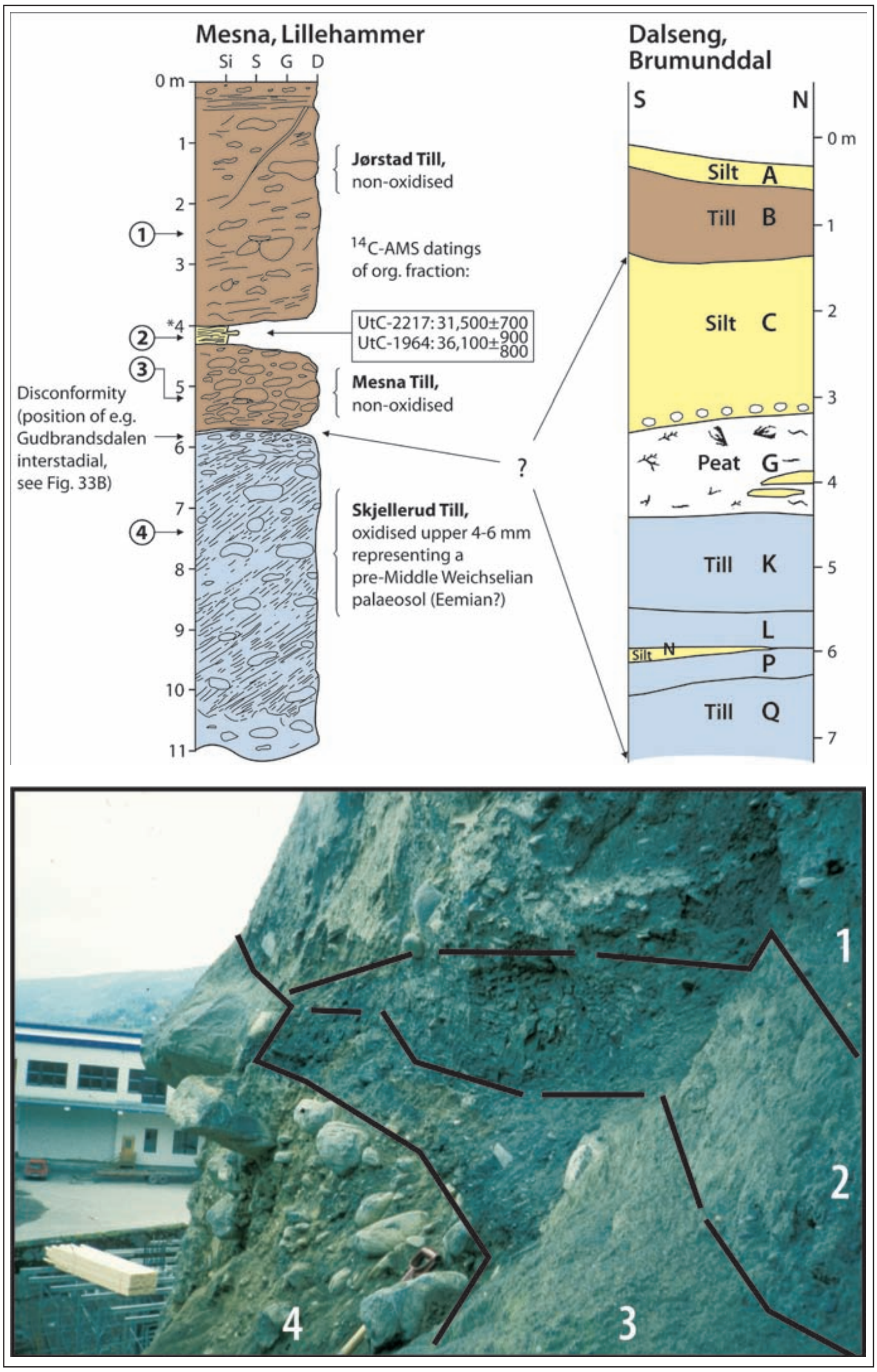


Figure 32. (a) Upper panel – *Lithostratigraphy of inferred Saalian to Weichselian deposits at Mesna, Lillehammer. To the right, a several metres thick Early, Middle and Late Weichselian sediment sequence from Dalseng (units from Helle 1978) is supposed to correlate with the position of the disconformity between units 3 and 4 at Mesna. Modified from Olsen (1985b, 1998). (b)* Lower panel – *Photograph from the Mesna section (L. Olsen 1990). Stratigraphical units 1–4 are indicated. For location of sites, see Figure 33a.*

southwesternmost part of Sweden. Similar data are recorded also from the Alnarp valley, east of Stenberget (Miller 1977). Only Late Weichselian tills overlie the Eemian interglacial beds there too.

Glacial deposits which are TL-dated to 60 cal ka indicate that the first ice advance from the Fennoscandian Weichselian ice sheet may have reached Poland during MIS 4. Furthermore, stratigraphical data comprising tills, glaciofluvial sediments and glaciotectonics indicate that ice advances from the east, from the Baltic basin reached the islands in southeastern Denmark both during MIS 4 and 3 (see review by Mangerud 2004).

Southern Finland–northwest Russia–the Baltic states. A MIS 5b ice may have reached and deposited till at the Kola Peninsula, in northwest Russia (Lundqvist 1992, Mangerud 2004). Except for that, no glaciers seem to have covered southern Finland, northwest Russia, Estonia, Latvia or Lithuania during the Early Weichselian. From a compilation of the Weichselian glacial history based on the glacial stratigraphy for the Baltic states made by Satkunas and Grigiené (1996), the first Fennoscandian Weichselian glacial advance reached this area during MIS 4, as indicated by till beds of this age recorded in Estonia and possibly in a narrow belt in adjacent areas of Latvia. According to these

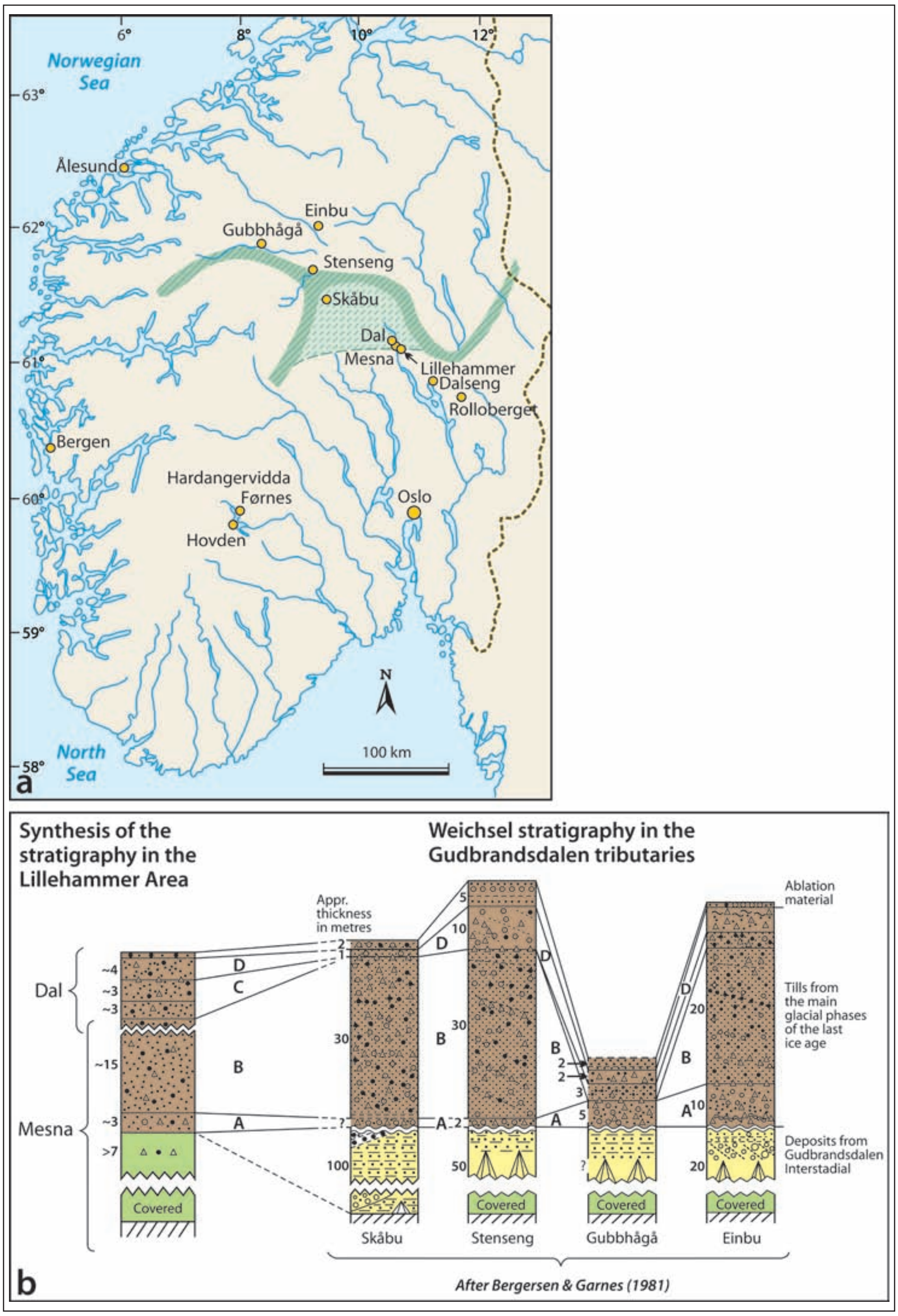


Figure 33. (a) Location map, with late LGM-interval ice-divide zone (shaded), and (b) correlation between lithostratigraphies from the Lillehammer and Gudbrandsdalen area, southeast central Norway. After Olsen (1985b).

authors, the glacial advance during MIS 3 may have reached to Estonia, but not as far as to Latvia or Lithuania.

Offshore areas in the north, northwest, west and southwest

New information on glacier dynamics and ice-front deposits on the shelf has come from the discovery and interpretation of submarine fans at the mouth of glacial troughs ('trough-mouth fans'), and the existence of distinct ice streams across the shelf during glaciations. A review of these is given by Vorren et al. (1998). More recently it has been shown, through detailed morphological mapping of the sea floor, that there have been a number of ice streams across the Norwegian shelf (Figure 6) (Ottesen et al. 2001, 2005) and in the southwest Barents Sea area (e.g., Andreassen et al. 2008). There are numerous large, parallel glacial lineations (megaflutes and megascale lineations) produced during combined glacial accumulation–erosion processes in the troughs, whereas features diagnostic of glacial flow are absent from the shallow ground. If such features ever existed in the shallow parts, then subsequent iceberg ploughing may have disturbed and deformed them beyond recognition.

Figure 34. Correlation chart of Late Pleistocene stratigraphies from Hardangervidda, central southern Norway. Modified from Vorren (1979), with revised age assignments based on data from Haug (2005). For location of the Hovden and Førnes sites, see Figure 33a. All other sites in the panel are from the same area.

Stratigraphical correlation chart

Climato-stratigraphy	Ice movement phase	LITHOSTRATIGRAPHY: Hovden	Førnes	Mår	Gøyst	Sterra	Hansbu	Holsbu	Svinto: Loc. f	Svinto: Loc. a-e	Regional correlation, revised age assignment
Førnes kryomer	IV									Svinto upper till	Late Weichselian
	III	upper till	upper till	upper till						Svinto intertill sedim. / Svinto lower till	
	II	Hovden	Førnes	Mår	Gøyst upper till	Sterra upper till			Upper till		Middle Weichselian
Førnes thermomer		Hovden sand	Førnes intertill sedim.	Mår subtill sedim.	Gøyst sand		Hansbu silt	Holsbu silt	Fine sand		
Hovden kryomer	I	Hovden lower till	Førnes lower till	Mår lower till		Sterra lower till			Lower till		Middle/Early Weichselian
Hovden thermomer		Hovden clay						?			Eemian

The interpretation is that there was only slow moving ice on the shallows. This and other relevant data, also from the shelf area, have been reviewed by, e.g., Mangerud (2004).

It is uncertain how many times and how far out on the shelf the western Fennoscandian ice margin reached during the Early/Middle Weichselian. However, both offshore data as well as indirectly also data from onshore positions (Jæren) indicate that the ice sheet grew big enough to produce an ice stream in the Norwegian Channel at least twice in this period (Larsen et al. 2000, Nygård 2003). It seems like most of the authors favour a MIS 4–3 age of these events (Larsen et al. 2000, Nygård 2003, Mangerud 2004). However, the more recent and presumably most precise result from seismic data and coring (MD99–2283) from the North Sea Fan suggests glaciogenic debris flow and corresponding distal laminated sediments from one major pre-Late Weichselian, possibly Early Weichselian ice-sheet expansion (with maximum MIS 5b age, i.e., about 90 ka), and in that case there is no indication of a major Middle Weichselian ice advance (Nygård et al. 2007, and A. Nygård, pers. comm. 2007).

Deposits from the present interglacial (the Holocene)

The erosional and depositional history of the Holocene includes many good examples of the overall and changing environment during an interglacial. However, as glacial deposits are in focus in this paper, and since sediments of the Holocene result from mainly nonglacial processes and represent significant parts of the modern landscape, this period is further reviewed in the accompanying paper that is focused on Quaternary landscape development (Fredin et al., 2013).

Summary and conclusions

An overview of glacial offshore and onshore deposits in Norway is given here (Figures 1–3), with additional examples from selected offshore areas and from several onshore locations from all regions of Norway. The location of sites with interglacial and interstadial deposits is presented on maps, and deposits of this type are also included in some of the selected Quaternary stratigraphical examples. This compilation may be used simply as it is referred to, i.e., an overview of the Quaternary deposits of Norway, but may also be used to consider the overall glacial impact in Norway, with erosion and deposition during the Quaternary (last *c.* 2.6 million years). For example:

The distribution of Quaternary glacial deposits on and beyond the shelf (Figures 2–3) indicates three major depocentres, i.e., the Mid-Norwegian shelf and the areas around the outer parts of the Norwegian Channel and the Bjørnøya Trench, including the adjacent trough-mouth fans. Almost all of the Mid-Norwegian glacial deposits are assumed to derive from the Norwegian mainland, whereas a significant or even major part of the products of glacial erosion stored in the two other depocentres may derive from other areas, e.g., the southern North Sea and the Baltic region in the south and the Barents Sea region in the north.

The volume of the glacial deposits offshore the Mid-Norwegian coast amounts to almost 100,000 km^3 (Dowdeswell et al. 2010), which represents erosion of a size similar to a *c.* 500 m-thick sheet of erosional products covering the overall 200,000 km^2 catchment area in Central Norway and Sweden. A sheet of erosional products of at least 300–400 m thickness covering all onshore areas (*c.* 370,000 km^2) of Norway is needed to illustrate the volume of the glacial deposits offshore all parts of Norway.

The glacial deposits offshore Norway have a volume that indicates sediment supply from erosion of the land with average more than 10 cm, probably *c.* 20 cm kyr^{-1} everywhere in Norway during the entire Quaternary. (The real erosion rate is, however, likely to vary between almost 0 cm to almost 1 m kyr^{-1}, since very old ground surfaces are recorded in some mountain areas, whereas a relief of, e.g., more than 2000 m in the Sognefjord area is thought to have been formed mainly during the Quaternary.)

The loose deposits of onshore areas in Norway are strongly dominated by glacial erosional products and amount to less than 1000 km^3 in volume (i.e., 6 m average sediment thickness in 25% of the area and 1 m in the remaining 75%, which give 2 m average sediment thickness everywhere and a total volume of *c.* 820 km^3).

Almost all of *the Quaternary deposits of onshore areas* in Norway are younger than 300 ka and probably >90% is younger than 115 ka. This gives an average net erosional rate of less than 1 cm kyr^{-1} during the two last glaciations, the Saalian and the Weichselian, and about 2 cm kyr^{-1} during the last glaciation.

The difference in net erosional rates based on the volumes of the offshore (*c.* 20 cm kyr^{-1}) and the onshore (1 cm kyr^{-1}) glacial deposits indicates that >90 % of the glacial erosional products are removed from onshore areas and deposited offshore during the Quaternary. This transport and depositional process must have occurred mainly during large glacier extensions as the glaciers grew to ice sheets reaching the shelves, and it demonstrates clearly the effectiveness of the ice sheets as transport agents for the available erosional products. In general terms, the stratigraphical record with more reworked older deposits and more of the sediments that are preserved derive from younger glaciations support strongly this model, which implies that most of the sediments deposited or overrun by the ice during one glaciation are eroded and redeposited or removed during the subsequent glaciation.

From the record of *the Quaternary glaciations in Fennoscandia* it is found that large ice sheets reached the shelves several times during the last 0.5–1.1 Ma, and clearly less frequently before that. The denudation rate of the land surface, which is estimated to be an order of magnitude higher during ice-sheet intervals than during intervals of moderate to minimum ice extension (Dowdeswell et al. 2010), is therefore likely to have increased significantly towards younger ages during the Quaternary.

The recorded *glacial stratigraphy from onshore sites* in Norway reaches from MIS 1 to MIS 10. In addition to dates, counting from the top of stratigraphical sediment units seems to work well in Norway as a method of stratigraphical correlations, at least for the Weichselian glaciation. However, this is not quite in agreement with the general glacial erosion – accumulation history for the entire Quaternary in Norway as described above.

Acknowledgements

The utilised information is from various sources, but focused on data from NGU where this has been possible (NGU-participation in research). In a few cases, both from land and seabed areas this has not been possible and external sources have been included.
An earlier version of the manuscript has been refereed by Stein Bondevik, Jan Sverre Laberg and Erland Lebesbye, and their comments have been considered and improved the paper substantially. Irene Lundqvist has made the drawings. We are grateful and thank all these persons for good help.

References

Aarseth, I. (1990) *Senkvartær stratigrafi i ytre Trødelag – sett fra Frøya*. University of Bergen, unpublished report, 6 pp.

Aarseth, I. (1995) Hvordan var det på Frøya like før siste istid? *Årbok for Fosen 1995*, 17–28.

Aarseth, I., Austbø, P.K., and Risnes, H. (1997) Seismic stratigraphy of Younger Dryas ice-marginal deposits in western Norwegian fjords. *Norsk Geologisk Tidsskrift*, **77**, 65–85.

Alm, T. (1993) Øvre Æråsvatn – palynostratigraphy of a 22,000 to 10,000 BP lacustrine record on Andøya, northern Norway. *Boreas*, **22**, 171–188.

Andersen, B.G. (1968) Glacial geology of Western Troms, North Norway. *Norges geologiske undersøkelse*, **256**, 1–160.

Andersen, B.G. (1981) Late Weichselian Ice Sheets in Eurasia and Greenland. *In* Denton, G.H. and Hughes, T.J. (Eds.): *The Last Great Ice Sheets*, pp. 3–65. John Wiley and Sons, New York.

Andersen, B.G. (1979) The deglaciation of Norway 15,000–10,000 years BP. *Boreas*, **8**, 79–87.

Andersen, B.G. (1980) The deglaciation of Norway after 10,000 B.P. *Boreas*, **9**, 211–216.

Andersen, B.G., Bakken, K., Dale, B., Fugelli, E., Henningsmoen, K.E., Høeg, H.I., Nagy, J., Read, A. and Tellemann, H. (1991) Weichselian stratigraphy at Oppstad, Høgemork and Foss-Eikeland, Jæren, SW Norway. *Striae*, **34**, 109–124.

Andersen, B.G., Bøen, F., Nydal, R., Rasmussen, A. and Vallevik, P. (1981a) Radiocarbon dates of marginal moraines in Nordland, North Norway. *Geografiska Annaler*, **63**, 155–160.

Andersen, B.G., Bøen, F. and Rasmussen, A. (1982) The Tjøtta glacial event in southern Nordland, North Norway. *Norsk Geologisk Tidsskrift*, **62**, 39–49.

Andersen, B.G. and Mangerud, J. (1989) The last interglacial-glacial cycle in Fennoscandia. *Quaternary International*, **3/4**, 21–29.

Andersen, B.G., Mangerud, J., Sørensen, R., Reite, A., Sveian, H., Thoresen, M. and Bergstrøm, B. (1995) Younger Dryas ice-marginal deposits in Norway. *Quaternary International*, **28**, 147–169.

Andersen, B.G., Nydal, R., Wangen, O.P. and Østmo, S.R. (1981b) Weichselian before 15,000 years B.P. at Jæren-Karmøy in southwestern Norway. *Boreas*, **10**, 297–314.

Andersen, B.G., Sejrup, H.-P. and Kirkhus, Ø. (1983) Eemian and Weichselian Deposits at Bø on Karmøy, SW Norway: A Preliminary Report. *Norges geologiske undersøkelse*, **380**, 189–201.

Andersen, B.G., Wangen, O.P. and Østmo, S.-R. (1987) Quaternary geology of Jæren and adjacent areas, southwestern Norway. *Norges geologiske undersøkelse Bulletin*, **411**, 1–55.

Andersen, J.L. and Sollid, J.L. (1971) Glacial chronology and glacial geomorphology in the marginal zones of the glaciers Midtdalsbreen and Nigardsbreen, South Norway. *Norsk Geografisk Tidsskrift*, **25**, 1–38.

Andreassen, K., Laberg, J.S. and Vorren, T.O. (2008) Seafloor geomorphology of the SW Barents Sea and its glaci-dynamic implications. *Geomorphology*, **97**, 157–177.

Andreassen, K., Vorren, T.O. and Johansen, K.B. (1985) Pre-Late Weichselian glacimarine sediments at Arnøy, North Norway. *Geologiska Föreningens i Stockholm Förhandlingar*, **107**, 63–70.

Anundsen, K. (1977) Radiocarbon dating and glacial striae from the inner part of Boknfjord area, South Norway. *Norsk Geografisk Tidsskrift*, **31**, 205–225.

Anundsen, K. (1985) Changes in shore-level and ice-front position in Late Weichsel and Holocene, southern Norway. *Norsk Geografisk Tidsskrift*, **39**, 205–225.

Anundsen, K. and Fjeldskaar, W. (1983) Observed and theoretical Late Weichselian shore-level changes related to glacier oscillation at Yrkje, South-West Norway. *In* Schroeder-Lanz, H. (Ed.): *Late- and Postglacial oscillations of glaciers – Glacial and Periglacial forms*, pp. 133–170. A.A. Balkema, Rotterdam.

Bakke, J., Dahl, S.O. and Nesje, A. (2000) Reconstruction of Younger Dryas and Holocene glacier fluctuations and paleoclimate at Folgefonna, southwestern Norway. *Norsk Geologisk Forening. Geonytt*, **1**, 36.

Bakke, J., Dahl, S.O. and Nesje, A. (2005a) Lateglacial and early Holocene palaeoclimatic reconstruction based on glacier fluctuations and equilibrium-line altitudes at northern Folgefonna, Hardanger, western Norway, *Journal of Quaternary Science*, **20**, 179–198.

Bakke, J., Dahl, S.O., Paasche, Ø., Løvlie, R. and Nesje, A. (2005b) Glacier fluctuations, equilibrium-line altitudes and palaeoclimate in Lyngen, northern Norway, during the Lateglacial and Holocene. *The Holocene*, **15**, 518–540.

Bargel, T.H. (2001) Løsmassekart over Nordland fylke, plottemålestokk M 1:400.000. *Norges geologiske undersøkelse*.

Bargel, T.H. (2003) *Quaternary geological mapping of Central Fennoscandia and Nordland: Deglaciation, deposition, stratigraphy and applications*. Dr.-ing. Thesis 2003:40. Department of Geology and Mineral Resources Engineering. Faculty of Engineering Science and Technology, NTNU, Trondheim. 324 pp.

Bargel, T.H. (1997) Oslo og Akershus. Løsmassekart – M 1:125.000. *Norges geologiske undersøkelse*.

Bargel, T., Huhta, P., Johansson, P., Lagerbäck, R., Mäkinen, K., Nenonen, K., Olsen, L., Rokoengen, K., Svedlund, J.-O., Väänänen, T. and Wahlroos, J.-E. (1999) Maps of Quaternary geology in Central Fennoscandia, sheet 3: Ice-flow Indicators, scale 1:1,000,000, and Quaternary stratigraphy, scale 1:2,000,000. *Geological Surveys of Finland (Espoo), Norway (Trondheim) and Sweden (Uppsala)*.

Bargel, T.H., Lagerbäck, R. and Nenonen, K. (Eds.) (2006) Beskrivning till de kvartärgeologiska kartorna innom Mittnordenområdet. Sveriges geologiska undersökning. *Rapporter och meddelanden*, **125**, 123 pp.

Baumann, K.-H., Lackschewitz, K.S., Mangerud, J., Spielhagen, R.F., Wolf-Welling, T.C.W., Henrich, R. and Kassens, H. (1995) Reflection of Scandinavian Ice Sheet fluctuations in Norwegian Sea sediments during the last 150,000 years. *Quaternary Research*, **43**, 185–197.

Bell, R.E., Studinger, M., Shuman, C.A., Fahnestock, M.A. and Joughin, I. (2007) Large subglacial lakes in East Antarctica at the onset of fast-flowing ice streams. *Nature*, **445**, 904–907.

Bergersen, O.F. and Garnes, K. (1981) Weichselian in central South Norway: the Gudbrandsdal Interstadial and the following glaciation. *Boreas*, **10**, 315–322.

Bergersen, O.F., Thoresen, M. and Hougsnæs, R. (1991) Evidence for a newly discovered Weichselian Interstadial in Gudbrandsdalen, Central South Norway. *Striae*, **34**, 103–108.

Berglund, B.E., Bergsten, H., Björck, S., Kolstrup, E., Lemdahl, G. and Nordberg, K. (1994) Late Weichselian environmental change in southern Sweden and Denmark. *Journal of Quaternary Science*, **9**, 127–132.

Bergstrøm, B. (1999) Glacial geology, deglaciation chronology and sea-level changes in the southern Telemark and Vestfold counties, southeastern Norway. *Norges geologiske undersøkelse Bulletin*, **435**, 23–42.

Bergstrøm, B., Olsen, L., Riiber, K. and Reite, A. (2010) Rogaland fylke, løsmassekart M 1:200.000. *Norges geologiske undersøkelse*.

Bergstrøm, B., Olsen, L. and Sveian, H. (1994) *Siste glasiasjon og deglasiasjon av Namdalskysten, Nord-Trøndelag*. 21. Nordiska Geologiska Vintermøtet, Luleå. Abstract hefte, 23.

Bergstrøm, B., Olsen, L. and Sveian, H. (2005a) The Tromsø-Lyngen glacier readvance (early Younger Dryas) at Hinnøya-Ofotfjorden, northern Norway: a reassessment. *Norges geologiske undersøkelse Bulletin*, **445**, 73–88.

Bergstrøm, B., Olsen, L., Sveian, H. and Tønnesen, J.F. (2005b) Leirkartlegging i Troms: Kvartærgeologien i Vangsvik, Sørreisa, Løksebotn og Lavangen, – et grunnlag for videre skredfarevurderinger. *NGU Rapport 2004.057*, 22 pp.

Bergstrøm, B., Olsen, L., Bang-Andersen, S. and Prøsch-Danielsen, L. (2007) The deglaciation and first colonization of the mountain areas between Lysefjorden and the inner Bjerkreim river system, SW Norway: events interpreted by geological, archaeological and palynological research. *NGF Abstracts and Proceedings*, **1**, 6.

Birks, H.H., Paus, Aa., Svendsen, J.I., Alm, T., Mangerud, J. and Landvik, J. (1994) Late Weichselian environmental change in Norway, including Svalbard. *Journal of Quaternary Science*, **9**, 133–145.

Blake, K. P. and Olsen, L. (1999) Deglaciation of the Svartisen area, northern Norway, and isolation of a large ice mass in front of the Fennoscandian Ice Sheet. *Norsk Geografisk Tidsskrift*, **53**, 1–16.

Bleil, U. (1989) Magnetostratigraphy of Neogene and Quaternary sediment series from the Norwegian Sea, Ocean Drilling Program Leg 104. *Proceedings of the Ocean Drilling Program, Scientific Results*, **104**, 829–901.

Blystad, P. and Selsing, L. (1988) Deglaciation chronology in the mountain area between Suldal and Setesdal, south-western Norway. *Norges geologisk undersøkelse Bulletin*, **413**, 67–92.

Blystad, P. and Selsing, L. (1989) Some erroneous radiocarbon dates of lacustrine sediments. *Norsk Geologisk Tidsskrift*, **69**, 201–208.

Bondevik, S., Birks, H.H., Gulliksen, S. and Mangerud, J. (1999) Late Weichselian marine ^{14}C reservoir ages at the western coast of Norway. *Quaternary Research*, **52**, 104–114.

Bondevik, S., Mangerud, J., Birks, H.H., Gulliksen, S. and Reimer, P. (2006) Changes in North Atlantic radiocarbon reservoir ages during the Allerød and Younger Dryas. *Science*, **312**, 1514–1517.

Boulton, G.S., Dongelmans, P., Punkari, M. and Broadgate, M. (2001) Palaeoglaciology of an ice sheet through a glacial cycle: the European ice sheet through the Weichselian. *Quaternary Science Reviews*, **20**, 591–625.

Brook, E.J., Nesje, A., Lehman, S.J., Raisbeck, G.M. and Yiou, F. (1996) Cosmogenic nuclide exposure ages along a vertical transect in western Norway: Implications for the height of the Fennoscandian ice sheet. *Geology*, **24**, 207–210.

Bugge, T. (1980) Øvre lags geologi på kontinentalsokkelen utenfor Møre og Trøndelag. *Continental Shelf Institute Publication*, **104**, 44 pp.

Bugge, T., Lien, R. and Rokoengen, K. (1978) Kartlegging av løsmassene på kontinentalsokkelen utenfor Møre og Trøndelag. *Continental Shelf Institute Publication*, **99**, 55 pp.

Carr, S., Haflidason, H. and Sejrup, H.-P. (2000) Micromorphological evidence supporting Late Weichselian glaciation of the northern North Sea. *Boreas*, **29**, 315–328.

Clark, P.U., Alley, R. and Pollard, D. (1999) Northern Hemisphere ice-sheet influences on global climate change. *Science*, **286**, 1104–1111.

Dahl, S.O., Lie, Ø., Linge, H., Pytte, A.-G. Bøe, Murray, A., Tveranger, J., Kvisvik, B.C. and Nesje, A. (2005) Weichselian glaciation history in the Rondane 'dry valleys' of central Scandinavia. Geological Society of America. *Abstracts with Programs*, **37**, 399.

Dahl, S.O. and Nesje, A. (1996) A new approach to calculating Holocene winter precipitation by combining glacier equilibrium-line altitudes and pine-tree limits: a case study from Hardangerjøkulen, central southern Norway. *The Holocene*, **6**, 381–398.

Dahl, S.O., Nesje, A., Lie, Ø., Fjordheim, K. and Matthews, J.A. (2002) Timing, equilibrium-line altitudes and climatic implications of two early-Holocene glacier readvances during the Erdalen Event at Jostedalsbreen, western Norway. *The Holocene*, **12**, 17–25.

Dahl, S.O., Nesje, A. and Øvstedahl, J. (1997) Cirque glaciers as morphological evidence for a thin Younger Dryas ice sheet in east-central southern Norway. *Boreas*, **26**, 161–180.

Dahlgren, K.I.T. (2002) *Late Cenozoic evolution, sedimentary environment and processes on the mid-Norwegian continental margin*. Dr. Sc. Thesis, University of Tromsø, 20 pp., plus four papers.

Dahlgren, K.I.T., Vorren, T.O. and Laberg, J.S. (2002) Late Quaternary glacial development of the mid-Norwegian margin – 65 to 68°N. *Marine and Petroleum Geology*, **19**, 1089–1113.

Denton, G.H. and Hughes, T.J. (Eds.) (1981) *The last great ice sheets*. John Wiley and Sons, New York. 484 pp.

Dowdeswell, J., Ottesen, D. and Rise, L. (2010) Rates of sediment delivery from the Fennoscandian Ice Sheet through an ice age. *Geology*, **38**, 3–6.

Ehlers, J. (1996) *Quaternary and Glacial Geology*. John Wiley and Sons Ltd., Chichester, 578 pp.

Ehlers, J. and Gibbard, P.L. (2007) The extent and chronology of Cenozoic Global Glaciation. *Quaternary International*, **164/165**, 6–20.

Eide, F. and Sindre, E. (1987) Late Eemian and early Weichselian sediments in the Vinjedalen valley, Vossestrand, West Norway. *Norges geologiske undersøkelse*, **409**, 21–27.

Eidvin, T., Riis, F. and Rundberg, Y. (1999) Upper Cenozoic stratigraphy in the central North Sea (Ekofisk and Sleipner fields). *Norsk Geologisk Tidsskrift*, **79**, 97–128.

Eidvin, T., Bugge, T. and Smelror, M. (2007) The Molo Formation, deposited by coastal progradation on the inner Mid-Norwegian continental shelf, coeval with the Kai Formation to the west and the Utsira Formation in the North Sea. *Norwegian Journal of Geology*, **87**, 75–142.

Feyling-Hanssen, R.W. (1981) Foraminiferal indication of Eemian Interglacial in the northern North Sea. *Bulletin of the Geological Society of Denmark*, **29**, 175–189.

Fjeldskaar, W. (2000) An isostatic test of the hypothesis of ice-free mountain areas during the last glaciation. *Norsk Geologisk Tidsskrift*, **80**, 51–56.

Fjeldskaar, W. and Kanestrøm, R. (1980) Younger Dryas geoid-deformation caused by deglaciation in Fennoscandia. *In* Mörner, N.-A. (Ed.): *Earth Rheology, Isostasy and Eustasy*, pp. 569–574. Wiley, New York.

Fjellberg, A. (1978) Fragments of a Middle Weichselian fauna on Andøya, north Norway. *Boreas*, **7**, 39.

Foged, N. (1978) Diatoms from the Middle and Late Weichselian and the Early Flandrian period on Andøya, north Norway. *Boreas*, **7**, 41–47.

Follestad, B.A. (1990a) Block fields, ice-flow directions and the Pleistocene ice sheet in Nordmøre and Romsdal, West Norway. *Norsk Geologisk Tidsskrift*, **70**, 27–34.

Follestad, B.A. (1990b) Eide 1320 IV, kvartærgeologisk kart M 1:50.000 (med beskrivelse). *Norges geologiske undersøkelse*.

Follestad, B.A. (1995) Løsmassekart over Møre & Romsdal fylke (kvartærgeologisk kart M 1:250.000). *Norges geologiske undersøkelse Skrifter*, **112**, 1–52.

Follestad, B.A. (2003a) Development of minor late-glacial ice domes east of Oppdal, Central Norway. *Norges geologiske undersøkelse*

Bulletin, **441**, 39–49.

Follestad, B.A. (2003b) Snøhetta – Kvartærgeologisk kart 1519 IV – M 1:50.000. *Norges geologiske undersøkelse*.

Follestad, B.A. (2005a) Oppdal – Kvartærgeologisk kommunekart – M 1:80.000. *Norges geologiske undersøkelse*.

Follestad, B.A. (2005b) Large-scale patterns of glacial streaming flow deduced from satellite imagery over Sør-Trøndelag, Norway. *Norwegian Journal of Geology*, **85**, 225–232.

Follestad, B.A. (2005c) Rondane–1718 I. Kvartærgeologisk kart – M 1:50.000, med beskrivelse. *Norges geologiske undersøkelse*.

Follestad, B.A. and Fredin, O. (2007) Late Weichselian ice flow evolution in south-central Norway. *Norwegian Journal of Geology*, **87**, 163–171.

Follestad, B.A. and Thoresen, M. (1999) Geologiske severdigheter langs bil- og sykkelveier og turstier i Alvdal. Med kvartærgeologisk kommunekart i M 1:60 000. *Norges geologiske undersøkelse, Gråsteinen*, **4**, 40 pp.

Fredin, O. (2002) Glacial inception and Quaternary mountain glaciations in Fennoscandia. *Quaternary International*, **95–96**, 99–112.

Fredin, O., Bergström, B., Eilertsen, R., Hansen, L., Longva, O., Nesje, A. and Sveian, H. (2013) Glacial landforms and Quaternary landscape development in Norway. *Norges geologiske undersøkelse, Special Publication,* **13**, 5–25.

Gjelle, S., Bergstrøm, B., Gustavson, M., Olsen, L. and Sveian, H. (1995) *Geology and landscape around the Arctic Circle in Norway*. Norges geologiske undersøkelse. 128 pp.

Gjessing, J. (1960) Isavsmeltingstidens drenering. Dens forløp og formdannende virkning i Nordre Atnadalen. Med sammenlignende studier fra Nordre Gudbrandsdalen og Nordre Østerdalen. Det Norske Geografiske selskab. *Ad Novas skrifter*, **3**, 492 pp. Universitetsforlaget, Oslo.

Griffey, N.J. and Worsley, P. (1978) The pattern of Neoglacial variations in the Okstindan region of northern Norway during the last millennia. *Boreas*, **7**, 1–17.

Haflidason, H., Sejrup, H.-P., Berstad, I.M., Nygård, A., Richter, T., Bryn, P., Lien, R. and Berg, K. (2003) A weak layer feature on the northern Storegga Escarpment. *In* Mienert, J. and Weaver, P. (Eds.): *European Margin Sediment Dynamics: side-scan sonar and seismic images*, pp. 55–62. Springer, Berlin.

Haldorsen, S., Rappol, M., Sønstegaard, E. and Henningsmoen, K. (1992) Interstadials and glaciotectonic deformations in Åstdalen, southeastern Norway. *Sveriges Geologiska Undersökning*, **Ca 81**, 125–132.

Hättestrand, C. (1998) The glacial geomorphology of central and northern Sweden (with map in scale 1:1 250 000). Geological Survey of Sweden. Research Papers. **Ca 85**, 47 pp.

Hättestrand, C. and Stroeven, A.P. (2002) A relict landscape in the centre of Fennoscandian glaciation: Geomorphological evidence of minimal Quaternary glacial erosion. *Geomorphology*, **44**, 127–143.

Haug, E. (2005) *OSL-dateringer av weichsel sedimenter på sørøstlige Hardangervidda, Sør-Norge*. Unpublished Master Thesis, University of Bergen, 64 pp.

Helle, M. (1978) *Jordartskartlegging og kvartær stratigrafi, Ringsaker, Hedmark*. Unpublished Cand. real. Thesis, University of Bergen, 172 pp.

Helle, M., Sønstegaard, E., Coope, G.R. and Rye, N. (1981) Early Weichselian peat at Brumunddal, SE Norway. *Boreas*, **10**, 369–379.

Helle, S.K., Anundsen, K., Aasheim, S. and Haflidason, H. (1997) Indications of a Younger Dryas marine transgression in inner Hardanger, West Norway. *Norsk Geologisk Tidsskrift*, **77**, 101–117.

Helmens, K.F., Räsänen, M.E., Johansson, P.W., Jungner, H. and Korjonene, K. (2000) The Last Interglacial-Glacial cycle in NE Fennoscandia: a nearly continuous record from Sokli (Finnish Lapland). *Quaternary Science Reviews*, **19**, 1605–1623.

Helmens, K.F., Johansson, P.W., Räsänen, M.E., Alexanderson, H. and Eskola, K.O. (2007) Ice-free intervals continuing into Marine Isotope Stage 3 at Sokli in the central area of the Fennoscandian glaciations. *Bulletin of the Geological Society of Finland*, **79**, 17–39.

Henrich, R. and Baumann, K.-H. (1994) Evolution of the Norwegian Current and the Scandinavian Ice Sheets during the past 2.6 m.y.: evidence from ODP Leg 104 biogenic carbonate and terrigenous records. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **108**, 75–94.

Hillefors, Å. (1974) The stratigraphy and genesis of the Dösebacka and Ellesbo drumlins. A contribution to the knowledge of Weichsel-glacial history in western Sweden. *Geologiska Föreningens i Stockholm Förhandlingar*, **96**, 355–374. Stockholm.

Hirvas, H. (1991) Pleistocene stratigraphy of Finnish Lapland. *Geological Survey of Finland Bulletin*, **354**, 123 pp.

Hirvas, H., Lagerbäck, R., Mäkinen, K., Nenonen, K., Olsen, L., Rodhe, L. and Thoresen, M. (1988) The Nordkalott Project: studies of Quaternary geology. *Boreas*, **17**, 431–437.

Hjelstuen, B.O., Sejrup, H.-P., Haflidason, H., Nygård, A., Berstad, I. and Knorr, G. (2004) Late Quaternary seismic stratigraphy and geological development of the south Vøring margin, mid-Norway. *Quaternary Science Reviews*, **23**, 1847–1865.

Holmsen, P. (1982) Jotunheimen. Description of the Quaternary geological outline map 1: 250,000. *Norges geologiske undersøkelse*, **374**, 1–75.

Holtedahl, H. (1993) Marine geology of the Norwegian continental margin. *Norges geologiske undersøkelse, Special Publication*, **6**, 1–150.

Houmark-Nielsen, M. (1999) A lithostratigraphy of Weichselian glacial and interstadial deposits in Denmark. *Bulletin of the Geological Society of Denmark*, **46**, 101–114.

Houmark-Nielsen, M. and Kjær, K.H. (2003) Southwest Scandinavia, 40–15 kyr BP: paleogeography and environmental change. *Journal of Quaternary Science*, **18**, 769–786.

Huybrechts, P. (2002) Sea-level changes at the LGM from ice-dynamic reconstructions of the Greenland and Antarctic ice sheets during the last glacial cycles. *Quaternary Science Reviews*, **21**, 203–231.

Imbrie, J., Hays, J.D., Martinson, D.G., McIntyre, A., Mix, A.C., Morley, J.J., Pisias, N.G., Prell, W.L. and Shackleton, N.J. (1984) The orbital theory of Pleistocene climate: support from a revised chronology of the marine d^{18}O record. *In* Berger, A., Imbrie, J., Hays, J., Kukla, G. and Salzman, B. (Eds.): *Milankovitch and Climate. NATO ASI Series C*, **126**, 269–305. D.Reidel, Dordrecht.

Janocko, J., Landvik, J.Y., Larsen, E., Sejrup, H.P. and Steinsund, P.I. (1998) Middle and Late Quaternary depositional history reconstructed from two boreholes at Lågjæren and Høgjæren SW Norway. *Norsk Geologisk Tidsskrift*, **78**, 153–167.

Jansen, E., Befring, S., Bugge, T., Eidvin, T., Holtedahl, H. and Sejrup, H.P. (1987) Large submarine slides on the Norwegian Continental Margin: Sediments, transport and timing. *Marine Geology*, **78**, 77–107.

Jansen, E. and Sjøholm, J. (1991) Reconstruction of glaciation over the past 6 Myr from ice-borne deposits in the Norwegian Sea. *Nature*, **349**, 600–603.

Johnsen, T.F., Olsen, L. and Murray, A. (2012) OSL ages in central Norway support a MIS 2 interstadial (25–20 ka) and a dynamic Scandinavian ice sheet. *Quaternary Science Reviews,* **44***, 96–111*. (On internet since 2010: doi:10.1016 /j.quascirev.2010.10.007).

Jungner, H., Landvik, J.Y. and Mangerud, J. (1989) Thermoluminescence dates of Weichselian sediments in western Norway. *Boreas*, **18**, 23–29. Oslo.

Kapitsa, A.P., Ridley, J.K., Robin, G.D., Siegert, M.J. and Zotikov, I.A. (1996) A large deep freshwater lake beneath the ice of central East Antarctica. *Nature*, **381**, 684–686.

King, E.L., Sejrup, H.-P., Haflidason, H., Elverhøi, A. and Aarseth, I. (1996) Quaternary seismic stratigraphy of the North Sea Fan: Glacially fed gravity flow aprons, hemipelagic sediments, and large submarine slides. *Marine Geology*, **130**, 293–315.

King, L.H., Rokoengen, K. and Gunleiksrud, T. (1987) *Quaternary seismostratigraphy of the Mid Norwegian Shelf, 65°–67°30'N – A till tongue stratigraphy*. IKU Sintef Group 114 (ISSN 0332-5288), 1–58, and seven map enclosures.

Klakegg, O., Nordahl-Olsen, T., Sønstegaard, E. and Aa, A.R. (1989) Sogn og Fjordane fylke, kvartærgeologisk kart – M 1:250.000. *Norges geologiske undersøkelse*.

Kleman, J. (1990) On the use of glacial striae for reconstruction of paleo-ice sheet flow patterns. *Geografiska Annaler*, **52A**, 217–236.

Kleman, J. (1992) The palimpsest glacial landscape in northwestern Sweden – Late Weichselian deglaciation landforms and traces of older west-centered ice sheets. *Geografiska Annaler*, **74**, 305–325.

Kleman, J. (1994) Preservation of landforms under ice sheets and ice caps. *Geomorphology*, **9**, 19–32.

Kleman, J. and Borgström, I. (1990) The boulder fields of Mt. Fulufjället, west-central Sweden – Late Weichselian boulder blankets and interstadial periglacial phenomena. *Geografiska Annaler*, **72A**, 63–78.

Kleman, J. and Borgström, I. (1996) Reconstruction of paleo-ice sheets: The use of geomorphological data. *Earth surface processes and landforms*, **21**, 893–909.

Kleman, J. and Hättestrand, C. (1999) Frozen-bed Fennoscandian and Laurentide ice sheets during the Last Glacial Maximum. *Nature*, **402**, 63–66.

Kleman, J., Hättestrand, C., Borgström, I. and Stroeven, A. (1997) Fennoscandian palaeoglaciology reconstructed using a glacial geological inversion model. *Journal of Glaciology*, **43**, 283–299.

Kleman, J., Stroeven, A.P. and Lundqvist, J. (2007) Patterns of Quaternary ice sheet erosion and deposition in Fennoscandia and a theoretical framework for explanatation. *Geomorphology*, **97** (2008), 73–90. Elsevier.

Knies, J., Vogt, C., Matthiessen, J., Nam, S.-I, Ottesen, D., Rise, L., Bargel, T. and Eilertsen, R.S. (2007) Re-advance of the Fennoscandian Ice Sheet during Heinrich Event 1. *Marine Geology*, **240**, 1–18.

Knudsen, C.G., Larsen, E., Sejrup, H.P. and Stalsberg, K. (2006) Hummocky moraine landscape on Jæren, SW Norway – implications for glacier dynamics during the last deglaciation. *Geomorphology*, **77**, 153–168.

Kohler, J. (2007) Lubricated lakes. *Nature*, **445**, 830–831.

Kolstrup, E. and Olsen, L. (2012) Palaeoenvironmental developments in the central Scandinavian mountains during deglaciation – a discussion. *Norsk Geografisk Tidsskrift – Norwegian Journal of Geography*, **66**, 30–51.

Kverndal, A.-I. and Sollid, J.-L. (1993) Late Weichselian glaciation and deglaciation in northeastern Troms, northern Norway. *Norsk Geografisk Tidsskrift*, **47**, 163–177.

Laberg, J.S. and Vorren, T.O. (1996) The Middle and Late Pleistocene evolution of the Bear Island Trough Mouth Fan. *Global and Planetary Change*, **12**, 309–330.

Laberg, J.S. and Vorren, T.O. (2004) Weichselian and Holocene growth of the northern high-latitude Lofoten contourite drift on the continental slope of Norway. *Sedimentary Geology*, **164**, 1–17.

Laberg, J.S., Eilertsen, R.S., Salomonsen, G.R. and Vorren, T.O. (2007) Submarine push moraine formation during the early Fennoscandian Ice Sheet deglaciation. *Quaternary Research*, **67**, 453–462.

Lagerbäck, R. (1988) Periglacial phenomena in the wooded areas of northern Sweden – a relict from the Tärendö Interstadial. *Boreas*, **17**, 487–499.

Lagerbäck, R. and Robertsson, A.-M. (1988) Kettle holes – stratigraphical archives for Weichselian geology and palaeoenvironment in northernmost Sweden. *Boreas*, **17**, 439–468.

Landvik, J.Y., Bondevik, S., Elverhøi, A., Fjeldskaar, W., Mangerud, J., Salvigsen, O., Siegert, M.J., Svendsen, J.I. and Vorren,T.O. (1998) The last glacial maximum of Svalbard and the Barents Sea area: Ice sheet extent and configuration. *Quaternary Science Reviews*, **17**, 43–75.

Landvik, J.Y. and Hamborg, M. (1987) Weichselian glacial episodes in outer Sunnmøre, western Norway. *Norsk Geologisk Tidsskrift*, **67**, 107–123. Oslo.

Landvik, J.Y. and Mangerud, J. (1985) A Pleistocene sandur in western Norway: facies relationships and sedimentological characteristics. *Boreas*, **14**, 161–174. Oslo.

Larsen, E. and Sejrup, H.-P. (1990) Weichselian land-sea interaction; western Norway – Norwegian Sea. *Quaternary Science Reviews*, **9**, 85–97.

Larsen, E., Andreassen, K., Knies, J., Nilssen, L.C. and Olsen, L. (2005) Barents Sea Region – erosion and uplift. *Geological Survey of Norway, Report 2005.006*, 35 pp.

Larsen, E., Attig, J.W., Aa, A.R. and Sønstegaard, E. (1998) Late-Glacial cirque glaciation in parts of western Norway. *Journal of Quaternary Science*, **13**, 17–27.

Larsen, E., Eide, F., Longva, O. and Mangerud, J. (1984) Allerød–Younger Dryas climatic inferences from cirque glaciers and vegetational development in the Nordfjord area, western Norway. *Arctic and Alpine Research*, **16**, 137–160.

Larsen, E., Gulliksen, S., Lauritzen, S.-E., Lie, R., Løvlie, R. and Mangerud, J. (1987) Cave stratigraphy in western Norway; multiple Weichselian glaciations and interstadial vertebrate fauna. *Boreas*, **16**, 267–292.

Larsen, E., Hald, M. and Birks, J. (2003) Tar temperaturen på fortiden. KlimaProg – Forskningsprogram om klima og klimaendringer (2002-2011). Tidsskrift fra Cicero Senter for klimaforskning. University of Oslo. *Cicerone*, **4**, 18–23.

Larsen, E., Klakegg, O. and Longva, O. (1988) Brattvåg and Ona. Quaternary geological maps 1220 II and 1220 IV – scale 1:50,000 with description. *Norges geologiske undersøkelse Skrifter*, **85**, 1–41.

Larsen, E., Lyså, A., Demidov, I., Funder, S., Houmark-Nielsen, M., Kjær, K.H. and Murray, A.S. (1999) Age and extent of the Scandinavian ice sheet in northwest Russia. *Boreas*, **28**, 115–132.

Larsen, E., Sejrup, H.-P., Janocko, J., Landvik, J.Y., Stalsberg, K. and Steinsund, P.I. (2000) Recurrent interaction between the Norwegian Channel Ice Stream and terrestrial-based ice across southwest Norway. *Boreas*, **29**, 185–203.

Lauritzen, S.-E. (1984) A symposium: arctic and alpine karst. *Norsk Geografisk Tidsskrift*, **38**, 139–143.

Lauritzen, S.-E. (1991) Uranium series dating of speleothems: A glacial chronology for Nordland, Norway, for the last 600 ka. *Striae*, **34**, 127–133.

Lauritzen, S.-E. (1995) High-resolution paleotemperature proxy record for the Last Interglacial based on Norwegian speleothemes. *Quaternary Research*, **43**, 133–146.

Lauritzen, S.-E., Løvlie, R., Moe, D. and Østbye, E. (1990) Paleoclimate deduced from a multidisciplinary study of a half-million-year-old stalagmite from Rana, Northern Norway. *Quaternary Research*, **34**, 306–316.

Lauritzen, S.-E., Nese, H., Lie, R.W., Lauritsen, Å. and Løvlie, R. (1996) Interstadial/interglacial fauna from Norcemgrotta, Kjøpsvik, north Norway. *In* Lauritzen, S.-E. (Ed.): *Climate change: The karst record, 89–92*. The Karst Waters Institute. Charles Town, West Virginia.

Lebesbye, E. (2000) *Late Cenozoic glacial history of the south-western Barents Sea*. PhD Thesis, University of Tromsø. 172 pp.

Linge, H., Lauritzen, S.-E. and Lundberg, J. (2001) Stable isotope stratigraphy of a late last interglacial speleothem from Rana, Northern Norway. *Quaternary Research*, **56**, 155–164.

Linge, H., Brook, E.J., Nesje, A., Raisbeck, G.M., Yiou, F. and Clark, H. (2006) In situ ^{10}Be exposure ages from southeastern Norway: implications for the geometry of the Weichselian Scandinavian ice sheet. *Quaternary Science Reviews*, **25**, 1097–1109.

Linge, H., Olsen, L., Brook, E.J., Darter, J.R., Mickelson, D.M., Raisbeck, G.M. and Yiou, F. (2007) Cosmogenic nuclide surface exposure ages from Nordland, northern Norway: implications for deglaciation in a coast to inland transect. *Norwegian Journal of Geology*, **87**, 269–280.

Lohne, Ø. (2000) *Sen-weichsel og holosen strandforskyvning i Os-området, Hordaland*. Unpublished Cand. Scient. Thesis, Department of Geology, University of Bergen.

Lohne, Ø. (2006) *Late Weichselian relative sea-level changes and glacial history in Hordaland, Western Norway*. PhD Thesis, University of Bergen. 34 pp.

Lohne, Ø., Bondevik, S., Mangerud, J. and Svendsen, J.I. (2007a) Sea-level fluctuations imply that the Younger Dryas ice-sheet expansion in western Norway commenced during the Allerød. *Quaternary Science Reviews*, **26**, 2128–2151.

Lohne, Ø.S., Mangerud, J. and Svendsen, J.I. (2007b) Alderen på Halsnøymorenen og det siste isdekket i Hardangerfjorden. *NGF Abstracts and Proceedings*, **1**, 56.

Lokrantz, H. and Sohlenius, G. (2006) Ice marginal fluctuations during the Weichselian glaciation in Fennoscandia, a literature review. Swedish Nuclear Fuel and Waste Management Co. *Technical report, TR-06-36*, 55 pp.

Longva, O. (1987) Ullensaker 1915 II. Beskrivelse til kvartærgeologisk kart – M 1:50.000. *Norges geologiske undersøkelse Skrifter*, **76**, 39 pp.

Longva, O. and Thorsnes, T. (1997) Skagerrak in the past and the present – an integrated study of geology, chemistry, hydrography and microfossil ecology. *Norges geologiske undersøkelse Special Publication*, **8**, 1–100.

Lowe, J.J. and Walker, M.J.C. (1997) *Reconstructing Quaternary Environments. 2nd Ed*. Addison Wesley Longman Ltd., 446 pp.

Lundqvist, J. (1969) Beskrivning till jordartskarta över Jämtlands län. *Sveriges geologiska undersökning*, **Ca 45**, 418 pp.

Lundqvist, J. (1992) Glacial stratigraphy in Sweden. *Geological Survey of Finland, Special paper*, **15**, 43–59.

Lyså, A. and Corner, G. (1993) Late Pleistocene glacial deglacial facies sequences and geologic history at Vuolgamasjåkka, Finnmarksvidda, Norway. *Norsk Geologisk Tidsskrift*, **74**, 9–23.

Mangerud, J. (1980) Ice-front variations of different parts of the Scandinavian Ice Sheet 13,000–10,000 years BP. *In* Low, J.J., Gray, J.M. and Robinson, J.E. (Eds.): *Studies in the lateglacial of North-West Europe, 23–30*. Pergamon, Oxford.

Mangerud, J. (1981) The Early and Middle Weichselian in Norway: a review. *Boreas*, **10**, 381–393.

Mangerud, J. (1991a) The Scandinavian Ice Sheet through the last interglacial/glacial cycle. *Paläoklimaforschung*, **1**, 307–330.

Mangerud, J. (1991b) The Last Ice Age in Scandinavia. *In* Andersen, B.G. and Königsson, L.-K. (Eds.): *Late Quaternary Stratigraphy in the Nordic Countries 150,000–15,000 BP.* Striae, **34**, 15–30.

Mangerud, J. (1991c) The Last Interglacial/Glacial Cycle in Northern Europe. *In* Shane, L.C.K. and Cushing, E.J. (Eds.): *Quaternary Landscapes*, 38–75. University of Minnesota Press, Minneapolis.

Mangerud, J. (2004) Ice sheet limits in Norway and on the Norwegian continental shelf. *In* Ehlers, J. and Gibbard, P. (Eds.): *Quaternary Glaciations – Extent and Chronology: Europe. Vol. 1*, pp. 271–294. Elsevier, Amsterdam.

Mangerud, J. and Gulliksen, S. (1975) Apparent radiocarbon ages of recent marine shells from Norway, Spitsbergen, and Arctic Canada. *Quaternary Research*, **5**, 263–273.

Mangerud, J., Bondevik, S., Gulliksen, S., Hufthammer, A.K. and Høisæter, T. (2006) Marine ^{14}C reservoir ages for 19th century whales and molluscs from the North Atlantic. *Quaternary Science Reviews*, **25**, 3228–3245.

Mangerud, J., Gulliksen, S., Larsen, E., Longva, O., Miller, G.H., Sejrup, H.-P. and Sønstegaard, E. (1981a) A Middle Weichselian ice-free period in Western Norway: the Ålesund Interstadial. *Boreas*, **10**, 447–462.

Mangerud, J., Løvlie, R., Gulliksen, S., Hufthammer, A. K., Larsen, E. and Valen, V. (2003) Paleomagnetic correlations between Scandinavian Ice-Sheet fluctuations and Greenland Dansgaard-Oeschger events, 45,000–25,000 yr B.P. *Quaternary Research*, **59**, 213–222.

Mangerud, J., Sønstegaard, E. and Sejrup, H.-P. (1979) The correlation of the Eemian (interglacial) Stage and the deep-sea oxygen-isotope stratigraphy. *Nature*, **279**, 108.

Mangerud, J., Sønstegaard, E., Sejrup, H.-P. and Haldorsen, S. (1981b) A continuous Eemian–Early Weichselian sequence containing pollen and marine fossils at Fjøsanger, western Norway. *Boreas*, **10**, 137–208.

Mangerud, J., Jansen, E. and Landvik, J. (1996) Late Cenozoic history of the Scandinavian and Barents Sea ice sheets. *Global and Planetary Change*, **12**, 11–26.

Martinson, D.G., Pisias, N.G., Hays, J.D., Imbrie, J., Moore, T.C.J. and Shackleton, N.J. (1987) Age dating and the orbital theory of the ice ages: Development of a high-resolution 0 to 300,000 year chronostratigraphy. *Quaternary Research*, **27**, 1–29.

Matthews, J.A., Dahl, S.O., Nesje, A., Berrisford, M.S. and Andersson, C. (2000) Holocene glacier variations in central Jotunheimen, southern Norway based on distal glaciolacustrine sediment cores. *Quaternary Science Reviews*, **19**, 1625–1647.

Mauring, E. and Rønning, J.S. (1993) Geophysical measurements in the Tana valley, Tana, Finnmark. *NGU Report 93.122*. Trondheim.

Mauring, E., Rønning, J.S. and Danielsen, E. (1995) Ground-penetrating radar and reflection seismic measurements in the Tana valley, Tana, Finnmark. *NGU Report 96.118*. Trondheim.

Menke, B. (1968) Beiträge zur Biostratigraphie des Mittelpleistozäns in Norddeutschland. *Meyniana*, **18**, 35-42.

Miller, U. (1977) Pleistocene deposits of the Alnarp Valley, southern Sweden – Microfossils and their stratigraphical application. Department of Quaternary Geology, University of Lund, *Lundqua thesis*, **4**, 125 pp.

Murray, A.S., Svendsen, J.I., Mangerud, J. and Astakhov, V.I. (2007) Testing the accuracy of quartz OSL dating using a known-age Eemian site on the river Sula, northern Russia. *Quaternary Geochronology*, **2**, 102–109.

Møller, J.J., Danielsen, T.K. and Fjalstad, A. (1992) Late Weichselian glacial maximum on Andøya, North Norway. *Boreas*, **21**, 1–13.

Nenonen, K. (1995) *Pleistocene stratigraphy and reference sections in southern and western Finland*. Geological Survey of Finland, Regional Office for Mid-Finland, 94 pp.

Nese, H. (1996) *Sedimentologisk utvikling av grottene i Kjøpsvik – med hovudvekt på Storsteinsholesystemet.* Unpublished C. Sc. Thesis, University of Bergen, 157 pp.

Nese, H. and Lauritzen, S.-E. (1996) Quaternary stratigraphy of the Sorsteinhola cave system, Kjøpsvik, north Norway. *Karst Waters Institute Special Publication*, **2**, 116–120.

Nesje, A., Anda, E., Rye, N., Lien, R., Hole, P.A. and Blikra, L.H. (1987) The vertical extent of the Late Weichselian ice sheet in the Nordfjord-Møre area, western Norway. *Norsk Geologisk Tidsskrift*, **67**, 125–141.

Nesje, A. and Dahl, S.O. (1990) Autochtonous blockfields in southern Norway: Implications for the geometry, thickness, and isostatic loading of the Late Weichselian Scandinavian ice sheet. *Journal of Quaternary Science*, **5**, 225–234.

Nesje, A. and Dahl, S.O. (1992) Geometry, thickness and isostatic loading of the Late Weichselian ice sheet. *Norsk Geologisk Tidsskrift*, **72**, 271–273.

Nesje, A., Dahl, S.O., Anda, E. and Rye, N. (1988) Blockfields in southern Norway: Significance for the Late Weichselian ice sheet. *Norsk Geologisk Tidsskrift*, **68**, 149–169.

Nesje, A., Dahl, S.O., Linge, H., Ballantyne, C.K., McCarroll, D., Brook, E.J., Raisbeck, G.M. and Yiou, F. (2007) The surface geometry of the Last Glacial Maximum ice sheet in the Andøya–Skånland region, northern Norway, constrained by surface exposure dating and clay mineralogy. *Boreas*, **36**, 1–13.

Nesje, A., Matthews, J.A., Dahl, S.O., Berrisford, M.S. and Andersson, C. (2001) Holocene glacier fluctuations of Flatebreen and winter-precipitation changes in the Jostedalsbreen region, western Norway: evidence from proglacial lacustrine sediment records. *The Holocene*, **11**, 267–280.

Nesje, A., McCarroll, D. and Dahl, S.O. (1994) Degree of rock surface weathering as an indicator of ice-sheet thickness along an east-west transect across southern Norway. *Journal of Quaternary Science*, **9**, 337–347.

Nygård, A. (2003) *Pleistocene sedimentary processes and glacial history of the Southern Norwegian continental margin*. Dr. Sc. Thesis, University of Bergen, 17 pp., plus five papers.

Nygård, A., Sejrup, H.P., Haflidason, H. and Bryn, P. (2005) The glacial North Sea Fan, southern Norwegian Margin: architecture and evolution from the upper continental slope to the deep-sea basin. *Marine and Petroleum Geology*, **22**, 71–84.

Olsen, L. (1983) Isbevegelser i Lillehammer-området, SØ-Norge, under siste nedisning. *Norges geologiske undersøkelse*, **378**, 83–91.

Olsen, L. (1985a) Lillehammer. Beskrivelse til kvartærgeologisk kart 1817 II – M 1:50.000 (med fargetrykt kart). Summary. *Norges* *geologiske undersøkelse Skrifter*, **60**, 1–47.

Olsen, L. (1985b) Weichselian Till Stratigraphy in the Lillehammer Area, Southeast Norway. *Norges geologiske undersøkelse Bulletin*, **401**, 59–81.

Olsen, L. (1988) Stadials and interstadials during the Weichsel glaciation on Finnmarksvidda, northern Norway. Boreas, **17**, 517–539.

Olsen, L. (1989) *Glasialgeologi og kvartærstratigrafi i to innlandsområder, Nordlige Mjøsregionen og Finnmarksvidda*. Dr. scient. Thesis, University of Bergen, 21 pp., plus nine published papers.

Olsen, L. (1993a) Siste nedisning belyst med dateringer fra noen lokaliteter i fastlands-Norge. *Norsk Geologisk Forening, Abstract, Geonytt*, **1**, 37.

Olsen, L. (1993b) Finnmark County, map of Quaternary stratigraphy, scale 1:1 million, with description (in Norwegian). Summary. *Geological Survey of Norway*.

Olsen, L. (1995a) Quaternary palaeosols in Norway – examples from selected areas. *Norges geologiske undersøkelse Bulletin*, **427**, 12–15.

Olsen, L. (1995b) *Glasiale variasjoner under sen Midt-/tidlig Sen-Weichsel i Norge – Glasiasjonskurver langs noen profiler*. Miljøgeologisk Konferanse i Bergen, Norge, 1995. Senter for Miljø- og Ressursstudier. Abstract. Internal report, University of Bergen.

Olsen, L. (1997a) Rapid shifts in glacial extension characterise a new conceptual model for glacial variations during the Mid and Late Weichselian in Norway. *Norges geologiske undersøkelse Bulletin*, **433**, 54–55.

Olsen, L. (1997b) Pedogenic magnetic susceptibility in Norwegian palaeosols and tills – a tool for stratigraphic correlation and palaeorainfall estimation. *Norges geologiske undersøkelse Bulletin*, **433**, 56–57.

Olsen, L. (1998) Pleistocene paleosols in Norway: implications for past climate and glacial erosion. *Catena*, **34**, 75–103.

Olsen, L. (2000) The last glaciation in Norway – glaciation curves along nine transects from inland to coast. *NGU, internal report 2000.122*, 49 pp.

Olsen, L. (2002) Mid and Late Weichselian, ice-sheet fluctuations northwest of the Svartisen glacier, Nordland, northern Norway. *Norges geologiske undersøkelse Bulletin*, **440**, 39–52.

Olsen, L. (2003) A Mid-Norwegian correlative to the Younger Dryas Vedde Ash Bed from western Norway. Norsk Geologisk Forenings XVIII. Vinterkonferanse, Oslo. *NGF Abstracts and Proceedings*, **1**.

Olsen, L. (2006) Fennoscandian M–L Weichselian glacial variations – much more than just local ice-margin fluctuations. Key-note lecture at the 27th Nordic Geological Winter Meeting, Oulu Univ., Finland. *Bulletin of the Geological Society of Finland, Special Issue, 1. Abstract*, **118**.

Olsen, L. (2010) A buried late MIS 3 shoreline in northern Norway – implications for ice extent and volume. *Norges geologiske undersøkelse Bulletin*, **450**, 1–14.

Olsen, L. and Bergstrøm, B. (2007) Glacier variations during the LGM interval in the Karmøy–Jæren district, SW Norway. *NGF Abstracts and Proceedings*, **1**, 73–74.

Olsen, L. and Grøsfjeld, K. (1999) Middle and Late Weichselian high relative sea levels in Norway: implications for glacial isostasy and ice-retreat rates. *Norges geologiske undersøkelse Bulletin*, **435**, 43–51.

Olsen, L. and Riiber, K. (2006) Osen 1623 IV, kvartærgeologisk kart i M 1: 50.000, (med beskrivelse). Digitalt plottekart. *Norges geologiske undersøkelse*.

Olsen, L. and Sveian, H. (1994) Namsfjorden–Salsnes. Hovedtrekk av kvartærgeologien. Ekskursjonsguide. *Norges geologiske undersøkelse Rapport 94.071*, 21–34.

Olsen, L. and Sørensen, E. (1993) Halden 1913 II, kvartærgeologisk kart i M 1:50.000, med beskrivelse. *Norges geologiske undersøkelse*.

Olsen, L. and Sørensen, E. (1998) Fredrikstad 1913 III, kvartærgeologisk kart i M 1:50.000, med beskrivelse. Fulldigitalt fargeplott. *Norges geologiske undersøkelse*.

Olsen, L., Bergstrøm, B. and Sveian, H. (2001e) New data indicates considerable Allerød–Younger Dryas ice-front fluctuations across Hinnøya and in the adjacent Ofotfjorden–Vestfjorden area, northern Norway. *Geonytt*, **1**, 88.

Olsen, L., Bergstrøm, B. and Sveian, H. (2004) *Glacial fluctuations in coastal southern Norway during the LGM interval – a transect of terrestrial sites along the Norwegian Channel*. Abstracts, Seminar in honour of Prof. Jan Mangerud, University of Bergen, Nov. 2004, p. 39.

Olsen, L., Mejdahl, V. and Selvik, S.F. (1996a) Middle and Late Pleistocene stratigraphy, chronology and glacial history in Finnmark, North Norway. *Norges geologiske undersøkelse Bulletin*, **429**, 1–111.

Olsen, L., Sveian, H. and Bergstrøm, B. (2001b) Rapid adjustments of the western part of the Scandinavian ice sheet during the Mid- and Late Weichselian – a new model. *Norsk Geologisk Tidsskrift*, **81**, 93–118.

Olsen, L., Bergstrøm, B., Reite, A. and Sveian, H. (2001d) Ice-sheet variations during the Late Weichselian in Norway. Norsk Geologisk Forenings XVII. Vinterkonferanse, Oslo, 2001. *Geonytt*, **1**, 88.

Olsen, L., Sveian, H., Bergstrøm, Ottesen, D. and Rise, L. (2013) Quaternary glaciations and their variations in Norway and on the Norwegian continental shelf. *Norges geologiske undersøkelse, Special Publication,* **13**, 27–78.

Olsen, L., Hamborg, M., Bargel, T.H. and Alstadsæter, I. (1987) Enontekiø. Quaternary geological map, scale 1:250,000, air-photo interpreted, with description (in Norwegian). Abstract. *Geological Survey of Norway*.

Olsen, L., Reite, A., Riiber, K. and Sørensen, E. (1996b) Finnmark fylke, løsmassegeologisk kart i M 1:500.000 (med beskrivelse). *Norges geologiske undersøkelse*.

Olsen, L., Sveian, H., Bergstrøm, B. and Riiber, K. (2005) Kvartærgeologisk kartlegging i Øsfold – M 1:125. 000 og 1:250.000. *NGF Abstracts and Proceedings*, **1**, 90–91.

Olsen, L., Sveian, H., Bergstrøm, B., Selvik, S.F., Lauritzen, S.-E., Stokland, Ø. and Grøsfjeld, K. (2001c) Methods and stratigraphies used to reconstruct Mid- and Late Weichselian palaeoenvironmental and palaeoclimatic changes in Norway. *Norges geologiske undersøkelse Bulletin*, **438**, 21–46.

Olsen, L., Sveian, H., Rokoengen, K. and Solberg, I.-L. (2007) The Allerød–Younger Dryas ice-front oscillations in the Trondheim region, Sør-Trøndelag, Norway. *NGF Abstracts and Proceedings*, **1**, 72–73.

Olsen, L., Sveian, H., van der Borg, K., Bergstrøm, B. and Broekmans, M. (2002) Rapid and rhytmic ice sheet fluctuations in western Scandinavia 15–40 Kya – a review. *Polar Research*, **21**, 235–242.

Olsen, L., van der Borg, K., Bergstrøm, B., Sveian, H., Lauritzen, S.-E. and Hansen, G. (2001a) AMS radiocarbon dating of glacigenic sediments with low organic content – an important tool for reconstructing the history of glacial variations in Norway. *Norsk Geologisk Tidsskrift*, **81**, 59–92.

Ottesen, D., Dowdeswell, J.A., Rise, L., Rokoengen, K. and Henriksen, S. (2002) Large-scale morphological evidence for past ice-stream flow on the Norwegian continental margin. *In* Dowdeswell, J.A. and Ó Cofaigh, C. (Eds.): Glacier-Influenced Sedimentation on High-Latitude Continental Margins. *Geological Society London, Special Publication*, **203**, 245–258.

Ottesen, D., Dowdeswell, J.A. and Rise, L. (2005a) Submarine landforms and the reconstruction of fast-flowing ice streams within a large Quaternary ice sheet: The 2500-km-long Norwegian–Svalbard margin (57°–80°N). *Geological Society of America Bulletin*, **117**, 1033–1050.

Ottesen, D., Rise, L., Andersen, E.S., Bugge, T. and Berg, K. (2007) Ice-sheet dynamics, land erosion and large-scale depositional pattern on the adjacent mid-Norwegian shelf during the last 3 million years. *NGF Abstracts and Proceedings*, **1**, 74–75.

Ottesen, D., Rise, L., Andersen, E.S., Bugge, T. and Eidvin, T. (2009) Geological evolution of the Norwegian continental shelf between 61°N and 68°N during the last 3 million years. *Norwegian Journal of Geology*, **89**, 251–265.

Ottesen, D., Rise, L., Knies, J., Olsen, L. and Henriksen, S. (2005b) The Vestfjorden – Trænadjupet palaeo-ice stream drainage system, mid-Norwegian continental shelf. *Marine Geology*, **218**, 175–189.

Ottesen, D., Rise, L., Rokoengen, K. and Sættem, J. (2001) Glacial processes and large-scale morphology on the mid-Norwegian continental shelf. *In* Martinsen, O. and Dreyer, T. (Eds.): Sedimentary environments offshore Norway – Palaeozoic to Recent. N*orwegian Petroleum Society Special Publications*, **10**, 441–449.

Paus, Aa., Velle, G., Larsen, J., Nesje, A. and Lie, Ø. (2006) Lateglacial nunataks in central Scandinavia: Biostratigraphical evidence for ice thickness from Lake Flåfattjønn, Tynset, Norway. *Quaternary Science Reviews*, **25**, 1228–1246.

Påsse, T. and Andersson, L. (2005) Shore-level displacement in Fennoscandia calculated from empirical data. *Geologiska Föreningens i Stockholm Förhandlingar*, **127**, 253–268.

Rasmussen, A. (1981) The deglaciation of the coastal area NW of Svartisen, northern Norway. *Norges geologiske undersøkelse*, **369**, 1–31.

Rasmussen, A. (1984) *Quaternary studies in Nordland, North Norway*. Unpublished Dr. Sc. Thesis, University of Bergen, 29 pp.

Raunholm, S., Larsen, E. and Sejrup, H.P. (2003, and references therein) Weichselian sediments at Foss-Eikeland, Jæren (southwest Norway): sea-level changes and glacial history. *Journal of Quaternary Science*, **17**, 241–260.

Raunholm, S., Larsen, E. and Sejrup, H.P. (2004) Weichselian interstadial sediments on Jæren (SW Norway) – paleo environments and implications for ice sheet configuration. *Norwegian Journal of Geology*, **84**, 91–106.

Rea, B.R., Whalley, W.B., Rainey, M.M. and Gordon, J.E. (1996) Blockfields, old or new? Evidence and implications from some plateaus in northern Norway. *Geomorphology*, **15**, 109–121.

Reille, M., Andrieu, V., de Beaulieu, J. L., Guenet, P. and Goeury, C. (1998) A longpollen record from Lac du Bouchet, Massif Central, France: For the period ca. 325–100 ka BP (OIS 9c to OIS 5e). *Quaternary Science Reviews*, **17**, 1107–1123.

Reite, A.J. (1990) Sør-Trøndelag fylke. Kvartærgeologisk kart M 1:250.000. Veiledning til kartet. *Norges geologiske undersøkelse Skrifter*, **96**, 1–39.

Reite, A.J. (1994) Weichselian and Holocene geology of Sør-Trøndelag and adjacent parts of Nord-Trøndelag county, Central Norway. *Norges geologiske undersøkelse Bulletin*, **426**, 1–30.

Reite, A.J. (1995) Deglaciation of the Trondheimsfjord area, Central Norway. *Norges geologiske undersøkelse Bulletin*, **427**, 19–21.

Reite, A.J., Sveian, H. and Erichsen, E. (1999) Trondheim fra istid til nåtid -landskaps-historie og løsmasser. *Norges geologiske under søkelse, Gråsteinen*, **5**, 40 pp.

Riiber, K. and Bergstrøm, B. (1990) Aust-Agder fylke. Kvartærgeologisk kart – M 1:250.000. Norges geologiske undersøkelse.

Riiber, K., Olsen, L. and Sveian, H. (1991) Lierne kommune. Foreløpig løsmassekart i M 1:100.000. *Norges geologiske undersøkelse*.

Riis, F. (1996) Quantification of Cenozoic vertical movements of Scandinavia by correlation of morphological surfaces with offshore data. *Global and Planetary Change*, **12**, 331–357.

Rise, L. and Rokoengen, K. (1984) Surficial sediments in the Norwegian sector of the North Sea between between 60°30' and 62°N. *Marine Geology*, **58**, 287–317.

Rise, L., Olesen, O., Rokoengen, K., Ottesen, D. and Riis, F. (2004) Mid-Pleistocene ice drainage pattern in the Norwegian Channel imaged by 3D seismic. *Quaternary Science Reviews*, **23**, 2323–2335.

Rise, L., Ottesen, D., Berg, K. and Lundin, E. (2005a) Large-scale development of the mid-Norwegian margin during the last 3 million years. *Marine and Petroleum Geology*, **22**, 33–44.

Rise, L., Ottesen, D., Larsen, E., Lundin, E., Olsen, L. and Thorsnes, T. (2002) Large scale development of the mid-Norwegian shelf and margin with emphasis on the last 3 million years. *NGU Report 2002.015*, Rev. 1, 200 pp.

Rise, L., Ottesen, D., Olesen, O., Longva O. and Nygård A. (2005b) *The Norwegian Channel – an important glacial drainage route to the shelf edge during the Pleistocene*. Poster presentation. International conference on Glacial Sedimentary Processes and Products, August 22–27, 2005, University of Wales, Aberystwyth, abstract volume, p.118.

Rise, L., Ottesen, D., Longva, O., Solheim, A., Andersen, E.S. and Ayers, S. (2006) The Sklinnadjupet slide and its relation to the Elsterian glaciation on the mid-Norwegian margin. *Marine and Petroleum Geology*, **23**, 569–583.

Rise, L., Rokoengen, K., Skinner, A.C. and Long, D. (1984) Nordlige Nordsjø. Kvartærgeologisk kart mellom 60°30' og 62°N og øst for 1°Ø – M 1:50.000. Continental Shelf Institute (IKU), Trondheim in cooperation with British Geological Survey, Edinburgh.

Rokoengen, K. and Frengstad, B. (1999) Radiocarbon and seismic evidence of ice-sheet extent and the last deglaciation on the mid-Norwegian continental shelf. *Norsk Geologisk Tidsskrift*, **79**, 129–132.

Rokoengen, K., Bell, G., Bugge, T., Dekko, T., Gunleiksrud, T., Lien, R., Løfaldli, M. and Vigran, J.O. (1977) Prøvetakning av fjellgrunn og løsmasser utenfor deler av Nord-Norge. *Continental Shelf Institute (IKU) Publication*, **91**, 67 pp.

Rokoengen, K., Bugge, T. and Løfaldli, M. (1979) Quaternary geology and deglaciation of the continental shelf of Troms, north Norway. *Boreas*, **8**, 217–227.

Rokoengen, K., Gulliksen, S., Løfaldli, M., Rise, L. and Sejrup, H.P. (1993b) Distribution of 30,000 year–old sand deposits in the northern North Sea. *Norges geologiske undersøkelse Bulletin*, **424**, 13–21.

Rokoengen, K., Olsen, L. and Selvik, S.F. (1993a) Sub-till sediments at Rokoberget, southeastern Norway. *Norges geologiske undersøkelse Bulletin*, **424**, 1–12.

Ronnert, L., Svedhage, K. and Wedel, P.O. (1992) Luminescence dates of pre-Late Weichselian reddish-brown clay in the south of the Middle Swedish End-Moraine Zone. *Geologiska Föreningens i Stockholm Förhandlingar*, **114**, 323–325.

Satkunas, J. and Grigiené, A. (1996) *Correlation of stratigraphic events of Upper Pleistocene in Central and Peripheral Parts of the Last Glaciation*. Excursion guide of the international workshop in Lithuania, October 3–6, 1996. Geological Survey of Lithuania. Vilnius.

Sejrup, H.P. (1987) Molluscan and foraminiferal biostratigraphy of an Eemian – Early Weichselian section on Karmøy, southwestern Norway. *Boreas*, **16**, 27–42.

Sejrup, H.P. and Knudsen, K.L. (1993) Paleoenvironments and correlations of interglacial sediments in the North Sea. *Boreas*, **22**, 223–235.

Sejrup, H.P., Aarseth, I., Haflidason, H., Løvlie, R., Bratten, Å., Tjøstheim, G., Forsberg, C. F. and Ellingsen, K. I. (1995) Quaternary of the Norwegian Channel: glaciation history and palaeoceanography. *Norsk Geologisk Tidsskrift*, **75**, 65–87.

Sejrup, H.P., Aarseth, I. and Haflidason, H. (1991) The Quaternary succession in the northern North Sea. *Marine Geology*, **101**, 103–111.

Sejrup, H.P., Haflidason, H., Aarseth, I., Forsberg, C.F., King. E., Long, D. and Rokoengen, K. (1994) Late Weichselian glaciation history of the northern North Sea. *Boreas*, **23**, 1–13.

Sejrup, H.P., King, E.L., Aarseth, I., Haflidason, H. and Elverhøi, A. (1996) Quaternary erosion and depositional processes: western Norwegian fjords, Norwegian Channel and North Sea Fan. *Geological Society of London*, **117**, 187–202.

Sejrup, H.P., Landvik, J.Y., Larsen, E., Janocko, J., Eiriksson, J. and King, E.L. (1998) The Jæren area, a border zone of the Norwegian Channel Ice Stream. *Quaternary Science Reviews*, **17**, 801–812.

Sejrup, H. P., Larsen, E., Haflidason, H., Berstad, I. M., Hjelstuen, B., Jonsdottir, H., King, E. L., Landvik, J., Longva, O., Nygård, A., Ottesen, D., Raunholm, S., Rise, L. and Stalsberg, K. (2003) Configuration, history and impact of the Norwegian Channel Ice Stream. *Boreas*, **32**, 18–36.

Sejrup, H.P., Iversen, M., Larsen, E., Landvik, J.Y. and Janocko, J. (1999) A stage 7 marine interglacial record (the Grødeland Interglacial) on Jæren, southwestern Norway; foraminiferal, stable isotopes and amino acid evidence. *Boreas*, **28**, 326–346.

Sejrup, H.P., Larsen, E., Landvik, J., King, E. L., Haflidason, H. and Nesje, A. (2000) Quaternary glaciations in southern Fennoscandia: evidence from southwestern Norway and the North Sea region. *Quaternary Science Reviews*, **19**, 667–685.

Shackleton, N.J. (1987) Oxygen Isotopes, ice volume and sea level. *Quaternary Science Reviews*, **6**, 183–190.

Šibrava, V. (1986) Correlation of European Glaciations and their Relation to the Deep-Sea Record. *Quaternary Science Reviews*, **5**, 433–442.

Sindre, E. (1979) Eem-avsetning i Vossestrand, Hordaland. Abstract. *Norsk Geologisk Forening, Geolognytt*, **12**, 19.

Sollid, J.-L. and Reite, A.J. (1983) The last glaciation and deglaciation of Central Norway. *In* Ehlers, J. (Ed.): *Glacial deposits in northwest Europe*, 41–60. A.A. Balkema, Rotterdam.

Sollid, J.-L. and Sørbel, L. (1979) Deglaciation of western Central Norway. *Boreas*, **8**, 233–239.

Sollid, J.-L. and Sørbel, L. (1994) Distribution of glacial landforms in southern Norway in relation to the thermal regime of the last continental ice sheet. *Geografiska Annaler*, **76A**, 25–35.

Sollid, J.-L., Andersen, S., Hamre, N., Kjeldsen, O., Salvigsen, O., Sturød, S., Tveitå, T. and Wilhelmsen, A. (1973) Deglaciation of Finnmark, North Norway. *Norsk Geografisk Tidsskrift*, **27**, 233–325.

Stalsberg, K., Larsen, E., Ottesen, D. and Sejrup, H.P. (2003) Middle to Late Weichselian ice stream deposits and morphology on Jæren, south-western Norway and eastern North Sea area. *Boreas*, **32**, 149–166.

Sutinen, R. (1984) On the glacial stratigraphy in Pudasjärvi area, Peräpohjola. *In* Königsson, L.-K. (Ed.): *Ten years of Nordic till research. Striae*, **20**, 91-94.

Sveian, H. (1997) Ice-marginal deposits and deglaciation chronology in Nord-Trøndelag and Fosen, Central Norway. *Norges geologiske undersøkelse Bulletin*, **433**, 52–53.

Sveian, H. and Olsen, L. (1991) 12.500 år gamle bein av grønlandshval – brikker i et geologisk "puslespill". *Norges geologiske undersøkelse, Årsmelding 1991*, 22–23.

Sveian, H. and Rø, G. (2001) Kvartærgeologi i Selbu og Tydal. *In* Rø, G. (red.): *Selbu og Tydal – geologi, gruvedrift og kulturminner*. Turbok. Selbu og Tydal Historielag, pp.11–52.

Sveian, H. and Solli, A. (1997) Tid og form – geologisk historie. *In* Dahl, R., Sveian, H. and Thoresen, M. (red.): *Nord-Trøndelag* *og Fosen - Geologi og landskap*, pp. 110–134. Norges geologiske undersøkelse.

Sveian, H., Aa, A.R. and Kjærnes, P. (1979) Isbevegelser og isavsmeltning i den sentrale delen av Saltfjellet, Nordland, Nord-Norge. *Norges geologiske undersøkelse*, **348**, 1–20.

Sveian, H., Reite, A. and Olsen, L. (2000) The elevation of the Younger Dryas ice surface in the Røros-Folldal area; two contradiction models. *In: NORPAST, Past climates of the Norwegian Region*. Abstracts. Internal report, Botanical and Geological Institutes, University of Bergen.

Sveian, H., Riiber, K., Bergstrøm, B. and Reite, A. (2005) Troms fylke, løsmassekart M 1: 310.000. *Norges geologiske undersøkelse*.

Svendsen, J.I. and Mangerud, J. (1987) Late Weichselian and Holocene sea-level history for a cross-section of western Norway. *Journal of Quaternary Science*, **2**, 113–132.

Svendsen, J.I., Alexanderson, H., Astakhov, V.I., Demidov, I., Dowdeswell, J.A., Funder, S., Gataullin, V., Henriksen, M., Hjort, C., Houmark-Nielsen, M., Hubberten, H.W., Ingólfsson, Ó., Jakobsson, M., Kjær, K.H., Larsen, E., Lokrantz, H., Lunkka, J.P., Lyså, A., Mangerud, J., Matioushkov, A., Murray, A., Möller, P., Niessen, F., Nikolskaya, O., Polyak, L., Saarnisto, M., Siegert, C., Siegert, M.J., Spielhagen, R.F. and Stein, R. (2004) Late Quaternary ice sheet history of northern Eurasia. *Quaternary Science Reviews*, **23**, 1229–1271.

Sættem, J., Rise, L., Rokoengen, K. and By, T. (1993) Glacial influence on geotechnical properties. A case study of complex variations of shear strength and consolidation at the Smørbukk Field off Mid-Norway. Proceedings 4th Canadian Marine Geotechnical Conference, 1993. *St. John's Newfoundland, Canada*, **3**, 1140–1162.

Sættem, J., Rise, L. and Westgaard, D.A. (1992) Composition and properties of glacigenic sediments in the southwestern Barents Sea. *Marine Geotechnology*, **10**, 229–255.

Sørensen, R. (1979) Late Weichselian deglaciation in the Oslofjord area, south Norway. *Boreas*, **8**, 241–246.

Sørensen, R. (1983) Glacial deposits in the Oslofjord area. *In* Ehlers, J. (Ed.): *Glacial Deposits in North-west Europe*, pp. 19–27. Balkema, Rotterdam.

Sørensen, R. (1992) The physical environment of Late Weichselian deglaciation of the Oslofjord region, southeastern Norway. *Sveriges Geologiska Undersökning*, **Ca 81**, 339–346.

Sørensen, R. (1999) En ^{14}C datert og dendrokronologisk kalibrert strandforskyvningskurve for søndre Østfold, Sørøst-Norge. *AmS-Rapport*, **12A**, 227–242.

The Nordkalott Project (1986) Map of Quaternary geology, Northern Fennoscandia, sheet 4. *Geological Surveys of Finland, Norway and Sweden*.

The Mid-Norden Project (1999) Map of Quaternary geology, Central Fennoscandia, sheet 3. *Geological Surveys of Finland, Norway and Sweden*.

Thieme, H. (1999) Jagd auf Wildpferde vor 400,000 Jahren. Fundplätze aus der Zeit des Urmenschen (Homo erectus) im Tagebau Schöningen, Landkreis Helmstedt. *In* Boetzkes, M., Schweitzer, I. and Vespermann, J. (Eds.): *Eiszeit*, 122–136. Stuttgart.

Thoresen, M. (1990) Quaternary map of Norway, scale 1:1 million, with description (in Norwegian). Summary. *Geological Survey of Norway*.

Thoresen, M.K., Lien, R., Sønstegaard, E. and Aa, A.R. (1995) Hordaland fylke, kvartærgeologisk kart M 1: 250.000. *Norges geologiske undersøkelse*.

Thoresen, M. and Bergersen, O.F. (1983) Sub-till sediments in Folldal, Hedmark, Southeast Norway. *Norges geologiske undersøkelse*, **389**, 37–55.

Urban, B. (1997) Grundzüge der eiszeitlichen Klima- und Vegetations-geschichte in Mitteleuropa. *In* Wagner, G. A. and Beinhauer, K. W. (Eds.): *Homo Heidelbergensis von Mauer – Das Auftreten des Menschen in Europa*, 241–263. HVA Heidelberg.

Valen, V., Larsen, E., Mangerud, J. and Hufthammer, A.K. (1996) Sedimentology and stratigraphy in the cave Hamnsundhelleren, western Norway. *Journal of Quaternary Science*, **11**, 185–201.

Valen, V., Lauritzen, S.E. and Løvlie, R. (1997) Sedimentation in a high-latitude karst cave: Sirijordgrotta, Nordland, Norway. *Norsk Geologisk Tidsskrift*, **77**, 233–250.

Vorren, T.O. (1972) Interstadial sediments with rebedded interglacial pollen from inner Sogn, west Norway. *Norsk Geologisk Tidsskrift*, **52**, 229–240.

Vorren, K.-D. (1978) Late and Middle Weichselian stratigraphy of Andøya, north Norway. *Boreas*, **7**, 19–38.

Vorren, T.O. (1979) Weichselian ice movements, sediments and stratigraphy on Hardangervidda, South Norway. *Norges geologiske undersøkelse*, **350**, 1–117.

Vorren, T.O. and Kristoffersen, Y. (1986) Late Quaternary glaciation in the south-western Barents Sea. *Boreas*, **15**, 51–59.

Vorren, T.O. and Laberg, J.S. (1997) Trough mouth fans – palaeoclimate and ice-sheet monitors. *Quaternary Science Reviews*, **16**, 865–881.

Vorren, T.O. and Mangerud, J. (2006) Istider kommer og går. Kapittel 15 (478–555) i Ramberg, I.B., Bryhni, I. and Nøttvedt, A. (red.): *"Landet blir til. Norges geologi."* Norsk Geologisk Forening, Trondheim. 608 pp.

Vorren, T.O. and Plassen, L. (2002) Deglaciation and palaeoclimate of the Andfjord–Vågsfjord area, North Norway. *Boreas*, **31**, 97–125.

Vorren, T.O. and Roaldset, E. (1977) Stratigraphy and lithology of Late Pleistocene sediments at Møsvatn, Hardangervidda, South Norway. *Boreas*, **6**, 53–69.

Vorren, T.O., Corner, G.D. and Nagy, J. (1981) Weichselian sediments containing redeposited interstadial /interglacial fossils at Slettaelva, North Norway. *Boreas*, **19**, 477–484.

Vorren, T.O., Hald, M., Edvardsen, M. and Lind-Hansen, O.-W. (1983) Glacigenic sediments and sedimentary environments on continental shelves: General principles with a case study from the Norwegian shelf. *In* Ehlers, J. (Ed.): *Glacial deposits in North-West Europe, 61–73*. A.A. Balkema, Rotterdam.

Vorren, T.O., Laberg, J.S., Blaume, F., Dowdeswell, J.A., Kenyon, N.H., Mienert, J., Ruhmohr, J. and Werner, F. (1998) The Norwegian–Greenland Sea continental margins: morphology and Late Quaternary sedimentary processes and environment.

Quaternary Science Reviews, **17**, 273–302.

Vorren, T.O., Lebesbye, E. and Larsen, K.B. (1990) Geometry and genesis of the glacigenic sediments in the southern Barents Sea. *In* Dowdeswell, J.A. and Scourse, J.D. (Eds.): Glacimarine environments: processes and sediments. *Geological Society of London, Special Publication*, **53**, 269–288.

Vorren, T.O., Vorren, K.-D., Alm, T., Gulliksen, S. and Løvlie, R. (1988) The last deglaciation (20,000 to 11,000 B.P.) on Andøya, northern Norway. *Boreas*, **17**, 41–77.

Zagwijn, W.H. (1992) The beginning of the ice age in Europe and its major subdivisions. *Quaternary Science Reviews*, **11**, 583–591.

Østmo, S.R. (1976) Gardermoen, kvartærgeologisk kart CQR O51052–20. *Norges geologiske undersøkelse*.

Appendix A

Principles for stratigraphical correlations used in northern and central Fennoscandia

A general stratigraphical model was established for northern Fennoscandia in the Nordkalott Project (Hirvas et al. 1988) (Figure A1) and modified and extended to central Fennoscandia in the Mid-Norden Project (Bargel et al. 1999). The main basis for correlations is general till stratigrahic data and dates of intercalated deposits from interstadial/ice-free intervals (e.g., Hirvas et al. 1988, Bargel et al. 1999). The age assignments are mainly based on luminescence (TL and OSL) dates of sediments from the last interglacial/glacial cycle, and stratigraphical position with respect to the dated units. The age model (Figure 11, main text) for the glacier fluctuations is based on dates from inland sites, with the implication that a TL or OSL dated ice-free unit indicates regional ice-free conditions and not only a minor ice-marginal retreat from a moderate to major ice extension.

The dates are not corrected for shallow traps, which previously were supposed to underestimate the ages, at least those of 100 ka or more with as much as 35% (Olsen et al. 1996a). The need for such corrections is so far not shown to be valid for sediments in Fennoscandia (Olsen in Lokrantz and Sohlenius 2006). However, a possible general underestimation of *c.*10% of older ages (>100 ka) should clearly be considered, in agreement with recent results from dating accuracy testing of OSL dates from northern Russia (Murray et al. 2007) and farther south in Europe (e.g., in Germany). The luminescence age intervals of the general age model overlap fairly well with most 'warm' isotope stages (Figure 11, main text), and indicate a much better matching with the MIS boundaries than if a general underestimation of ages is included (stippled curve in Figure 11, main text), but MIS 5a seems to be less well represented by luminescence dates. Alternatively, the luminescence age interval representing MIS 5a is 10 kyr younger (underestimated) than the orbitally tuned MIS 5a age boundaries after Martinson et al. (1987).

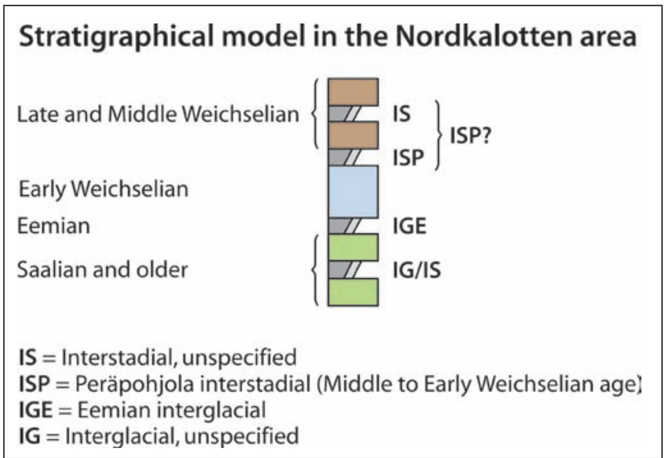


Figure A1: Generalised Quaternary stratigraphical model for northern Fennoscandia (The Nordkalott Project 1986).

The till stratigraphy of Finland, as represented by the till beds named Till 1 (youngest) to Till 6 (oldest), and the intercalated sediment units, is used as a stratigraphical framework for the whole inland area of northern and central Fennoscandia. The updated version of the stratigraphical framework is given in Table A1.

The key unit to recognise for correlation in each studied area is the regional till bed no. 3 (Till 3, which is of Early Weichselian age) counted from the top, with its lithological properties, clast fabric and stratigraphical relationship to the most prominent glacial landforms (for example, this till appears morphologically as NW–SE-oriented megascale drumlins in northern Sweden), and to the other recorded typical regional glacial and nonglacial units. Till 3 is assigned an age of MIS 5d (Hirvas et al. 1988, Olsen 1988, Hirvas 1991, Nenonen 1995, Olsen et al. 1996a) or 5b, as indicated from the studies in the Sokli area, northeastern Finland, by Helmens et al. (2000).

However, based on the complexity of the stratigraphy and variation of the lithology of this region it is tempting to suggest that there are two Till 3 units of which one correlates with 5d and the other with 5b. A two-substage model for Till 3 seems to be the best-fit choice to explain all the reported, relevant observations and may now be regarded as a working hypothesis (Larsen et al. 2005).

Interglacial organic beds (peat, gyttja) have been found between Tills 3 and 4, and they have all been correlated to the last interglacial, the local Tepsankumpu and the regional northwest-European Eemian interglacial (MIS 5e), whereas those found between Tills 4 and 5, at one site only (Naakenavaara, Kittilä), must be older than the Eemian. The interglacial deposits in northern Finland cannot be distinguished merely on a palynological basis (Hirvas 1991), so a correlation based on these beds must also consider their stratigraphical relationships to the regional till beds, and dates (if available).

Organic deposits from two forested Early Weichselian interstadials and one Middle Weichselian interstadial characterised by tundra vegetation are recorded in a stratigraphical succession at Sokli, northern Finland (Helmens et al. 2000). All these deposits are separated and overlain by a till bed. Only inorganic waterlain sediments have been found between Tills 1 and 2 in Finland so far (Hirvas 1991).

The stratigraphical correlation of Tills 1–3 between northern Finland and Finnmarksvidda, northern Norway, is carried out directly based on a collaborative excavation–based fieldwork, using the same methods in both areas (Olsen 1988). Consequently, the correlation between the (youngest) Saalian tills, named Till 4 in northern Finland and Tills 4–5 in northern

Table A1: Stratigraphical framework for northwest Europe, with special emphasis on northern and central Fennoscandia. Modified from Larsen et al. (2005).

		Marine isotope stage	Stratigraphic units/phases used at a national scale		
Stage	**Substage**	**MIS**	*Finland*	*Sweden*	Norway
Weichselian	LGM	2	Tills 1 and 2	Tills 1 and 2	Tills 1 and 2
	Younger Middle Weichelian interstadials	3	Y. MW interst.(?)	Tärendö interst., younger phase (?)	Sargejohka interst., younger phase
	Younger MW stadial	3	Till 2, middle	Till 2, middle (?)	Till 2, middle
	Older MW interstadial	3	MW interstadial, type Sokli	Tärendö interst.	Sargejohka interst., older phase
Average age;	Older MW stadial	4	Till 2, older type Sokli	Till 2, older	Till 2, older
	Odderade interstadial (Early Weichselian)	5a	Y. EW interstadial, type Sokli	Jämtland interstadial, younger phase	Eiravarri interstadial, younger phase
	Younger EW stadial	5b	Till 3, younger, type Sokli	Cold phase	Glacial deformation, type Vuolgamasjohka
	Brørup interstadial	5c	O. EW interstadial, type Sokli	Jämtland interstadial, older phase	Eiravarri interstadial, older phase
	Older MW stadial	5d	Till 3, older (not found at Sokli)	Till 3	Till 3
Eemian interglacial	Eemian interglacial	5e	Tepsankumpu Eemian interglacial	Leväaniemi Eemian interglacial	Eemian interglacial palaeosol, Sargejohka
Saalian *(sensu stricto)*	Warthe and Drenthe stadials	6	Till 4	Till 4	Tills 4 and 5
Saalian Complex *(sensu lato)*	Wacken–Dömnitz–Schöningen interglacial	7	Naakenavaara interglacial	Oje interglacial	Bavtajohka interglacial
	Cold phase; Fuhne	8	Till 5	–	Till 6
	Warm phase; Reinsdorf interglacial	9	Deglaciation phase between tills 5 and 6	–	Palaeosol 5, Sargejohka
	Cold phase (stadial)	10	Till 6	–	Till 7
Holsteinian interglacial	Holsteinian interglacial	11	–	–	Palaeosol 6, Sargejohka
Elsterian	Elsterian	12	–	–	Degl. sediments, unit K, Sargejohka

Norway, seems like a best choice since these tills in both areas occur between interglacial deposits of which the youngest represents the Eemian. The uncertainties are mainly connected to the underlying beds.

Based on counting from the top, stratigraphical relationship to other recorded regional events and luminescence dates the Bavtajohka interglacial from Finnmarksvidda is inferred to correlate with MIS 7, possibly an early part of the stage (MIS 7e) (Appendix B, Table B2) (Olsen et al. 1996a), but a recent re-evaluation of the dates suggests a correlation with a later part, i.e., MIS 7a–7c (Figure 14, main text). Moreover, the stratigraphical position suggests also a correlation with the Naakenavaara interglacial from northern Finland. The overall pollen signature from these interglacials does not disprove such a correlation (Hirvas 1991, Olsen et al. 1996a). If this correlation is correct, then it follows that Till 6 from Finnmarksvidda correlates most likely with Till 5 from northern Finland and, furthermore, that Till 7 from Finnmarksvidda correlates with the Finnish Till 6 (Table A1).

Overview and summary of the Weichselian glacial deposits (described chronologically and from north to south)

Glacial deposits from the Early to Mid Weichselian (MIS 5 to 3)

Tills deposited during a MIS 5d glaciation (*c. *100–110 ka)

No deposits from Weichselian glacial advances prior to LGM 2 have been recorded on Varangerhalvøya, northern and eastern parts, so far, e.g., (1) at Komagelva (Figure 22b, main text), late Saalian–Eemian sand is directly overlain by late Weichselian gravel and LGM 2 or younger till and deglaciation sediments, and (2), at Leirelva, pre-Weichselian gravel is overlain by late Weichselian ice-dammed sediments and LGM 2 or younger till and deglaciation sediments (Olsen et al. 1996a).

MIS 5d ice flowing eastwards and southwards from the mountains deformed Eemian sediments on Finnmarksvidda, but no till from this phase is found so far in this area. The older part of Till 3 in the inland of northern Fennoscandia is assumed to be of MIS 5d age (see above). Maximum ice extension during 5d has probably reached almost, but not completely the inner fjord areas of southern Troms and mid-Nordland, because speleothems grew continuously from the Eemian to *c.* 100 ka in Stordalsgrotta (920 m a.s.l., Stordalen, southern Troms) (Figure 4, main text) and to *c.* 90 ka in mid-Nordland (Fauske–Rana area), and were abruptly ended at these times.

The MIS 5d ice reached almost to Fjøsanger (Bergen) in the west and deposited sediments that demonstrated a glacial climate during the Gulstein stadial (Mangerud et al. 1981b) (Figure 28, main text, silt G), and it deposited till beds (Tills P–Q) at Dalseng (Brumunddalen) in southeast Norway (Figure 32a) (Helle 1978) and probably reached the Oslofjord area.

Tills deposited during a MIS 5b glaciation (*c. *85–90 ka)

The Gardejohka till on Finnmarksvidda, and the younger part of Till 3 in large areas in the inland of northern Fennoscandia, including the Sokli area in northeast Finland, are now reconsidered to have been deposited by a MIS 5b ice (Helmens et al. 2000, Larsen et al. 2005, Olsen 2006) and not a MIS 5d ice as previously suggested (Hirvas et al. 1988, Olsen et al. 1996a). The 5b–ice extension may have reached the innermost fjord areas of mid-Nordland since speleothem growth was interrupted there at *c.* 90 ka. However, continuous speleothem growth from the Eemian to 71–73 ka in caves at 160–220 m a.s.l. in the Fauske–Rana area, indicates that the 5b glacier ended at the fjord heads.

The Bønes till at Fjøsanger, in the coastal area close to Bergen, was deposited by a 5b glacier (Mangerud et al. 1981), which must therefore have reached the sea (Norwegian Channel) in the west. The 5b glacier also deposited tills (Tills K–L) at Dalseng in southeast Norway (Helle 1978) and probably reached the Oslofjord area, similar to the 5d glacier.

Tills deposited during a MIS 4 glaciation (*c. *60–70 ka)

The Vuoddasjavri till on Finnmarksvidda, known as Till 2 in large areas in the inland of northern and central Fennoscandia, was deposited by a MIS 4 ice which extended to the coastal zone in the northwest, as indicated by the interrupted speleothem growths at low altitudes in mid-Nordland.

This ice advance seems to have reached beyond Brumunddalen in southeast Norway, as mentioned before and indicated by a U/Th-dating at 59 ka of the Brumunddalen interstadial peat (age indicates time for closure of previous open circulation and thereby starting the 'U/Th-clock'). A till bed (the Karmøy diamicton) at Bø on Karmøy in southwest Norway is also thought to have been deposited during MIS 4 (Andersen et al. 1983, Sejrup 1987), and this glacier must therefore have reached the sea/Norwegian Channel.

The record of ice-rafted detritus (IRD) off the Norwegian coast shows the highest Early to Mid-Weichselian peak at *c.* 55 ka (Baumann et al. 1995), and the IRD input in sandy mud beyond the shelf break west of the Lofoten islands was intense in the earliest part of the interval 63–54 ka (Laberg and Vorren 2004, and pers. comm. 2007), which suggest that the ice extension during MIS 4–3 reached its maximum off the coast to the west and started to retreat at this time.

Tills deposited during a MIS 3 glaciation, older phase (*c. *44–49 cal ka)

MIS 3 ice extension may have reached the outer coast or even offshore in northern Norway, Mid-Norway, southwest Norway, as well as in southeast Norway where the ice advance may have reached almost to Vendsyssel in Denmark (Houmark-Nielsen and Kjær 2003). In the north, glaciomarine sediments with *c.* 44 cal ka shells from several sites in onshore positions, e.g., at Leirhola (Arnøya), in Løksebotn (Salangen) and at Bleik (Andøya, Møller et al. 1992), indicate considerable glacioisostatic depression in a period with generally low global sea level (e.g., Shackleton 1987). This suggests a considerable ice volume in the northwest at or just before 44 cal ka. Sediments from the deglaciation of this ice are recorded and TL dated to 37–41 cal ka on Finnmarksvidda.

Till beds with shells of age *c.* 44 cal ka are recorded several places in Troms, e.g., at many islands, such as Arnøya (Figures 4 and 23, main text), Vanna, Kvaløya, Grytøya and Hinnøya, and also at other sites in the fjord areas. Similar data exist for Nordland, both from sites on islands and in the fjord districts. For example, shell dates from a complex ice-marginal terrace at Skogreina at the coast close to the Arctic Circle indicate a phase with the ice-margin position located at this site at *c.* 44 cal ka (Olsen 2002). Ice dammed/marine sediments with resedimented shell fragments of age *c.* 50 cal ka may indicate a *c.* 44 cal ka ice advance crossing the Hundkjerka cave in Velfjord, southern Nordland (Figures 4 and 26, main text).

In Trøndelag this ice advance may have reached Vikna in the northwest, as indicated by dates of shells in till (Bergstrøm et al. 1994, Olsen et al. 2001a). In Gauldalen south of Trondheim, Mid-Norway, till beds and intertill sediments, which include sediments with partly decomposed marine fossils, contain also plant remains that have been dated (Figures 4 and 27b, main text). These data indicate ice-margin fluctuations in this area several times around *c.* 44 cal ka, as well as younger fluctuations (Olsen et al. 2001b, c).

Ice-dammed sediments in the cave Skjonghelleren at Møre, farther south along the coast, include a geomagnetic signal (in clay L, Figure 28a, main text) which is correlated with the Laschamp excursion (*c.* 42–47 cal ka). Consequently, the ice advanced beyond the coast at Møre *c.* 44 cal ka. The Sandnes interstadial marine and glaciomarine sediments at high altitudes on Høgjæren in southwest Norway are thought to indicate considerable glacioisostatic depression due to a big ice volume close to this area around 44 cal ka. This ice may have been located onshore, as well as in the Norwegian Channel (Larsen et al. 2000).

At Sørlandet in southernmost Norway, and in southeast Norway subtill sediments with marine fossils/other components at high altitudes include *c.* 38–40 cal ka or older plant remains, which also indicate fast deglaciation of a big *c.* 44 cal ka ice.

The Mesna till from Lillehammer, southeast Norway, has been dated to (framed) between 40 and 44–48 cal ka, which points to a *c.* 44 cal ka age for the associated ice advance, which is thought to be represented by till in a wide area in the inland of southeast Norway (Figure 33b, unit A, main text) and may well have reached the coastal area in the southeast.

Glaciotectonics in the Skara area (northeast of Gothenburg, Sweden) are recorded in reddish-brown clay which is TL and OSL dated to *c.* 43 and 45 cal ka (Ronnert et al. 1992). This means that a glacial event existed in southern Sweden around or after *c.* 43–45 cal ka, and before the southerly ice flows during the Late Weichselian glaciation. This glacial event may therefore correspond to a stadial *c.* 44 cal ka, or a younger event.

Glacial deposits from the Late Weichselian (MIS 2)

Tills from MIS 3/2 and MIS 2 glacial fluctuations (c. 34–17 cal ka)

The sedimentary stratigraphies and glacial fluctuations during this period are thoroughly reviewed by Olsen et al. (2001a, b, c). Therefore, this compilation will only briefly mention data known before the year 2001 (e.g., as those indicated in Figure 16, main text) and mainly concentrate on new information from this period, which includes the biggest Weichselian ice-marginal fluctuations. A new understanding of ice-marginal dynamics is represented by the composite glacial curve after Olsen (1997) (see Olsen et al., 2013, fig. 9bc, which is a synthesis of glaciation curves from nine different transects from inland to shelf). It has as one of its implications that precise dating and age estimates of events are even more important for correlations now than before, a time when most glacial geologists believed in glacial stability, with the ice-margin fluctuations during LGM constrained to the shelf to coast area, i.e., in almost maximum position for thousands of years.

Offshore data, including glacial deposits from more than one phase with the ice margin in the maximum position at the shelf edge during the LGM interval, are very scarce, but still represented both in the north and the south. Off Troms and in the southwest Barents Sea area, Vorren et al. (1990) describe deposits from two maximum phases (LGM I and II), separated by an ice-retreat phase. More precise data, representing more than one LGM advance phase are reported from the Andfjorden area, where both marine and terrestrial sediments indicate at least two major Late Weichselian ice advances, that Vorren and Plassen (2002) describe as Egga I and II (here named LGM 1 and 2) as they infer that both these advances reached the shelf edge. These advances were separated by a complex ice-retreat phase, i.e., an overall ice retreat–ice advance (the Bjerka Substage)–ice retreat phase. The Andfjorden area is located at some distance from the shelf edge and therefore its significance for the glacial maximum on the shelf rely fully on Vorren and Plassen's suggested correlations, which the present authors find reasonable.

At the mouth of the Norwegian Channel in the south (Figure 4, main text), Olsen et al. (2004) speculated from adjacent land data that the ice margin may have reached the maximum position at least three times between 29–18.5 cal ka. This was recently confirmed by Nygård et al. (2007) based on data from the North Sea Fan and a conceptual model where debris flows are initiated by the ice front in the maximum position. They found that this occurred three times during the LGM interval (30–19 cal ka).

Till deposits at the coast, e.g., at Arnøya, northern Norway (Andreassen et al. 1985, and new data recorded by NGU) (Figure 23, main text), and ice-dammed sediments in caves at the coast in west Norway (Larsen et al. 1987, Valen et al. 1996) indicate that a regional ice advance *c.* 33–34 cal ka crossed the coastline. It is supposed to have reached its maximum position at least to around halfway to the shelf edge, similar to that indicated for the glacier during MIS 3 (*c.* 44 cal ka) (Olsen et al. 2001b, c).

At Bø on Karmøy, southwest Norway, the upper till (the Haugesund diamicton, Andersen et al. 1983, Sejrup 1987) has recently been subdivided in at least two different tills with intercalated sediments (Figure 30) (Olsen et al. 2004, Olsen and Bergstrøm 2007). The oldest of these tills is framed in age between 38.5 and 27.9 cal ka, whereas the uppermost part of the upper regional till, which was deposited during a regional phase with W-trending drumlins, is younger than 18.6 cal ka.

Seven additional localities to that from Karmøy and to those with indications of LGM-interval oscillations as reported by Olsen et al. (2001a, b, c) have recently been recorded. These are found in different parts of Norway, i.e., one in the north (Arnelund), two in the central areas (Meråker and Kvikne), one in the southwest (Foss–Eikeland, Figure 31), and three in the southeast (Braarød, Korterød and Børsåsen) (Figure 4, Olsen et al. 2004). The uppermost regional till at all these and previously reported Norwegian LGM oscillation-sites, is generally younger than 19–21 cal ka (Olsen et al. 2001a, b, c, Olsen et al. 2004, Olsen and Bergstrøm 2007, Appendix B, Figure B5).

Tills from MIS 2 and early MIS 1 glacial fluctuations (16 cal ka, and younger)

The last ice retreat from the shelf occurred during the beginning of this period, and the surficial till is of this age in most parts of Norway where the ice sheet produced till during general ice retreat. The oldest post-LGM onshore glacial deposits that are recorded so far are listed in Table B11 (Appendix B) (See also fig. 20 in the accompanying paper of 'Quaternary glaciations', this issue).

Much of the surficial tills proximal to the Nordli–Vuku moraines at the fjord heads in Nordland and Trøndelag (Andersen et al. 1995, Sveian 1997) and the corresponding ice margin in other parts of the country may be of early Holocene (Preboreal) age.

Appendix B

Table B1: Name of all geographical places and sites mentioned in the main text, with geographical positions indicated by numbers (and dots) in Figure B1. (a) Sites arranged successively according to their number, and (b) in alphabethical order.

1	Vardø	44	Ørnes	87	Glåmdalen
2	Leirelva, Komagelva	45	Meløya	88	Venabu
3	Straumsnesa, Kongsfjorden	46	Åmøya, Bogneset, Bjærangsfjorden	89	Vinstra, Sorperoa, Gudbrandsdalen
4	Varangerfjorden	47	Grønligrotta	90	Nordfjord
5	Pasvik	48	Hamarnesgrotta	91	Sognefjorden
6	Tanafjorden	49	Mo i Rana	92	Kollsete
7	Risvika	50	Nordland	93	Kroken, (Inner Sogn)
8	Finnmark	51	Røssvatnet	94	Møklebysjøen
9	Porsangerfjorden	52	Hattfjelldal	95	Lillehammer, Mesna, Stampesletta
10	Gamehisjohka	53	Fiskelauselva	96	Øvre Åstbrua
11	Buddasnjarga	54	Hundkjerka, Hommelstø, Velfjorden	97	Dokka
12	Balucohka	55	Vikna, Langstrandbakken	98	Hunndalen
13	Sargejohka	56	Namsen	99	Dalseng, Brumunddal
14	Kautokeino	57	Lierne	100	Rokosjøen, Rokoberget
15	Vuolgamasjohka	58	Steinkjer	101	Bergen, Herdla, Fjøsanger
16	Vuoddasjavri	59	Follafoss	102	Halsnøy
17	Iesjavri	60	Trøndelag	103	Hardangerfjorden
18	Alta	61	Fosenhalvøya	104	Haugesundshalvøya
19	Lauksundet	62	Trondheimsfjorden	105	Karmøy, Bø
20	Leirhola, Arnøya	63	Trondheim	106	Rogaland
21	Vanna	64	Meråker	107	Jæren, Lågjæren, Høgjæren
22	Troms	65	Langsmoen	108	Foss-Eikeland
23	Lyngsalpene	66	Flora, Drivvollen	109	Lysefjorden
24	Kvaløya, Slettaelva	67	Byneset, Hangran	110	Hardangervidda
25	Arnelund, Balsfjorden	68	Grytdal	111	Mårvatn, Mår
26	Senja	69	Hauka	112	Møsvatn, Førnes, Hovden
27	Æråsvatnet, Øvre & Nedre Åsvatnet	70	Skjenaldelva	113	Gardermoen (airport)
28	Andøya, Flesen	71	Frøya, Svellingen, Skarsvågen	114	Oslo
29	Andfjorden	72	Surna	115	Ås, Ski
30	Løksebotn, Salangen	73	Røros	116	Passebekk
31	Vesterålen	74	Kvikne, Kvikneskogen	117	Herlandsdalen, Rundhaugen
32	Grytøya	75	Trollheimen	118	Oslofjorden
33	Hinnøya	76	Oppdal	119	Halden
34	Lofoten	77	Møre, Nordmøre, Sunnmøre	120	Hvaler
35	Langøya	78	Ålesund	121	Jomfruland
36	Narvik	79	Skjonghelleren	122	Skagerak
37	Vestfjorden	80	Hamnsundhelleren	123	Sørlandet
38	Kjøpsvik, Tysfjorden	81	Skorgenes	124	Lista
39	Steigen	82	Lesjaskog		
40	Værøy	83	Galdhøpiggen, Jotunheimen		
41	Røst, Trenyken	84	Dovre		
42	Fauske, Okshola	85	Rondane		
43	Skogreina	86	Jutulhogget		

Table B1: (b) in alphabethical order.

Table B2: Correlation chart for the late Middle Pleistocene stratigraphy from Norway, Germany, and France, and the marine oxygen isotope stratigraphy (MIS). Modified from Olsen et al. (1996a) and Larsen et al. (2005).

Northern Norway Sargejohka (Olsen et al. 1996, Olsen 1998)	**Northern Germany** Wacken (Menke 1968, a.o.)	**Southern Germany** Schöningen (Urban 1997, Thieme 1999)	**Southern France** Velay (Reille et al. 1998)	**MIS**
Weichselian	Weichselian	Weichselian	(Last glaciation, local ice cap)	2–5d
EEMIAN PALEOSOL	EEMIAN	EEMIAN	RIBAINS INTERGLACIAL	5e
Stadial (T4) -	Saale (Drenthe)	Saale (Drenthe)	Costaros glacial	6
interstadial -		BUDDENSTEDT 2	BOUCHET III	7a
stadial (T5)			Belvezet stadial	7b
sediment complex		BUDDENSTEDT 1	BOUCHET II	7c
			Bonnefond stadial	7d
BAVTAJOHKA	WACKEN	SCHÖNINGEN	BOUCHET I INTERGLACIAL	7e
Glacial (T6)	Fuhne (?)	Fuhne	Charbonnier glacial	8
interstadial			AMARGIER; with ash bed	9a
sediment			Monteil stadial	9b
complex			USSEL	9c
			Cayres stadial	9d
PALEOSOL 5		REINSDORF	BOUCHET I INTERGLACIAL	9e
Glacial (T7)			Bargette glacial	10
		MISSAUE 2 + SU A	JAGONAS 2	11a
			Pradelle 2 stadial	11b
		MISSAUE 1	JAGONAS 1	11c
			Pradelle 1 stadial	11d
PALEOSOL 6	HOLSTEINIAN	HOLSTEINIAN	PRACLAUX INTERGLACIAL	11e
Elsterian deglaciation				
sediments; Sargejohka unit K				
(no till recorded)	Elsterian	Elsterian	Barges glacial	12

Table B3: Maxima in glacier extension of the Fennoscandian ice sheet during the Middle to Late Pleistocene. Late Pleistocene included for comparison. After Larsen et al. (2005).

Glacial Stage	Substage	MIS (marine isotope stage), age (in calendar ka)	Maximum extension–Ice marginal position			
			North	West	South	East
Weichselian	1. YD (Younger Dryas)	Late MIS 2, 11.5–13	Coast, Norway	Coast, Norway	Coast, Norway, and south Sweden inland	South Finland–northwest Russia
	2. LGM 2 (Last glacial max. 2)	MIS 2, 19 (and 18?)	Outer shelf area	Shelf edge–the Norwegian channel	Central Denmark–north Germany–central Poland	Russia, close to Arkhangelsk
	3. LGM 1 (Last glacial max. 1)	MIS 2/3, 26	Shelf edge	Shelf edge–the Norwegian channel	Central Denmark–north Germany–central Poland	NW Russia (?)
	4. Late M.-Weichselian	MIS 3, 32	Inner shelf area	Shelf, possibly shelf edge	Southern Sweden	Finland–NW Russia (?)
	5. Middle Weichselian	Middle MIS 3, 45	Inner shelf area	Middle shelf area	South Sweden–east Denmark–north Germany–Latvia–Estland	NW Russia (?)
	6. Early M.-Weichselian	MIS 4, 65	Outer coastal zone	Outer coastal zone, possibly shelf and Norw. Channel	South Sweden–east Denmark–north Germany–Latvia–Estland	NW Russia (?)
	7. Late E.-Weichselian	MIS 5b, 85	Inner fjord area	Outer coastal zone	Southern Sweden	Pudasjarvi moraines, north Finland–NW Russia
	8. Early E.-Weichselian	MIS 5d, 110	Inner fjord area	Outer fjord area	Gulf of Bothnia	Lapland moraines, north Finland
Saalian (sensu stricto)	9. Younger Late Saalian *(sensu lato)*	MIS 6, 140	Shelf edge	Shelf edge–the Norwegian Channel	South Germany–south Poland–Bela Russia	NW Russia, east of Arkhangelsk
	10. Older Late Saalian *(sensu lato)*	MIS 6, 185	Coast, possibly shelf	Shelf edge–the Norwegian Channel	South Germany–south Poland–Bela Russia	NW Russia, east of Arkhangelsk
Saalian Complex	11. Younger Middle Saalian *(s.l.)*	MIS 8, 260	Shelf, possibly shelf edge	Shelf (?)–the Norw. Ch. (?)	Southern Baltic basin area (?)	Finland–NW Russia (?)
	12. Older Middle Saalian *(s.l.)*	MIS 8(?), 280–320(?)	Coast, possibly shelf area	Middle shelf area	Southern Baltic basin area (?)	Finland–
	13. Early Saalian *(sensu lato)*	MIS 10(?), 350(?)	Shelf, possibly Shelf edge	Shelf edge–the Norw. Channel	Southern Baltic basin area (?)	Finland–NW Russia (?)
(Elsterian?)	14. Pre-Saalian	MIS 12(?), 430(?)	Coast, possibly shelf area	Shelf edge– the Norwegian Channel	South Germany–south Poland–Bela Russia	NW Russia, east of Arkhangelsk

Table B4: N–S distribution of stratigraphic sites.

Number of localities from various age intervals, in (A) North Norway, (B) Mid-Norway (between Mosjøen and Ålesund), and (C) South Norway				
Age	**A**	**B**	**C**	**Total**
Pre-Eemian	6	2	3	11
Eemian	11	5	11	27
Early Middle Weichselian/ Early Weichselian	12	2	9	23
Early Middle Weichselian	15	8	10	33
Late Middle Weichselian	14	17	18	49
LGM interval	11	17	13	41
Post LGM– pre Older Dryas	4	6	2	12
Lateglacial	common	common	common	many
Holocene	common	common	common	many

Table B5: Pre-Eemian sites, most of these (8 of 11 sites) include Eemian sediment or palaeosol as an upper reference horizon.

Locality		Stratigraphy	Comments
1.	Leirelva, Finnmark, Northern Norway	Late Weichsel. till and sediment/ older sediments	TL-dating: 370 ka => possibly Saalian age sediment
2.	Gamehisjohka, Finnmarksvidda	Eemian sediment/till/sand	Till and sand of probably Saalian age (MIS 6)
3.	Buddasnjarga, Finnmarksvidda	Eemian sediment/till	Till of probably Saalian age
4.	Sargejohka, Finnmarksvidda	Eemian palaeosol/multiple tills and sediment units	Tills and sediment of pre-Eemian, probably MIS 6–11 age
5.	Vuoddasjavri, Finnmarksvidda	Eemian sediment/multiple tills and sediment units	Tills and sediments of pre-Eemian, probably Saalian age
6.	Vuolgamasjohka, Finnmarksvidda	Eemian palaeosol/sediment/ till	Till of pre-Eemian, probably Saalian age (MIS 6)
7.	Skarsvågen, Frøya, Mid-Norway	Eemian marine sediment/ till	Till of pre-Eemian, probably Saalian age (MIS 6)
8.	Ålesund (e.g., Godøya and Vigra)	Multiple tills and sediment units overlain by Early Weichsel. sed.	Tills and sed. of pre-Early Weichsel, probably of pre-Eemian age
9.	Fjøsanger, Western Norway	Eemian marine sediment/till (Paradis till)	Till of pre-Eemian, probably Saalian age (MIS 6)
10.	Grødeland, Jæren, Southwest Norway	Multiple tills and sediment units with marine fossils	Tills and sed. of MIS 6–9 age, based on AAR analyses
11.	Mesna, Lillehammer, Southeast Norway	Pre-Holocene interglacial palaeosol/till (Skjellerud till)	Till of pre-Eemian, probably Saalian age (MIS 6)

Localities:	Geographical area:	References:
1, 2, 3, 4, 5, 6	Northern Norway	Olsen et al. (1996a)
7	Mid-Norway	Aarseth (1995)
8	Mid-Norway	Landvik and Mangerud (1985), Jungner et al. (1989)
9	Southern Norway	Mangerud et al. (1981b)
10	Southern Norway	Janocko et al. (1998)
11	Southern Norway	Olsen (1985b, 1998)

Table B6: All reported Eemian sites from onland positions in Norway, and selected offshore Eemian sites.

Locality	Dating material	Methods	Comments	References:
1. Komagelva	sand, subtill position	OSL	117 and 123 ka => Eemian	Olsen et al. (1996a)
2. Vuolgamasjohka	palaesol in sand, subtill position	TL	stratigraphy and palaeosol indicate Eemian age	Olsen et al. (1996a)
3. Vuoddasjavri	sand, subtill position	TL	114, 123, 126 and 134 ka => Eemian age	Olsen et al. (1996a)
4. Sargejohka	palaeosol (poszol) in sand, subtill position	TL	>50 ka, interglacial pollen => probably Eemian	Olsen et al. (1996a)
5. Gamehisjohka	gyttja, sand, subtill position	C14, pollen	Eemian sediment/multiple tills and sediment units	Olsen et al. (1996a)
6. Buddasnjarga	palaeosol in till, subtill position		correlation to locality 4 and 5 => probably Eemian	Olsen et al. (1996a)
7. Slettaelva	foraminifers in till, resedimented	AAR	probably Eemian, from AAR–age	Vorren et al. (1981)
8. Stordalsgrotta, cave	speleothem	U/Th	Eemian, from U/Th–age	Lauritzen (1995)
9. Okshola, cave	speleothem	U/Th	Eemian, from U/Th–age	Lauritzen (1995)
10. Gammalmunnåga	shells in till, resedimented	C14, AAR	>48 ka (C14) and AAR–result indicate Eemian age	Olsen et al. (2001a), Olsen (2002)
11. Hamarnesgrotta and Grønligrotta, caves	speleothems	U/Th	Eemian, from U/Th–age	Linge et al. (2001)
12. Skarsvågen	pollen and shells in subtill sediments	AAR	stratigraphy and AAR–age => probably Eemian age	Aarseth (1990, 1995)
13. Follafoss	shells in till, resedimented, and in intratill sediment	C14	>48 ka and high elevation => probably early Eemian	Olsen et al. (2001a)
14. Drivvollen and Langmoen	foraminifers in silt, subtill position		interglacial foraminifers => probably Eemian age	Olsen et al. (2002)
15. "Møre", several sites	shells in till, resedimented	AAR	Eemian age, from AAR analyses	Mangerud et al. (1981a)
16. Kroken, Sogn	pollen in till/ subtill sediments	pollen (picea)	pollen and stratigraphic pos. => Eemian age	Vorren (1972)
17. Fjøsanger	pollen and shells in subtill marine sed.	AAR, TL	warm interglacial flora and fauna => Eemian age	Mangerud et al. (1981b)
18. Vinjedalen, Vossestrand	peat (2 cm thick), subtill position	pollen (picea)	stratigraphy and pollen => Eemian age	Sindre (1979)
19. Bø, Karmøy	shells in marine sediments, subtill position	AAR	warm fauna and AAR–age => Eemian age	Andersen et al. (1983), Sejrup (1987)
20. SW Norway, Haugesunds-halvøya and Jæren	pollen and shells in till/ subtill sed.	pollen, AAR	interglacial flora/ fauna => probably Eemian age	Vorren and Mangerud (2006)
21. Hovden	pollen in till/ subtill sediments	pollen (picea)	warm interglacial flora and stratigraphic pos. => Eemian	Vorren and Roaldset (1977)
22. Lågen–Gausa deltaet	shell (glycimeris), resedimented in delta	C14	>50 ka and warm interglacial shell => Eemian age	Olsen and Grøsfjeld (1999)
23.			stratigraphy and character of palaeosol => Eemian age	Olsen (1985b, 1998)
24. Central SE Norway, several sites	sand, subtill position, resedimented	TL, OSL	110–140 ka and strat. pos. => probably Eemian sed.	Myklebust (1991), (O.F. Bergersen, unpubl. 1991)
Offshore sites:				
102. Smørbukk, Mid-Norwegian shell	Strata including Eemian beds			Sættem et al. (1993)
2501 Statfjord, North Sea Plateau	Strata including Eemian beds			Feyling-Hanssen (1981)
5.1/5.2 Troll, Norwegian Channel	Strata including Eemian beds			Sejrup et al. (1991, 1994)
Eem-site in Denmark:				
Apholm	Strata including Eemian beds			Knudsen and Sejrup (1999)

Table B7: Early Weichselian and early Middle Weichselian sites (with sediments and tills). Average number of younger (overlying) stadials/glacial units is c. 2.65 (n=23).

Locality		Stratigraphy	Comments	Overlying glacial units	References:
1.	Gamehisjohka, Finnmarksvidda	Till overlying Eemian palaeosol and overlain by LW* till and deglaciation sediments	=> till of probably EW* to early MW* age	1	Olsen et al. (1996a)
2.	Buddasnjarga, Finnmarksvidda	Till overlying Eemian palaeosol and overlain by LW till and deglaciation sediments	=> till of probably EW to early MW age	2	Olsen et al. (1996a), (L.Olsen, unpubl. 1997)
3.	Sargejohka, Finnmarksvidda	Till overlying Eemian palaeosol and overlain by MW–LW sediments	=> till of EW to early MW age	3	Olsen et al. (1996a)
4.	Vuoddasjavri, Finnmarksvidda	Till overlying TL-dated Eemian beds and overlain by MW–LW tills	=> till of probably EW to early MW age	4	Olsen et al. (1996a)
5.	Vuolgamasjohka, Finnmarksvidda	Till overlying TL-dated Eemian sediment and overlain by MW–LW tills/sediments	=> till of EW age	4	Olsen et al. (1996a), Lyså and Corner (1993)
6.	Kautokeino, Finnmarksvidda	Palaeosol with ice wedge cast between two TL-dated pre-MW and pre-LW degl. units	=> degl./glacial sediments of EW to early MW age	3	Olsen et al. (1996a), Olsen and Often (1996)
7.	Vuoskujavri, Finnmarksvidda	Till overlying sand with interglacial pollen and overlain by MW–LW tills	=> till of probably EW to early MW age	2	Olsen et al. (1996a), Olsen and Often (1996)
8.	Ås'kal, Finnmarksvidda	Deglaciation sediments with interglacial pollen overlain by MW and LW tills	=> probably degl./glacial sediments of EW age	2	Olsen and Hamborg (1984), (L.Olsen, unpubl.)
9.	Slettaelva, Kvaløya, Troms	Till overlain by MW–LW sediments and tills, with marine shells	stratigraphy and AAR of shells => EW to MW age	3	Vorren et al. (1981)
10.	Storelva, Grytøya, southern Troms	Till overlain by MW intratill sediments with C14- and AAR dated shells	stratigraphy and AAR of shells => EW to MW age	2	Olsen and Grøsfjeld (1999), Olsen et al. (2001a)
11.	Skogreina, mid Nordland	Ice marginal complex from MW and LW, reworked till/sediment, AAR dated shells	stratigraphy and AAR of shells => EW till/sediment	2	Olsen et al. (2001a)
12.	Gammalmunnåga, mid Nordland	Reworked till/sediment overlain by LW till, C14- and AAR dated shells	stratigraphy and AAR of shells => EW	1	Olsen et al. (2001a)
13.	Skarsvågen, Frøya, Trøndelag	Till overlying in situ Eemian marine and terrestrial sediments, AAR dated shells	stratigraphy and AAR of shells => probably EW–MW	1	Aarseth (1990, 1995)
14.	Folldal, northern Hedmark	Till overlain by MW–LW tills/sediments, C14-and U/Th dates from overlying sediment	stratigraphy and dates from overlying units => EW–MW till	3	Olsen et al. (2001), (L.Olsen, unpubl.)
15.	Skjonghelleren, Valderøy, Møre	Ice-dammed sediments underlying sed. with 50–60 ka (U/Th) old speleothems	stratigraphy and U/Th age of overlying units => EW sed.	4	Larsen et al. (1987)
16.	Dalseng, southern Hedmark	Tills underlying Brumunddalen interstadial peat of EW–MW age	Stratigraphy => EM tills	3	Helle et al. (1981)
17.	Fjøsanger, western Norway	Bønes till, overlying in situ Eemian and EW sediments, AAR dated shells from the till	Stratigraphy and dates => probably EW–MW age	2	Mangerud et al. (1981)
18.	Bø, Karmøy, southwestern Norway	Karmøy diamicton (till) between Bø and Torvastad interstadials	Stratigraphy => EW till	3	Andersen et al. (1983), Sejrup (1987)
19.	Auestad, Jæren, southwestern Norway	Skretting diamicton (till) of EW age, correlated with Auestad diamicton (till) 4	Stratigraphy and regional correlation => EW age of till	2	Janocko et al. (1998), Larsen et al. (2000)
20.	Skretting, Jæren, southwestern Norway	Skretting diamicton (till), EW age, overlying LS* Auestad clay, AAR dated shells	Stratigraphy and dates => EW age of till	2	Stalsberg et al. (1999), Larsen et al. (2000)
21.	Mår, Hardangervidda	Mår lower till, correlated with Hovden lower till and overlain by OSL dated MW–LW sediments	Stratigraphy and dates => EW–MW age of till	4	Vorren (1979), Haug (2005)
22.	Hovden, Hardangervidda	Hovden lower till, between OSL dated MW–LW sediments and Hovden clay of Eemian age	Stratigraphy and dates => EW–MW age of till	4	Vorren (1979), Haug (2005)
23.	Førnes, Hardangervidda	Førnes lower till, correlated with Hovden lower till	Stratigraphy and regional correlation => EW age of till	4	Vorren (1979), Haug (2005)

*LW = Late Weichselian; MW = Middle Weichselian; EW = Early Weichselian; and LS = Late Saalian

*Table B8: Early Middle Weichselian sites (with sediments and tills). Average number of younger (overlying) stadials/glacial units is c. 1.72 (n=33). *Mainly ^{14}C-dates, ages are in ^{14}C yr BP (± 1std). Other dates are also included (U/Th, AAR) and these are in cal yr BP.*

Locality					
1, Vanna, Troms	Till with reworked till/sed. with shells	39,495 +/-870	Probably resedimented early MW till/sediments	1	Olsen (2004), (L.Olsen, unpubl.)
2, Leirhola I-II, Arnøya, Troms	Till with reworked till/sed. with shells	48,635 +2595/-1960 44,755 +1745/-1435	Probably resedimented early MW till/sediments	2	Olsen (2004), (L.Olsen, unpubl.)
3, Kvalsundet, Kvaløya, Troms	Till with reworked sediments/ shells	40,600 +2100/-1700	Possibly MW till	1	Vorren (1979)
Kvaløya, Troms	sediments/shells		and sediments		
4, Slettaelva, Kvaløya, Troms	Till with reworked sediments/ shells	41,900 +2800/-2200	Possibly MW till and sediments	2	Vorren et al. (1981)
5, Lavangsdalen and Arnelund	Till with reworked sediments/ shells	c. 44,000 > 48,300 (+/- 2std)	Possibly MW till and sediments	2	Olsen (2004), (L.Olsen, unpubl.)
6, Bleik, Andøya, Nordland	Glaciomarine sed. with reworked sed.	> 40,000	Ice proximal milieu, possibly MW age	0	Møller et al. (1992)
7, Løksebotn, southern Troms	Tills/intratills sed., with reworked sed.	44,560 +/-2000 47,815 +2305/-1790	Possibly MW tills and sediments	2	Olsen (2004), (L.Olsen, unpubl.)
8, Storelva, Grytøya, Troms	Glaciomarine sed. with reworked sed.	41,660 +/-1500	Ice proximal milieu, possibly MW age	1	Olsen and Grøsfjeld (1999)
9, Mågelva II, Hinnøya	Till with reworked sediments/ shells	45,560 +/-2400	Possibly MW till and sediments	2	Olsen and Grøsfjeld (1999)
10, Raudskjer, Hinnøya	Till with reworked sediments/ shells	42,260 +1165/-1020	Possibly MW till and sediments	1	Olsen (2004), (L.Olsen,
11, Kjøpsvik, cave Nordland	Bone underlying ice-dammed sed.	41,120 +1480/-1250	Ice proximal milieu, possibly MW age	2	Lauritzen and Nese (1996)
12, Grytåga, Nordland	Till with reworked sediments/ shells	41,460 +/-900	Possibly MW till and sediments	1	Olsen et al. (2001a)
13, Gammalmunnåga, Nordland	Till with reworked sediments/ shells	> 44,800	Possibly MW till and sediments	1	Olsen (2002), (L.Olsen, unpubl.)
14, Bogneset, Nordland	Tills/intratills sed., with reworked sed.	40,025 +/-965	Possibly MW tills and sediments	3	Olsen (2002), (L.Olsen, unpubl.)
15, Rana, cave Nordland	Concretions in sediments	46,560 +2700/-2000	Possibly MW degl. sed. and interstadial	0	Olsen et al. (2001a)
16, Hundkjerka, cave Nordland	Glacial diamiction, reworked sed./ shells	46,340 +/-1620	Possibly MW interstadial and ice advance	2	(L.Olsen, unpubl.)
17, Vikna, Trøndelag	Till with reworked sediments/ shells	>40,000	Possibly MW till and/ or MW reworked sed.	1	Bergstrøm et al. (1994)
18, Nordli, Lierne Trøndelag	Intratill sediments with plant fragments	41,000 +3000/-2000	Possibly MW till and/ or MW reworked sed.	2	Olsen et al. (2001a), (L.Olsen, unpubl.)
19, Follafoss I-II Trøndelag	Intratill sediments with shell fragments	46,905 +/-4020 47,565 +/-4680	Possibly MW till and/ or MW reworked sed.	1	Olsen et al. (2001a)
20, Svellingen, Frøya Trøndelag	Till with reworked sediments/ shells	42,400 +1280/-1110	Possibly MW till and/ or MW reworked sed.	1	Aarseth (1990)
21, Grytdal, Trøndelag	Tills/intratills sed., with plant remains	41,800 +1000/-1100	Possibly MW tills and/ or MW reworked sed.	3	Olsen et al. (2001a)
22, Ertvågøya, Møre	Till with reworked sediments/ shells	41,300 +3130/-2240	Possibly MW till and/ or MW reworked sed.	1	Follestad (1992)
23, Skjonghelleren, cave, Møre	Speleothem overlain by ice-dammed sed.	55,700 +/-4000 (U/Th)	MW ice proximal env. and MW interstadial	3	Larsen et al. (1987)
24, Gråbekken, Folldal, Hedmark	Concretions in sub till sediments	41,300 +900/-1000	Possibly MW ice proximal env./ice-free cond.	2	Olsen et al. (2001a), (L.Olsen, unpubl.)
25, Kollsete, Sogn and Fjordane	Gyttja overlain by ice-dammed subtill sed.	43,800 +3700/-2500	MW interstadial and ice proximal conditions	1	Aa and Sønstegaard (1997)
26, Fåvang, Gudbr.d. central south Norway	Mammoth bone from subtill sed., sandur	45,300 +/-2900 (U/Th)	Possibly MW ice proximal env./ice-free cond.	2	Idland (1992)
27, Sæter, Søre Ål, Lillehammer	Mammoth bone from till/ reworked sediments	45,400 +1500/-1200 42,400 +/-500 (U/Th) 52,300 +/-900 (U/Th) 53,900 +/-900 (U/Th)	MW interstadial sed. and MW till	3	Heintz (1974) Idland (1992) Idland (1992) Idland (1992)
28, Øvre Åstbrua, central south Norway	Subtill sediments with plant remains	>48,000 and >50,000	Stratigraphy, dates and pollen => MW or older	2	Haldorsen et al. (1992)
29, Rokoberget, southeast Norway	Subtill sediments with plant remains	47,000 +4000/-3000	Stratigraphy, dates and pollen => MW	2	Rokoengen et al. (1993), Olsen and Grøsfjeld (1999)
30, Hardangervidda, southern Norway	Intratill sediments	c. 40,000 (OSL)	Possibly MW till and/ or MW ice-proximal sed.	3	Haug (2005)
31, Bø, Karmøy, soutwest Norway	Bø interstadial sed. overlain by sed./tills	c. 50,000–55,000, from C14 and AAR data	Early MW interstadial and MW glacial sed.	3	Andersen et al. (1983), Sejrup (1987)
32, Oppstad, Jæren soutwest Norway	Subtill sediments with shells/ forams.	41,300 +6200/-3500 AAR indicates MW age	Possibly MW till and/ or MW interstadial sed.	2	Andersen et al. (1991), Andersen et al. (1987)
33, Høgemork, Jæren southwest Norway	Subtill sediments with shells/ forams.	AAR indicates MW age	Possibly MW till and/ or MW interstadial sed.	3	Andersen et al. (1987)

*) See Table caption

*Table B9: Late Middle Weichselian sites (with sediments and tills). Average number of younger (overlying) stadials/glacial units is c. 1.39 (n=49). [1]Ages are shown in ^{14}C yr BP (± 1std) for ^{14}C dates and in cal yr BP for other dates. *BPR= Bulk plant remains, **Sargejohka interstadial, ***Ørnes interstadial (coast) = Hattfjelldal interstadial II (inland), ****Stratigraphy including known palaeomagnetic signals, *****Trace amounts of marine organisms/fossils (e.g., dinocysts).*

Locality	Dating[1]	Lab. Number	Material/ comments	Overlying glacial units	References
1, Skjellbekken, Finnmark	C14: 34,000 ±600	UtC 4039	BPR*, in subtill sediments	2	Olsen et al. (2001a)
2, Sargejohka, Finnmark	C14: 35,100 ±1600	Ua 319	BPR, in subtill sediments (Sargejohka interstadial**)	1	Olsen et al. (1996a)
3, Kautokeino, Finnmark	TL: 37,000 ±5000 TL: 41,000 ±5000	R-823820a R-823820b	Sand, resedimented interstadial** material	0	Olsen (1988), Olsen et al. (1996a)
4, Arnøya, Troms	C14: 27,400 ±1500 C14: 29,000 ±4200	T-3509 T-4020	Shell, in till and subtill sediments	2	Andreassen et al. (1985)
5, Bøstranda, Langøya, Nordland	C14: 39,150 ±900	T-3942	Shell, in till	1	Rasmussen (1984)
6, Kjøpsvik, cave Nordland	C14: 31,160 ±300 U/Th: 36,000 ±3600	TUa-489 ULB-863	Bone, in sediments under lying ice-dammed sed.	1	Nese (1996), Nese and Lauritzen (1996)
7, Urdalen, Nordland	C14: 27,580 ±220	UtC 8459	BPR, in subtill sediments	2	Olsen et al. (2001a)
8, Hakvåg, Nordland	C14: 36,200 ±500 C14: 39,200 ±700	UtC 13556 UtC 13555	Shell, in till	1	(L.Olsen, unpubl.)
9, Grytåga, Nordland	C14: 35,400 ±500	UtC 5557	BPR, reworked sediments in till	1	Olsen et al. (2001a)
10, Risvasselva, Nordland	C14: 36,800 ±600	UtC 5558	BPR, in subtill sediments	2	Olsen et al. (2001a)
11, Åsmoen, Nordland	C14: 28,355 ±235 C14: 29,075 ±370	TUa-567 TUa-1094	Shell, in subtill sediments (Ørnes interstadial***)	1	Olsen (2002)
12, Bogneset, Nordland	C14: 28,355 ±430 C14: 35,940 ±1455	TUa-1240 TUa-1239	Shell, in subtill sediments***	2	Olsen (2002)
13, Kjeldal, Nordland	C14: 33,700 ±400 C14: 35,800 ±600	UtC 8312 UtC 8311	Shell, in subtill sediments	2	Olsen (2002)
14, Luktvatnet, Nordland	C14: 30,600 ±300	UtC 4715	BPR, reworked sediments in till	1	Olsen et al. (2001a)
15, Fiskelauselva, Nordland	C14: 28,000 ±500 C14: 29,400 ±500	UtC 2215 UtC 3466	BPR, in subtill sediments (Hattfjelldal interst. I, II)	2	Olsen (1997), Olsen et al. (2001a)
16, Røssvatnet, Nordland	C14: 29,700 ±500 C14: 31,000 ±500	UtC 3469 UtC 3468	BPR, in subtill sediments (Hattfjelldal interst. I, II)	1	Olsen et al. (2001a)
17, Hattfjelldal, Nordland	C14: 25,370 ±170 C14: 34,900 ±400	UtC 4721 UtC 4722	BPR, in subtill sediments (Hattfjelldal interst. I, II)	2	Olsen et al. (2001a)
18, Langstrandbakken, Nord-Trøndelag	C14: 36,950 ±2700	T-12564	Shell, in till	2	Olsen et al. (2001a)
19, Namskogan, Nord-Trøndelag	C14: 28,700 ±400	UtC 3465	BPR, reworked sediments in till	1	Olsen et al. (2001a)
20, Gartland, Nord-Trøndelag	C14: 28,000 ±200	UtC 4719	BPR, reworked sediments in till	1	Olsen et al. (2001a)
21, Sitter, Nord-Trøndelag	C14: 30,200 ±400	UtC 2103	BPR, reworked sediments in till	2	Olsen et al. (2001a)
22, Sæterelva, Sør-Trøndelag	C14: 39,140 ±900	TUa-1238	Shell, in till	1	Olsen et al. (2001a), Olsen and Riiber (2006)
23, Nesavatnet, Sør-Trøndelag	C14: 36,815 ±590	TUa-2526	Shell, in till	1	(L.Olsen, unpubl.)
24, Skjenaldelva, Sør-Trøndelag	C14: 33,620 ±470 C14: 34,155 ±620	TUa-2996 TUa-2997	Shells (forams.) in subtill sediments	2	(L.Olsen, unpubl.)
25, Renåa, Sør-Trøndelag	C14: 28,700 ±300 C14: 31,600 ±400	UtC 5549 UtC 5552	BPR, reworked sediments in till	2	Olsen et al. (2001a)
26, Stærneset, Sør-Trøndelag	C14: 25,240 ±180	UtC 5556	BPR, reworked sediments in till	2	Olsen et al. (2001a)
27, Grytdal, Sør-Trøndelag	C14: 28,400 ±300 C14: 37,200 ±600	UtC 5564 UtC 5560	BPR, reworked sediments in till	2	Olsen et al. (2001a)
28, "Ålesund interstadial" sites, Møre	C14: 35,700 ±1100 (Eidsvik)	T-2657	Shells, in till, shells of various ages, also late MW	1	Mangerud et al. (1981a)
29, Kortgarden, Møre	C14: 26,940 ±670	T-7281	Shell, in till	1	Follestad (1990)
30, Hamnsundhelleren, cave, Møre	C14: 24,387–31,905	Also palaeomag. signals	Bones in sediments**** underlying ice-dammed sed.	1	Valen et al. (1996) (several dates)
31, Skjonghelleren, cave, Møre	C14: 28,900–34,400 U/Th:23,900–28,000	Also palaeomag. signals	Bones in sediments underlying ice-dammed sed.	1	Larsen et al. (1987) (several dates)

Locality	Dating[1]	Lab. Number	Material/ comments	Overlying glacial units	References
32, Gråbekken, Folldal Hedmark	C14: 32,520 ±650 C14: 36,300 ±600	T-3556B UtC 4724	BPR and concretions in subtill sediments	1	Thoresen and Bergersen (1983), Olsen et al. (2001a)
33, Haugalia, Oppland	TL: 42,000 ±4000 (C14, U/Th, AAR)	R-897010, also OSL	Mammoth bones in subtill sediments	1	Bergersen and Garnes (1981), Idland (1992), (L.Olsen, unpubl.)
34, Sorperoa, Oppland	TL: 37,400–40000 (range of 4 dates)	R-…, also OSL	Aeolian sand, age supposed older than youngest till	0	Bergersen et al. (1991), (S.O.Dahl, pers. comm. 2004)
35, Fåvang, Oppland	TL: 32,000 ±3000 U/Th: 45,300 ±2900	R-…, also OSL	Mammoth bones in subtill sediments	1	(O.F.Bergersen, pers. comm. 1991), Idland (1992), (L.Olsen, unpubl.)
36, Stampesletta, Oppland	C14: 32,300 ±500	UtC 1965	BPR, in reworked subtill sediments	2	Olsen et al. (2001a)
37, "Øst-Jotunheimen", Oppland	C14: 26,000 ± …	…	BPR in subtill sediments	1	(S. Sandvold, pers. comm. 1997)
38, Dokka, Oppland	C14: 26,800 ±400	UtC 3462	BPR in subtill sediments	2	Olsen et al. (2001a), (L.Olsen, unpubl.)
39, Mesna, Lillehammer Oppland	C14: 31,500 ±700 C14: 36,100 ±900	UtC 2217 UtC 1964	BPR in subtill sediments	2	Olsen (1985b, 1998)
40, Hunndalen, Gjøvik, Oppland	C14: 34,200 ±600	UtC 14607	BPR in subtill sediments	1	(L.Olsen, unpubl.)
41, Rokoberget, Oppland	C14: 33,800 ±800 C14: 47,000 ±4000	UtC 1963 UtC 1962	BPR in subtill sediments, traces of marine fossils*****	1	Rokoengen et al. (1993a), Olsen and Grøsfjeld (1999)
42, Møsvatn sites, Hardangervidda	OSL:35,000 ±3000 OSL:41,000 ±4000	R-33507 R-33508	Subtill sand	1	Vorren (1979), Haug (2005)
43, Hovden & Grytkilvika, Hardangervidda	OSL:32,000, 35,000 and 48,000 ±4000	R-33502,33503 and 33510	Subtill sand	2	Vorren (1979), Haug (2005)
44, Bø, Karmøy, Rogaland	C14: 26,510 ±240 C14: 34,000 ±500	TUa-5267 UtC 13562	Shell, in till	2	Ringen (1964), Andersen et al. (1983), Sejrup (1987), (L.Olsen, unpubl.)
45, Vatnedalen, Rogaland	C14: 35,850 ±1180	T-2380	Palaeosol in subtill sed.	1	Blystad and Selsing (1988)
46, Elgane, Jæren, Rogaland	C14: 33,480 ±1520 C14: 34,820 ±1165	TUa-…	Shell, in reworked subtill sediments	1	Janocko et al. (1998)
47, Passebekk, Telemark	C14: 28,600 ±300	UtC 6044	BPR in reworked subtill sediments	2	Olsen et al. (2001a)
48, Rundhaugen, Telemark	C14: 32,000 ± …	UtC …	BPR in reworked subtill sediments*****	1	Roaldset (1980), Olsen and Grøsfjeld (1999)
49, Herlandsdalen, Telemark	C14: 28,300 ±240 C14: 32,000 ±300	UtC 4729 UtC 4728	BPR in reworked subtill sediments	2	Olsen et al. (2001a)

*Table B10: LGM interval oscillation sites (with sediments and tills). *Ages are shown in ^{14}C yr BP ±1std for ^{14}C dates and in cal yr BP for other dates. **BPR= Bulk plant remains. Average number of younger (overlying) stadials/glacial units is c. 1.16 (n=42), or c. 1.00 (n=32) with all sites which have no dates in the interval 15–21 ^{14}C-ka excluded (10 of 42 sites).*

Locality	Material	Dating*	Lab.refr.	Comments	Overlying glacial units	References
1, Leirelva, Finnmark	BPR** in subtill sediments	C14:17,110–17,290 and 18,680 ±170	UtC 1800,1799 and 3460	Probably LGM 1–2 oscillation, also TL and OSL	1	Olsen et al. (1996a), Olsen et al. (2001a)
2, Skjellbekken, Finnmark	BPR in subtill sediments	C14: 25,860 ±280	UtC 4040	Pre-LGM 1–LGM oscillation	2	Olsen et al. (2001a)
3, Arnelund, Troms	BPR in subtill sediments	C14: 16,580 ±100	UtC 12691	LGM 1–LGM 2 oscillation	1	(L.Olsen, unpubl.)
4, Andøya and Andfjorden sites	Ice marginal deposits, marine/lake sediments	C14 (several dates) range 17,940–21,800	TUa- …	LGM 1, Andøya interst., LGM 2, and younger	1	Vorren (1978), et al.(1988), Møller et al. (1992), Alm (1993)
5, Kjøpsvik, cave Nordland	Bone in sed. underlying ice-dammed sediments	C14: 20,110 ±250 C14: 20,210 ±130	TUa-436 TUa-488	LGM 1–LGM 2 oscillation	1	Nese and Lauritzen (1996), Olsen et al. (2001a)
6, Urdalen, Nordland	BPR in reworked sediment between till beds	C14: 20,470 ±110	UtC 8458	Pre-LGM 1–LGM 1– LGM 2 oscillations	1	Olsen et al. (2001a)
7, Meløya, Nordland	BPR in subtill sediments	C14: 17,700 ±80	UtC 8456	LGM 1–LGM 2 oscillation	1	Olsen et al. (2001a)
8, Kjeldal, Nordland	Succession of tills/ subtill sed. with resed. org.	C14: 18,880 ±100	UtC 8457	Ørnes interst.–LGM 1–Kjeldal interst.–LGM 2	1	Olsen (2002)
9, Bogneset, Nordland	Succession of tills/ subtill sed. with resed. org.	C14: 20,880 ±130	UtC 10109	Ørnes interst.–LGM 1–Kjeldal interst.–LGM 2	1	Olsen (2002)
10, Fiskelauselva Nordland	Succession of tills/ subtill sed. with resed. org.	C14: 19,500 ±200	UtC 2216	Hattfjelldal interst. II– LGM 1–LGM 2 oscillation	1	Olsen (1997)
11, Hattfjelldal Nordland	Succession of tills/ sub till sed. with resed. org.	C14: 23,500 ±240	UtC 4809	Hattfjelldal interst. II–LGM 1–LGM 2 oscillation	2	Olsen (1997)
12, Langstrandbakken Nord-Trøndelag	BPR in subtill sed., with trace of marine org.	C14: 18,700 ±500	UtC 5974	Andøya–Kjeldal interst.–LGM 2 ice advance	1	Olsen et al. (2001a)
13, Namsen, Nord-Trøndelag	BPR in subtill sed., with trace of marine org.	C14: 16,110 ±120 C14: 18,580 ±140	UtC 4811 UtC 4812	Andøya/ Kjeldal/ Trofors interst.–LGM 2 advance	1	Olsen et al. (2001a)
14, Øyvatnet, Nord-Trøndelag	BPR in subtill sed., with trace of marine org.	C14: 19,340 ±150	UtC 4800	Andøya/ Kjeldal/ Trofors interst.–LGM 2 advance	1	Olsen et al. (2001a)
15, Gartland, Nord-Trøndelag	BPR in reworked sediment in till	C14: 16,250 ±190	UtC 4871	Trofors interstadial–LGM 2 ice advance	1	Olsen et al. (2001a)
16, Sitter, Nord-Trøndelag	BPR in subtill sed., with trace of marine org.	C14: 21,150 ±130	UtC 4717	Andøya–Kjeldal interst.–LGM 2 ice advance	2	Olsen et al. (2001a)
17, Ø. Tverråga, Nord-Trøndelag	BPR in subtill sediment	C14: 17,830 ±190	UtC 3464	Trofors interstadial–LGM 2 ice advance	1	Olsen et al. (2001a)
18, Blåfjellelva I–II Nord-Trøndelag	BPR in sediments between till beds	C14: 19,710 ±110 C14: 20,040 ±100	UtC 5565 UtC 5566	LGM 1–Trofors interst.–LGM 2 ice advance	1	Olsen et al. (2001a)
19, Hangran, Sør-Trøndelag	BPR in subtill sed., with trace of marine org.	C14: 24,550 ±240	UtC 14602	Hattfjelldal II /Ørnes interst.– LGM 1/LGM 2 advance(s)	2	Olsen et al. (2007)
20, Renåa, Sør-Trøndelag	BPR in subtill sed., with trace of marine org.	C14: 16,850 ±90 C14: 19,880 ±160	UtC 5550 UtC 5551	LGM 1(?)–Trofors interst.–LGM 2 ice advance	1	Olsen et al. (2001a)
21A, Langsmoen, Sør-Trøndelag	Subtill sed., with resed. marine microfossils	OSL: 22,300 ±1700 (mean age, n=7)		Trofors interstadial– LGM 2 ice advance	1	Olsen et al. (2002), Johnsen et al. (2012)
21B, Flora, Sør-Trøndelag	BPR in subtill/ intertill sediments	C14: 17,550 (mean age, n=8)	UtC …	LGM 1–Trofors interstadial, followed by LGM 2 advance	1	Olsen et al. (2001a)
22, Stærneset, Sør-Trøndelag	BPR in sediments between till beds	C14: 18,820 ±110	UtC 5555	Hattfjelldal II–LGM 1–Trofors interstadial–LGM 2	1	Olsen et al. (2001a)
23, Surna, Møre and Romsdal	BPR in subtill sediment	C14: 19,090 ±100	UtC 10110	Trofors interstadial– LGM 2 ice advance	1	(L.Olsen, unpubl.)
24, Grytdal, Sør-Trøndelag	BPR in sediments between till beds	C14: 18,970 ±150	UtC 6040	Hattfjelldal II–LGM 1–Trofors interstadial–LGM 2	1	Olsen et al. (2001a)
25, Hauka, Sør-Trøndelag	BPR in subtill sediment	C14: 23,770 ±240 C14: 23,910 ±220	UtC 14605 UtC 14606	Hattfjelldal interstadial II–LGM 1/LGM 2 advance(s)	2	(L.Olsen, unpubl.)
26, Kvikneskogen Hedmark	BPR in sediments between till beds	C14: 16,660 ±100	UtC 12701	LGM 1(?)–Trofors interst.–LGM 2 ice advance	1	(L.Olsen, unpubl.)
27, Gamlemsveten Møre and Romsdal	BPR in soil overlain by blocks in block field	C14: 19,900 ±210	T-4384	Probably Andøya/Kjeldal/ Trofors interstadial	0	Mangerud et al. (1981a), (J.Mangerud, pers. comm. 1981)

Locality	Material	Dating*	Lab.refr.	Comments	Overlying glacial units	References
28, Hamnsundheller-en, Møre and R.	Bones in sed. between ice-dammed sediments	C14: 24,387 ±960 C14: 24,555 ±675	TUa-806 I TUa-806	Hamnsund/Ørnes/Hattfj.II int.st.–LGM 1/2 advance(s)	1	Valen et al. (1996)
29, Folldal, Hedmark	BPR in sediments between till beds	C14: 23,260 ±160	UtC 4710	Hattfjelldal interstadial II–LGM 1/LGM 2 advance(s)	2	Olsen et al. (2001a)
30, Kollsete, Sogn and Fjordane	BPR in subtill sediment	C14: 22,490 ±180	UtC 6046	Hamnsund/Ørnes/Hattfj.II int.st.–LGM 1/2 advance(s)	1	Aa and Sønstegaard (1997), Olsen et al. (2001a)
31, Stampesletta, Oppland	BPR in subtill/ intertill sediments	C14: c. 16,000 ± …	TUa-…	Trofors interstadial– LGM 2 ice advance	1	Olsen et al. (2001a)
32, Mesna, Oppland	BPR in subtill/ intertill sediments	C14: 16,030 ±100	UtC 6041	Trofors interstadial– LGM 2 ice advance	1	Olsen et al. (2001a)
33, Dokka, Oppland	BPR in palaeosol/subtill sediments	C14: 18,900 ±200	UtC 2218	Trofors interstadial– LGM 2 ice advance	1	Olsen (1998), Olsen et al. (2001a)
34, Bø, Karmøy, Rogaland	Shells from sediments in and between tills	C14: 18,770 ±160 (Mya truncata)	TUa-4519	LGM 1–Andøya/Kjeldal interst.–LGM 2 advance	1	Olsen and Bergstrøm (2007)
35, Foss-Eikeland Rogaland	BPR in subtill sediment	C14: 19,895 (mean age, n=4)	UtC …	Andøya/ Kjeldal interst.–LGM 2 ice advance	1	Olsen et al. (2004), Olsen and Bergstrøm (2007)
36, Haugastaulen, Hardangervidda	Subtill sand	OSL: 25,000 ±3000 OSL: 26,000 ±2000	R-33506 R-33504	Ice free conditions, and LGM 1/2 ice advance(s)	2	Haug (2005)
37, Passebekk, Telemark	BPR in subtill sediment	C14: 21,000 ±400	UtC 5987	Andøya/Trofors interstadial– LGM 2 ice advance	1	Olsen et al. (2001a)
38, Herlandsdalen, Telemark	BPR in subtill sediments	C14: 23,250 ±170	UtC 6045	Hattfjelldal II followed by LGM 1/LGM 2 advance(s)	2	Olsen et al. (2001a)
39, Skjeberg, Østfold	BPR in subtill sediments	C14: 16,770 ±190 C14: 19,480 ±200	UtC 1802 UtC 1801	Andøya/Kjeldal interstadial– LGM 2 ice advance	1	Olsen et al. (2001a)
40, Braarød, Østfold	BPR in subtill sediments	C14: 19,260 ±130	UtC 12705	Andøya/Kjeldal interstadial– LGM 2 ice advance	1	Olsen et al. (2004), Olsen and Bergstrøm (2007)
41, Korterød, Østfold	BPR in subtill sediments	C14: 16,680 ±140	UtC 12707	Andøya/Kjeldal interstadial– LGM 2 ice advance	1	Olsen et al. (2004), Olsen and Bergstrøm (2007)
42, Børsåsen, Østfold	BPR in subtill sediments	C14: 15,110 ±90	UtC 12703	Ice free conditions and LGM 2 or younger ice advance	1	Olsen et al. (2004), Olsen and Bergstrøm (2007)

Table B11: Post LGM–pre-Older Dryas oscillation sites (with sediments and tills).

Post LGM–pre Older Dryas localities. Mean age of oldest post-LGM oscillation on land = 17.5 cal ka (14.5 ^{14}C ka) (N=18)		
Locality	**^{14}C age (ka)**	**Comments**
1, Komagelva	15.2 (N=4)	Subtill position, plant remains
2, Vuoddasjavri	13.8	Subtill position, plant remains, possible young C contamination
3, Andøya	c. 16	Glaciomarine and freshwater sed., plant remains
4, Hinnøya	13.9 and 14.0	Subtill position, dislocated, plant remains, traces of marine fossils
5, Domåsen	14.1 and 14.7	Subtill position, possible subgl. resed./or young C contamination
6, Myrvang	14.4	Subtill position, plant remains, traces of marine fossils
7, Hangran	14.7	Subtill position, plant remains, traces of marine fossils
8, Rønningen	13.9	Subtill position, plant remains, possible young C contamination
9, Flora	14.7	Subtill position, plant remains, possible young C contamination
10, Grytdal	13.5	Subtill position, plant remains, possible young C contamination
11, Bø	15.3	Subtill position, marine shell (Mya truncata)
12, Lista	c. 13.5–14.0	End moraine (Lista Substage)/Ice stream 'lateral shear moraine', estimated age
13, Børsåsen	15.1	Subtill position, plant remains

Localities:	**Geography:**	**References:**
1, 2	North Norway	Olsen et al. (1996a)
3	North Norway	Alm (1993), Vorren et al. (1999)
4	North Norway	Olsen et al. (2001a)
5, 6, 9, 10	Mid Norway	Olsen et al. (2001a)
7	Mid Norway	(L. Olsen, unpublished 2006)
8	Mid Norway	Olsen et al. (2007)
11	South Norway	Olsen and Bergstrøm (2007)
12	South Norway	Andersen (1960, 2000), (NGU unpubl.)
13	South Norway	Olsen et al. (2004)

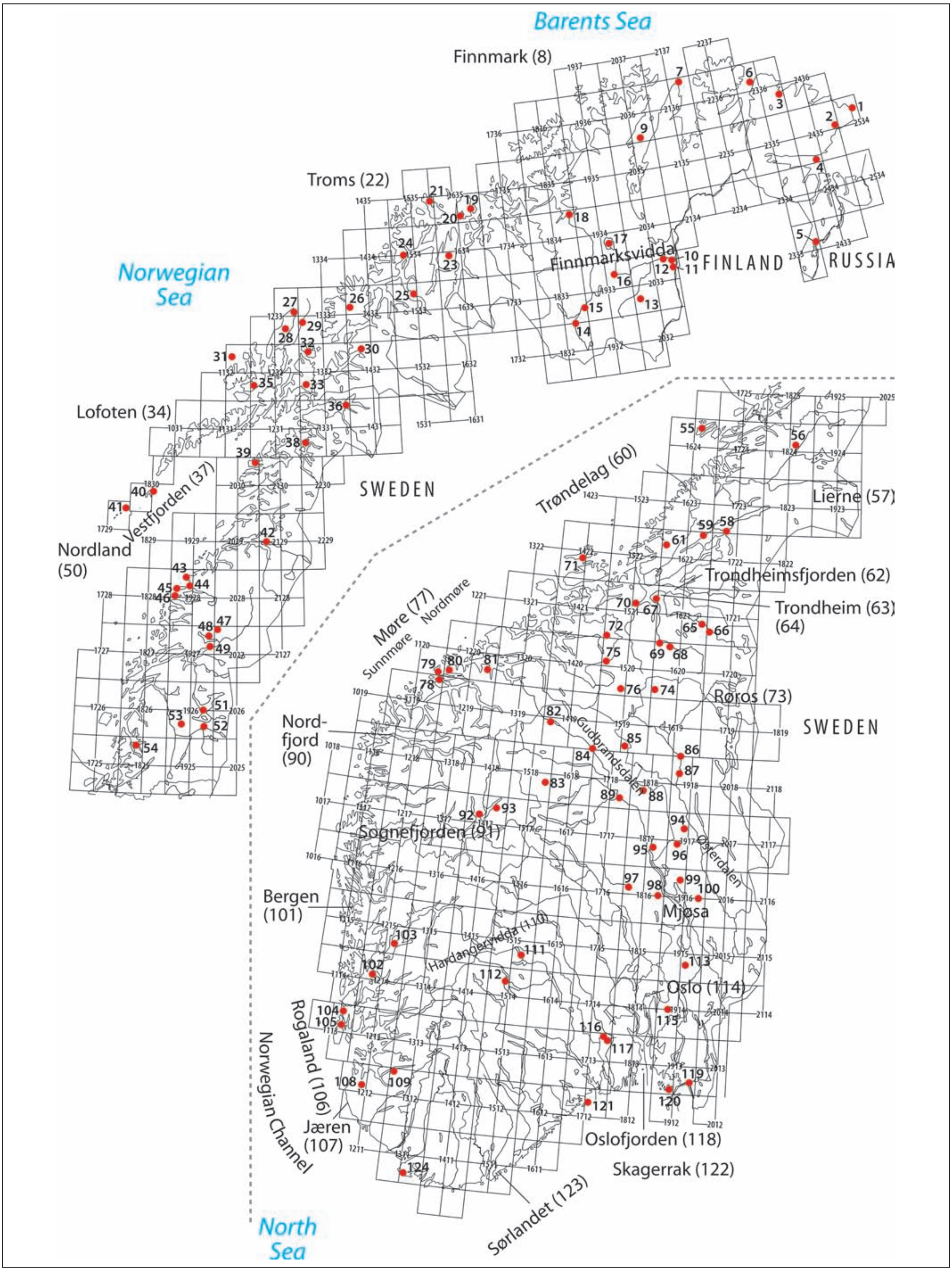


Figure B1: Location of sites and places listed by numbers and names in Table B1.

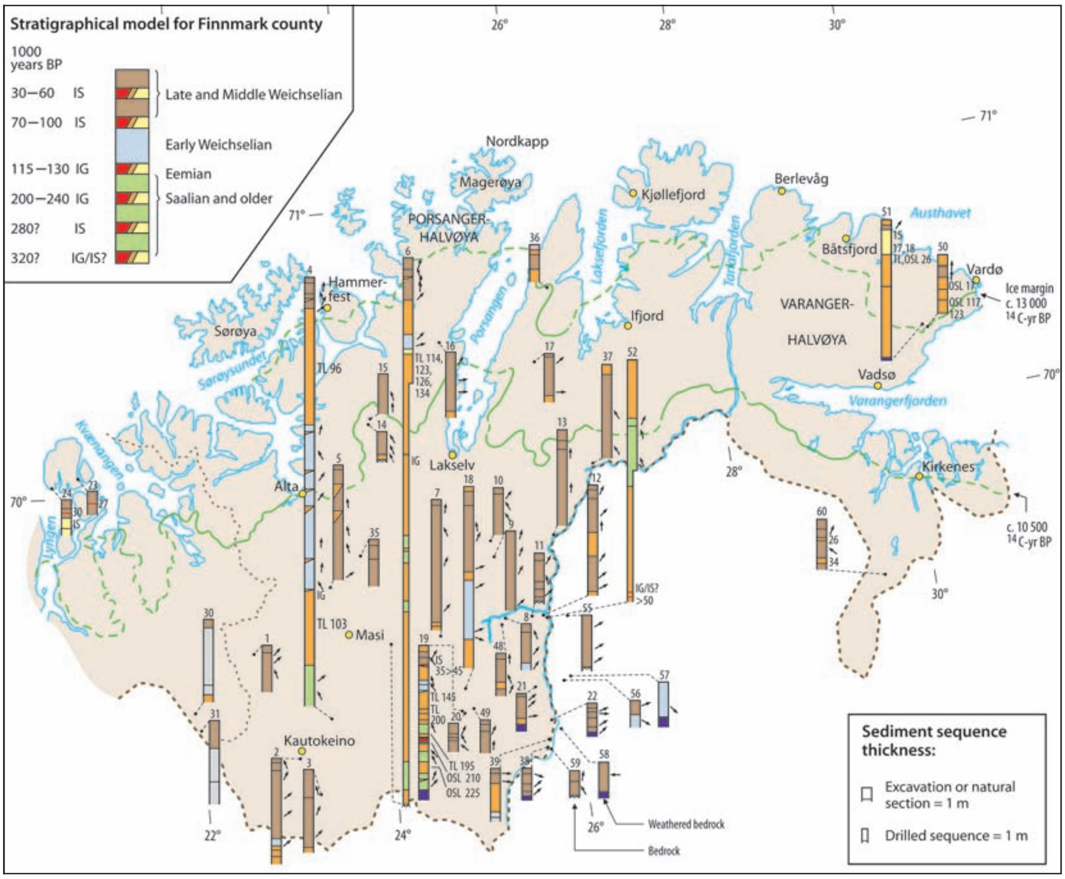


Figure B2: Part of the Quaternary stratigraphical map of Finnmark (Olsen 1993b). The logs from sites 4, 6, 52 and 19 here are shown as nos. 1, 2, 4 and 6, respectively, in Figure 13 (main text).

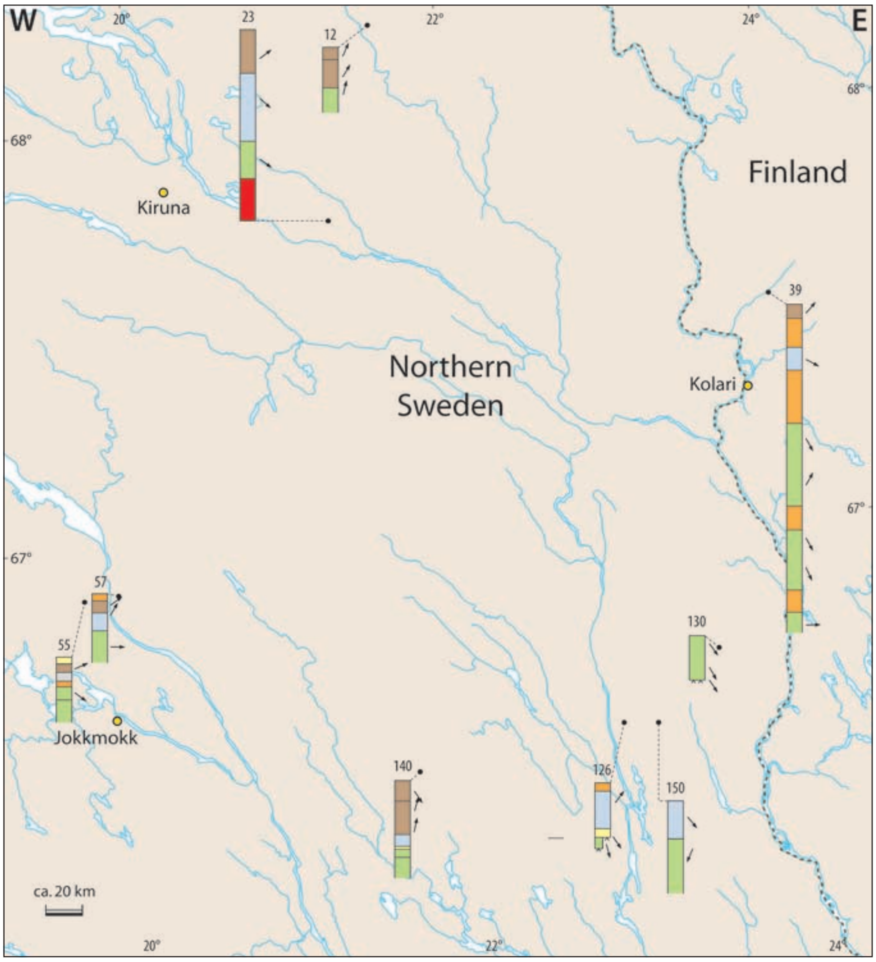
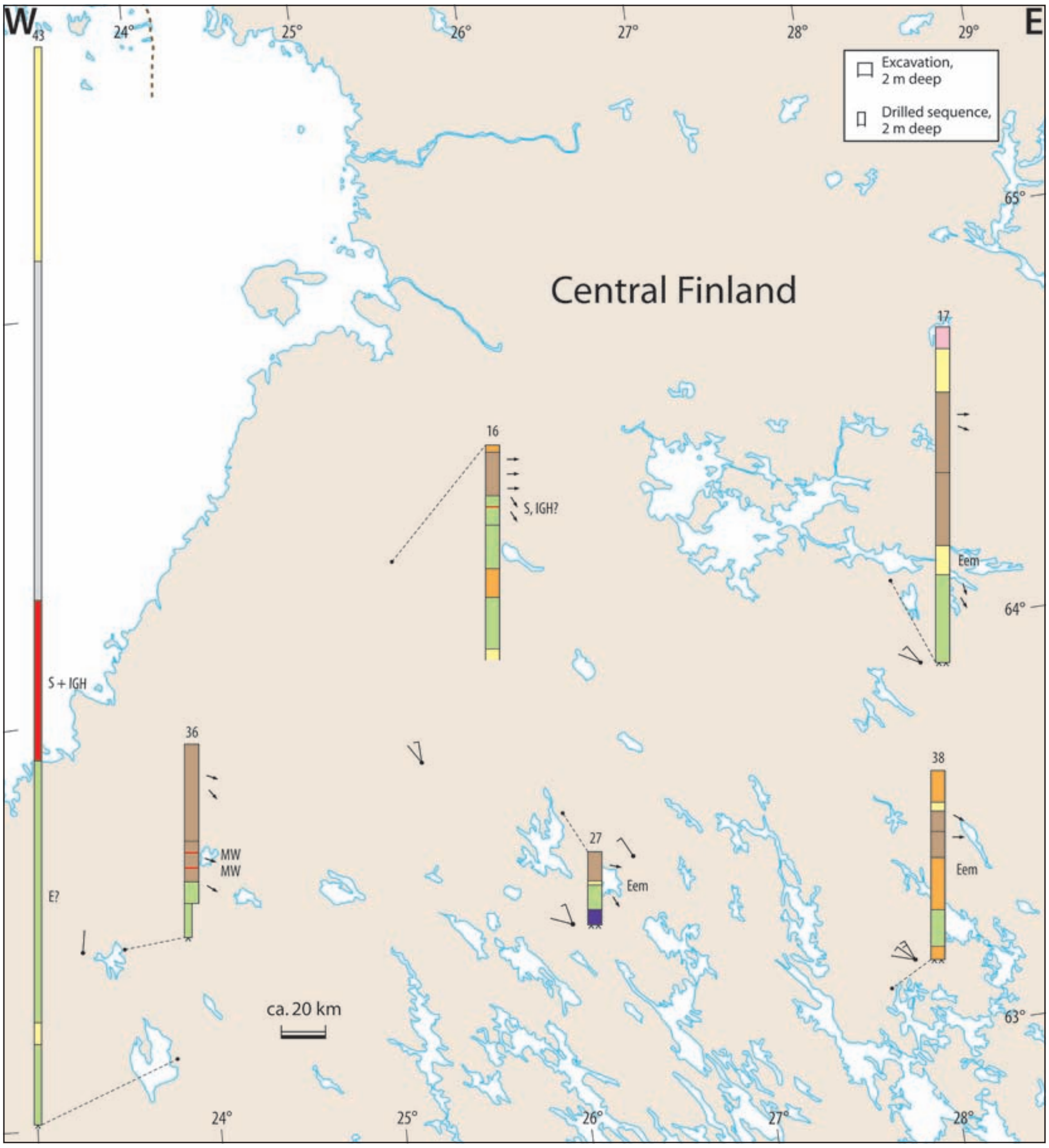


Figure B3: Logs from selected sites in the central part (mainly Sweden) of the Quaternary stratigraphical map of northern Fennoscandia (The Nordkalott Project 1986).

Figure B4: Logs from selected sites in the eastern part (Finland) of the Quaternary stratigraphical map of central Fennoscandia (The Mid-Norden Project 1999).



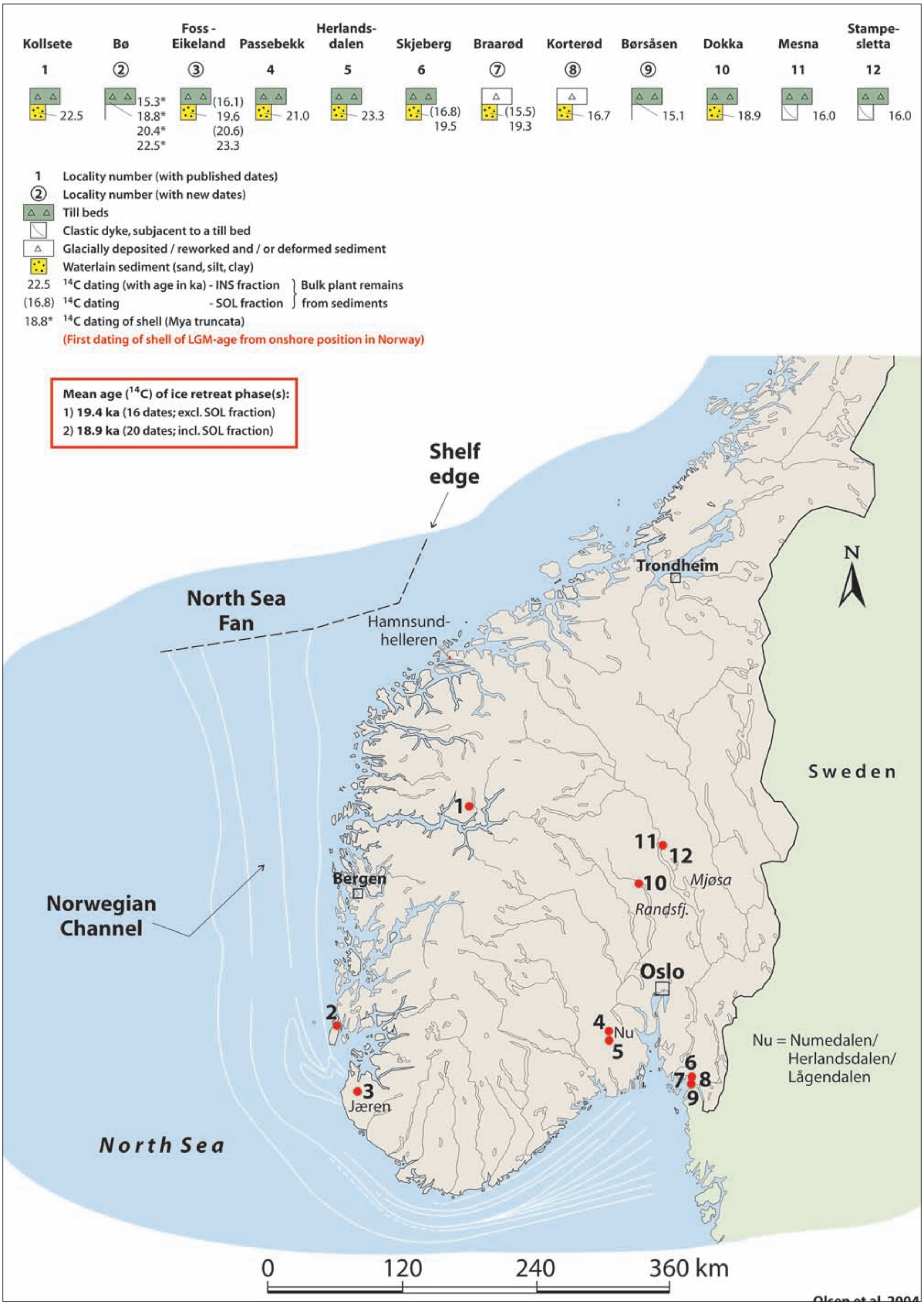


Figure B5: LGM sites on land adjacent to the Norwegian Channel along the coast of southern Norway. After Olsen et al. (2004).