Introduction

The aim of this study is to elucidate sedimentary processes and the environment during deglaciation of a fjord basin in Ullsfjorden, North Norway (Fig. 1). Many authors have focused on sediment supply related to glaciomarine environments during recent years (e.g. Elverhøi et al. 1983; Cowan & Powell 1991; Andrews & Syvitski 1994; Smith & Andrews 2000). It is generally agreed that sediment accumulation lessens with increasing distance from the glacier margin (Boulton 1990; Powell 1991; Andrews et al. 1994; Plassen & Vorren 2002). However, varying sediment supply related to glacier margin oscillations during deglaciation has received less attention. A very active depositional regime marked by a large sediment discharge to the fjords during the Allerød recession period, has been reported from the Andfjord-Vågsfjord area (Vorren & Plassen 2002). On the upper continental slope, in the northern part of the Norwegian Sea, the Younger Dryas glacier re-advance was characterised by reduced sediment input compared to the Allerød and Preboreal warming (Hald & Aspeli 1997).

Sediments in fjord basins contain the history of the last phases of deglaciation and provide a record of the sedimentary processes and environmental conditions during this time span. The amount and processes of sediment delivery to proximal and distal environments during different phases of a deglaciation, are important parameters for understanding the sedimentary environment in glaciomarine settings. The objective of this paper is to find the amount of sediment supplied during different phases of a glacier margin retreat-advance cycle in fjord settings, and thereby contribute to a better understanding of sedimentation by temperate tidal glaciers.

Two well-known marginal moraine positions confine the investigated basin temporally and spatially (Figs. 1C & 2). The outer moraine, the Skarpnes moraine (Andersen 1968; Vorren & Elvsborg 1979), is situated on a bedrock threshold. It contains glaciomarine and marine sediments with a total thickness of up to 150 m. Four major seismostratigraphic units have been correlated with a dated lithostratigraphy. A lowermost unit A occurs as infill in basement depressions, and reflects a high sediment accumulation rate in an ice proximal environment during the earliest deglaciation. Unit B was deposited during the Allerød glacial recession and the Younger Dryas re-advance. It is characterised by draping of laminated clayey silt with gravity flow layers. We observe a higher sedimentation rate during the Allerød than during the Younger Dryas. Unit C was deposited during the Younger Dryas/Preboreal glacial retreat. It is characterised by clayey silt with ice rafted debris (IRD), in addition to sandy turbidites. The sedimentation rate was slightly higher during the Younger Dryas/Preboreal withdrawal than during the Younger Dryas re-advance. Between 10 and 9.8 14C ka BP the sedimentary regime changed, from being tidewater glacier dominated to one receiving sediment supply from onshore glaciers. About 9.5 14C ka BP, open marine conditions commenced. The uppermost unit D reflects slow accumulation of sandy sediments in a bottom current affected environment.

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Fig. 1. (A) Location map. (B) Map of the Ullsfjorden area, showing location of the investigated basin (Fig. 1C) and geo-seismic profile (Fig. 2). (C) Map of the investigated basin, showing location of high-resolution acoustic data and sediment cores. The Skarpnes and Tromsø-Lyngen moraines are indicated. Profiles shown in Figs. 3, 6 and 7 are marked with bold lines.

Fig. 2. Interpreted seismic profile showing the general sediment distribution along Ullsfjorden (after Vorren et al. 1989) (for location, see Fig. 1B).
Physiographic setting

Ullsfjorden is a 70 km long, north-south oriented fjord, located in Troms County, North Norway (Figs. 1A & 1B). The maximum depth exceeds 280 m in its outer parts. In the inner part Ullsfjorden branches into Sør-fjorden and Kjosenfjorden. A sediment thickness of up to 200 m is found in Ullsfjorden (Fig. 2). Most of the sediments are glacimarine trough fills, deposited from suspension, close to the ice margin (Vorren et al. 1989). On the thresholds, tills are occasionally discerned. Glaciifluvial deposits are associated with the Tromsø-Lyngen moraine (Lønne 1993).

The Ullsfjorden area was deglaciated between about 13 and 10 $^{14}$C ka BP. The exact age of the Skarpnes and Tromsø-Lyngen moraines (Fig. 1C) has been discussed in several publications (Andersen 1968; Fimreite et al. 2001; Vorren & Plassen 2002). For the Vågsfjord area Vorren & Plassen (2002) recently suggested $^{14}$C-ages of 12.2 and 10.7-10.3 ka BP, respectively, for these glacial events. The marine limit in the area is about 65 m a.s.l. (Andersen 1968). The investigated basin is located within a bedrock province of quartz-biotite schist to the west and mica schist and phyllite, with bands of quartzite, to the south and the east. The Lyngen Alps area just east of Ullsfjorden, reaching a maximum altitude of 1833 m a.s.l., is composed of gabbroic rocks (Zwaan et al. 1998).

Material and methods

This study is based on high-resolution acoustic data and sediment cores (Fig. 1C) acquired by the research vessels "Johan Ruud" and "Jan Mayen", University of Tromsø. A GPS (Global Positioning System) was used for navigation. Bathymetry was in accordance with soundings recorded by the Norwegian Hydrographic Office.

The acoustic data included 160 km 3.5 kHz and boomer profiles, in addition to side scan sonar data, and were recorded during three cruises in 1999, 2000 and 2001 (Fig. 1C). The acoustic system consisted of: a) 5 kW hull-mounted Geoacoustic/Ferranti O.R.E. 3.5 kHz penetration echo sounder (bandpass filter setting 3-5 kHz), b) 300 J Geoacoustic/Ferranti O.R.E. Model 5813A boomer (bandpass filter setting 0.5-1.5 kHz) with a single channel Fjord streamer as receiver, and c) 100/500 kHz EG&G DF-1000 side scan sonar. Deep-towed boomer profiles recorded by Statoil in 1982, and sparker/boomer profiles, recorded by the University of Tromsø in 1979/1988/1989, have also been available.

Sediment thickness is displayed in metres, calculated from a measured average P-wave velocity of 1500 m/s. The software program Autocad 13 with surface modelling system QuickSurf 5.2 was employed for computation of areas and volumes. Sediment flux was calculated using a dry bulk density of 1350 kg/m$^3$.

Two piston cores were recovered (Fig. 1C; Table 1). The piston corer had a weight of 1600 kg and an inner diameter of 10 cm. Laboratory analyses performed, included Multi-sensor core logging, X-radiographs, Munsell color determination, water content, shear strength and grain-size analysis by wet sieving and Sedigraph. Impedance, P-wave velocity, density and magnetic susceptibility were recorded every half cm. Undrained shear strength and water content were sampled every 50 cm.

Bivalve samples for accelerator mass spectrometry (AMS) radiocarbon age determinations were retrieved from the cores (Table 1). The samples were produced at the Radiological Dating Laboratory, Trondheim, Nor-

<table>
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* The radiocarbon ages were corrected for a reservoir effect equal to 440 yr (Mangerud & Gulliksen 1975).
Cal. ages in [ ] are calibrated to an uncertain region or a linear extension to the calibration curve (Stuiver et al. 1998).
Fig. 3. (A) 3.5 kHz profile from the central part of the basin and across the Skarpnes moraine. Note that unit B is also present as erosional remnants on top of the Skarpnes moraine. Unit C onlaps the Skarpnes moraine and unit D wedges out south of the Skarpnes moraine. Tie point to line JR01-004 (Fig. 7) is indicated. (B) Boomer profile showing the general seismic stratigraphy. Units A, B and C constitute Late Weichselian/early Holocene glacimarine sediments, while unit D is Holocene marine sediments. Note that unit A onlaps the Skarpnes moraine. Gravity flow deposits appearing as layers and lenses in unit B are indicated. The deep trench at the northern side of the Skarpnes moraine could be a moat caused by current erosion, or it could be an erosion feature from seeping groundwater or seeping gas (Hovland & Judd 1988). For location, see Fig. 1C.
way, and the dating carried out at the T. Svedborg Laboratory, Uppsala, Sweden. Radiocarbon ages were corrected for a reservoir effect equal to 440 yr (Mangerud & Gulliksen 1975). The dates were calibrated using the 1998 marine calibration dataset with ΔR = 464 ± 35 (Stuiver et al. 1986; Stuiver et al. 1998). Dates from other sources and estimated ages older than 12 14C ka BP were calibrated according to Hughen et al. (2000).

Results of the acoustic studies

Glacimarine and marine sediments, with a total thickness of up to 150 m, occur in the basin between the Skarpnes and the Tromsø-Lyngen moraines (Figs. 1C & 2). Four major seismostratigraphic units, A-D, have been identified (Fig. 3B). Compared to the stratigraphic classification by Vorren et al. (1989) (Fig. 2), unit B corresponds to the sediments inferred to have been deposited between 12 and 10 14C ka BP. Units C and D correspond to the sediments inferred by them to have been deposited during the last 10 14C ka.

Acoustic basement

The acoustic basement is, based on our data, partly defined by the Skarpnes moraine and partly by crystalline bedrock. Glacial deposits define the acoustic basement across the Skarpnes moraine. Further inwards in the basin, crystalline bedrock defines the acoustic basement. The maximum depth to basement, exceeding 200 m, occurs in a northeast to southwest directed trough in the central parts of the basin (Fig. 4). Across the Skarpnes moraine, the depth to basement is about 100 m. At Skardmunken-Hjellneset, the threshold between Ullsfjorden and Sørfjorden, the minimum depth to crystalline bedrock is about 100 m in the submarine channel (Figs. 2 & 4). At Hjellneset, the headland east of the channel, the depth is 80-100 m below present day sea level (Neeb 1981; Lønne 1993).

Unit A

The lowermost unit A occurs in the central and deepest parts of the basin (Fig. 5A). It has a volume of 0.16 km³. The maximum thickness, exceeding 50 m, is found in the deepest basement depressions. Unit A has an onlap fill geometry and appears acoustically transparent (Figs. 3B and 6). The upper boundary reflects to some degree the basement morphology (Fig. 3B), indicating that the unit has been compacted after deposition (“complex ponded stratigraphic style” according to Syvitski (1989)).

The origin of unit A could be 1) till deposits, 2) overridden glacimarine sediments, or 3) early deglaciation sediments deposited when the ice margin receded from the Skarpnes moraine position. Since unit A onlaps the Skarpnes moraine (Fig. 3B) we suggest alternative 3) as the most likely origin.

Unit B

Unit B is present in the entire basin (Fig. 5B). It has a volume of 0.75 km³. The maximum thickness exceeds 120 m in the inner southwestern part, near the Tromsø-Lyngen ice front position. We have not been able to map it further southwards, but according to Vorren et al. (1989) unit B corresponds to sediments that constitute the upper part of the submarine threshold between Ullsfjorden and Sørfjorden (Fig. 2). The unit thins along the western and eastern basinal margins. On top of the Skarpnes moraine erosional unit B-remnants are found (Fig. 3A).

Draped bedding and acoustic lamination characterise unit B (Fig. 6). The draping reflects even minor undulations of the subsurface. According to Syvitski (1989) this bedding style represents high suspension fallout and low bottom current activity. The acoustic lamination is more disrupted near the Tromsø-Lyngen ice front position than in the rest of the basin. Layers and lenses have a chaotic reflection pattern and interfinger...
Fig. 5. (A) Isopach map of unit A. The maximum thickness is found in the deepest basement depressions. (B) Isopach map of unit B. The maximum thickness is found near the Tromsø-Lyngen ice front position. (C) Isopach map of unit C. (D) Isopach map of unit D. Note different contour intervals.
the distinct lamination. They are supposed to represent gravity flow deposits (Fig. 3B).

On the 3.5 kHz records, vertical columns of acoustically transparent sediments cut the distinct lamination throughout unit B (Figs. 3A, 6 & 7). Additionally some blurring zones are present (Fig. 6). Along the western side of the basin unit B tends to be domal at a few sites. This is best exemplified in Fig. 7, where a dome structure cuts through the overlying units. These seismic signatures and structures indicate that fluids are present in the sediments (Hovland & Judd 1988; Plassen & Vorren 2003).

Unit C
Unit C covers the whole basin (Fig. 5C). It has a maximum thickness of about 20 m and a volume of 0.15 km$^3$. Across the Skarpnes moraine unit C is eroded in the central fjord (Fig. 3A), but is present as a thin cover on the eastern side of the moraine (Fig. 7). Three internal reflections can be followed throughout the basin (Figs. 3A & 7). The two lowermost ones are very distinct; the uppermost is broader and more diffuse. The sediments below the lowermost reflection have infill geometry and comprise about half the thickness of unit C (Figs. 3A & 7). This sediment package is acoustically transparent compared to the overlying semi-transparent sediments. The sediments above the lowermost reflection show some disturbance and indications of mass movement along the basin margins, especially along the slope of the Skarpnes moraine (Fig. 7).

In the southeastern part of the basin, unit C shows bulging over an area several hundred metres across (Fig. 6). In the central part of the bulged zone the two lowermost internal reflections terminate. The bulged zone is thought to represent fluid loaded sediments or mass movement deposits (Plassen & Vorren 2003).

Unit D
The uppermost unit D occurs in the central and eastern parts of the basin (Fig. 5D). It has a volume of 0.03 km$^3$ and a maximum thickness of about 7 m. On the 3.5 kHz records, the unit appears transparent (Figs. 3B & 6). Unit D wedges out towards the southwestern part of the basin and towards the Skarpnes moraine. This seismic signature and geometric pattern are characteristic of postglacial marine deposits in the Troms region (Plassen & Vorren 2002).

Many pockmarks found on the seafloor, cutting into unit D, or into the upper part of unit C where unit D is
absent (Fig. 7), indicate that fluids are escaping from the sediments (Hovland & Judd 1988; Plassen & Vorren 2003).

Results of the core studies

Core JM00-1380

Core JM00-1380 was recovered from the eastern side of the Skarpnes moraine (Figs. 1C & 7; Table 1). Four lithostratigraphic units (I-IV) are recognised in the core (Fig. 8). The physical property logs agree well with the lithology. Unit I shows marked differences in all logs, compared to the underlying units. The marked magnetic susceptibility peaks between 522 and 562 cm correspond to a clast-rich bed. Marked peaks in impedance, P-wave velocity and density in the lower part of this bed are due to two large clasts. The bed with frequent clasts at 980 cm is only marked with higher magnetic susceptibility values.

The upper unit I (0-15 cm) is a Holocene homogeneous calcareous silty sand with clasts. The three lowermost units comprise sediment with ice rafted debris (IRD), structures and fossils witnessing a glacimarine environment. Unit II (15-512 cm) is a bioturbated, diffusely laminated clayey silt, with few clasts and a *Portlandia arctica* fauna. Age determinations at 38 and 394 cm gave ages of 10580 ± 100 and 10950 ± 100 14C yr BP (12.49 and 12.9 cal. ka BP), respectively. Unit III (512-830 cm) is a laminated clayey silt with scattered clasts, except for the bed between 522 and 562 cm that is particularly rich in clasts. Unit IV (830-1029 cm) is a diffusely laminated clayey silt with *Nucula tenuis* and *Portlandia arctica*, and generally few clasts. The interval between 970 and 1005 cm is rich in clasts. A date at 930 cm gave an age of 11045 ± 95 14C yr BP (12.97 cal. ka BP).

Core JM00-1379

Core JM00-1379 was recovered from the northern central part of the basin (Figs. 1C & 7; Table 1). The physical property logs correspond well with the lithology, where layers with clasts and sand show marked peaks (Fig. 9). Three lithostratigraphic units (I-3) are recognised in the core. Unit 1 (0-38 cm) is a homogeneous bioturbated calcareous sandy silt. A date at 24 cm gave
Fig. 8. Core data for JM00-1380. Numbered horizons (4 and 5) refer to correlated seismic reflections in Fig. 7.

Fig. 9. Core data for JM00-1379. Numbered horizons (1-3) refer to correlated seismic reflections in Fig. 7.
an age of 5280 ± 85 14C yr BP (6.03 cal. ka BP). Unit 2 (38-260 cm) is a homogeneous bioturbated clayey silt. The great variability in the physical properties of the upper part is due to disturbance during sampling. Unit 3 (260-1055 cm) is a clayey silt with clasts and horizons of diffuse lamination. The uppermost part of unit 3, between 260 and 350 cm, is rich in clasts. Two sandy layers with normal grading occur between 390 and 455 cm. These layers are interpreted as turbidites. The interval between 850 and 920 cm contains clastic and sandy layers. Unit 3 contains a Bathyarca glacialis mollusc fauna. Dates at 309 and 704 cm gave ages of 9865 ± 95 and 10025 ± 95 14C yr BP (11.14 and 11.34 cal. ka BP). The occurrence of clasts (IRD) in unit 3 indicates a glacimarine environment with iceberg rafting.

Discussion

Correlation and age

We have not been able to sample seismostratigraphic unit A (Fig. 3B) but suggest it represents early deglaciation sediments. Unit A postdates the Skarpnes moraine. The age of the Skarpnes event is dated to c. 12.2 14C ka BP (Vorren & Elvsborg 1979). Thus we infer that c. 12.2 14C ka BP (14 cal. ka BP) is a maximum age for unit A. Vorren & Plassen (2002) estimated an average recession rate of 67 m/yr for the Fennoscandian Ice Sheet in the Astafjorden area after the Skarpnes event. Assuming the same order of recession rate in Ullsfjorden, the investigated basin was deglaciated during a period of less than 100 years. Perhaps the upper boundary of unit A signals a transition to a more distal environment when the glacier margins had receded to Sørfjorden and Kjosen. If so, unit A might have been deposited during a time span of about or less than 100 cal. years. Thus we tentatively suggest an age of 13.9 cal. ka BP (12.1 14C ka BP) for top unit A.

Core JM00-1380 was recovered from seismostratigraphic unit B (Fig. 7), except for the uppermost 15 cm. When comparing seismic signatures with the lithology and physical properties in core JM00-1380 (Figs. 7 & 8), it seems likely that the distinct seismic lamination represents sand and clast layers, and impedance contrasts caused by the sedimentary lamination. The marked impedance peaks at 550 cm represent two large clasts (Fig. 8), and are therefore excluded as a continuous reflection. The core levels at 360 and 940 cm are, based on impedance contrasts and depth, interpreted to represent two distinct reflection levels (4 and 5, Fig. 7).

The correlation from core site JM00-1380 to the basin is not straightforward, and is based on cross tying of seismic lines. The uppermost part of unit B may be disturbed and eroded along the slope of the Skarpnes moraine, but the deeper lying undisturbed horizons 4 (near the dated level of 10.95 14C ka BP) and horizon 5 (near the dated level of 11.05 14C ka BP) can be traced to the uppermost parts of seismostratigraphic unit B in the basin (Fig. 7).

ThePortlandia arcticafauna present in core JM00-1380, and thus the upper parts of unit B, are Younger Dryas, near glacier indicators in the region. However, it also occurs in sediments of supposedly Allerød age (Andersen 1968). Based on correlation with dated intervals and the fauna, we infer that unit B sediments represent Allerød as well as Younger Dryas. Correlation with the core indicates that the Allerød-Younger Dryas boundary, often cited to be 11 14C ka BP (Mangerud et al. 1974), lies about 7 m below unit B’s upper boundary in the basin (Fig. 7).

The Tromsø-Lyngen moraine appears today as a raised, sandy, ice-contact delta at Skardmunken and Hjellneset (Andersen 1968; Lønne 1993) (Figs. 1C & 2). Clayey sediments below the deltaic (ice-contact) sediments, obviously belonging to unit B, can be observed along the shore. Consequently, these clayey sediments on the submarine threshold predate the emerged Tromsø-Lyngen ice-contact delta. A date of 10.4 14C ka BP represents a phase when the main part of the ice-contact delta was deposited, but pre-dates a late Younger Dryas re-advance to the Skardmunken moraine position (Andersen 1968). This date indicates that most of unit B was deposited some time before 10.4 14C ka BP.

Core JM00-1379 was recovered from seismostratigraphic unit C (Fig. 7). The lithological/physical properties in the core can be correlated to the three marked seismic reflections (Figs. 7 & 9). The upper diffuse reflection corresponds to the zone of clasts and turbidites between 260 and 460 cm. The two lower distinct reflections probably correlate with the level of clasts at 640 cm and the impedance contrast at 760 cm, respectively. The dates show that seismostratigraphic unit C commenced accumulation before 10 14C ka BP, and continued to accumulate some time after 9.87 14C ka BP. The average sedimentation rate between the dates at 700 (11.34 cal. ka BP) and 300 cm (11.14 cal. ka BP) is 1.75 cm/cal. yr (excluding the turbidites). Extrapolating this value gives cal. ages of about 11.8 and 11 (10.2 and 9.5 14C ka BP) for the base and top of seismic unit C at this site, respectively. This age corresponds well with the fact that aBathyarca glacialisfauna occurs in the upper part of core JM00-1379. This is found elsewhere in the fjord region of Troms at the Younger Dryas/Preboreal transition according to Andersen (1968).

Tracing of dated levels from the core site on the Skarpnes moraine to the basin indicates that the uppermost date of 10580 14C ka BP of core JM00-1380 (Fig. 8), may correlate with the boundary between units B and C. However, this correlation is rather doubtful, since...
there are indications of disturbance and erosion along the slope of the Skarpnes moraine (Fig. 7). We infer therefore that the 14C-age of about 10.2 ka BP, based on extrapolation of the sedimentation rate, is more reliable for the boundary between seismostratigraphic units B and C. Based on this, the lowermost acoustically transparent part of unit C was deposited between about 10.2 and 10 14C ka BP.

Seismostratigraphic unit D is present only as a thin cover at the core sites (Fig. 7). In core JM00-1379, the middle part of the uppermost unit 1 was dated to 5.3 14C ka BP (Fig. 9). Assuming the lower boundary of unit D to be about 9.5 14C ka BP (11 cal. ka BP), then this unit represents sediments deposited in an open marine environment during the Holocene.

Sediment flux and sedimentation rates

Based on the calculated volumes and inferred ages for the seismostratigraphic units A-D, we have estimated sediment flux and sedimentation rates as shown in Table 2. Maximum sediment flux and sedimentation rate, of 294 kg/m²/cal. yr and 22 cm/cal. yr respectively, occurred during deposition of unit A, 14-13.9 cal. ka BP (12.2-12.1 14C ka BP). This result is assumed to reflect deposition in an ice proximal sedimentary environment.

The sediment accumulation decreased by an order of magnitude during deposition of unit B, 13.9-11.8 cal. ka BP (12.1-10.2 14C ka BP), a period including the Allerød glacial recession and the Younger Dryas re-advance. In core JM00-1380, representing the upper parts of unit B, at the Allerød/Younger Dryas transition, the average sedimentation rate between dated levels at 930 and 394 cm was 7.7 cm/cal. yr (5.6 cm/14C yr). Between the dated levels at 394 and 38 cm the average sedimentation rate was 0.9 cm/cal. yr (1.0 cm/14C yr). The average sedimentation rate between 930 and 38 cm was 1.9 cm/cal. yr (1.9 cm/14C yr). Based on the seismic data, average sedimentation rate during deposition of unit B was 1.9 cm/cal. yr (2.1 cm/14C yr). The thickness of unit B, of about 45 m at core site JM00-1379, gave estimated sedimentation rates of 4.2 and 0.6 cm/cal. yr (3.5 and 0.9 cm/14C yr) below and above the 11 14C ka BP (13 cal. ka BP) level, respectively. These results indicate that the sedimentation rate was markedly higher during the Allerød than during the Younger Dryas.

The unit C phase, 11.8-11 cal. ka BP (10.2-9.5 14C ka BP), had an average sediment flux and sedimentation rate somewhat lower than the unit B phase. The average sedimentation rate between dated levels in core JM00-1379 (excluding turbidites), in the upper parts of unit C, was 1.75 cm/cal. yr (2.2 cm/14C yr). Based on seismic mapping, the sedimentation rate was 1.1 cm/cal. yr (1.3 cm/14C yr) during deposition of unit C. Sedimentation rates in unit C were somewhat higher than the Younger Dryas estimate of unit B, and lower than the Allerød estimate.

Minimum sediment accumulation occurred during the Holocene when normal marine environmental conditions prevailed. A rate of 0.03 cm/cal. yr (0.04 cm/14C yr) was estimated from the seismic data.

Extremely high accumulation rates, exceeding 200 cm/yr, are found in modern, temperate, meltwater dominated glacial regimes in McBride Inlet, Alaska (Powell & Molnia 1989). Compared to this, a sedimentation rate of 22 cm/cal. yr during the early deglaciation of Ullsfjorden is not overwhelming. Sedimentation rates of 1-2 cm/cal. yr during the later part of the deglaciation are comparable to deglaciation results of 2.4 cm/yr in the fjord head of Kangerdlugssuaq Fjord, Greenland (Svitski et al. 1996), and to about 4 cm/yr in the Baffin Island fjords (Stravers & Svitski 1991). Deglaciation sedimentation rates from the Andfjord-Vågsfjord region (Plassen & Vorren 2002) are somewhat lower than the Ullsfjorden results, except for some high values estimated from cores during the early, final deglaciation. The low observed Holocene sedimentation rates compare well with Holocene sedimentation rates from the Andfjord-Vågsfjord region (Plassen & Vorren 2002), western Norwegian fjords (Aarseth 1997) and the Baffin Island fjords and shelf (Andrews 1987).

Table 2. Sediment flux and sedimentation rates

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<th>Unit</th>
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<th>Cal. ka BP Duration</th>
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Sediment flux and sedimentation rates based on the seismic stratigraphy and estimated from the isopach maps.
Sedimentary environment during the deglaciation

After the glacier front receded from the Skarpnes moraine position at about 12.2 \(^{14}\)C ka BP (Figs. 1C & 10A), seismostratigraphic unit A was deposited as infill sediments, in an ice proximal environment with high sediment accumulation (Fig. 10 B). The outlet fjord glacier from the Fennoscandian Ice Sheet (the "Ullsfjord glacier") was probably the main sediment source. The investigated basin is inferred to have been deglaciated during a time span of about or less than 100 years.

During the Allerød and main part of the Younger Dryas (about 12.1-10.2 \(^{14}\)C ka BP), seismostratigraphic unit B was deposited (Figs. 10C & 10D). The unit is characterised by the accumulation of laminated clayey silt which drapes the seafloor. Shorter phases of high IRD influx and gravity flowage occurred. Average sediment accumulation during deposition of unit B was an order of magnitude smaller than during the early deglaciation (unit A). During the Younger Dryas the glacier re-advanced to Skardmunkene-Hjellneset, and deposited the Tromsø-Lyngen moraine (Figs. 1C & 10D). The glacier advanced and eroded Allerød sediments. The moraine/ice-contact delta was accumulated on top of Allerød/early Younger Dryas laminated clayey silt.

Based on correlation with dated levels in core JM00-1380, the main part of unit B was presumably deposited during the Allerød. This implies that the sedimentation rate was higher during the Allerød than during the Younger Dryas. In other parts of the Troms region, the glacier fronts receded to the fjord heads during the Allerød (Eilertsen 2002; Vorren & Plassen 2002). Assuming the same situation in Ullsfjorden, the major part of unit B was deposited in a distal glacimarine environment, with a rather high sediment supply. Local valley glaciers as well as the "Ullsfjord glacier" were probably sediment sources. High sediment discharge to the fjords, during the Allerød recession, compared to the Younger Dryas re-advance, is also indicated from southerly parts of the Troms region (Vorren & Plassen 2002).

Seismostratigraphic unit C is supposed to have been deposited between about 10.2 and 9.5 \(^{14}\)C ka BP (Figs. 10E & 10F). During this period, the outlet fjord glaciers of the Fennoscandian Ice Sheet in Troms County retreated in a stepwise manner (Andersen 1968; Corner 1980). Unit C is characterised by clayey silt with IRD, in addition to sandy layers, some interpreted as turbidites. Average sedimentation rate was reduced compared to the unit B depositional phase, but was higher than the Younger Dryas estimate for this phase.

The upper parts of unit C, deposited after about 10 \(^{14}\)C ka BP, show signs of mass movement along the basin margins. This may relate to several rock avalanche and gravitational faulting events in Troms County shortly after the deglaciation (10-9.5 \(^{14}\)C ka BP), supposedly caused of palaeoseismic activity (Dehls et al. 2000). Another influential factor may have been exposure of unstable sediments on land due to a rapid early Holocene regression (Andersen 1968; Corner 1980; Hald & Vorren 1983). The Younger Dryas/Preboreal transition indicator \emph{Bathyarca glacialis} is present at core levels dated between 10025 and 9865 \(^{14}\)C yr BP. Lack of IRD in the upper parts of core JM00-1379 indicates that iceberg free conditions commenced about 9.8 \(^{14}\)C ka BP (Fig. 10F). It is therefore supposed that the sedimentary
environment changed some time between 10 and 9.8 14C ka BP from being tidewater glacier dominated to one where the main sediment supply was from glacier rivers draining onshore cirque and valley glaciers.

The open non-glacial marine environment is assumed to have commenced about 9.5 14C ka BP. The remainder of the Holocene is characterised by low sediment supply of sandy sediments, and the asymmetric distribution of unit D indicates a bottom current affected sedimentary regime (Fig. 10G).

Conclusions
1. The early deglaciation (about 12.2-12.1 14C ka BP) was characterised by an ice proximal environment with high sedimentation rates of 22 cm/cal. yr.

2. The Allerød recession and the Younger Dryas re-advance (about 12.1-10.2 14C ka BP) were characterised by accumulation of laminated clayey silt draping the seafloor. This alternated with shorter-lived phases of high IRD influx and gravity flowage. The average sedimentation rate was 1.9 cm/cal. yr.

3. The Allerød recession shows a higher sedimentation rate than the Younger Dryas re-advance.

4. The late Younger Dryas/early Preboreal withdrawal (about 10.2-9.5 14C ka BP) was characterised by deposition of clayey silt with IRD, in addition to sandy layers interpreted as turbidites. The average sedimentation rate of 1.1 cm/cal. yr was slightly higher than during the Younger Dryas re-advance. During the time interval 10-9.8 14C ka BP the sediment source changed, from fjord glacier to river input from onshore valley and cirque glaciers.

5. Mass movement at the Younger Dryas/Preboreal transition may be related to postglacial neotectonic activity and/or exposure of unstable sediments on land.

6. Normal marine conditions commenced about 9.5 14C ka BP. The remainder of the Holocene is characterised by very limited accumulation of sandy sediments, in a bottom current affected environment. The average sedimentation rate was 0.03 cm/cal. yr.

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