Deglaciation history and post-glacial mass movements in Balsfjord, northern Norway

Matthias Forwick & Tore O. Vorren

The deglaciation history of Balsfjord, northern Norway, and post-glacial mass movement events were investigated. Radiocarbon dates indicate that the Balsfjord glacier retreated from the Tromsø–Lyngen moraines about 10.4 ^{14}C Ky BP. Between ca. 10.3 ^{14}C Ky BP and 9.9 ^{14}C Ky BP, deposition of a distinct end moraine—the Skjevelnes moraine—in the central part of Balsfjord occurred. The transition from glacimarine to open marine sedimentary environment took place before 9.6 ^{14}C Ky BP. Between ca. 9.5 ^{14}C Ky BP and 8.4 ^{14}C Ky BP, at least one local and three regional mass movement events occurred. After this period, no gravity flow activity is preserved in the cores. The high frequency of mass movements in the early post-glacial period is presumed to be due to fast sea level changes and/or tectonic activity induced by rapid isostatic uplift.

M. Forwick & T. O. Vorren, Dept. of Geology, University of Tromsø, N-9037 Tromsø, Norway.

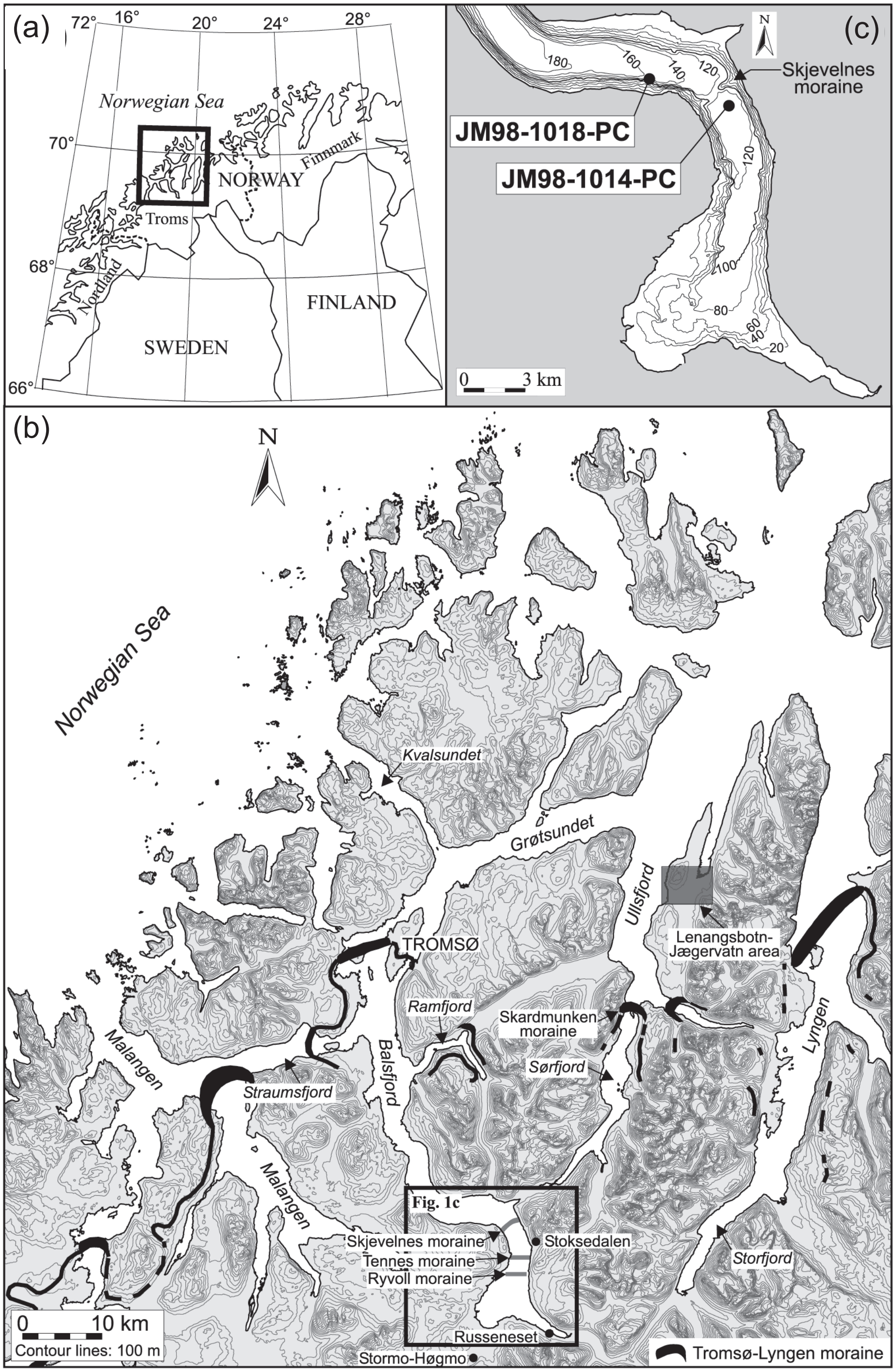
The aim of this study is to reconstruct the deglaciation history of Balsfjord, northern Norway, and to discuss post-glacial mass movement events. In Troms County, the glacier retreat from the Tromsø–Lyngen moraines (Fig. 1) occurred around 10.3 ^{14}C Ky BP or earlier, according to Andersen et al. (1995), Fimreite et al. (2001) and Vorren & Plassen (in press). Moraines inside the Tromsø–Lyngen moraines (Fig. 1b) were deposited during so-called Stordal events that were dated to Preboreal age (10.0 - 9.0 ^{14}C Ky BP) (Andersen 1968, 1980; Corner 1980). According to Andersen (1968), the Skjevelnes moraine in Balsfjord (Fig. 1b) was deposited during one of the Stordal events. During the subsequent retreat, the Balsfjord glacier deposited two minor end moraines, the Tennes and Ryvoll moraines (Fig. 1b) (Hansen 1998; Vorren et al. 2000). However, the exact datings are still poorly known.

During the final phase of deglaciation and the early post-glacial period, increased avalanche activity occurred in northern and western Norway (Blikra 1999; Longva et al. 1999; Blikra & Longva 2000; Dehls et al. 2000; Blikra et al. 2001). We analysed our material with the aim of finding the age and frequency of large mass movement events in Balsfjord.

Physiographic setting and oceanography

Balsfjord is 46 km long and 5 km across at its widest point (Fig. 1). The fjord is located in northern Norway, about 10 km south of Tromsø, and is surrounded by up to 1500 m high mountains, composed of metamorphic Caledonian nappes (Krogh 1992a, 1992b; Zwaan et al. 1998).

Close to the mouth, the fjord has its shallowest depth of about 35 m. The Skjevelnes moraine, at ca. 110 m water depth, divides Balsfjord's inner and outer basins (Fig. 1c). These have water depths of 130 m and 190 m, respectively. Water exchange between the fjord and the open ocean occurs via inlets (e.g. Straumsfjord, Kvalsundet, Grøtsundet) (Fig. 1b) having water depths ranging from ca. 20 m to about 200 m. Balsfjord is characterized by comparatively low fluvial input, relatively high water temperatures and no present-day influence by glaciers (Wassmann et



(a)
72°
16°
20°
24°
28°
Norwegian Sea
70°
Finnmark
NORWAY
Troms
68°
Nordland
FINLAND
SWEDEN
66°
(c)
N
180
160
140
120
Skjevelnes moraine
JM98-1018-PC
JM98-1014-PC
120
100
80
60
40
20
0
3 km
(b)
N
Norwegian Sea
Kvalsundet
Grøtsundet
Ullsfjord
Lenangsbotn-Jægervatn area
TROMSØ
Ramfjord
Skardmunken moraine
Sørfjord
Lyngen
Malangen
Straumsfjord
Balsfjord
Malangen
Fig. 1c
Skjevelnes moraine
Stoksedalen
Tennes moraine
Ryvoll moraine
Storfjord
Russeneset
Stormo-Høgmo
0
10 km
Contour lines: 100 m
Tromsø-Lyngen moraine

al. 1996). Svendsen (1995) describes Balsfjord as a fjord with "moderate run-off". Despite the shallow threshold at the mouth, as well as no direct connection to the open sea, an impact of warm and more saline Atlantic Water can be detected (Wassmann et al. 2000).

Material and methods

Two piston cores and onshore data provide the basis for this study. Core JM98-1018-PC (10.01 m long) was retrieved from a water depth of 160 m in the outer basin, about 2 km west of the Skjevelnes moraine, at 69° 21.19' N, 19° 15.74' E (Fig. 1c). The 9.96 m long core JM98-1014-PC was taken from 130 m water depth in the inner basin, less than 1 km south-east of the moraine (69° 20.38' N, 19° 21.41' E).

A lithostratigraphy for the cores (Fig. 2) was established based on the results of laboratory analysis, including Multi-sensor core logging of the whole core. X-radiographs were acquired from the split core. Undrained shear strength, using the fall cone test (Hansbo 1957), water content and carbonate content were measured. Sediment colour determination was based on the Munsell Soil Color Chart. Grain size analysis was carried out by dry sieving of fractions > 63 µm and Sedigraph measurements for material < 63 µm. A total of nine radiocarbon dates from bivalve tests was obtained from the cores (Fig. 2, Table 1).

Radiocarbon dating of paired shells (*Macoma calcarea*) from Stoksedalen was obtained to get a minimum age of deglaciation and the Skjevelnes moraine (Fig. 1, Table 1). The material was recovered 4 km proximal to the Skjevelnes moraine, about 30 m a.s.l. Dated samples of bivalves and balanoides from secondary sandy infill between large blocks from a rock avalanche at Russeneset, innermost Balsfjord (Fig. 1b, Table 1) are also of great importance for understanding the deglaciation chronology.

The dated material sampled from the cores was prepared at the Radiocarbon Laboratory in Trondheim, Norway, and measured at the Svedberg Laboratory in Uppsala, Sweden, using accelerator mass spectrometry (AMS). Samples from Russeneset were prepared and measured at the Radiocarbon Laboratory. Material from Stoksedalen was prepared and measured at the Leibnitz Labor for Radiometric Dating and Isotope Research, Christian-Albrechts University of Kiel, Germany. All dates were corrected for a reservoir effect of 440 years (see Mangerud & Gulliksen 1975) and calibrated using the INTCAL98 database (Stuiver et al. 1998). Standard deviation for the calibrated ages was ± 1σ.

Fig. 1 (opposite page). (a) Location map of the study area. (b) Map of the Balsfjord area. Locations of the Tromsø–Lyngen moraines (according to Andersen 1968 and Corner 1980), as well as moraines deposited by the Balsfjord glacier inside the Tromsø–Lyngen moraines, are shown. (c) Bathymetric map of Balsfjord, showing the locations of the cores analysed in this study.

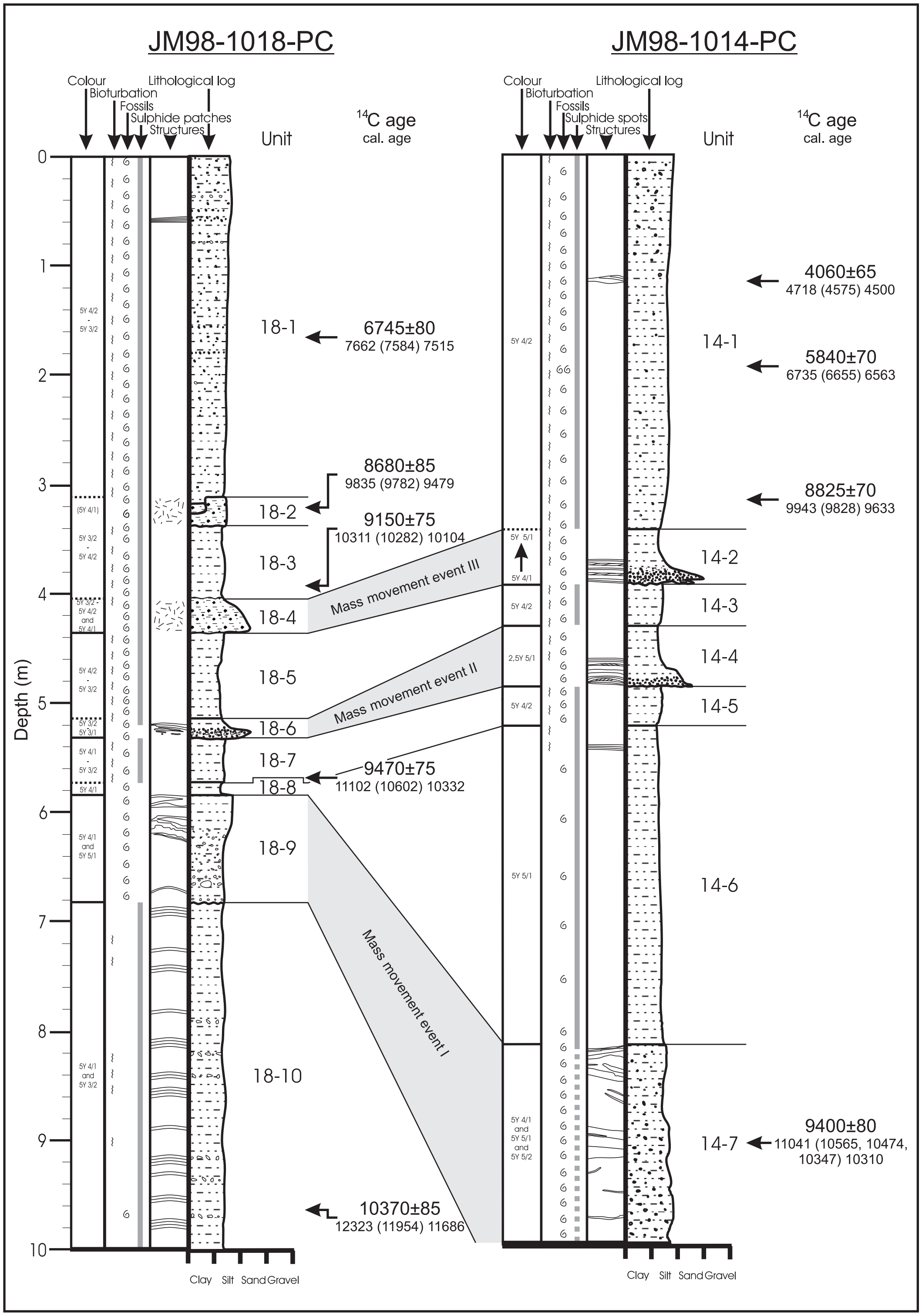
Lithostratigraphy / chronology

Core JM98-1018-PC was grouped into 10 units (Fig. 2). The lowermost unit of the core (unit 18-10) comprises cyclic glacimarine deposits. Two paired bivalves and one single shell (*Yoldiella lenticula*) from the lower part of this unit (967 cm) were dated to 10 370 ± 85 ^{14}C years BP (Fig. 2, Table 1). A coherent slump deposit (unit 18-9) that is covered with 11 cm of suspension fall-out sediments (unit 18-8) truncates the glacimarine sediments. Further upward, open marine sedimentation (units 18-7, 18-5, 18-3, 18-1) is interrupted by the deposition of gravity flows in the form of one high density turbidity current (unit 18-6) and two cohesive debris flows (units 18-4 and 18-2). Bivalve tests, taken close to the bases of units 18-7 and 18-3 were dated to 9470 ± 75 ^{14}C years BP and 9150 ± 75 ^{14}C years BP, respectively (Fig. 2, Table 1). One resedimented shell, dated to 8680 ± 85 ^{14}C years BP, was found in unit 18-2. The youngest dated sample from the core (taken from unit 18-1) yielded an age of 6745 ± 80 ^{14}C years BP.

Core JM98-1014-PC contains seven units (Fig. 2). Deposits of a mudflow (unit 14-7) are covered with suspension fall-out (unit 14-6). Further upward, open marine sedimentation (units 14-5, 14-3, 14-1) is interrupted by deposition of two low-density turbidites (units 14-4 and 14-2).

Within unit 14-7, a paired and resedimented shell was dated to 9400 ± 80 ^{14}C years BP (Fig. 2, Table 1). Three additional dates of 8825 ± 70 ^{14}C years BP, 5840 ± 70 ^{14}C years BP and 4060 ± 65 ^{14}C years BP were obtained from the open marine sediments composing unit 14-1.

Based on lithostratigraphy, radiocarbon dates


JM98-1018-PC
JM98-1014-PC
Colour
Bioturbation
Fossils
Sulphide patches
Structures
Lithological log
Sulphide spots
Unit
14C age
cal. age
Depth (m)
0
1
2
3
4
5
6
7
8
9
10
18-1
18-2
18-3
18-4
18-5
18-6
18-7
18-8
18-9
18-10
6745±80
7662 (7584) 7515
8680±85
9835 (9782) 9479
9150±75
10311 (10282) 10104
9470±75
11102 (10602) 10332
10370±85
12323 (11954) 11686
Mass movement event III
Mass movement event II
Mass movement event I
14-1
14-2
14-3
14-4
14-5
14-6
14-7
4060±65
4718 (4575) 4500
5840±70
6735 (6655) 6563
8825±70
9943 (9828) 9633
9400±80
11041 (10565, 10474,
10347) 10310
Clay Silt Sand Gravel

and calibrated ages, the following units of the sediment cores were correlated (Fig. 2): 18-9 and 14-7; 18-8 and 14-6; 18-7 and 14-5; 18-6 and 14-4; 18-5 and 14-3; and 18-4 and 14-2.

Radiocarbon dating of the onshore material yielded the following results. The shells from Stoksedalen were dated to 9900 ± 50 ^{14}C years BP, whereas the samples from Russeneset had ages of 9555 ± 75, 9610±80 and 9615 ± 70 ^{14}C years BP (L. H. Blikra, pers. comm.) (Table 1).

Discussion

Deglaciation history

Generally, the final retreat from the Younger Dryas moraines in Norwegian fjords occurred rapidly (e.g. Aarseth 1980; Corner 1980; Andersen et al. 1995). The onset of the final glacier retreat from the Tromsø–Lyngen moraines occurred around 10.3 ^{14}C Ky BP (see Andersen et al. 1995; Fimreite et al. 2001; Vorren & Plassen 2002). Andersen (1968) suggested that material sampled from folded glacimarine sediments on the proximal side of the Tromsø–Lyngen moraines at Skardmunken, in Ullsfjord (Fig. 1b), dated to 10 390 ± 200 ^{14}C years BP, was deposited prior to a late advance of the ice front.

The radiocarbon age of 10 370 ± 85 ^{14}C years BP sampled close to the bottom of core JM98-1018-PC from Balsfjord (Fig. 2, Table 1), at a site about 50 km proximal to the Tromsø–Lyngen moraines on Tromsø island and 30 km proximal to Skardmunken (Fig. 1), constitutes an apparent discrepancy with the observations of Andersen (1968) and Andersen et al. (1995), mentioned above. This is probably explained by the location of the dates on a ^{14}C plateau of the calibration curves (Stuiver et al. 1998).

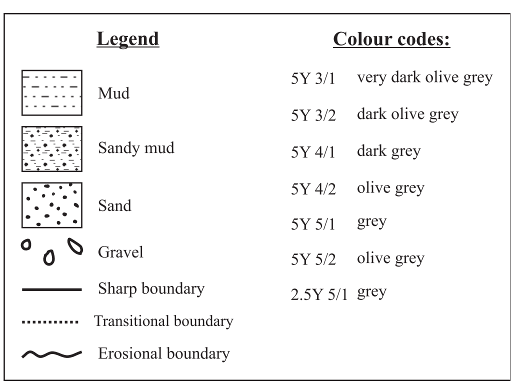
Assuming that the radiocarbon date of 10 370 ± 85 ^{14}C years BP from our study is reliable, it is suggested that the Balsfjord glacier started a rapid retreat from the Tromsø–Lyngen moraines about 10.4 ^{14}C Ky BP (Fig. 3). This suggestion supports the assumptions of Fimreite et al. (2001), as well as Vorren & Plassen (2002), that glacier retreat from the Tromsø–Lyngen moraines occurred prior to 10.3 ^{14}C Ky BP. Furthermore, it correlates with investigations carried out in Nordland County and southernmost Troms County, both in northern Norway (Fig. 1a), where Andersen et al. (1981) suggest that the Tromsø–Lyngen moraines and moraines correlated with them were deposited prior to 10.5 - 10.4 ^{14}C Ky BP.

The radiocarbon ages of 10 370 ± 85 ^{14}C years BP from core JM98-1018-PC (Fig. 2, Table 1) and 9900 ± 50 ^{14}C years BP from glacimarine sediments from Stoksedalen (Fig. 1b, Table 1) bracket the ages of the Skjevelnes moraine. More exact dating for the deposition of the Skjevelnes moraine is still difficult. Our data suggest that the Skjevelnes moraine was deposited between ca. 10.3 - 9.9 ^{14}C Ky BP (Fig. 3, Table 1). This means that the moraine was deposited during the final phase of the Younger Dryas or during the very early Preboreal. This suggestion supports observations from Andersen (1968), who mentions that a moraine at the mouth of Gratangen fjord could represent a phase between the Tromsø–Lyngen and the Stordal events.

During its retreat from the Skjevelnes moraine, the Balsfjord glacier deposited two minor end moraines: the Tennes and Ryvoll moraines (Hansen 1998; Vorren et al. 2000) (Figs. 1b, 3). Based on the radiocarbon dates from Stoksedalen and Russeneset (Fig. 1b, Table 1) (L. H. Blikra, pers. comm.; Blikra & Longva 2000), these were deposited between 9.9 and 9.6 ^{14}C Ky BP (Fig. 3).

The Russeneset dates also indicate that the whole of Balsfjord was deglaciated before 9.6 ^{14}C Ky BP. This accords well with the time of deglaciation of the neighbouring Lyngen fjord

Fig. 2 (opposite page). Lithostratigraphy of the studied cores. The occurrence of bioturbation, fossils and sulphide patches are presented. Sediment structures, division of the cores, radiocarbon ages and calibrated ages are also shown. Correlation of lithostratigraphic units is indicated. Legend (below) notes the sediment colours.



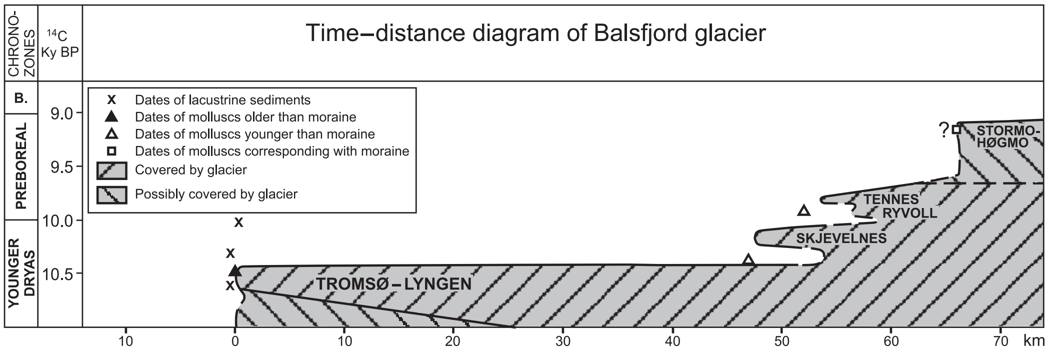


Fig. 3. Time–distance glaciation diagram of the Balsfjord glacier. Seen in a regional context, the age of the Stormo–Høgmo event is probably too young.

(Corner 1980). An onshore glacifluvial delta located at Stormo–Høgmo (Figs. 1b, 3) is dated to around 9.1 ^{14}C Ky BP (Table 1) (Andersen 1968). However, other dates in Troms (e.g. Eilertsen 2002) indicate that this is a minimum date.

Post-glacial mass movement events

Post-glacial sedimentation in Balsfjord has occurred from suspension fall-out, as well as by deposition from gravity flows (Fig. 2). The radiocarbon dates from Russeneset are taken from post-avalanche infill sediments (Blikra & Longva 2000). These dates indicate that avalanche activity commenced immediately after the deglaciation of the fjord. It is reasonable to believe that when gravity flow deposits occur synchronously on both sides of the Skjevelnes moraine, a regional trigger mechanism is indicated. The two cores indicate three syn-

Table 1. Overview of dated material. Radiocarbon ages are presented with ± 1σ standard deviation. Calibrated dates are presented as maximum cal. age, cal. age intercepts (in parentheses) and minimum cal. age, in that order. (Table continues next page.)

Location	Core depth (cm)	Occurrence	Dated material	Lab no.	Age (^{14}C BP)
Core JM98-1018-PC	967	Glacimarine sediments	*Yoldiella lenticula*	TUa-2508	10 370 ± 85
Core JM98-1018-PC	566.5	Marine sediments	*Nuculana pernula*	TUa-2507	9470 ± 75
Core JM98-1018-PC	399	Marine sediments	*Nuculana pernula*	TUa-2506	9150 ± 75
Core JM98-1018-PC	327	Debris flow deposit	*Hiatelle arctica*	TUa-2830	8680 ± 85
Core JM98-1018-PC	171.5	Marine sediments	*Yoldia hyperborea*	TUa-2829	6745 ± 80
Core JM98-1014-PC	906	Debris flow deposit	*Bathyarca glacialis*	TUa-2505	9400 ± 80
Core JM98-1014-PC	319.5	Marine sediments	*Yoldiella lenticula*	TUa-2504	8825 ± 70
Core JM98-1014-PC	198 - 200	Marine sediments	*Yoldia hyperborea* & *Nuculana pernula*	TUa-2503	5840 ± 70
Core JM98-1014-PC	115	Marine sediments	*Yoldia hyperborea*	TUa-2502	4060 ± 65
Stoksedalen	Sampled onshore	Glacimarine sediments	*Macoma calcarea*	KIA 9216	9900 ± 50
Russeneset	Sampled onshore	Secondary infill in rock avalanche	*Mya truncata*	T-13805	9555 ± 75
Russeneset	Sampled onshore	Secondary infill in rock avalanche	Balanoides	T-13806	9610 ± 80
Russeneset	Sampled onshore	Secondary infill in rock avalanche	Balanoides	T-13807	9615 ± 70
Stormo–Høgmo	Sampled onshore	? Bottomset beds of an outwash delta	*Macoma calcarea* & *Mya truncata*	T-510 B T-510 A	9100 ± 150 9190 ± 160

chronous events: mass movement events I, II and III (Fig. 2). They are represented by the units 18-9 and 14-7, 18-6 and 14-4, and 18-4 and 14-2, respectively. These events all occurred between ca. 9.5 ^{14}C Ky BP and 9.1 ^{14}C Ky BP. After that, one local gravity flow event, archived in core JM98-1018-PC, can be dated to around 8.4 ^{14}C Ky BP, calculated from linear sedimentation rates between the 6.7 ^{14}C Ky BP and 9.1 ^{14}C Ky BP levels.

Various factors, e.g. sea level fluctuations and earthquakes, affect slope stability in fjords (Syvitski et al. 1987). Triggering of gravity flows is a combination of several factors rather than the result of one single factor (Bjerrum 1971; Bøe et al. 2000).

A nearby shoreline displacement curve from Lenangsbotn–Jægervatn (for location see Fig. 1b; Corner & Haugane 1993), shows that the most rapid shoreline displacement occurred between ca. 10.0 and 8.5 ^{14}C Ky BP. It can thus be assumed that this time span of fast sea level change reflects a period with relatively high frequency of slope failures.

According to Bøe et al. (2000), one should expect a close correlation between a steep uplift gradient and earthquake frequency/magnitude. Blikra (1999), Blikra & Longva (2000), Blikra et al. (2001) and Dehls et al. (2000) mention that the period between 10.0 and 9.5 ^{14}C Ky BP is characterized by increased activity of rock avalanches due to seismic triggering. The results of this study indicate that the time period of increased regional avalanche activity can be extended until ca. 9.1 ^{14}C Ky BP. After 8.4 ^{14}C Ky BP, i.e. subsequent to the rapid rise of the shoreline at Lenangsbotn–Jægervatn (Corner & Haugane 1993), no gravity flow deposits are preserved in the cores (Fig. 2).

Range of calibrated ages (BP)	Reference
12 323 (11 954) 11 686	This paper
11 102 (10 602) 10 332	This paper
10 311 (10 282) 10 104	This paper
9835 (9782) 9479	This paper
7662 (7584) 7515	This paper
11 041 (10 565, 10 474, 10 347) 10 310	This paper
9943 (9828) 9633	This paper
6735 (6655) 6563	This paper
4718 (4575) 4500	This paper
11 597 (11 155, 10 946, 10 875) 10 848	This paper
11 122 (10 799) 10 369	L.H. Blikra (pers. comm.)
11 136 (11 022, 11 003, 10 820) 10 609	L.H. Blikra (pers. comm.)
11 136 (11 027, 10 999, 10 822) 10 615	L.H. Blikra (pers. comm.)
not calibrated	Andersen (1968)

Summary and conclusions

- The Balsfjord glacier retreated rapidly from the Tromsø–Lyngen moraines about 10.4 ^{14}C Ky BP.
- The Skjevelnes moraine was deposited between ca. 10.3 and 9.9 ^{14}C Ky BP, i.e. during the final phase of the Younger Dryas, or very early Preboreal.
- The Balsfjord glacier deposited the Tennes and Ryvoll moraines after 9.9 ^{14}C Ky BP, but before 9.6 ^{14}C Ky BP.
- Before 9.6 ^{14}C Ky BP, the glacier disappeared from the fjord.
- The period between 9.5 and 9.1 ^{14}C Ky BP is characterized by a high frequency of regional slope failures, suggested to be caused by effects of fast sea level change and/or seismic triggering due to isostatic rebound.
- One local mass movement event that occurred at ca. 8.4 ^{14}C Ky BP is preserved in one core.

Acknowledgements.—This work was financed by the Research Council of Norway through their funding of the Strategic University Programme SPINOF (Sedimentary Processes and Palaeoenvironment in Northern Fjords). The core material was collected in 1998 with the RV *Jan Mayen*. Steinar Iversen assisted during sampling of the cores. Jan P. Holm contributed with figures. Lars Harald Blikra, Norwegian Geological Survey, made dating material from Russeneset available to us. Finally, comments of two anonymous reviewers contributed to the improvement of the manuscript. To all these persons and institutions we extend our most sincere thanks.

References

Aarseth, I. 1980: Glaciomarine sedimentation in a fjord environment: example from Sognefjord. In O. Orheim (ed.): *Glaciation and deglaciation in central Norway. Field guide to excursion*. Pp. 16–21. Oslo: Norwegian Polar Institute.

Andersen, B. G. 1968: *Glacial geology of western Troms, north Norway. Nor. Geol. Unders. 256*. Oslo: Universitetsforlaget.

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

Andersen, B. G., Bøen, F., Nydal, R., Rasmussen, A. & Valelvik, P. N. 1981: Radiocarbon dates of marginal moraines in Nordland, north Norway. *Geogr. Ann. 63A*, 3–4.

Andersen, B. G., Mangerud, J., Sørensen, R., Reite, A., Sveian, H., Thoresen, M. & Bergström, B. 1995: Younger-Dryas ice-marginal deposits in Norway. *Quat. Int. 28*, 147–169.

Bjerrum, L. 1971: *Subaqueous slope failures in Norwegian fjords. Nor. Geotek. Inst. Publ. 88*. Oslo: Norges Geotekniske Institutt.

Blikra, L. H. 1999: Rock avalanches, gravitational faulting and its potential palaeoseismic cause. In J. Dehls & O. Olesen (eds): *Neotectonics in Norway: annual technical report. NGU Rapp. 99.007.* Pp. 88–92. Trondheim: Norges Geologiske Undersøkelse.

Blikra, L. H. & Longva, O. 2000: Gravitational-slope failures in Troms: indications of palaeoseismic activity? In J. Dehls & O. Olesen (eds): *Neotectonics in Norway: annual technical report. NGU Rapp. 2000.01.* Pp. 31–40. Trondheim: Norges Geologiske Undersøkelse.

Blikra, L. H., Longva, O. & Sletten, K. 2001: Palaeoseismic activity and gravitational-slope failures. In O. Olesen (ed.): *Neotectonics in Norway: final report. NGU Rapp. 2000.2*. Pp. 33–43. Trondheim: Norges Geologiske Undersøkelse.

Bøe, R., Hovland, M., Instanes, A., Rise, L. & Vasshus, S. 2000: Submarine slide scars and mass movements in Karmsundet and Skudenesfjorden, southwestern Norway: morphology and evolution. *Mar. Geol. 167*, 147–165.

Corner, G. D. 1980: Preboreal deglaciation chronology and marine limits of the Lyngen–Storfjord area, Troms, north Norway. *Boreas 9*, 239–249.

Corner, G. D. & Haugane, E. 1993: Marine-lacustrine stratigraphy of raised coastal basins and postglacial sea-level change at Lyngen and Vanna, Troms, northern Norway. *Nor. Geol. Tidsskr. 73*, 175–197.

Dehls, J. F., Olesen, O., Olsen, L. & Blikra, L. H. 2000: Neotectonic faulting in northern Norway; the Stuoragurra and Nordmannvikdalen postglacial faults. *Quat. Sci. Rev. 19*, 1447–1460.

Eilertsen, R. 2002: *Sedimentological and geophysical investigation of valley-fill sediments in Målselv, northern Norway.* Dr. Scient. thesis, University of Tromsø.

Fimreite, S., Vorren, K.-D. & Vorren, T. O. 2001: Vegetation, climate and ice-front oscillations in the Tromsø area, northern Norway during the Allerød and Younger Dryas. *Boreas 30*, 89–100.

Hansbo, S. 1957: *A new approach to determination of the shear strength of clay by the fallcone test. R. Swed. Geotech. Inst. Proc. 14.* Stockholm: Royal Swedish Geotechnical Institute.

Hansen, T. 1998: *Sedimentasjons- og deglasiasjonshistorien i Balsfjorden belyst med høyoppløselig seismikk*. *(Sedimentation and deglaciation history in Balsfjorden inferred from high-resolution seismics.)* Cand. Scient. thesis. University of Tromsø.

Krogh, E. J. 1992a: Den kaledonske fjellkjede dannes. (The origin of the Caledonian mountain range.) *Ottar 190(2)*, 17–26.

Krogh, E. J. 1992b: Geologien i Troms—rester etter gammel fjellkjede. (Geology of Troms—remnants of an old mountain range.) *Ottar 190(2)*, 3–8.

Longva, O., Blikra, L. H., Mauring, E., Thorsnes, T. & Reither, E. 1999: *Testprosjekt Finneidfjord; integrert skredfarekartlegging—metodevurdering. (Pilot project Finneidfjord; integrated hazard mapping of avalanches—an evaluation of the methods.) NGU Rapp. 99.051.* Trondheim: Norges Geologiske Undersøkelse.

Mangerud, J. & Gulliksen, S. 1975: Apparent radiocarbon ages of recent marine shells from Norway, Spitsbergen, and Arctic Canada. *Can. Quat. Res. 5*, 263–272.

Stuiver, M., Reimer, P. J., Bard, E., Beck, J. W., Burr, G. S., Hughen, K. A., Kromer, B., McCormac, G., van der Plicht, J. & Spurk, M. 1998: INTCAL98 radiocarbon age calibration, 24,000 - 0 cal BP. *Radiocarbon 40*, 1041–1083.

Svendsen, H. 1995: Physical oceanography of coupled fjord–coast systems in northern Norway with special focus on frontal dynamics and tides. In H. R. Skjodal et al. (eds.): *Ecology of fjords and coastal waters: proceedings of the Mare Nor Symposium on the Ecology of Fjords and Coastal Waters, Tromsø, Norway, 5 - 9 December, 1994.* Pp 149–164. Oxford: Elsevier.

Syvitski, J. P., Burrell, D. C. & Skei, J. M. 1987: *Fjords: processes and products.* New York: Springer.

Vorren, T. O., Corner, G. D., Dahlø, A., Forwick, M., Grøsfjeld, K., Eilertsen, R., Hald, M., Husum, K. & Plassen, L. 2000: Sedimentary processes and palaeoenvironment in northern fjords—preliminary palaeoclimatic results. Paper presented at the symposium Rapid Oceanographic Changes in the Arctic: Causes and Effects. Danish Meteorological Institute, Copenhagen, Denmark, 13 April.

Vorren, T. O. & Plassen, L. 2002: Deglaciation and palaeoclimate of the Andfjord–Vågsfjord area, north Norway. *Boreas 31*, 97–125.

Wassmann, P., Reigstad, M., Øygarden, S. & Rey, F. 2000: Seasonal variation in hydrography, nutrients, and suspended biomass in a subarctic fjord: applying hydrographic features and biological markers to trace water masses and circulation significant for phytoplankton production. *Sarsia 85*, 237–249.

Wassmann, P., Svendsen, H., Keck, A. & Reigstad, M. 1996: Selected aspects of the physical oceanography and particle flux in fjords of northern Norway. *J. Mar. Syst. 8*, 53–71.

Zwaan, B. K., Fareth, E. & Grogan, P. W. 1998: *Geologisk kart over Norge; berggrunnskart Tromsø, M 1:250 000. (Geological map of Norway; bedrock map of Tromsø, scale 1:250 000.)* Trondheim: Norges Geologiske Undersøkelse.