Mid and Late Weichselian, ice-sheet fluctuations northwest of the Svartisen glacier, Nordland, northern Norway

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During the last decade, general Quaternary geological mapping in Nordland county, northern Norway, has provided field-data, supported by radiocarbon dating, which have been used as a basis for reconstructing the palaeoclimatic and glacial history for the interval 40-10 ka BP. Much of the lateglacial (13-10 ka BP) history was known from previous investigations, but the new results necessitate significant modifications in some areas. These include both ice extension, mainly during the Younger Dryas Chron, and glacial conditions, as well as timing of events. Radiocarbon dating of shells from sediments underlying and overlying till from the previously described ice phase, the Vassdal event, also referred to as Substage A which is represented by the Vega Moraine farther south, indicates that this ice advance represents the Older Dryas ice advance northwest of Svartisen, central Nordland at c. 12.2 ka BP. Earlier knowledge of the glacial variations and palaeoclimate during the late glacial maximum (30-13 ka BP), and the Middle Weichselian intervals before that, was very modest for the central and southern parts of Nordland county. The new data suggest that there were significant glacial and palaeoclimatic variations during most of the interval 40-13 ka BP. Occurrences of shells of the marine mollusc Arctica islandica, e.g., on the island of Åmøya, indicate that temperate Atlantic water reached the coast of Norway at least as far north as 66°47' N latitude at c. 32-38 ka BP. Similar occurrences of shells with an age of c. 41-42 ka BP are reported from sites farther north, e.g. at 67°20' N, 68°48' N and 69°42' N. The associated temperate sea-surface conditions occurred contemporaneously with fern growing in the inland area at Hattfjelldal, southern Nordland. Major ice advances occurred three times separated by significant ice-retreat phases in the area northwest of the Svartisen glacier between 30 and 13 ka BP.

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Introduction

Studies of the Quaternary geology along the coast of central Nordland, northern Norway, some 20–30 years ago revealed a detailed deglaciation history supported by radiocarbon dating of numerous shell samples from this area (Andersen 1975, Andersen et al. 1981, 1982, Rasmussen 1981, 1984). The Geological Survey of Norway carried out Quaternary geological mapping in the fjord and inland areas of Nordland in the same period (e.g., Alstadsæter 1981, Alstadsæter & Hollund 1981a, b, Follestad 1981, 1989, 1990, Sveian & Vallevik 1983, Sveian 1984a, b), and has continued working in these areas also during the last decade (e.g., Follestad 1992, 1993, Bergstrøm 1995, Bargel & Olsen 1996, Olsen et al. 1996a, b, 1997, 2000a, b, c, Olsen 2000, Olsen & Bergstrøm 2000a, b). Some geological reconnaissance studies have also been performed in the Saltfjellet – Svartisen region in recent years (Gjelle et al. 1995). All this effort has provided new data that require some extensions and modifications of the last deglaciation history described by Andersen and co-workers during the period 1975–1984, and reviewed by Andersen et

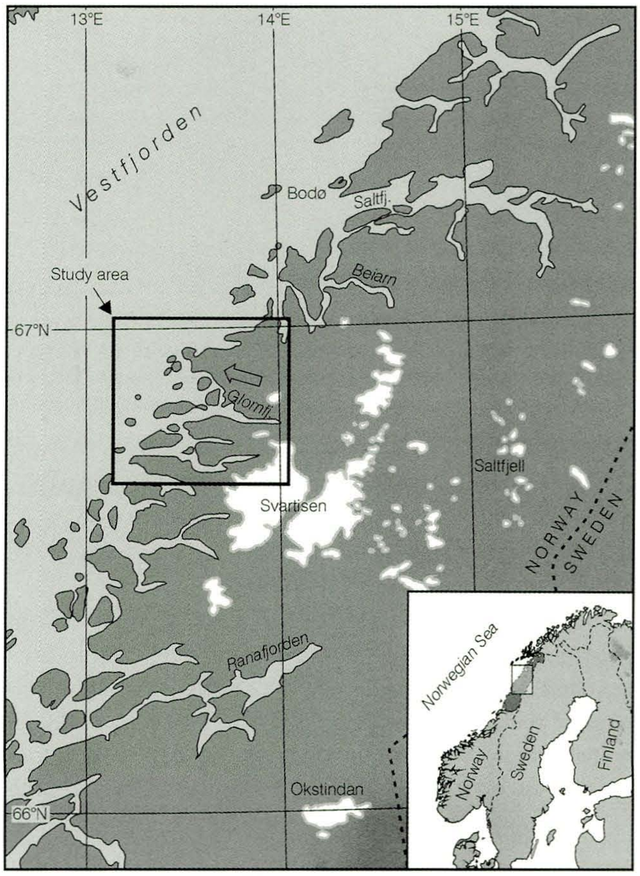

Fig. 1: Location map of the study area. The main ice-flow direction is indicated (broad arrow). Nordland county is indicated by shading (dark grey) on the inset map.

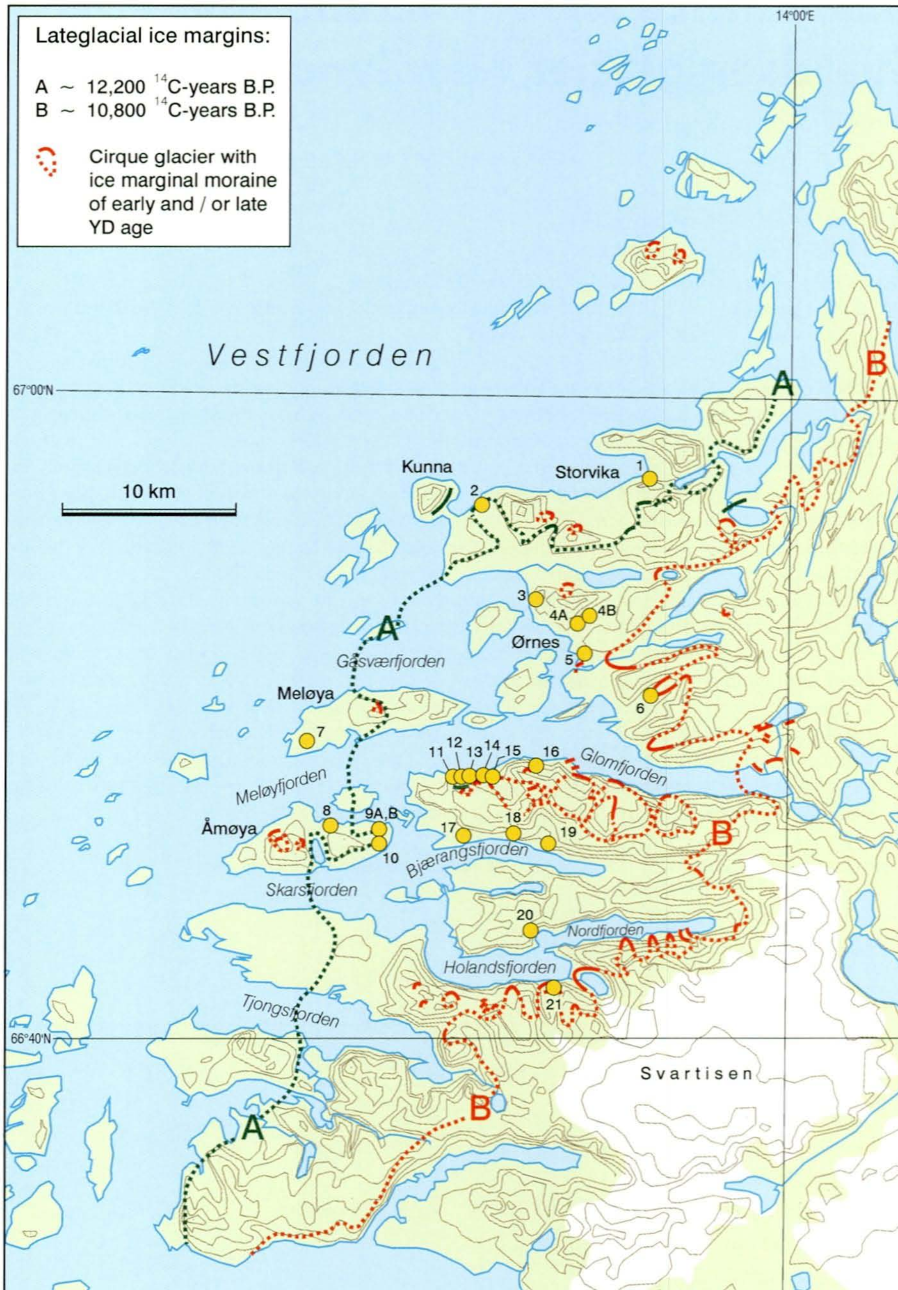

Fig. 2: Location of stratigraphic sites and dates. Inferred position of ice margin at c. 12,200 ^{14}C-yr BP, as well as during the main Younger Dryas (YD) ice advance are indicated. Cirque glaciers during the YD interval, with location both distally and proximally to the main YD ice margin position are also included. The precise age of the early lateglacial moraine (thick line) at Kunna is not known. For names of sites and comments, see Table 1.

al. (1995), but more important, the field data and radiocarbon dating during the last decade have provided a considerably improved understanding of the last glacial intervals prior to the last deglaciation in this area.

The aim of this article is to present some of the Quaternary stratigraphic information and radiocarbon dates acquired during the last decade, mainly from the area northwest of the Svartisen glacier (Fig.1). In addition, palaeoclimatic interpretations and a model of the ice-sheet fluctuations based on the new data are presented, including some comparisons with the newly published model of rapid shifts in glacial extensions during the last glaciation in Norway (Olsen 1997, Olsen et al. 2001a, b, c).

Geology and climate

The bedrock in the coastal area west and northwest of the Svartisen glacier consists of two almost equally extensive (surficially outcropping) groups of rocks, both of which form part of the Caledonian mountain chain. These are the mica schists, mica gneisses and marbles of the Rødingsfjellet Nappe Complex; and subjacent, parautochthonous to allochthonous granites and granodiorites of Precambrian (Mesoproterozoic) age.

The landscape of this region is a typical fjord landscape with fjords of variable dimensions and numerous islands and islets immediately offshore. The fjords are oriented mainly east-west, which made them the preferred routes for rapid ice flow from the east to the shelf during the numerous Pleistocene ice-growth periods. The present climate in this area is typical for the temperate North Atlantic zone, with humid and fairly warm summers, relatively wet winters, and winter temperatures often at or just below 0°C. Annual mean precipitation ranges from c. 1500 mm in the west to 2500 mm in the inner fjord areas and 3000 – 4000 mm in the mountain areas in the east. Mean temperature for the coldest month (January) is +4 to 0°C at the outer coast, 0 to -4°C in the fjord areas, and -4 to -8°C in the east where the Svartisen glacier is located. Mean temperature for the warmest month (July) is 12–16°C in the fjord areas and 8–12°C in the mountain areas. These data represent the 1931–1960 normal period (e.g., Dannevig 1985), but is not much different today.

Methods

Standard stratigraphical methods employed at the Geological Survey of Norway were used at some few localities during the course of this work (Figs. 2–3; Table 1), but in most cases only reconnaissance studies were carried out. More work is therefore required before attempts are made

Table 1: Stratigraphical sites (1-21) referring to Fig. 2.

No.	Site name	Comments
1	Storvika**	Diamicton (till); late Younger Dryas (YD)
2	Skogreina* (Bolden)	Older Dryas (OD) moraine + MW deposits
3	Stigen*	OD till
4	Åsmoen* (4A, 4B)	OD till + LW/MW deposits
5	Djupvika**	YD till; late YD
6	Neverdalen*	Diamicton/glaciomarine sediment; OD
7	Meløya	LGM 2 till
8	Furumo**, Åmøya	Diamicton; late YD (after Rasmussen 1981)
9	Bogneset** (I, II)	Diamicton (YD) + LW/MW deposits
10	Stamnes*	Diamicton (OD) + Bølling glaciomarine sed.
11	Vargvika*	Diamicton (OD) + Bølling glaciomarine sed.
12	Gammalmunnåga	LW/MW till + older sediments
13	Ytresjøen	LW till + MW till and sediments
14	Vassdal ferry quay	LW/MW till + MW sediments
15	Vassdal	LW/MW till + older sediments
16	Sandvika*	OD till + older till and sediments
17	Aspåsen	LW/MW till
18	Oldra	LW/MW tills and glaciomarine sediments
19	Kjelddal (I-II)	LW/MW tills and glaciomarine sediments
20	Nattmålsåga*	OD/Allerød deglaciation sediments
21	Fonndalen*	YD moraine + Allerød deglaciation sediments

* Stratigraphy associated with the OD glacial oscillation.
** Stratigraphy associated with the ice shelf extension during the YD interval.

to reconstruct maps of detailed ice-flow patterns for each ice-advance phase. However, the preliminary studies involved both ^{14}C and AMS-^{14}C dating of marine mollusc shells, amino acid measurements of a few shell samples, and, with variable success, attempts to find foraminifera and dinoflagellates in some sediment samples. The results of these analyses have been used for preliminary interpretations of palaeoclimatic and glacial variations.

Conventional radiocarbon dating of shell samples was carried out at the Radiological Dating Laboratory in Trondheim, Norway (T numbers; Table 2), and AMS dating was performed at the T. Svedborg Laboratory, Uppsala University, Sweden (TUa numbers) and at the R.J. Van de Graaff Laboratory, Utrecht University, The Netherlands (UtC numbers). Some of the AMS dates were obtained from the dating of bulk organic sediment fractions with > 90–95 % plant remains. The samples for AMS-dating in Uppsala were prepared, and graphite targets produced, at the Radiological Dating Laboratory in Trondheim. All ages cited in this article, if not otherwise indicated, are in radiocarbon years before the present (BP).

Table 2: Radiocarbon dates (conventional and AMS) of shells and sediments (organic fraction with > 90-95 % plant remains).

Locality	Field no.	Lab. no.	Weight of C	Mollusc shell	$d^{13}C$	^{14}C-yrs.	+/- 1sd
Meløya	13.-98	UtC-8310	1.98 mg	One shell fragment	2.7	38 200	700
Skavika, Ågskaret	M6-92	T-10798		Div. species	*	11 865	60
Stamnes, Åmøya	M5-92	T-10541		Div. species	*	12 420	105
Bogneset I, Åmøya	M4-92	T-10540		Div. species	*	32 100	2600
Bogneset I, Åmøya	2.-6/6-93	TUa-947		Div.	*	40 025	965
Bogneset I, Åmøya	II-6/7-94	TUa-1239		Arctica islandica, a.o.	*	35 940	1455
Bogneset I, Åmøya	III-6/7-94	TUa-1240		Div.	*	28 355	430
Bogneset I, Åmøya	IV-6/7-94	TUa-1241		Arctica islandica, a.o.	*	38 090	1675
Bogneset II, Åmøya	1.-17/6-94	T-11784		Mya	*	11 165	105
Storvika, Gildeskål	2.-14/9-95	UtC-4727		One shell fragment	-6.1	11 110	80
Skogreina	1.-5/6-93	TUa-743		Div. species	*	38 545	835
Skogreina	3.-5/6-93	TUa-946		Div. species	*	37 730	735
Skogreina	2.-5/6-93	TUa-1092		Div. species	*	38 060	710
Stigen	19.-98	UtC-8314	1.98 mg	One shell fragment	1.1	12 200	60
Åsmoen, Ørnes	M7-92	TUa-567		Hiatella arctica	*	28 355	235
Åsmoen, Ørnes	05.06.93	TUa-744		Macoma, a.o.	*	12 520	85
Mosvollelva, Ørnes	08.07.94	TUa-1094		Fragm. of one species	*	29 075	370
Djupvika, Ørnes	M8-92	T-10543		Macoma calcarea	*	10 430	185
Vargvika	M3-92	T-10797		Div. species	*	12 450	195
Gammalmunnåga	M2-92	T-10539		Hiatella, Mya, Macoma	*	> 44.800	
Ytresjøen	22.-98	UtC-8315	2.18 mg	Fragm. of one species	0.4	28 720	240
Ytresjøen	23.-98	UtC-8316	2.19 mg	One shell fragment	1.9	35 500	600
Vassdal ferry quay	1.-6/6-93	TUa-944		Div. species	*	35 280	575
Vassdal	M1-92	T-10796		Div. species	*	30 610	3950
Holmåga	11.-98	UtC-8308	2.16 mg	One shell fragment	1.8	9 059	39
Sandvika	12.-98	UtC-8309	1.95 mg	One shell fragment	0.3	12 600	60
Neverdalsvatnet	1.-7/7-94	T-11785		Chlamys islandica	*	12 520	205
Nattmålsåga	1.-14/9-95	T-12567		Div. species	*	11 975	155
Fonndalen	21.-96	UtC-5465		Fragm. of one species	0.66	11 990	60
Aspåsen	1.-27/7-95	TUa-1386		Div. species	*	36 455	530
Oldra	2.-30/9-93	TUa-745		Div. species	*	32 510	395
Oldra	1.-20/7-95	TUa-1385		Mya truncata	*	33 040	315
Oldra II	3.-20/7-95	TUa-1387		One shell fragment	*	33 975	515
Kjelddal I	15.-98	UtC-8311	2.36 mg	One shell fragment	1.4	35 800	600
Kjelddal II	17.-98	UtC-8312	2.06 mg	One shell fragment	-1	33 700	400

Locality	Field no.	Lab.no.	Fraction	Weight of C	Material	$d^{13}C$	^{14}C-yrs.	+/- 1sd
Meløya	14.-98	UtC-8456	INS	0.53 mg	>90-95% plant remains	-25.4	17 700	80
Kjelddal I	16.-98	UtC-8457	INS	0.33 mg	>90-95% plant remains	-24.8	18 880	100
Kjelddal II	18.-98	UtC-8313	INS	1.57 mg	>90-95% plant remains	-24.5	24 858	161

$d^{13}C$: ratio $^{13}C/^{12}C$ in per mil with respect to PDB-reference.
* : Estimated $d^{13}C$-value.

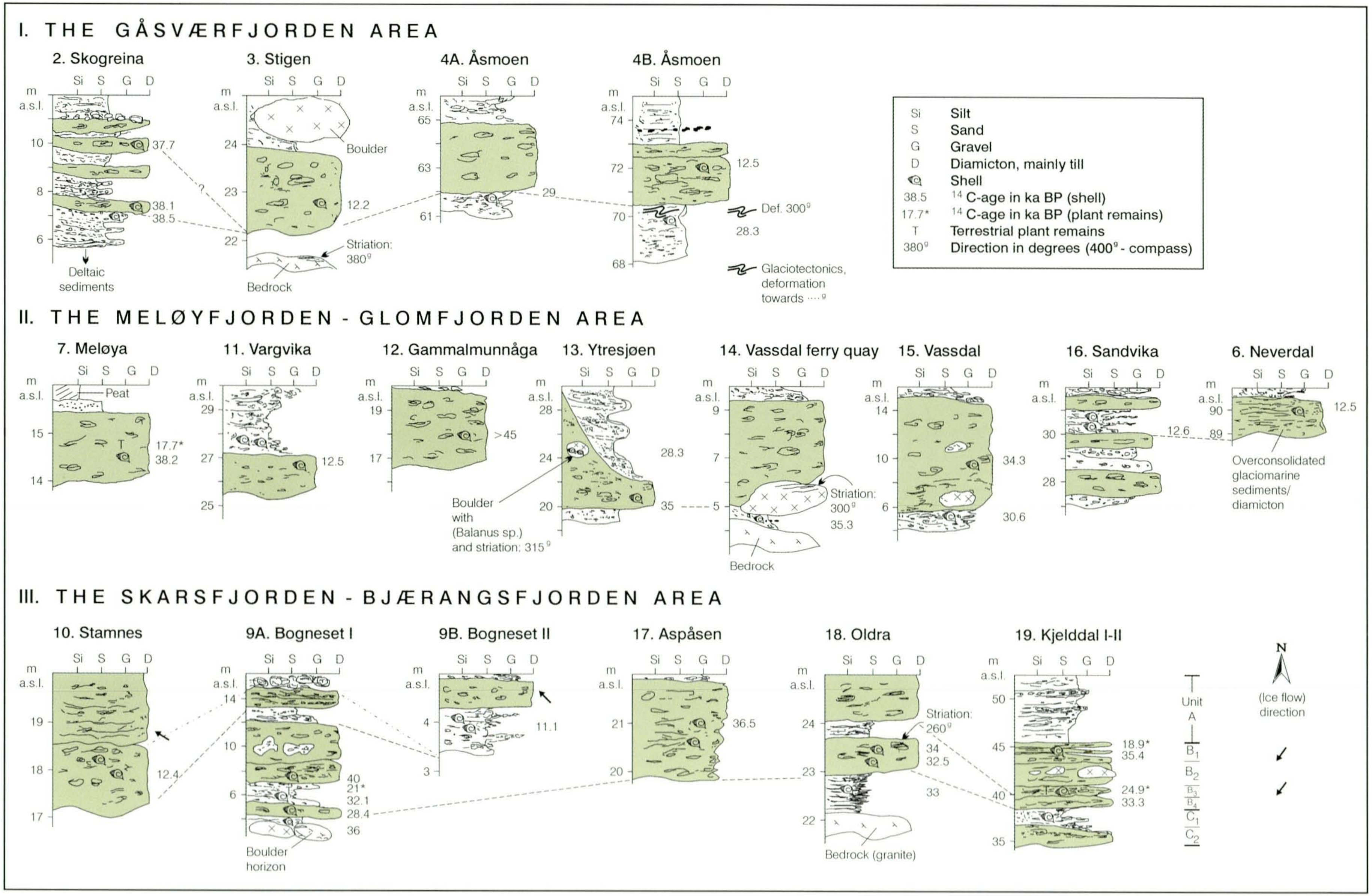

Fig. 3: Generalised stratigraphical logs from various sites in the described areas.

Amino acid racemization (AAR) measurements of shell samples were carried out at the Department of Geology, University of Bergen. Eleven samples were measured, the objective being to distinguish shells dating to between 35,000 and 45,000 yr old and those of Early Weichselian or older age, which is beyond the range of the radiocarbon method. This led to the identification and exclusion of 4 pre-Middle Weichselian samples (Table 3). For details of the analytical and preparation procedures see, e.g., Miller & Brigham-Grette (1989).

Foraminifera were separated following standard methods described by, e.g., Steinsund & Hald (1994). Heavy liquid with specific weight 1.8 g/cm^3 was used during separation. Results of the analyses are briefly mentioned in the text and, for one site (Kjelddal), included in Table 5.

Standard palynological procedure for the preparation and analysis of dinoflagellates (Barss & Williams 1973) was followed. Hydrofluoric acid (50% concentration) and hydrochloric acid (10% conc. HCl) were used to dissolve the minerals. The material was sieved through a 0.01 mm mesh. To calculate the productivity of the dinoflagellate cysts, spores of *Lycopodium clavatum* were added. One tablet contains 13,911 spores, and one tablet per sample was added. Ultrasonic treatment for maximum 60 seconds was used to remove the organic particles which stick to the palynomorphs, and to concentrate the palynomorphs. The organic material was finally cast in Elvacite to produce the preparates.

At least 300 dinocysts are generally counted per sample in order to obtain proper statistics with regard to environmental interpretations. This is possible where the productivity of dinoflagellate cysts is high, but in this work the sediments used have only low and very low productivity. Therefore, during these preliminary studies the counting was stopped at lower levels, but this was high enough to obtain the main trends recorded.

Results and interpretations

At the Arctic Circle in the coastal part of Nordland, some radiocarbon dates of bulk-organic sediment samples and marine mollusc shells in tills and sub-till sediments suggest that the last major ice advances beyond the coastline occurred after the period 18–28 ka BP (Table 2, Fig. 2). Stratigraphic successions and various data from some key areas which are presented briefly below, constitute the main basis for the interpretations given in this article. The areas are described from north to south and the localities, in most cases, from west to east (Fig. 1).

The Gåsværfjorden area

Radiocarbon dating of shells and the stratigraphy from four sites in this area (sites 2–5, Fig. 2), including amino acid measurements of a shell fragment from site 2 (Tables 2–3), reveal a complex palaeoclimatic and glacial history with redeposition of marine sediments from the last interglacial (the Eemian), the Middle Weichselian interstadial-complex (30–39 ka BP), the lateglacial Bølling Chron and the Younger Dryas (YD) Chron.

At *Skogreina* (site 2, also named Bolden, Rasmussen 1981; Fig. 2), an ice-marginal glacial-glaciofluvial complex terrace (the Skogreina Moraine) may encompass most of the above-mentioned history. A glaciofluvial deltaic terrace containing resedimented Eemian – Middle Weichselian marine shells is overlain by 1–4 metres of till with intercalated sand beds (Fig. 3), and overlain by a wave-washed ice-marginal moraine on top in the proximal parts. The surface of this site is located 12–15 m a.s.l., and is covered by shore deposits (mainly boulders, cobbles and pebbles) produced from heavily wave-washed and redeposited glacial-glaciofluvial material. AMS-^{14}C dating and amino acid measurements of fragments of marine shells (Table 2, TUa-743, 946 & 1092, Table 3) found in gravelly sand in the till-covered distal part of the complex indicate Eemian – Mid Weichselian ages of the redeposited sediments. It is supposed that the lower part of the complex represents an ice-marginal formation from a Mid Weichselian glaciation, possibly from the ice-advance that occurred at c. 40 ka BP (Olsen 1997, Olsen et al. 2001a, b), or a younger ice-margin oscillation c. 28–29 ka BP (see below). The moraine-covered proximal part is thought to represent the ice-marginal formation of the lateglacial Substage A (the Older Dryas (OD) cold phase) some 12–12.5 ka BP (Rasmussen 1981, Andersen et al. 1981, Gjelle et al. 1995).

At *Stigen* (site 3, Figs. 2–3), in a proximal position to the

Table 3: Amino acid ratios – site name and inferred age of shells are included.

No.	Lab. refr.	Location	Field no.	m a.s.l.	Species	HYD	Average/ std. dev.	FREE	Average/ std. dev.	Probable age based on the AAR ratios
1	BAL 3392	Skogreina	1-5/6-93	10	*Mya?*	0.158	0.156	0.36	0.361	Early Weichselian -
						0.154	0.003	0.361	0.001	Eemian
2	BAL 3393A	Vassdal	1-1/10-92	5	*Cardium*	0.022	0.022	ND		Postglacial age
					edule	0.021	0.001	ND		
	BAL 3393B	Vassdal	1-1/10-92	5	*Cardium*	0.021	0.018	ND		Postglacial age
					edule	0.015	0.004	ND		
3	BAL 3394	Gml.m.åga	2-1/10-92	20	*Mya*	0.113	0.114	0.382	0.395	Early Weichselian -
						0.115	0.001	0.407	0.018	Eemian
4	BAL 3395	Bogneset	4-25/8-96	8	*Arc. isl.*	0.105	0.1	0.276	0.273	Mid Weichselian
						0.095	0.007	0.27	0.004	

Skogreina ice-marginal deposit and distally to the YD – moraines, there is a coarse-grained till containing shell fragments of lateglacial age. An AMS-^{14}C date of one of these shell fragments yielded an age of 12,200 +/- 60 ^{14}C-yr BP (Table 2, UtC-8314), which indicates that a lateglacial ice advance of pre-YD age (the OD – ice advance) reached beyond this site after 12.2 ka BP.

At *Åsmoen* (sites 4A–4B, Fig. 2), c. 1 km from Ørnes and some few kilometres distally to the Younger Dryas ice marginal zone, till-covered ice-marginal, outwash-sediments indicate, in part, a similar history to that recorded at Skogreina. AMS-^{14}C dating of shell fragments from the sub-till sediments indicates that these ice-marginal sediments have a maximum age of c. 28–29 ka BP (Fig. 3, Table 2, TUa-567 & 1094), indicating an ice-marginal position in the vicinity of Åsmoen approximately at this time or later. A radiocarbon dating of a shell fragment from the overlying till gave an age of c. 12,520 +/- 85 ^{14}C-years BP (Table 2, TUa-744), which indicates that the Older Dryas ice advance reached beyond the Åsmoen site after c. 12.5 ka BP.

Radiocarbon-dated shell in till at Djupvika (site 5, Fig. 2, and Table 2, T-10540) indicates that an ice advance in the last part of the Younger Dryas Chron reached at least slightly beyond this site, which is located c. 2–3 km distally to the main ice-marginal zone during the YD interval.

The Meløyfjorden – Glomfjorden area

Radiocarbon dating and amino acid measurements of shells and stratigraphy from eight sites in this area (sites 6, 7 & 11–16, Figs. 2–3) reveal a similar palaeoclimatic and glacial history as in the Gåsværfjorden area (see above).

At *Meløya* (site 7, Figs. 2–3), distally to the Substage A (Older Dryas) moraines, a fine-grained, compact, bluish-grey lodgement till contains redeposited shell fragments and other marine as well as terrestrial organic material (Olsen et al. 2001c). The redeposited material represents a mixed assemblage of sediments of supposed Mid to Late Weichelian age, as indicated by dates giving different ages for different materials (shells vs. terrestrial material; Fig. 3). The organic fraction (> 90–95 % plant remains) of a bulk sediment sample yielded an age of 17,700 +/- 80 ^{14}C-yr BP (Table 2, UtC-8456), which indicates that the last major ice advance flowed across this island (Meløya) after c. 18 ka BP.

Conventional ^{14}C and AMS-^{14}C dating of shells (e.g., *Arctica islandica*) in till and sub-till sediments at *Ytresjøen, Vassdal ferry quay and Vassdal* (sites 13–15, Figs. 2–3) indicate that temperate Atlantic water reached the coast at least as far north as these latitudes c. 28–36 ka ago. This age interval is also a maximum age for the ice advance which is represented by the overlying till at these sites, and the ice advance in question may be the same as that recorded at Åsmoen, and possibly also at Skogreina, at c. 28–29 ka BP.

At *Gammalmunnåga* (site 12, Figs. 2–3), ^{14}C-dating and amino acid measurements of shells in till indicate redeposition of Eemian marine sediments (Table 2, T-10539, and Table 3). ^{14}C-dating of shells from marine sediments overlain by till at *Vargvika* and *Sandvika*, and also overrun by the ice at *Neverdalen* (sites 6, 11 & 16, Figs. 2–3), indicate a last glacial readvance after 12,600 +/- 60, as well as after 12,520 +/- 205 and 12,450 +/- 195 (Table 2, UtC-8309, T-11785 & T-10797) in the outer Glomfjorden area. The ice margin during this readvance reached to Risneset (the Risneset Moraine in Åmnessund) on the northern coast of Åmøya in the west.

The ice-marginal zone during the main (early) Younger Dryas phase crossed the innermost part of Glomfjorden, implying that most of the Glomfjorden area has been ice-free since the Allerød Chron (Fig. 2; Rasmussen 1981, Andersen et al. 1981).

The Skarsfjorden – Bjærangsfjorden area

Radiocarbon dating, amino acid measurements and stratigraphy from this area (sites 9A, 9B, 10 & 17–19, Figs. 2–3) indicate a similar palaeoclimatic and glacial development as in the other two fjord areas described above. However, no *in situ* or redeposited Eemian sediments have so far been recorded here. Both amino acid measurements (Table 3) and radiocarbon dating indicate Mid Weichselian ages for the oldest sub-till sediments found in this area.

Stratigraphical logs from *Stamnes* and *Bogneset* I and II on Åmøya island (sites 9A, 9B & 10, Figs. 2–3; and Fig. 4), indicate a complex stratigraphy with alternating marine or glaciofluvial – glaciomarine –

Chronozone	Lithostratigraphy (locality)	Marine shells	^{14}C-dates, ( )= other sites	Palaeomilieu, - climate and time (BP= before present)
	boulders & stones			Shore deposit, postglacial
Younger Dryas (YD)	diamicton, glaciomarine sediments (Bogneset II)			Ice advance during YD, or c. 11,100 ^{14}C-yr BP, did not reach as far as Åmøya; possible ice shelf development, glaciomarine sedimentation and glacial reworking.
Allerød interstadial	silt-sand (Bogneset II)	*Macoma calcarea, Mya truncata, Hiatella arctica*	11,165 +/- 105 (11,990 +/- 60)	Ice margin retreated inland; glaciomarine - marine, temperate
Older Dryas (OD)	till (Stamnes)			Ice cover; ice advance between 12,200 and 12,000 ^{14}C-yr BP, the ice margin crossed over Åmøya island.
interstadial	silt-sand (Stamnes)	*Macoma calcarea, Mya truncata, Arctica islandica, Hiatella arctica*	12,420 +/- 105 (12,200 +/- 60) (12,600 +/- 60)	Ice margin retreated in the fjord areas; glaciomarine - marine environment, temperate conditions.

Fig. 4: Stratigraphic data from Stamnes and Bogneset II, Åmøya, Nordland, c. 66°47' N. Comments on depositional environment and palaeoclimate are based on lithology and marine shells.

m a.s.l.	Lithostratigraphy		Marine shells (only fragments)	Aminoacid analysis HYD	FREE	^{14}C-dates, conv. and AMS*	Palaeomilieu, - climate and time (BP= before present)
16	1	stones					Shore deposit, postglacial
15–14	2	till					Ice cover; ice advance c. 12,200 ^{14}C-yr BP (between 12,200 and 12,000 ^{14}C-yr BP), 'Older Dryas'.
13	3	S G-S	Shells found in correlative unit at adjacent sites: Shells as in unit 8				Bølling interstadial; 12,200-13,000 ^{14}C-yr BP.
12–9	4	till					Ice cover; ice advance after 17,700 - 21,000 ^{14}C-yr BP. LGM 2
8–7	5	till				40,025 +/- 965	Ice cover; ice advance after 21,000 ^{14}C-yr BP. LGM 1 or LGM 2
	6	G-S S G-S	*Nuculana pernula, Macoma calcarea, Mya truncata, Arctica islandica**, Hiatella arctica*	0.100 +/- 0.007	0.273 +/- 0.004	*20,880 +/- 130 T 32,100 + 2600 /-2000	Glacio-/marine; resedimented, temperate**, interstadial
5	7	till				*28,355 +/- 430	Ice cover; ice advance after 28,400 ^{14}C-yr BP; LGM 1?
4	8	G-S	As in unit 6, except Nuculana pernula			*35,940 + 1455	As for unit 6
	9	boulders				/-1230	Shore deposit?

* AMS - ^{14}C dating; ** Temperate sea-water indicator; T = Terrestrial material (bulk sample).

Fig. 5: Bogneset I stratigraphy – sedimentary units, shells, AAR ratios and dates, including environmental interpretations. Location: c. 66°47' N. Lithology: S - sand; G - gravel.

m a.s.l.	Lithostratigraphy		Dinocysts/ markers	Foraminifera	Pollen	Palaeomilieu, - climate and time
16	1	stones				For units 1 - 5, 7 and 9, see Fig. 5
15–14	2	till				Ice covered; Older Dryas ice advance
13	3	S G-S				Bølling interstadial
12–9	4	till				Ice covered; LGM 2
8–7	5	till				Ice covered; LGM 1 or LGM 2
6	6	G-S S G-S	*4/385; Protoperidinium spp.: 4* *49/410; ----- " ------ : 38* *94/915; Operculodinium centrocarpum: 94*	7 observed 53 benthic obs. > 10 observed	only spores observed resedimented pollen very few pollen obs.	Interstadial, marine, cold (?) Marine, resedimented, temperate Marine, resedimented, temperate
5	7	till				Ice covered; LGM 1 (?)
4	8	G-S				Marine, resedimented, temperate
	9	boulders				

Fig. 6: Bogneset I stratigraphy – sedimentary units and microfossils, including environmental interpretations. Lithology: S - sand; G - gravel.

marine units and till units spanning an age interval from at least 40 ka BP to the Younger Dryas Chron. Shells of the marine mollusc *Arctica islandica*, which is an indicator of temperate Atlantic water (Peacock 1989), are found in the lower parts of the Bogneset I stratigraphy. AMS-^{14}C dating supported by amino acid measurements indicate that the northerly cool – temperate Atlantic water reached this area at c. 32–38 ka BP (Fig. 5). The preliminary analyses of dinoflagellates, which indicate a strong dominance of the species *Operculodinium centrocarpum* and *Protoperidinium spp. (cf. P. conicoides)*, also support this interpretation (Fig. 6).

Four ice advances between c. 28.4 ka BP and the Allerød Chron are represented by till units on Åmøya (Figs. 3 & 7). Correlation between the units and sites indicates that the youngest of these advances occurred during the Older Dryas phase after 12,420 +/- 105 ^{14}C-years BP (Table 2, T-10541), and this ice advance reached only 2–3 km farther west on the island (Fig. 2; Rasmussen 1981, Gjelle et al. 1995). The subsequent Younger Dryas Scandinavian ice-sheet readvance did not reach farther west than to the innermost parts of the fjord areas dealt with here, i.e. some 10–15 km east of Åmøya. The upper diamict unit at Bogneset II (Fig. 6) is inferred to represent glaciomarine/-iceberg-moulded sediments, or sediments influenced by a partly grounded shelf ice from the Younger Dryas interval. This diamict unit is less compacted than, for example, the upper diamict unit thought to be a till at the Stamnes site. Another difference between these diamict units is that the diamicton at Stamnes contains fragments of broken marine shells, whereas no shells are found in the diamicton at Bogneset II. The glaciomarine unit underlying the diamicton at Bogneset II contains, however, an abundance of unbroken shells, one of which is dated to 11,165 +/- 105 (Table 2, T-11784).

Glaciofluvial and glaciomarine sediments with redeposited marine sediments are interbedded with the tills, and also underlie the tills at Bogneset I (Fig. 7), indicating ice-retreat phases between the ice advances. It is thought that the tills and glacial diamictons in the Bogneset I stratigraphy represent several ice advances during the last glacial maximum (LGM), as well as one during the lateglacial period (the Older Dryas ice advance). The preliminary investigation provides a moderate precision for the age-range of these ice advances, which occurred between ice-retreat phases at c.

Table 4: ^{14}C dates associated with the Older Dryas ice advance in the area NW of Svartisen. Maximum (1-6) and minimum (7-12) ages. Ice advance between 12.0 and 12.2 ka BP.

No.	Lab. no. / reference	Ice advance vs. shelldates ^{14}C-yr BP; +/- 1 sd	Location (site)	Host material
1	UtC - 8309	< 12,600 +/- 60	Sandvika	Subtill glaciomarine sed.
2	TUa - 744	< 12,520 +/- 85	Åsmoen	Till
3	T - 11785	< 12,520 +/- 205	Neverdalen	Tillised glaciomarine sed.
4	T - 10797	< 12,450 +/- 195	Vargvika	Till
5	T - 10541	< 12,420 +/- 105	Stamnes	Till
6	UtC - 8314	< 12,200 +/- 60	Stigen	Till
7	UtC - 5465	> 11,990 +/- 60	Fonndalen	Endmoraine (YD)
8	T - 12567	> 11,975 +/- 155	Nattmålsåga	Glaciofluvial fan
9	T - 10798	> 11,865 +/- 60	Skavik	Glaciomarine sediment
10	Rasmussen (1981)	> 11,740 +/- 100	Bratsberg	--------- " ---------
11	------- " -------	> 11,720 +/- 200	Engavågen	--------- " ---------
12	------- " -------	> 11,700 +/- 150	Ågskaret	--------- " ---------

24.9*- 28.4, 17.7*- 20.9, 12.2*- 12.6* and 11.1- 12.0* ka BP (* dates from other sites in the study area). These results improve the precision of the age-range estimation of the last glacial maximum in this area by making the interval at least 7,000 years shorter compared to previous estimations (Rasmussen 1981, Andersen et al. 1981). In addition, the LGM interval is no longer regarded as a long interval of continuos ice cover, but an interval of alternating phases of ice advances and retreats, occasionally with considerable ice-free areas included. The extent of the ice advances, however, can only be found through correlations with formations closer to the ice margin on the continental shelf, but that topic is beyond the scope of this article.

Dating and stratigraphy at *Aspåsen, Oldra* and *Kjelddal* (sites 17–19, Figs. 2–3) indicate an ice-marginal retreat during the interval c. 32–37 ka BP, as well as during the younger ice-retreat phases c. 25 and 19 ka BP, of similar size as, or even larger than during the lateglacial Allerød interstadial. The intercalated waterlain sediments and the upper till units at Kjelddal include some plant fragments, redeposited shells and foraminifera which indicate a harsh climate during mainly Arctic conditions (e.g., Table 5). AMS-^{14}C dates of shells and foraminifera from the upper till yielded ages of c. 33-36 ka BP (Table 2, UtC-8311, 8312 & 10100), whereas dates of the organic material (> 90–95 % plant remains and algae) of bulk sediment samples from the intermediate and upper sub-units of the upper till yielded ages of 24,858 +/- 161 and 18,880 +/- 100 ^{14}C-yr BP, respectively (Table 2, UtC-8313 & 8457). The Kjelddal stratigraphy is inferred to represent an ice advance (lower till; subunit C2) possibly older than 33–36 ka BP (40 ka BP?), a subsequent interstadial (C1) followed by a readvance of the ice after 33 ka BP (upper till; B4), a new interstadial c. 25 ka BP (upper till; diamict material B3), another ice advance (LGM 1; B2) and then another interstadial c. 19 ka BP (intercalated waterlain sediments in subunit B1), followed by the last ice advance (LGM 2), which is represented by the diamictons in the uppermost part (B1) of the upper till (Olsen et al. 2001c). In this reconstruction the Kjelddal stratigraphy seems to comprise all major glacial fluctuations during the LGM interval 15 - 30 (40?) ka BP.

Lithostratigraphic unit	Shells	Palaeoenvironment and palaeoclimatic conditions
6	*Nuculana pernula* *Macoma calcarea* *Mya truncata* *Arctica islandica* *Hiatella arctica*	Glaciomarine-marine; mainly resedimented micro- and macrofossils which reflect temperate sea-surface conditions; probably colder conditions during deposition of unit 6
8	*Macoma calcarea* *Mya truncata* *Hiatella arctica* *Arctica islandica*	Glaciomarine-marine; mainly resedimented micro- and macrofossils which reflect temperate sea-surface conditions; probably colder conditions during deposition of unit 8

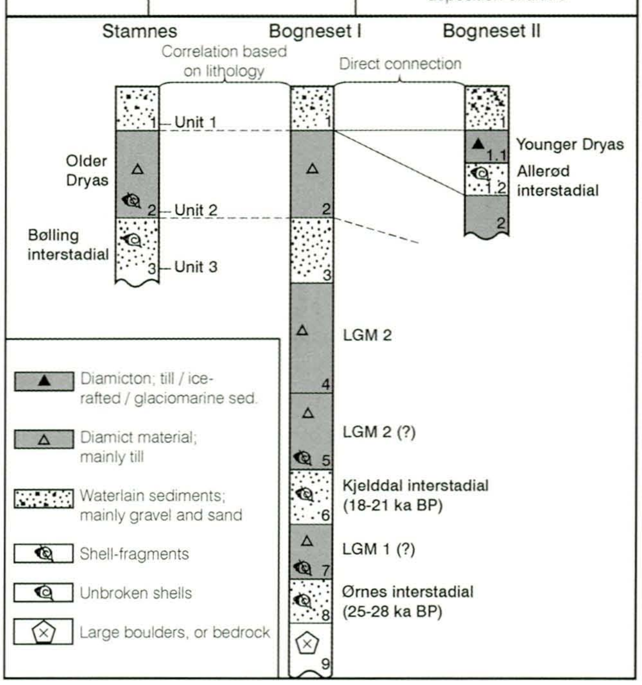

Fig. 7: Correlation chart – Stamnes, Bogneset I & II.

The Holandsfjorden area

Dating of shells from a glaciofluvial – marine fan deposit at *Nattmålsåga* and from the end moraine complex at the outlet of *Fonndalen* (sites 20 & 21, Fig. 2) indicate an early deglaciation of the entire Holandsfjorden area. The ice retreat after the Older Dryas ice advance seems to have reached these sites before c. 11,975 +/- 155 and 11,990 +/- 60 ^{14}C-years BP (Table 2, T-12567 and UtC-5465), which gives a minimum age for the Older Dryas phase in this area.

The age of the Vassdal event/ Substage A, northwest of Svartisen

The oldest, lateglacial, ice-margin position in Nordland, represented by the Vega moraines and named *Substage A* after

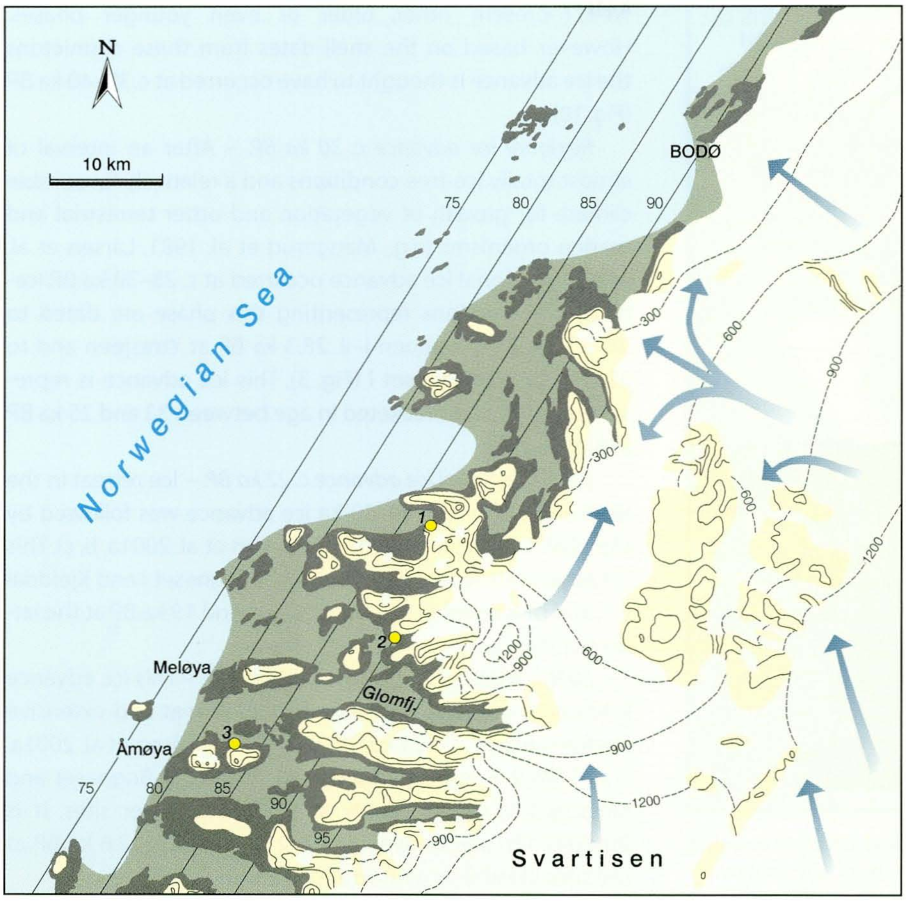

Fig. 8: Suggested extension of shelf ice (light grey) and the inland ice (white colour on land areas) during the Younger Dryas interval. The locations of sites (1 - Storvika, 2 - Djupvika, 3 - Furumo) with associated stratigraphic information are also indicated in Fig. 2, but with different loc. nos. (1, 5 & 8, respectively). Present land areas submerged by the sea during the YD interval is also indicated (black colour). Isobases for the YD sea-level are indicated as well (m a.s.l.). Arrows indicate some of the main YD ice flow directions.

Table 5: Results from foraminifera analyses of samples from the Kjelddal I-II stratigraphy. Sample no. 1A, B-7/8-98 (from unit B1) and no. 2A, B-7/8-98 (from unit B3).

Species	Sample no. 1A-7/8-98		Sample no. 1B-7/8-98		Sample no. 2A-7/8-98		Sample no. 2B-7/8-98	
	No.	%	No.	%	No.	%	No.	%
Elphidium excavatum	184	53.8	164	48.8	80	24.5	62	19.9
Cassidulina reniforme	71	20.8	94	28.0	64	19.6	67	21.5
Islandiella helenae	28	8.2	24	7.1	47	14.4	46	14.7
Protelphidium albiumbidicatum	10	2.9	4	1.2	32	9.8	41	13.1
Buccella tenerrima	6	1.8			30	9.2	25	8.0
Islandiella norcrossi	10	2.9	6	1.8	26	8.0	32	10.3
Elphidium subarcticum					14	4.3	+	
Nonionella auricula	+		1	0.3	9	2.8	6	1.9
Astrononion gallowayi	+		1	0.3	3	0.9	4	1.3
Elphidium asklundi	6	1.8	7	2.1	3	0.9	+	
Nonion labradoricum					3	0.9		
Buccella frigida	9	2.6	19	5.7	2	0.6	7	2.2
Cibicides lobatulus	+		2	0.6	2	0.6	8	2.6
Protelphidium orbiculare	14	4.1	4	1.2	2	0.6	9	2.9
Trifarina fluens					2	0.6	1	0.3
Protelphidium magellanicum			1	0.3	1	0.3	2	0.6
Stainforthia loeblichi	3	0.9	6	1.8	1	0.3	1	0.3
Stainforthia skagerakensis	1	0.3						
Fissurina laevigata	+							
Guttulina glacialis	+							
Guttulina lactea	+		1	0.3			1	0.3
Islandiella islandica	+							
Nonion barleeanum	+							
Oolina borealis	+							
Neogloboquadrina pachyderma					+(D)			
Globorotalia sp.					+			
Indetermined species			2	0.6	5	1.5		
Sum	342	c.100	336	c.100	326	c.100	312	c.100
No. of species	20		17		19		17	

Andersen et al. (1981), has traditionally been correlated with the Skarpnes Substage farther north, and would therefore be expected to have an age of c. 12.2 ka BP (Andersen et al. 1995). The Vassdal event/ Substage A is represented by the Skogreina and Risneset moraines in the area northwest of Svartisen (Rasmussen 1981). Based on new radiocarbon dates of shells from sediments underlying and overlying till which represents the ice readvance during Substage A (Figs. 2–3, and Table 4), the age of this ice readvance is c. 12.0–12.2 ka BP. This result seems to support quite strongly both an Older Dryas age and a correlation with the Skarpnes Substage of Substage A northwest of Svartisen.

Discussion and regional correlations

The glacier fluctuations as inferred from the stratigraphical successions in Fig. 3 indicate several ice advances and retreats in the interval 10–40 ka BP (Figs. 9–11). The fluctuations may have been of variable extent, but seem to correspond well in number and time with the regional ice-sheet fluctuations described for the western part of Fennoscandia (Olsen 1997, Olsen et al. 2001a, b, c). However, problems of chronological character, such as a lack of shell dates, but several dates of terrestrial material in the interval 13 to 28 ka BP and ^{14}C dating of sediments with a low organic content, which were thoroughly discussed by Olsen et al. 2001a, are still issues which must be

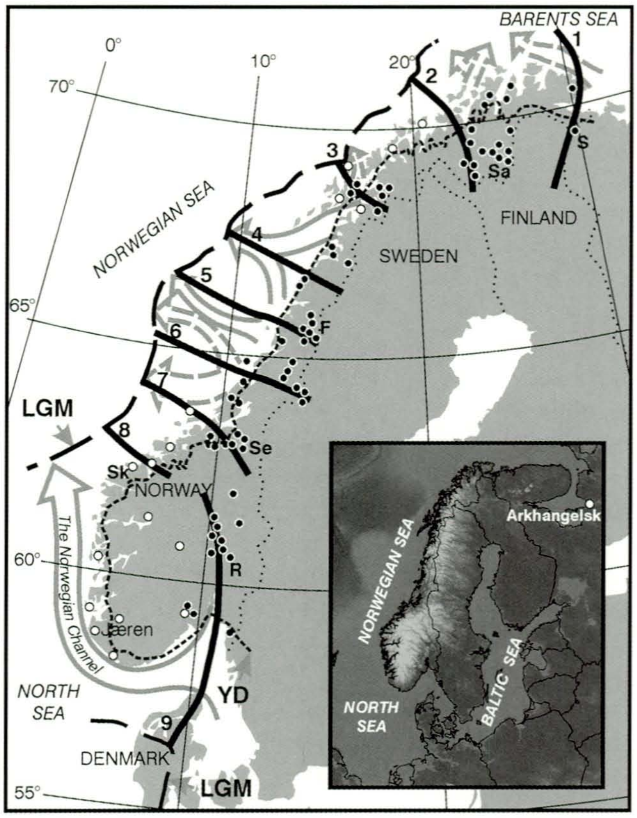

Fig. 9: Map of Fennoscandia with transects (1-9) of glaciation curves of which three are indicated in Fig. 10. Inset map: Topography of Fennoscandia and adjacent areas. Modified from Olsen 1997.

considered during future studies of ice-sheet fluctuations and their timing.

Regional ice advance c. 40 ka BP. – This ice advance, which is recorded in other parts of Norway (e.g., western Norway: Larsen et al. 1987; central Norway: Olsen et al. 2001a, b, c; southeastern Norway: Olsen 2001e, Olsen et al. 2001a), is not clearly represented in the available data from the area northwest of Svartisen. Sedimentary units (glacial diamictons) which could possibly represent candidates for this phase, as e.g. the lower strata at Skogreina and Kjelddal, may well represent other, older or even younger phases. However, based on the shell dates from these diamictons the ice advance is thought to have occurred at c. 38–40 ka BP (Fig. 10).

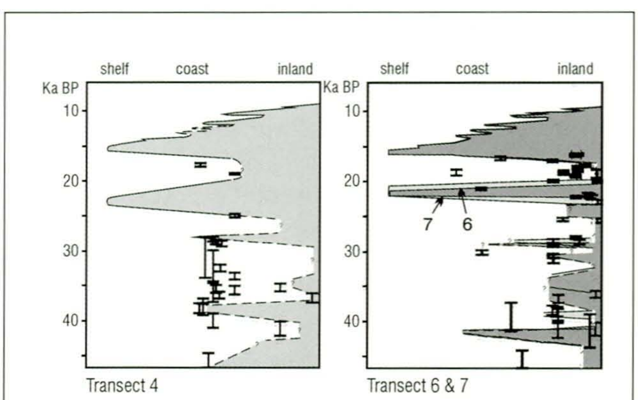

Fig. 10: Glaciation curves from the area northwest of Svartisen (transect 4) and central Norway (transects 6 & 7). Ice covered areas are indicated with grey shading. Modified from Olsen et al 2001c.

Regional ice advance c. 30 ka BP. – After an interval of almost totally ice-free conditions and a relatively favourable climate for growth of vegetation and other terrestrial and marine organisms (e.g., Mangerud et al. 1981, Larsen et al. 1987), a regional ice advance occurred at c. 28–30 ka BP. Ice-margin fluctuations representing this phase are dated to 28–29 ka BP at Åsmoen I-II, 28.3 ka BP at Ytresjøen and to 28.4 ka BP at Bogneset I (Fig. 3). This ice advance is represented by till and bracketed in age between 33 and 25 ka BP at Kjelddal I–II.

LGM 1, regional ice advance c. 22 ka BP. – Ice retreat in the fjord areas after the 28–30 ka ice advance was followed by the LGM 1 advance (Olsen 1997, Olsen et al. 2001a, b, c). This ice advance is represented by tills at Bogneset I and Kjelddal I–II, and bracketed in age between 25 and 19 ka BP at the latter site (Fig. 3).

LGM 2, regional ice advance c. 16 ka BP. – This ice advance followed a phase of considerable ice retreat and extensive ice-free areas, c. 17–21 ka BP (Olsen 1997, Olsen et al. 2001a, b, c). LGM 2 is represented by tills at Meløya, Bogneset and Kjelddal I–II, and probably at numerous other sites. It is bracketed in age between 17.7–21 ka BP and 12.6 ka BP at the sites illustrated with stratigraphic logs in Fig. 3.

Older Dryas (OD), regional ice advance c. 12.2 ka BP (Fig. 11). – The oldest regional ice advance during the lateglacial period is well represented and bracketed in age between c. 12.0 and 12.2 ka BP in this area (Table 4). The minimum length of this advance was at least 10 km from Åsmoen I (site 4B) to the OD ice margin at Skogreina (site 2) in the northwest and at least 15 km from Neverdal (site 6) to the ice margin at Meløya in the west (Olsen 2001d).

The OD ice advance is represented by the Repparfjord Substage in Finnmark county (Marthinussen 1960, 1961, 1962, 1974, Sollid et al. 1973), the Skarpnes Substage in Troms (Marthinussen 1962, Andersen 1968), the Vassdal event in the area northwest of Svartisen (Rasmussen 1981), the Substage A (Vega Moraines) in the coastal areas of Nordland as a whole (Andersen et al. 1981, 1982), the Uran and Osen events in Nord-Trøndelag (Olsen & Sveian 1994, Olsen & Riiber, unpublished material 1997), the 'Outer Coastal' Substage in Sør-Trøndelag (Reite 1994), the Tingvoll Substage in northern Møre & Romsdal (Follestad 1985), and so on, with additional correlatives farther south along the coast. Reite (1994) has reported marginal moraines representing this substage in the fjord areas of Sør-Trøndelag, but he could not find correlative moraines in the land areas between the fjords. Therefore, he suggested that this glacial event may have been a result of the unstable physical conditions along the glacial margins of the ice itself, during deglaciation, and not a result of a climatic variation. However, as the OD ice advance is recorded in all parts of

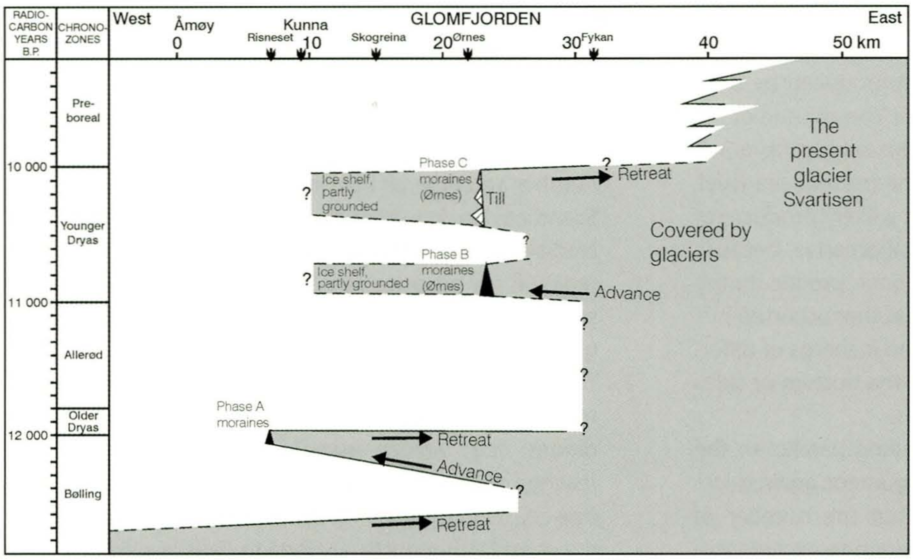

Fig. 11: Glaciation curve for the lateglacial period in the area northwest of Svartisen. Modified from Olsen et al. 2001d.

Norway (e.g., Marthinussen 1962, Andersen 1968, 1979, Mangerud 1970, 1977, Anundsen 1977, Vorren & Elvsborg 1979, Mangerud 1980, Andersen et al. 1981, 1982, Sørensen 1983, Follestad 1985, Sørensen 1992, Reite 1994, Bergstrøm 1999), it is thought by most authors to be linked to a period of climatic deterioration. This is supported by vegetation data from some areas. For example, a short interval at c. 12.0 – 12.2 ka BP of slightly colder conditions than the mean temperature for the Bølling – Allerød interval (13–11 ka BP) as a whole is documented in pollen records from some basins along the coast of western Norway (Paus 1988, 1989, 1990, Birks et al. 1994). The OD climatic fluctuation at c. 12 ka BP is also documented in marine records from the North Sea and the Norwegian Sea areas (e.g., Koc Karpuz & Jansen 1992, Koc & Jansen 1994), and may also be reflected farther north in a significant ice advance of approximately the same age at the western margin of the Svalbard-Barents Sea ice sheet (e.g., Svendsen et al. 1996).

The documented length of the OD ice advance is normally only some few km, but reached a length similar to that recorded northwest of Svartisen (> 10 km) in at least one more area, which is situated along the coast of Nord-Trøndelag (Sveian & Olsen 1991, Olsen & Sveian 1994).

Younger Dryas (YD), regional ice advances c. 10–11 ka BP (Fig. 11). – The main ice advance event northwest of Svartisen during this interval is recorded and named the Glomfjord event by Rasmussen (1981). This event is correlated with the Tjøtta Substage, which occurred in two phases at c. 10.8–10.9 and 10.5–10.6 ka BP, and which represent the main YD ice advance phases for Nordland county as a whole (Andersen et al. 1982, 1995). The new information reviewed here does not require significant changes for the reconstructed position of the ice margin during the Glomfjord event, which is generally situated at the end of the fjord-valleys in this area (Fig. 8; Rasmussen 1981, Olsen 2001d). However, a change with a considerably more extensive YD ice (> 5–15 km) than reported earlier is recorded north of Bodø, during the corresponding Straumøy event (Olsen 2001b).

The glacial conditions and ice-sheet fluctuations seem to have been more complex and therefore more difficult to reconstruct during the later part of the YD interval. During the Glomvasshaug event (Rasmussen 1981), which probably corresponds to the Nordli Substage at 10.1–10.2 ka BP for Nordland as a whole (Andersen et al. 1995), the ice advance in the area north of Glomfjorden may, in places, have reached a position distally to the main YD moraines. Similar ice extensions may have occurred during an early part of the YD interval. However, this suggestion is not based on the occurrence of ice-marginal moraines, but on shell dates of late Allerød to mid-YD age in tills /glacial diamictons from sites which are located distally to the early YD Glomfjord

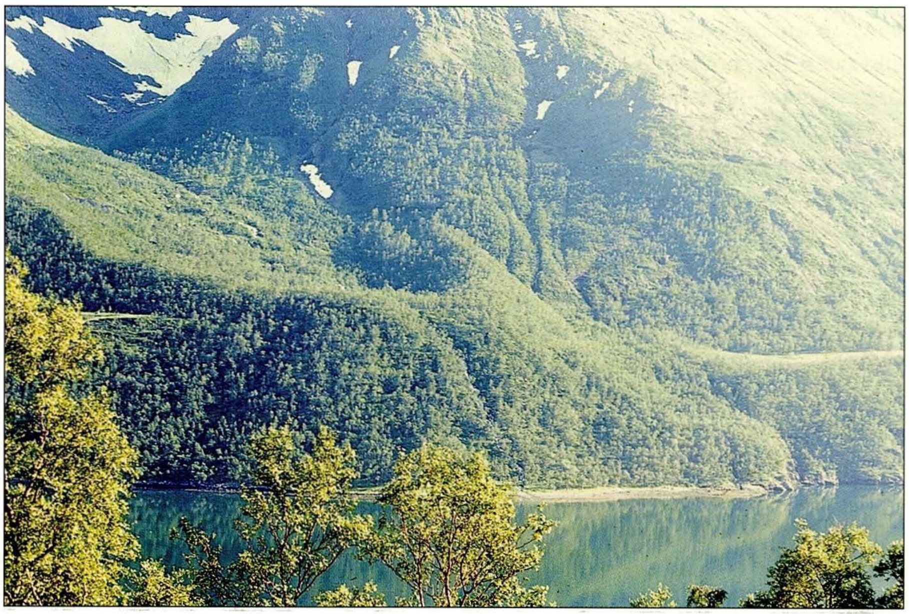

Fig. 12: Photograph of a cirque moraine. The glacier crossed the Allerød – early YD shoreline (in bedrock) at the mouth of Tenøyrsdalen, south of Nordfjorden (the eastern part of Holandsfjorden).

event moraines (e.g., at Storvika (1) east of the Skogreina Moraine, at Djupvika (2), Ørnes, and at Furumo (3), Åmøya). Diamictons of this type may have been produced by thick sea-ice, icebergs or grounded ice shelves. The altitude of the recorded localities with these diamictons ranges from just below the YD sea level to just above the present sea level, which indicates that thick sea-ice is not a likely producer of the diamictons. Icebergs are a better alternative, because the production of icebergs must have been prolific during the intensive calving and rapid ice retreat that occurred just before and after the YD ice advances, and icebergs of different sizes could be grounded and reach the bottom or sides of the fjords at any depth in many places.

Clast fabrics in the diamictons trending parallel to the main ice-flow directions may be an argument against icebergs and for a grounded ice shelf, but the number of recorded localities is so far not high enough to exclude icebergs as a producer of the diamictons. Numerous icebergs floating together may freeze and grow together during favourable climatic conditions, as was the case during parts of the YD interval. An iceberg complex of this type can probably move like a fjord glacier in some areas, and where grounded it can probably produce diamictons similar to the type we have recorded for the YD interval. However, it is thought, as a working hypothesis, that an ice shelf developed in this area during the YD interval (Fig. 8; Olsen 2001d, Olsen et al. 2001d). This shelf ice was grounded in places and remoulded and redeposited shell-bearing diamictons as tills, e.g. at Djupvika and Storvika. A similar glacial development with shelf ice in contact with land-based ice is also suggested for the late YD interval in Nord-Trøndelag (Olsen & Sveian 1994), where the reconstructed ice extension is also based on stratigraphical evidence (shell-bearing tills with a clast fabric trending parallel to the main ice-flow direction) and not ice-marginal deposits. During such glacial conditions no ordinary ice-marginal moraines would have been deposited, but grounding-line moraines may have accumulated where suitable ice-grounding conditions occurred. The glacial diamicton recorded at Spilderneset and Korsneset in the outer part of the small bay of Spildervika adjacent to the Djupvika till site, may represent such a grounding-line moraine from the late YD interval (Olsen 2001d).

Several cirque glaciers occurred distally to the inland ice sheet during the YD interval in the area northwest of Svartisen (Rasmussen 1981). It is not known whether small cirque glaciers also existed during the Allerød interstadial in some of these locations. Shorelines developed during the Allerød and early YD intervals were crossed by different cirque glaciers (e.g., Fig. 12), which indicate that such glaciers existed during both the early and the late parts of the YD interval (Rasmussen 1981, Gjelle et al. 1995).

Conclusions

The main conclusions of this compilation are as follows:-

1. The ice-sheet fluctuations during the 10–40 ka BP interval in the area northwest of Svartisen follow closely, in number and time, all but one of the major regional, west Scandinavian, ice-sheet fluctuations (stadials and interstadials) of this interval (Olsen et al. 2001a, b, c). The regional ice advance at c. 40 ka BP is probably represented, but not well documented, in the available stratigraphic record from this area (Fig. 10).
2. Temperate Atlantic water, inferred from the presence of marine fossils which indicate temperate sea-surface conditions (e.g., *Arctica islandica;* underlined in Fig. 7), reached at least to latitude 67° N during periods of ice-free coasts in the interval 28–38 ka BP. Similar data from the coast farther north, at Grytåga, Fauske, c. 67° 20' N, at Grytøya, Harstad, c. 68° 48' N and at Slettaelva, Tromsø, c. 69° N, for an older ice-free period at c. 41–42 ka BP have previously been reported by Olsen et al. (2001c), Olsen & Grøsfjeld (1999) and Vorren et al. (1981), respectively.
3. The lateglacial Substage A (Andersen et al. 1981), which is represented by, e.g., the Risneset and Skogreina Moraines (Fig. 1) and tills at several sites (Stigen, Åsmoen, Vargvika, Sandvika & Stamnes), is ^{14}C-dated to 12.0 - 12.2 ka BP (Table 4). It is, therefore, indeed an Older Dryas glacial advance event, as suggested but not well documented by dates previously reported from this region. The length of this advance is at least 10–15 km in this area (Fig. 11).
4. The glacial history with ice extension and glacial development during the Younger Dryas interval is characterised by rapid ice-margin fluctuations, intensive calving with iceberg production and the inferred development of shelf ice in contact with land-based ice, and glacial diamictons (tills), but with few ordinary, late YD ice-marginal moraines in the coastal zone (Figs. 8 & 11; Olsen 2001d, Olsen et al. 2001d). This is a similar situation to that recorded in the coastal area of Nord-Trøndelag (Olsen & Sveian 1994).

Acknowledgements

The information reviewed and used in this paper is a compilation of various data, mainly acquired during Quaternary geological mapping carried out by the Geological Survey of Norway (NGU). The new data derive from fieldwork financed by NGU during the years 1992–1998 in Nordland county. Radiocarbon dates of shells (partly financed by the Norwegian Research Council) and other organic material were determined at the Universities of Trondheim (conventional ^{14}C dating), Uppsala (AMS) and Utrecht (AMS). V. Clausen Hope and H. P. Sejrup analysed the AAR ratios of selected shell samples, K. Buvarp carried out foraminifera separation, D. Bøe analysed foraminifera and K. Grøsfjeld analysed dinoflagellates in some samples. The drawings are prepared by I. Lundqvist. A. Nesje and A. Reite refereed the manuscript, and D. Roberts corrected the English text. I thank all these persons and institutions for their invaluable help, which is highly appreciated.

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