The Tromsø-Lyngen glacier readvance (early Younger Dryas) at Hinnøya-Ofotfjorden, northern Norway:a reassessment

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Based on radiocarbon dates, marine seismic data, mapping of surficial deposits, observations of marine limits and shoreline correlations, we have documented a considerable glacier readvance during the Tromsø-Lyngen event in the early Younger Dryas Chron, reaching farther west and northwest in the Hinnøya–Ofotfjorden area than previously suggested. The continental ice sheet advanced across Tjeldsundet and occupied parts of eastern Hinnøya where it coalesced with local glaciers. The ice margin was located in the inner part of Vågsfjorden near Tjeldsundet. In the southern parts of the study area, the results indicate an extensive Tromsø-Lyngen readvance (more than 50 km) in Ofotfjorden reaching at least to the Offersøy area. The maximum position for the ice front was most likely located even farther west, in the inner parts of Vestfjorden. The maximum T-L readvance took place between c. 10.7 and 10.4 (^{14}C) ka BP. Prior to the Younger Dryas Chron, marked glacial recessions occurred during the Bølling and the Allerød Chrons, but the innermost ice-front positions are still not known. However, the northern and the southern parts of Tjeldsundet, Ramsundet and the outer parts of Ofotfjorden were deglaciated during the Allerød Chron.

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Introduction

The early Younger Dryas (YD) glacier readvance deposited prominent marginal moraines in Fennoscandia (Fig. 1). Synchronously, a relatively stable sea-level led to the formation of distinct shorelines in many fjords. These marginal deposits are called the Tromsø-Lyngen (T-L) moraines in Troms County, northern Norway, and the corresponding shoreline the Main shoreline. The shorelines in North Norway and the shoreline diagrams have been an important tool for correlating moraines and reconstructing different stages of the deglaciation. Grønlie (1922, 1940) studied late- and postglacial shorelines and proposed ice-marginal lines, for the "stationary Tromsø-Lyngen stage". He reported already in 1922 some irregularities in his shoreline observations from Tjeldsundet. Marthinussen (1960, 1962) constructed a shoreline diagram and mapped the isobases of the Main shoreline. He also dated marine sediments and suggested a late Bølling/Older Dryas (OD) age for the deglaciation in inner Vågsfjorden. Northeast of Vågsfjorden, Andersen (1968) mapped and dated glacial deposits, calculated the glaciation limits and used the Main shoreline isobases almost in agreement with Marthinussen (1960). He applied the term Tromsø-Lyngen moraines for the most prominent moraines of YD age, and the term Skarpnes moraines for the late Bølling (Older Dryas) marginal deposits.

Mapping of the horizontal extent of the Tromsø-Lyngen glacier and reconstructions of its margins have been a subject of research for several decades. In the Hinnøya-Vågsfjorden–Ofotfjorden region (Figs. 1, 2), previous authors have presented various interpretations and alternative models. A deglaciation chronology based on suggested ice-recessional lines and the isobases of the Main shoreline was proposed by Møller & Sollid (1972) in the Lofoten-Vesterålen-Ofotfjorden area and the Tromsø-Lyngen ice-front position was suggested to be located in the inner/middle part of Ofotfjorden (Fig. 2A). They argued for a local, isolated ice cap covering the central part of Hinnøya around Gullesfjordbotn during the Skarpnes event and claimed that Gullesfjorden was totally deglaciated in the YD. Later, Andersen (1975) suggested the Tromsø-Lyngen ice margin to be located east and southeast of Hinnøya (Fig. 2B), where it crossed Ofotfjorden at Barøya, about 40 km west of the position proposed by Møller & Sollid (1972). An isolated ice cap covering much of Hinnøya during the YD Chron (Fig. 2B) was later proposed by Rasmussen (1984).

Submarine ice-front deposits, formed during the Skarpnes and the T-L events, have been mapped in Troms based on seismic data, e.g. from the Astafjorden area (Lyså & Vorren (1997) (Fig. 3). These events have been dated to 12.2 ka and 10.7-10.3 ka BP, respectively (Vorren & Elvsborg 1979, Fimreite et al. 2001). Deposits from five marginal glacial events prior to 13 ka BP were recorded in the Andfjorden area and the deglaciation of Vågsfjorden was considered to have occurred between 13.2 and 12.2 ka BP (Vorren & Plassen 2002). The submarine location of their D-event (Fig. 3) has previously not been confirmed. However, recent seismic profiling carried out by NGU (Sveian & Bergstrøm 2004) revealed a moraine ridge between Bjarkøy and Senja (Figs. 3,

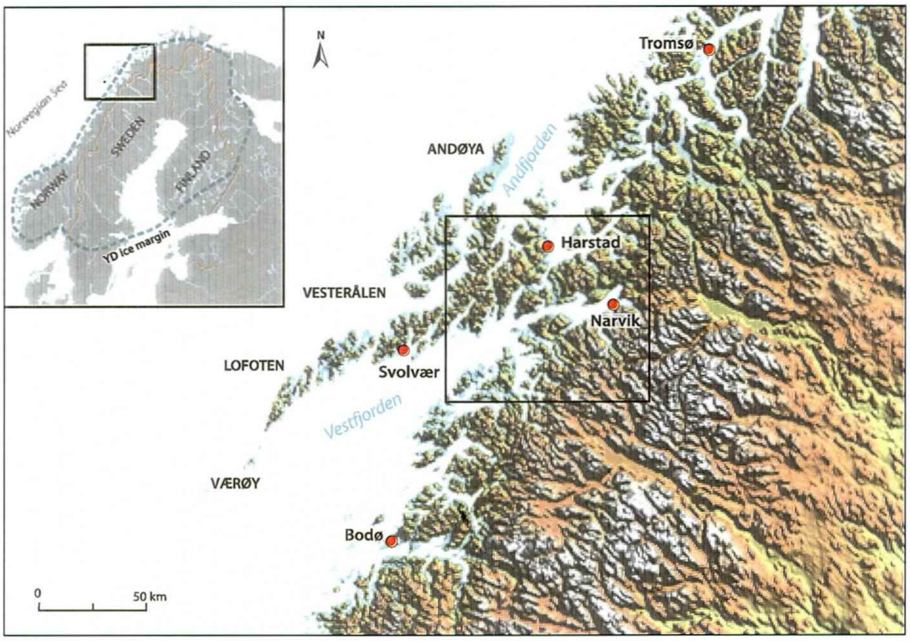

Fig. 1. Location map with the study area framed.

Bedrock and morphology

Precambrian (autochthonous) rocks, mainly granite and granitic gneiss cover the western part of the studied region, while Caledonian (allochthonous) rocks occur east of Hinnøya and in the Harstad area in the northeastern part of the island. Metasedimentary rocks (mica schist, marble) of inferred Vendian to Silurian age predominate in the Caledonian nappes, and igneous rocks such as metagabbro and amphibolite occur locally. The landscape on Hinnøya is characterised by a mountainous, alpine topography with high summits, cirques, hanging valleys and deeply incised fjords and valleys. This marked relief has strongly influenced the ice movement and the behaviour of the ice sheet during the glaciations. East of Hinnøya, in the low relief of the less resistant Vendian-Silurian bedrock, the sound Tjeldsundet and the complex Vågsfjorden basin were formed as a result of tectonics and glacial erosion. The sea-floor relief is mostly irregular and comprises many small basins.

4), very close to the tentative location given by Vorren & Plassen (2002).

New information concerning the Tromsø-Lyngen readvance and the deglaciation in the northeastern parts of Hinnøya - the largest island in Norway - and the adjacent Tjeldsundet-Ofotfjorden area, has been acquired during the last years of Quaternary geological mapping. The studies included mapping of surficial deposits, observation of new sites of marginal moraines, marine seismic data, registrations of marine limits (ML), and ^{14}C dates of mollusc shells from till and sub-till sediments. A new configuration of the YD continental ice sheet is presented here and the extent of the Tromsø-Lyngen glacial readvance is reconstructed for Vågsfjorden-eastern Hinnøya, and tentatively also for southern Hinnøya and Ofotfjorden-inner Vestfjorden.

Methods

Quaternary geological mapping, at scales of 1:60,000 for the municipality of Harstad (Bergstrøm et al. 2002), 1:15,000 for Sandstrand (Sveian et al. 2005a) and 1:250,000 (Sveian et al. 2005b) for the entire county of Troms, has been carried out by NGU according to standard methods (Bergstrøm et al. 2001a).

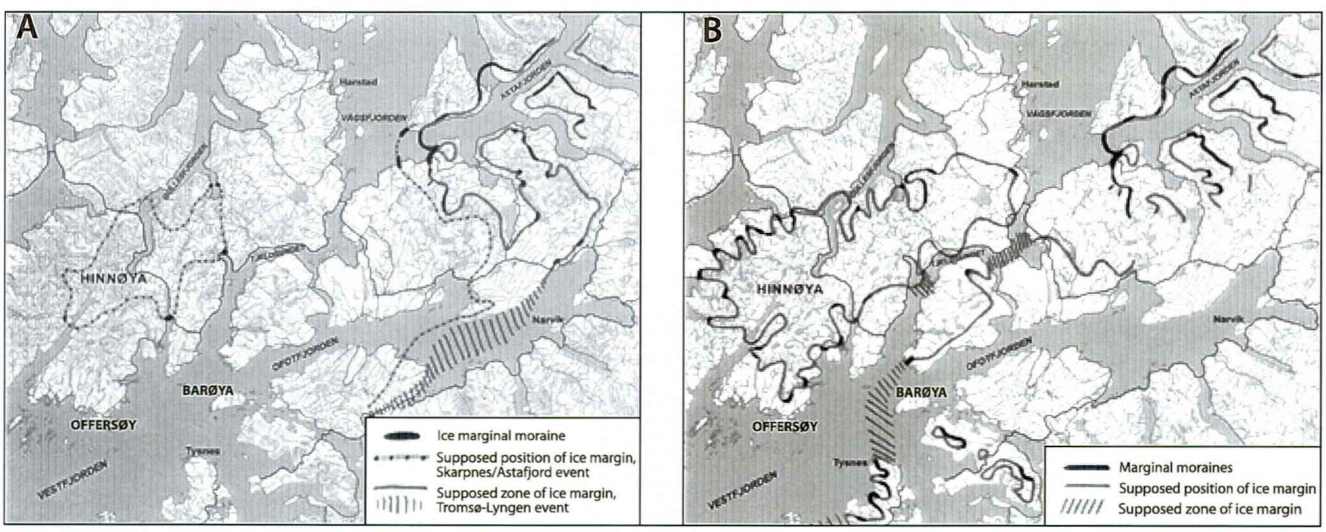

Fig. 2. (A) The Skarpnes/Astafjorden and Tromsø-Lyngen (T-L) ice margins, after Møller & Sollid (1972). (B) The Tromsø-Lyngen ice margins, the continental ice sheet after Andersen (1975) and a proposed Hinnøya ice cap after Rasmussen (1984).

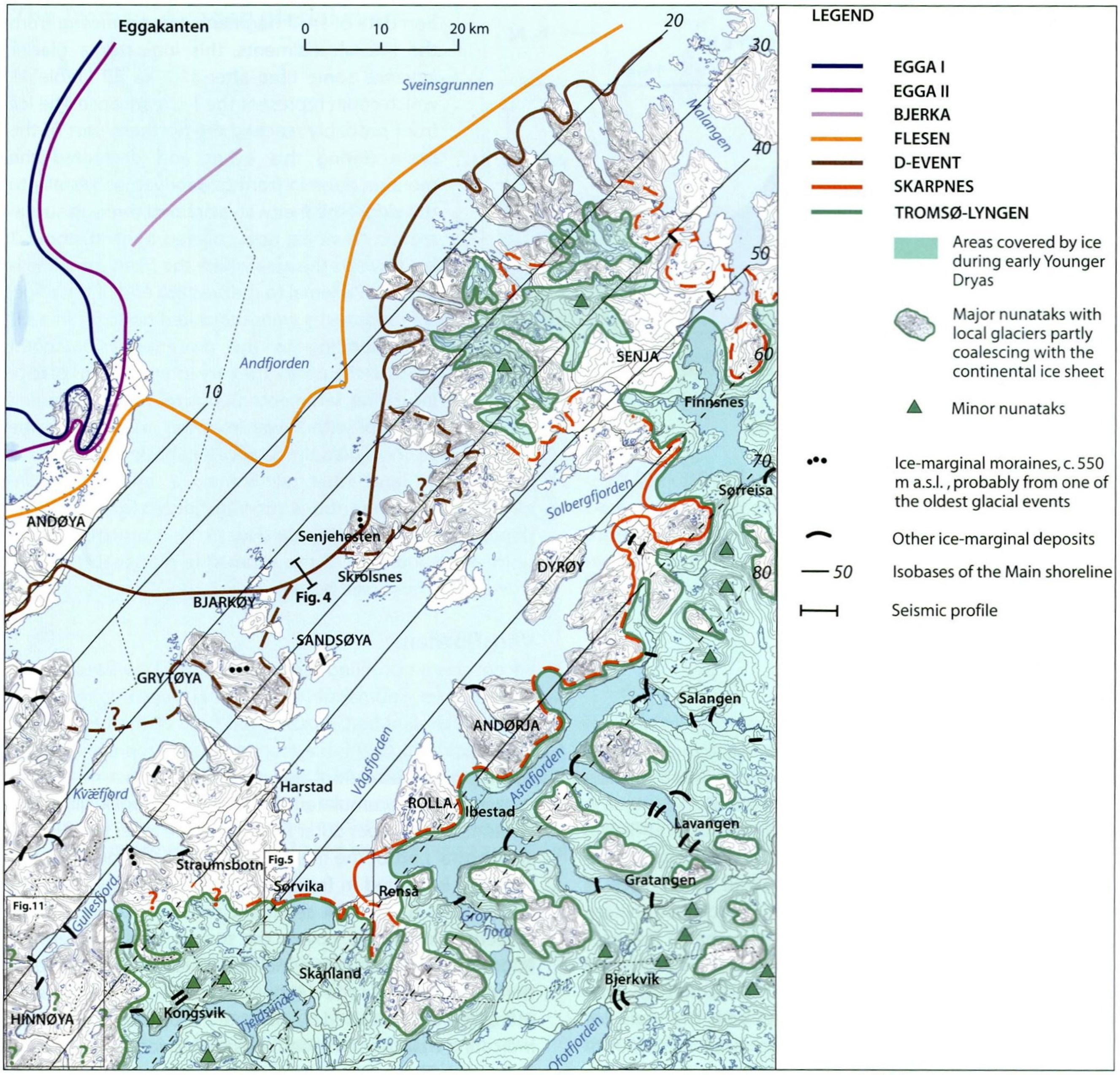

Fig.3. Ice-marginal events in the Andfjorden-Vågsfjorden area. The map is modified from Sveian & Bergstrøm (2004) and based mainly on data in Vorren & Plassen (2002), with additional information about the T-L (present paper) and Skarpnes events (Sveian et al. 2005b). The reconstruction of the local YD glaciers at Hinnøya are not shown, see Figs. 5 and 12. Isobases of the Main shoreline are after Marthinussen (1960). The seismic profile in Fig. 4 is located east of Bjarkøy. Suggested alternative locations for the D-line are shown by dashed brown lines (see the text for discussion).

All ages referred to in this article are in radiocarbon years. Ages in calendar years are given in Table 1, calibrated after Marine 04.14C (Hughen et al. 2004). Conventional dating (^{14}C) of marine mollusc shells was performed at the National Laboratory for ^{14}C-dating in Trondheim (T), and AMS-^{14}C dating at the Tandem Accelerator Laboratory, University of Uppsala (Tua) and at the University of Utrecht (UtC). The dates have been corrected for a standard marine reservoir age of 440 years (Mangerud & Gulliksen 1975).

The geochronological and chronostratigraphic subdivisions of the lateglacial period in chrons and chronozones follow mainly those proposed by Mangerud et al. (1974), with one modification only. This is based on the ^{14}C-ages of 12.2-12.0 ka BP, which have been determined for the Older Dryas readvance at several places in Norway (see review by Olsen 2002).

A network of seismic profiling from the NGU research vessel ´Seisma` was carried out systematically in the inner part of Vågsfjorden, with single profiles in Tjeldsundet, Gullesfjorden and Sagfjorden. The acoustic sources Sleevegun, Boomer and Topas were used. The Olex map plotter system based on GPS was used for navigation.

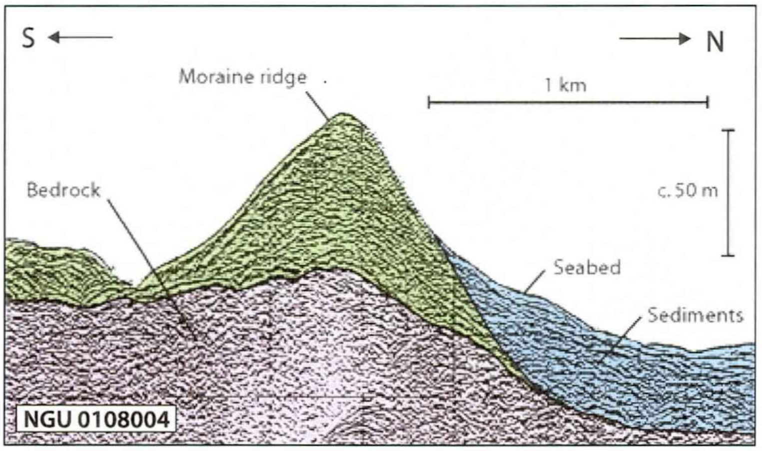

Fig. 4 Reflection seismic profile (NGU-line 0108004) across the submarine moraine between Bjarkøy and Skrolsnes (see Fig. 3).

Sediment thickness is presented in ms (milliseconds) two-way travel time (TWT) or in metres based on an estimated acoustic velocity of 1600 ms^{-1}. The bathymetric map from Vågsfjorden is based on the data provided from our own echo-sounding profiles.

Regional description

The Renså - Sandstrand area

The two prominent moraines across the mouth of Astafjorden (Figs. 3, 5) have been correlated to the Skarpnes and Tromsø-Lyngen (T-L) events, respectively (Marthinussen 1960, 1962, Andersen 1968, 1975, Møller et al. 1986, Lyså & Vorren 1997). The T-L glaciofluvial deltaic deposits at Renså, resting upon glaciomarine clay of Allerød age, were described and dated by Andersen (1968) and Vorren & Plassen (2002). The continuation of the T-L ice margin cannot be traced by lateral moraines for more than a few kilometres south of Renså. In the high mountains enclosing the Pungdalen area, local moraines (Sveian et al. 2005b) show that numerous cirque glaciers merged with the main ice sheet (Fig. 5). Recent detailed mapping (scale 1:20,000) of the areas below the ML at Renså-Sandstrand (Sveian et al. 2005a) has revealed new information about the T-L ice margin. A broad, complex moraine ridge with an undulating surface and a marked ice-contact slope is situated at the northern end of Sandvatnet (Fig. 5), indicating ice movement from the south. This marginal moraine ridge consists mostly of coarse-grained glaciogenic sediments. A remarkable unit of marine unconsolidated silt and clay (1–5 m thick) is situated on the top and the distal side of the central part of the ridge (82 m a.s.l.). A few marine foraminifers were found in the clay, which was deposited above the highest marine limit in the area (the Skarpnes event shoreline was probably at 75–78 m a.s.l. and the Main shoreline at 68–69 m a.s.l.). We suggest that these marine sediments were glaciotectonically pushed up from the Sandvatnet basin during the T-L readvance. At Nylund, 200–300 m proximal to the eastern end of this ridge, there is a small moraine ridge covering glaciotectonically disturbed littoral sediments (Fig. 5). Together with a radiocarbon date of shell fragments (*Mya truncata*) from the littoral sediments, this indicates a glacier advance some time after 11.2 ka BP (Table 1), which could represent the T-L readvance. The ice front probably reached the northern part of the basin during this event and deposited the moraine ridge in front of Sandvatnet. Distally to this ridge, the meltwater drained through supramarine channels, now covered by peat, about 1 km towards the area where the Main shoreline is located. Proximal to the western end of the ridge, silty sediments were deposited up to 74 m a.s.l., corresponding to the present-day passpoint towards the north. They are interpreted as glaciolacustrine sediments deposited during the first phase of withdrawal from the ridge, before the sea occupied the Sandvatnet basin.

West of Sandvatnet, at Fornes, a minor promontory/morainic spur intrudes into Vågsfjorden from the steep slopes along its eastern side (Figs. 5, 6). It probably represents a continuation of the submarine marginal moraines crossing the fjord (see below).

Vågsfjorden

Recent seismic profiling carried out by NGU revealed a complex zone of submarine ice-marginal deposits, the Vågsfjorden marginal belt, crossing the fjord at the head of the inner basin (Fig. 6). This is a prominent zone represented by a 0.5–1.5 km broad belt of sediments. Ice-contact ridges and terraces have accumulated distally to a bedrock sill, which separates the deeper outer basin from the inner part (Fig. 6). The central part of the marginal zone has the form of a terrace and is located in front of a steep, 50 m-high, bedrock ridge. A 10–20 m thick sediment package, where chaotic reflections dominate, covers the terrace to the outermost edge. On the distal slope, inclined reflections are dipping northward towards the deeper basin. The underlying sediments are characterised by disrupted subparallel reflections indicating that the sediment beds have been disturbed and deformed. This probably occurred during a glacial readvance from the south through Tjeldsundet. The maximum ice-front position was at the edge of the terrace close to the uppermost slope break. The distal inclined beds were formed in front of the glacier and probably deposited as meltwater and debris-flow deposits.

Near the eastern side the Vågsfjorden marginal belt is formed as a broad sediment ridge up to 40 m high and with a gentle sloping proximal surface and a steeper distal slope (Fig. 7). The internal reflections are chaotic. Distally to this main ridge and separated by a narrow gully, there is another and more complex accumulation characterised by discontinuous and irregular internal reflections. The hummocky surface with small ridges and the upper disturbed bed indicate that post-depositional gravity processes have occurred and slump/slide deposits were formed. This outer, ridge-like accumulation probably represents the distal part of the marginal belt.

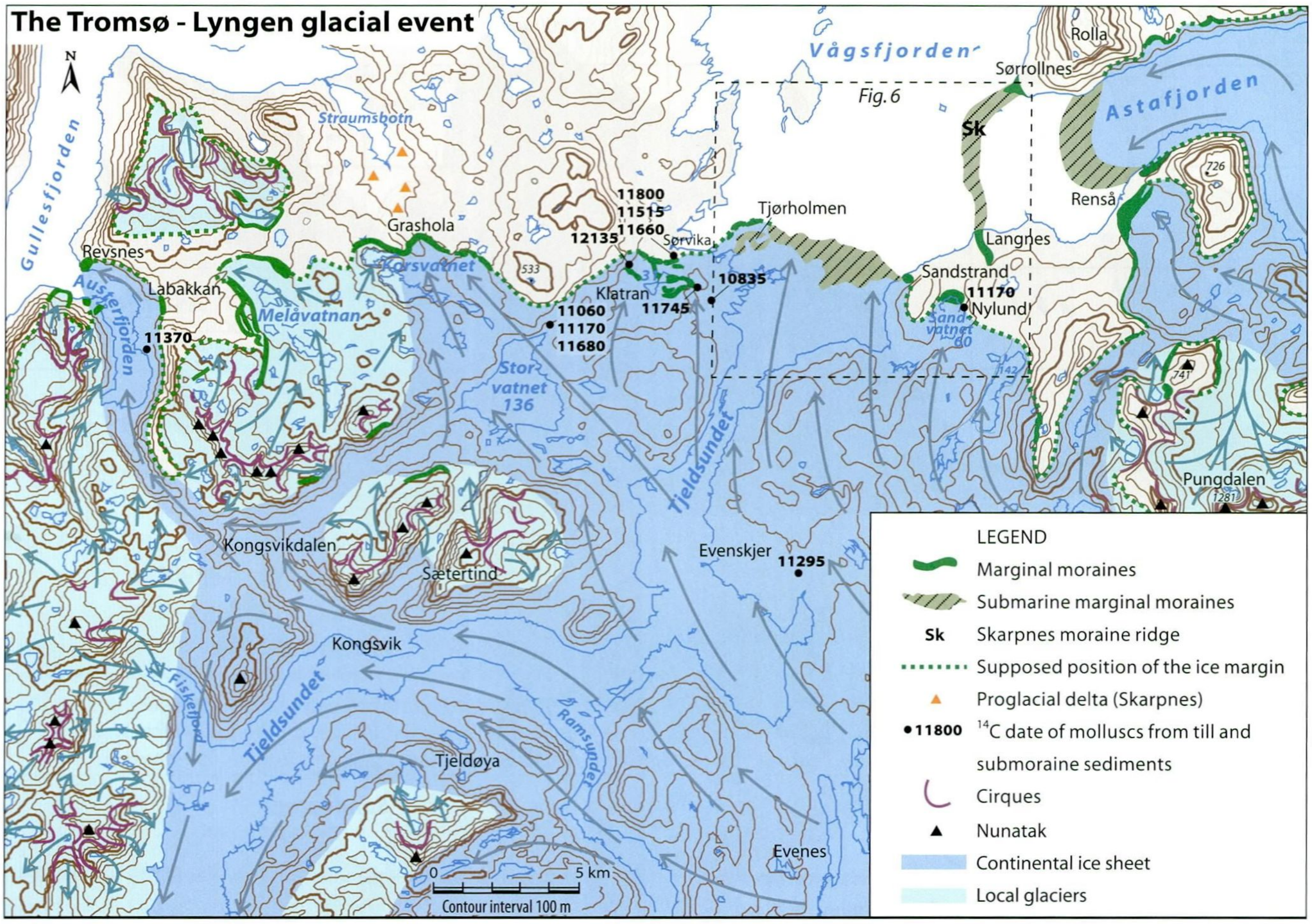

Fig. 5. Map of the glacial scenario during the Tromsø-Lyngen event (early Younger Dryas) at Hinnøya, Tjeldsundet and Vågsfjorden-Astafjorden. The continental ice sheet advanced across Tjeldsundet and occupied the eastern parts of Hinnøya where it coalesced with local glaciers. The direction of movements is indicated by blue (continental ice sheet) and green arrows (local glaciers). The highest peaks appeared as nunataks.

The western part of the marginal zone is characterised by a more complex set of minor ridges (Fig. 6), indicating variations in the location of the grounding line during the deposition of the sediments. These ridges appear to continue into low ridges located in the littoral zone at Tjørholmen.

Distally to the Vågsfjorden marginal belt there are some scattered sediment ridges in the fjord, which are interpreted either as small older moraine ridges deposited during the general retreat of the ice margin in the fjord, or as sediment accumulations deposited during the Skarpnes readvance.

The Sørvika-Klatran area, Hinnøya

Surficial deposits in this area have been mapped at the scale 1:60,000 (Fig. 8). Between Sørvika and Klatran, parallel marginal moraine ridges can be traced for 2–3 km in an east-west direction before they disappear in the hills 1–2 km west of the fjord (Figs. 8, 9). The ridges were deposited in front of a glacier coming from the south and comprise a 1.5-2 km-broad, complex zone of ice-marginal deposits (Fig. 5).

In the distal part of this marginal zone at Sørvika, there is a 4 m section of a shell-bearing till above gravelly sand. Two radiocarbon dates of fragments of *Mya truncata* in the till gave ages of about 11.8 and 11.5 ka BP, and one date from the underlying sediments gave c. 11.7 ka BP (Table 1). These dates indicate that the ice margin retreated from Sørvika during the early Allerød period. After mid-Allerød the glacier readvanced and mollusc shells were incorporated in the till. The gravelly sand layers were most likely deposited by meltwater in front of the advancing ice margin.

Between two of the marginal moraines at Klatran there is a narrow terrace of glaciofluvial material located along the western side of the valley, about 60–65 m a.s.l. In a ditch about 55 m a.s.l. and c. 100 m distally to the youngest moraine ridge, a glaciotectonically deformed glaciomarine silt (loc. 3, Fig. 10) containing shell fragments of *Mya truncata, Balanus sp., Macoma calcarea and Chlamys islandica* was found upon deformed sand of supposed shallow-marine origin. Above the silt layer is a poorly sorted material, which grades laterally into a till bed. Radiocarbon dating of fragments of *Mya truncata* from the silt gave an age of about 12.1 ka BP (Table 1), indicating ice-free conditions already in late Bølling. As this age corresponds with the Skarpnes event, a possible scenario could be that the glacier

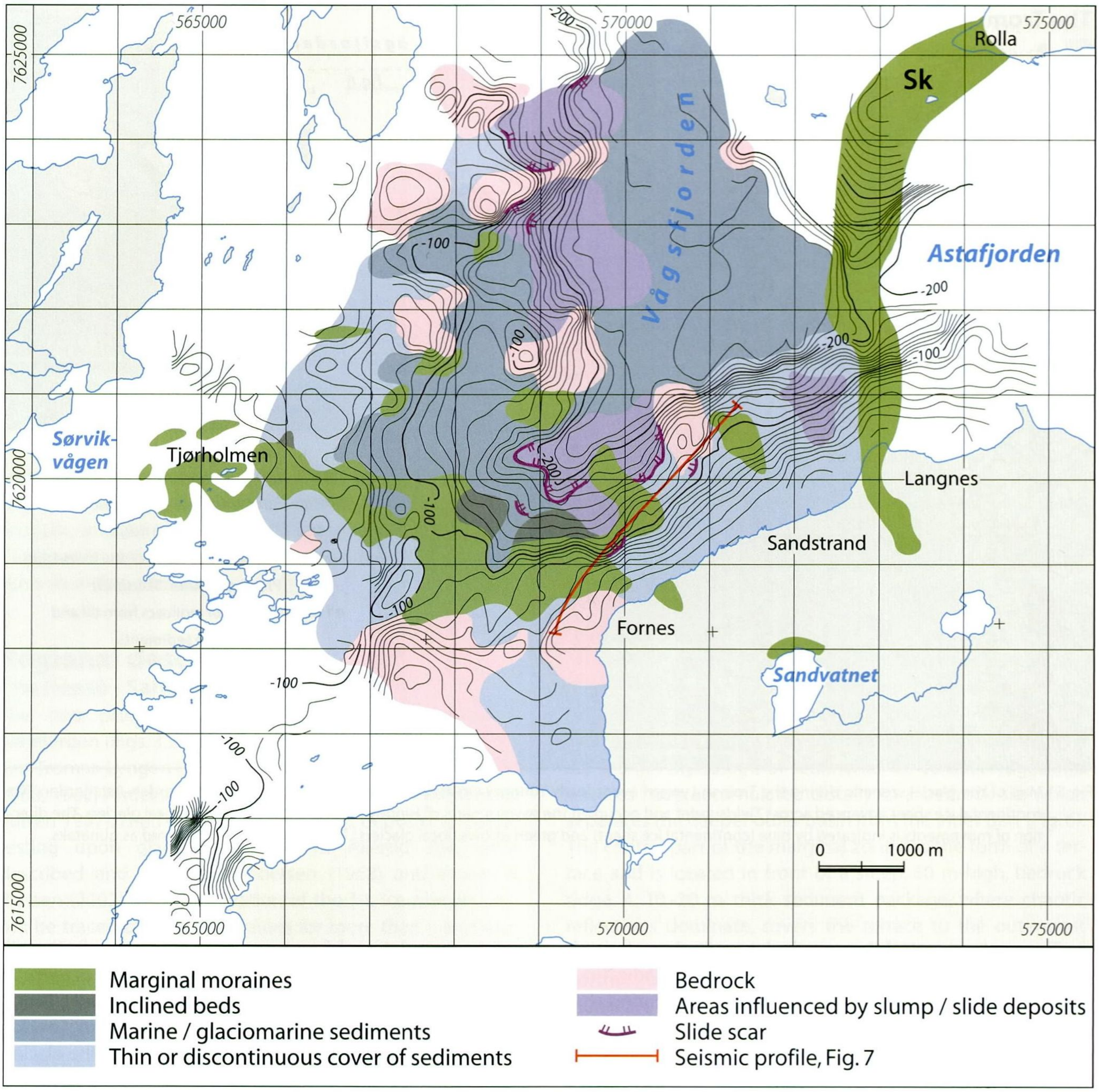

Fig. 6. Bathymetry and submarine deposits in the inner basin of Vågsfjorden. The Skarpnes moraine (Sk) between Rolla and Langnes is previously described by Andersen (1968) and Lyså & Vorren (1997). The map is based on a dense grid of seismic profiles, revealing a complex zone of ice-marginal deposits, the Vågsfjorden marginal belt, crossing the inner part of the fjord between Tjørholmen and Fornes.

advanced twice, i.e. during both the Skarpnes and the T-L events. Alternatively, the Skarpnes event, which has not been mapped in detail at Klatran, may be somewhat older.

Fragments of molluscs, mostly of *Mya truncata*, were found incorporated in one of the moraine ridges at Nøkketjern, and radiocarbon-dated to c. 11.7 ka BP. Their high position, c. 100 m a.s.l. and 40 m above the marine limit (Fig. 8), indicates that the molluscs have been brought up to this altitude by ice during the T-L readvance and transported at least 2 km from the nearest marine areas in the southeast. Proximal to these marginal moraines (about 700 m) at Fauskevåg, shell fragments were found at 40 m a.s.l. in a consolidated silty till with some boulders and lenses of sand. The shells, mostly of *Mya truncata, Chlamys islandica and Balanus sp.*, were dated to c. 10.8 ka BP, which indicates a maximum age of the last oscillation during the T-L readvance in this area (Fig. 5).

In the southern, proximal part of the Klatran-Sørvika ice-marginal zone (Fig. 8), deltas were built up to a former sea level at 60–62 m a.s.l. when the ice started retreating. The marine limit, 62–63 m a.s.l., at Klatran is not quite in accordance with the constructed YD isobases (Marthinussen

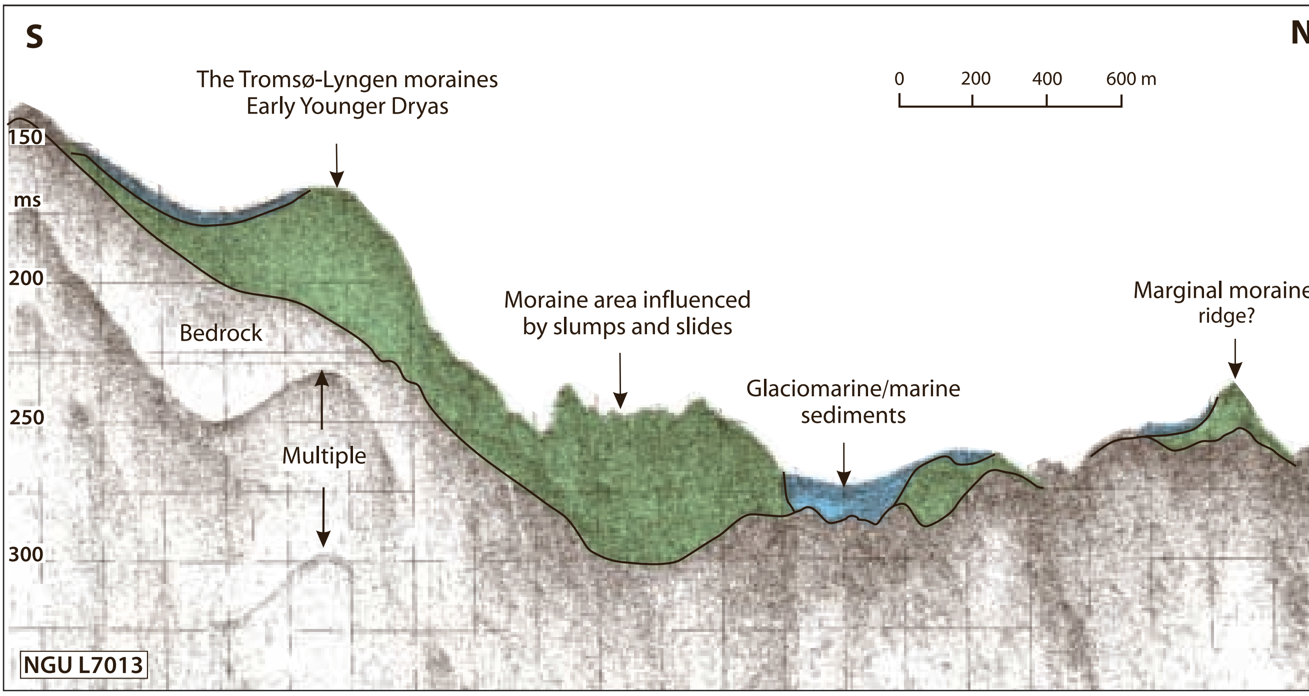

Fig. 7. Seismic profile from Vågsfjorden (for location, see Fig. 6). The Tromsø-Lyngen ice-marginal moraine is formed as a broad ridge with a gentle sloping proximal surface and a steeper distal slope. Distally to this main ridge there is another and more complex ridge-formed accumulation influenced by post-depositional gravity processes. This outer part could be a distal part of the T-L moraines, or it might represent the earlier Skarpnes event.

1960), that indicates the Main shoreline to be situated at 56-58 m a.s.l. at this site (see discussion).

The Storvatnet - Straumsbotn area, Hinnøya

At Mågelva northeast of Storvatnet (Figs. 5, 8), c. 160 m a.s.l. and 100 m above the marine limit, marine sediments occur in a wedge-shaped structure between till beds, all with fragments of molluscs (loc. 2, Fig. 10). Shell fragments of *Mya truncata* from the intercalated sediments were radiocarbon-dated to c. 11.7-11.0 ka BP (Fig. 5, Table 1). The succession of the marine sediments at this locality is similar to that of a typical i*n situ* marine sediment succession connected to an oscillating ice front. However, the high elevation of the site excludes an *in situ* position of these late Allerød marine sediments, which most likely were eroded and ice-transported at least 6–7 km from the nearest marine areas in the southeast during the T-L readvance. This interpretation is supported by some small-scale deformation structures and the overlying proper till bed containing glacially abraded and striated pebbles with a strong clast fabric orientation trending northwest and a dip towards the southeast (Fig. 10). A ^{14}C date of one shell fragment from the lower till bed at this locality gave a Middle Weichselian age (Olsen & Grøsfjeld 1999), which may support a general re-location mechanism for shells at this site. However, a representation of a very high, Middle Weichselian, relative sea-level here cannot be excluded because *in situ* shallow-marine sediments with whole Middle Weichselian shells at a very high elevation are reported from Grytøya just north of our study area (Olsen & Grøsfjeld 1999).

At Grashola, c. 7 km west of Klatran, a marginal moraine is crossing the valley between Storvatnet and Straumsbotn (Fig. 5). A marked moraine ridge occurs at the bottom of the valley (80 m a.s.l.), and towards the west a zone of boulders can be observed up the steep slope to Korsvatnet (200 m a.s.l.). It continues as a distinct belt with boulders and diffuse ridges, ending up as a prominent ridge towards a steep slope of exposed bedrock c. 250 m a.s.l. East of the valley this moraine appears mostly as a belt of boulders and small discontinuous ridges. We correlate the Grashola moraine with the Sørvika-Klatran moraines of early YD age. Proglacial streams of meltwater have eroded older glaciofluvial sediments between Grashola and Straumsbotn and formed terraces at 45–50 m a.s.l., which correspond to the Main shoreline.

The Kongsvik-Fiskefjord-Austerfjord area, Hinnøya

The glaciation limit during YD is calculated to c. 500 m a.s.l. in this area (Andersen 1968) and c. 400 m a.s.l. on northern Hinnøya (Bergstrøm 1973). Above this limit, both the alpine landscape with high peaks and cirques, and plateau-like areas favored the growth of local ice. The highest peaks appeared as nunataks. We speculate that remnants of the continental ice sheet might have survived in this part of Hinnøya during Allerød and been reactivated during YD. Distinct marginal moraines existing on the plateau at 400-500 m a.s.l. east of Austerfjorden, show that a local glacier moved towards the north from a row of north-facing high cirques south of Melåvatnan (Fig. 5). At Austerfjorden, a

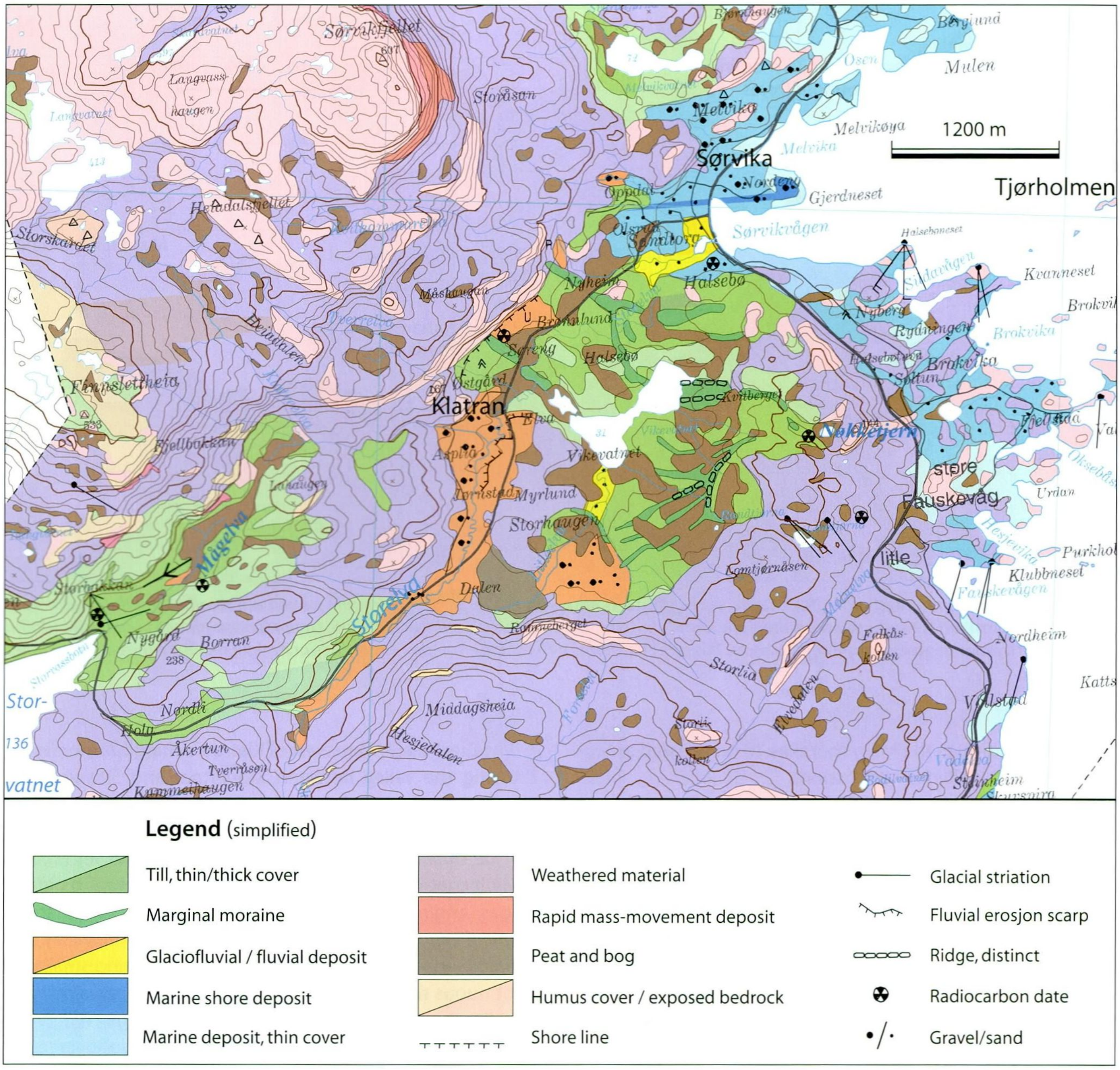

Fig. 8. The Klatran-Sørvika area, outline from the Quaternary geological map "Harstad kommune" (Bergstrøm et al. 2002). Surficial deposits have been mapped in a scale of 1:60,000. Parallel moraine ridges are situated in a broad (1.5-2.0 km) complex zone of ice-marginal deposits trending east-west. Glaciofluvial deltas were built up to a former sea level at 60-62 m a.s.l. when the ice started retreating. Sites with radiocarbon dates of molluscs are shown. At Storvatnet and Nøkketjern mollusc shells of Allerød age were found 100 and 40 m above the marine limit, respectively.

radiocarbon date of a shell fragment of *Mya truncata* in till some 5 m a.s.l. yielded an age of c. 11.4 ka BP (Figs. 5, 10, Table 1). This indicates that the T-L readvance most likely reached Revsnes at the mouth of the fjord.

The Gullesfjorden-Kanstad area, Hinnøya

Around Gullesfjordbotn we find the most prominent alpine landscapes and the largest north-facing cirques on Hinnøya (Figs. 11, 12). However, no distinct local moraines appear in front of the cirques here, in contrast to northern Hinnøya (Bergstrøm 1973, Rasmussen 1984). In the Gullesfjorden-Kanstad area the highest observed marine limit and morphological shore features correlate with the late-YD shorelines according to the isobases (Fig. 11). Due to the absence of higher shorelines and distinct cirque moraines we propose that the inner part of Gullesfjorden and the Kanstad area were glaciated in early-YD, a view supported also by the model of Rasmussen (1984). It should not be excluded that ice remnants have survived in this area during Allerød and been activated during the T-L advance.

The seismic data suggest the presence of a submarine ridge, possibly an ice-front deposit (the Forøya moraine) northwest of Forøya in Gullesfjorden (Fig. 11). A few kilometres farther north there is another zone of ice-marginal

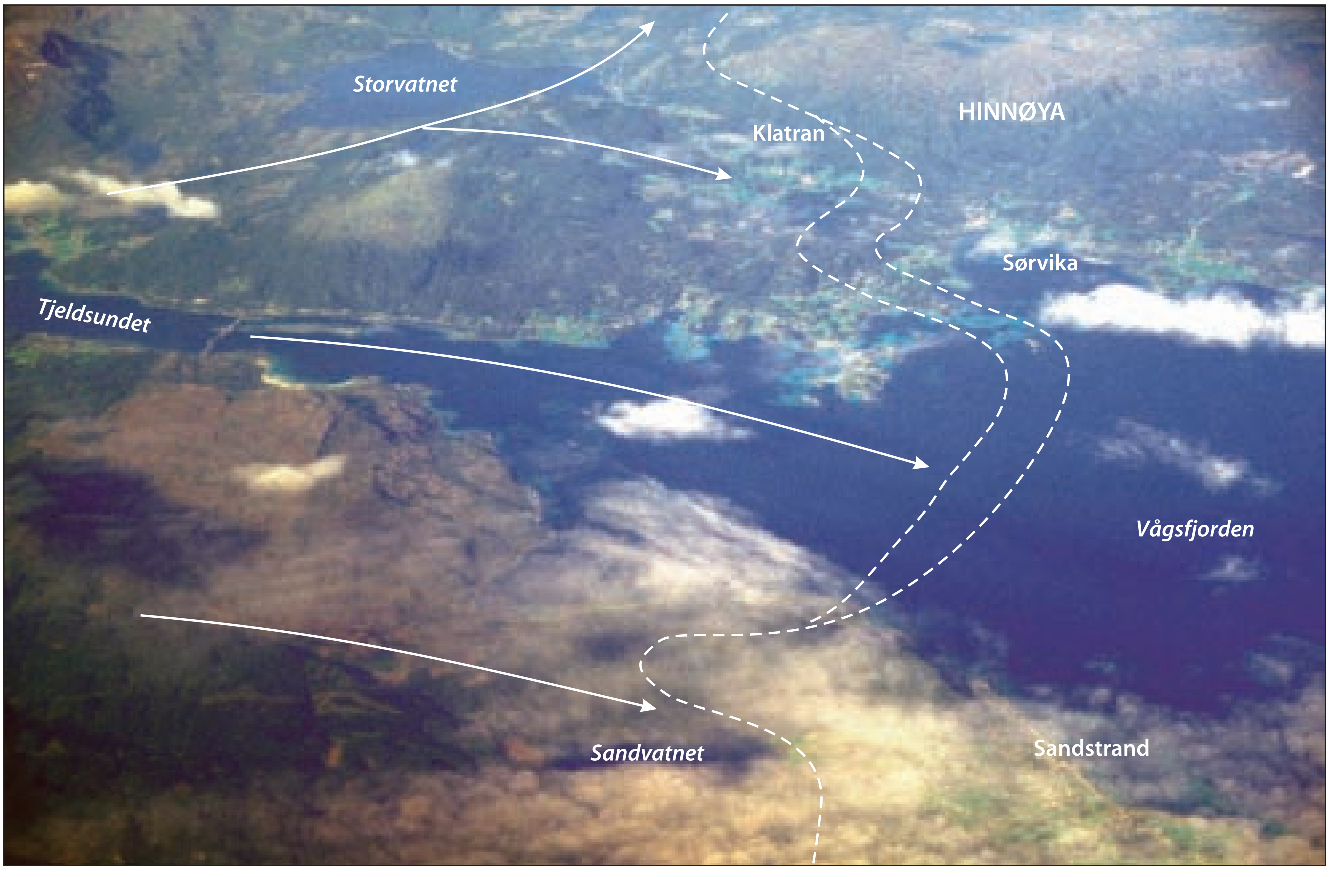

Fig. 9. Northern Tjeldsundet/ inner Vågsfjorden and eastern Hinnøya, view towards west. The ice-marginal zone during the Tromsø-Lyngen event is drawn on the photo. In the background is the area at Klatran-Sørvika where the zone of marginal moraine ridges are located. Arrows indicate the direction of the ice movement. After Bergstrøm (2004).

Table 1. Radiocarbon dates (conventional and AMS), mainly of mollusc shells. Ages are given in ^{14}C-years before present (BP) with (1) and without (2) subtraction of reservoar age (440 yr), and in calendar years (+/- 1sd) BP (3) calibrated after Marine04.14C from Hughen et al. (2004). For location, see Fig. 12.

Loc.no	Locality	Lab. no	Dated material	14C-age (1)	+/- 1sd	14C-age (2)	Cal-age (3)
1	Seljeneset, Austerfjorden	T-14685	Mya truncata	11370	175	11810	13410-13120
2a	Mågelva, Storvatnet	UtC-7348	Shell fragment	11060	70	11500	13090-12930
2a	Mågelva, Storvatnet	UtC-7346	Shell fragment	11270	80	11710	13250-13120
2a	Mågelva, Storvatnet	UtC-7347	Shell fragment	11680	70	12120	13670-13450
3	Klatran	T-14168	Mya truncata	12135	70	12575	14100-13960
4	Sørvika	Tua-4050	Mya truncata	11800	65	12240	13760-13650
4	Sørvika	Tua-4051	Mya truncata	11515	75	11955	13440-13310
4	Sørvika	Tua-4052	Mya truncata	11660	65	12100	13650-13440
5	Nøkketjern, Fauskevåg	T-14169	Mya truncata	11745	145	12185	13780-13450
6	Fauskevåg	T-14683	Div. species	10835	55	11275	12880-12840
7	Nylund, Sandsvatnet	Tua-4049	Mya truncata	11170	70	11610	13180-13070
8	Evenskjer	T-14684	Mya truncata	11295	145	11735	13310-13100
9	Skutvik*	T-10065	Whalebone	11535	120	11975	13550-13290
10	Risøya, Offersøya	Tua-3541	Shell fragment	11135	75	11575	13140-12980
11	Neshaugen, Lødingen	T-14687	Mya truncata	10715	100	11155	12850-12760
12	Veigrotta, Kjøpsvik*	T-10525	Hiatella sp.	11120	145	11560	13200-12920
13	Breidvikbotn, Tjeldøya	Tua-2604	Mya truncata	11000	85	11440	13050-12890
14	Nonsfjellet, Kjelde	T-15722	Mya truncata	11465	185	11905	13540-13210
15	Grøsnes, Gratangen	Tua-3195	Shell fragment	10935	85	11375	12950-12860

* All information from locality no. 12 is from Nese (1996); and the dated whalebone from loc. 9 Skutvik, was collected by Tor Dahle, 1991.

deposits. The observations of the relatively high marine limits north of the Forøya moraine indicate that these levels correspond to pre-Allerød shorelines. South of Forøya the ML observations are grouped at or slightly below the Main shoreline (Møller & Sollid 1972), indicating an early YD age for this marginal moraine. Its position is near the T-L ice-front position assumed by Rasmussen (1984) and supports his interpretation that the T-L glacier also occupied Lang-vatnet and deposited the double marginal moraine ridge at the isthmus between Austpollen and Langvatnet. Distal to the moraine we observed the ML at Austpollen close to 45 m a.s.l., in agreement with Møller & Sollid (1972), indicating an open fjord environment in Austpollen during the Skarpnes event. Consequently, the OD glacier in Gullesfjorden could not have advanced notably longer than during the T-L event. The marine limit at 34 m a.s.l. from Austpollen reported by Rasmussen (1984) is probably not the marine limit, but a large terrace corresponding approximately to the Main shoreline (Møller & Sollid 1972).

Stratigraphical sites in the Vestfjorden-southeastern Hinnøya-Ofotfjorden area

Skutvik (loc. 9, Figs. 10, 12). At the little town Skutvik, in a 6 m-high section at 50 m a.s.l., there is a 3 m-thick unit of strongly consolidated silt and clay. The sediment contains foraminifers, fragments of mollusc shells and a 70 cm-long fragment of a whalebone. The distribution of the foraminifers in the lower unit indicates a cold, probably late-glacial environment (T. Eidvin, written comm. 1992), in agreement with the ^{14}C date of the whalebone, which yielded an Allerød age (Table 1). We suggest that the over-consolidation of the silt and clay, which according to the construction workers could not be removed without using explosives (T. Dahle, written comm. 1992), was a result of a readvance of the glacier over this site during the early YD.

Risøya (loc. 10). At Risøya, just north of Offersøy on Hinnøya, a unit of consolidated silt was exposed in a section along the road, c. 4 m a.s.l. The silt contained a few pebbles and fragments of *Mya truncata, Macoma calcarea*, a.o. It showed deformation structures (faults and folds), and was wave washed at the top. A ^{14}C date of one shell fragment of *Mya truncata* yielded an age of c. 11.1 ka BP (Table 1). It is not clear whether the site was overrun by the glacier during the YD readvance. If the deformation structures in the silt are post-depositional, and possible glacial features, then this may very well have happened. Alternatively, the (T-L) ice margin may have been located just at or very close to this site, as indicated by the ice-proximal character of the sediments, their consolidation and structures.

Neshaugen (loc. 11). About 30 m a.s.l., in a section along the road at Neshaugen, Hinnøya, a thin glaciomarine silt is overlain by 1 m-thick, consolidated till and a 0.5 m-thick bouldery and gravelly shore deposit on top. A 10-20 cm-thick bed of sand with shells of *Mya truncata* is situated in a deformed, wedge-shaped structural unit between the silt and the overlying till. Striation on the bedrock close to this site is directed towards the west (WNW–WSW) and indicates that the till was deposited during a regional movement of a glacier, which reached Hinnøya and Vestfjorden from Ofotfjorden. A ^{14}C date of shells of *Mya truncata* from the sand wedge gave an age of c. 10.7 ka BP (Table 1), which is

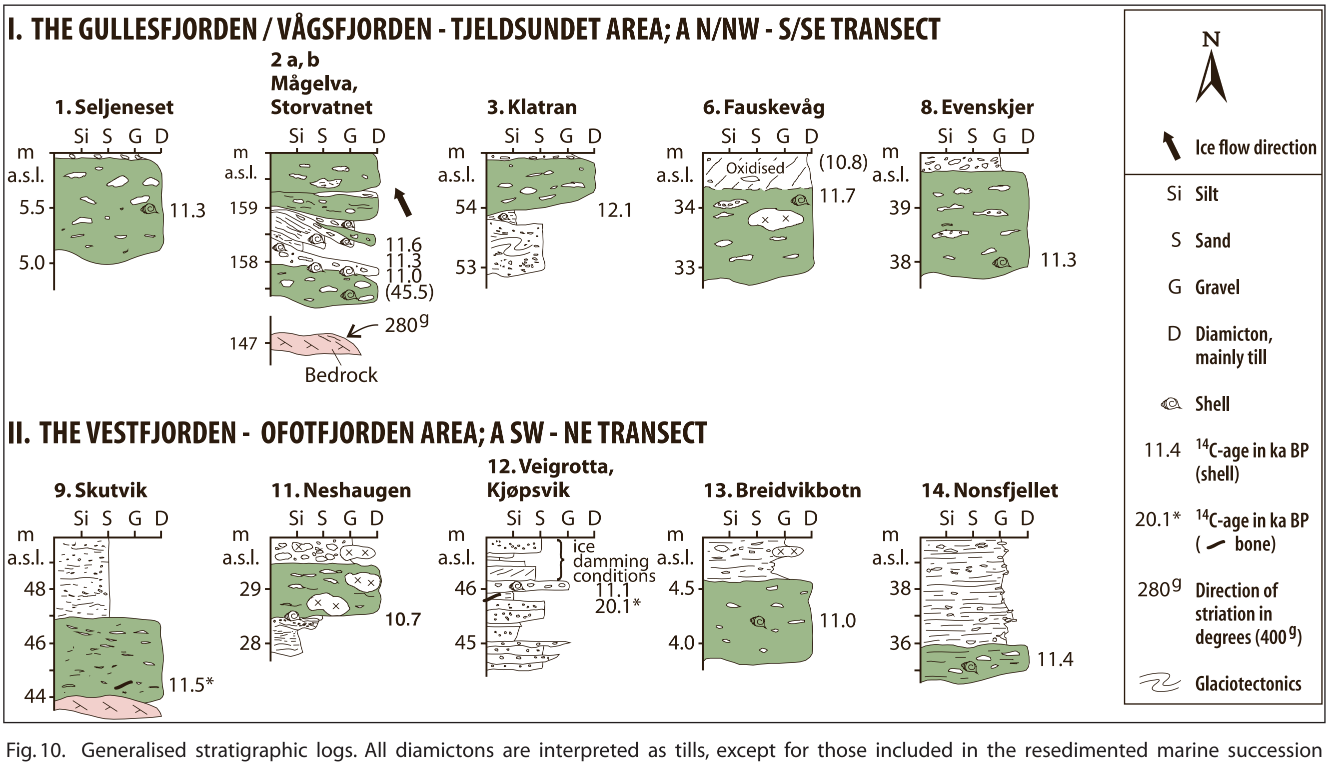

Fig. 10. Generalised stratigraphic logs. All diamictons are interpreted as tills, except for those included in the resedimented marine succession between 158 and 159 m a.s.l. at Mågelva (log 2a, b). Position and age of dates are shown for each log. Dates between parentheses are from corresponding stratigraphic levels at neighbouring sites. Ice flow direction inferred from preferred long axis-orientation of till clasts based on fabric analysis is indicated from Mågelva. For location of sites, see Fig.12.

the youngest maximum age we have found for the probable T-L readvance in this study.

Veigrotta (loc. 12). The uppermost 2.5 m of a section through a succession of sediments located in a cave named Veigrotta, close to the town of Kjøpsvik in the Tysfjorden area, has been described by Nese (1996), supported by some data from other nearby caves (Lauritzen et al. 1996, Nese & Lauritzen 1996). The most intriguing parts in this context are the traces of ice-free conditions and the subsequent ice dammed sediments which occur twice in the upper two metres of the sediment column. A bone of a polar bear (*Ursus maritimus*) from the sand and silt at c. 1.2 m depth was ^{14}C dated to c. 20.2 and 22.5 ka BP, indicating ice-free conditions between the two major LGM ice advances (LGM 1 and 2) (Olsen et al. 2002). The corresponding interstadial is referred to as the Andøya Interstadial for Lofoten – Vesterålen (Vorren & Laberg 1996), the Kjelddal Interstadial farther south along the coast (Olsen 2002), and the Trofors Interstadial for the inland areas of Nordland (Olsen 1997). These ice-dammed sediments were probably deposited during the LGM 2 ice advance. Above these sediments another succession of ice-dammed sediments follows, starting with a shell-bearing glaciofluvial gravel at the base, c. 1.0 m from the top (Fig. 10). A ^{14}C date of a shell (c. 11.1 ka BP) of *Hiatella sp*. from this unit indicates ice-free conditions here during the Allerød (Table 1). The subsequent ice-damming conditions are therefore thought to be a result of the T-L readvance.

Breidvikbotn (loc. 13). The uppermost 70 cm of a deformed, consolidated, glaciomarine sediment with shell fragments of Mya truncata a.o. was recorded in a section c. 5 m a.s.l. along the road at Breidvikbotn on Tjeldøya. A thin unit of gravelly shore deposits is present at the top. A ^{14}C date of one shell fragment of Mya truncata from the deformed sediment gave an age of c. 11.0 ka BP (Table 1), suggesting that the ice overran the site during the T-L readvance.

Nonsfjellet (loc. 14). The topmost 60 cm of a shell-bearing diamicton, underlying 4 m of gravelly deposits of inferred shore origin, was recorded in a section c. 40 m a.s.l. along the road at the foot of Nonsfjellet, near the village named Kjelde. A ^{14}C date of fragments of *Mya truncata* from the diamicton, interpreted as till, yielded an age of c. 11.5 ka BP (Table 1), which indicates that during the Allerød the ice retreated at least back to the central Ofotfjorden area. The till derives most likely from the T-L glacier.

Discussion

Shorelines

The Main shoreline (line S_0 or P_{12} in Marthinussen 1960) has been reported to be more like a zone or a belt than a single line in the equidistant diagrams (Marthinussen 1962, Andersen 1968, Møller & Sollid 1972). Parts of the Main shoreline features may therefore have been formed somewhat later than the T-L moraines. This view is supported by the fact that the highest shorelines at Tjeldsundet and outer Ofotfjorden (previously used to construct the isobases of the Main shoreline) now appear to have been formed in a later phase of YD, as we argue for in this paper. Andersen (1968) also stated that the lowest-lying part of the YD shoreline belt probably represents a very late phase of the T-L event, or possibly the beginning of the subsequent melting phase. At Espenes in Troms, two distinct YD shorelines abraded in glacigenic sediments are elevated 4–5 m apart (Sveian et al. 2005c). Follestad & Hamborg (1985) presented a radiocarbon date at Repparfjord pointing to a late YD age for the Main shoreline in Finnmark.

Even if the Main shoreline was formed partly in late YD, there is still a disagreement in the shoreline datasets from the Hinnøya-Tjeldsundet-Ofotfjorden region. The established isobases do not fit all of the previous or recent ML observations. According to our model, indicating fully glacial conditions in Tjeldsundet and outer Ofotfjorden during the T-L readvance, no shorelines (ML) here should be located higher than the Main shoreline. However, in the literature some shorelines have been reported several metres higher. In our new data there is a disagreement between YD sea levels of 62–63 m at Klatran and those of 70 m at Ibestad, 70–72 m at Renså and 68 m at Sandstrand. Relative to the others the elevation at Klatran, observed just proximal to the T-L moraines, is apparently c. 5 m above the established Main shoreline (Fig. 3). Altogether, these discrepancies call for a correction of the isobases around Tjeldsundet. Alternatively, if the established isobases system is correct, the shorelines proximal to the Klatran moraines are older than the Main shoreline, which is in disagreement with all our radiocarbon dates.

At Gullesfjorden the deglaciation has not been dated, but the shoreline elevations point to a pre-YD age north of Forøya. A late-YD/early Preboreal age is now suggested for the innermost part of Gullesfjorden. Consequently, the ML south of the Forøya moraine (YD) should be slightly lower than the Main shoreline. Møller & Sollid (1972), however, reported marine limits c. 5 m above their suggested Main shore zone at four localities. The most distinct shorelines in the area, 40–45 m a.s.l., fit in very well with their Main shore zone, bringing up another implication for the need of correcting the Main shoreline isobases. The shorelines at inner Gullesfjorden should, thereby, turn out to be slightly younger than the Main shoreline. Rasmussen (1984) characterised them as less distinctive than the Main shoreline proper.

The reasons for the suggested irregularities of the isobases around Hinnøya could be neotectonic movements of the crust, an effect of local isostatic recovery resulting from an inferred late-glacial ice dome over Hinnøya/-Vesterålen, or more likely a combination of both.

Deglaciation in the Vågsfjorden-Gullesfjorden areas

The deglaciation in the Andfjorden-Vågsfjorden area (Fig. 3)

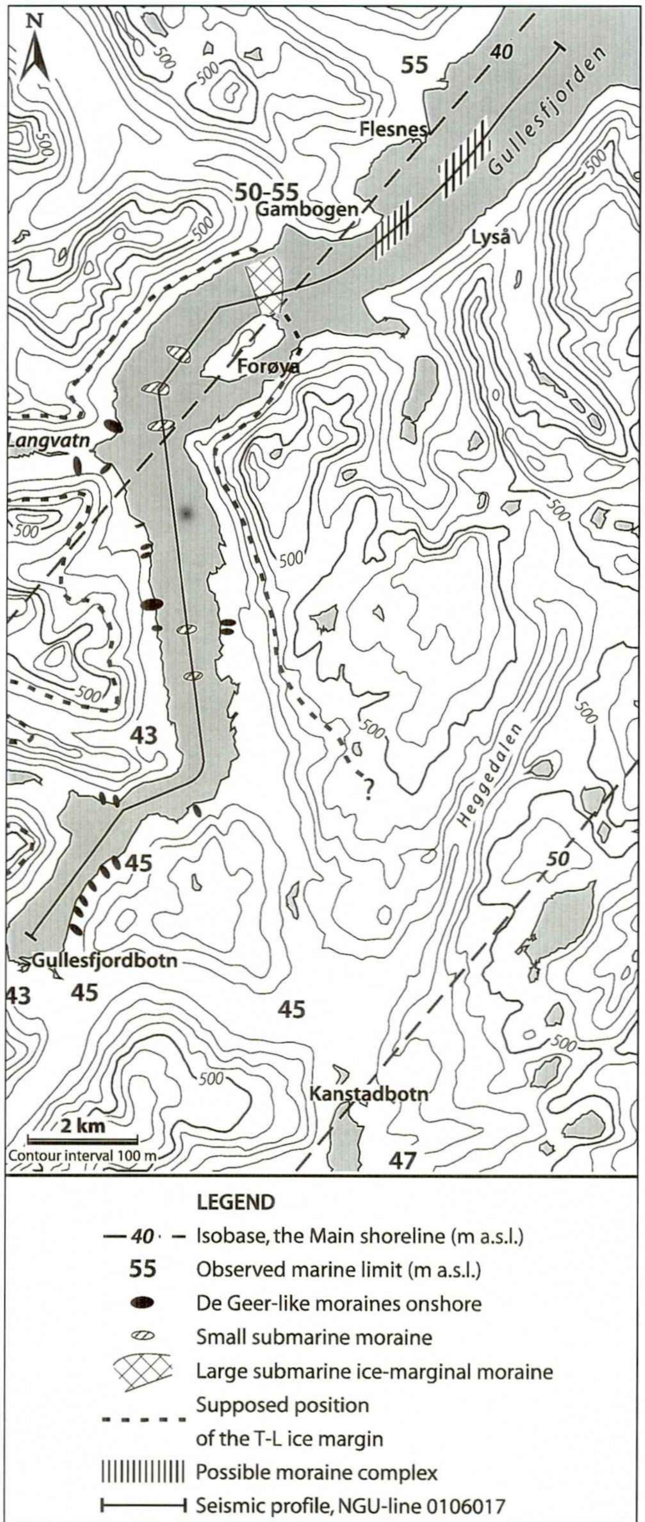

Fig. 11. Map of the inner Gullesfjorden area with isobases (Andersen 1975), marginal moraines, ML-observations and seismic line. The position of the T-L ice margin is tentatively reconstructed. For location of the map, see Fig. 3.

is summarized in Vorren & Plassen (2002) and adopted in Sveian & Bergstrøm (2004) with additional information east of Bjarkøy and in the Tjeldsundet area. In this paper we propose an alternative and more southerly position for the western part of the ice margin during the D-event, based on the location of the ice-contact delta at Bjarkøy (Møller et al. 1986), ML observations at Sandsøya and studies of previously reported high shorelines from the outer Kvæfjord region. At southern Senja the alternative location is based on some minor moraines (Sveian et al. 2005b). The inner part of Vågsfjorden was probably deglaciated during late Bølling according to Marthinussen (1962), Vorren & Plassen (2002) and our new radiocarbon date at Klatran (c. 12.1 ka BP).

The appearance of Skarpnes moraines in Vågsfjorden and Gullesfjorden is uncertain. The moraines may be included in the YD ridge systems or overridden and eroded by the T-L readvance. Smaller distal moraines deposited in Vågsfjorden could be weak traces of the ice margin during the Skarpnes event (Fig. 6). There is an indication that the Skarpnes moraines may have been situated in the Grashola area and possibly overridden by ice during the T-L readvance. In the inner Straumsbotn area where the Main shoreline appears at 48-50 m a.s.l., four minor proglacial deltas/sandurdeltas occur, indicating a maximum sea level at 58-59 m a.s.l. during the deposition (Fig. 5). Based on a sea level during the Skarpnes event 8-10 m above the T-L Main shorelines (Andersen 1968), we propose that the four deltas may correspond to the Skarpnes event, indicating a Skarpnes ice margin located only few kilometres from the deltas.

Based on seismic stratigraphy Vorren & Plassen (2002) registered an Allerød glacial recession in Astafjorden at least to the fjord heads, before the T-L readvance commenced. At Grøsnes in Gratangen (Fig. 12, loc. 15) a radiocarbon dating on shell fragments in till yielded a maximum age of c. 10.9 ka BP for the T-L readvance (Table 1).

The new radiocarbon dates and stratigraphical information presented in this paper provide strong evidence that the prominent marginal zone crossing the inner part of Vågsfjorden represents a submarine continuation of the Tromsø-Lyngen moraines, correlated with terrestrial marginal moraine ridges at Sørvika-Klatran and Grashola in the west and at Sandvatnet in the east (Figs. 5, 9). The complex system and internal structures of the submarine marginal deposits show that the grounding line of the glacier was not quite stable during the formation of the moraines (Figs. 6, 7), as indicated also by a zone of several parallel narrow ridges between Sørvika and Klatran (Figs. 5, 8).

Rasmussen (1984) mapped the moraines at Sørvika-Klatran and suggested a T-L age. In his model, without knowing about the submarine continuation in Vågsfjorden, he suggested that these were formed by ice flowing towards an open fjord in Tjeldsundet from a large local Hinnøya ice cap. This was a reasonable suggestion at that time, based on Andersen's (1975) reconstruction of the T-L ice margin in Tjeldsundet (Fig. 2B). However, glacial striae and the occurrence of shell-bearing marine sediments incorporated in till

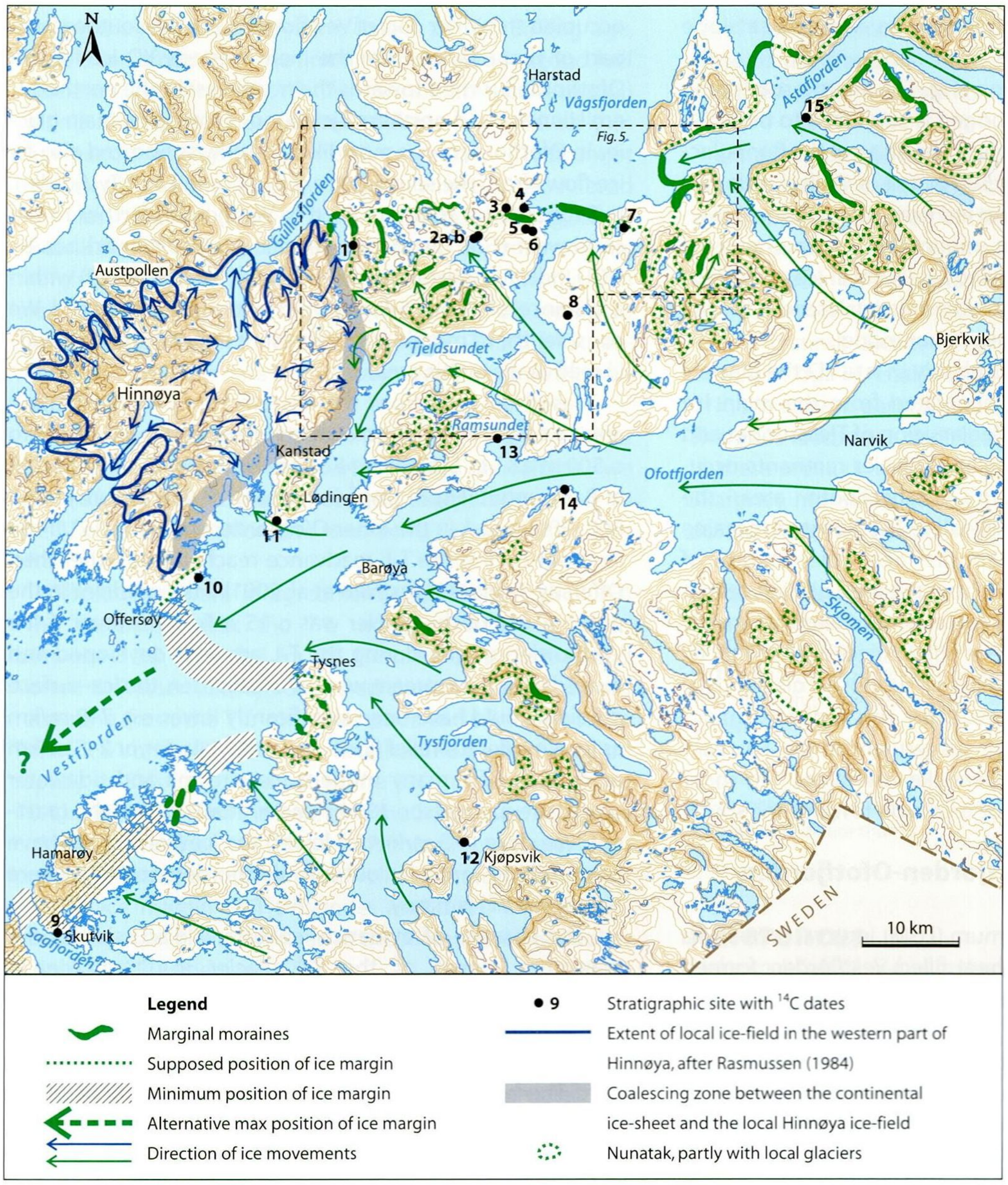

Fig. 12. Reconstruction of the Tromsø-Lyngen event (early Younger Dryas) in the Hinnøya-Ofotfjorden area. In Ofotfjorden-Vestfjorden the ice front during the T-L readvance reached at least to the Offersøy-Tysnes area, as shown on the map. Most likely the maximum position of the ice margin was located even farther west, somewhere in the inner to central parts of Vestfjorden.

in the Storvatnet-Klatran area clearly demonstrate deposition by an advancing continental ice sheet from the southeast during YD (Figs. 5, 9). Møller & Sollid (1972) correlated the same moraines with the Astafjord (Skarpnes) moraines on the basis of shoreline observations and reconstruction of the isobase system (Fig. 2A), which is in conflict with our results.

A possible YD scenario envisaged by the location and orientation of the Grashola marginal moraine is a situation of ice advance from two directions - the main movement from the southeast through the Storvatnet basin, and a northeasterly moving ice towards Korsvatnet from the local plateau glacier situated at c. 500 m a.s.l. farther west at Melåvatnan (Fig. 5).

In the high mountains west of Kongsvikdalen, no moraines from local ice caps or cirques glaciers have been observed. In our opinion the reason for this could be that the area was completely covered by local ice, which merged with the continental ice sheet in a zone from Austerfjorden to Fiskefjord and farther along the western side of southern Tjeldsundet (Figs. 5, 12). If this interpretation is correct, the water divide between Kongsvikdalen and Austerfjord (370 m a.s.l.) was covered by ice flowing from the main ice sheet protruding along Kongsvikdalen and also from local glaciers on both flanks. Consequently, the ice also reached Austerfjorden where the radiocarbon date indicates a readvance to the mouth of the fjord. If so, the lateral moraine situated at 80–110 m a.s.l. at Labakkan also should be correlated with the T-L glacier in Austerfjorden. Terraces on the western side of this moraine were deposited when the glacier started receding and the river Melåa eroded in the moraine. Detailed topographical maps show an upper accumulation level of these terraces at c. 50 m a.s.l., apparently some metres above the Main shoreline, which is at 45–46 m a.s.l. according to Marthinussen (1960) and Møller & Sollid (1972). However, the isobases most likely need to be corrected in this area (see discussion) so that the Main shoreline comes closer to 50 m at Labakkan. Thus, we suggest, in agreement with the radiocarbon date, that the Revsnes and Labakkan moraines correlate with the T-L event. Rasmussen (1984) proposed that a glacier lobe occupied the small valley east of Labakkan and deposited the moraine, in conflict with our model (Fig. 5). The morphology of the Labakkan moraine indicates an ice-contact slope towards the fjord.

In the Gullesfjorden region (Fig. 11), a large submarine end moraine at Forøya-Gambogen is supposed to be of T-L age, indicating that the minimum elevation of the fjord glacier in inner Gullesfjorden was 500 m a.s.l. at Gullesfjordbotn-Kanstadbotn, where it was also fed from merging local glaciers covering much of the mountains of southeastern Hinnøya during early YD. Consequently, local ice also occupied much of Kanstadfjorden where it coalesced with the continental ice sheet according to our model.

During the deglaciation, probably in late YD, the glaciers on Hinnøya were gradually separated from the main ice sheet. Calving led to a rapid deglaciation of Tjeldsundet and several minor fjords, while isolated glacier remnants occupied, e.g., the Kanstadbotn-Gullesfjordbotn area, the Storvatnet basin and Kongsvikdalen. The Kanstad moraine and minor ice-marginal deposits near the mouth of Kongsvikdalen were deposited from the local glaciers at that time. At inner Gullesfjorden a few sediment exposures have been briefly studied and these show successions with till overlying disturbed sand and silt of supposed glaciofluvial or shallow-marine origin. Most likely this indicates minor local advances of the ice front subsequent to the T-L readvance. Several small de Geer-like moraines in inner Gullesfjorden indicate rapid ice recession towards the south.

Deglaciation in the Vestfjorden-Ofotfjorden area

During the Last Glacial Maximum (LGM) interval c. 28-15 ka BP, the Fennoscandian ice sheet filled Vestfjorden, formed localised ice streams and reached the shelf edge at least twice (Olsen 1997, Dahlgren 2002, Olsen et al. 2002; Ottesen et al. 2005). During the deglaciation the ice front readvanced several times and formed huge moraine accumulations at the grounding line transverse to Vestfjorden. The two most prominent of these, the Tennholmen and the Værøy moraines, are located northwest of Bodø (Dekko 1975, Rokoengen et al. 1977, Ottesen et al. 2005) and are probably c. 13.7-13.1 ka BP or slightly older (R. Eilertsen, J. Knies & D. Ottesen, pers. comm. 2003). No distinct marginal moraines of the OD/Skarpnes event have been found, but along the southern side of Vestfjorden (between Ofotfjorden and Bodø) there are indications of readvances during the OD and YD events where the ice margin supposedly crossed the coastline and invaded parts of the Vestfjorden basin (Olsen 2000, 2002).

The radiocarbon dates obtained along Ofotfjorden and inner Vestfjorden indicate that the ice front during Allerød retreated at least eastward to the wide and deep central part of Ofotfjorden (Figs. 10, 12). At Tysfjorden, resedimented shells of Allerød age, found in the lower part of a succession of ice-dammed cave sediments (Lauritzen et al. 1996, Nese 1996), indicate a similar scenario with ice retreat at least back to Kjøpsvik before the early YD readvance. Based on the stratigraphies and ^{14}C dates from Risøya and Neshaugen (loc. 10, 11), we suggest that during the T-L readvance the ice occupied this inner part of Vestfjorden and the southeastern part of Hinnøya. Ice from the main westerly YD ice flow in Ofotfjorden turned towards the northwest in the northeastern Hinnøya and northern Tjeldsundet areas. The main glacier in Ofotfjorden was most likely heavily supported also by ice flows from the southeast, e.g. in Skjomen and Tysfjorden. In Sagfjorden, a tributary fjord to Vestfjorden farther to the southwest (Fig. 12), marine seismic profiles carried out by NGU indicate several moraines west of Skutvik (loc. 9) within a distance of about 5 km from the mouth of the fjord. We consider these moraines to represent a minimum of the (T-L) readvance in this area.

Based on data from the eastern Hinnøya-Vågsfjorden areas we have reconstructed the surface of the T-L glacier to c. 500 m a.s.l. at Storvatnet-Kongsvikdalen and c. 700 m a.s.l. at Ramsundet (Fig. 5), implying at least 500 m at Barøya and 800–900 m a.s.l. in the inner Ofotfjorden area (Fig. 12). If the ice front during the T-L readvance reached no farther than Offersøy-Tysnes (Bergstrøm et al. 2001b), the gradient in the outer 40 km of the glacier was c. 15 m/km. However, if the Vestfjorden glacier during the T-L advance developed and moved like an ice stream west of Ofotfjorden, the ice-surface gradient could have been significantly lower, e.g. 7–9 m/km as for a moderate-relief fjord- and valley glacier, or 2–5 m/km as recorded for many modern ice streams and tidewater glaciers (e.g., Paterson 1994, Funder et al. 1998). If the gradient was close to 5 m/km (or lower) the ice front would have been able to reach far out into Vestfjorden, to somewhere southwest of Hamarøy.

The absence of evidence makes any discussion of the maximum extent of the YD glacier in Ofotfjorden - Vestfjorden speculative. Still, some general considerations can be made, such that the YD ice front must have oscillated due to calving, particularly in the very deep parts of the fjord. The bathymetric conditions must have influenced the YD glacier dynamics significantly in this area. The calving has destabilized, whereas the grounding of the ice in shallow areas has stabilized the ice front, at least for a brief span during each step of deglaciation.

The marked threshold between Ofotfjorden and Vestfjorden at Barøya highly influenced the YD ice-front dynamics. An ice-margin position crossing this island was previously correlated with the T-L readvance (Andersen 1975). New marine seismic profiles obtained by NGU around Barøya show large marginal moraines, indicating a halt of the ice margin here. As a consequence of our T-L reconstruction, the Barøya 'threshold' must represent a younger YD event. Subsequently, during the late YD, the ice margin retreated to the head of Ofotfjorden where the Narvik-Bjerkvik moraines were deposited c. 10 ka BP (Andersen 1975).

Timing of the Allerød -Younger Dryas oscillation

The 19 dates yielding maximum ages for the T-L readvance (Table 1) range from 10715 to 12135 yr BP. They are all obtained from fossils in sediments originally deposited during ice-free conditions and subsequently reworked or overrun by the ice sheet. Only one date is of late Bølling age, while 6 are grouped in the first half and 9 in the second half of Allerød, and 3 in early YD. The considerable ice recession during Allerød therefore seems to have occurred early in that period at Vågsfjorden, northern parts of Tjeldsundet and possibly also in inner Vestfjorden where a mid-Allerød age was obtained from a bone- and shell-bearing till at Skutvik (loc. 9). Towards the end of Allerød the retreating ice margin reached at least to the central/inner Ofotfjorden area and into the tributaries of Astafjorden, according to shell-bearing tills at loc. 12 and 15 (Fig. 12). This is in agreement with previous data from Astafjorden (Vorren & Plassen 2002).

Ten dates are grouped within the interval 10.7-11.3 ka BP. Assuming that our radiocarbon dates are reliable, we contend that the T-L readvance most likely started close to the Allerød/YD transition and reached its maximum position after 10.7 ka BP.

These results are in agreement with Hald et al. (2003) who concluded that the T-L moraines were deposited between 10.8 and 10.3 ka BP. Fimreite et al. (2001) and Vorren & Plassen (2002) suggested that the glacier started retreating from the T-L moraines prior to 10.3 ka BP, while Forwick & Vorren (2002) concluded that the glacier retreated rapidly in Balsfjord proximal to the T-L moraines at about 10.4 ka BP. These data indicate that the T-L glacier readvance culminated before 10.3–10.4 ka BP. This timing is also supported by previous studies of shorelines located proximal to the T-L ice margin at Tjeldsundet and outer Ofotfjorden, occurring at an elevation close to the Main shoreline (Møller & Sollid 1972, Andersen 1975).

Conclusions

From recent regional mapping and radiocarbon dates, it is concluded that the Tromsø-Lyngen (T-L) glacier readvanced farther west and northwest in the Hinnøya-Vestfjorden region than previously suggested. The continental ice sheet invaded the northeastern part of Hinnøya from the southeast and reached Austerfjorden and Vågsfjorden, and coalesced with local glaciers which existed at that time in the eastern and central parts of the island.

The Vågsfjorden marginal belt, crossing the inner part of Vågsfjorden, represents the submarine continuation of the T-L moraines. It is correlated with terrestrial marginal moraine ridges at Sørvika-Klatran and Grashola in the west and Sandvatnet in the east. The Sandvatnet marginal moraine ridge most likely corresponds to the Renså moraines of T-L age and represents a link between the ice-marginal line at Renså and Vågsfjorden-Hinnøya.

In Ofotfjorden-Vestfjorden the T-L readvance extended more than 50 km and the ice front reached at least 15 km west of Barøya to the Offersøy-Tysnes area. The maximum position of the ice margin was probably located farther west, somewhere in the inner to central parts of Vestfjorden, if the Vestfjorden glacier moved like an ice stream with a surface gradient significantly lower than normal fjord-glaciers.

The readvance to the T-L moraines most likely started close to the transition Allerød/Younger Dryas (11.0 ka BP) and reached its maximum position between c. 10.7 and 10.4 ka BP.

The T-L isobases over Hinnøya and Ofotfjorden probably need to be corrected. According to our radiocarbon dates and observed altitudes of the Main shoreline, the isobases should be curved and drawn a few kilometres farther west. That will be in better agreement with the new model of the deglaciation in the studied region.

No distinct Skarpnes moraine corresponding to the Langnes ridge in Astafjorden has been found in Vågsfjorden or in the eastern part of Hinnøya. It is an open question if the Skarpnes readvance deposited any marginal moraines at all in these areas, or the later T-L glaciers have overridden the Skarpnes moraines. In some areas the ice-front positions during these two events might have been identical.

Acknowledgements

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