Glacial geology, deglaciation chronology and sea-level changes in the southern Telemark and Vestfold counties, southeastern Norway

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A revised and more detailed deglaciation chronology is presented in the southern Telemark and Vestfold, southeastern Norway, based mainly on information and results from mapping projects on the superficial deposits carried out by NGU during the last 20 years. The deglaciation of this area started about 13,000 years B.P. when the receding ice margin was grounded along the coast. Distally to Jomfruland, submarine moraine ridges deposited in front of the ice may correlate with the Gøteborg Moraine on the west coast of Sweden dated to 12,900-12,600 years B.P. The ice margin retreated some distance proximally to the Jomfruland island before 12,240 ± 80 years B.P. A glacier advance occurred at 12,200-12,000 years B.P. and the ice margin reached Jomfruland, probably correlating with the Tjøme-Hvaler ice-marginal deposits in the outer Oslofjord area. The position of the Slagen-Onsøy ice margin about 11,400-11,200 years B.P. is tentatively reconstructed westward from Oslofjord. During the late Allerød/early Younger Dryas (after 11,300 years B.P.), the glaciers readvanced and in the Kragerø area the ice front moved at least 10 km, and most likely 17-18 km to form the distinct Ra (Younger Dryas) moraines at about 10,800-10,600 years B.P. The submarine Ra moraines have been mapped by seismic profiling and show a concave calving ice margin in the outer Langesundfjord area (the Langesund Channel) during the deposition. The Eidanger ice-marginal deposits are dated to 10,400-10,300 years B.P. and correlated with the Ås moraines. The Geiteryggen ice-marginal deposits are complex and indicate a marked halt and readvance of the ice margin 10,100-10,000 years B.P. corresponding to the Ski moraines in the Oslofjord area. After the Geiteryggen event, the ice margin receded rapidly and the Akkerhaugen (9,800 years B.P.) and Nordagutu (9,700 years B.P.) ice-marginal deposits were formed. An equidistant shoreline diagram has been constructed based on the upper marine limits in the studied area. A modified shorelevel displacement curve from the Kragerø area is presented.

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Introduction

Quaternary geological mapping carried out by NGU (Geological Survey of Norway) during the last 20 years in Vestfold and the southern part of Telemark, southwest of Oslo (Fig. 1), has provided new information about the Late Weichselian and Early Holocene deglaciation and shorelevel changes in the region west of Oslofjord (Bergstrøm 1984, 1985, 1988, 1995c, 1997 and in press, Olsen & Løwe 1984, Bargel & Lien 1990, Sørensen et al. 1990, Klakegg 1991, Klakegg & Sørensen 1991, Bergstrøm et al. 1992, Dahl et al. 1997). Reflection seismic profiling in the Langesundsfjord/Langesund Channel has provided new information about the submarine ice-contact deposits which correspond to the terrestrial Ra moraines.

Based on this information and results from additional studies in the coastal areas, it is now possible to present a more detailed and somewhat revised deglaciation chronology from this region. Correlations have tentatively been made with the classical Oslofjord region where a detailed chronology has been presented by Holtedahl (1953) and subsequently revised by Sørensen (1979, 1983, 1990b, 1992) and Klakegg & Sørensen (1991). Recent studies of the shorelevel displacement, based on radiocarbon datings of isolation-contacts in basins and molluscs in marine deposits (Bergstrøm 1997, K. Henningsmoen, pers. comm. 1997), indicate that the previous shorelevel curves constructed from the Kragerø area by Stabell (1980) and Henningsmoen (1979) require modification. An equidistant shoreline diagram has

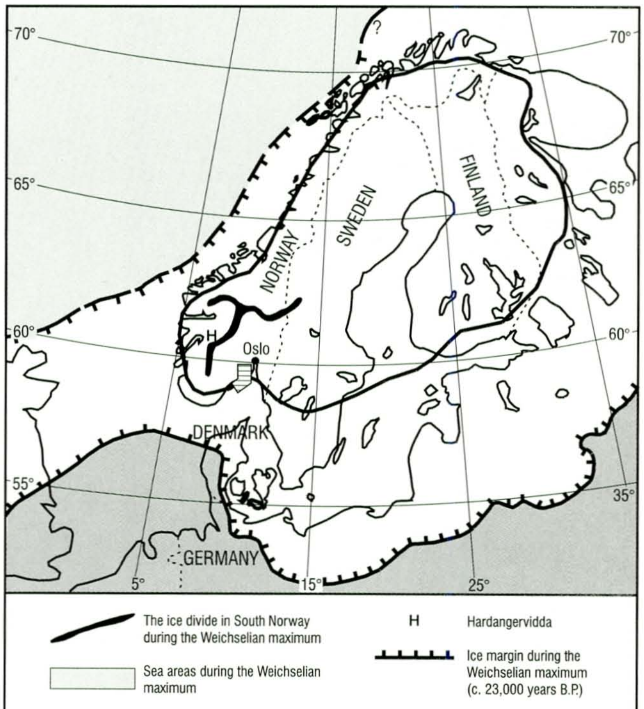


Fig. 1. The extent of the Scandinavian continental ice sheet during the Late Weichselian maximum and the Younger Dryas. The investigated area (SW of Oslo) is shown by a small box.

been reconstructed on the basis of marine limits in the mapped areas and previously published data from the Oslofjord region (Sørensen 1979).

Bedrock and geomorphology

The bedrock in the region west of Oslofjord (Fig. 2) consists of four *main units* (Dons & Jorde 1978, Larsen et al. 1978). *Precambrian rocks*, mainly gneiss, amphibolite and quartzite, predominate in the western part of the region. *Vendian (Eocambrian) rocks*, consisting of carbonatites and feldspathoid-rich rocks, occur in the Fen area at Nordsjø, northwest of Skien. *Cambro-Silurian rocks*, mainly sandstone, shale and limestone, are present in a narrow belt in the Skien-Porsgrunn-Langesund area. *Permian rocks*, mainly plutonic (larvikite, alkali syenite, ekerite) and volcanic rocks (rhomb-porphyry, basalt), cover the eastern part of the region in the Oslo district.

The topography is noticeably influenced by the bedrock, and in particular by the major faults and fractures. The major features are the ice-eroded (U-shaped) valleys and fjords surrounded by a hilly, undulating, highland terrain dissected by narrow fracture-controlled valleys.

The coastal area is dominated by exposed bedrock and characterised by a coastline with numerous skerries, islands, promontories, sounds and bays, together with narrow inlets projecting inland into the low-relief, undulating terrain. This coastal type is classified as a fjärd coast (Klemsdal 1982). The mature paleic landform on the mainland is a peneplain that slopes very gently towards the sea. In the Precambrian areas west of Langesundsfjord, the land surface is controlled by the 600 Ma old sub-Cambrian peneplain, which is only slightly modified by glacial erosion. However, glacial erosion has been active along zones of weakness, resulting in a number of narrow fault- and joint-valleys in the bedrock. The two dominant trends are c. NE-SW (the 'Caledonian' trend) and c. NW-SE, producing an uneven coastline and a dissected topography inland (Fig. 3).

In Skagerrak, parallel to the coast of Telemark, a deep narrow trench, the Norwegian Channel, curves around the southern coast. It probably originated as a combined result of tectonics and glacial erosion. From the mouth of Langesundsfjord a submarine channel, the Langesund Channel, extends down to and joins the main channel at a depth of nearly 600 m. The course of the Langesund Channel is considered to be largely structurally controlled, situated along the boundary between the Precambrian rocks to the west and the Permian rocks in the Oslo Region to the east (Holtedahl 1986) (Fig. 2). The channel is strongly influenced by glacial erosion.

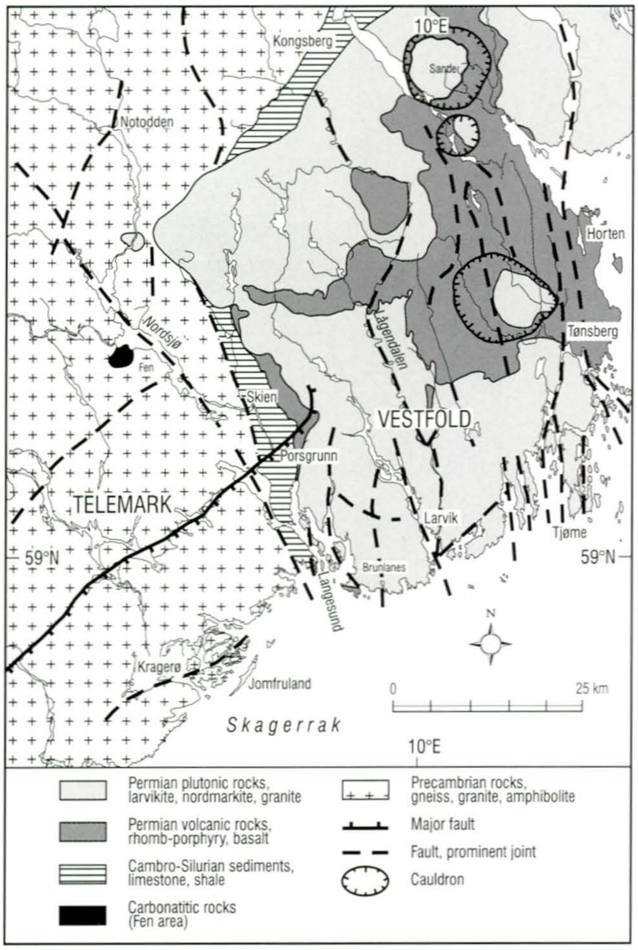


Fig. 2. Simplified bedrock map of the region west of Oslofjord. After Dons & Jorde (1978) and Larsen et al. (1978).

Methods

Field mapping

Quaternary geological mapping in scale 1:50,000 following the standard methods used by NGU has been carried out in the studied area. The maps and the geological information acquired during the fieldwork have been of fundamental importance for the present study. The correlation of the terminal moraines and glaciofluvial ice-contact deposits and the reconstruction of ice-front oscillations are mainly based on morphology, lithostratigraphy, ice-flow patterns and shoreline studies.

Radiocarbon dating

The radiocarbon datings have been carried out on molluscs from marine deposits and on silty gyttja from the bottom of lacustrine basins. Dating by the conventional radiocarbon method was carried out at the Radiological Dating Laboratory in Trondheim (T). AMS (Accelerator Mass Spectrometry) dates were produced at the R.J. Van de Graaff Laboratorium, Utrecht (UtC) and the Tandem Accelerator Laboratory, University of Uppsala (Tua). The dates of the marine molluscs have been corrected for a marine reservoir age of 440 years (Mangerud & Gulliksen 1975). All ages referred to in this article are in radiocarbon years.

Geophysical measurements

Reflection (CDP) and refraction seismic profiling and resistivity measurements (pole-dipole configuration) have been carried out in order to obtain more information about the stratigraphy of the Ra moraines. Submarine reflection seismic profiling was carried out in the outer Langesundsfjord and

Fig. 3. The Kragerø coastal area is dominated by exposed bedrock (Precambrian) and characterised by numerous skerries, islands, sounds and narrow inlets into the low-lying mainland. The land surface is controlled by the sub-Cambrian peneplain. The prominent Jomfruland island in the foreground is an emerged part of the Ra moraines and is clearly different in character from the interior areas. View towards WSW. Photo: Fjellanger Widerøe AS.

the Langesund Channel by the NGU research vessel 'Seisma' in 1990. The acoustic source 'Elma', which is an electromagnetic sound source operating at frequencies between 240 and 1200 Hz, was used. 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}.

Superficial deposits

Most of the area above the marine limit is dominated by exposed bedrock or a thin and discontinuous cover of till. A continuous and locally thick cover of till is found in a few valleys and mainly on slopes facing the direction of the ice movement. Glacial transport of till material cover a distance more than 10 km has been recognised (Bergstrøm 1984, 1988).

In the southern coastal areas below the marine limit, especially in the Precambrian area, the lack of superficial deposits is very striking, except in areas where marked ice-marginal deposits were formed during the deglaciation. The Ra moraines are the most prominent of these deposits. Some of the marginal deposits in locations exposed to the sea, such as Jomfruland (Fig. 3) and Mølen, have been heavily washed by waves and currents during the postglacial uplift and covered by well rounded boulders and cobbles. Fine-grained marine sediments, up to 60 m thick, dominate in the main valleys and the large basins. The largest and thickest glaciofluvial deposits were formed along the main drainage routes and built up as marine deltas, in particular along the ice-marginal zones, e.g., the Geiteryggen ice-marginal deposit.

The weathering material is closely related to the type of bedrock. Some rock-types are more susceptible to weathering processes than others. The products of the Cambro-Silurian shales and limestones are mainly fine-grained, while material weathered from Permian basaltic rocks normally consists of silt and fine sand (Bergstrøm 1984, 1995c). The weathering zones in the Permian larvikite are characterised by coarse sand and gravel and pronounced 'core-stone' development (Sørensen 1988). The carbonatites in the Fen area are covered by rust-coloured weathering material, mainly of sand and silt.

Most of the superficial deposits were formed during the Late Weichselian and Holocene. Older sediments have been found in Hærlandsdalen, a tributary valley to Lågendalen, where Roaldset (1980) has described overconsolidated sub-till clay sediments situated at about 250 m a.s.l., which is 75 m above the highest postglacial marine level in the area. The clay sediments were interpreted to have been deposited in a marine environment, based mainly on their Ce-deficient lanthanide abundance patterns, and they are considered to be of Middle Weichselian age and correlated with the Sandnes Interstadial. During the geological mapping in the area, a radiocarbon (AMS) dating of the sub-till organic-bearing clay at Rundhaugen (Roaldset 1980, Figs. 2 and 3) gave an age of 32,000 ± 300 ^{14}C-years B.P. for the NAOH-insoluble fractions (UtC-4728, Van de Graaff Laboratorium, Utrecht). This indicates a late Middle Weichselian age and supports Roaldset`s (1980) assumption of a correlation with the Sandnes Interstadial. This major ice recession about 30,000-40,000 years ago has been recorded at many places in Norway and there appears to have been a nearly complete deglaciation of the country during this period (Olsen 1997).

Ice-flow directions

The oldest ice movements detected in the region were directed towards the south (Fig. 4). The main ice divide during the Late Weichselian maximum, according to Vorren (1977), was situated at a considerable distance east and southeast of the watershed in Hardangervidda and the central part of eastern Norway. Nesje et al. (1988), however, suggested a low-gradient, poly-centred ice sheet with the main ice divide located close to the watershed.

In the coastal areas, glacial striae turning towards SSW indicate a convergence of the ice streams into the deep Norwegian Channel where they joined the 'Skagerrak glacier', the major ice flow from the inner part of Skagerrak (Longva & Thorsnes 1997).

When the glacier in the Skagerrak finally started to break up, the ice flow in the area of the Telemark/Vestfold coastline gradually turned towards the south-southeast and southeast. An active ice dome was regenerated on the southwestern part of the Hardangervidda mountain plateau, from which southeasterly directed ice streams flowed towards the southern Telemark and Vestfold regions and gave the early Younger Dryas glacier advance at 11,000-10,600 years B.P. (Bergstrøm 1995b). The ice flows were mostly not deflected by the local topography, but there was a weak convergence towards the main fjords and valleys.

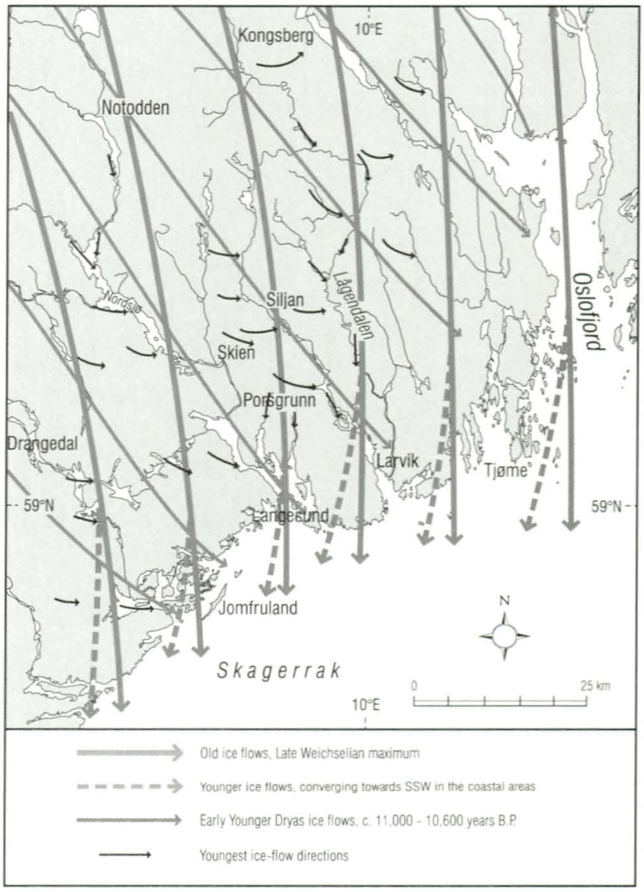


Fig. 4. Reconstruction of the ice movements during the Late Weichselian.

The final deglaciation was characterised by ice movements that were strongly dependent on the topographical conditions and the ice flows converged towards the larger valleys and fjords.

Late Weichselian deglaciation

The Late Weichselian ice sheet had its maximum extension about 23,000 years B.P. (Fig. 1). During the deglaciation, the ice sheet thinned and the glacier started to break up. In Skagerrak, the ice stream in the Norwegian Channel broke up at approximately 15,000 years B.P. and the ice margin was established along the Norwegian coast (Longva & Thorsnes 1997). Due to further thinning and calving, the margin retreated landwards and reached the outer coastal areas around 14,000-13,500 years B.P. The ice recession occurred more slowly and partly stopped when the ice grounded along the coast. In the outer part of the Kragerø area, parallel submarine moraine ridges occurring distally to the Jomfruland island (Figs. 5, 7, 14) (Holtedahl & Bjerkli 1975) were probably formed in front of the ice when the margin grounded in water depths of about 200 m. Radiocarbon dates from Jomfruland indicate that this occurred before 12,240 ± 80 years B.P. (p. 36). These moraine ridges may correlate with the Gøteborg Moraine on the west coast of Sweden, which is dated to 12,900-12,600 years B.P., and represent a pronounced standstill in the ice recession (Berglund 1978, Påsse 1986).

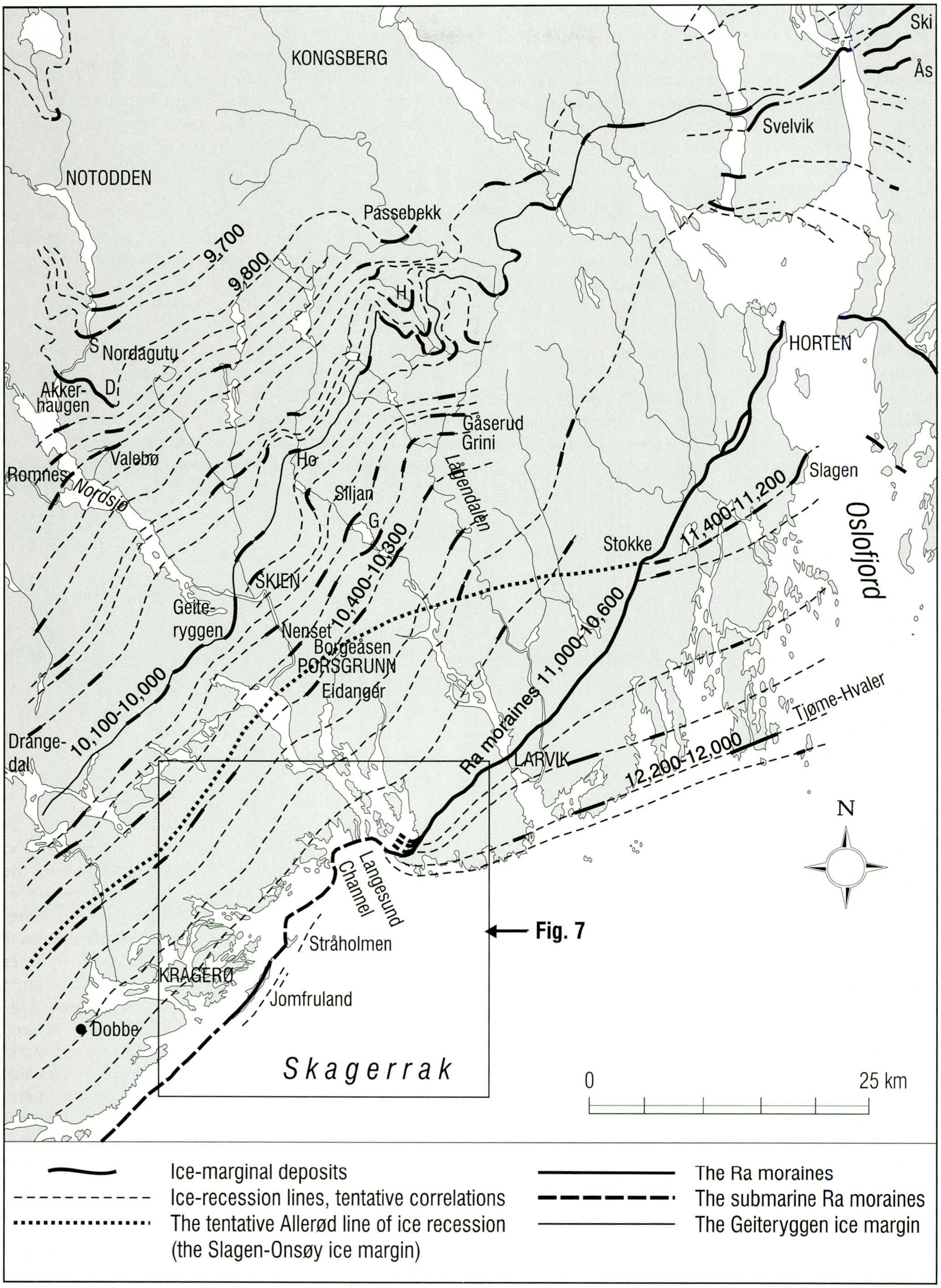


Fig. 5. Ice-marginal deposits and ice-recession lines in the region west of Oslofjord. (D) Dalsvatn, (G) Gorningen, (H) Hærlandsdalen, (Ho) Hogstad, (S) Sundsmoen.

The Tjøme-Hvaler ice-marginal deposits

After the formation of the submarine moraine ridges, the ice margin retreated some distance proximally to the Jomfruland island (Fig. 6). A radiocarbon date of a mollusc fragment in the boulder clay at Jomfruland (Fig. 16) indicates that the margin retreated behind Jomfruland as early as during the late Bølling Chron, before 12,240 ± 80 years B.P. Then the glacier advanced, but how far the ice margin actually reached is uncertain. Most likely the margin reached the Jomfruland island, due to the fact that the radiocarbon-dated mollusc, picked up by the ice during the advance, was incorporated in the till (boulder clay) and deposited on the island.

This event may correlate with the formation of the Tjøme-Hvaler ice-marginal deposits (Fig. 5) in the outer Oslofjord area (Sørensen 1983, 1992). At Tjøme, corresponding marginal moraines are overlain by glaciomarine clays with shells of *Portlandia arctica*, radiocarbon dated to 11,975 ± 155 years B.P., which indicates a minimum age for these marginal deposits (Bergstrøm et al. 1992). If this correlation between the Oslofjord and the Kragerø area is correct, the Tjøme-Hvaler ice-marginal deposits were formed between 12,240 ± 80 and 11,975 ± 155 years B.P.

Corresponding ice-marginal deposits and stratigraphical evidence of glacier advances have been found in many other areas along the coast of Norway, suggesting that a regional climatic deterioration occurred when the Tjøme-Hvaler ice-marginal deposits were formed during the late Bølling Chron (12,200-12,000 years B.P.) (Andersen 1968, 1979, Mangerud 1970, 1977, 1980, Follestad 1989, Bergstrøm et al. 1994, Follestad et al. 1994, Reite 1994, Bergstrøm 1995a, Sveian & Solli 1997, Olsen & Riiber in press).

In Bohuslän on the west coast of Sweden, the Tjøme-Hvaler ice-marginal deposits have been correlated with the Trollhättan Moraine (Berglund 1979, Sørensen 1979).

The Allerød ice-marginal deposits

During the early deglaciation of the coastal area west of the Oslofjord the ice margin was unstable due to intensive calving, and the recession was highly dependent on the topographical conditions, particularly on water depth. In the deep outer Oslofjord the calving continued and the fjord basin deglaciated rapidly. Westwards, the ice margin grounded in shallow water on the low, undulating coastal plain and the ice recession took place more slowly. Towards

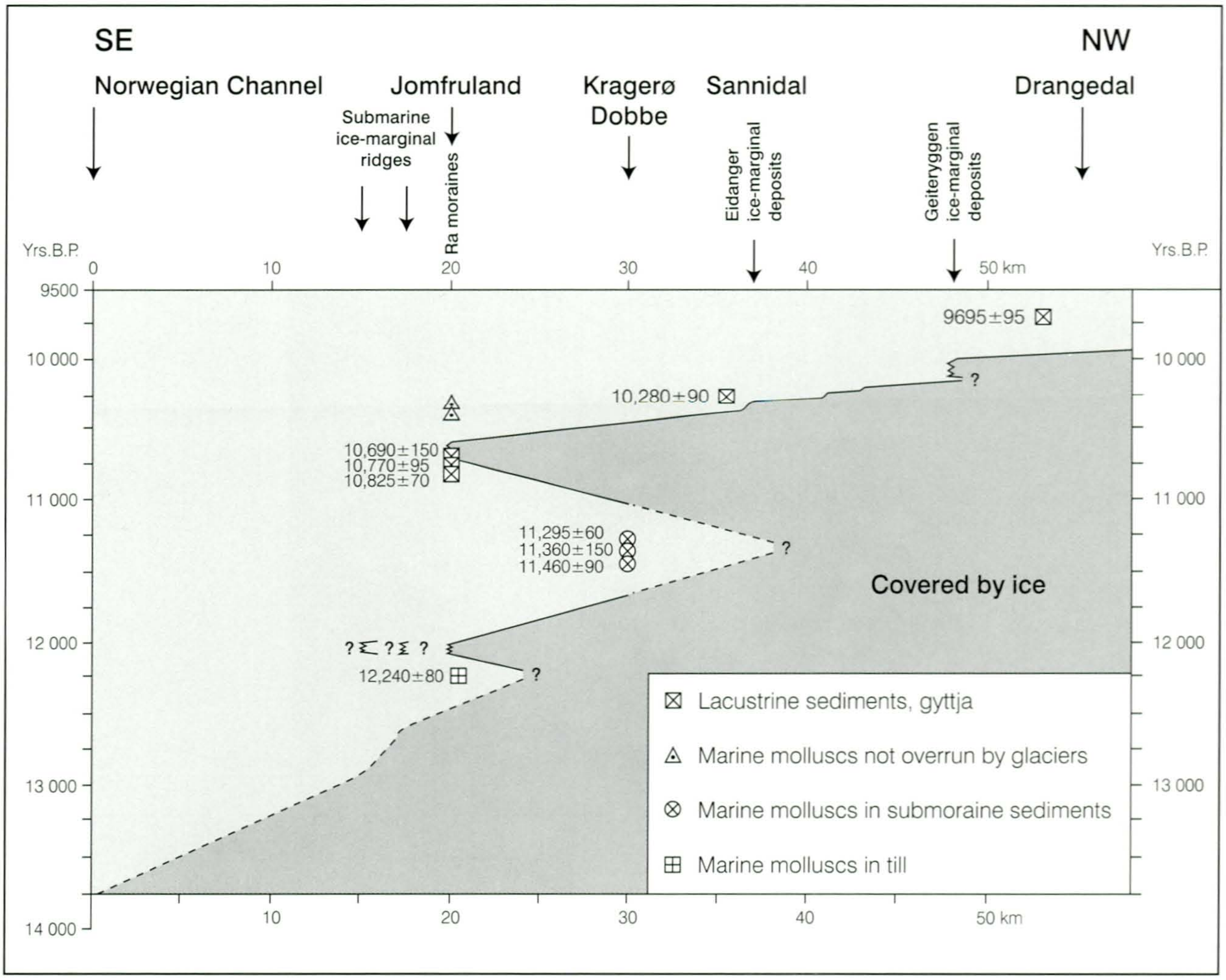


Fig. 6. Time-distance diagram (SE-NW) from the southern part of Telemark (the Jomfruland - Kragerø area) shows the glacier oscillations during the deglaciation.

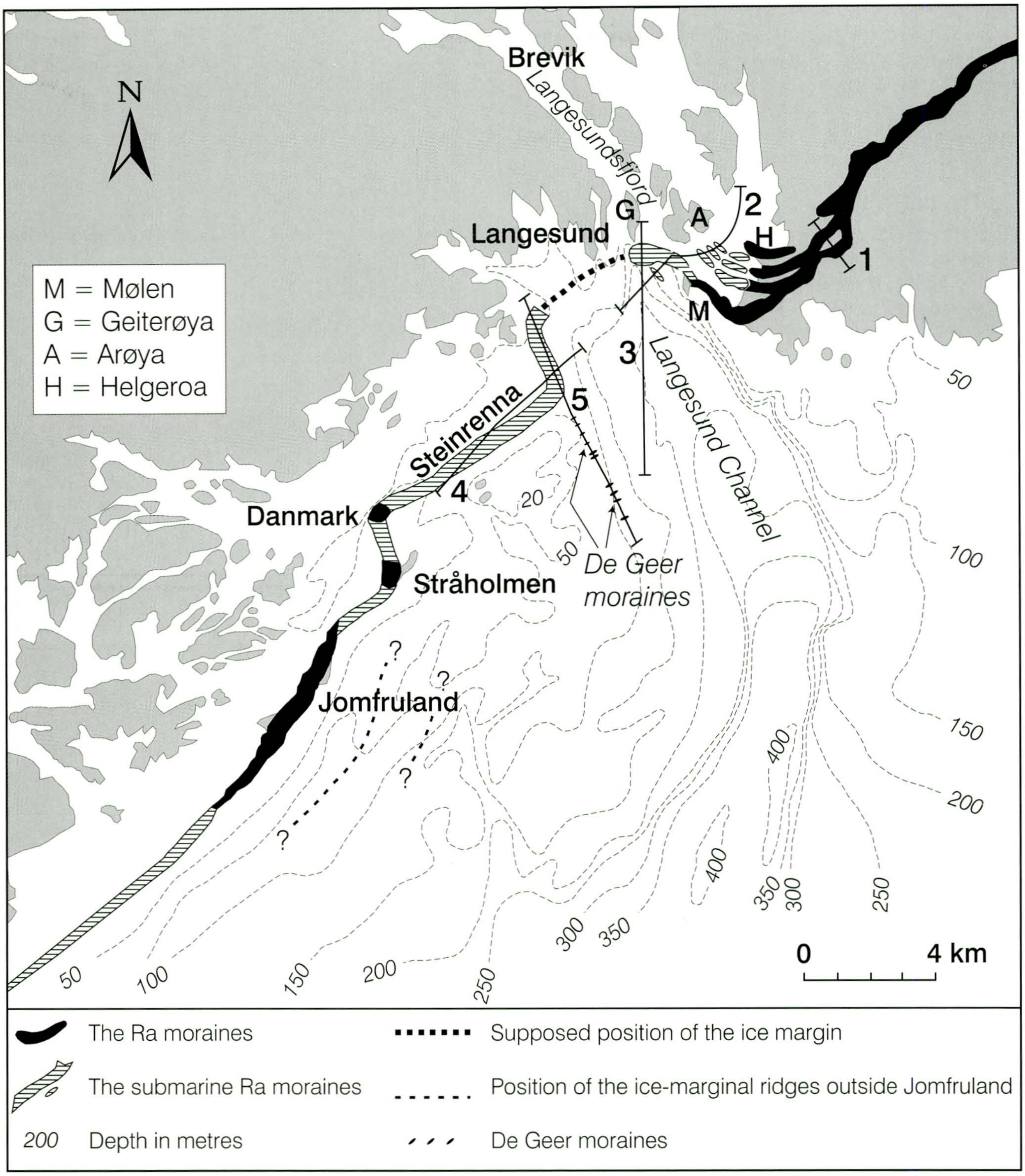


Fig. 7. The Ra moraines in the Langesundsfjord and adjacent marine areas. The interpretation of the submarine moraines is mainly based on the seismic reflection profiles. The position of the ice-marginal ridges outside Jomfruland is based on Holtedahl & Bjerkli (1975, Fig. 1). Sites for seismic profiles 1-5 are shown (Figs. 8-12).

Langesundsfjord (Fig. 5) the oldest ice-marginal lines, reconstructed from marginal deposits, approach each other. The marginal deposits, however, are not easily separated due to the later wave and sea ice activity and erosion during the crustal uplift.

At about 11,400-11,200 years B.P. the glacier had receded to the Slagen-Onsøy ice-marginal deposits (Sørensen 1992), which can be morphostratigraphically correlated with the Levene Moraine in Bohuslän (Berglund 1979, Sørensen 1979). The corresponding ice-marginal moraines can be followed westwards to Stokke (Fig. 5) where they are cut by the younger Ra moraines and no continuation can be found. The Slagen-Onsøy ice margin in the western areas was most likely situated in a proximal position to the Ra moraine ridges (Sørensen 1992, Bergstrøm 1995b). In the Kragerø area, the margin receded at least 10 km to Dobbe, and most likely more than 17-18 km, behind the zone of Ra moraines, during the Allerød Chron (Bergstrøm 1993, 1995b) (Figs. 5, 6).

The Ra (Early Younger Dryas) ice-marginal deposits

During the late Allerød (after 11,300 years B.P.) and the early Younger Dryas Chrons the glaciers readvanced (Bergstrøm 1995b) (Fig. 6) and the distinct Ra ice-marginal deposits were formed (Fig. 5). The Ra margin can be traced nearly continuously from Oslofjord and southwestwards to Mølen at Langesundsfjord as a low and broad ridge complex (Hansen 1910, Sørensen 1983, 1992, Andersen et al. 1995). From Mølen, the moraine ridges cross the fjord and can partly be followed off the coast to Stråholmen and Jomfruland, where they emerge above the present sea level (Fig. 7). Farther towards the southwest the Ra moraine continues for almost 60 km as a straight, submarine ridge parallel to the coast (Holtedahl 1989).

In general, the Younger Dryas marginal moraines are very distinct in Norway and can be traced and followed almost continuously along the coast from the Swedish border in the southeast to the Russian border in the north (Andersen et al. 1995) (Fig. 1).

The Mølen area

The Ra moraine ridges in Vestfold were mostly formed below sea level (marine limit 150-200 m a.s.l.) and are therefore usually covered with beach sediments. The composition of the ridges is variable, but generally they consist of a clayey matrix-supported diamicton (boulder clay) (Sørensen 1990a, 1992). In some areas the diamicton has a higher content of sand. Stratified diamicton and glaciofluvial deposits may also occur.

The Ra moraines in the area east of Langesundsfjord are a complex of ridges (Figs. 5, 7). East of Helgeroa the Ra consists of two parallel moraine ridges (Bergstrøm in press). A seismic-refraction profile across these ridges (Tønnesen 1991) indicates a maximum thickness (depth) to bedrock of more than 50 m (Fig. 8). The seismic velocities (1700-1800 m/s) indicate till deposits, except in the upper part where shore deposits (1-3 m thick) overlie the ridges. Most of the ridges probably consist of a clayey diamicton (boulder clay). Parts of the Ra moraine ridges are rich in large boulders, erratics moved by the ice over considerable distances from different areas in southeastern Norway.

Towards Langesundsfjord the Ra moraines split into 4-5 ridges which disappear below sea level (Sørensen 1992, Bergstrøm 1995b). Mølen is the largest of these ridges. During the crustal uplift the ridges were highly influenced by waves and currents and covered by coarse beach sediments. Along the seaward side of the Mølen peninsula there are numerous beach ridges consisting of well rounded stones and boulders.

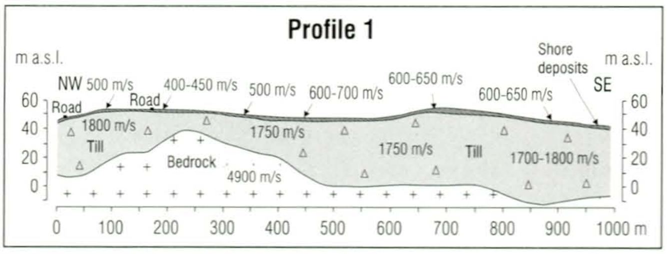


Fig. 8. Seismic refraction profile 1 across the terrestrial Ra moraines northeast of Mølen, modified after Tønnesen (1991). Seismic velocities are given in m/s. For location, see Fig. 7.

Submarine ice-marginal deposits can partly be traced from the Mølen area across the mouth of the eastern part of Langesundsfjord, based on data from bathymetric maps (Sørensen 1985, 1992).

Langesundsfjord

To obtain more information about the submarine ice-marginal (Ra) moraines in the outer Langesundsfjord, reflection seismic profiling has been carried out by NGU (Fig. 7).

In the fjord north of Mølen, a seismic profile, *profile 2* (Fig. 9), has revealed 5-6 submarine ridges which seem to correspond to the terrestrial Ra moraines (Fig. 7). The most distinct ridge (Fig. 9), outside Arøya, is double crested and distally 30-40 m high, consisting of till underlain by disturbed glaciomarine/marine sediments.

The disturbed sediments were most likely deposited during the recession in the Allerød and then overridden by the glacier during the early Younger Dryas readvance. The outermost ridge, outside Geiterøya, situated at the edge of the channel probably represents the maximum ice-front position during this readvance. However, this ridge is located in the most obvious position for the grounding line of the glaciers during the deglaciation in the pre Younger Dryas time and, even though this is not clearly seen in the seismic records, the ridge may be composed of sediments from older stages as well. Most likely the ridge may contain sediments of the Tjøme-Hvaler moraines formed during the Bølling/Older Dryas Chrons as described above.

A profile in the central part of the Langesund Channel, *profile 3*, (Fig. 7) , shows a double ridge at 75 m water depth (Fig. 10). The ridge lies just outside the threshold into the main part of Langesundsfjord and is the only marginal deposit in the trench between Geiterøya and Arøya. This infers that there was a stable ice margin over the threshold while it retreated towards the northeast south of Arøya, where the Ra moraines split into several ridges. The proximal part consists of two ridges which are about 25-30 m high on the ice-contact side. They have steep proximal and distal slopes of 10-12° and 13-15°, respectively. On the distal side there are inclined reflections dipping 5-10° southwards towards the deeper part of the channel. They are interpreted as foreset beds deposited in a submarine fan and most of them are probably debris-flow and turbidite deposits (Aarseth et al.1997, Lyså & Vorren 1997). Till beds may be interbedded with the foresets layers. At the base of the distal slope complex, hummocky and chaotic reflections with tilted blocks indicate sliding and slumping from the ridge. More distally, subparallel, low-angle reflections represent stratified glaciomarine sediments deposited during the early Younger Dryas. An irregular surface and partly disturbed sediment layers indicate avalanche activity during the deposition.

In the southern part of profile 3 (Fig. 7) there is a large bedrock basin filled up with sediments (Fig. 10). The stratigraphy corresponds with the general stratigraphy found in previous profiles from other parts of the Langesund Channel (Holtedahl 1986, Olsen 1992). Four different acoustic units are distinguished. The upper 40 m (Unit 1) is acoustically transparent and interpreted as postglacial sediments (post Ra deposits). Unit 2 has very distinct and mostly continuous reflectors, which most likely represent glaciomarine sediments deposited mainly during the early Younger Dryas (Ra). The lower units are disturbed by side echoes, but the more transparent sediments below (Unit 3) indicate a distal position of the ice margin and were probably deposited during the major retreat in the Allerød Chron. The lower unit (Unit 4) is interpreted as proglacial sediments deposited during the deglaciation of this area (Holtedahl 1986).

West of the Langesund Channel, in the Steinrenna basin, the seismic *profile 4* (Fig. 11, location Fig. 7) reveals a thick belt of till and disturbed glaciomarine/marine sediments (up to more than 50 m thick), which can be followed southwestwards along the coast in the direction of Jomfruland. The small, boulder-covered island, Danmark, represents a minor supramarine part of this moraine belt (Fig. 7).

A *profile 5* (Fig. 12) along the western margin of the Langesund Channel shows a thick, broad, submarine moraine ridge situated at the crossing of profile 4 near the edge of the slope.

Based on the profiles 4 and 5, the position of the submarine Ra moraines southwest of the outer Langesundsfjord is tentatively reconstructed as shown in Fig. 7. The thick deposits of glacigenetic sediments in the Steinrenna basin and the boulder island Danmark are interpreted as the main continu-

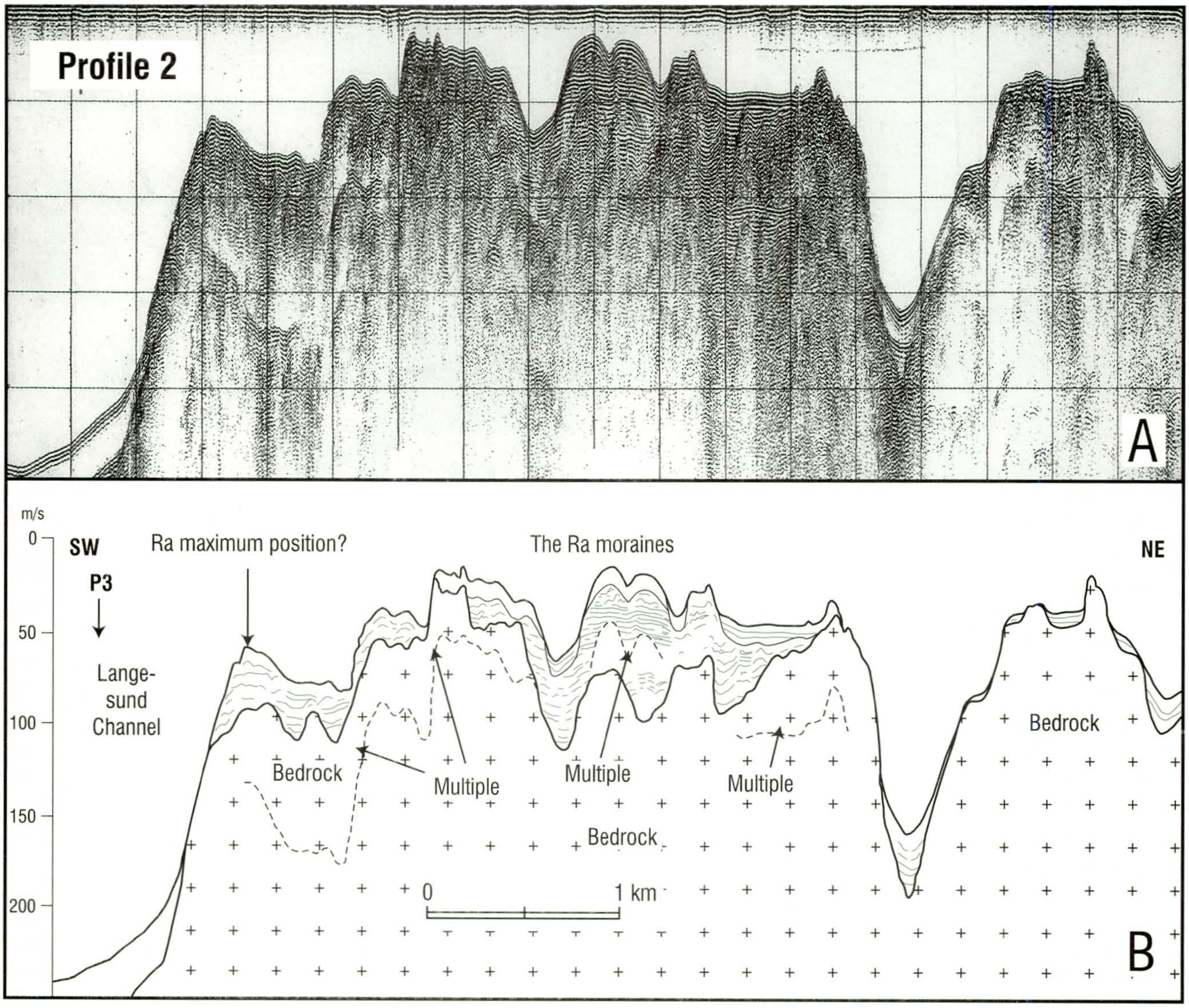


Fig. 9. A: Submarine seismic reflection profile 2 in the Langesundsfjord north of Mølen. For location, see Fig. 7. B: Interpretation of the profile 2.

ation of the Ra moraines from Jomfruland and Stråholmen northwards to the Langesund Channel, where the moraines seem to turn northwards along the edge of the channel.

Morphological evidence of younger and smaller ice oscillations during the early Younger Dryas is found proximally to the main Ra moraines in profile 5 as two small, but distinct terminal moraines. In the southern part of this profile (Fig. 12) many small moraine ridges occur at depths between 100 and 150 m. They are orientated transversely to the Langesund Channel and situated outside the Younger Dryas ice-limit, resembling very much the submarine De Geer moraines described from the Møre area, western Norway (Larsen et al. 1991, O. Longva, pers. comm. 1999). These ridges are thought to have been formed at the grounding line by glacier push. If the interpretation of the De Geer moraines in Langesundsfjord is correct, the deposition of these ridges has occurred in front of the retreating glacier during the deglaciation of the Langesund Channel, most likely during the early or middle part of the Bølling Chron. However, some of the moraine ridges, particularly the inner ones, might have been formed during the late Bølling glacier advance, corresponding to the Tjøme-Hvaler ice-marginal deposits.

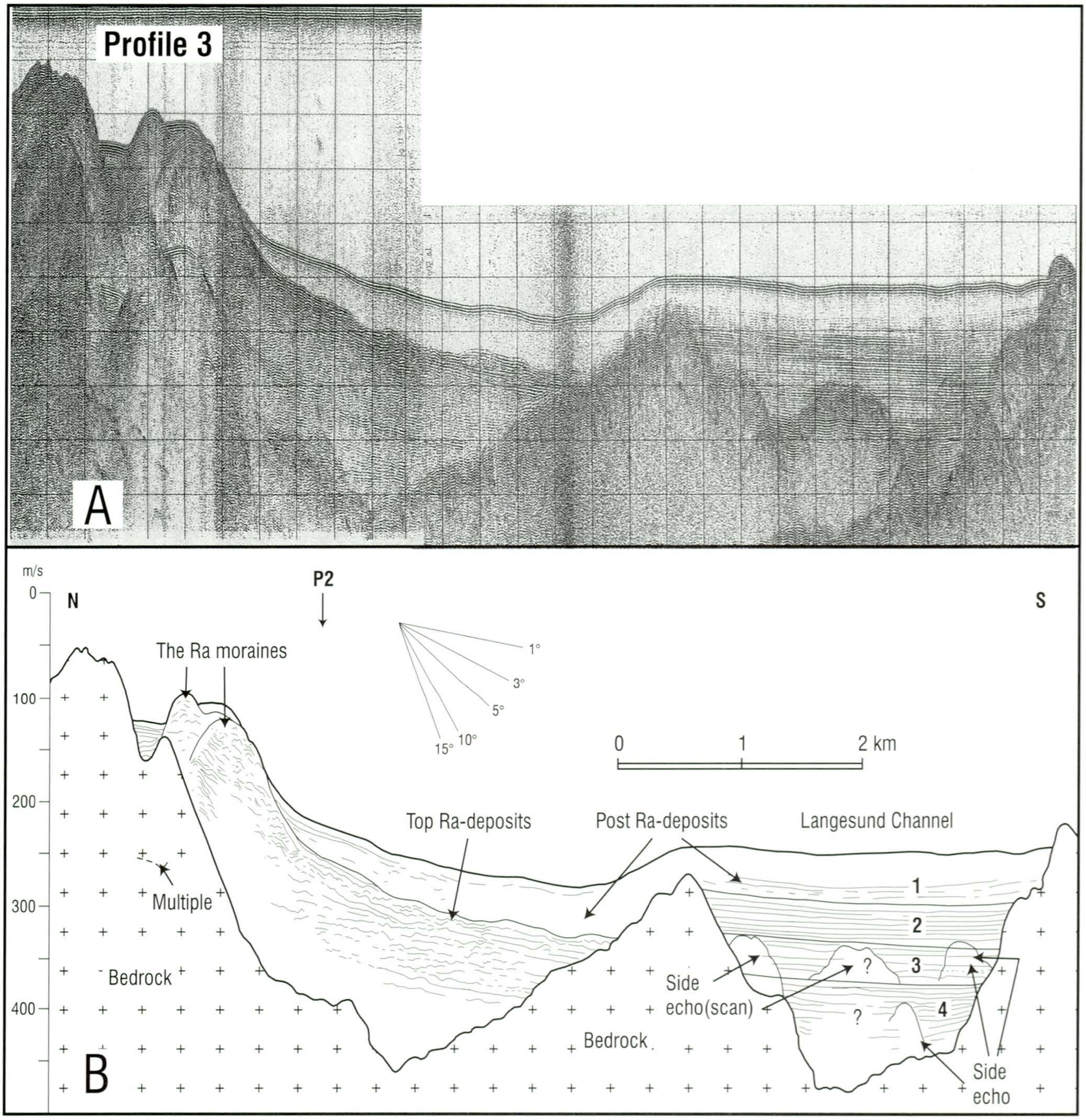


Fig. 10. A: Submarine seismic reflection profile 3 in the Langesundsfjord area . For location, see Fig. 7. B: Interpretation of the profile 3.

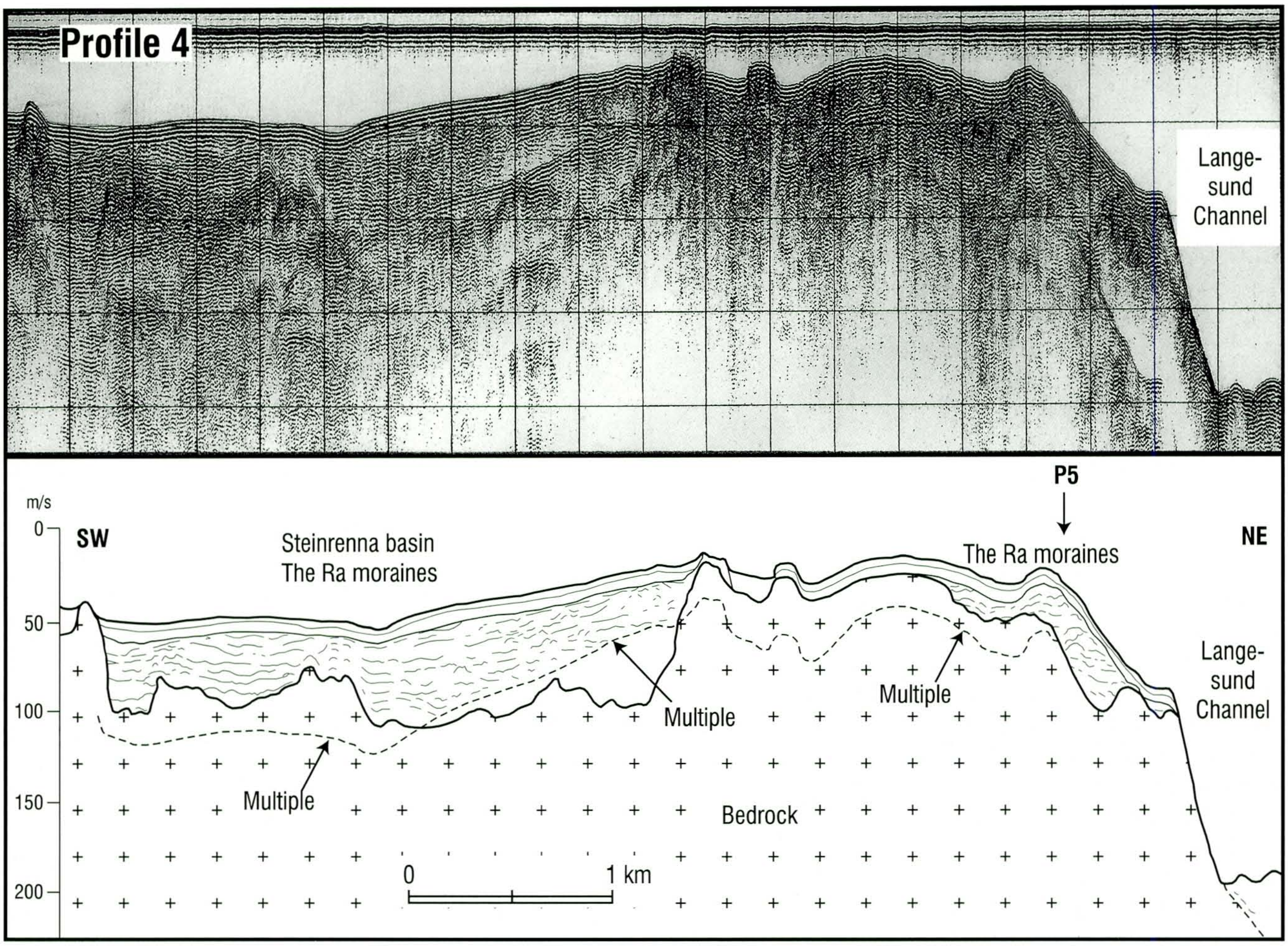


Fig. 11. A: Submarine seismic reflection profile 4 in the Langesundsfjord area. For location, see Fig. 7. B: Interpretation of the profile 4.

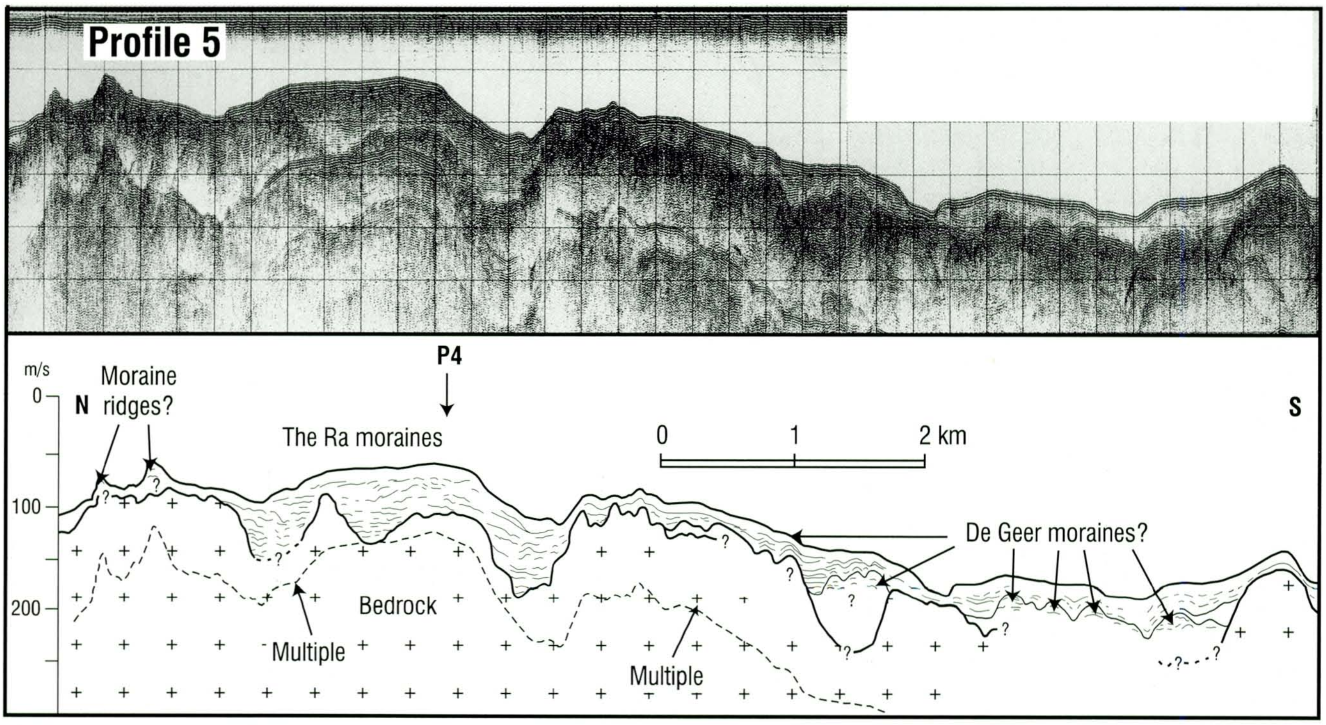
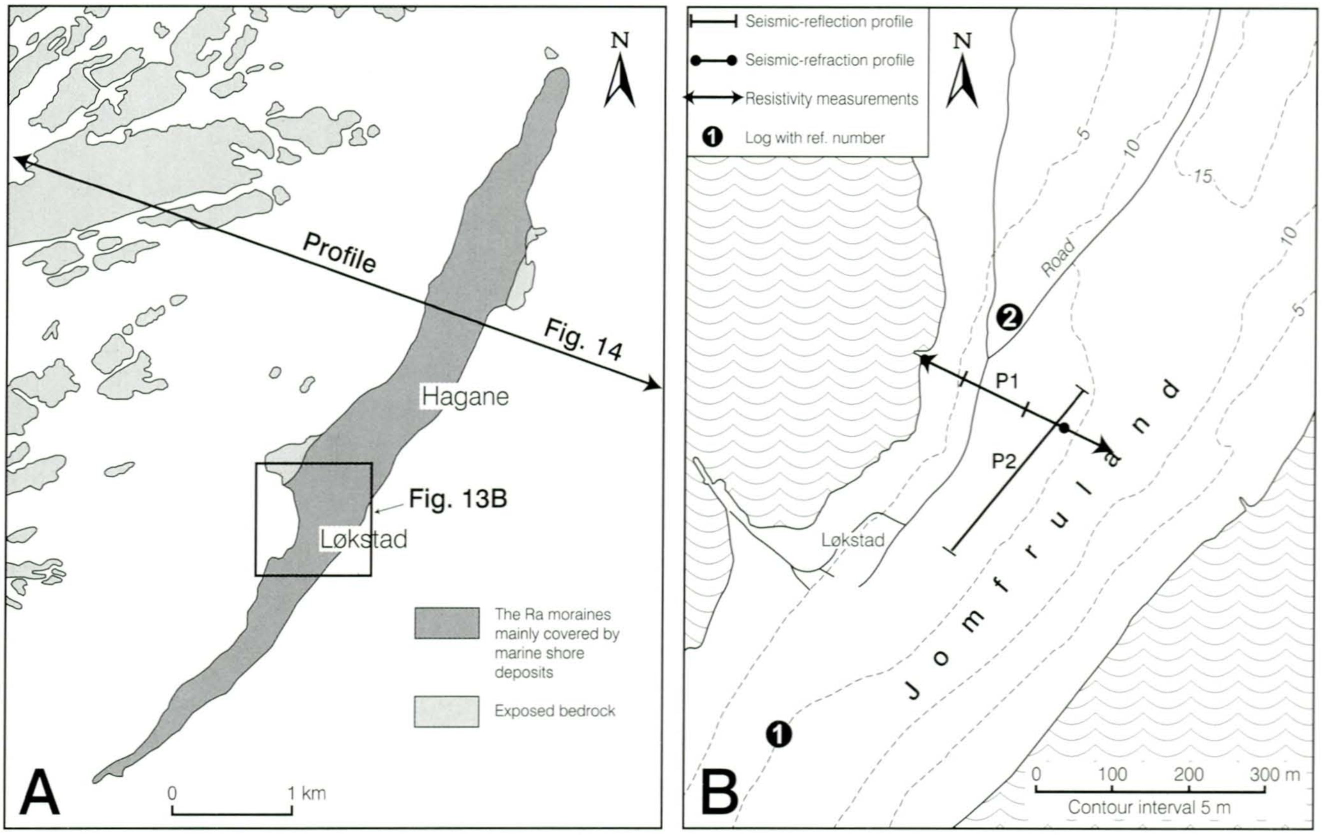


Fig. 12. A: Submarine seismic reflection profile 5 in the Langesundsfjord area. For location, see Fig. 7. B: Interpretation of the profile 5.



13. A: Location map of Jomfruland. B: Location map with sites of seismic and electrical profiles at Jomfruland.

Jomfruland island

Jomfruland is an emerged part of the Ra moraine and the island is 7.5 km long and up to 1 km wide (Figs. 3, 13). The highest point is about 20 m a.s.l. The island has been visited and described by many geologists (Keilhau 1842, Hansen 1910, Holtedahl 1953), but we still don't know much about its internal composition and structure. From old boreholes near the lighthouse, 2-5 m-thick beach deposits above consolidated clay have been reported (Keilhau 1842, Hansen 1910). Later on, a 40 m-deep drilling down to bedrock was carried out mainly through 'soft clay' near the new lighthouse (Jansen 1982, 1987), but no further information about the stratigraphy has been available. Parallel submarine moraine ridges (Fig. 14) occur off the coast on the distal slope of Jomfruland (Holtedahl & Bjerkli 1975).

Recently, geophysical measurements were carried out at Løkstad and Hagane (Figs. 13, 15) in order to obtain more information about the sediments (Mauring & Tønnesen 1992). At Løkstad, refraction seismic profiles show depths to bedrock varying between 15 and 60 m (Fig. 15). Reflection seismic measurements (CDP) show reflectors at a depth of 40-45 m, which indicate that marine sediments in the deepest part of the basin formed in an early ice-free period (older than the Younger Dryas advance). A reflector at a depth of 20-30 m most likely represents an erosion boundary formed by a glacial advance. The sediments above are interpreted as 'clayey till' (boulder clay). Resistivity measurements (pole-dipole configuration) have recorded three layers with high resistivity which indicate coarse material such as glaciofluvial deposits or gravelly/sandy till. This indicates minor ice-marginal oscillations, possibly during the late Weichselian deglaciation (late Bølling/Older Dryas and late Allerød/early Younger Dryas Chrons). This complex stratigraphy of the Jomfruland moraine ridge is quite similar to the stratigraphy of the Ra moraine at Fokserud in Vestfold where glaciofluvial material (sandy gravel) underlies clayey diamicton (Sørensen 1992).

The upper part (0-5 m) of the loose deposits has been studied in exposures associated with well digging. Most of the island is covered by beach deposits. In the most exposed

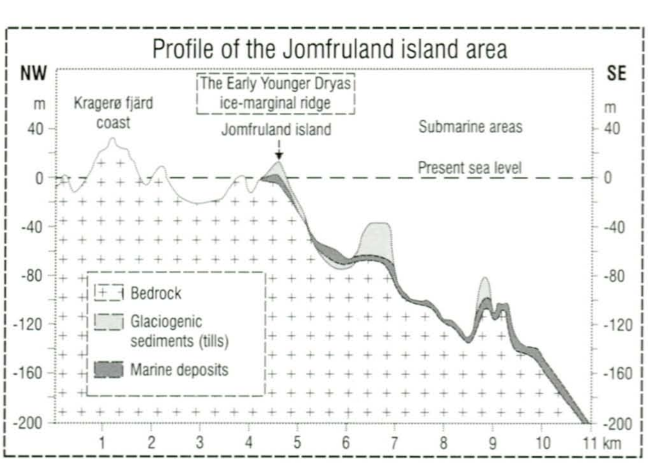


Fig. 14. Profile from the outer coastal area across the Jomfruland island area (NW-SE). Submarine part modified after Holtedahl & Bjerkli (1975). For location, see Fig. 13A.

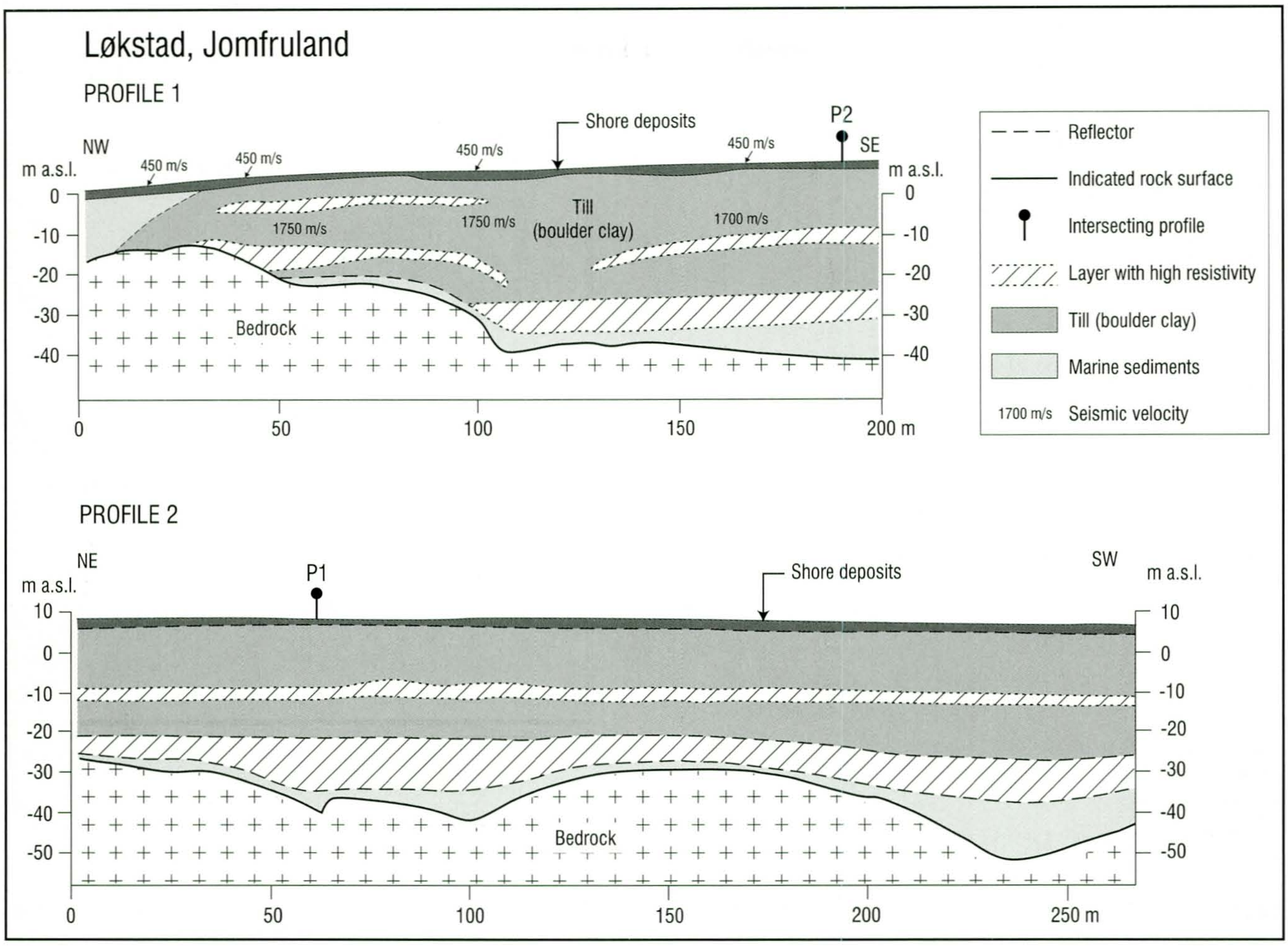


Fig. 15. Seismic and resistivity profiles at Jomfruland, modified after Mauring & Tønnesen (1992).

areas there are a lot of beach ridges containing well rounded cobbles and boulders. The underlying till consists of a consolidated, clayey, matrix-supported diamicton (boulder clay), partly with shell fragments of arctic molluscs. The content of clay and silt varies between 25 to 35 % and 30 to 35 %, respectively. A borehole (log 1) down to 10.5 m depth near the crest of the highest ridge at Løkstad (Fig. 16) shows softer diamict material below the consolidated diamicton. The composition of the material less than 16 mm is quite similar, but the content of cobbles and boulders is decreasing downward. This indicates that there is a gradual transition into the underlying glaciomarine sediments. During the Younger Dryas advance, much material from these sediments was picked up by the glacier and incorporated in the Ra moraines. The high content of silt and clay in the boulder clay indicates a glaciomarine origin. Radiocarbon dates of mollusc fragments, mostly *Macoma calcaria* and *Portlandia arctica,* in the till give ages between 10,690 ± 150 (UtC-2220) and 10,825 ± 70 years B.P. (Tua-935). One fragment of *Macoma calcarea* was dated to 12,240 ± 80 years B.P. (Tua-629) and indicates an earlier ice-free period during the late Bølling Chron.

In the lower part of the proximal slope of Jomfruland, the consolidated boulder clay is covered by more than 3 m of glaciomarine/marine sediments which are coarsening upward from clay to sandy silt. There is a major hiatus to the upper shore deposits, which coarsen upward from sand to big rounded cobbles and boulders, (log 2, Fig. 16). Mollusc shells from the lower and middle parts of these marine sediments were dated, and gave ages between 10,340 ± 105 (T-10777) and 8585 ± 105 years B.P. (T-10776).

The stratigraphy and the radiocarbon dates indicate that the ice margin retreated some distance proximally to Jomfruland as early as during the Bølling Chron, before 12,240 ± 80 years B.P. Then, the glacier advanced, due to the fact that the radiocarbon-dated mollusc was picked up by the ice and incorporated in the till (boulder clay) on the island. It is difficult to interpret how far the ice margin reached, but the stratigraphy indicates that the margin extended at least as far as Jomfruland. The glacier could have overridden Jomfruland and terminated on the distal side where the submarine moraine ridges were formed (Holtedahl & Bjerkli 1975) This implies that there must have been a major advance and a considerable increase in the ice thickness if the glacier should have been able to form these terminal ridges at a depth of more than 150 m. However, the lack of stratigraphical records in the adjacent areas of such a considerable advance indicates only a minor increase in the glacial activity. Most likely, Jomfruland island due to its topographically favourable position at the edge of the coastal plain, represents the maximum ice-front position during this advance.

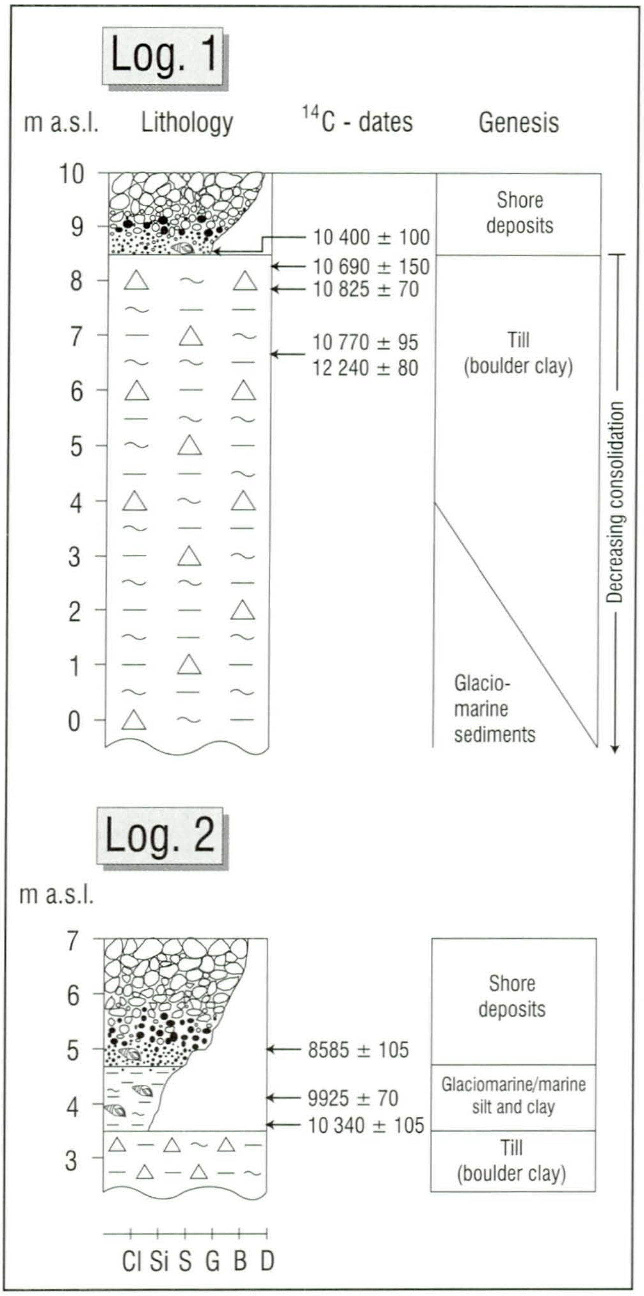


Fig. 16. Stratigraphical logs from the upper part of the Jomfruland ice-marginal deposit. ^{14}C-dates in years B.P. For location, see Fig. 13B. The laboratory numbers of the dates (see methods, p. 24) are listed from the top to the bottom of the logs. *Log 1*: Tua-1211, UtC-220, Tua-935, Tua-1210 and Tua-629. *Log 2*: T-10776, T-10775 and T -10777.

Subsequently, during the Allerød Chron, the ice margin receded at least 17-18 km inland from the Ra moraines (Bergstrøm 1995b). The glacier readvance started at the end of the Allerød Chron, after 11,300 years B.P., and terminated off the coast at Jomfruland. The complex stratigraphy of the Ra moraines at Jomfruland indicates smaller oscillations of the ice margin during their formation, which probably started at about 10,800 years B.P. The radiocarbon dates of the mollusc fragments incorporated in the upper part of the till suggest that the last readvance to the Ra moraines occurred shortly after 10,690 ± 150 years B.P. The final glacier retreat from the island started later than 10,690 ± 150 years BP and before 10,340 ± 105 years B.P., and most likely at around 10,600 years B.P.

After the deglaciation, Jomfruland was covered by the sea and fine-grained marine sediments were deposited at a water depth of more than 100 m. During the emergence of the upper part of the island, the fine-grained marine sediments were eroded and the moraine ridge was covered by boulders and cobbles washed out from the till by the waves (log 1, Fig. 16). At the lower and less exposed part of the proximal slope of the island, some of the fine-grained marine sediments still remain (log 2). Radiocarbon dates of molluscs indicate a minimum age of the moraine ridge of 10,340 ± 105 years B.P. Fragments of molluscs from the coarse-grained shore deposits are washed out from the older sediments and the dates give only a maximum age, 8585 ± 105 years B.P., for the time when the top of the ridge was influenced by the waves during the emergence of the island.

The Eidanger ice-marginal deposits

After the Ra event, the ice margin began to recede towards the northwest (Fig. 5). The presence of dropstones in the poorly sorted glaciomarine/marine clay and silt, overlying the Ra moraine ridge on the Jomfruland island, indicates that there were drifting icebergs in this area during the early part of the ice-free period, radiocarbon-dated to approximately 10,600-10,350 years B.P. When the ice margin reached the higher inland areas, the floating ice-marginal parts became grounded and the calving processes diminished. Some scattered glaciofluvial fans or small deltas were deposited near this grounding line west of Langesundsfjord (Fig. 5). They are correlated with the Eidanger ice-marginal deposit (Fig. 6), a glaciofluvial frontal ridge formed in a submarine position (not built up to sea-level) during a short halt or stagnation in the ice recession in Langesundsfjord (Bergstrøm 1995c). Northeast of the fjord, corresponding ice-marginal deposits have been mapped in the valleys Siljandalen and Lågendalen.

The Eidanger ice-marginal deposits are tentatively correlated with the Ås Moraines (Bergstrøm 1995c, Sørensen 1983,1992). A radiocarbon date of gyttja from a bog situated a few km distally to the Eidanger ice margin indicates that the area was ice-free from at least 10,280 ± 90 years B.P. (Henningsmoen 1979). Based on information from the Oslofjord area and Jomfruland, the most likely age of the Eidanger event is between 10,400 and 10,300 years B.P.

The Geiteryggen ice-marginal deposits

During the ice recession, the calving processes gradually decreased due to the general higher topographical level of the inland area and more of the ice margin was situated in a supramarine position. Only in the major valleys was the ice still in contact with the sea. This resulted in concave calving bays and converging ice flows towards these fjord valleys.

In the valley between Skien and Porsgrunn, north of Eidanger, minor glaciofluvial deposits were formed in the sea in front of the ice at Borgeåsen and Nenset (Fig. 5). Corresponding terminal moraine ridges and glaciofluvial ice-con-

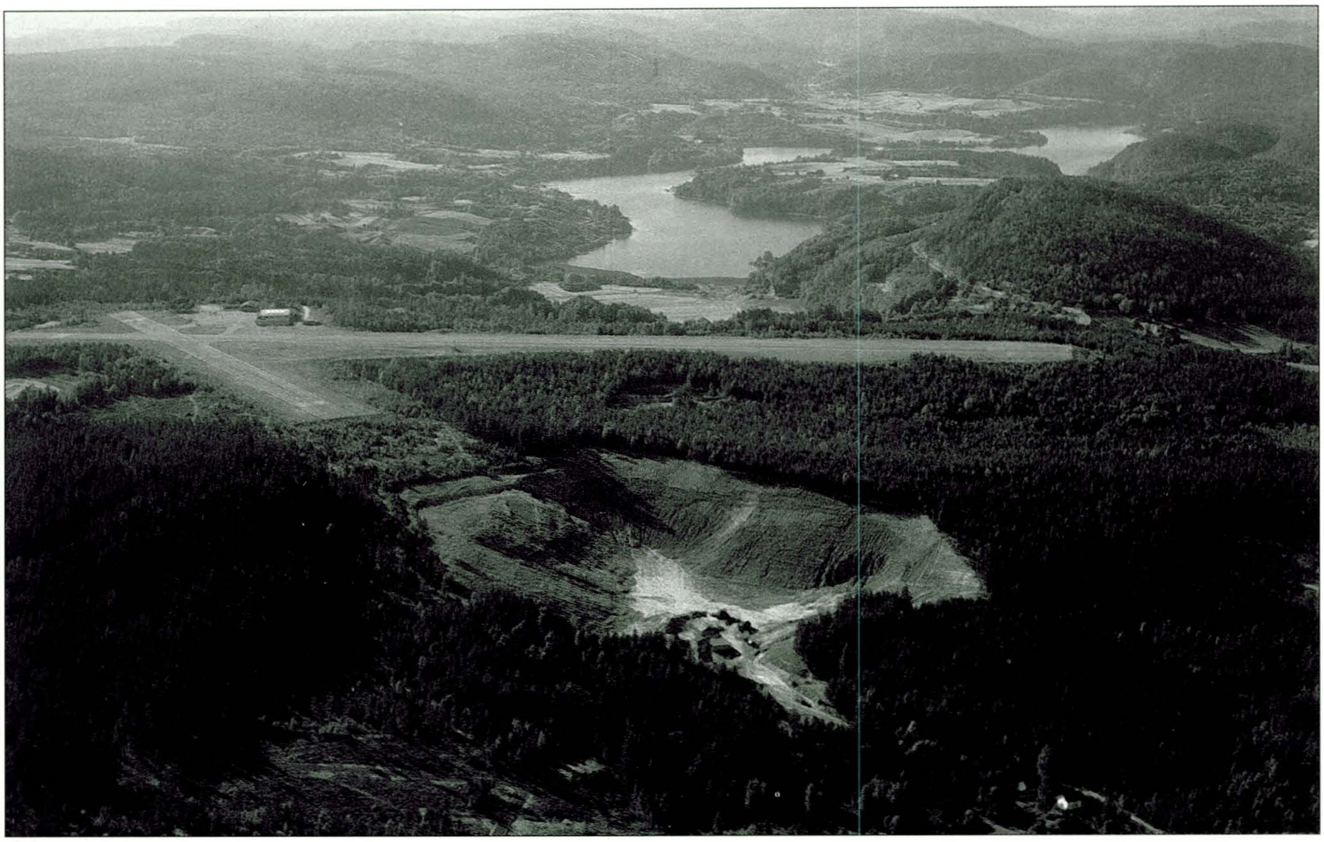


Fig. 17. During the Geiteryggen event, the ice front was situated at the southeastern end of lake Nordsjø. The complex marginal Geiteryggen delta was built up to the marine limit (c. 145 m a.s.l.) in front of the glacier in the Nordsjø basin. View towards west and the former glacier. The Nordsjø lake in the background.

tact deposits occur at lake Gorningen in Siljandalen and in Lågendalen, e.g. Grini, Gåserud (Bergstrøm 1988). To the southwest of the Langesundsfjord area, there are only minor scattered marginal deposits (Bergstrøm 1997). They do not represent any readvances or long standstills.

From Nenset the ice margin retreated to the southeastern end of Nordsjø in the Skien area where the large Geiteryggen ice-marginal deposit was formed (Fig. 17) (Jansen 1980, 1986, Bergstrøm 1985). The northern and middle parts consist of ridges of coarse sand and gravel rich in cobbles. Georadar profiles (Storrø et al. 1992) show distinct, but irregular undulating reflectors indicating a complex formation of the ridges close to the ice front. Distally, more uniform foreset beds are sloping towards the east. The southern part of Geiteryggen is a glaciofluvial delta built up to the marine limit, 145-146 m a.s.l. Foreset beds of sand and gravelly sand are covered by 2 m-thick topset beds consisting mostly of coarse gravel and cobbles. Seismic refraction profiles show a maximum thickness of the Geiteryggen deposit of more than 100 m (Jansen 1980, Johansen 1980).

The complex ice-marginal deposit at Geiteryggen indicates minor oscillations of the ice front during its formation. Corresponding terminal moraines occur southwest of Geiteryggen. Towards the northeast, glaciofluvial ice-marginal deltas or fans at Hogstad in Siljandalen are correlated with the Geiteryggen event. In Hærlandsdalen, a tributary valley to Lågendalen, distinct lateral moraines indicate an active ice lobe with an ice-surface gradient of 5-10 % near the front, while the gradient in the inner part is 1-2 (1.5) % (Bergstrøm 1988). Based on this reconstruction, an average gradient of c. 3 % has been used by Sørensen (1992) as a 'master profile' for the glacier lobes during the Geiteryggen event.

The Geiteryggen ice margin can be followed, morphologically, eastward to Drammensfjord and Oslofjord (Fig. 5), and corresponds to the Ski ice-marginal ridges, dated to 10,200-10,000 years B.P. (Sørensen 1983, 1992). In the area of Geiteryggen, a few radiocarbon dates of gyttja from bogs have been carried out in order to derive a more precise age for the formation, but contamination by roots has given dates that are mostly too young. Proximally to the Geiteryggen (5 km), a radiocarbon date of 9695 ± 95 years B.P. (Tua-774A) provides a minimum age for the deglaciation, but pollen analysis indicates a loss of the oldest organic material during the sampling. The lack of pioneer flora in the bottom sediments indicates that the deglaciation occurred prior to this date, but probably not more than 200-300 years earlier. The immigration of tree birch was rapid during this period. Based on the data from the Oslofjord area and the local radiocarbon date distally to the ice margin (Henningsmoen 1979), the age of the Geiteryggen ice-marginal delta is considered to be between 10,100 and 10,000 years B.P.

The Akkerhaugen ice-marginal deposits

After the Geiteryggen event the ice margin retreated rapidly towards the north and northwest. In the deep Nordsjø basin, a local calving bay was formed. At Romnes, where the basin is narrower, a short halt in the ice recession occurred and a marginal moraine ridge was formed (Fig. 5) (Bergstrøm 1984). Corresponding front deltas exist north of Valebø (Fig. 5), dated to be about 150 to 200 years younger than the end of the Geiteryggen event (based on shoreline data). The average ice recession in the Nordsjø basin is calculated to be c. 125 m/year.

At the northern end of the lake Nordsjø, a prominent ice-front accumulation, not built up to sea-level, extends across the valley at Akkerhaugen (Fig. 18). It comprises two glaciofluvial ridges on either side of the river and consists mostly of sorted sand and gravel. Foreset beds are dipping towards the southwest. The thickness of the deposit above bedrock varies between 30 and 70 m (Bergstrøm 1984). Corresponding lateral moraines are situated southeast of Akkerhaugen, and can be followed towards the southeast into the basin of Dalsvatn (Fig. 5) where the ice lobe dammed a lake. The main outlet was over the col in the south at about 190 m a.s.l. Glaciolacustrine fine sediments were deposited and glaciofluvial terraces of sand were built up to this level. The existence of lateral, ice-dammed lakes at higher levels (up to 275 m a.s.l.) is indicated by overflow channels across the mountain ridge west of Dalsvatn. The lateral moraines at Akkerhaugen indicate a steep front to the Akkerhaugen lobe in the main valley with a gradient up to 150 m/km (15 %) in the outermost part (0-1 km). The Dalsvatn ice lobe has a surface gradient of 20-30 m/km (2-3 %) near the front (2-5.5 km from the front).

The Akkerhaugen ice-marginal deposit has tentatively been correlated with the Eggar lateral moraine at Passebekk in Lågendalen and with the Aker Moraines in the Oslofjord area. Based on a plot of the ML at Akkerhaugen in the equidistant diagram (Fig. 20) and data from the Oslofjord area, the Akkerhaugen event is dated to 9,800-9,750 years B.P.

The Nordagutu ice-marginal deposits

Subsequent to the Akkerhaugen event the ice front retreated about 5 km northward to Nordagutu (Fig. 5, 18) where a large ice-marginal delta was formed. Proximally, on the top of the eastern part of this delta (Sundsmoen), a frontal moraine ridge crosses the terrace, indicating a short advance of the front at the terminal stage of deposition of the delta. Lateral glaciofluvial erosion and deposits in the eastern valley side, northeast of Sundsmoen, were probably formed during the Nordagutu event. Pollen analysis and a radiocarbon date from a bog proximally to the Sundsmoen delta indicate a minimum age of 9,420 ± 190 years B. P. (T-4266) (Bergstrøm 1984). The first pioneer flora is not represented in the pollen diagram. This indicates that the oldest organic material at the bottom of the bog has been lost during the sampling, and

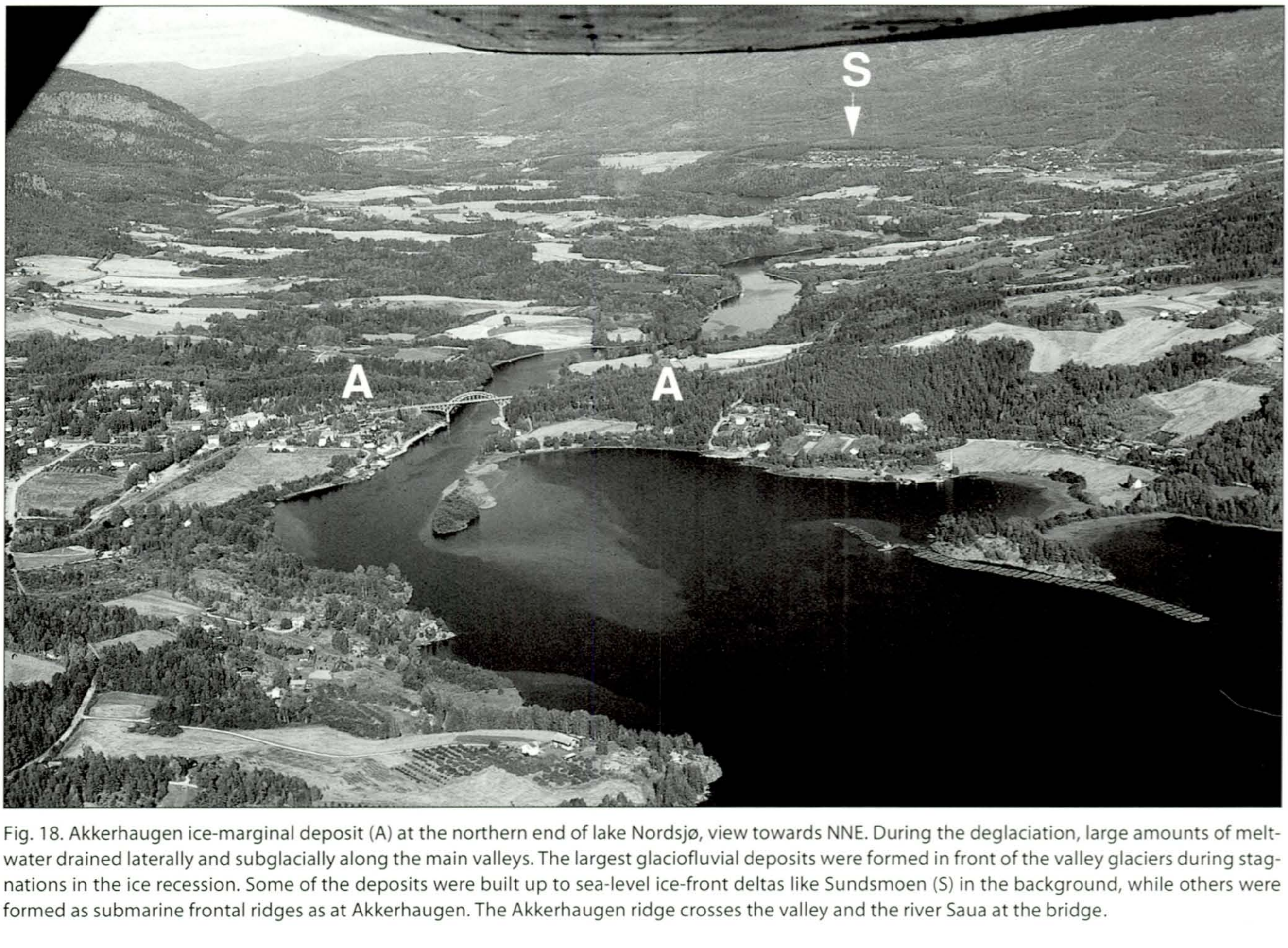


Fig. 18. Akkerhaugen ice-marginal deposit (A) at the northern end of lake Nordsjø, view towards NNE. During the deglaciation, large amounts of meltwater drained laterally and subglacially along the main valleys. The largest glaciofluvial deposits were formed in front of the valley glaciers during stagnations in the ice recession. Some of the deposits were built up to sea-level ice-front deltas like Sundsmoen (S) in the background, while others were formed as submarine frontal ridges as at Akkerhaugen. The Akkerhaugen ridge crosses the valley and the river Saua at the bridge.

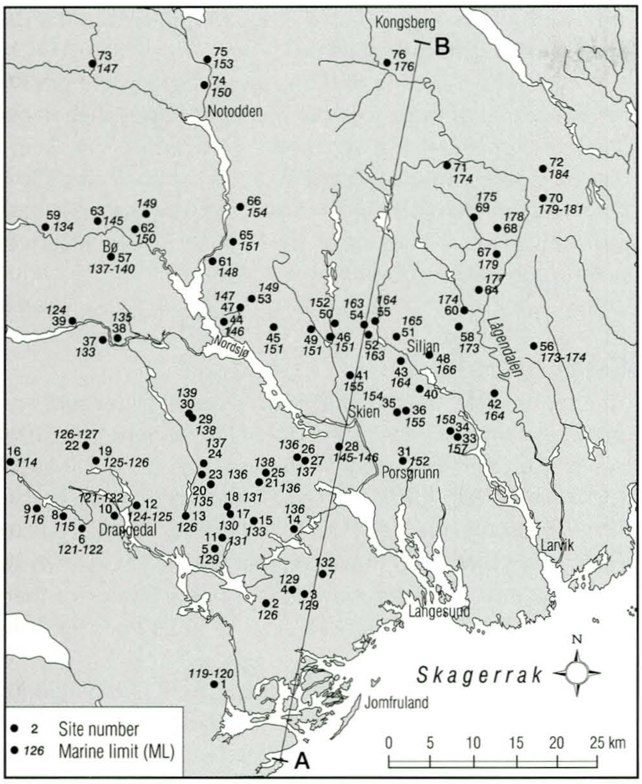


Fig. 19. Sites of ML localities with projection line A-B (N10°E) for the shoreline diagrams.

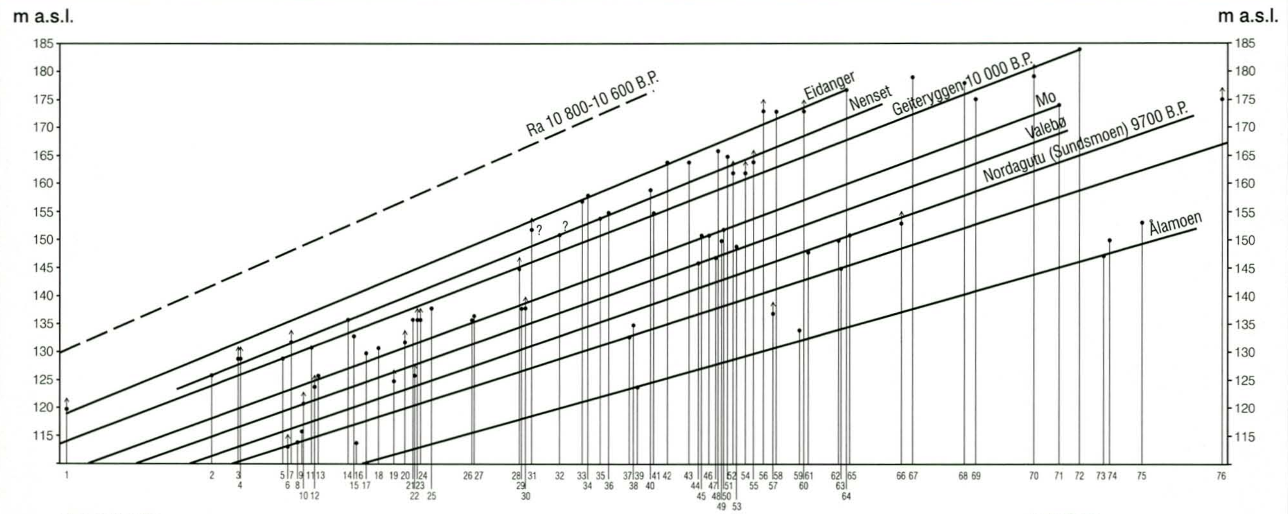
that the deglaciation of the area occurred at least 200 years previously. Based on information from shorelines and shore-level changes in the area, the age of the Nordagutu ice-marginal delta is suggested to be about 9,700 years B.P., i.e. 300 years younger than the Geiteryggen event.

Sea-level changes

Shorelines

During the deglaciation the sea followed the receding glaciers and large areas were submerged. The upper marine limits have been determined in different parts of the studied area west of the Oslofjord (Fig. 19) and are the basis for the construction of an equidistant shoreline diagram (Fig. 20). The gradient of the tilt has been analysed by projecting synchronous shorelines onto a projecting line, the direction of which gave the best fit to the marine limit observations in the area. This direction is estimated to be N10°E, and perpendicular to the local isobase direction during the deglaciation. Data from previous work in the adjacent Oslofjord area (Sørensen 1979) have provided a useful basis for these calculations. In the Lågendalen area, Jørgensen & Sørensen (1979) have constructed a shoreline diagram with a N-S trend for the projection line.

Fig. 20. Equidistant shoreline diagram. For location of the projection line and sites of ML localities, see Fig. 19.



LOCALITIES

1. Brynemoen
2. Mo
3. Storfiskvatnet
4. Fjølbuvatnet
5. Kåsheia
6. Nonsfjell
7. Skogen
8. Sandvik
9. Bostrak
10. Drangedal
11. Moen
12. Solberg
13. Henneseid
14. Storefjell
15. Kallestad
16. Tørrdal
17. Sætertjern
18. Kroktjern
19. Åkre
20. Nymoen
21. Sølstad
22. Lensegrav
23. Rønningen
24. Høydal
25. Dampedal
26. Høgebrun
27. Klyve
28. Geiteryggen
29. Rønjumstua
30. Tekslе
31. Ramsåstjern
32. Svartangtjern
33. Tjørna
34. Lia
35. Skifjell
36. Mensvatn
37. Stormo (J)
38. Verpemoen
39. Nesmoen (J)
40. Bjortjern
41. Doksrød
42. Rimstad
43. Torsholt
44. Brenne
45. Valesæter
46. Mo
47. Valebø
48. Sand
49. Stulen
50. Eikonrød
51. Grandalen
52. Rød
53. Spiredalen
54. Solverød
55. Hogstad
56. Østhaug
57. Nordbømoen (J)
58. Lofstad
59. Herremoen (J)
60. Hannevold
61. Akkerhaugen
62. Folkestad (J)
63. Oterholt (J)
64. Gåserud
65. Sundsmoen
66. Holtsås
67. Ramberg
68. Brandsrud
69. Kviberg
70. Nordby
71. Passebekk
72. Goverud
73. Ålamoen (J)
74. Nymoen (J)
75. Hove (J)
76. Skollenborg (B)

LEGEND

- • Marine limit
- ↕ Marine limit, uncertain determination
- (J) After Jansen (1986)
- (B) After Bargel & Lien (1990)

The gradient of the early Younger Dryas (Ra) shoreline, 1 m/km, is based mainly on data from the Lågendalen area, due to the lack of suitable localities in the investigated area. The estimated age of the marine shorelines is based on the height of the Geiteryggen shoreline, which is dated to 10,000 years B.P. The gradient is calculated as 0.95 m/km. The levels of the oldest marine shorelines, older than the Geiteryggen shoreline, are very uncertain due to the lack of reliable ML observations in the southern coastal areas.

Information on the highest shorelines has been important in the correlations of the ice-marginal deposits and the reconstruction of the ice recession lines.

Anundsen (1985) has calculated the approximate trend of the 9,000 B.P. isobases to be about N80°E - S80°W based on Stabell`s (1980) shorelevel data from Porsgrunn and Kragerø. That means that the isobases may have shifted to a more southwesterly direction during the late Preboreal Chron. However, this calculation is partly based on inaccurate dates of the isolation contacts in the actual basins. Subsequent radiocarbon dates of molluscs and isolation contacts (Bergstrøm 1997, K. Henningsmoen, pers. comm.1997) indicate that the basin from the Kragerø area (basin no. 3 in Stabell 1980) used in the calculation was isolated earlier than 8,800 years B.P. and probably at about 9,200 years B.P. This indicates that there is no evidence of any shift of the isobase directions at 9,000 years B.P., as suggested by Anundsen`s (1985) calculations.

Shorelevel displacement

Previously, three shorelevel displacement curves have been constructed from the studied area. In the Porsgrunn and Kragerø areas, Stabell (1980) has constructed two shorelevel displacement curves based on diatom analysis and radiocarbon dates. The elevations of the studied basins have not been corrected for the uplift gradients. Anundsen (1985) attempted to make such corrections to the curves on the basis of uplift data from the Oslofjord area (Sørensen 1979). In southern Vestfold, Henningsmoen (1979) published a shorelevel displacement curve based on pollen and diatom analyses and radiocarbon dates.

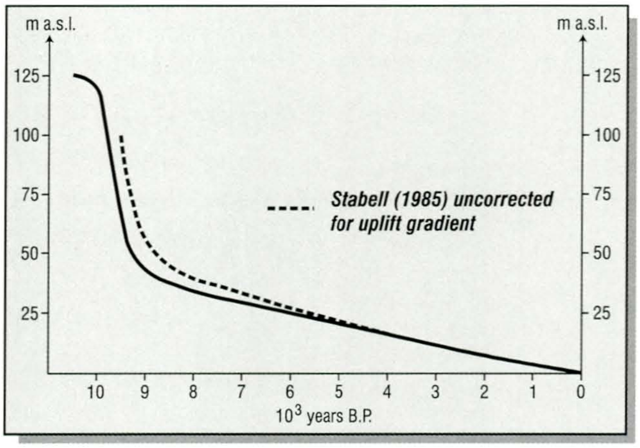


Fig. 21. A modified shorelevel displacement curve for the Kragerø area, based on Stabell (1980). The curve is corrected for uplift gradient. The older part of the curve (> 8000 years B.P.) is based on new radiocarbon dates (Bergstrøm 1997, K. Henningsmoen, pers. comm. 1997).

During the mapping of the Kragerø district, some radiocarbon dating of molluscs from marine terraces, shell banks and other shell-bearing sediments was carried out. These dates indicate some changes (Fig. 21) in the early part of the shorelevel fluctuation curve constructed by Stabell (1980) from this area. A revision of the local shorelevel displacement curve will be published elsewhere.

Conclusions

The deglaciation of the outer coastal areas in Vestfold and Telemark started when the shelf ice in the Skagerrak broke up and the glacier grounded at the coast at around 14.000-13,500 years B.P. The Jomfruland island was ice free before 12,200-12,300 years B.P. (12,240 ± 80 B.P.) Then, a glacier advance occurred and the ice margin reached at least as far as Jomfruland. A correlation with the Tjøme-Hvaler ice-marginal deposits in the Oslofjord area, at 12,200-12,000 years B.P., seems most likely.

During the Allerød Chron, the deep Oslofjord basin deglaciated rapidly due to calving processes, but towards the west the ice margin grounded in shallow water and retreated more slowly. The oldest marginal lines approach each other towards Langesundsfjord. The Slagen-Onsøy ice-marginal deposits were formed in Oslofjord at about 11,400-11,200 years B.P. Westwards, the position of the Slagen-Onsøy ice margin continued proximally to the Ra moraines. In the Kragerø area the distance between the two marginal lines was at least 10 km, but most likely more than 17-18 km.

During the late Allerød/early Younger Dryas (after 11,300 years B.P.) the glaciers advanced and the marked Ra (early Younger Dryas) ice-marginal deposits were formed at 10,800-10,600 years B.P. The Ra moraine ridges can be followed continuously from Oslofjord to Langesundsfjord, where there was a concave calving bay during the early Younger Dryas. From Langesundsfjord and southwestwards to Arendal, the Ra moraine ridges are trending parallel to the coast, mostly in a submarine position. The Jomfruland island is an emerged part of the Ra moraines.

After the Ra event, at about 10,600 years B.P., the ice margin receded towards the northwest. In the Langesundsfjord area the Eidanger ice-marginal deposits were formed at 10,400-10,300 years B.P. Corresponding marginal deposits occur in Siljandalen and Lågendalen. These deposits are tentatively correlated with the Ås moraines in the Oslofjord area.

During the ice recession from Eidanger, minor ice-contact deposits were formed without representing any readvance or long standstill. The large and complex ice-marginal deposits at Geiteryggen indicate a readvance of the ice front during their formation at 10,100-10,000 years B.P. Several terminal moraines and deltas correspond to the Geiteryggen deposit. Lateral moraines in Hærlandsdalen, a tributary valley to Lågendalen, indicate an active ice lobe with a surface gradient of 5-10 % near the front, and 1-2 % in the inner part. The Geiteryggen ice-marginal deposits are correlated with the Ski ice-marginal moraines in the Oslofjord area which are dated to 10,200-10,000 years B.P (Sørensen 1992).

From the Geiteryggen ice-marginal deposit, the ice margin retreated rapidly with an average recession calculated to be 125 m/year. The Akkerhaugen ice-marginal deposits indicate a small readvance at c. 9,800 years B.P. Lateral moraines indicate an active ice lobe with a surface gradient of 15 % in the outermost part (0-1 km from the front), while the gradient of the tributary lobe at Dalsvatn is 2-3 % in the inner part (2-4 km from the front).These deposits are correlated with the distinct Eggar lateral moraine in Lågendalen and with the Aker moraines in the Oslofjord area.

The large Nordagutu ice-marginal deltas, deposited about 5 km proximally to the Akkerhaugen marginal deposits, are calculated to be 50-100 years younger. Frontal moraine ridges on top of the delta terrace indicate small oscillations of the ice front during their formation.

An equidistant shoreline diagram has been constructed on the basis of marine limits in the investigated area and data from the adjacent Oslofjord area.

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