Radiocarbon dated raised beaches and glacial history of the northern coast of Spitsbergen, Svalbard

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Abstract

Raised beaches, glacial erratics, glacial striae and ice marginal features along the north coast of Spitsbergen have been studied. Two series of raised beaches occur in the area bordering the outer part of Woodfjorden. The lower marine limit has an altitude of approximately 40 m and is close to 11,000 years in age. The upper marine limit is at 80 m above sea level and predates 40,000 years B.P. Emergence between 11,000 and 10,000 years ago took place at a rate exceeding 2 m/century, and approximately one-half of the total emergence took place during this interval.

Three main directions of glacier ice movement are recorded, and marginal features from the Late Weichselian maximum glaciation occur on both sides of Liefdefjorden.

Sediment cores from six shallow lakes on Reinsdyrflya show extremely slow rates of sedimentation and low organic production. The maximum sediment thickness encountered was 143 cm (Lake F, at 35 m above sea level). No radiocarbon dates have been obtained from these lakes.

The Younger Dryas (11,000 to 10,000 years B.P.) seems to be a period of deglaciation. The deglaciation on the northern coast of Spitsbergen predates the final deglaciation in a number of other Arctic regions. *Mytilus edulis* immigrated to the area about 9400 years ago or earlier, indicating a warm early Holocene climate on the north coast of Spitsbergen.

Introduction

The study presented in this paper is a continuation of investigations started in 1975 (Salvigsen 1977). A preliminary outline of the glacial history of the north-western corner of Spitsbergen was also presented in Salvigsen (1979) and Salvigsen & Nydal (1981).

This paper deals mainly with areas bordering Bockfjorden, Liefdefjorden, and the outer part of Woodfjorden (Fig. 3), but results from other areas in the northern part of Spitsbergen also will be presented. Field work was carried out by both of us during the summer expeditions of Norsk Polarinstitutt in 1977 and 1978, and by O.S. in 1979. A total of two months was devoted to this study.

Our study has provided new information about the ice movements and raised beaches in the area, but many questions have been raised which cannot be answered without additional field work. This is especially true with regard to the determination of the elevation and ages of marine limits.

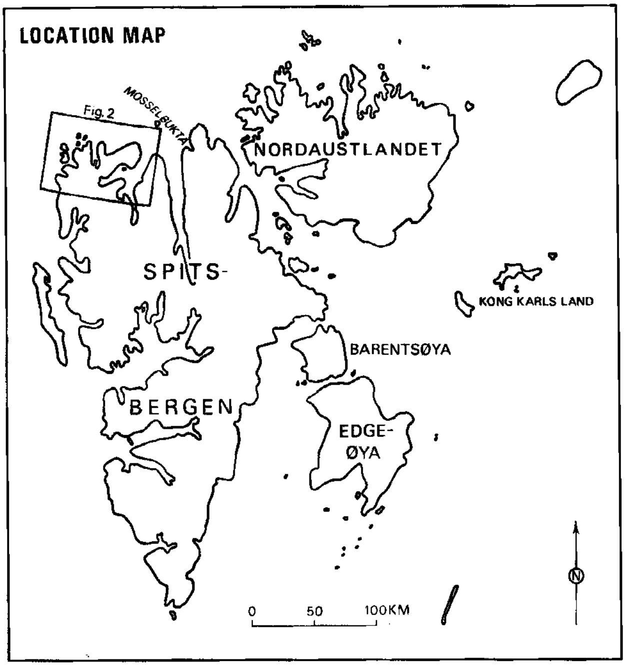

Fig. 1.

Location map of Svalbard.

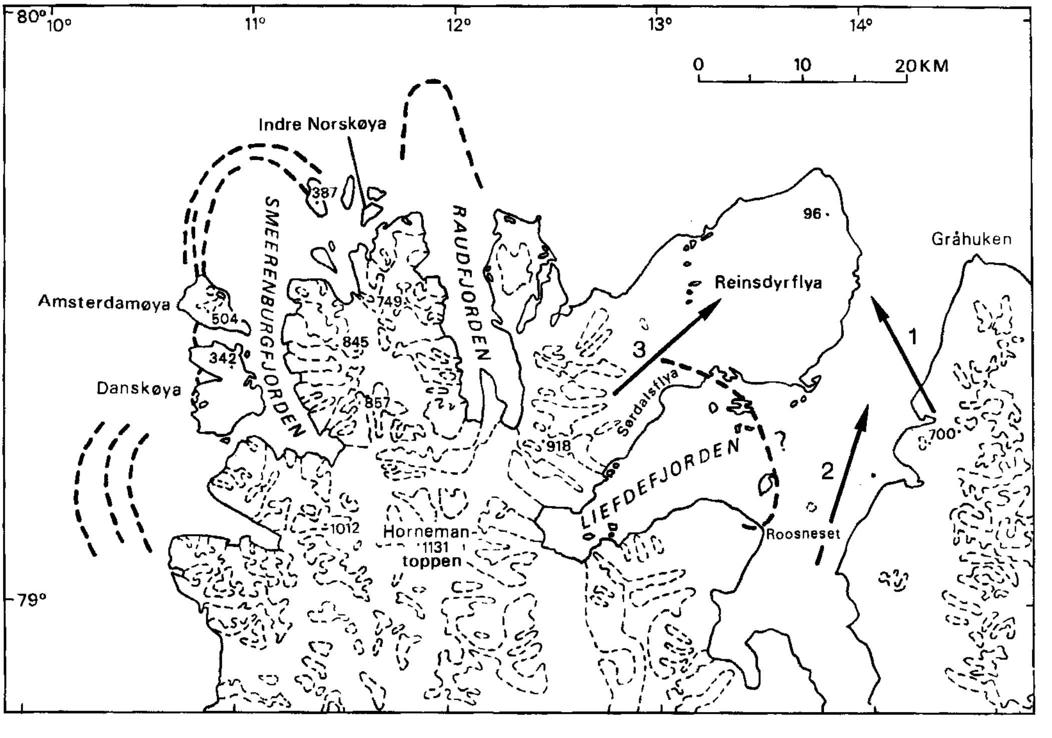

Fig. 2. *Location map of northwestern Spitsbergen. Dotted lines indicate the margins of the Weichselian glaciation. Arrows indicate the main directions of glacier flow. No. 1: oldest; No. 3: youngest.*

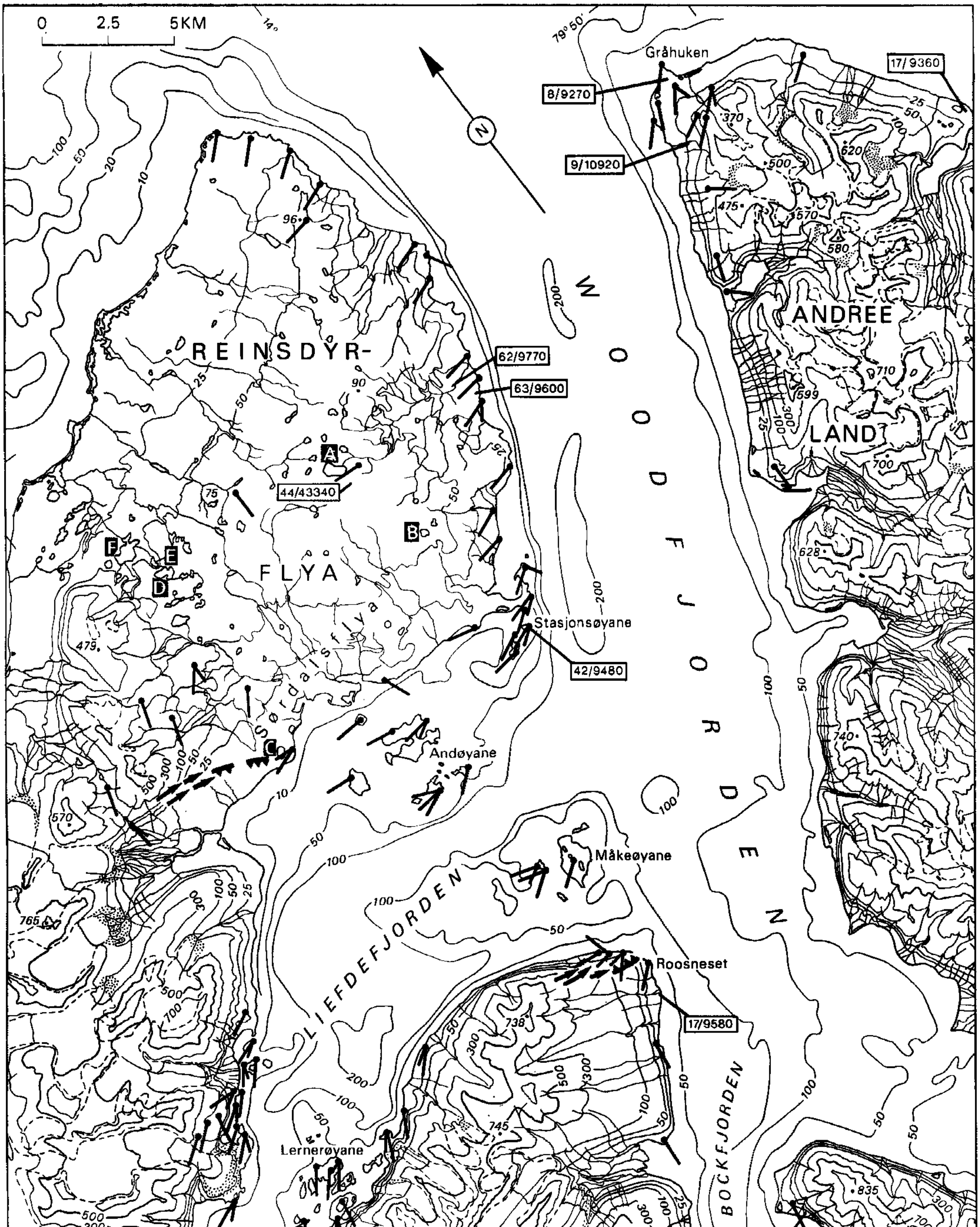

Fig. 3. *Topographic map with selected glacial features of Woodfjorden — Liefdefjorden and adjacent areas.*

Many scientists have previously visited the area and made scattered observations, but no systematic study has been carried out by quaternary geologists. G. De Geer's first general conclusion about this area has proved to be true (De Geer 1914, p. 277): "It is, of course, no easy task in such a country as Spitsbergen where local glaciation and frost-weathering play such an important part, to distinguish the often effaced traces of general glaciation of the Ice Age, but still, just on the hard rocks along the northwestern corner of the land there may be better chances than elsewhere to discover important evidence in the form of striae as well as erratics, bearing upon this interesting question." The bedrock geology of the area is described by Winsnes et al. (1962) and Hjelle (1974).

Raised beaches

Marine limits

The marine limit at the head of Liefdefjorden reaches only 4—5 m at the northern side where its maximum altitude in several places can be determined from the lower limit of perched boulders. The marine limit rises from the inner to the outer part of the fjord and from the northern shores to the southern shores of Liefdefjorden (Fig. 4).

Inside the ice marginal features (which will be described later) at Sørdalsflya the marine limit reaches a maximum of 23 m above sea level. Outside these marginal features there are two different marine limits. This can best be seen in the northern part of Andrée Land where the lower limit can be morphologically followed as a distinct beach ridge terrace for long distances

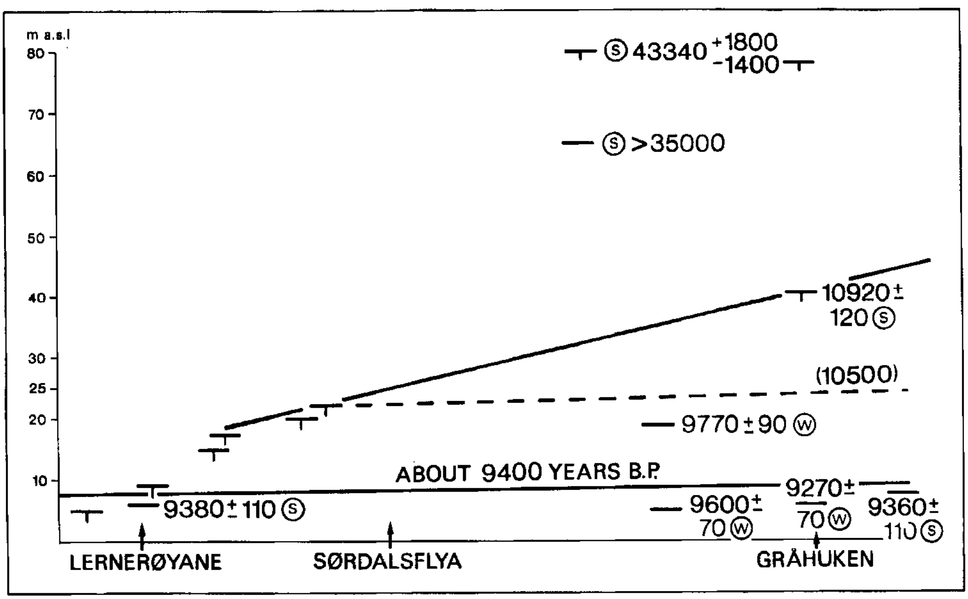

Fig. 4. *Distance diagram showing the rise of strandlines from the head of Liefdefjorden to Gråhuken. Observed marine limits are shown as well as ages of dated samples.* T = *Marine limit; s.* = *shells; w.* = *whalebones. The projection axis along Liefdefjorden is independent of isobase directions in the area.*

(Fig. 5). Its maximum height is 42 m above sea level, and it was first mentioned by Nansen (1922, p. 197) as a "sharply marked shore-line, cut in solid rock 41 m above sea level". Dege (1938) describes it as the particularly well developed 40—41 m terrace. This low marine limit can also be seen at Reinsdyrflya, but it is not as pronounced as in Andrée Land. In the northern part of Andrée Land and on Reinsdyrflya marine features also exist above the 40 m level. They are less definite than the lower-lying features, but in a few places near Gråhuken a distinct upper marine limit was found 78 m above sea level as the upper termination of beach ridges. On Reinsdyrflya a beach ridge terrace was found about 80 m above sea level (Salvigsen 1979). This beach is interpreted as being the approximate level of the upper marine limit. Small shell fragments were found at higher levels in a few places on Reinsdyrflya, but they are considered to be erratics derived from the underlying till.

It was impossible to find good locations for determination of marine limits in the Bockfjorden area. Levels higher than the 60 m terrace reported by Hoel & Holtedahl (1911) were not found. The highest measured marine limit in the Mosselbukta area was about 85 m above sea level, but it was impossible to establish two marine limits there.

"Old" beaches

In Salvigsen (1979) two radiocarbon dates on shells from the highest beach sequences of Reinsdyrflya (T-2701 and T-2702), showed remarkable ages. However, by mistake the dating laboratory reported values from a preliminary counting as final ages. Two fractions of the highest shell were redated, and they gave a mean value of 43,340 $^{+\,1800}_{-\,1400}$ years (Salvigsen & Nydal 1981). No age difference between the two dated fractions could be shown, but such high ^{14}C ages, which have been obtained from sediments and beaches in several places in Svalbard (Salvigsen & Nydal 1981), may well be minimum ages. Different dating methods (Boulton 1979; Troitsky et al. 1979; Salvigsen & Nydal 1981) suggest that Svalbard had a Middle Weichselian interstadial, but one or more older Weichselian interstadials may also have existed. Amino acid analyses of six shell samples from levels between 43 m and 75 m at Reinsdyrflya show no Holocene or near Holocene ages (G.M. Miller, pers. comm.). Our conclusion that the upper marine limit at Reinsdyrflya and Andrée Land is more than 40,000 years old, but not necessarily much older.

On Indre Norskøya (Fig. 2) a well developed rock terrace predating the last glacial stadial exists on the southeastern side, 20 to 22 m above sea level. It was first recognized on air photos and is a very distinct feature in the landscape. It has a thin cover of till, but ice erosion was minimal, probably because of its location near the outer margin of the Late Weichselian ice sheet (Salvigsen 1979).

The "old" beaches have been destroyed elsewhere within the area covered by Late Weichselian ice. Outside this area, especially on Reinsdyrflya and in Andrée Land, the high and "old" levels have been preserved even if weathering and a variety of geomorphological processes have obscured them in many places. However, our knowledge of interstadial sea levels and beaches in this area is limited, and more work is needed.

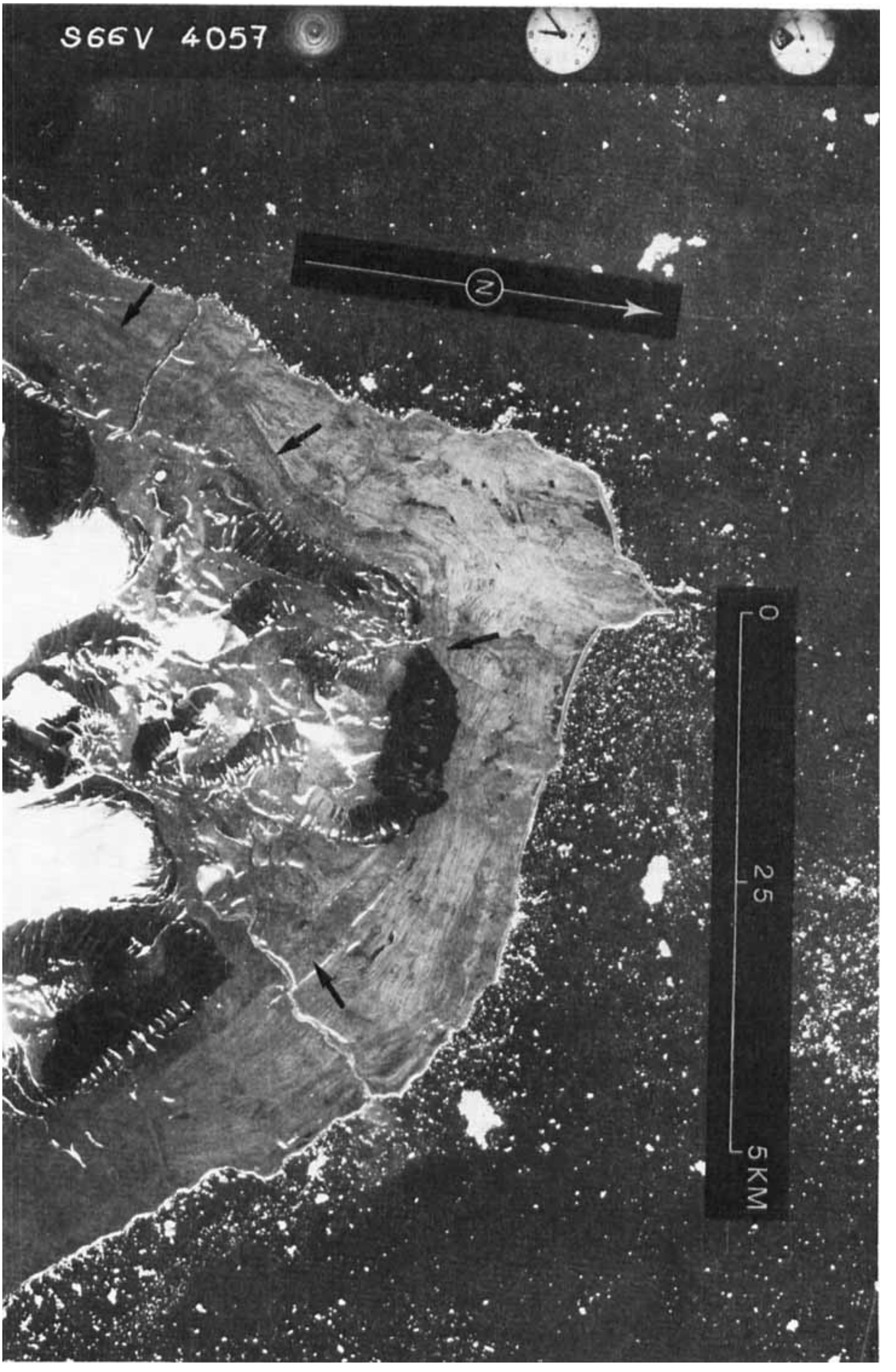

Fig. 5. *The northern tip of Andrée Land, bordered by raised beach sequences. The 40 m terrace (black arrows) is a very distinct feature in the landscape. Norsk Polarinstitutt: S66V 4057, July 24, 1966.*

The "11,000 year-beach" and younger beaches

An age of 11,000 years seems to be approximately correct for the lower marine limit at Gråhuken and most probably for the surrounding areas also. Red marine mud (clay) is found in many places in Andrée Land, but never above the lower marine limit. This red mud usually underlies the coarse material of the 40 m terrace, and *Hiatella arctica* shells from the clay of this level have been dated to 10,920 ± 120 years B.P. (T-3099). Behind this distinct beach ridge terrace there is usually a wide depression, 1—2 m lower

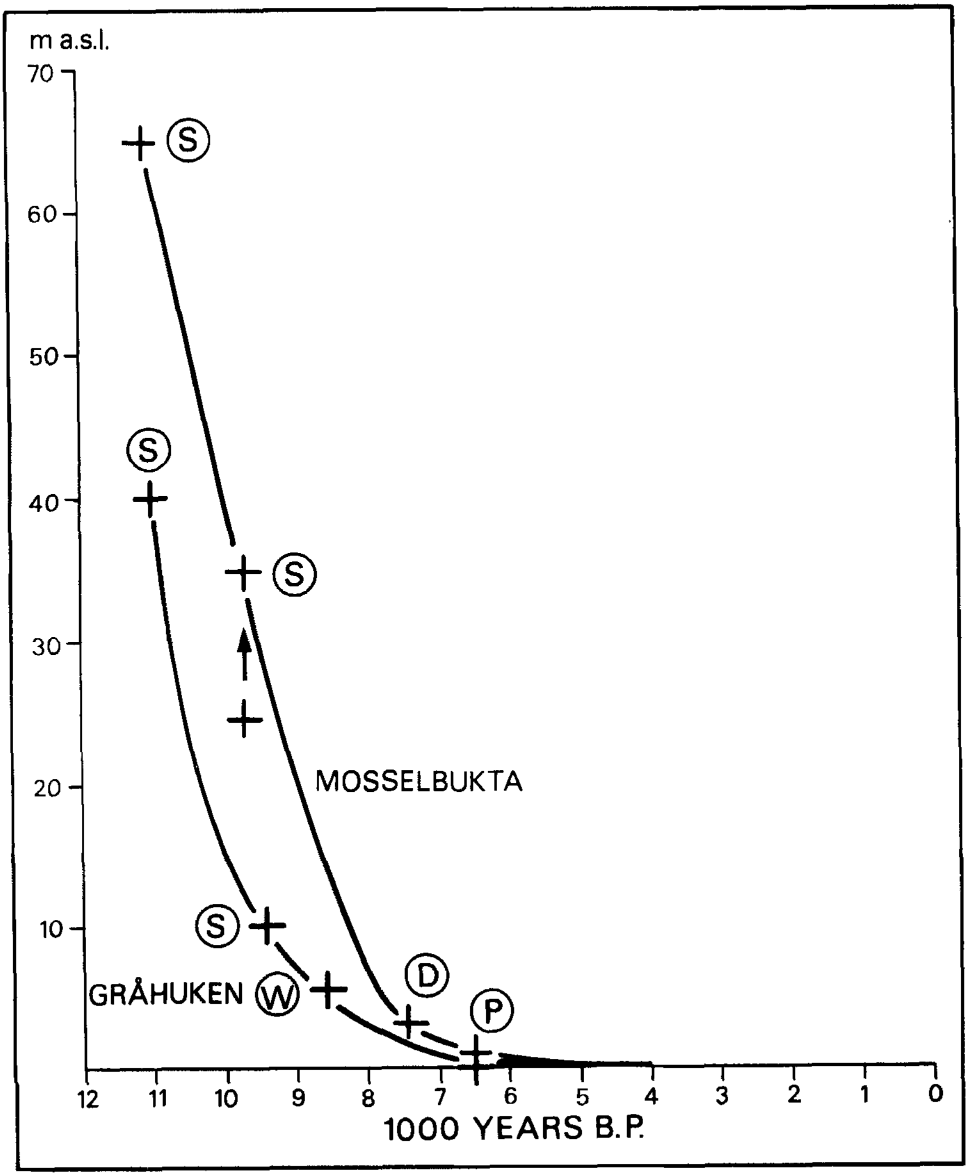

Fig. 6. *Shoreline displacement curves for Gråhuken (left) and Mosselbukta (right). S = shells; W = whale bone; D = driftwood; P = pumice.*

than the crest level, indicating that the ridge terrace was formed during a standstill or a transgression of the sea about 11,000 years ago.

Observations on marine limits in the inner part of Liefdefjorden have been plotted in Fig. 4. *Mya truncata* shells were found in frost sorted material on the surface of a terrace about 6 m above sea level. The age of 9380 ± 110 years (T—2700) shows that the area was deglaciated before that time. A sample of *Mytilus edulis* found east of Gråhuken at an elevation of 8 m above sea level is 9360 ± 110 years old (T-3098). One interpretation of these two dates is that the 9400 years old shoreline rises only slightly from the head of Liefdefjorden towards Gråhuken (Fig. 4). The reported ages of three whale bone samples are included in Fig. 4. According to the investigation of Mangerud & Gulliksen (1975), about 500 years should be subtracted when comparing dates on whale bone with shell dates in the Svalbard area. T-2703 seems to be young compared with other samples. However, since it is from a small piece of a single rib found on the surface, less importance should be attached to it. The two other dates are from large crania with better bone quality and are therefore more dependable for age determination of former sea levels, even if it is not possible to establish their exact relation to a given position of the sea level has taken place during the last 6500 years (the approximate age of of laboratory pretreatment are such that bone dates are often somewhat younger than the results on driftwood from the same levels (Salvigsen 1978, 1981b).

In the northern part of Reinsdyrflya, west of Andrée Land, pumice was never found above the surf limit of the present sea level. Abundant quantities of pumice were found on the shores of outer Woodfjorden together with

Fig. 7. *A series of raised beach ridges in the Mosselbukta area.*

Table 1.

Radiocarbon dates from the northern coast of Spitsbergen.

Location	m a.s.l.	Field No (Year No)	Lab. No	Material	^{14}C age
Liefdefjorden, south of Lernerøyane	6	—77, 27	T-2700	*Mya truncata*	9380 ± 110
Reinsdyrflya	65	43	T-2701	*Mya truncata* & *Hiatella arctica*	$>35{,}000$
Reinsdyrflya	80	44	T-2702	*Hiatella arctica*	$43{,}340 \pm {}^{1800}_{1400}$
Reinsdyrflya, east	19	62	T-2703	Whale rib	9770 ± 90
Vulkanhamna, Bockfjorden	21.5	39	T-2837	Whale rib	$10{,}050 \pm 110$
Reinsdyrflya, east	5	63	T-2838	Whale cranium	9600 ± 70
Roosneset, Woodfjorden	2	17	T-2917	*Mya truncata*	9580 ± 150
Bockfjorden valley	35	36	T-2918	*Mya truncata* & *Hiatella arctica*	$10{,}050 \pm 120$
Stasjonsøyane, Liefdefjorden	4	42	T-2919	*Mya truncata*	9480 ± 140
Gråhuken	6	—78, 8	T-3097	Whale cranium	9270 ± 70
Vogtvannet, Andrée Land	8	17	T-3098	*Mytilus edulis*	9360 ± 110
Gråhuken	41	9	T-3099	*Hiatella arctica*	$10{,}920 \pm 120$
Mosselbukta	5	—79, 10	T-3454	*Picea* sp.	7530 ± 100
Mosselbukta	25	7	T-3734	*Mya truncata*	9800 ± 110
Mosselbukta	65	3	T-3735	*Mya truncata* & *Hiatella arctica*	$11{,}110 \pm 140$

modern flotsam and jetsam. This indicates that no uplift of land relative to sea level has taken place during the last 6500 years (the approximate age of the highest pumice level elsewhere in Svalbard). Along the eastern shore of Mosselbukta (Fig. 1) pumice was found up to 4 m above mean tide level (Donner & West 1957; Boulton & Rhodes 1974).

Our investigations have shown that the average rate of emergence in the Gråhuken area was more than 2 m/100 years in the period between 11,000 and 9400 years B.P. (see Fig. 6). Combining the information in Figs. 4 and 6, we may assume that the highest observed levels inside the marginal features at Sørdalsflya must be at least 10,500 years old, and most probably are closer to 11,000 years in age.

Dated levels in Bockfjorden show a still more rapid emergence about 10,000 years ago, than in the Gråhuken area.

Three radiocarbon dates from areas near Mosselbukta give information about the emergence of the land after 11,000 years B.P. (Figs. 6 and 7 and Table 1). Shell fragments from frost sorted material about 65 m above sea level were dated to 11,100 ± 140 years (T-3735) and give a maximum age for this level. In situ shells from 25 m above sea level in a raised delta were dated to 9800 ± 110 years (T-3734). Most probably these shells date the surface level of the delta which is approximately 34 m above sea level, and the emergence curve (Fig. 6) has been drawn through this level. A log *(Picea* sp.) buried in a beach ridge was dated to 7530 ± 100 years (T-3454). It dates a sea level some 3 m above the modern shore. Hyvärinen (1970) has dated organic sediments relevant for the isolation of a lake south of Mosselbukta, altitude 14 m above sea level. The dates are seemingly inaccurate and show a higher age than should be expected from our curve. The rate of emergence in Mosselbukta between 11,000 and 9800 years B.P. is at least 2.3 m/100 years, and about 1.3 m/100 years between 9800 and 7500 B.P. We can conclude that Younger Dryas time in this area was a period with a high rate of emergence.

So far, we know too little about the extent of the Late Weichselian ice sheet in the Svalbard area to explain the pattern of emergence along the north coast of Spitsbergen. However, we assume that local ice sheets in the mountain areas of Spitsbergen, as well as the more extensive Barents Sea ice sheet, have contributed to the resulting pattern.

Ice movement

Erratics

An intrusion of coarse, reddish monzogranite (Hjelle 1974) is found south and southwest of Smeerenburgfjorden (Fig. 2). It has been named Horneman granite after the 1131 m-high mountain peak, Hornemantoppen (Fig. 2), which consists of this characteristic type of granite. Erratics of Horneman granite are easy to distinguish in the field, and they give unambiguous information about former ice movement in the area. Erratics of Horneman granite are frequent on Danskøya, and one large block was also found on Indre Norskøya. Eastwards they have been transported to the shores of Liefdefjorden and to Reinsdyrflya. Most of them are found below the 100 m level, but west of Reinsdyrflya some were found more than 500 m above sea level. Blocks of Horneman granite also were found at high levels (more than 400 m)

Fig. 8. *Crossing striae in Devonian red sandstone, Måkeøyane. The ice movement was from the top of the photo.*

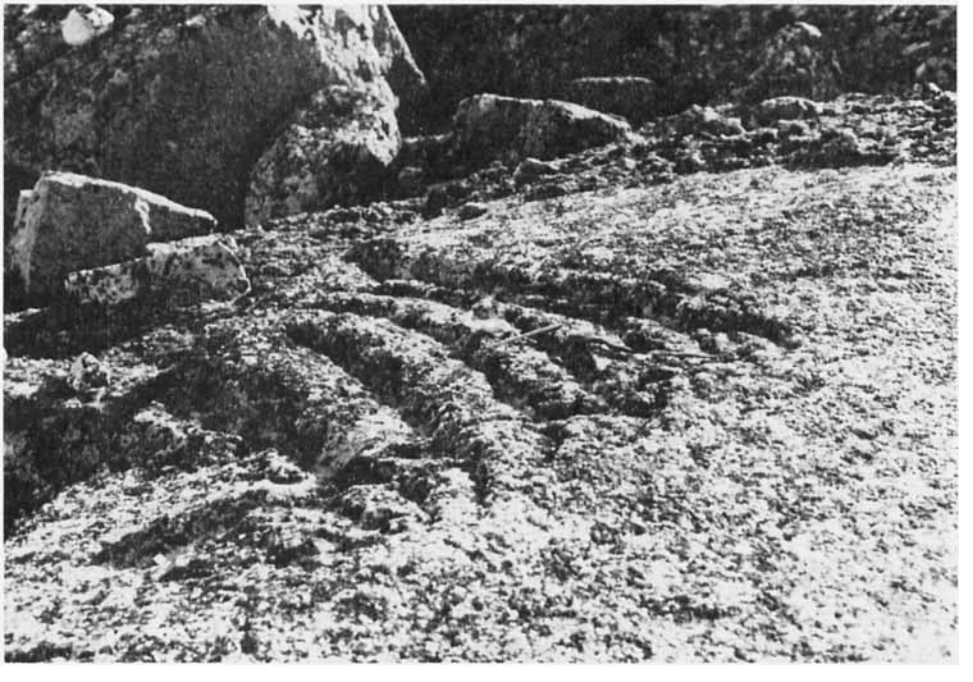

Fig. 9. *Crescentic gouge at Indre Norskøya. For size, note the pencil and compass in the middle of the photo.*

on Amsterdamøya. The distribution of Horneman granite erratics shows that glaciers have transported rocks of this type from the area of Hornemantoppen toward the west, north and east. Horneman granite erratics were not found east of Woodfjorden and no transport of glacial erratics toward the west could be established in the Liefdefjorden—Woodfjorden area.

Glacial striae

The glacial influence on the landscape is obvious everywhere in the area investigated. The fjords are trough-shaped and rôches moutonnées are found in many places.

From Amsterdamøya and Danskøya we have a good picture of the directions of ice movement (Salvigsen 1977). Crescentic gouges, up to 2 m across, were observed on Indre Norskøya together with glacial striae (orientation: 330 g), and De Geer (1914) observed striae from the southeast on Risen, the northernmost little island in this area.

The directions of the most significant glacial striae observed by us are shown in Fig. 3. The striae are extremely well preserved in the Hecla Hoek rocks of the western part of the area as well as in the Devonian sandstones which outcrop to the east (Fig. 8). Glacially sculptured rock surfaces with plastically moulded details are frequent in the inner part of Liefdefjorden, e.g. on Lernerøyane. The best preserved glacial striae are usually found near the present shore where rock surfaces have been exposed recently. Striae are rarer at higher levels where weathering has erased the finer details. The information from glacial striae supplements the observations on erratics and gives us a more detailed knowledge of ice movements in the area. In three places on Reinsdyrflya we found striae oriented approximately southeast-northwest and indicating ice movement from east of Woodfjorden. They are probably the oldest striae preserved in this area, and they were situated in marked lee positions with relation to younger ice movement directions. Later the ice flowed in a south to north direction along Woodfjorden.

Most of the striae on outer Reinsdyrflya show ice movements from directions between southwest and west, the ice center having been in the high mountains west of Liefdefjorden. Ice from this center has spread over Reinsdyrflya, but does not seem to have crossed Woodfjorden and reached Andrée Land.

In Andrée Land the ice flowed northward, following the strike of the mountain range and Woodfjorden. Striae engraved from the east are probably the results of movement of ice from local glaciers after the ice disappeared from Woodfjorden.

In the inner part of Liefdefjorden the oldest striae are oriented parallel with the shore. The younger striae, however, indicate movements at greater angles to the contour lines. The explanation must be that the ice front retreated most rapidly in the deeper, middle part of the fjord, forming calving bays.

The information provided by erratics and striae lead us to the interpretation that three main directions of ice movement predating the Late Weichselian can be established in the area (Fig. 2). The oldest is a movement from ice centered east of Woodfjorden. This ice center later shifted to areas south of Woodfjorden, causing an ice movement towards the north.

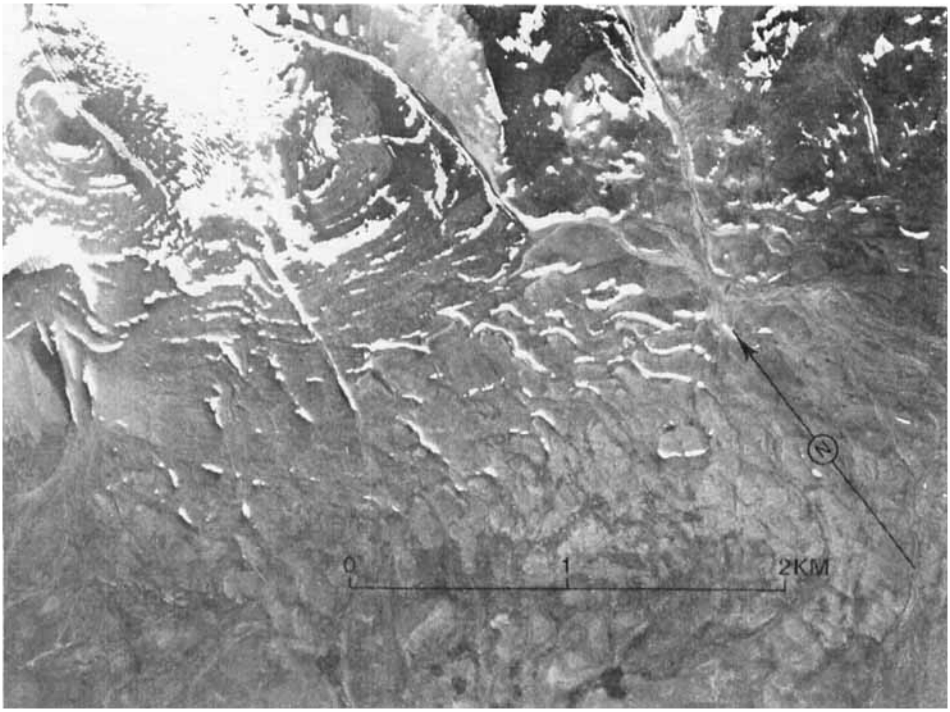

Fig. 10. *Zone of marginal meltwater channels west of Sørdalsflya.*

In the latest episode of this glacial stadial, the ice center was located west of Liefdefjorden and Reinsdyrflya, and Liefdefjorden was deglaciated from east to west. These three directions probably can be attributed to an extensive glaciation in the Early Weichselian (Salvigsen & Nydal 1981), and they show the development of this glaciation. In Late Weichselian time there was a local glaciation with an ice sheet centered west of Liefdefjorden. The approximate extension of ice during this last glaciation is indicated in Fig. 2. It is noteworthy that glacial striae are frequent on Reinsdyrflya and Gråhuken, even if more than 50,000 years seem to have elapsed since they were engraved. But, as expected, the freshest and best preserved glacial sculptured forms with striae are located inside the borders of the Late Weichselian ice in Liefdefjorden.

Ice marginal features

Main marginal zone

Distinct marginal features in Liefdefjorden, at Sørdalsflya and Roosneset (Fig. 3) most likely represent the eastern margin of the ice cover which reached Amsterdamøya and Danskøya and formed the submarine ridges off these islands (Liestøl 1972; Salvigsen 1977, 1979). Numerous meltwater channels are seen on the mountain slope of Sørdalsflya (Fig. 10). They are marginal drainage channels developed in loose material as well as in bedrock, lying between 60 m and 150 m above sea level. In loose material the channels are wide and about 2 m deep, whereas they are 5 m deep in bedrock.

A zone of morainic ridges is also found in this area. Some of the ridges are several hundred meters long, but most of them are shorter. The ridges are found at lower levels than the meltwater channels and are highest near the present shoreline where one of them faces the sea in an abrasion cliff approximately 10 m high.

A distinct marginal zone also exists on the opposite side of the fjord at Roosneset (Fig. 11). The meltwater channels are much deeper there, some of them forming 15 to 25 m-deep gorges cut in bedrock (Fig. 12). The morainic ridges are also very distinct on this side of the fjord, but because of the steeper mountain slope, the marginal zone is not as wide as on Sørdalsflya.

The location of this marginal zone shows that Liefdefjorden was filled with glacier ice coming from the head of the fjord. Both the meltwater channels and the morainic ridges are exceptionally well developed features for Svalbard indicating that the ice front occupied that position for a rather long time.

Age determinations

The exact age of these marginal features cannot be determined, but the strandline pattern allows us to calculate approximate ages. The moraines north of Amsterdamøya are less than 28,500 years old, according to radiocarbon dating of erratic shells found in the moraines (Salvigsen 1977). The maximum extension of the Late Weichselian ice sheet in this area may well have been reached 18,000 to 20,000 years ago as assumed for the Scandinavian ice sheet. The deglaciation seems to have started rather late, but probably before 11,000 years B.P.

The highest marine limit observed inside the marginal features is about 23 m. The strandline through this level must have a greater tilt than the 9400 year-level in Fig. 4, and must be at least 10,500, but probably 11,000 years old. The younger Dryas thus seems to be a period of deglaciation, and the sedimentation of red mud below the lower marine limit is probably a result

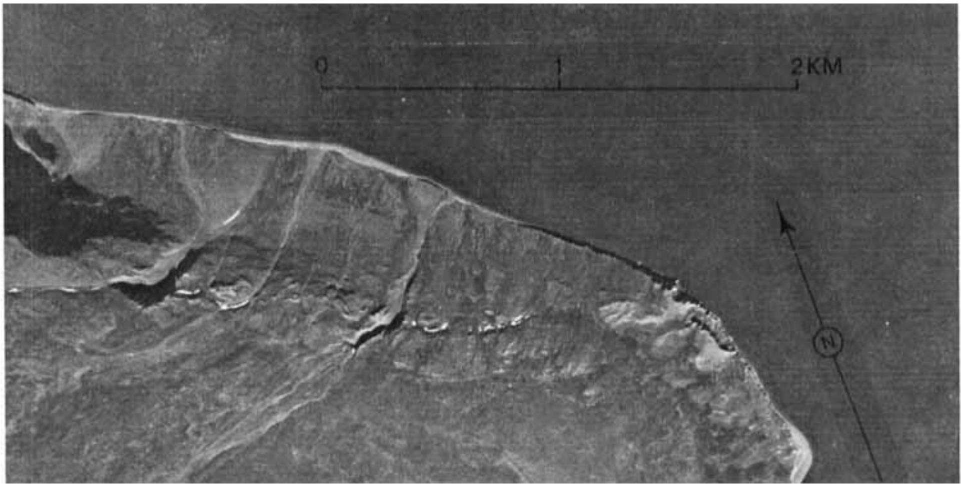

Fig. 11. *Ice marginal features, meltwater channels, and morainic ridges at Roosneset.*

Fig. 12. *A 15 m-deep meltwater channel cut into bedrock at Roosneset.*

of this deglaciation in Liefdefjorden and adjacent areas. Gråhuken and Mosselbukta both underwent rapid emergence in Younger Dryas time (see Fig. 6).

Various other glacial features

Smaller deposits from glacial and glacifluvial activity were found in several places, especially inside the ice marginal features in Liefdefjorden. They cannot, however, be dated or placed in any system. They are morainic or glacifluvial features covered by a veneer of till (Fig. 13). Bessarabov (1975) has described stadial moraines in three valleys on the northern side of Liefdefjorden. After airphoto studies and investigations in the field, we cannot accept his conclusions on terminal moraines and the "frontal apron terraces" linked to them.

In Andrée Land only mountain glaciers seem to have existed in Late Weichselian time, and the glacier fronts have extended less than one kilometer further out than at present. Most of the glaciers in Svalbard had their maximum Holocene extension about 1900 A.D., and the northern coast in the vicinity of Liefdefjorden is no exception to the rule. As is usually the case in Spitsbergen, major ice cored moraines related to the last maximum extension are seen near the present fronts of most of the glaciers in the area. Monacobreen, at the head of Liefdefjorden, for example, partly covered the southernmost island of Lernerøyane. The glaciers in Bockfjorden and in the valley south of the head of that fjord show no signs of having had a greater extension than the position of the ice cored moraines. Glacial striae down the main valley seem to cross the present glacier beds on the southwestern side of the valley.

Fig. 13. *Morainic ridge west of the marginal zone of Sørdalsflya, deposited from the south (right) during the last deglaciation of Liefdefjorden.*

Lake sediments

Sample collection

Cores of bottom sediments were collected from six lakes at altitudes between 4.5 m and 76 m on Reinsdyrflya in an effort to identify possible marine facies in the lakes. The composition of the diatom assemblage in the sediments gives a good indication of the environmental conditions at the time of deposition. We also hoped that some of the cores would contain sufficient organic material to date the deglaciation in this area.

Very few studies of the diatom flora in lake sediments from Svalbard have been published (Häggblom 1963; Hyvärinen 1968, 1969, 1970; and Bøyum & Kjensmo 1980).

Sediment samples were taken by a Livingstone sampler with an inner tube diameter of 56 mm. Samples were taken from the deepest part of the lakes; a small inflatable boat was used during our operations. At least two parallel sample series were taken from each lake in an attempt to obtain sufficient material for radiocarbon analyses. The cores were retained in the tubes until analyses could be undertaken. In the laboratory the samples were first heated in H_2O_2 to eliminate organic material. Fine mineral material was separated by repeated suspension, sedimentation and decantation. The shells of the diatoms were concentrated by centrifuging the remaining material in test-tubes. The laboratory work was carried out by H. Ö. at the Geological and Paleontological Institute, University of Helsinki, and at the Faculty of Education, Åbo Akademi, Vasa, Finland.

Description of the lakes and their sediments

The lakes we have investigated have no official names and are therefore marked with the letters A to E on the map in Fig. 3. The most significant information about the lakes is summarized as follows:

Lake	Area (km^2)	m a.s.l.	Max. water depth (m)	Max. thickness sediments (cm)	Water temp. (°C)	1977 Date
A	0.30	76	0.9	37	3.3	21.8
B	0.06	55	0.8	32	3.5	21.8
C	0.10	4.5	2.9	95	6.4	18.8
D	0.21	58	2.1	59	3.5	26.8
E	0.06	49	6.8	70	3.7	26.8
F	0.50	35	4.7	143	3.7	26.8

The lakes have rather small drainage areas and most of their water supply is derived during the snow melting period. The sediments in lakes A, B, and C consist of grey clay and gyttja, while lakes D, E, and F have grey and red clays. The sediments seem to rest on layers of stones in most of the lakes. The organic content was extremely low, and radiocarbon dating was considered possible only for lake C. The sampling tube from this lake was unfortunately destroyed by fire in the refrigerator before it could be sent for dating.

Diatom shells indicating marine facies, e.g. *Cassidulum* sp., *Elphidia* sp., and *Virgulia* sp., were completely lacking in the sediment cores except in those from lake C. Marine diatoms as well as species indicating lacustrine environment were found in the lower 10 cm of these cores. The fresh water forms have probably been deposited by creeks bringing water from land to the bay which later was transformed into a lake by land upheaval. Shells of the genera *Navicula, Pinnularia* and *Cymbella,* mostly corroded fragments, were dominant among the fresh water diatoms in the cores. This agrees with results of investigations on Bjørnøya and Nordaustlandet (Hyvärinen 1968, 1969), and is also in accordance to the recent composition of the diatoms in the lakes (Foged 1964, p. 152—153). The total number of diatoms in the samples was small, however, and no conclusions about former sea levels and glacial history can be made from these investigations.

Early Holocene climate

No living *Mytilus edulis* shells have been found in Svalbard, and they are therefore considered extinct in this area. They have been recorded in Holocene deposits from most of the Svalbard area, but very few radiocarbon dates exist. In Billefjorden, *Mytilus edulis* have been found between 2 and 42 m above sea level, and thus this pelecypod lived there throughout most of the Holocene. A sample from the Mytilus terrace, 6 m above sea level, gave an age of about 400 years (Feyling-Hanssen 1965). Blake (1961) found 9200 ± 190 year-old *Mytilus edulis* (U-173) in the northwestern part of Nordaustlandet. This date, together with that on a sample from Gråhuken of 9360

± 110 years, shows that *M. edulis* immigrated to the northern coast of Svalbard earlier in the Holocene than it did in other Arctic regions (cf. Andrews 1972; Blake 1973; Hjort & Funder 1974). *Mytilus edulis* was also found in Mosselbukta 8 m above sea level, but according to the emergence data for this area it must be somewhat younger than the Gråhuken sample.

Although the occurrence of *Mytilus edulis* cannot be used as a direct indicator of specific temperatures, it does indicate that the climate in early Holocene time was warmer than it is today.

The robust *Mya truncata* shells approximately 9500 years old (T-2917 and T-2919) are also remarkable. Single valves weighed more than 30 g, and it is obvious that conditions were especially favourable for the growth of this large clam. A whale skeleton in Bockfjorden was dated to 10,050 ± 110 years (T-2837) which shows that large whales penetrated into the fjords at the beginning of the Holocene.

The radiocarbon dates listed in the present paper, together with those from other localities in Svalbard (e.g., see Salvigsen 1981a, 1981b) indicate that the last deglaciation of Svalbard predated the deglaciation in a number of other Arctic areas. Events taking place about the beginning of Holocene time were not necessarily synchronous all over the Arctic.

Conclusions

Some major conclusions derived from this study can be summarized as follows:

1. Two series of raised beaches occur on Reinsdyrflya and in Andrée Land. The lower marine limit has an altitude of approximately 40 m and is close to 11,000 years in age. The upper marine limit predates 40,000 years B.P. and has an altitude of approximately 80 m. The 11,000 year-old shells 65 m above sea level in Mosselbukta indicate an increasing isostatic depression, and subsequent rebound of the land toward the east in Late Weichselian time.

2. Emergence curves from Gråhuken and Mosselbukta show a high rate of emergence 11,000 to 10,000 years ago. This, together with observations of marine limits in Liefdefjorden, led us to conclude that there was no Younger Dryas advance of the glaciers in this area, and that the Younger Dryas was mainly a period of deglaciation.

3. Three main directions of glacier movement predating the Late Weichselian are recorded from glacial striae on bedrock. A Late Weichselian ice sheet was centered west of Liefdefjorden, and marginal features from its maximum extension occur on both sides of Liefdefjorden. Erratics of Horneman granite provide unambiguous information about the former direction of ice movement in the area.

4. Sediment cores from six shallow lakes on Reinsdyrflya show extremely slow rates of sedimentation and low organic production. No radiocarbon dates have been obtained on these lake sediments.

5. *Mytilus edulis* immigrated to the area about 9400 years ago or earlier, indicating a warm early Holocene climate on the north coast of Spitsbergen. Large whales also penetrated into the fjords at the beginning of the Holocene.

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