Holocene glacial advances and moraine formation at Albrechtbreen, Edgeøya, Svalbard

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Terrace remnants close to the marine limit as well as two separate moraine ridges are observed in front of the glacier Albrechtbreen. The stacking of marine sediments from an original elevation of ca. 60–80 m a.s.l. into the Little Ice Age Moraine gives evidence for a considerably smaller glacier following the early Holocene deglaciation compared to that of the present. The outer moraine is composed of glacial diamicton. Radiocarbon datings of whale ribs, shell fragments and a log taken from sediment in front of Albrechtbreen indicate that the initial deglaciation occurred before 9,400 B.P. and that the outer moraine was formed during a younger Holocene glacial advance. Lithological differences between the two moraine ridges suggest that the first ice advance occurred during a period with limited permafrost, whereas permafrost was more extensive during the Little Ice Age.

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Albrechtbreen is the northern land-based outlet glacier from the ice cap Edgeøyjøkulen on Edgeøya, eastern Svalbard (Fig. 1). In front of Albrechtbreen there are terrace remnants and two separate moraine ridges characterized by differences in sediments, morphology and vegetation. River cuttings in front of Albrechtbreen expose sediment thicknesses in excess of 20 m in the terrace remnants and in the outer moraine. Glaciotectonic stacking of marine sediments caused the Little Ice Age Moraine to be more than 50 m high. In this paper we discuss the genesis and chronology of the Albrechtbreen moraines.

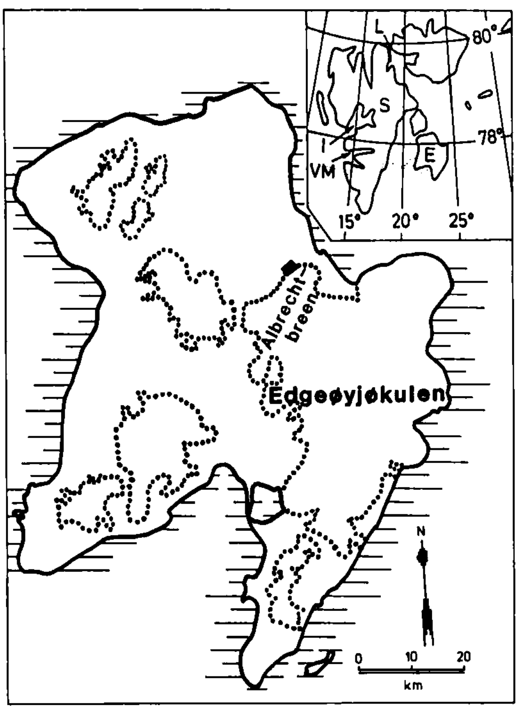

Fig. 1. Map of Edgeøya. The investigated area is marked with a solid square. Dotted lines indicate the present ice cover. The inset map shows the Svalbard archipelago (E = Edgeøya, S = Spitsbergen, VM = Van Mijenfjorden, L = Lomfjorden, I = Isfjorden).

The Albrechtbreen area

The morphology and sediments in front of Albrechtbreen are generalized in Fig. 2 and described below.

The terrace and the lower plain

Distal from the moraine complex is a terrace 82 m a.s.l. (Figs. 3 and 4), which we estimate to be close the marine limit (cf. Mangerud et al. 1992). The ice-distal slope of the terrace dips 16°, reaching a silt and clay plain with marine shore deposits

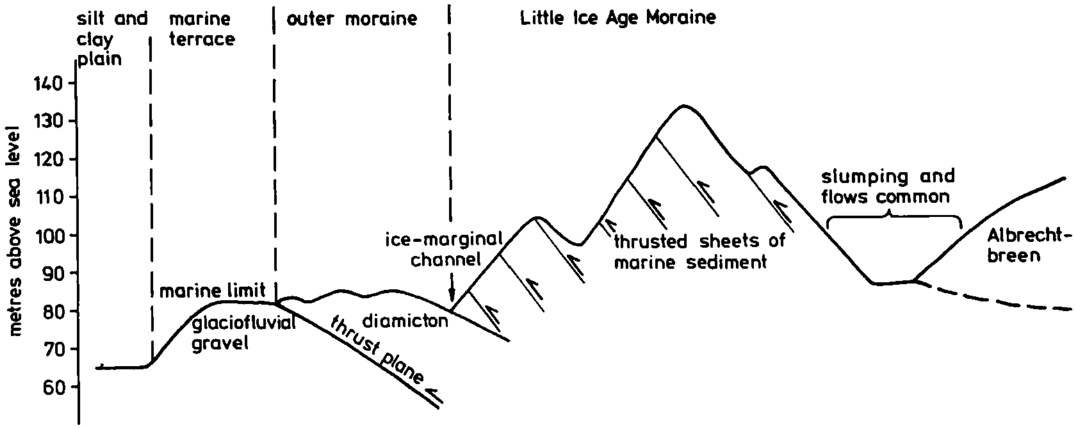

Fig. 2. Generalized interpreted section in front of Albrechtbreen as discussed in text.

at the surface at an altitude of approximately 60 m. Both the terrace remnants and the lower silt and clay plain show a smooth surface almost completely covered with vegetation. The entire surface is cryoturbated.

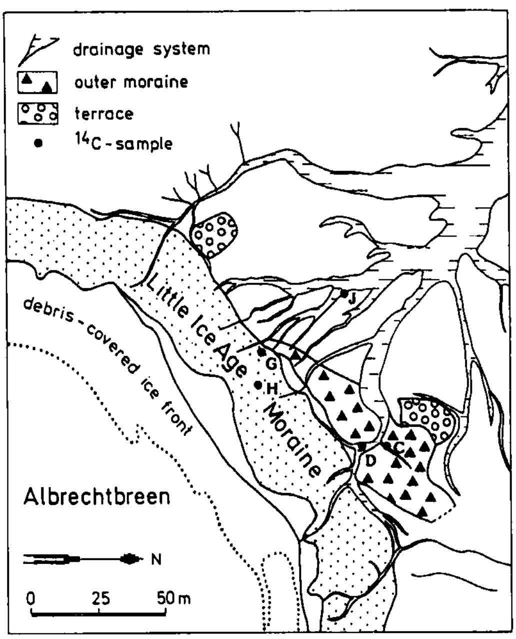

Fig. 3. Generalized geomorphological map from the investigated area in front of Albrechtbreen (Fig. 1). The white area between the debris-covered ice front and the Little Icc Age Moraine is a proglacial depression into which slumping and flows occur from both the ice front and the moraine. The area outside the terrace and the moraines is sloping towards the silt and clay plain mentioned in the text. The map is based on field observations and infrared air photographs S90 2454 and 2455 from Norsk Polarinstitutt, enlarged to a scale of 1:12,500. ^{14}C-samples are referred to site 2401 (see Table 1).

The section cut by the river (Fig. 4) is 20 m high and composed mainly of coarse, foreset-bedded gravel, interpreted to be of glaciofluvial origin. This is the lowermost Quaternary stratigraphic unit recorded in the area. The upper 1 m, however, has imbricated pebble layers sloping gently down valley, indicative of a shore deposit. The valley side to the northeast is composed of weathered shale. The other terrace remnant, to the southwest, reaches an altitude of 81 m and is composed of sand and gravel with foreset beds indicating deposition from the general direction of the present drainage system (to the northwest).

The outer moraine

This moraine ridge is situated immediately outside the pronounced Little Ice Age Moraine (Fig. 3) and reaches an altitude of 85 m a.s.l. The ice-proximal part of the outer moraine, where not covered by the Little Ice Age Moraine, slopes approximately 8° to 10° up glacier while the ice-distal side slopes approximately 25° down towards the silt and clay plain 15 to 20 m below. Escarpments, probably representing earlier detachment of sediment flows, occur most frequently on the ice-distal slope. The ridge surface is characterized by small depressions, up to 10 m in diameter, interpreted to be kettle holes. Some depressions seem to be forming at present, but the section along the river shows no indication of remnant glacier ice in the ridge. The surface morphology is generally fresh with forms not yet levelled out by the intense solifluction processes that are typical in the area (Figs. 5 and 6). The older moraine contrasts both the flat surface of the terrace and

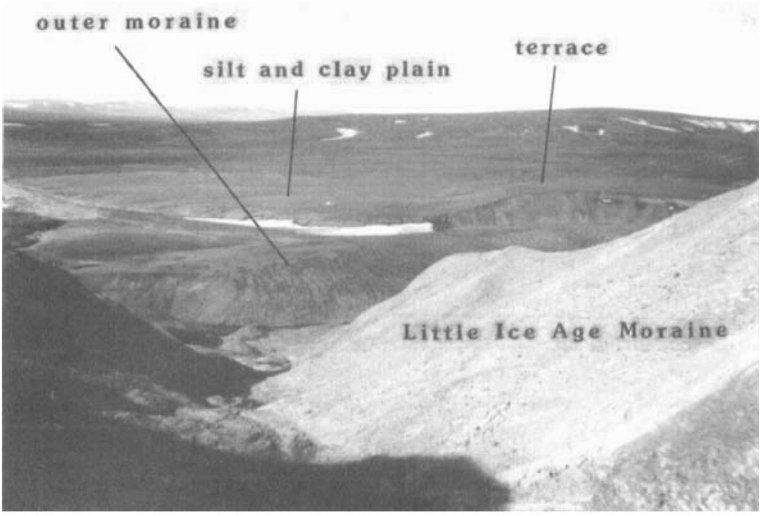

Fig. 4. View from the Little Ice Age Moraine showing the outer moraine, the terrace and the lower silt and clay plain. The thrust plane differentiating the terrace and the outer moraine is visible but is better seen in Fig. 5. Note also the differences in vegetation and surface morphology.

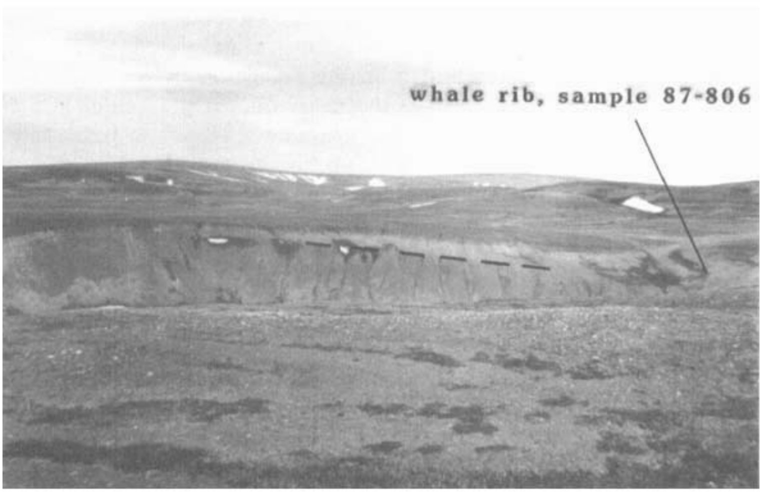

Fig. 5. The thrust plane (dashed line) in the section on the north side of the river is emphasized by the difference in sediment colour and slope gradient. The surface morphology and degree of vegetation cover on the outer moraine is seen in the lower half of the photograph. The location of sample 87-806 is marked.

Fig. 6. View towards the Little Ice Age Moraine showing its composition of stacked marine sediments. The surface morphology and vegetation cover on the outer moraine is seen in the lower half of the photograph.

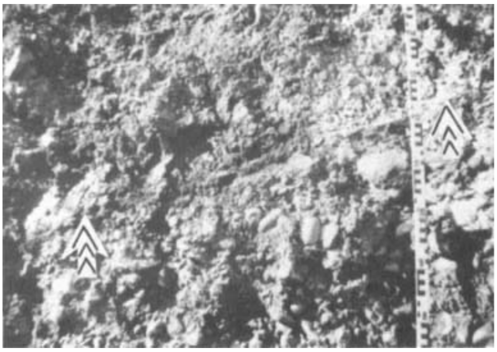

Fig. 7. The contact between the terrace sediments and the outer moraine is seen as an unconformity (arrows) between the stratified gravel and the overlying clayey diamicton.

Fig. 8. Photo of the whale rib (sample 87-806) dated to 9,360 ± 105 B.P. The bar is divided into 0.1 m long segments.

the sharp relief of the Little Ice Age Moraine (see below). The extent of vegetation cover is intermediate between the terrace and the non-vegetated Little Ice Age Moraine.

The section on the western side of the river from Albrechtbreen shows that the sediments in the ridge consist predominantly of a clayey diamicton, discordantly overlying glaciotectonized glaciofluvial gravel (Fig. 7), probably belonging to a glacially overrun proximal part of the terrace described above. The contact between the glaciofluvial gravel and clayey diamicton is a shear plane oriented 060°/20°S, i.e. dipping toward Albrechtbreen. On the north side of the river (Fig. 3) a similar stratigraphic relation on a larger scale is observed. The underlying gravel is cut by ravines (Fig. 5) while the diamicton unit above the thrust plane has a lower surface gradient.

Two radiocarbon dates from whale ribs found on the moraine surface have been obtained (Table 1). Sample 87-806 is from a one metre long piece of whale rib picked from the eroded moraine surface inside the terrace (Fig. 8). The other sample, 87-807, is from the diamicton surface along the river, only 20 m outside the subrecent moraine. Both bones are interpreted to have been released from the diamicton by fluvial erosion related to the subrecent or present meltwater outlet of Albrechtbreen. The bones must have been picked up inside the present limit of Albrechtbreen and redeposited during the advance that formed the moraine. These dates are thus maximum dates for this glacier advance. Both dates, 9,360 ± 105 and 8,635 ± 125 B.P. respectively (see Table 1), are also minimum dates of the early Holocene deglaciation.

The Little Ice Age Moraine

Just outside and paralleling the front of Albrechtbreen is a moraine with high relief, c. 50 m, that we assume to have been formed during the Little Ice Age. It has a crosscutting relationship with the outer moraine (Fig. 3). The western part of the moraine is composed of stacked sheets of marine sediments (Fig. 6). This stacking can be

Table 1. Radiocarbon dates. A marine reservoir age correction of −440 years has been made on the shell and whale bone samples (cf. Mangerud & Gulliksen 1975). Sites are referred to PONAM-number 2401.

Field no.	Site	Elevation (m a.s.l.)	Material	Lab. no.	Age (radiocarbon yr B.P.)
87-806	C	68	Whale rib	T-9910	9,360 ± 105
87-807	D	61	Whale rib	T-9911	8,635 ± 125
87-810	J	72	Log	T-9912	9,405 ± 70
87-808	G	94-103	Shell frag.	Lu-3374	9,260 ± 140
87-809	H	103-133	Shell frag.	Lu-3375	9,110 ± 110

seen in ravines on the ice-distal side of ridges and they show that large sediment volumes are present and that there is no ice core in this part of the moraine. However, an ice core has been observed in the more morphologically subdued north-eastern part of the moraine. Restricted to this area, there are wet and dark spots on the slopes that typically occur in ice-cored moraines when they melt. There is no vegetation on the moraine surface.

In the western part of the moraine, up to 50 m of marine sediments have been stacked up during the time period that is represented by the ice advance during the Little Ice Age. Shell fragments (*Mya truncata*, *Hiatella arctica*, *Balanus sp.*) and whale bones found up to the crest of the moraine demonstrate a marine origin. Shell and driftwood samples yielded radiocarbon dates older than 9,100 B.P. (Table 1), consistent with the early Holocene deglaciation.

Discussion

The terrace is built up close to the marine limit of the early Holocene deglaciation, which compares with other marine limit determinations on NE Edgeøya (Mangerud et al. 1992). Available sea level displacement curves from eastern Svalbard show a rapid glacioisostatic rebound following deglaciation (e.g. Salvigsen 1978, 1981; Forman 1990; Mangerud et al. 1992). Glaciomarine sediments deposited at or only a few tens of metres below the marine limit must have been deposited approximately within one thousand years after deglaciation. This is consistent with our radiocarbon dates that show minimum ages of both the deglaciation and the marine limit (Table 1). The formation of the Little Ice Age Moraine is assumed to have terminated approximately 1900 A.D. which was the time when most glaciers in Svalbard had their maximum Holocene extension (Salvigsen & Österholm 1982; Boulton et al. 1982).

It is more problematic to estimate the age of the outer moraine which we believe to have been formed considerably earlier than the Little Ice Age. This interpretation is supported by (a) the striking difference in vegetation cover and morphology and (b) the crosscutting relationship between the two moraine ridges (Fig. 3) that possibly shows a slight shift in ice dome position of the glacier Edgeøyjøkulen during the time interval between their formation (cf. Dugmore & Sugden 1991).

The outer moraine represents more than a small readvance during general early Holocene deglaciation because (a) there is a difference in vegetation cover and morphology between the moraine ridge and the adjacent terrace and valley slopes, and (b) large volumes of marine sediments at high altitudes in the Little Ice Age Moraine indicate that the glacier had receded well inside the present ice margin at the time shown by the radiocarbon dates.

Our interpretation suggests that the glacial impact on the marine sediments was different during the two glacial advances. During the older advance the glacier eroded and homogenized sediments into a diamicton unit whereas large quantities of marine sediments were left intact beneath the glacier. During the subrecent advance these marine sediments were glacially pushed and stacked but not homogenized. This implies a difference in resistance within the sediments crossed by the glacier. Since both glacial advances occurred over more or less the same stratigraphic sequence, we propose that this was due to a difference in permafrost distribution. Models exist for proglacial stacking of both frozen (e.g. Bluemle & Clayton 1984) and unfrozen sediment (e.g. van der Wateren 1985), but we believe that the homogenization of marine sediments into a diamicton close to the glacier margin during the older advance most likely occurred with limited permafrost. Stacking of marine sediments into the Little Ice Age Moraine therefore, assuming a different permafrost distribution during the two glacial advances, occurred when the permafrost reached deeper. The permafrost distribution through time on Svalbard has been generalized by Landvik et al. (1988) who proposed a zone of no or discontinuous permafrost along the coastline that has recently emerged from the sea. It is reasonable to believe that this situation also applied for the sediments in front of Albrechtbreen in the early Holocene before permafrost was established.

The paleoclimatic setting of the Svalbard archipelago during the Holocene, the time when the interpreted glacial advances of Albrechtbreen occurred, has been interpreted mainly through datings of glacial variations on Spitsbergen (Fig. 1). An advance of Paulabreen in Van Mijenfjorden (Fig. 1) occurred approximately 7,850 to 8,550 B.P., but was interpreted as a result of a surge (Punning et al. 1976) and is thus of no reliable climatic significance. Beget (1983) suggested that a world wide climatic cooling of about the same amplitude as the recent Neoglaciation occurred between 8,500 and 7,500 B.P. Troickij & Punning (1984) reinterpreted the age of an ice advance in the Lomfjorden area, NE Spitsbergen, to about 7,800 B.P. Salvigsen et al. (1990) reported glacier advances on two lowland peninsulas on the northern shore of Isfjorden (Fig. 1), western Spitsbergen. One glacier, Esmarkbreen, advanced shortly after 9,500 B.P. In front of the other glacier, Wahlenbergbreen, a moraine was formed subsequent to 9,000 B.P. and there were, as in this study, differences in vegetation cover and the effect of cryogenic processes between the older Holocene moraine and the Little Ice Age Moraine. Werner (1988) made a thorough review of Holocene glaciation in Spitsbergen. Based on lichenometry, he found four episodes of moraine formation that approximated 1,500 B.P., 1,000 B.P., 650 B.P., and during the last centuries. From studies of lacustrine sediments in Linnévatnet, western Spitsbergen, Svendsen & Mangerud (1992) concluded that glaciers upstream from this lake began forming some 2,000–3,000 years ago. Thus the existing dates on glacial advances from Spitsbergen point in two directions, one toward early Holocene, 9,500 to 7,800 B.P. (Punning et al. 1976; Troickij & Punning 1984; Salvigsen et al. 1990), and one toward late Holocene, from 3,000 B.P. (Werner 1988; Svendsen & Mangerud 1992).

The occurrence of the thermophilous mollusc *Mytilus edulis* might be the best available indicator of warmer seasurface temperatures than at present. Radiocarbon datings of *Mytilus edulis* from Spitsbergen have been reviewed by Salvigsen et al. (1992) and show warmer marine conditions between 9,500 and 3,500 B.P., and during a short period around 1,000 B.P. The warm period was probably shorter on eastern Svalbard due to differences in sea currents. Based on findings of *Mytilus edulis* this warm period is preliminarily interpreted by Hjort et al. (1992) to have lasted from 8,500 to 5,000 B.P.

Werner (1988) argued that Holocene glacial advances on Spitsbergen correlate with cool climate. Warren (1991) concluded from his work in West Greenland that land-based glaciers respond primarily to changes in summer temperature. Calving glaciers are, on the other hand, not reliable as climatic indicators (Warren 1991). Surging glaciers are common in Svalbard today (cf. Hagen 1988; Liestøl 1988) and a surging Albrechtbreen cannot be excluded. Increased winter precipitation, possibly as a response to increased seasurface temperatures, could have triggered an advance. It is also possible that a different spatial distribution of winter precipitation changed ice divide positions (cf. Dugmore & Sugden 1991), thereby increasing the amount of ice drained by Albrechtbreen.

The discussion above shows that the most conservative age estimate of the glacial advance that formed the outer moraine is bracketed between 8,635 ± 125 B.P. and the Little Ice Age. However, discussions on the permafrost distribution points to a glacial advance during the first half of the Holocene, while most general paleoclimatic assessments favour an advance after 3,000 B.P.

The redeposition of marine sediment in the Little Ice Age Moraine shows that Albrechtbreen had receded beyond its present margin after the deglaciation, probably due to calving during the deglaciation when sea level was 82 m higher than at present. The extent of the maximum readvance during the Holocene may be compared to advances of more than 12 km reported from some places in Spitsbergen during the Little Ice Age (Boulton et al. 1982).

Summary

Based on the evidence and discussion presented above, we suggest the following scenario for the Albrechtbreen area during the Holocene (Fig. 2). The investigated area was deglaciated and a glaciofluvial delta was built up in front of the glacier close to the marine limit, 82 m a.s.l. The glacier margin receded well beyond its present position between 9,405 ± 70 and 8,635 ± 125 B.P., as suggested by the radiocarbon dates (Table 1).

Later, between 8,635 ± 125 B.P. and the Little Ice Age, Albrechtbreen advanced and partly overran the delta. A moraine was deposited along the ice margin of that time, and the glacier receded once again to an unknown position.

During the Little Ice Age, Albrechtbreen advanced once more, stacking the marine sediments into 50 m high moraine ridges parallel to the ice margin, after which a slow glacial retreat began.

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References

Beget, J. E. 1983: Radiocarbon-dated evidence of worldwide early Holocene climate change. *Geology 11*, 389–393.

Bluemle, J. P. & Clayton, L. 1984: Large-scale glacial thrusting and related processes in North Dakota. *Boreas 13*, 279–300.

Boulton, G. S., Baldwin, C. T., Peacock, J. D., McCabe, A. M., Miller, G., Jarvis, J., Horsefield, B., Worsley, P., Eyles, N., Chroston, P. N., Day, T. E., Gibbard, P., Hare, P. E. & von Brunn, V. 1982: A glacio-isostatic facies model and amino acid stratigraphy for late Quaternary events in Spitsbergen and the Arctic. *Nature 298*, 437–441.

Dugmore, A. J. & Sugden, D. E. 1991: Do the anomalous fluctuations of Sólheimajökull reflect ice-divide migration? *Boreas 20*, 105–113.

Forman, S. 1990: Post-glacial relative sea-level history of northwestern Spitsbergen, Svalbard. *Geol. Soc. Am. Bull. 102*, 1580–1590.

Hagen, J. O. 1988: Glacier surge in Svalbard with examples from Usherbreen. *Norsk Geografisk Tidsskrift 42*, 203–213.

Hjort, C., Adrielsson, L., Bondevik, S., Landvik, J. Y., Mangerud, J. & Salvigsen, O. 1992: Mytilus edulis on eastern Svalbard – dating the Holocene Atlantic Water influx maximum. *Lundqua Report 35*, 171–175.

Landvik, J. Y., Mangerud, J. & Salvigsen, O. 1988: Glacial history and permafrost in the Svalbard area. Pp. 194–198 in Senneset, K. (ed.): *Proceedings, 5th International Conference on Permafrost, Trondheim, August 1988*. Tapir, Trondheim.

Liestøl, O. 1988: The glaciers in the Kongsfjorden area, Spitsbergen. *Norsk Geografisk Tidsskrift 42*, 231–238.

Mangerud, J. & Gulliksen, S. 1975: Apparent radiocarbon age of recent marine shells from Norway, Spitsbergen and Arctic Canada. *Quat. Res. 5*, 263–273.

Mangerud, J., Bondevik, S., Ronnert, L. & Salvigsen, O. 1992: Shore displacement and marine limits on Edgeøya and Barentsøya, eastern Svalbard. *Lundqua Rep. 35*, 51–60.

Punning, J.-M., Troitsky, L. & Rajamäe, R. 1976: The genesis and age of the Quaternary deposits in the eastern part of Van Mijenfjorden, West Spitsbergen. *Geografiska Föreningens i Stockholm Förhandlingar 98*, 343–347.

Salvigsen, O. 1978: Holocene emergence and finds of pumice, whalebones and driftwood at Svartknausflya, Nordaustlandet. *Norsk Polarins. Årbok 1977*, 217–228.

Salvigsen, O. 1981: Radiocarbon dated raised beaches in Kong Karls Land, Svalbard, and their consequences for the glacial history of the Barents Sea area. *Geog. Ann. 63A*, 283–291.

Salvigsen, O., Elgersma, A., Hjort, C., Lagerlund, E., Liestøl, O. & Svensson, N.-O. 1990: Glacial history and shoreline displacement on Erdmannflya and Bohemanflya, Spitsbergen, Svalbard. *Polar Res. 8*, 261–273.

Salvigsen, O., Forman, S. L. & Miller, G. H. 1992: Thermophilous molluscs on Svalbard during the Holocene and their paleoclimatic implications. *Polar Res. 11*, 1–10.

Salvigsen, O. & Österholm, H. 1982: Radiocarbon dated raised beaches and glacial history of the northern coast of Spitsbergen, Svalbard. *Polar Res. 1*, 97–115.

Svendsen, J. I. & Mangerud, J. 1992: Paleoclimatic inferences from glacial fluctuations on Svalbard during the last 20,000 years. *Climate Dynamics 6*, 213–220.

Troickij, L. S. & Punning, J.-M. 1984: On the early Holocene stage of glaciation in Spitsbergen. *Materialy gljaciologiceskich issledovanij 50*, 203–208. (In Russian. Internal translation Norsk Polarinstitutt, Oslo).

Warren, C. R. 1991: Terminal environment, topographic control and fluctuations of West Greenland glaciers. *Boreas 20*, 1–15.

van der Wateren, D. F. M. 1985: A model of glacial tectonics, applied to the ice-pushed ridges in the Central Netherlands. *Bull. Geol. Soc. Denmark 34*, 55–75.

Werner, A. 1988: Holocene glaciation and climatic change on Spitsbergen, Svalbard. Ph.D. Thesis. Department of Geological Sciences, University of Colorado, USA. 296 pp.