Glacial history, Holocene shoreline displacement and palaeoclimate based on radiocarbon ages in the area of Bockfjorden, north-western Spitsbergen, Svalbard

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Age determinations of bivalve shells indicate that Bockfjorden, a fjord in north-western Spitsbergen, Svalbard, was deglaciated shortly before 10 Kya, and that the upper marine limit in this area, with an altitude of about 50 m a.s.l., has the same age. During most of the Holocene, the glaciers in Bockfjorden were less extensive than they are today. Their maximum Holocene extension occurred during the Little Ice Age. The initial shoreline emergence after the deglaciation was rapid, and former shorelines younger than 8.5 Ky are below the present sea level. A mid-Holocene transgression of the sea is traced as well as a transgression during the last thousand years.

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Bockfjorden is a small branch of Woodfjorden, the westernmost large fjord on the north coast of Spitsbergen (Fig. 1). Mapping and investigations in the Bockfjorden area started early in the previous century (von Bock 1908). This work resulted in an overview map without details (making it difficult to compare with later, more detailed maps and aerial photographs). The geology of Bockfjorden was first described by Hoel & Holtedal (1911). They produced a general map accompanied by a description that included substantial information on the Quaternary geology of the area. The age of the Sverre volcano has been discussed by Semevskii (1965) and Skjelekvåle et al. (1989). The former postulated an age as young as the Middle Holocene, whereas the latter concluded that the last volcanic activity in Bockfjorden took place during the last interglacial. The first radiocarbon age determinations from Bockfjorden were presented by Salvigsen & Österholm (1982), showing that molluscs were living in Bockfjorden when the Holocene commenced. Radiocarbon dates from raised beaches in Bockfjorden were also presented by Brückner & Halfar (1994). Their research was carried out under the German Geoscientific Spitsbergen Expedition 1990–92, based in Liefdefjorden. This project resulted in several papers and maps with geological and geomorphological information, including coverage of the Bockfjorden area (Blümel 1993; Blümel et al. 1994); one of the geomorphological maps covers the Bockfjorden area north of Karlsbreen. Recent work on the geology of the area concerns the warm springs in Bockfjorden (Banks et al. 1998; Salvigsen & Høgvard 1998; Banks et al. 1999).

The study reported here aimed to contribute to a better understanding of the glacial history of the fjord areas of northern Spitsbergen. Glacial history and deglaciation in northern Spitsbergen had been investigated by Boulton & Rhodes (1974) and Salvigsen & Österholm (1982), but the ice extent and the timing of deglaciation have remained debatable (Mangerud et al. 1992; Landvik et al. 1998). The most recent study of the glacial history of northern Spitsbergen has been presented by Eitel et al. (2002), who have made detailed studies of sediments from the last degla-

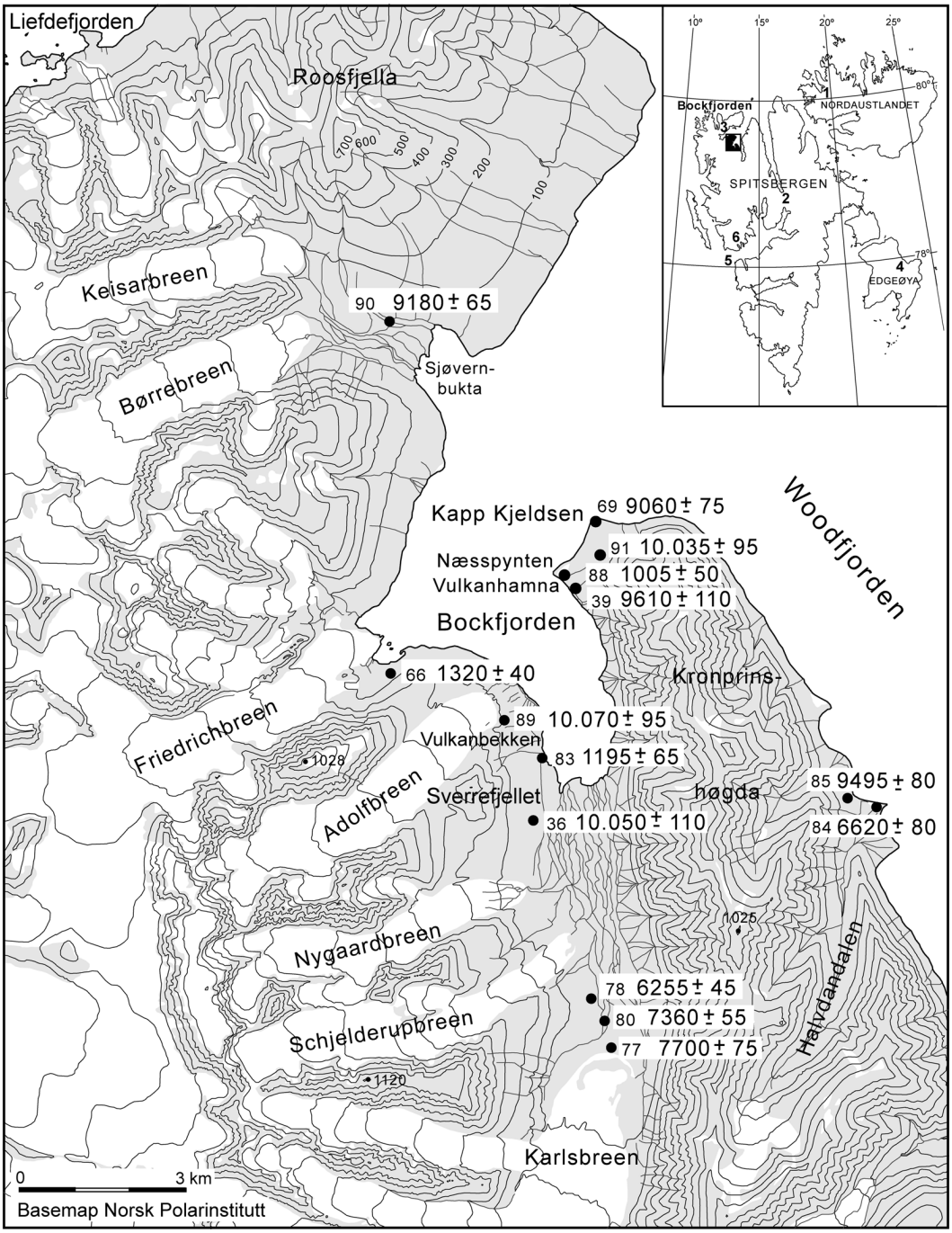

Fig. 1. Map of the Bockfjorden area showing the location (black dots) of samples that have been radiocarbon dated. Initial two-digit numbers refer to samples from 1995 (see Table 1 for details); ages are given in a larger type size. Numbers on the inset map indicate the locations of these glaciers: 1) Vestfonna, 2) Mittag-Lefflerbreen, 4) Albrechtbreen and 6) Esmarksbreen. The fjord Liefdefjorden is marked 3) and the lake Linnèvatnet is labelled 5).

ciation.

Another important objective of this study was to get a Holocene shoreline displacement curve for the Bockfjorden area. Only a few such curves from northern Spitsbergen have been made; see Forman (1990), Bondevik et al. (1995) and Forman et al. (2004). Additional information is useful for the drawing of isobase maps for Svalbard (see Bondevik et al. 1995 and Landvik et al. 1998).

Physical setting

Bockfjorden is about 5 km long. The fjord continues as a valley, the upper and inner reaches of which are occupied by the glacier Karlsbreen. Karlsbreen terminates about 6 km from the head of the fjord, and large parts of the valley floor between the fjord and the frontal moraine of Karlsbreen constitute a tidal and fluvial plain with fine-grained sediments. Two pingos occur on this flat (Liestøl 1977). Analysis of aerial photographs taken in 1966 indicated that Karlsbreen then had an area of 104 km^2 and a volume of 19 km^3 (Hagen et al. 1993); the glacier is now significantly smaller (see below). The mountaintops on both sides of the valley achieve maximum heights of approximately 1000 m a.s.l. The outer part of the fjord has a maximum depth of about 120 m.

The main bedrock geology of the Bockfjorden area have been described by Piepjohn (1992) and Hjelle (1993). Metamorphic basement rocks occur west of the fjord, mainly gneisses and shales of pre-Cambrian age. The eastern side is comprised of Devonian sandstones. The most conspicuous geological features in Bockfjorden are two areas of thermal springs and Sverrefjellet, an extinct volcano cone of Pleistocene age more than 500 m high (Salvigsen & Høgvard 1998).

Methods

Fieldwork for this study took place in 1995, during from 28 July to 8 August. Additional observations were made during a one-day visit to Bockfjorden on 13 August 1997.

Finding and sampling organic material suitable for radiocarbon dating to reconstruct glacial history, former sea levels and past climatic conditions were the main tasks during the 1995 fieldwork. Driftwood and whale bones yield the most the credible age determinations for the beaches where they are found, but such material is seldom seen above the present beach in Bockfjorden. *Mytilus edulis* was preferred among the shells because this is typically a low tidal zone species. Altitudes were determined either by precise levelling or by repeated barometric measurements from an estimated mean sea level. The accuracy of altitude determinations is estimated to ± 1 m.

Relatively large samples—more than 30 g of shells and 100 g of wood and whale bone—were sent to the Radiological Dating Laboratory in Trondheim, Norway. Ages were determined by the conventional radiocarbon method, with the exception of Tua-1641, which is an AMS date from one shell fragment. Ages are given in uncalibrated radiocarbon years, and ages of samples of marine origin are corrected for a reservoir age of 440 years (Mangerud & Gulliksen 1975).

Results and discussion

Glacial features

The fjord and the U-shaped valley of Bockfjorden probably result from glacial erosion during several glaciations. Glacial erratics are strewn over the cone of Sverrefjellet, all the way to its summit, but the search for glacier erratics in the surrounding mountains was not thorough enough to conclude whether erratics occur there. One big boulder of Precambrian rocks, roughly 2×3 m in size, has been observed in the valley north of Halvdandalen. The erratics on the Sverrefjellet volcano consist of granitic blocks (the so-called Hecla Hoek suite) and have been the subject of particular discussion. Hoel & Holtedahl (1911) discussed alternative processes to account for the transport of erratics and concluded that the blocks had most likely been transported by flowing lava or volcanic explosions. Skjelekvåle et al. (1989), however, suggested that these blocks were glacial erratics. We also found the occurrence of erratics on Sverrefjellet compatible with glacial transport and final deposition during melting of glacier ice. Thus, Sverrefjellet is most probably older than the last (Late Weichsealian) glaciation, but a more exact age is not known. Skjelekvåle et al. (1989) suggested volcanic activity during an Early Weichselian glaciation.

Glacial striae on bedrock occur in several places in the Bockfjorden area. The main direction of

former ice movements are shown in Salvigsen & Österholm (1982). Our observations in 1995 show glacier movements parallel to the valley and the fjord.

No unconsolidated sediments older than the last glacial phase have been identified in the Bockfjorden area, indicating efficient glacial erosion during the Late Weichselian.

Deglaciation

Shells from the valley of Bockfjorden were dated to 10 050 ± 120 yr BP (T-2918) by Salvigsen & Österholm (1982); this gave a minimum age for the deglaciation of the area. The study reported here found support for this with two additional age determinations of shells: 10 070 ± 95 yr (Tua-1641) and 10 035 ± 95 yr (T-12226). Shell-rich sediments occur along the small stream in Vulkanhamna up to about 35 m a.s.l. Small *Mya truncata* shells were found in situ in clayey, glacial marine sediments directly on striated bedrock. Among the highest occurring shells found in the Bockfjorden area, the age of these shells was determined to 10 035 ± 95 yr (T-12226). The highest lying shell fragments along the small stream, Vulkanbekken, on the west side of the fjord near the glacier Adolfbreen, are also dated. They occur in beach sediments of sand and gravel and appear in small sections eroded by water during the annual snow melt periods. A fragment of *M. truncata* revealed an age of 10 070 ± 70 yr (Tua-1641). These three almost identical age determinations indicate that the deglaciation of Bockfjorden took place shortly before the Holocene's commencement.

Brückner & Halfar (1994) present similar ages on shells from deposits south of Kapp Kjeldsen and near Vulkanhamna. The deposits on Kapp Kjeldsen dated by Brückner & Halfar (1994) are most probably a result of active littoral processes in unconsolidated glacimarine sediments from the last deglaciation.

Large *M. truncata* shells in living position occur in red clay/silt sediments in a shore section north of Halvdandalen, Woodfjorden. The sediments were lying directly on glacial sculptured bedrock, but no dropstones were identified and the shells revealed an age of 9495 ± 80 yr (T-12232), which constitutes a minimum age for the deglaciation of this part of Woodfjorden. Along the outer part of Woodfjorden, 11.5 Ky old shells have been found on levels below the Late Weichselian marine limit there (Salvigsen & Österholm 1982; Brückner & Halfar 1994; Brückner et al. 2002; Brückner & Schellmann 2003). Radiocarbon age determinations of material from raised beaches in north-western Spitsbergen therefore indicate that Bockfjorden and inner Woodfjorden were deglaciated at least 1500 years later than the outer part of Woodfjorden.

Holocene glacier retreat

The glaciers in Bockfjorden seem to have been less extensive during most of the Holocene than they are today. Raised beaches are found near Karlsbreen up to at least 30 m a.s.l., and most of Karlsbreen's frontal moraine consists of relocated marine sediments which are more or less disturbed by the subsequent glacier push. Marine sedimentation took place at least 1 km inside the present position of the glacier front, and these sediments have later been pushed up and forward in front of the advancing glacier. Three radiocarbon age determinations from Karlsbreen's frontal moraine indicate when the valley was part of the fjord. Shells and shell fragments occur in many places on the surface and in sections within the moraine. A section of thick sublittoral sediments occur in the most distal part of the moraine. Paired and almost unbroken *Mytilus edulis* shells yielded an age of 6255 ± 45 yr (T-12229). The highest lying fragments of *M. edulis* on the surface of the moraine were also dated, yielding an age of 7700 ± 75 yr (T-12230). A large driftwood log found within the moraine not far from these shells yielded an age of 7360 ± 55 yr (T-12231).

These age determinations indicate that the fjord inundated the valley of Bockfjorden between 8 Kya and 6 Kya, if not for longer. This period includes the Holocene climatic optimum in Svalbard (Salvigsen et al. 1992; Hjort et al. 1995; Salvigsen 2002), and the occurrence of thermophilous *M. edulis* indicates relatively warm water at the head of the former fjord. No influence of cold meltwater entering the fjord from nearby glaciers during this period can be shown.

The former diminished extent of glaciers elsewhere in Svalbard has been shown in several studies. Blake (1988) presented age determinations of shells from moraines which show that outlet glaciers from Vestfonna in Nordaustlandet were much reduced in size in the early Holocene. Marks & Wysokinski (1986) and Stankovski (1989) have shown that Mittag-Lefflerbreen, the glacier at the

head of Wijdefjorden, was much reduced about 8 Kya. Svendsen & Mangerud (1997) showed that a small glacier in the catchment area of Linnévatnet in western Spitsbergen probably disappeared completely for a considerable period in the Holocene. It is therefore also possible that the glaciers in Bockfjorden totally disappeared during the Holocene climatic optimum.

Based on our own field observations and the other studies referred to above, our conclusion is that Bockfjorden most probably had only small glaciers, or no glaciers at all, during the Holocene climatic optimum. However, we have no indications which can exclude the existence of small mountain glaciers in that area. Almost nothing is known about how Karlsbreen fluctuated during the Holocene before the "Little Ice Age".

Little Ice Age advance

The term "Little Ice Age" (LIA) generally denotes the cool period spanning the 14th or 15th century to the 19th, although the starting and ending dates are defined variably. During the LIA glaciers in many parts of the word expanded and fluctuated about more advanced positions than those they occupied in the centuries before or after this generally cooler interval (Grove 1990). The LIA for Svalbard usually refers to the period 600 to 100 years ago. Only fragmentary evidence of Holocene expansion before the LIA has been found in Svalbard. Werner (1993) studied moraines in the forefields of Spitsbergen glaciers using lichenometry. He concluded that the youngest (LIA) advances were the most extensive, and they obliterated most evidence of earlier Neoglacial events. Pre-LIA moraines occur as isolated remnant segments that have deflected younger advances. Ronnert & Landvik (1993), working on the island of Edgeøya, described an advance of the glacier Albrechtbreen between 8.6 Kya and the LIA. Salvigsen et al. (1990) show that the glacier Esmarkbreen, on the north coast of Isfjorden in central Spitsbergen, readvanced after 9.5 Kya.

Exact dating of the LIA advances is difficult in the Bockfjorden area, as elsewhere in Svalbard. One driftwood log was found in front of the southern marginal moraine of Friedrichbreen (Fig. 1). The log is 2.8 m and has a diameter between 25 and 30 cm, and was dated to 1320±40 yr BP (Salvigsen & Høgvard 1998). Bearing many scratches and dents from stones, the log shows many signs of having been incorporated in debris-rich glacier ice or a moraine. We interpret this log to have been transported by the glacier from the shore up to its present level about 40 m a.s.l. during the last advance of Friedrichbreen. It suggests that the maximum Holocene extension of Friedrichbreen was more recent than 1.3 Ky.

Furrer et al. (1991) dated organic material underlying till in front of the marginal moraine of the glacier Adolfbreen to 710±60 yr BP. They concluded that the till was deposited by a glacier advance in the 12th or 13th century. These age determinations related to the youngest moraines of two glaciers in Bockfjorden indicate that the glaciers had their greatest Holocene extent during the LIA. Much of the retreat from the LIA maximum position probably took place in the 20th century.

In the Canadian Arctic, active push moraines are prominent features, usually in front of advancing or more or less stagnant large valley glaciers (Evans 1989; King & Hell 1993). They consist of pushed-up plates of frozen, often marine sediments. In Svalbard, similar push moraine features occur as relict forms originating from the LIA advances (Lehmann 1992; King & Hell 1993; Huddart & Hambrey 1996; Boulton et al. 1999). The frontal moraine of Karlsbreen (Fig. 2) seems to be similar to the push moraines described from the Canadian Arctic and from Svalbard. Large parts of the moraine of Karlsbreen consist of marine sediments which were probably originally deposited between 6 and 8 Kya and were subsequently pushed and thrusted to the moraine's present position during the LIA. After that time the glacier has had only minor fluctuations which did not destroy the distal part of the moraine. Figure 2 shows the front of Karlsbreen in 1966 and 1990 and demonstrates the recent retreat of Karlsbreen. The front's 1966–1990 retreat is about 0.5 km, which works out to about 20 m/yr.

Holocene marine limit

Solifluction and vegetation hamper the reliable determination of the marine limit in Bockfjorden. The maximum marine limit has been reported previously to 60 m in Bockfjorden (Hoel & Holtedahl 1911). Our investigations in Bockfjorden did not confirm this altitude. The dated shells from Vulkanhamna were found at 35 m a.s.l., providing a safe minimum value for the marine limit

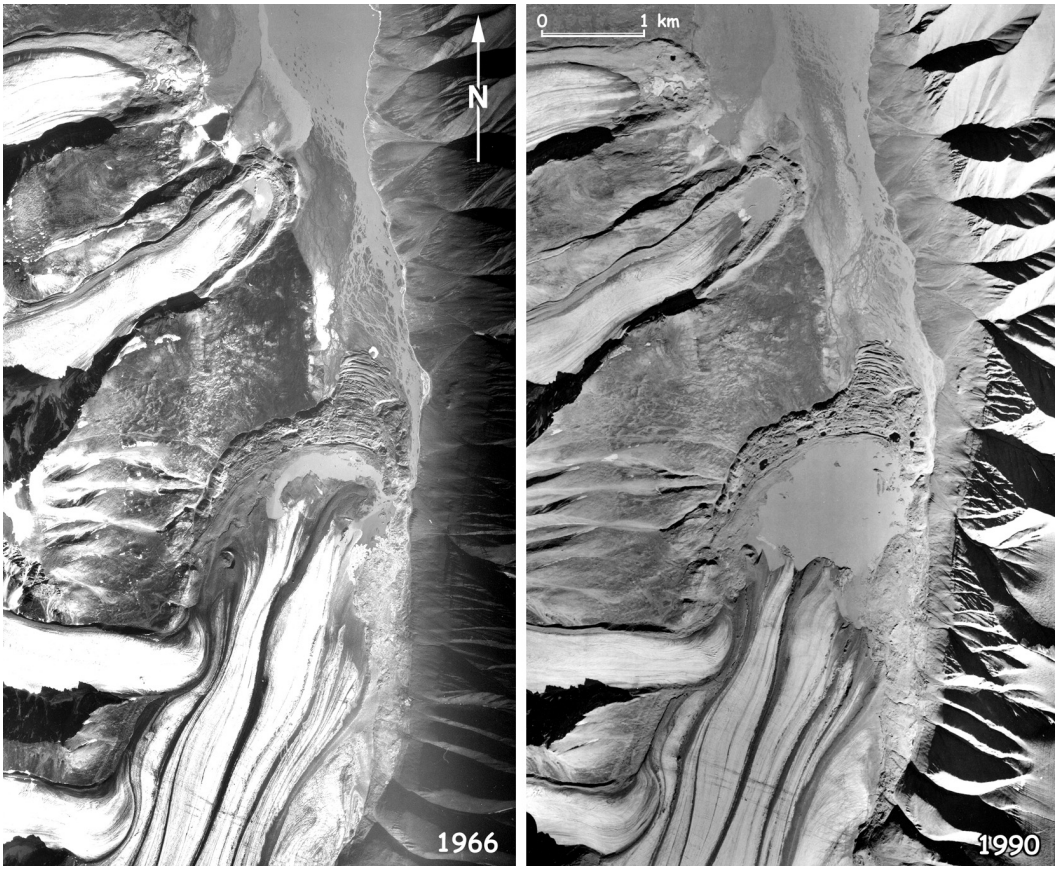

Fig. 2. Aerial photographs from the head of Bockfjorden to Karlsbreen showing the extent of glaciers in 1966 and 1990. For scale and orientation, see Fig. 1. (Photos: Norwegian Polar Institute S66V 4343 and S90 3208.)

in Bockfjorden. The glacial marine sediments associated with the shells seem to have been undisturbed by any shore activity so the water depth of the living molluscs must be taken into account. Seen from this locality a marine limit of >45 m a.s.l. seems reasonable. Marine sediments were found up to 50 m a.s.l., close to the mountain foot in Vulkanhamna along the rivulet east of the dated shells (T-12226). These particular sediments are undated, but we suggest that they are of Late Weichselian/Holocene age. No sediments or features at higher levels showed convincingly any traces of marine activity, so our estimate for the marine limit in Bockfjorden is 50 m a.s.l.

The three samples of the oldest shells in Bockfjorden, discussed above, provide a minimum age of about 10 Ky for the marine limit in Bockfjorden.

Shoreline displacement curve

The pattern of glacio-isostatic uplift has been the classic tool to reconstruct the Late Weichselian ice sheet in Svalbard and the western Barents Sea. (Schytt et al. 1968; Salvigsen 1981; Forman 1990; Lambeck 1996; Landvik et al. 1998; Forman & Ingólfsson 2000; Forman et al. 2004). A satisfactory reconstruction requires an even distribution of high quality uplift data (Salvigsen 1978; Bondevik et al. 1995). The age of the raised beach levels along the northern coast of Spitsbergen has not been determined with high precision (Boulton & Rhodes 1974; Salvigsen & Österholm 1982; Brückner et al. 2002; Brückner & Schellmann 2003) and the uplift data from this area should therefore be used with greater caution compared to other areas of Svalbard.

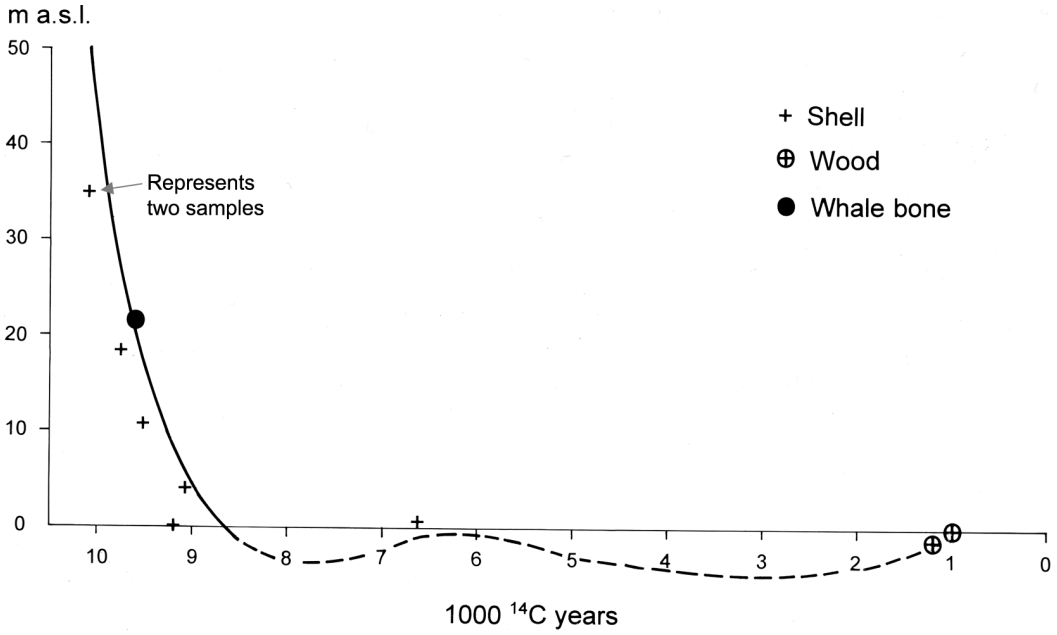

Fig. 3. Tentative shoreline displacement curve for the Bockfjorden area.

One of the main objectives of this study was to determine as accurately as possible the Holocene shoreline displacement in the area of Bockfjorden. The scarcity of driftwood and whale bones on the raised shorelines limits temporal and elevational resolution with respect to defining the sea level history. The dating of former shorelines in north-western Spitsbergen is also hampered by the fact that many levels are currently submerged. The shoreline displacement curve for an area like Bockfjorden is based on available driftwood and whale bone ages combined with selected ages of mollusc shells. Ten radiocarbon ages are used to constrain a shoreline displacement curve for Bockfjorden (Fig. 3). Six of the dated samples are from a small area encompassing Vulkanhamna, Næsspynten and Kapp Kjeldsen. These dates are supported by four additional samples found <8 km from Vulkanhamna (Fig. 1). The whale bone in Vulkanhamna probably represents the level where it was found, 21.5 m a.s.l., or a slightly higher level. Its age, 9610±110 yr (T-2837), is now corrected for the oceanic reservoir effect, in contrast to the age published in Salvigsen & Österholm (1982). The fragments of *M. edulis* at Kapp Kjeldsen were found in shore gravel and most probably represent a sea level less than 5 m higher than present. The age, 9060±75 yr (T-12227), indicates that the curve dips below the present sea level a few hundred years after 9 Kya. The shells dated by Brücker & Halfar (1994) and our *M. edulis* shells from Sjøvernbukta have lived at an unknown water depth, but their ages (Table 1, Fig. 1) support the curve.

Inferred change in relative sea level is rapid between 10 and 9 Kya, on the order of 4 mm/100 yr. Shorelines in Bockfjorden younger than 8.5 Ky are below the present sea level so the curve for this period can only be tentatively drawn. Fragments of *M. edulis* found on the present beach outside Halvdandalen seemed to have been washed out of fine-grained sediments near to the present shore. They yielded an age of 6620±80 yr (T-12369), suggesting a sea level rise around this time. A similar transgression is also manifested in several shore displacement curves from the west coast of Spitsbergen, e. g. Landvik et al. (1987), Salvigsen & Elgersma (1993) and several curves shown in Forman (1990).

Two age determinations of driftwood indicate that the sea level about one thousand years ago was lower than the present sea level. In Vulkanhamna, an old beach with driftwood was found inside the lagoon Kræmerlaguna. Its elevation

was near to the present mean tide level and about 1.5 m below the crest of the modern beach ridge. One of the logs from the former beach has been dated to 1005±50 yr BP (T-12367). At the head of Bockfjorden (western side) three driftwood logs were observed stuck in sediments about 1 m below the mean tide level; one of these logs yielded an age of 1195±65 yr (T-12368). These two age determinations indicate that the sea level a thousand years ago was at least 1 m below the present sea level. Most probably there is still an ongoing transgression in the area. The rate of the transgression is uncertain, but could be at a magnitude of about 1 mm/yr. A late Holocene transgression was inferred by Forman et al. (1987) and further documented in Forman (1990) for the west coast of Spitsbergen.

Holocene climate

Marine molluscs apparently immigrated to the area of Bockfjorden prior to 10 Kya. *M. truncata*, *Hiatella arctica* and *Macoma calcarea* seem to constitute the first fauna of large marine molluscs in Bockfjorden. These species point to rather cold climatic conditions at the beginning of the Holocene, as has been shown for elsewhere in Svalbard, most thoroughly by Feyling-Hanssen (1955) for the area of inner Isfjorden.

The appearance of *M. edulis* on the northern coast of Spitsbergen has been dated to about 9.4 Kya, which is only 200 years later than on the western coast of Spitsbergen. The mollusc lived in the north until at least 5.3 Kya (Salvigsen 2002).

The Early Holocene is characterized by a two-step warming of surface water at the continental margin of Arctic Eurasia, at 10.2 Ky and at 9.8 Ky (Hald & Aspeli 1997). The immigration of *M. edulis* to the west coast of Svalbard coincides with the last warming. Within a few hundred years this mollusc was widely distributed, reflecting the influx of Atlantic water along the western and northern coasts of Spitsbergen (Salvigsen 2002). During most of the Holocene, the summer surface temperature was probably at least 1-3 °C higher than it is today (Salvigsen et al. 1992; Salvigsen 2002). The uplift curve (Fig. 3) shows that only beaches older than 8.5 Ky are above the present sea level, and sampling of in situ younger shells is therefore not possible. In Bockfjorden, however, the push and thrust moraines in front of Karlsbreen contain many fragments and whole shells of *M. edulis*. The two dated samples from the moraine of Karlsbreen indicate that *M.*

Table 1. Radiocarbon dates from the Bockfjorden area. All age determinations on samples of marine origin have been corrected for a reservoir age of 440 years.

Site	Age	Lab. no.	Field no.	Material	M a.s.l.	Remarks
Vulkanbekken	10070±95	TUa-1641	95, Sa. 89	*M. truncata*		Small fragments in beach material
Bockfjorden	10050±110	T-2918	77, Sa. 36	*M. truncata*/ *H. arctica*	35	Salvigsen & Österholm 1982
Vulkanhamna	10035±95	T-12226	95, Sa., 91	*M. truncata*	35	Small shells above bedrock
Vulkanhamna	9785±75	HD15709-15478	SPE-32a	*M. truncata*	18	Brückner & Halfar 1994
Vulkanhamna	9610±110	T-2837	77, Sa.,39	Whale rib	21.5	Salvigsen & Österholm 1982
Vulkanhamna	9560±70	HD15710-15166	SPE-34a	*M. truncata*.	12	Brückner & Halfar 1994
Halvdandalen	9495±80	T-12232	95, Sa.,85	*M. truncata*.	4	Large shells above bedrock
Sjøvernbukta	9180±65	T-12370	95, Sa., 90	*M. edulis*	1	Fragments on modern beach
Kapp Kjeldsen	9060±75	T-12227	95, Sa., 69	*M. edulis*	4	Fragments from raised beach
Karlsbreen	7700±75	T-12230	95, Sa., 77	*M. edulis*	40	Frontal moraine
Karlsbreen	7360±55	T-12231	95, Sa., 80	*Picea* sp.	29	Frontal moraine
Halvdandalen	6620±80	T-12369	95, Sa., 84	*M. edulis*	1	Fragments on modern beach
Karlsbreen	6255±45	T-12229	95, Sa., 78	*M. edulis*	11	Frontal moraine
Friedrichbreen	1320±40	T-12368	95, Sa., 66	*Picea* sp.	40	Frontal moraine
Bockfjorden	1195±65	T-12228	95, Sa., 83	*Larix* sp.	–1	Sublittoral sediments
Vulkanhamna	1005±50	T-12367	95, Sa., 88	*Picea* sp.	0	Subrecent beach
Adolfbreen	710±60	UZ-2636/ETH-6913		Plant detritus		Furrer et al. 1991

edulis lived in Bockfjorden continuously in the period 9 - 6 Kya. The Holocene climatic optimum in Svalbard seems to have culminated between 8.8 and 7.2 Kya (Salvigsen et al. 1992; Salvigsen 2002). As can be seen from the uplift curve (Fig. 3), no marine fauna of the climatic optimum can be expected to be found in situ on land in Bockfjorden. However, *Modiolus modiolus*, which is considered more thermophilous than *M. edulis*, lived at the head of Woodfjorden about 8.3 Kya (Salvigsen 2002).

In inner Liefdefjorden, finds of plant remnants as well as ostracods in a dated section indicate relative favourable climatic conditions also after 5 Kya (Furrer 1994). Among the plants were *Vaccinium uliginosum*, which has previously only been reported from the Isfjorden area.

Conclusions

Our conclusions are summarized as follows:

1) Bockfjorden was deglaciated more than 10 Kya.
2) During most of the Holocene, the glaciers of Bockfjorden, primarily Karlsbreen, were probably less extensive than they are today.
3) The Holocene maximum glacier extension in Bockfjorden occurred during the LIA.
4) The post-glacial marine limit in Bockfjorden is estimated at least 50 m a.s.l. and was formed prior to 10 Kya.
5 Shorelines more recent than than 8.5 Ky are now below present sea level. A small transgression has probably occurred during the last thousand years.
6) The marine climate in Bockfjorden was warmer than the present during the first half of the Holocene.

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