Pleistocene stratigraphy of Kongsfjordhallet, Spitsbergen, Svalbard

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Open sections along Kongsfjordhallet, the north-western coast of Kongsfjorden, Svalbard, exhibit marine and glacigenic sediments of Early to Late Pleistocene age. Glaciation, deglaciation and subsequent isostatic rebound caused the formation of three sedimentary successions (A, B and C) that comprise till grading upward into glaciomarine mud, followed by shell-bearing sand, and finally littoral sand and gravel. Six major lithostratigraphic units are recognized. Succession C comprises units 1 and 2, which were deposited during an Early Pleistocene glaciation, followed by deglaciation and subsequent beach progradation. Succession B is divisible into units 3 and 4 and reflects glaciation and eventual emergence as a result of isostatic response. The youngest succession (A) comprises units 5 and 6, and reflects fiord glaciation followed by a regression during an Early Weichselian glaciation-deglaciation episode. Ice-free conditions may have prevailed until the Late Weichselian, when a glaciation, confined to the fiord trough, covered parts of Kongsfjordhallet. Deglaciation and isostatic rebound are recorded by Holocene marine terraces up to ca 40 m a.s.l.

Marine and glacial events from Kongsfjordhallet are compared with stratigraphic evidence from adjacent regions and it is suggested that the Late Weichselian ice configuration was of a more restricted nature than proposed by previous authors. Glaciers draining through the larger fiord troughs reached the shelf break, while at the same time other parts of western Svalbard could have experienced restricted glaciation.

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Introduction

The present study deals with the Pleistocene stratigraphy and, in particular, the Weichselian glaciation history of Kongsfjordhallet, Svalbard. Special attention is paid to the question of terrestrial evidence for major Late Weichselian ice cover in the Kongsfjorden region. The Late Pleistocene stratigraphy from Kongsfjordhallet is compared with data from three other sites along the western coast of Spitsbergen, between Isfjorden and Kongsfjorden. Previously unknown Early–Middle Pleistocene deposits and their rich marine molluscan faunas from Kongsfjordhallet are briefly described. These will be dealt with in more detail in a later publication. Field work was carried out in 1993 under the PONAM project (Polar North Atlantic Margins: Late Cenozoic Evolution), as reported by Houmark-Nielsen et al. (1993). Additional sampling was made during shorter visits in 1996 and 1997.

Previous work

Stratigraphic studies from a locality east of Kapp Guissez (Boulton 1979) indicated three cycles of emergence related to glaciation and subsequent marine deposition during isostatic rebound. The youngest cycle was ^{14}C-dated to the Late Weichselian-Holocene transition, and related to the retreat of a local glacier, which, according to Boulton (1979), did not extend to the locality he investigated. High marine terraces at 66 m above present sea level were correlated with similar high marine terraces with ^{14}C ages of around 40 Ky from Brøggerhalvøya, and ascribed to isostatic rebound after an earlier glaciation. The relative sea level changes and glacial history from northernmost Prins Karls Forland (Boulton 1979) show a close resemblance to events from the Kongsfjorden localities. Boulton concluded that a major glaciation reached the outer shelf before 40 Kya. Late Weichselian glaciation was local, and

Table 1. Radiocarbon dates, Kongsfjordhallet.

Unit	Loc.	Altitude (m a.s.l.)	Sample No.	Type	Lab ID	^{14}C Age (Ky)	^{13}C ‰ PDB
6	1312a	50	100217	shell: U	AAR1360	>37	+1.6
5	1301	28	100222B	shell: Ha	AAR3091	>41	+1.1
5	1301	29	100222A	shell: Mc*	AAR3090	22.4 ± 0.4	+1
5	1301	29	100222C	shell: Ha*	AAR3809**	>44	+1.3
5	1301	29	110222C	shell: Ha*	AAR3809***	35	+1.3
5	1305a	21	95621	shell: Ab	AAR1358	>43	+1.2
5	1312b	38	100218	shell: Ha*	AAR1359	>41	+2.1

U = unidentified shell fragment, Ab = *Astarte borealis*, Ha = *Hiatella arctica*, Mc = *Macoma calcarea*. * = In situ shells. ** = Inner fraction. *** = Outer fraction.

possibly no more extensive than at present or during the Little Ice Age.

Lehman & Forman (1992) described beach gravels considerably above the supposed Late Weichselian-Holocene marine limit from Kongsfjordhallet. These beach sediments contain fragments of *Hiatella arctica* with amino acid ratios similar to those characterizing episode C of Brøggerhalvøya (Miller et al. 1989). It was noted that the raised marine deposits show no evidence of glacier overriding; however, a lateral moraine, trending almost parallel to the coast, cross-cuts the older marine sediments. The moraine was considered to be of Late Weichselian age, although it might represent only a minimum extent of this ice cover (Lehman & Forman 1992). It was argued that the Late Weichselian-Holocene marine limit descends towards the west from approximately 42 m a.s.l. to about 36 m a.s.l. along Kongsfjordhallet. This ocean-ward tilting was supposedly caused by isostatic recovery from a Late Weichselian glacier occupying Kongsfjorden. Cores containing till overlain by shell-bearing glaciomarine diamicton (dated at ca. 14–12 Kya in the trough outside Kongsfjorden) is taken as evidence for Late Weichselian glacial cover and subsequent deglaciation from the shelf adjacent to the mouth of the fiord (Landvik et al. 1998).

Methods

Open sections were logged for lithostratigraphic classification and interpretation of sediment genesis, while marine molluscan faunas were studied to aid palaeoecological interpretations. Total alle:Ile ratios are used for inter-site correlation and comparison with amino episodes at sites in the Kongsfjorden region. Six samples of marine mollusc shells (*Hiatella arctica*, *Macoma calcarea* and *Astarte borealis*) were ^{14}C dated by the AMS method (Table 1). Two sediment samples that have been luminescence-dated using the single aliquot regeneration protocol on sand-sized quartz grains (Murray & Roberts 1998; Murray & Mejdahl 1999) are presented in Table 2. Twelve samples of marine mollusc shells (*Mya truncata* and *Hiatella arctica*) have been analysed for amino acid epimerization (alle:Ile) in the hydrolysed (total) and free fractions using standard procedures described by Sejrup (1990) (Table 3).

Geomorphology

Kongsfjordhallet is a 1–2 km wide and 6–7 km long strandflat at the north-western shore of Kongsfjorden (Fig. 1). It rises from about 40 m a.s.l. at the coast to ca. 100 m at the foot of the mountain. Unconsolidated Quaternary sediments unconformably overlie the strongly folded and metamorphosed Hecla Hoek Fm (Hjelle & Lauritzen 1982) and consist of 15–35 m thick deposits of interfingering till, glaciomarine diamictons, littoral sand and gravel, and smaller quantities of

Table 2. Luminescence dates succession A, Kongsfjordhallet.

Unit	Loc.	Altitude (m a.s.l.)	Sample	Lab ID	Age (Ky)
6	1309	27	100107	R 951009	75 ± 10
5	1301	31	100214	R 951010	91 ± 9

Table 3. Amino acid alle/Ile ratios in shells* from Kongsfjordhallet.

Unit	Loc.	Altitude (m a.s.l.)	Sample ID	Total hydrolysate Avg** ±	Free fraction Avg** ±
5	1301	28	100202 Bal3244	0.028 ± 0.001	0.135 ± 0.000
5	1305a	20	100108 Bal3200	0.03 ± 0.001	0.207 ± 0.017
5	1305a	21	95621 Bal3031	0.227 ± 0.011	0.765 ± 0.011
5	1307	19	100102 Bal3196	0.036 ± 0.001	0.249 ± 0.013
5	1309	27	95623 Bal3319	0.026 ± 0.003	0.223 ± 0.002
5	1309	27	95623 Bal3195	0.030 ± 0.001	0.164 ± 0.007
5	1312b	39	100218 Bal3201	0.030 ± 0.000	0.173 ± 0.006
2	1303	16	95625 Bal3032	0.239 ± 0.011	0.789 ± 0.024
2	1304	10	100203 Bal3197	0.165 ± 0.008	0.640 ± 0.030
2	1305a	10	95619 Bal3030	0.138 ± 0.007	0.655 ± 0.013
2	1306	9	100205 Bal3199	0.238 ± 0.004	0.810 ± 0.016
2	1306	9	100205 Bal3198	0.035 ± 0.001	0.805 ± 0.013

*All shells are *Mya truncata* except Bal3199 (*Hiatella arctica*).
**Average of two measurements in each of two valves.

alluvial fan and slope deposits. Examined sections are located between Tønsneset and Kapp Guissez, about 10–15 km north-west of Ny-Ålesund.

A stony and boulder-rich veneer with far-travelled erratics laps onto the mountain slopes up to 120 m a.s.l. south-west of Kappfjellet, and up to more than 200 m a.s.l. north of Tønsneset. These levels are assumed to indicate the maximum extension of glaciers moving through the fiord (Fig. 2). Patches of glacigenic sediments in hummocky and elongated ridges rise from about 40 m a.s.l. south of Kapfjellet to more than 150 m a.s.l. north of Tønsneset (Fig. 2), and constitute an apparently fresh and undisturbed lateral moraine which marks the extent of the youngest ice cover in the area. Raised beaches older than the Late Weichselian and overlying glacial deposits are found up to 80 m a.s.l. They cover major parts of the strandflat and build up the youngest littoral deposits exposed in most cliff sections and inland exposures. Scattered rocks and boulders, but no till, are found on the raised marine terraces inside the moraine.

An erosional scarp in the raised marine terraces north of Tønsneset suggests that the Late Weichselian–Early Holocene marine limit did not exceed 43 m a.s.l. A slightly younger, marked scarp cut into the older marine deposits at about 30 m a.s.l. is found in the western and eastern end of the cliff exposures. Although not dealt with in the present investigation, we accept the extent of the Late Weichselian–Holocene marine limit given by Lehman & Forman (1992), which suggests a westward decline of about 1 m/km.

The youngest geomorphical features on the Kongsfjordhallet are represented by the proposed neo-glacial phenomena shown in Fig. 2. Gullies and young meltwater channels have cut through the Quaternary cover into the bedrock as a result of the relative sea level lowering and melting of (sub-) recent glaciers in the hinterland.

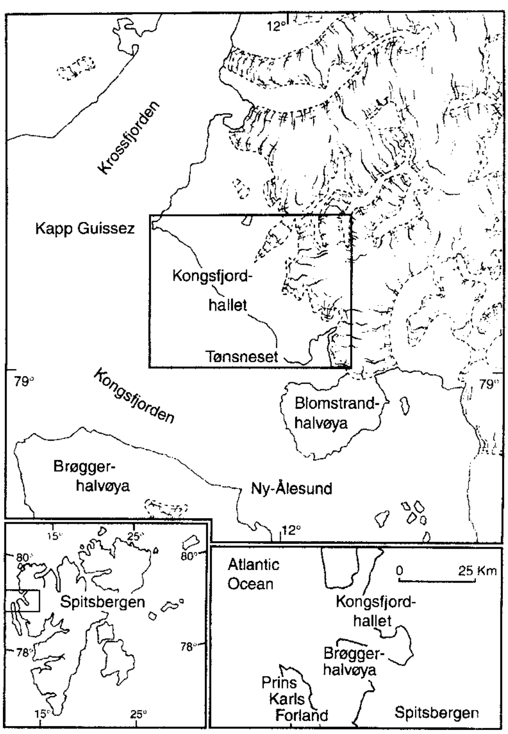

Fig. 1. Key and location map of Kongsfjordhallet showing land, sea and modern glaciers.

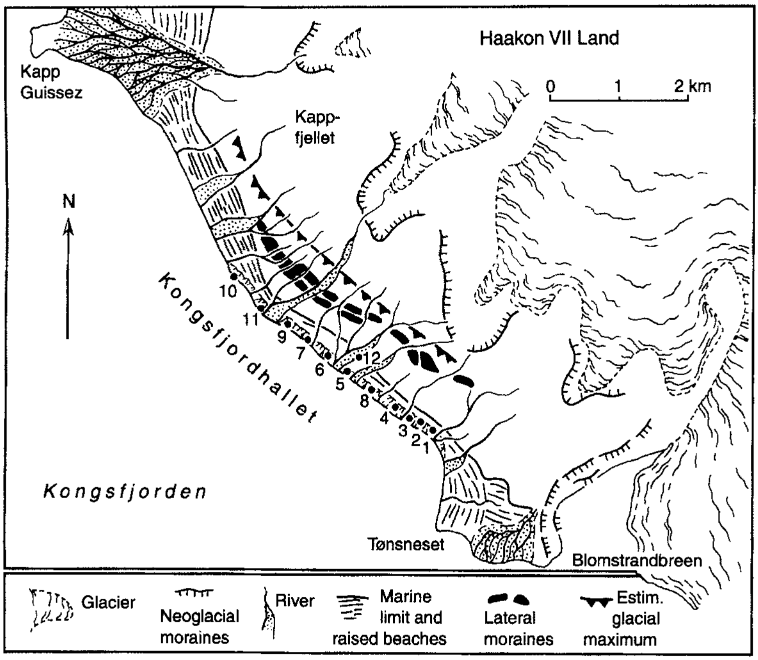

Fig. 2. Geomorphic features along the coast of Kongsfjordhallet based on reconnaissance and studies of aerial photograph S90 6768 (Norsk Polarinstitutt 1990). The Late Weichselian–Holocene marine limit is not distinguished from older marine limits. Numbers indicate positions of investigated sites (1301–1312).

Stratigraphy

Ten sites located along the coastal cliffs and two sites about 0.5 km inland were investigated (Fig. 2, points 1–9 & 12; Fig. 3, 1301–1312), and used to compile three composite facies successions (A, B, C) in which six lithostratigraphic units have been recognized. Some successions are simple coarsening upwards sequences while others may be composite, or even chaotic in nature. In Fig. 3 we have distinguished four major facies comprised of diamictons (either deposited as till or as ice proximal glaciomarine sediments) which indicate successive glaciations and deglaciations. It should be noted that the format of Fig. 3 does not allow distinction between closely related facies such as till and glaciomarine diamictons. Mud refers to a spectrum of clast-bearing to clast-free fine sediments deposited from ice-rafting and suspension in an ice-distal setting beneath the wave-base. Sand and gravel represent sublittoral and littoral deposition under high energy conditions.

Succession C

The oldest facies succession is preserved in a bedrock depression in the central parts of the cliff exposures (Fig. 3), and comprises units 1 and 2. These represent one or several glacial cycles.

Unit 1 consists of at least 10 m of red to black, dark-banded, matrix-supported diamicton which contains striated stones and shell fragments. It generally rests directly on bedrock. The lower part of the diamicton is interpreted as a till, deposited from glacier ice which moved down either from the mountains of the hinterland, or through the fiord. The upper 2–3 m grade into clast-poor silty diamicton and mud with dropstones and lenses of fine sand. These have a characteristic reddish and chocolate brown colour. The sediment contains shells in life position, and was deposited under distal glaciomarine conditions. At site 1305, the fauna contains a high proportion of *Mya truncata* and *Hiatella arctica* in life position in their burrows, and among the minor constituents, the extinct *Cyrtodaria angusta*. Two metres of unsorted, dense, pebbly, silty sand is found in unit 1 at site 1303, with a marine fauna comparable to that of unit 2. The fauna of unit 1 is dominated by *H. arctica* and *Astarte borealis* while the characteristic *C. angusta* is also present, and the close resemblance to the fauna of unit 2 indicates that they may be quasi-contemporaneous.

The lower part of unit 2 is more than 10 m thick,

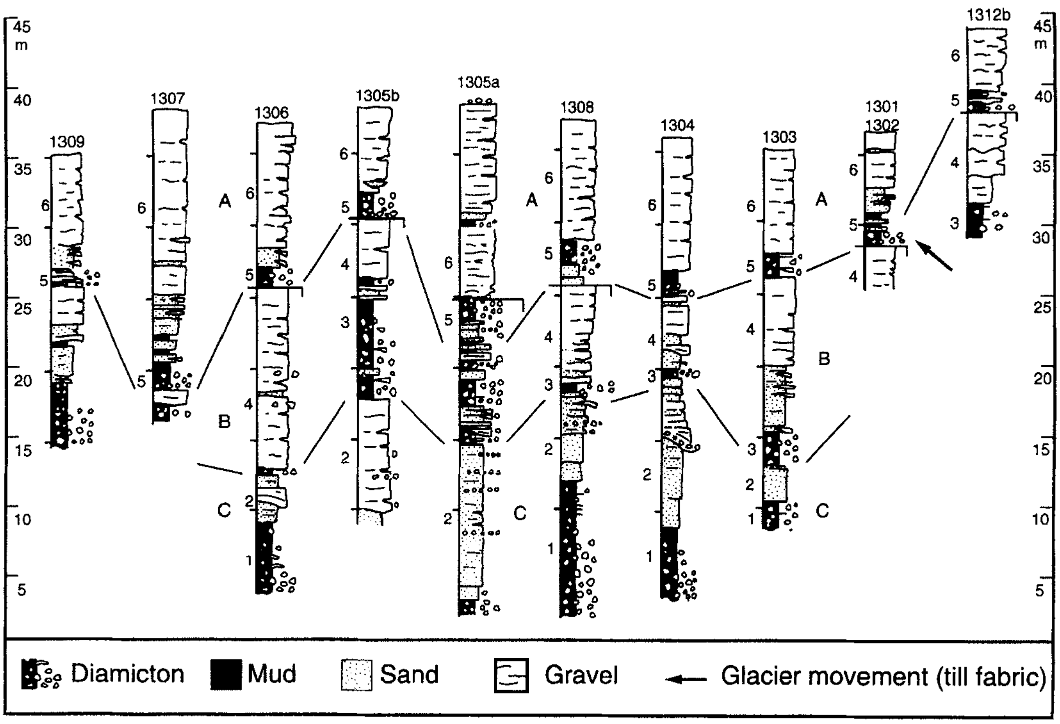

Fig. 3. Lithostratigraphic logs and correlation between sites along the coast of Kongsfjordhallet. Numbers indicate stratigraphic units (1–6), letters refer to sedimentary successions (A, B and C).

and consists of well-sorted sand with pebbles and shell horizons. It overlies the muddy silt of unit 1 with a gradational transition, and is sharply and erosionally limited upwards by coarse, clast-supported gravel or muddy diamicton. It is characterized by an apparent lack of well-defined sedimentary structures (apart from crude sub-horizontal bedding). Another conspicuous feature is the richness and diversity of marine bivalve shells, often in life position. Preliminary results were published by Funder (1993) and a detailed study is under way. Dominant species consist of *C. angusta* (extinct), large *Serripes groenlandicus*, *Astarte montagui* and *Macoma calcarea*, while very thick *M. truncata* and *A. borealis* are locally common. Among the many minor constituents are *Mytilus edulis* and *Semibalanus balanoides*.

The upper part of unit 2 unconformably overlies the shell-bearing sand with an erosional contact. It is composed of sandy gravel with abundant well-rounded boulder-sized clasts at the base, fining upwards into pebbly sand at site 1304. These sediments probably originated from alluvial fans deposited under low sea level conditions, which were later reworked by waves as sea level rose during glacio-isostatic loading.

Amino acid ratios from five samples in unit 2 cluster in two groups, with ratios of 0.138–0.165 and 0.235–0.239 (Table 3).

Succession B

The middle succession comprises units 3–4 and is built up of a number of facies consisting of coarse and occasionally boulder-rich gravel, shell-bearing sand and muddy matrix-supported diamicton (Fig. 3).

Unit 3 comprises metre-sized clasts of shell-bearing sand and large blocks of crystalline rocks embedded in matrix-supported diamicton, and crudely bedded gravel all deposited by a glacier which must have been capable of reworking marine sediments from the fiord. Other parts of unit 3 consist of shelly, interfingering lenses and beds of sand, gravel and reddish muddy matrix-supported diamicton. The diamicton were deposited as subaqueous debris flows and fallout from suspension, and material dropped from ice in a glaciomarine environment under conditions of relatively high sea level. Unit 4 includes stony and sandy clast-supported gravel more than 10 m in thickness, with lenses of sorted coarse sand and fine gravel. It represents deposition under littoral environments at progressively lower relative sea levels.

Faulting and sliding

A phase of faulting and sliding took place prior to, and possibly also during deposition of unit 5. Along the coast, units 1–4 (including the lower part of unit 5 at site 1305a) dip 15–30° northeastward. This was most probably caused by rotational sliding and faulting of unconsolidated sediments along the cliffs, where the muddy facies of unit 1 acted as the surface of décollement. The presence of tilted sedimentary packages suggests the removal of support, by melting of glacier ice in the fiord, and subsequent lowering of sea level, which allowed blocks to slide toward the fiord.

Succession A

The upper facies succession is composed of units 5 and 6 (Fig. 3). Unit 5 is a reddish to grey, matrix-supported diamicton with striated clasts and boulders from the inner fiord zone. It is generally less than 2 m thick. Fabric analyses of long-axis orientations at site 1301 and 1302 show a significant NW–SE orientation, with a preferred dip toward the south-east. The diamicton is interpreted as a till, deposited by a glacier moving north-west toward the fiord mouth. The till contains shell fragments of the robust *M. truncata* and *H. arctica*. At site 1309, the fragments also include the subarctic *Chlamys islandica*. A single battered specimen of *Lacuna vincta* was found on the cliff surface. The latter species is now absent from Svalbard, but is known from the underlying *Cyrtodaria* beds (also containing *C. islandica*) from which, it is suggested, the fauna is reworked. At site 1305a, a lens of sand incorporated into muddy diamicton, contains abundant, but fragmented, shells from a diverse fauna dominated by *M. truncata*, *Macoma calcarea* and *A. borealis*. Minor constituents are *A. montagui*, *H. arctica*, *Serripes groenlandicus*, *Balanus crenatus* and *S. balanoides*. Fragments of *Cyrtodaria angusta* are also common, and the fauna is very similar to that of the underlying unit 2. The possibility of reworking from unit 2 is supported by amino acid ratios of 0.227, which are similar to those of unit 2 (Table 3). Stones with preserved foot-plates of *Balanus crenatus* and crusts of *Lithothamnion* show that the sediments have been reworked as one allochthonous unit.

Upwards, the diamicton changes into a shell-bearing mud containing *M. truncata*, paired shells of *H. arctica* and *Macoma calcarea* together with ice-rafted pebbles. This facies of unit 5 was most probably deposited in a glaciomarine environment. At sites 1305 and 1309, sandy lenses contain a sublittoral arctic fauna dominated by *Macoma calcarea* and *Serripes groenlandicus*. At inland site 1312 (up to 40 m a.s.l.), unit 5 comprises shell-bearing marine mud with a sparse fauna consisting of *H. arctica* in life position and fragments of *M. truncata*, covered by littoral gravels (Fig. 3). Deposits beneath the mud (unit 4) have suffered reverse faulting from the south and south-east caused by an overriding glacier in the fiord.

Unit 6 is less than 10 m thick. It is composed of muddy sand with burrows, overlain by bedded sand, and frequently overlain unconformably by clast-supported stony gravel. All facies contain shell fragments. Along the cliff sections, the gravel is found at maximum altitudes between 35 and 40 m a.s.l., while it reaches up to at least 50 m at inland sites. The sediments are interpreted as sublittoral sand and mud, overlain by littoral gravels and beach deposits, which were laid down regressively during glacio-isostatic rebound. At cliff sites, the very top of unit 6 could have been reworked under the highest relative sea level stand of the Late Weichselian–Holocene.

Age

Successions A, B and C represent at least three emergence cycles showing upward coarsening sedimentary sequences suggesting repeated glaciation, followed by glaciomarine and littoral sedimentation during subsequent isostatic rebound.

Palaeomagnetic measurements taken in 1994 from the upper part of unit 1 at site 1305a show reversed polarity (R. Løvlie and J. Mangerud pers. comm. 1997). In combination with the high amino acid ratios, this suggests an age in the Matuyama chron of 0.74–2.48 My for succession C. This is in agreement with the molluscan fauna, which could indicate an age of ca 1 My or more (Funder 1993). It also confirms the assumption of Miller (1982), based on amino acid stratigraphy, that very old Pleistocene marine sediments are present along the south coast of Kongsfjorden.

From succession B we have no age-suggestive faunas, dates, or amino acid values. The sediments reflect a regional glaciation followed by ice-free conditions which caused a lowering of the relative sea level, possibly to present day levels. Glaciotectonic structures in the upper part of succession B indicate subsequent glaciation.

Succession A is characterized by aIle : Ile values of 0.026–0.036 indicating that the entire marine sequence in this succession belongs to the same depositional episode (Table 3). Radiocarbon dating of shells indicates deposition before 40 Kya (Table 1). One sample of paired shells of *Macoma calcarea* is dated to 22.4 Kya (sample AAR 3090). However, this sample was so undersized that it was not possible to perform the usual acid etching of the outer 25% of the shell to remove possible surface contamination. Although its age is technically finite, careful examination of sample AAR-3809 from the same bed at site 1301 suggests a much older age (J. Heinemeier pers. comm. 1998). With AAR-3809, paired shells of *H. arctica* were dated in two fractions. The first fraction of CO_2, evolved from the shell during acidification (i.e. the outer part of the shell), yielded an apparent finite age of 36 Ky, whereas the second fraction (i.e. the fraction remaining after surface etching) yielded a non-finite age of >45 Ky. This difference indicates that the *in situ* surface contamination of shells, at least from this site, is a serious source of error.

Luminescence dating of succession A indicates deposition between 91 ± 9 Kya and 75 ± 10 Kya (Table 2), and confirms the non-finite radiocarbon ages of *in situ* shells. Since the ages overlap with one standard deviation, and only two dates are available, our data indicate that a major glacier passed through Kongsfjorden during the Early Weichselian, some time between 100 Kya and 65 Kya. It was followed by an ice-free interval with isostatic recovery and deposition of littoral sediments and beach gravel. The latest ice advance, which deposited boulders and formed the lateral moraine covering unit 6, has not been dated directly. However, it is probably considerably younger than unit 6, and could be of Late Weichselian age, as proposed by Lehman & Forman (1992).

Correlation and Weichselian glacial history

Regarding Brøggerhalvøya, Miller et al. (1989) and Forman (1989) advocated that only regional glaciation occurred during the Early Weichselian, and that stratigraphic evidence for later glaciation was missing. However, raised Holocene shorelines and beach deposits indicate younger Weichselian glaciation in the region. Succession A (units 5 and 6) amino acid values correspond to those of "episode B" on nearby Brøggerhalvøya (Fig. 4). These have been given an Early to Middle Weichselian age of 80 and 70 Ky (Miller et al. 1989), which is comparable to those of our succession A. The deposits most probably experienced the same thermal history, and we correlate the tills beneath the marine deposits with each other, indicating that they represent the same regional Early Weichselian glaciation. This age is supported by the presence of supposed Eemian sub-till deposits at Brøggerhalvøya. Glaciomarine and sublittoral deposits overlying till at Poolepynten, Prins Karls Forland, have also been correlated with episode B (Andersson et al. 1999). ^{14}C dates of kelp show non-finite ages (>49 Ky), whereas amino acid ratios in these deposits are considerably lower than at Brøggerhalvøya and Kongsfjordhallet and cannot be distinguished from values found in ^{14}C-dated Late Weichselian–Holocene marine deposits (Fig. 4). Assuming equal duration of Late Weichselian–Holocene submergence below sea level at all localities, this may account for two-thirds of the epimerization found in episode B and succession A sediments. A Late Weichselian glacier, which did not reach Prins Karls Forland, could account for the higher epimerization at Brøggerhalvøya and Kongsfjorden.

The glacial maximum (Fig. 2) is thought to depict the distribution of the Early Weichselian glaciation as the bouldery veneer indicating this maximum is covered by unit 6 gravel from 80 m a.s.l. and below. The lateral moraine cross-cutting Kongsfjordhallet marks the limit of an ice advance during the Late Weichselian glaciation, but whether it represents the maximum extension, or a readvance, cannot be judged from our data. The scattered rocks and boulders found on the raised pre-Late Weichselian beaches inside the moraine may originate from the melting of this glacier. Alternatively, the moraine could correspond to the unit 5 till in the sections. This assumption would be supported by the almost total absence of glacial

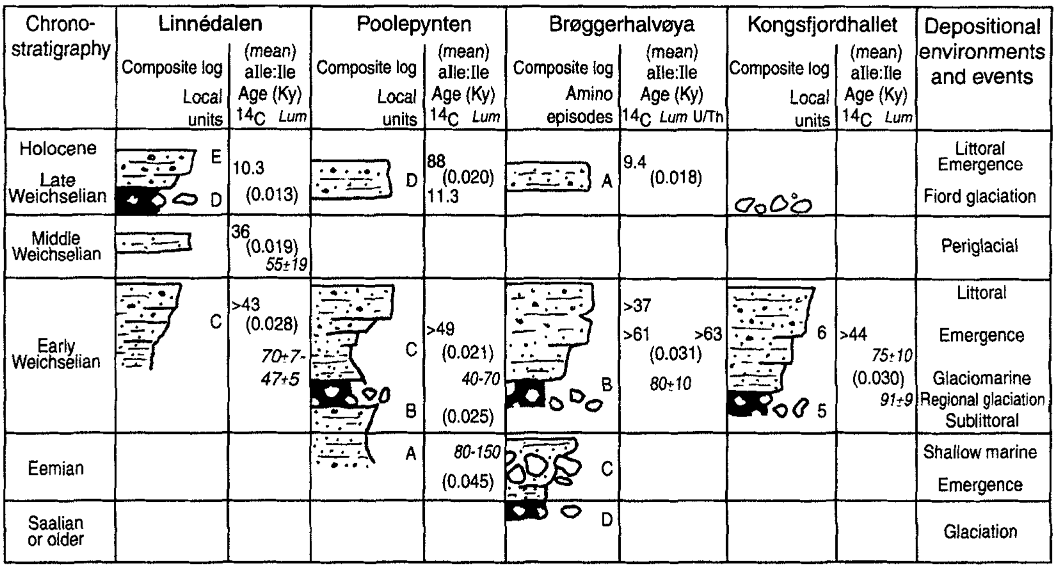

Fig. 4. Composite stratigraphic scheme correlating Late Pleistocene successions exposed in open sections at Kongsfjordhallet, Brøggerhalvøya, Poolepynten and Linnédalen. For legend see Fig. 3. Compiled from Miller et al. (1989), Mangerud et al. (1998), Andersson et al. (1999) and the present study.

features that characterize the surface of the raised beaches (unit 6) in inland areas, and the undisturbed nature of the deposits seen in open sections. However, the freshness of the moraine and the scatter of rocks and boulders inside it suggest otherwise. We therefore favour the possibility that the Kongsfjorden region experienced two fiord-glaciations during the Weichselian, one in the Early Weichselian and one during the Late Weichselian. In the Middle Weichselian the area underwent isostatic recovery, and we suggest that this may have been under periglacial conditions, despite the apparent lack of supporting evidence of sediments and other features.

At Isfjorden, to the south in Linnédalen (Fig. 4), unit C has amino acid values similar to succession A and a corresponding or slightly younger age (Lønne 1997; Mangerud et al. 1998). In Linnédalen, these deposits and younger Middle Weichselian marine strata are overlain by till deposited during the last glacial maximum (unit D) which is covered by marine littoral deposits (unit E). Correlation of sedimentary units from Kongsfjorden, Brøggerhalvøya, Prins Karls Forland and Linnédalen, allows us to suggest that the outer parts of the larger fiords in Spitsbergen were occupied by glaciers during the Late Weichselian, while other parts of the coast were left more or less ice-free.

Discussion

Recent publications describing Pre-Holocene glacigenic and marine sedimentary successions on Svalbard have exposed differences in the interpretation of stratigraphic data from on shore open sections (Elverhøi et al. 1998). This has led to opposing models for the glacial history of the archipelago and various opinions as to the timing and extent of Late Weichselian glaciers. A maximum model based on the combination of core data from the shelf and deep sea drilling reveals a Late Weichselian Barents Sea ice cap reaching the shelf break, not only through the fiord mouths, but also over a wide and straight front off the coast of Spitsbergen (Landvik et al. 1998). Contrary to this, Boulton et al. (1982) and Larsen et al. (1991) confine the youngest ice advance to glaciers within the fiords. Evidence from land shows restricted occurrences of Late Weichselian till (Forman 1989; Miller et al. 1989; this study), a conclusion also reached by Andersson et al. (1999). The latter authors advocate that the lack of glacial features and very low amino acid epimerization of Early Weichselian deposits signal regionally ice-free conditions during the Late Weichselian in the region around Forlandsundet. Submergence and subsequent isostatic rebound have raised the Late Weichselian–Holocene marine deposits and terraces in the whole region to heights between 40 and 30 m a.s.l. Using Lehman & Forman's (1992) data, the westward decline in the height of raised Late Weichselian–Holocene shorelines along Kongsfjordhallet suggest that isostatic equilibrium along Kongsfjordrenna is reached at the shelf break. This suggests the presence of a substantial Late Weichselian ice sheet in the region. Whether the young shorelines were formed as a result of depression beneath the ice, or in the zone in front of it, or both, is not clear.

The crucial point when discussing the Late Weichselian distribution of glaciers is the apparent lack of traces of onshore evidence such as till or glaciotectonic deformation in open sections, in comparison with offshore evidence which suggests extensive glaciation in fiord mouths and on the shelf (Mangerud et al. 1998). Landvik et al. (1998) argue that glaciers may have overridden the terrain without leaving traces of erosion or deposition of till, while Mangerud et al. (1998) suggest that there was ice cover over Brøggerhalvøya for a considerable time (≥10 Ky) based on differences in amino acid ratios between the Holocene episode A and the Early Weichselian episode B. Svendsen et al. (1996) concluded that a Late Weichselian glacier reached the outer shelf through the Isfjorden trough, to the south of Kongsfjorden. Cores from the shelf containing till overlain by shell-bearing glaciomarine diamicton indicate glacial cover and subsequent deglaciation, around 14.8 Kya on the outer shelf and 12.3 Kya at the fiord mouth. Even though a similar glacier could have reached the shelf break through the mouth of Kongsfjorden, leaving large quantities of glacigenic diamicton on the trough bottom, there is no evidence for this on either side of the fiord, at Kongsfjordhallet (this study), or on Kvadehuksletta, the north-western tip of Brøggerhalvøya (Forman & Miller 1984; Lehman & Forman 1992).

Large ice tongues flowing through the fiords are not incompatible with restricted glaciation on the adjacent land areas. Although the existence of an extensive ice lobe outside Kongsfjorden is un-

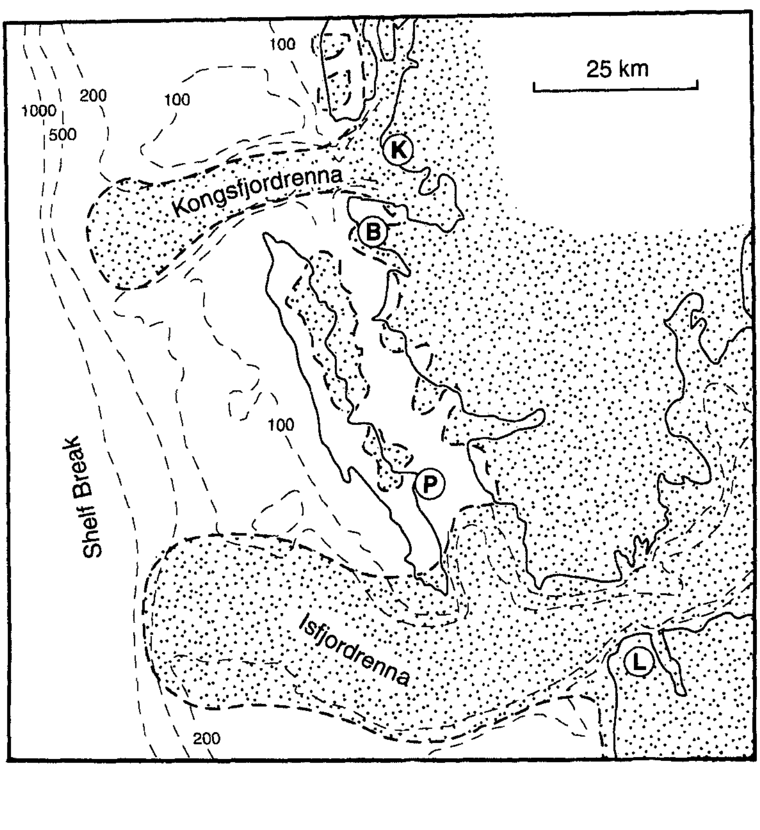

Fig. 5. Possible Late Weichselian ice configuration in central western Spitsbergen. Data compiled from Forman (1989), Miller et al. (1989), Lehman & Forman 1992, Svendsen et al. 1996, Mangerud et al. (1998), Andersson et al. (in press) and the present study. K = Kongsfjorden, B = Brøggerhalvøya, P = Poolepynten, L = Linnévannet.

proven, it is quite plausible, so we have depicted a putative glacier configuration based on data collected from open sections on Spitsbergen and marine core data from the shelf (Fig. 5). This minimum model allows for glaciation on the shelf break outside Isfjordrenna and Kongsfjordrenna. In both areas, thin or absent "onshore" tills are accompanied by large accumulations of diamicton in the fiord and troughs on the shelf. This suggests most drainage from large uplands through the major fiords, with little drainage through minor fiords between Isfjorden and Kongsfjorden due to restricted uplands. Local glaciation on Prins Karls Forland is proposed following the suggestion of Andersson et al. (1999). Data from the westernmost part of Spitsbergen, east of Prins Karls Forland, indicate that glaciation was restricted to filling valleys and smaller fiord troughs (Forman 1989).

Summing up the evidence for the extent of Late Weichselian glaciation in the Kongsfjorden region, we have shown that traces of such a glaciation are sparse on the raised Early Weichselian beaches and lacking in coastal sections. Nevertheless, our data indicate that at least the inner part of Kongsfjorden was subjected to glaciation, but are insufficient to determine whether the lateral moraine on Kongsfjordhallet depicts the maximum extent of glaciation. We have combined our evidence with data from other authors into a minimum ice extent even though the previously published results have been interpreted in favour of a larger expansion of ice. The latter interpretation is supported by evidence for strong ice-rafting west of the shelf, with a debris supply from Svalbard during isotope stage 2 (Mangerud et al. 1998). Further evidence, based on the nature of isostatic rebound, has suggested larger and more extensive glaciation along the west coast of Spitsbergen (Landvik et al. 1998).

Conclusions

(1) The coastal cliffs at Kongsfjordhallet show evidence for at least four phases of glaciation dating back to the Early Pleistocene (≥1 Mya). The oldest glacial-interglacial strata have been dated by very high amino acid ratios of shells, and a characteristic fauna which includes the extinct *Cyrtodaria angusta*.

(2) The third glaciation apparently took place in the Early Weichselian (100–65 Kya). Till and glaciomarine mud, overlain by littoral sand and gravel all contain shells with amino acid aIle:Ile ratios of 0.026–0.036. These values are similar to other Early Weichselian amino acid ratios from nearby areas which experienced a Late Weichselian glacier cover.

(3) A comparison with other stratigraphic studies from Brøggerhalvøya and Prins Karls Forland suggests that a glacier tongue filled Kongsfjorden during the Late Weichselian and deposited lateral moraines at either side of the fiord. Whether this glaciation reached the shelf break via the Kongsfjorden trough can only be determined by studies in the trough and on the shelf outside the fiord.

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