Late Quaternary glacial and environmental history of Kongsøya, Svalbard

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On western Kongsøya, Svalbard, three coarsening-upwards sequences of marine to littoral sediments, separated by tills, are recognised in sections at ca 50–92 m above present sea level. These sequences show major glaciations in the northern Barents Sea, resulting in substantial glacioisostatic downpressing of Kongsøya. Till fabrics indicate ice movements controlled by the local topography, while glaciotectonic deformations suggest that ice moved from an ice divide northeast of Kongsøya, independent of the local topography. The stratigraphical evidences show two pre-Holocene ice-free periods, when the climate was similar to or slightly warmer than at present. The age of these periods is not clear. It is suggested that the elder ice free interval is older than isotope stage 5c. The younger ice free interval could be of Eemian or Early Weichselian age. The uppermost succession of sublittoral–littoral sediments is of early Holocene age. It relates to the high (≥100 m) postglacial marine limit, dated to approximately 10,000 BP.

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Introduction

Kongsøya (191 km^2) is the largest of a number of islands comprising Kong Karls Land in the easternmost part of the Svalbard archipelago (Fig. 1A). The island is mainly made up of Jurassic and Early Cretaceous strata, and the low (≤300 m) mountains on eastern and western Kongsøya (Fig. 1B) are erosional remnants of a Cretaceous plateau, capped by basaltic lavas (Smith et al. 1976). Quaternary sediments mainly occur below 100 m a.s.l. (Salvigsen 1981). The purpose of the present investigation has been to locate and study pre-Holocene glacial and marine sediments on the western part of the island. Preliminary results were reported by Ingólfsson et al. (1992), Rögnvaldsson (1992) and Ingólfsson & Lirio (1993).

Previous studies

Geological observations were begun when Pike (1898) and Nathorst (1901) described raised marine beaches on the island and reported finds of driftwood at levels up to ca 40 m a.s.l. The idea of a glacier occupying the Barents Sea basin was first suggested by De Geer (1900). Nathorst (1901), who observed striated boulders on the plateau between Retziusfjellet and Tordenskjoldberget (Fig. 1C), suggested that a Nordaustlandet glacier could have covered the Barents Shelf as far east as Franz Josef Land. Strömberg (1972) found glacial sculptures almost totally lacking on western Kongsøya. He discovered glacial striae at two localities, at high levels above cirques on Sjögrenfjellet and Tordenskjoldberget (Fig. 1C). Strömberg mapped the directions of glacial striae as indicating ice movements from SSW–SSE and concluded that most probably the striae were formed by former local glaciers of modest extent. Schytt et al. (1968) and Hoppe (1972) used the Kongsøya striae when reconstructing an extensive Weichselian Barents Ice Sheet, with an ice divide somewhere to the south-southeast of Kongsøya.

Knape (1971) reported driftwood from raised beaches up to 36 m a.s.l. and pre-Holocene marine shells from altitudes up to 89 m. The driftwood samples were ^{14}C dated and used for constructing an uplift curve (Schytt et al. 1968; Hoppe

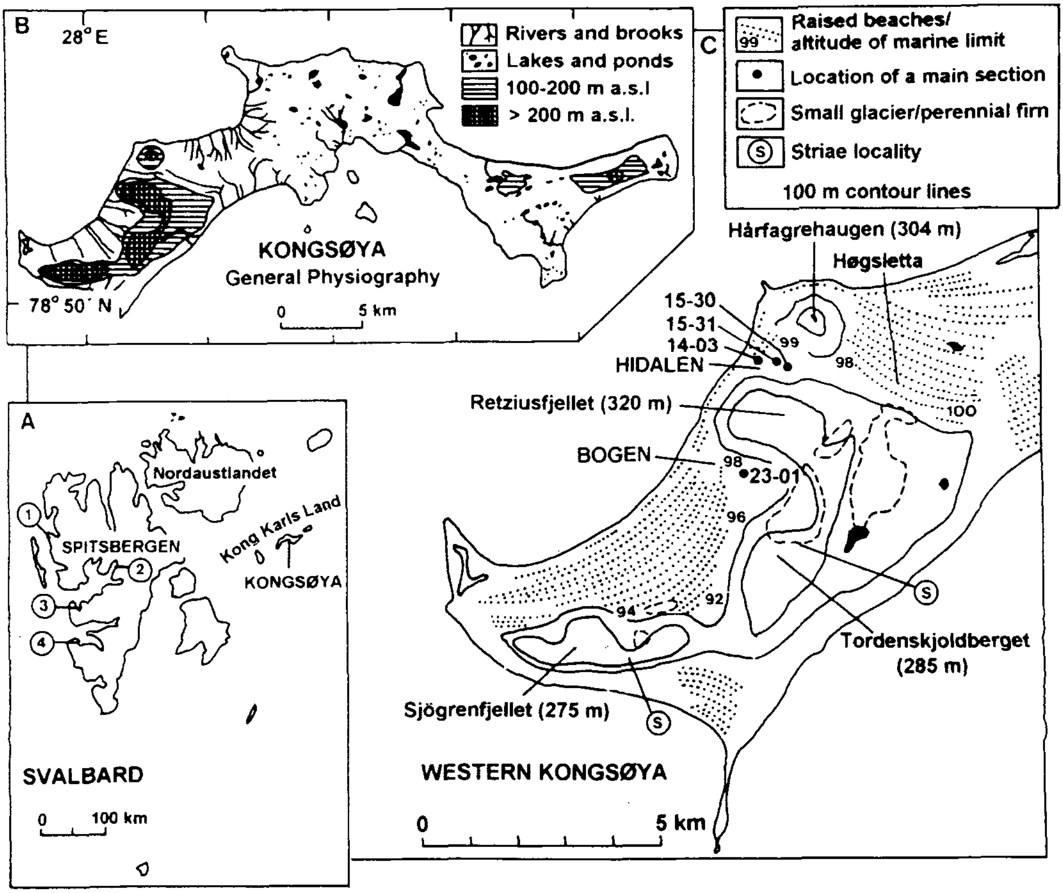

Fig. 1. A: Svalbard location map. Localities mentioned in the text: (1) Brøggerhalvøya; (2) Kapp Ekholm; (3) Linnédalen; (4) Skilvika/Bellsund. B: The general physiography of Kongsøya. C: Western Kongsøya. The location of raised beaches is shown as an approximation of areas where beach ridges occur rather than location of individual ridges.

1972), indicating that beaches below 36 m were younger than 7000 BP Boulton (1979) suggested that there were two sets of beaches on Kongsøya, a lower Holocene set, and a higher >40,000 BP set extending to the marine limit at 100 m. He suggested that Kong Karls Land had not been glaciated except by small glaciers during the Late Weichselian. Salvigsen (1981) published new radiocarbon dates from Kong Karls Land and presented an emergence curve for eastern Kongsøya. He showed that a shoreline displacement of more than 100 m had taken place during the Holocene, and his emergence curve is the strongest evidence presented for a Late Weichselian Barents Ice Sheet over Kongsøya. Marine geological data from the Barents Shelf (Elverhøi & Solheim 1983; Vorren et al. 1988; Elverhøi et al. 1990; Solheim et al. 1990; Polyak & Solheim 1994) show glaciations several times during the Pleistocene. Geomorphic features on the sea floor in the northern Barents Sea, some 150 km south of Kongsøya, are interpreted as fluted surfaces and *De Geer* moraines, thought to show that the Barents Shelf had been covered by a sliding temperate glacier, at least in the observation area (Solheim et al. 1990; Elverhøi et al. 1990).

Although the existence of a large Late Weichselian ice sheet covering the northern and central Barents Sea area is now generally accepted, its extension, thickness and duration are still discussed and debated (e.g. Mangerud et al. 1992; Elverhøi et al. 1993; Forman et al. 1995; Lambeck 1995; Siegert & Dowdeswell 1995). Forman (1990) described the spatial variation in emergence records from Svalbard, and concluded that the uplift pattern in Nordaustlandet, the islands in the Barents Sea and on central and western Spitsbergen, reflect glacial loading of the Barents Ice Sheet during the Late Weichselian. This conclusion strongly indicates that the same ice dome or separated ice domes in dynamic equilibrium have caused the isostatic depression observed. Thus, almost synchronous interglacial/interstadial events in the whole Svalbard area could be expected, provided that this pattern of emergence is valid for earlier deglaciations. Mangerud et al. (1992) concluded that prior to the Late Weichselian glacial build-up, the Barents Ice Sheet was small or non-existent, and that glaciers on and around Svalbard were not much larger than today when the advance to the last glacial maximum started sometime after 25,000 BP.

Methods

The stratigraphic investigations were concentrated at two main localities, the col of *Hidalen* and in the *Bogen* cirque (Fig. 1C). The sites were spotted by shell fragments in scree, and then cleared by digging. Elevations of sections and of raised beaches were surveyed by repeated measurements by AIR-HB-1A electronic altimeter and some were levelled by theodolite. Samples were collected for analysing grain-size, plant and insect macrofossil content, foraminifera and mollusc species, Thermoluminiscence (TL) and ^{14}C determinations and amino acid diagenesis. The ^{14}C age determinations were performed at Lund University's Radiocarbon Laboratory, and the TL-dating was carried out at the Nordic Laboratory for Luminiscence Dating in Risø, Denmark, using sand-sized potassium feldspars. Amino acid diagenesis was measured in the protein matrix of fossil molluscs at the Bergen Amino Acid Laboratory, following the procedure described by Miller et al. (1983).

Glacial morphology

Glacial sculpturing and erratics

The landscape of Kongsøya (Fig. 1B) indicates that basal sliding and glacial erosion occurred when the island was completely covered with ice. On western Kongsøya the glacial erosion is concentrated in shallow cols, valleys and cirques, leaving the plateaux relatively unmodified. The plateaux of Hårfagrehaugen, Retziusfjellet, Tordenskjoldberget and Sjögrenfjellet, as well as basaltic bedrock outcrops at lower altitudes, have been searched for glacial sculpturing, striae and erratics. The basalt plateaux are deeply weathered, and no clear glacial sculpturing is evident. Usually the surface is covered with regolith and crude soils. In a few localities bedrock outcrops show stoss-and-lee topography, but none were found to carry glacial striae. The only erratics found on the plateaux were remains of petrified Cretaceous tree trunks, probably eroded by the glacier from the local sedimentary bedrock and only transported a short distance.

Raised beaches and the marine limit

The marine limit on western Kongsøya is at 94–98 m a.s.l. (Fig. 1C), which is in good agreement with Knape's (1971) results. The highest beach ridges on Høgsletta were levelled to ca 100 m a.s.l., which is about 10 m lower than Salvigsen's (1981) marine limit on eastern Kongsøya. Salvigsen & Nydal (1981) found that isostatic uplift has been greater in the eastern than in the western part of Kongsøya during the last 7000 ^{14}C years, and they took this as an indication of a Late Weichselian ice centre east of Kongsøya. The material in raised beach ridges on western Kongsøya is primarily of local basaltic provenance, but crystalline rocks, granites and gneisses, are also found. These have probably been carried to the island by sea ice. The beach ridges at altitudes between ca 40 m and 60–70 m a.s.l. on Høgsletta, formed between ca 9000 BP and 7000 BP (Salvigsen 1981), are composed of well-rounded cobbles and boulders, with little gravel or sand, while the finer grain sizes are more characteristic for beach ridges above and below. This could indicate a higher energy in the coastal environment and less annual sea-ice cover during the formation of intermediate altitude beach ridges. This is supported by the lack of driftwood on beaches above 35–40 m.

Glacial stratigraphy of Hidalen

Fluvial erosion in Hidalen (Fig. 1C) has exposed Late Quaternary sediments resting on Triassic and Lower Jurassic bedrock. Knape (1971)

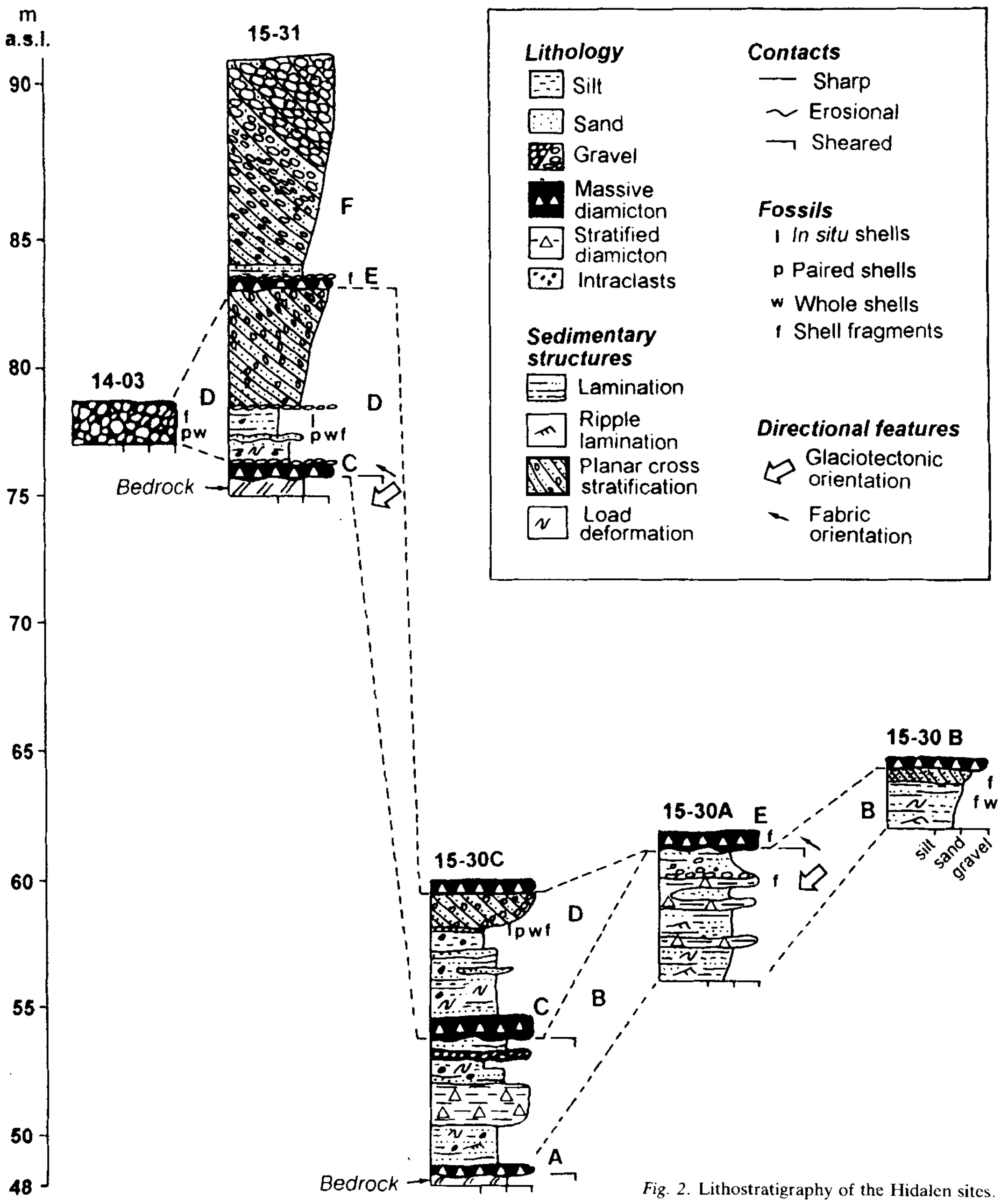

Fig. 2. Lithostratigraphy of the Hidalen sites.

reported shell samples of >38,000 and >40,000 BP from 89 and 67 m a.s.l. from scree on the northern side of Hidalen. We found shells, both whole and fragmented, in scree, at a number of localities. Four sites (numbered 15-30A, 15-30B, 15-30C and 15-31) were investigated in detail, and one additional site (14-03) was briefly surveyed and sampled. The lithostratigraphy of each site and correlations between sites are shown on Fig. 2. A cross section of the Hidalen stratigraphy, with location of sites studied, and correlation between sites is shown in Fig. 3.

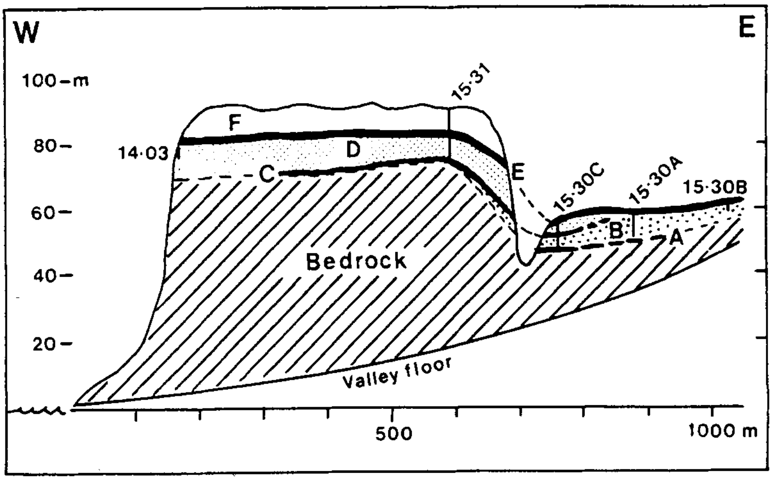

Fig. 3. A cross section of the Hidalen stratigraphy, with location of sites studied.

Unit A

Unit A is the lowermost stratigraphical unit in Hidalen. It is only exposed in section 15-30C. It is a 0.4 m thick massive, compact, silty-sandy diamicton. Striated clasts were recognised in the diamicton. Its lower contact to the stratified, unlithified Jurassic sand is sharp but deformed. Lenses of the sand have been incorporated into the diamicton and smeared out, and wedges of diamicton have been thrust into the substratum. The deforming force came from an easterly direction. The diamicton is interpreted to be a till.

Unit B

Unit B consists of a number of lithofacies, recognised in sections 15-30A, 15-30B and 15-30C, which are interpreted to have been deposited in a marine environment. In the lower part of the unit, laminated silts and sands and massive silts, with occasional outsized clasts, dominate. Contacts between lithofacies are usually conformable, sometimes loaded. The thickness of the lowermost silty-sandy facies of the unit is 1–3 m. Mollusc shells, fragments and some whole, were sampled from a sandy-gravelly lag-horizon in section 15-30B. This part of the unit is interpreted as a stratified glaciomarine deposit, with dropstones.

In the middle part of the unit, stratified diamictons and massive or laminated sands dominate. The diamictons carry numerous pebbles and cobbles, but a fabric studies did not reveal any preferred orientation of clasts (Fig. 4A). Occasional thin intrabeds of gravels occur, as well as pebble and cobble clasts. Ruptured and bent substratum below a clast, indicating drop, was noted at two sites. Shell fragments were sampled from one of the diamictons, but could not be identified to species. This part of the unit is interpreted to be a sublittoral glaciomarine sediment, influenced by meltwater input and slumping. Its thickness in the sections is 1–2 m.

In the upper part of the unit, massive diamicton, gravel and sand with many pebbles and cobbles, occur together with laminated sand and silt. The massive diamicton facies has a thickness of 0.7 m, and consists of a silty-sandy matrix carrying rounded to sub-angular pebbles. It has a sharp to erosional lower contact to the laminated facies below. The massive gravel and sand facies is about 0.25 m thick. It grades upwards from granules and coarse sand to coarse and medium sand. Its lower contact is erosional. The massive bed grades into interstratified, laminated sand and silt, with occasional granules and pebbles. Together, the lithofacies indicate decelerating flow during deposition from a meltwater current entering the sublittoral environment. The uppermost lithofacies in unit B, found only in section 15-30B, is a thin bed (≤20 cm) of well-sorted, planar cross-bedded sand. It has an erosional lower contact and carries shell fragments. It is interpreted as a littoral deposit.

Unit B in section 15-30A is heavily glaciotectonised, and a tight, recumbent syncline has developed (Fig. 5) below a thrust plane. The fold

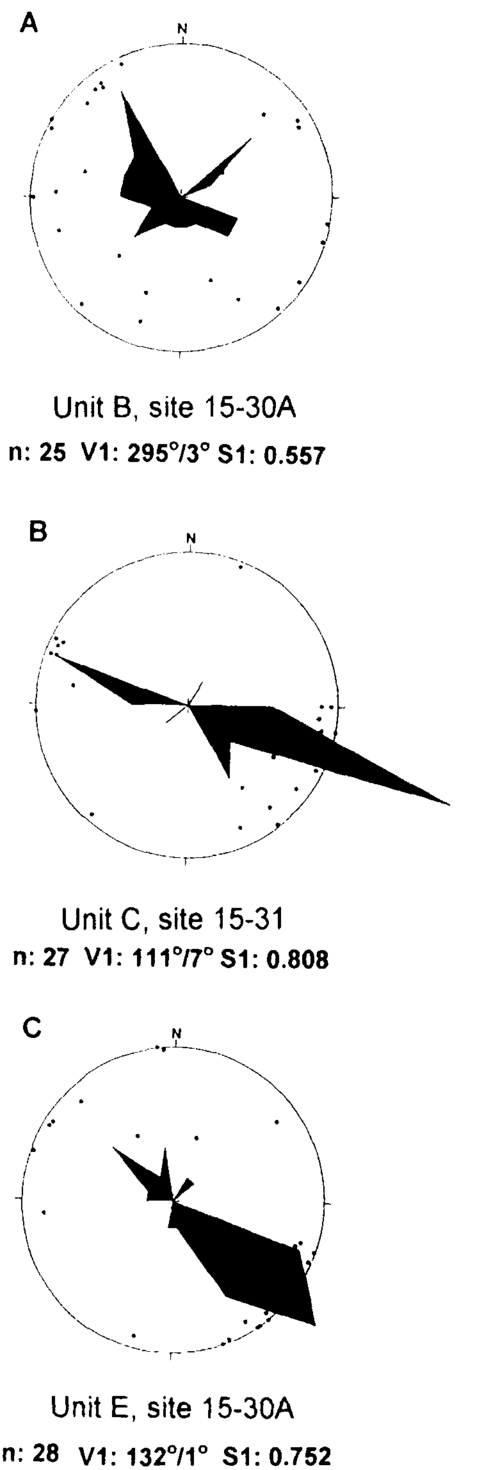

Fig. 4. Fabric analyses from western Kongsøya. A: fabric from a diamicton facies in unit B, site 15-30A; B: fabric from unit C at site 15-31; C: fabric from unit E at site 15-30A.

axis trend NW–SE, and the fold reflects over-folding towards the southwest, with ice movements from the northeast.

Molluscs and foraminifera. – The mollusc fauna of unit B is poor, with only three species recognised (Table 1), and it can only be used to confirm a marine environment. All shells and fragments are of large, robust individuals. Fifteen samples from section 15-30A were prepared for foraminifera content, but none were found. Six samples prepared from section 15-30C, yielded three specimens of benthic and one specimen of planktonic foraminifera (Table 2). The specimens were worn and fragmented, and could not be identified to species. The almost total absence of foraminifera as well as juvenile and smaller molluscs in the sediments could be the result of dissolution.

Plant macrofossils. – One sample from unit B, section 15-30A, was analysed for plant macrofossils and was found to contain one fruit of pondweed (*Pontamogeton*), together with a number of unspecified leaves, as well as bryophytes (Table 3). Wetland and moist heath bryophytes are well represented in this sample, comprising *Aulacomnium turgidum*, *Drepanocladus* (s. str.) sp., *Philonotis fontana/tomentalla*, *Pohlia wahlenbergii* and *Tayloria* sp. *Drepanocladus* species usually occur in nutrient-enriched environments. *Philonotis* species and *P. wahlenbergii* grow in moving water. *Brachythecium reflexum*, *Ceratodon purpureus*, *Hylocomium* cf. *splendens* and *Pogonatum* occur in mineral-poor places. *Brachythecium reflexum* and *Hylocomium* indicate stable ground, whereas most of the other taxa indicate more unstable conditions, with a sparse cover of vascular plants. *Sanionia orthothecioides* is today a coastal plant in northern Europe and Svalbard, reaching southwards to southern Finland, Sweden, Norway and Scotland (Hedenäs 1989; Long 1992, 1993). It is typically found in shore meadows and rock crevices.

The species recorded from unit B still occur on Svalbard. The few remains of vascular plants and the moss record show a poor vegetation of phanerogams during the period when unit B was deposited. The wetland bryophytes and those of drier habitats indicate that a large part of the environment was mineral-poor, in contrast with the mineral-rich conditions usually found in periglacial environments or in areas which have recently been deglaciated (Miller 1987; Hedenäs

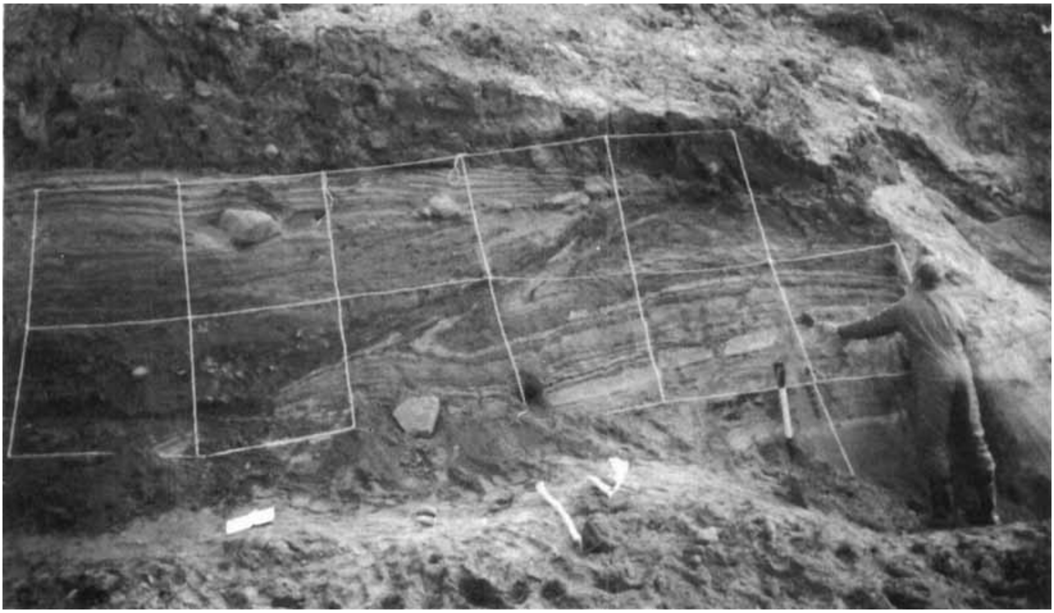

Fig. 5. Site 15-30A in Hidalen. The section is orientated E (left) to W (right).

1992, 1994). Thus, the bryophytes suggest an environment where the minerals have been leached out, which could suggest that the ground had been ice free for a considerable period of time.

Unit C

Unit C is a massive, silty-sandy diamicton, with abundant rounded to angular pebbles and cobbles and some shell fragments, recognised in sections 15-30C and 15-31. Its thickness is 0.6–1 m in the sections. Striated clasts occur, and a fabric study at site 15-31 (Fig. 4B) showed preferred orientation of clasts with dip towards ESE. The lower contact of the unit is erosive and sheared, and unit B below is at places sheared and folded below the contact. In a small, overturned anticline at the contact between units B and C in section 15-31 the axial plane dipped towards northeast and the fold axis trended NW–SE, indicating that the deforming push came from the northeast. Unit C

Table 1. Subfossil molluscs from western Kongsøya. Identified by S. Funder.

Site Unit	15-30B B	15-30C D	15-31 D	14-03 D	23-01
BIVALVIA					
Chlamys islandica		c	1	f	
Serripes groenlandicus					c
Macoma calcarea	1	f	s	2	f
Hiatella arctica	f	f	f	f	f
Mya truncata	f	c	f	s	f
ECHINODERMATA					
Strongylocentrotus droebachensis		1			s
CIRRIPEDIA					
Balanus balanus			1	2	

f: frequent (>20 valves/fragments); c: common (11–20); s: scarce (4–10); 1–3: rare (number of valves/fragments).

Table 2. Foraminiferal species recorded in samples from units B and D in Hidalen. The upper number of each species refers to the actual number of counted specimens in the sample while the lower number refers to number of individuals when related to 100 g of dry sediment. Identified by H. Bergsten.

Sample number	95-427	95-407	95-409	95-422	95-424	95-430	95-434	95-437
Site	15-30C	15-30C	15-30C	15-30C	15-30C	15-30C	15-31	15-31
Unit	B	B	B	D	D	D	D	D
Species								
Astrononion gallowayi							4	154
Loeblich & Tappan							4.8	171.6
Buccella hannai arctica				22				2
Voloshinova				22.9				2.2
Cassidulina reniforme								21
Norvang								23.4
Elphidium asklundi								2
Brotzen								2.2
Elphidium excavatum				1			1	
(Terquem)				1			1.2	
Haynesina orbiculare								2
(Brady)								2.2
Islandiella helenae				164			34	86
Feyling-Hanssen & Buzas				170.7			40.5	95.9
Reophax sp.						1		
						1.1		
Spiroplectammina biformis								1
(Parker & Jones)								1.1
Verneulina arctica				21	54	3	5	10
Höglund				21.9	58.2	3	6	11.1
Varia: calcareous species		1	2	8	1		6	5
		1.1	1.9	8.3	1.1		7.1	5.6
Varia; agglutinated species				1	1	1	4	1
				1	1.1	1	4.7	1.1
Planktonic foraminifera	1							
No of benthic foraminifera in the sample	–	1	2	217	56	5	54	284
No of specimens related to 100 g sediment (dried)	0.7	1	2	226	60.3	5	64.3	316.5

is interpreted to be a lodgement till, deposited by a glacier flowing from the east through the Hidalen col. The till fabric indicates that the deforming push came from the southeast, while the sub-till fold geometry shows an ice movement from the northeast. We suggest that the deformation took place under a thick ice flowing across Kongsøya from the northeast and that the till fabric indicates ice push through the Hidalen col and relates to a later deposition phase, with thinner ice and topographically controlled iceflow.

Unit D

Unit D is a facies association of laminated silts and sands, overlain by cross-stratified sands and gravels and cobble-gravels, reflecting a shallowing-upwards, marine to littoral sediments. The thickness of the unit is 5–8 m in sections 15-30C and 15-31, respectively. The lowermost 2–3 m are a succession of laminated sand and laminated to massive silt. Contacts between lithofacies are usually conformable, sharp or graded. Thin intrabeds of well sorted sand and lags of granules and pebble gravels, with erosive lower contact, occur scattered in the unit. The laminates sand and silt facies carry mollusc shells (Table 1), paired as well as single and fragments, and single shells and fragments also occur in the sandy intrabeds. This part of the unit is interpreted to be a sublittoral sediment. Lag horizons and intrabeds of sand were caused by current activity and small scale slumping.

The sublittoral sediments are discordantly overlain by a 1.5–4 m thick deposit of cross-stratified gravels and sands. The gravels are alternatively clast- and matrix-supported, and pebbles are usually well rounded. The unit grades upwards from pebble gravels at the base to cobble gravels at the top. Shell fragments occur throughout the unit. A 1.5 m high section was excavated in the mouth of the Hidalen valley, at 72 m a.s.l. (section 14-03), consisting mainly of angular to well-rounded clast-contact cobbles and boulders, with a silty-sandy matrix. The matrix contains abundant fossil molluscs with many large, paired individuals of *Chlamys islandica* (Table 1). The sediments are similar to those in the present day beach ridges, where paired valves of *C. islandica* are also frequent. It is concluded that this part of unit D was deposited as a beach foreset, under similar conditions as the present, with seasonal open water and substantial wave action.

Molluscs and foraminifera. – The mollusc fauna of unit D is poor, with five bivalve and one echinoderm species and fragments of *Balanus balanus* (Table 1). As with the fauna from the underlying unit B, the shells are biased towards large and thick individuals and the species composition does not define any clear mollusc community. The presence of *Chlamys islandica* does, however, show that the marine environment was influenced by Atlantic water. *C. islandica* is present around Kongsøya today, but does not enter high-arctic waters.

Foraminiferal specimens were found in five samples from unit D (Table 2). Both calcareous and agglutinated species were noted. Many specimens were fragmented or showed surface wear which could be the result of dissolution and diagenetic effects. The most abundant species are *Islandiella helenae*, *Verneuilina arctica*, *Astronion gallowayi*, *Buccella hannai arctica* and *Cassidulina reniforme*. When comparing the foraminiferal faunas of unit D with those previously reported from Svalbard (Feyling-Hansen & Ulleberg 1984; Miller et al. 1989; Nagy 1984; Lycke et al. 1992), the unit D sediments contain a comparatively poor fauna. However, the species in unit D occur at many other Svalbard sites, and are also found in the recent fauna (Hansen & Knudsen 1992). The faunas of unit D indicate seasonally open water, with marine conditions resembling those of today.

Plant and insect macrofossils. – Four samples from unit D in Hidalen were analysed for plant and insect macrofossil content (Table 3). Remains of bryophytes dominate the record, just as in unit B. The samples from unit D were slightly richer in remains of vascular plants than unit B, and insect remains were also found. Among the vascular plants, *Potamogeton filiformis* is an aquatic growing in eutrophic but clear shallow water on sandy or gravely bottoms (Mossberg et al. 1992). It is widespread with an almost circumpolar distribution, but it is not found growing on Svalbard today (Hultén & Fries 1986; Rønning 1979). *Selaginella selaginoides* grows on wet calcareous ground such as spring mires and along the borders of brooks and lakes. It is circumpolar with a northern distribution limit along the Arctic coast of Scandinavia, Russia, Siberia, and Alaska, where it is found up to the low arctic zone. It is not found today on Svalbard (Hultén & Fries 1986; Mossberg et al. 1992; Rønning 1979).

Among the four taxa of insect, rove beetles (Staphylinidae) of the genus *Stenus* are usually found along the margins of water or other wet places (Harde 1984). The larvae of caddis flies (Trichoptera) are mainly found in fast moving streams, rivers and ponds. The larvae of midges (Chironomidae, Diptera) are also mainly aquatic, and many of them live in the muddy bottoms of lakes (Fitter & Manuel 1986). The diversity of the present insect fauna on Svalbard is very low, and neither beetles nor caddis flies have been recorded on Kongsøya (Danielsson pers. commun. 1994). Two of the vascular plants as well as two of the identified insect taxa have a more southerly distribution today and are not found on Svalbard, which suggests that the climate was slightly warmer than today when unit D sediments were deposited.

The bryophytes were badly preserved and few fragments could be identified to species. Among those, wetland plants were very sparse, comprising *Aulacomnium turgidum*, *Plagiomnium ellipticum*, *Pseudocalliergon brevifolium*, *Scorpidium cossoni* and *Warnstorfia sarmentosa* (Table 3). *Pseudocalliergon brevifolium* and *S. cossoni* are found mainly in mineral-rich to calcareous wetland environments, *A. turgidum* grows mainly in intermediately mineral-rich or sometimes rather mineral-rich places. *Warnstorfia sarmentosa* is a species of intermediately mineral-rich habitats, in springs or in spring-influenced environments, whereas *P. ellipticum* is found in different wet and not too mineral-poor environments. Most of the identified taxa indicate unstable, open habitats with a sparse cover of

Table 3. Vascular plants, insects and Bryphytes found in samples from Hidalen and Bogen, western Kongsøya. Vascular plants and insects identified by G. Lemdahl. Bryophytes identified by L. Hedenäs. The nomenclature of Mossberg et al. (1992) is used for the vascular plants, whereas the nomenclature for the bryophytes generally follows Söderström et al. (1992).

Site	15-30A Hidalen	15-30C Hidalen	15-31 Hidalen	23-01 Bogen
Unit	B	D	D	
TAXON				
Salix sp.			+TW,W	
Selaginella selaginoides		11MS	5MS	3MS
Potamogeton filiformis		1F		
Carex sp.			1F	
Cerastium sp.			1S	
Papaver sp.		1S		
Potamogeton sp.	1F			
unspecified leaves	+			++
unspecified wood				+
Stenus sp.		1Mts		
Staphylinidae indet.			1As	
Trichoptera indet.		+Lc	+Lc	
Amblystegiaceae sp.	3S	1S + 2L	2L	8S
Aulacomnium palustre				2S
Aulacomnium turgidum	1S + 1L	1S + 2L		3L
Bartramia ithyphylla		1S		
Brachythecium reflexum	1S			
Brachythecium trachypodium				1L
Bryoerythrophyllum recurvirostrum		1S		
Bryum cf. *pseudotriquetrum*			1S	>8S
Bryum sp.	3S	8S	4S + 1L	5S + 2L
Ceratodon purpureus	1S	1S	1S	
Dicranella sp.				1S
Dicranum cf. *majus*	1S + 2L			
Dicranum cf. *scoparium*				2S + 3L
Dicranaceae sp.			1S + 1L	
Distichium sp.		8S	1S	1S
Ditrichum flexicaule		12S		
Drepanocladus s. str.	1S			
cf. *Grimmia* sp.		1S		
Hylocomium splendens (incl. *H. alaskanum*)				2S
Hylocomium cf. *splendens* (incl. *H. alaskanum*)	1S			
Hypnum bambergeri		1S + 1B		
Hypnum revolutum		2S/B		
cf. *Lophozia hyperborea/floerkei*				1S
Lophozia sp.				1S
Oncophorus virens				1S
Philonotis fontana/tomentella	1S			
Plagiomnium ellipticum			1L	
Pogonatum dentatum		1L		1L
Pogonatum dentatum/urnigerum	2L			
Pogonatum/Polytrichum sp.	2S			20S/3L*
Pohlia wahlenbergii	1S			
Pohlia cf. *wahlenbergii*		1S		
Pohlia sp.	1S	1S + 2L	2S	3S
Polytrichaceae sp.		7S + 5L	1S + 1L	
Polytrichastrum alpinum		1S + 1L	2L	3S
Polytrichastrum sexangulare				1S
Polytrichastrum/Polytrichum sp.		4L	1S	
Polytrichum commune (incl. *P. jensenii*)				1S
Polytrychum hyperboreum			1S + 1L	
Polytrichum juniperinum/strictum		3L	1L	
Polytrichum sp.		1S + 1L		3S
Pottiaceae sp.	2S			
Pseudocalliergon brevifolium		1S/B		
Racomitrium sp.		2S	1S	

Table 3. (Continued)

Site Unit	15-30A Hidalen B	15-30C Hidalen D	15-31 Hidalen D	23-01 Bogen
Sanionia orthothecioides				3S
Sanionia cf. *orthothecioides*	1S			
Sanionia uncinata			1S/B	1S
cf. *Sanionia uncinata*		1B		3S
Sanionia sp.	1S			
Scorpidium cossoni		1S/B		
Straminergon stramineum				4S
Tayloria sp.	2S			
Tortula sp.				1L
Warnstorfia exannulata				6S + 1L**
Warnstorfia sarmentosa		1S/B		
Indet. akrokarp	11S	13S	2S	
Indet. pleurokarp	1S	5S/B + 1L	2S	1S
Indet. perigonium			1†	
Indet.				1L

S = shoot; B = branch; L = leaf; MS = megaspore; F = fruit; TW = twigs; W = wood; S = seed; Mts = metasternum; Lc = larval case; Th = thorax; Relative frequence, + = 1–10, ++ = 10–100.
†With antheridia and paraphyses.
*These 20 stems and leaves were not checked for species identity (no transverse sections made).
**Most of the shoots are of the same phenotype as is usually found in the large late snow-beds in the Scandinavian mountain range today.

vascular plants. Some taxa, such as *Bryoerythrophyllum recurvirostrum*, *Distichium* sp., *Ditrichum flexicaule*, *Hypnum bambergeri* and *H. revolutum* are typical of mineral-rich to calcareous environments, whereas *Bartramia ithyphylla*, *Ceratodon purpureus*, *Pogonatum dentatum*, *Polytrichastrum alpinum*, the *Polytrichum* species and *Racomitrium* sp. are either found in poorer habitats or have a rather wide range as regards the mineral status of the habitat. The moss species found in the present study still grow on Svalbard, except for *Pseudocalliergon brevifolium*, which has its closest locality in the Scandinavian mountain range.

Unit E

Unit E discordantly overlies unit D. It is a 0.5 m-thick, sometimes matrix supported and sometimes clast supported, massive diamicton. It carries striated, angular clasts and shell fragments. At places it is a massive deposit of clast-contact, angular boulders, with silty-sandy matrix. A fabric analysis showed preferred orientation of clasts in a southeast-northwest direction, with dip towards the southeast (Fig. 4C). It was observed in section 15-31 and on top of section 15-30A. It is tight and compact and conducts groundwater on its upper surface. It could be followed as a moisture-bearing horizon in the walls of the Hidalen ravine from section 15-31 towards and over section 14-03. It is interpreted to be a till from a glacier that has moved through the Hidalen col, from east towards west.

Unit F

Unit F is a 0.5 m thick deposit of stratified fine to coarse sand with silt laminae, interpreted as sublittoral sediments, which are in turn discordantly overlain by a 8–10 m thick deposit of cross-stratified sands and gravels. The base of the unit is at 79 m a.s.l. The unit is upward coarsening, from sand and pebble gravels at the base of the cross-stratified facies, to cobble gravels at the top, at ca 92 m a.s.l. The uppermost 2–3 m are cobbles and boulders which can be followed on the surface above the Hidalen ravine to the coarse-grained high-energy beach ridges that mark the marine limit at ca 100 m a.s.l. in the mouth of Hidalen.

It is interpreted to be a succession of sublittoral to littoral sediments, deposited when the sea stood at the postglacial marine limit.

The glacial stratigraphy of Bogen

Section 23-01 (Fig. 6) is located about 1.5 km from the coast, in a shallow side ravine to the main Bogen gully (Fig. 1C), inside the Bogen cirque. The top of the section is at 82 m a.s.l. The cirque mouth is transversed by a 94–98 m high boulder ridge, marking the marine limit.

The section is composed of two interstratified lithofacies, laminated sand and laminated silt, with minor intrabeds of massive sand and massive silt. The thickness of the strata as exposed at site 23-01 is about 7 m. The clayey-sandy sediments carry in situ shells and abundant shell fragments. The deposition has been continuous, with moderate sediment input, and minor current reworking during deposition, probably in a shallow-water, low-energy marine environment. Dropstones occur, mainly as occasional granules and pebbles. The section is capped by thin colluvium. The whole section has been glaciotectonically deformed, and pushed up-slope from the floor of the Bogen valley. In the northern part of the section (left on Fig. 6), a gently inclined, tight anticlinal fold has developed, and in the southern part of the section the sequence is transected by series of tightly spaced low angle reverse faults. The fold axis has a SE–NW direction, and the deforming thrust has come from the northeast. The tightly spaced low angle reverse faults have an imbricated pattern, slightly concave with apparent dip towards the north. The faulting has occurred subsequent to the folding in a NE–SW orientated stress field. The direction of glaciotectonic deformations in section 23-01 shows that the glacier which overran the site had advanced across the 300 m high Retziusfjellet plateau, into the cirque. Thus the glacier has been a part of a larger ice sheet covering Kongsøya and probably this part of the Barents Sea.

Molluscs. – Only four species of bivalves and one echinoderm were recognised (Table 1). The shells were biased towards large individuals, and no juveniles were recognised. This, together with the total absence of foraminifera, indicates that carbonates may have dissolved in the sediments.

Plant macrofossils. – Only one taxon of vascular plants, *Selaginella selaginoides*, was recognised, together with fragments of leaves, stems and wood (Table 3). The bryophyte assemblage is similar to the flora in unit B in Hidalen, with well-

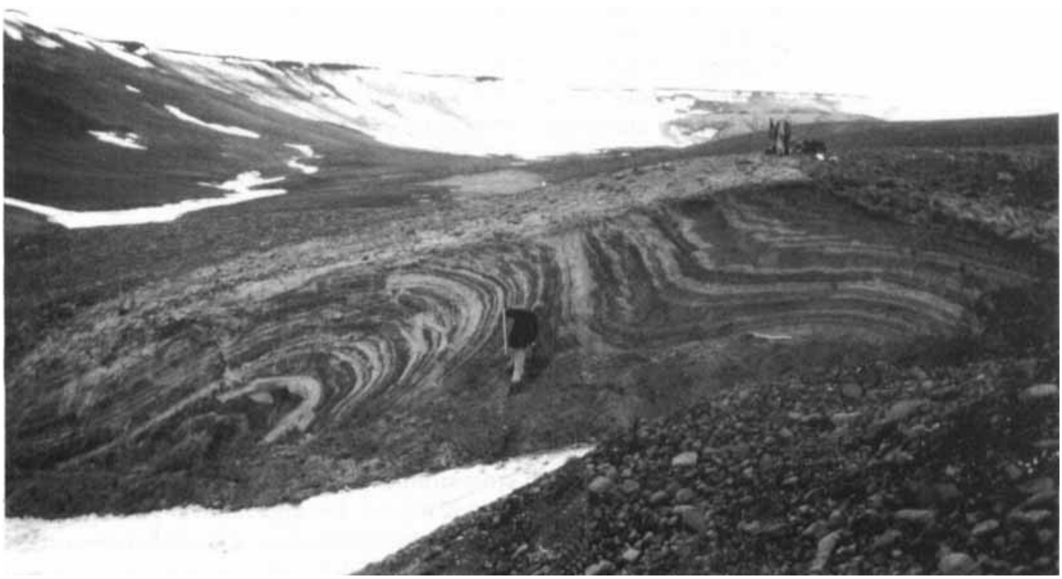

Fig. 6. Site 23-01 in Bogen. North to the left of the photo. The anticlinal fold shows a glacial push from northeast and that the sediments have been pushed up-slope from the floor of the Bogen cirque.

represented wetland species. This assemblage has more species indicative of drier habitats than unit B in Hidalen, but taken together the flora shows poor vegetation of vascular plants and bryophytes in mineral-poor, leached out soils. The presence of *Selaginella selaginoides* suggests that the climate was slightly warmer on Kongsøya during the deposition of these sediments than today.

Age and correlations

Radiocarbon and TL ages

Four ^{14}C age determinations were made on samples from units B and D in Hidalen and the Bogen strata. All gave infinite ages (Table 4). One TL dating from the Bogen strata yielded an age of 148 ± 15 ka.

Amino acid ratios

The degree of isoleucine epimerization, expressed as aIle/Ile ratios, were measured in 21 samples from five different sites in Hidalen and from the Bogen site. The samples were prepared by the method described by (Miller et al. 1983) and the aIle/Ile ratios in the total (bound + free) and free fraction are presented in Table 5. Most of the shells were of the species *Hiatella arctica* and

Table 4. Radiocarbon dated pelecypod samples from western Kongsøya.

Site	Sample No.	Lab. No.	Age BP	δC-13 (‰)
Hidalen 15-30C	95-405	Lu-3823	>38,000	−1.9
Hidalen 15-31	95-438	Lu-3821	>40,000	2.5
Hidalen 14-03	95-439	Lu-3822	>40,000	3.1
Bogen 23-01	95-440	Lu-3824	>37,000	3.2

All samples are of in situ *Mya truncata* except sample 95-439 from site 14-03 where a reworked, paired specimen of *Chlamys islandica* was dated.

Table 5. Amino acid aIle/Ile ratios from western Kongsøya, Svalbard.

Site	Unit	BAL-number	Species	Hydrolysed aIle/Ile ratio	Free aIle/Ile ratio	Comments
15-30C	D	2529	*Mya truncata*	0.039 ± 0.006	0.243 ± 0.072	from scree
	D	2612	*Hiatella arctica*	0.049 ± 0.001	0.233 ± 0.009	from scree
	D	2613	*Mya truncata*	0.050 ± 0.004	0.303 ± 0.022	from scree
	D	3073	*Mya truncata*	0.029 ± 0.004	0.199 ± 0.014	in situ
15-31	D	2575	*Hiatella arctica*	0.056 ± 0.005	0.229 ± 0.028	from scree
	D	2610	*Hiatella arctica*	0.035 ± 0.000	0.207 ± 0.069	from scree
	D	2611	*Hiatella arctica*	0.044 ± 0.001	0.192 ± 0.019	from scree
	D	3074	*Mya truncata*	0.034 ± 0.001	0.188 ± 0.015	in situ
14-03	D	3072	*Mya truncata*	0.043 ± 0.003	0.194 ± 0.006	not in situ
15-30A	E	2693	*Hiatella* sp.	0.046 ± 0.000	0.241 ± 0.016	fragment
	E	2694	*Hiatella* sp.	0.054 ± 0.001	0.258 ± 0.013	fragment
	E	2695	*Hiatella* sp.	0.046 ± 0.001	0.290 ± 0.020	fragment
			Mean:	0.043 ± 0.008	0.231 ± 0.038	
15-30B	B	2530	*Mya truncata*	0.085 ± 0.008	0.372 ± 0.025	not in situ
	B	2531	*Hiatella arctica*	0.074 ± 0.006	0.425 ± 0.008	not in situ
1530A	B	2574	*Mya* sp.	0.080 ± 0.003	0.354 ± 0.002	fragment
	E	2528	*Hiatella* sp.	0.071 ± 0.016	0.301 ± 0.086	fragment
23-01		2524	*Mya truncata*	0.095 ± 0.002	0.433 ± 0.016	in situ
		2525	*Mya truncata*	0.085 ± 0.002	0.401 ± 0.016	in situ
		2527	*Mya truncata*	0.095 ± 0.002	0.381 ± 0.003	in situ
		2576	*Mya truncata*	0.082 ± 0.005	0.373 ± 0.013	in situ
			Mean:	0.083 ± 0.009	0.380 ± 0.042	

The BAL-number is the sample number at the Bergen amino acid laboratory.

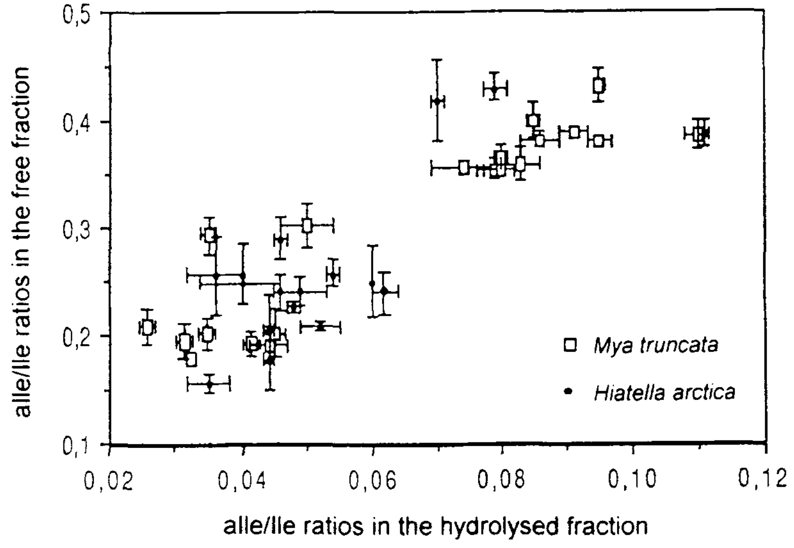

Fig. 7. Amino acid alle/Ile ratios in all measured samples from western Kongsøya.

Mya truncata, but some fragments could not be identified. On the basis of amino acid ratios (method described by Andrews et al. 1985) they were identified as *Hiatella* sp. and *Mya* sp. The sample material falls into two groups of different age (Fig. 7). The older group, with an average of 0.083 ± 0.009 in the hydrolysed fraction for 8 samples, of shells from unit B in section 15-30B in Hidalen and from section 23-01 in Bogen, as well as a fragment from unit E in section 15-30A. The younger group, with an average of 0.043 ± 0.009 for the hydrolysed fraction for 12 samples, consists of shells from unit D at sites 15-30C, 15-31 and 14-03, together with fragments sampled from unit E in section 15-30A.

The relatively large variations in ratios within the groups might reflect different temperature history as a result of burial depth as some of the samples were found in scree material at or close to the surface. Six samples, coming from unit D but collected from surface scree, yielded an average ratio of 0.045 ± 0.007 for the hydrolysed fraction and 0.234 ± 0.038 for the free fraction. Two samples collected in situ from the same deposit, near the base of the active layer at 0.4–0.6 m in the sediments, yielded an average ratio of 0.031 ± 0.003 for the hydrolysed fraction and 0.193 ± 0.007 for the free fraction. We consider the mean alle/Ile ratio from in situ shells as more reliable than the total mean for the younger group.

The amino acid ratios confirm the stratigraphical evidence of two ice-free intervals, during deposition of units B and D, in Hidalen. The amino acid ratios suggests that the marine beds in Bogen correlate with unit B in Hidalen.

Correlating the Kongsøya stratigraphy to Spitsbergen

Correlations between different sites on Spitsbergen is difficult because of lack of reliable absolute dating methods. Therefore such correlations of possible Early Weichselian and Eemian sites have relied heavily on amino acid ratios (Miller et al. 1989; Sejrup & Larsen 1991, Mangerud & Svendsen 1992; Landvik et al. 1992). Even if other factors than diagenetic temperature may influence on the on the degree of epimerisation, the temperature is the most crucial (Sejrup & Haugen 1994). Therefore, in order to use the amino acid ratios for regional stratigraphic correlations and establishing relative chronologies, the temperature history has to be comparable from site to site (Sejrup 1990). As demonstrated with the data from Kongsøya, burial depth during ice-free conditions can seriously affect the alle/Ile ratios on samples of same age.

A composite stratigraphical scheme for Kongsøya is shown in Fig. 8. The TL determination from Bogen indicates that the older ice free interval on Kongsøya is older than isotope stage 5e. The

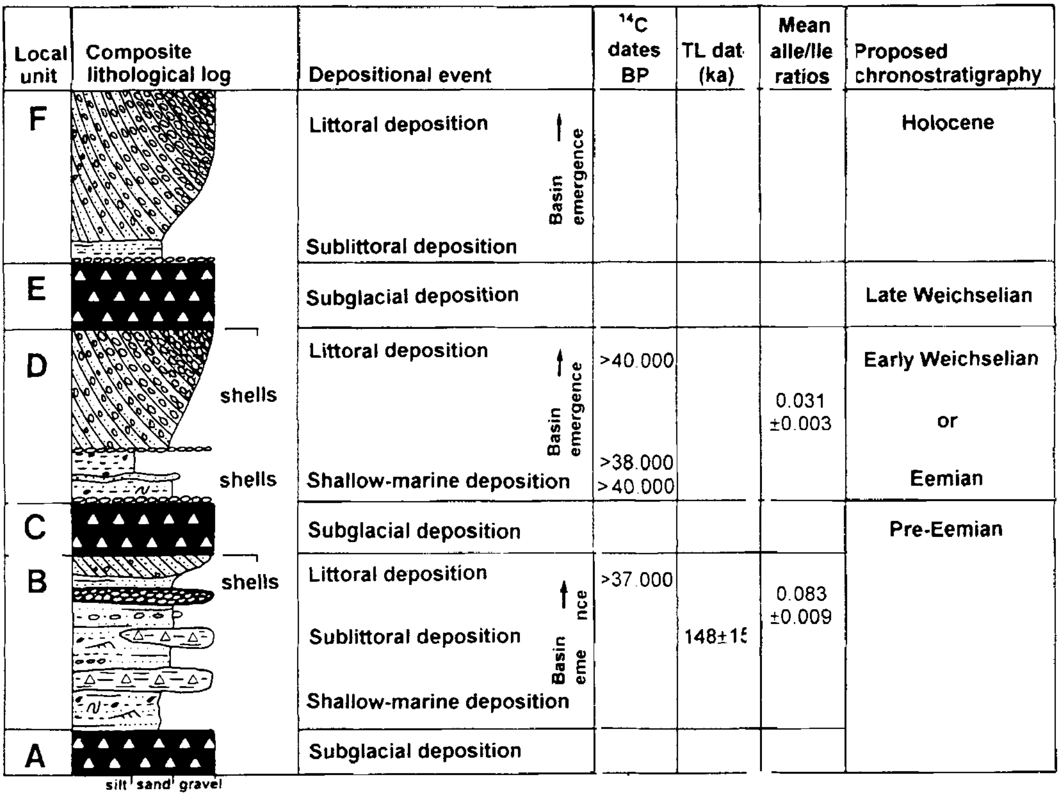

Fig. 8. Composite stratigraphy of western Kongsøya. Unit thicknesses are arbitrary. Lithological legend in Fig. 2

Table 6. Amino acid ratios in pelecypod shells from sites on Spitsbergen. For comparison, the amino acid values from Kongsøya and their proposed age.

Isotope stage	Chronostratigraphy	Brøggerhalvøya	Kapp Ekholm	Linnédalen	Skilvika	Kongsøya
1	Holocene		0.015 ± 0.003			
2	Late Weichselian					
3	Middle Weichselian		0.026 ± 0.004	0.019 ± 0.003		
4						
5a	Early Weichselian	0.031 ± 0.003		0.027 ± 0.003		0.031 ± 0.003
5b						
5c			0.063 ± 0.013		0.037 ± 0.008	
5d						
5e	Eemian	0.044 ± 0.004	0.069 ± 0.008			
	Pre-Eemian		0.121 ± 0.009			0.083 ± 0.009

Based on Miller et al. (1989), Mangerud & Svendsen (1992), Lønne & Mangerud (1991) and Landvik et al. (1992)

mean amino acid ratios are considerably higher than those obtained from assumed Eemian deposits on Spitsbergen (Table 6), and we suggest that unit B pre-dates isotope stage 5e. Amino acid ratios in the same range as the older group on Kongsøya have been reported from Nordaustlandet (Blake 1989).

If the glacier advance which deposited unit E, the uppermost till, correlates with a Late Weichselian Barents Ice Sheet, the younger ice free interval, unit D, could possibly correlate with the Kapp Ekholm interstadial. Mangerud & Svendsen (1992) assign it the age of 40,000–50,000 BP and argue that then the whole Barents Sea area was ice free. The aIle/Ile ratios obtained from in situ shells from unit D on Kongsøya are slightly higher than mean ratios from the Kapp Ekholm interstadial deposits. Since the Kongsøya samples come from altitudes of between ca 55 and 75 m a.s.l., as compared to <25 m a.s.l. for the Kapp Ekholm samples, and the annual mean temperature is lower on Kongsøya than at Kapp Ekholm, one would expect that similar aIle/Ile ratios would indicate higher age for the Kongsøya deposits. We suggest that unit D sediments are either of Early Weichselian or Eemian age. If our correlations are correct, our data support the conclusion of Sejrup & Larsen (1991) that a biostratigraphical distinction between interglacial and interstadial deposits at such high latitudes may be difficult.

Summary and conclusions

The stratigraphic data from Kongsøya show three coarsening-upwards successions of marine to littoral sediments, separated by tills. These show at least three Late Quaternary major glaciations of the northern Barents Sea, with ice thick enough to cause substantial glacioisostatic downpressing of western Kongsøya. The high (≥100 m) postglacial marine limit, dated to around 10,000 BP, suggests that this part of the Barents Sea was covered by an ice sheet during the Late Weichselian, and the uppermost till in the Kongsøya stratigraphy is related to that glacial event. Glaciotectonic deformations suggest that ice at some time moved independently of the local topography from an ice-divide northeast of Kongsøya. The stratigraphical evidence shows two pre-Holocene ice-free periods, where the climate was similar to or slightly warmer than at present. The age of these ice free intervals is not clear. We suggest that the older ice free period predates isotope stage 5e. The younger ice free period could either be of Eemian or Early Weichselian age.

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