Recent foraminiferal distribution in Freemansundet and Early Holocene stratigraphy on Edgeøya, Svalbard

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The present foraminiferal distribution (live + dead) in Freemansundet between Barentsøya and Edgeøya, Svalbard, has been compared with assemblages in raised marine Holocene deposits in Guldalen on Edgeøya. Four distinct foraminiferal assemblages were identified in Freemansundet, the *Elphidium excavatum-Cassidulina reniforme* assemblage, the *Elphidium hallandense* assemblage, the *Cibicides lobatulus* assemblage and the *Elphidium incertum-Haynesina orbiculare* assemblage. Four assemblage zones (Zones A–D) have been established in the glaciomarine to marine sediment sequence in Guldalen. Only two of the recent faunal types were represented here. The *Elphidium excavatum-Cassidulina reniforme* assemblage, which reflects a proximal glacier environment, was found in the lowermost Zone A (the *Elphidium excavatum* Zone) and in Zone C (the *Elphidium excavatum-Cassidulina reniforme* Zone) in the Guldalen stratigraphy; the *Elphidium incertum-Haynesina orbiculare* assemblage, which reflects ameliorated shallow water conditions, was found in the uppermost Zone D in Guldalen. The marine sequence in Guldalen represents a relatively short period of time during the Early Holocene (ca 9700 to 8300 BP). The succession of the foraminiferal assemblages suggests that the deglaciation was interrupted by a cold period with glacial stagnation just after 9600 BP (Zone B, the *Astrononion gallowayi-Nonionellina labradorica* Zone).

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Introduction

The Weichselian deglaciation of the Svalbard-Barents Sea area seems to have started at ca 15,000 BP in the Barents Sea and at ca 13,000 BP on western Spitsbergen, whereas it appears to have occurred as late as ca 10,000 BP in the eastern Svalbard area (see e.g. Elverhøi et al. 1992; Forman 1990; Landvik et al. 1995). Landvik et al. (1995) suggest that both the eastern and the western coast of Edgeøya were deglaciated at ca 10,300 BP (Fig. 1).

Today Late Quaternary raised marine deposits cover large areas of the outer parts of the valleys and the forelands of Edgeøya. The marine limit in the area is found at 85–90 m above present day sea level (a.s.l.), and its age is close to 10,000 BP (Bondevik et al. 1995).

This paper presents the foraminiferal stratigraphy and chronology of early Holocene deposits in the valley of Guldalen on Edgeøya (Fig. 1). The general features of glaciomarine sedimentation on Edgeøya have previously been dealt with by Büdel (1968), Gläser (1968), Boulton et al. (1982) and Boulton (1990), while Landvik et al. (1992) gave a detailed description of the lithology and stratigraphy of the deposits. Late Weichelian-Holocene foraminiferal stratigraphy from Edgeøya has previously been treated by Nagy (1984) and from adjacent areas in Svalbard by e.g. Feyling-Hanssen (1965), Elverhøi et al. (1980), Lycke et al. (1992), Landvik et al. (1992) and Hald et al. (1994).

In order to support the environmental interpretations, some Recent foraminiferal assemblages from Freemansundet between Edgeøya and Barentsøya (Fig. 1) are also presented. A preliminary report of the Recent total (live + dead) faunas in Freemansundet was presented by Hansen & Knudsen (1992). In the present paper these results are summarised and supplemented by living records. The distribution of Recent shallow water assemblages in certain areas around the coasts of Svalbard has previously been reported by e.g. Nagy (1965), Rouvillois (1966), Aasgaard (1978), Lycke et al. (1992), Slinning (1993) Hald et al. (1994) and Steinsund et al. (in press).

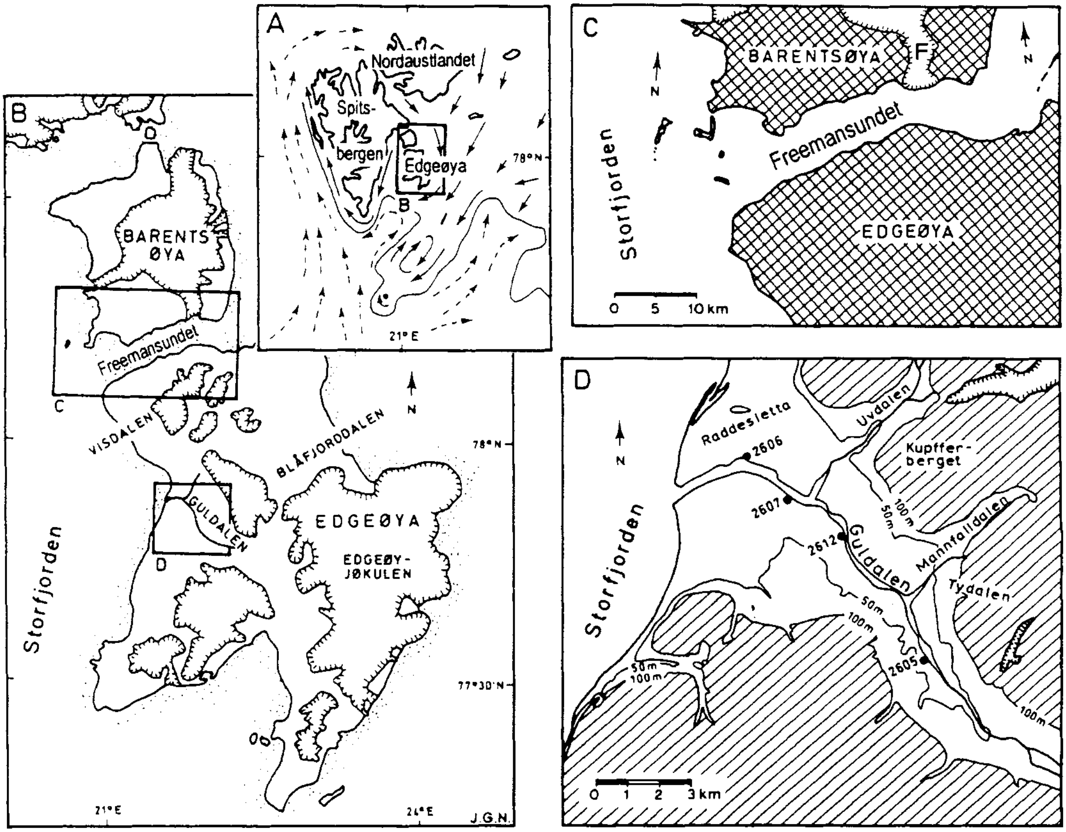

Fig. 1. Location maps. Map A: Modern surface water circulation (Loeng 1991). Stippled arrows indicate warm Atlantic current; full arrows mark the cold currents; the solid line indicates the Polar Front. Map B: Barentsøya and Edgeøya, separated by Freemansundet. Insert maps of Freemansundet and Guldalen shown in Maps C and D. Map C: Freemansundet. See also Fig. 2. Map D: The Guldalen area with the location of the four studied profiles in the valley (2606, 2607, 2612 and 2605). Hatching indicates areas higher than 100 m above present day sea level.

Material and methods

The material examined in the present study consists of Recent samples from Freemansundet and of samples from the Late Quaternary in Guldalen, Edgeøya (Fig. 1). The samples were collected in August 1991 during the PONAM (Polar North Atlantic Margin, Late Cenozoic Evolution) expedition to eastern Svalbard.

Sea bottom samples were obtained from 27 stations in Freemansundet (water depth 2–47 m) located along three transects termed the Eastern, the Middle and the Western Transect (Figs. 1 and 2). The sampler was a mini grab which collects a total of 2–3 litres of sediment. The upper 1–2 cm of sediment was used in the present foraminiferal analysis. The samples were preserved in 60% ethanol and stained with Rose Bengal. In general, problems were encounted in obtaining sufficient sample material from the deeper stations, partly because the relatively light grab did not penetrate deep enough into the bottom sediments, and partly because some material was washed out of the grab before reaching the surface. Therefore, the stained assemblage would probably not always fully represent the original live assemblage at the sample site.

A total of 72 samples were collected from Late Quaternary deposits in four profiles along the valley of Guldalen (Figs. 1 and 6). The sampling intervals varied between 10 and 100 cm, depending on the change in sediment character.

All the samples (usually 100 g dry weight) were

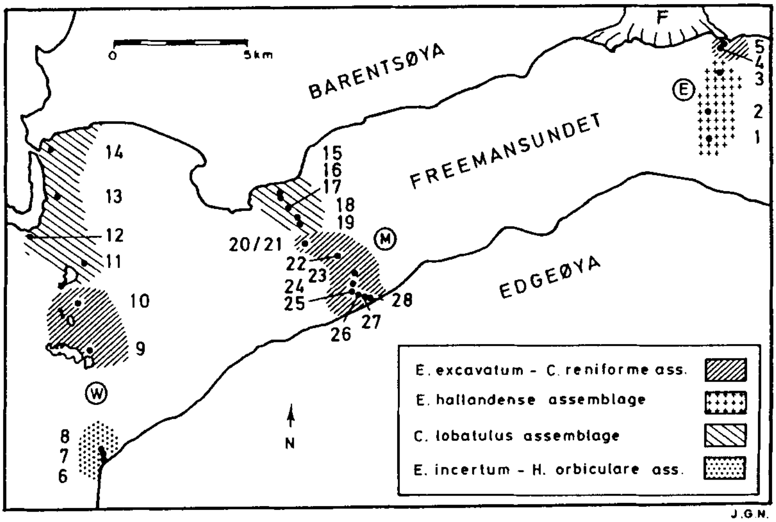

Fig. 2. Sampling stations along the three transects in Freemansundet (E = Eastern Transect; M = Middle Transect; W = Western Transect). The areal distribution of the four characteristic foraminiferal assemblages (total faunas) are indicated. F = Freemanbreen glacier. (Redrawn after Hansen & Knudsen 1992).

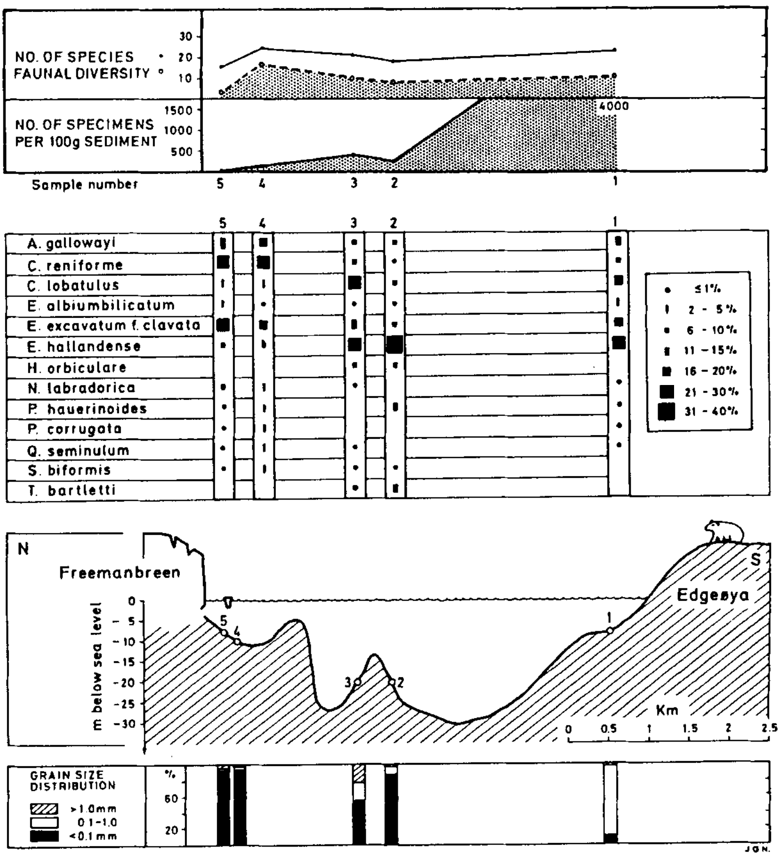

Fig. 3. Percentages of the most common foraminiferal species (total faunas) in the samples from the Eastern Transect (location, Figs. 1 and 2). The faunal parameters are shown in addition to the grain distribution at each station. (Redrawn after *Hansen & Knudsen 1992*).

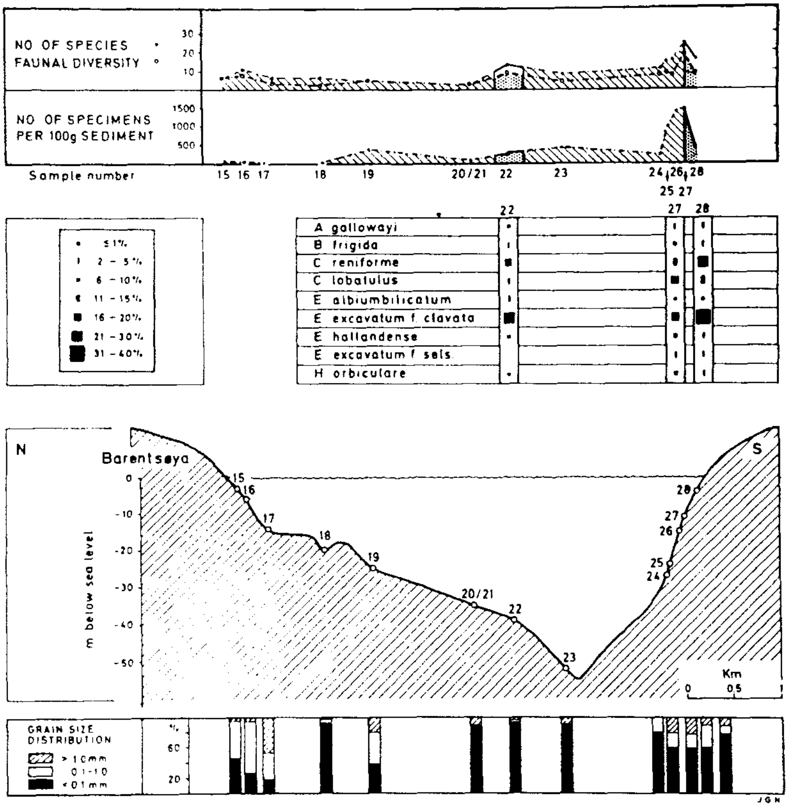

Fig. 4. Percentages of the most common foraminiferal species (total faunas) in the specimen-rich samples from the Middle Transect (location, Figs. 1 and 2). The faunal parameters are shown for the same samples, and approximate values are given for specimen-poor samples. In addition, the grain size distribution is shown for each sample. (Redrawn after Hansen & Knudsen 1992).

processed according to the standardised method described by Feyling-Hanssen et al. (1971) and Meldgaard & Knudsen (1979). They were washed through sieves with mesh diameters of 0.1 and 1.0 mm. The grain size distribution shown in Figs. 3–5 is, therefore, presented with these grain size fractions. The foraminifera in the 0.1–1.0 mm fraction were concentrated using the heavy liquid carbon tetrachloride (CCl_4).

At least 300 specimens were identified and counted, where possible. The number of living (stained) specimens was usually lower than that. The number of specimens of the most common foraminiferal species from Freemansundet (living and total) per 100 g sediment is given in Table 1, while percentage distributions for the specimen-rich samples (at least 100 specimens counted) are illustrated in Figs. 3–5, together with faunal parameters (total number of specimens per 100 g sediment, faunal diversity index (Walton 1964) and number of species). Results from Guldalen are shown in Figs. 7–14, where both the relative and absolute abundance distributions are illustrated for each profile, together with the lithology, ^{14}C dates (Table 2), faunal parameters and assemblage zones (Hedberg 1976). Actual counts are given for the specimen-poor samples.

The most common foraminiferal species in the material are illustrated in Figs. 17 and 18, and a total list of the foraminiferal species recorded is given in Table 3. The species, which are used in calculating the arctic-boreal content and the shallow water/low salinity group (see Gudina & Evzerov 1973; Feyling-Hanssen 1980, 1983; Seidenkrantz & Knudsen 1993) are marked in this list. Due to its uncertain environmental indication, *Elphidium albiumbilicatum* has been extracted from the arctic-boreal group and shown separately (Figs. 7, 9, 11 and 13).

Freemansundet

Hydrography and sediments

The water masses in the Barents Sea are influ-

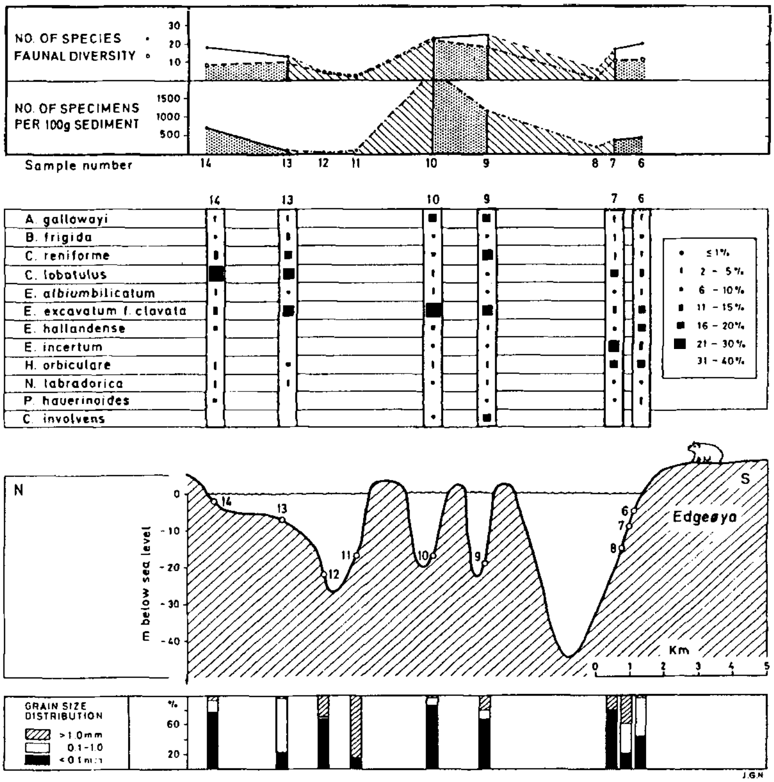

Fig. 5. Percentages of the most common foraminiferal species (total faunas) in the specimen-rich samples from the Western Transect (location, Figs. 1 and 2). The faunal parameters are shown for the same samples, and approximate values are given for specimen-poor samples. In addition, the grain size distribution is shown for each sample. (Redrawn after Hansen & Knudsen 1992).

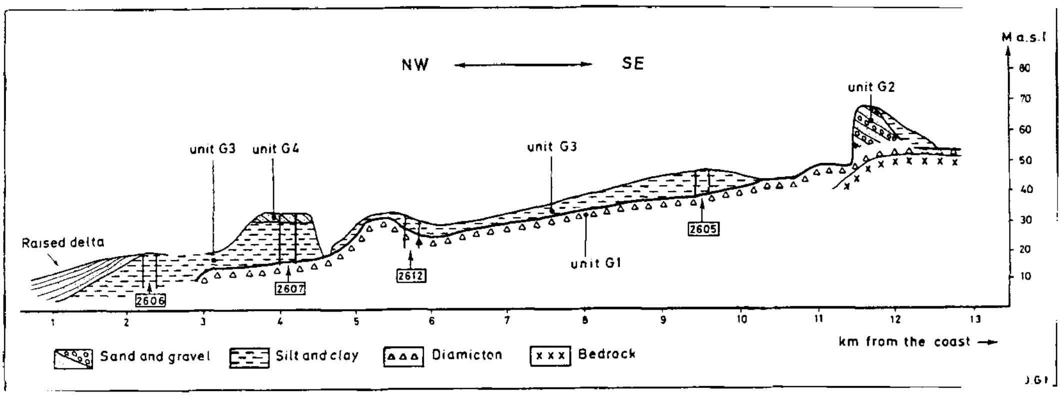

Fig. 6. A cross-section from NW to SE through Guldalen with the sedimentary units (after Landvik et al. 1992). *Unit G1*, a matrix-supported diamicton with a sandy silty matrix which is interpreted as a subglacial till. *Unit G2*, a ridge-shaped deposit of sand and gravel flanked by silt and clay on its southern slope. This ridge is situated at the southeast side of the valley about 12 km from the coast. *Unit G3*, mainly a laminated muddy sediment of glaciomarine to marine origin. It rests on Unit G1 with a sharp lower boundary. *Unit G4*, sand and gravel. The investigated profiles are indicated.

Table 1. Number of specimens (living and total) per 100 g sediment of selected foraminiferal species in samples from the three Transects (East, West and Middle) in Freemansundet. * = samples with very small sample size (5–10 g sediment).

FREEMANSUNDET																				
TRANSECT	SAMPLE NUMBER	Astrononion gallowayi	Buccella frigida	Cassidulina reniforme	Cibicides lobatulus	Cornuspira involvens	Elphidiella arctica	Elphidium albiumbilicatum	Elphidium exc. f. clavata	Elphidium exc. f. selseyensis	Elphidium hallandense	Elphidium incertum	Haynesina orbiculare	Nonionellina labradorica	Patellina corrugata	Pateoris hauerinoides	Pseudopolymorpha novangliae	Quinqueloculina seminulum	Trichohyalus bartletti	NUMBER OF SPECIMENS IN 100g SEDIMENT. living / total.
EAST	1	50 / 491	176	13 / 416	680		25	152	3 / 731	62	26 / 932	50		13	25	38 / 38	38	13 / 38		176 / 4145
	2	3 / 16	2 / 3	1 / 3	3 / 16		7	2	13 / 21	2 / 4	55 / 88	2	18			31 / 31			29 / 29	155 / 247
	3	1 / 18	1	16	57	1	1	2	1 / 27	2	56	1	12	2			1 / 2	2	1	4 / 204
	4	2 / 32		5 / 37	4		1	2	2 / 26	1	15	11		4	1 / 6	5	1 / 1	4		11 / 168
	5	3		1 / 8	1			1	1 / 9		2	1		2	1 / 2	1 / 1		1 / 1		5 / 32
WEST	6	4 / 12	4 / 25	13	49		1 / 6	4 / 15	33 / 61	1 / 4	25 / 79	57	34 / 83	1 / 4		9	4	3		114 / 374
	7	3 / 9	10 / 11	7 / 11	3 / 82		3 / 5	3 / 8	36 / 60	3 / 8	6 / 37	10 / 91	34 / 80	1		4 / 4		1 / 4		120 / 412
	8*	20			60		20				20	20	60							200
	9	45 / 225	9	12 / 267	15	93 / 93	21	9	27 / 231		30	3	51	12 / 33		3		3 / 15		198 / 1101
	10	36 / 387	27	81 / 171	72	3	18	54	117 / 819		144	36	99	36 / 36	45		9 / 9			288 / 2235
	11*				20											20				40
	12	10 / 10	5 / 5					5 / 5												20 / 20
	13	7	14	2 / 23	29		1	1	3 / 27	1 / 1			10	6				1 / 1		8 / 123
	14	3 / 23	7 / 7	7 / 94	3 / 270			3 / 16	7 / 87	3	3 / 66		7 / 27	20	3	60	3	13		40 / 766
MIDDLE	15	4		4 / 4	16				12		4			4						4 / 44
	16	2 / 2	1 / 1	1 / 1	9 / 9				5 / 5	5 / 5	2 / 2	2 / 2	4 / 4	1 / 1				4 / 4		36 / 36
	17				1 / 1	1	2	1	2		1									1 / 9
	18			2	8 / 10		2 / 2		12		4 / 4	4 / 4	4 / 4							22 / 38
	19*				40 / 100		20 / 20				80	60 / 100	60 / 60							180 / 360
	20/21*			30	20 / 20				30 / 40											50 / 100
	22	8 / 28	10	58	18		3 / 26	3 / 8	38 / 86		8 / 26	23 / 26	3	3 / 6			5			104 / 337
	23*	10 / 30		50 / 200	20 / 20			20 / 20	50 / 80		30 / 30			20 / 20		20		20		200 / 450
	24*	20		40	20 / 20				40 / 40		20		40 / 40			20		20		120 / 240
	25*	20 / 100	20 / 40	80 / 100	20 / 20		60	20	100 / 180		20 / 80		40 / 120			20 / 20		20 / 20		540 / 960
	26*	40 / 40		460 / 520					160 / 200		80 / 100		200 / 240	20 / 20	20	120 / 120		40 / 40		1160 / 1360
	27	40 / 70	25 / 85	45 / 150	266	10 / 15	65	25	15 / 221	45	5 / 85	10 / 60	15 / 140	5 / 15	5	10 / 10			5	236 / 1436
	28	3 / 24	11 / 25	65 / 123	55	1 / 1	5	5	70 / 165	9	4 / 26		1 / 17	7			2 / 8	4		172 / 487

J.G.N.

Analysis: Anette Hansen

45 living / 150 total } Specimens per 100g

Table 2. Radiocarbon dating results obtained from shell samples at sections 2605 and 2607 in Guldalen (see also Landvik et al. 1992 and 1995; Gulliksen et al. 1992). A reservoir correction of 440 years (Mangerud & Gulliksen 1975) has been applied to the radiocarbon age BP, resulting in the reservoir corrected radiocarbon age BP* (Rcorr. BP*). Samples with T-laboratory numbers were prepared and measured at the Radiological Dating Laboratory, Trondheim, Norway, using the conventional counting technique. The TUa-sample was prepared (for AMS) in Trondheim, Norway, and measured at the tandem accelerator, The Svedberg Laboratory, Uppsala, Sweden. AAR-samples were prepared and measured at the Aarhus AMS ^{14}C Dating Laboratory, Denmark.

Sample no.	Loc. no.	Position	Elevation (m a.s.l.)	Species	Lab. no.	Rcorr. age BP*
86-481	2605	77°50'N 21°49'E	40.4	Shell fragment	AAR-1124	9450 ± 120
86-431	2605	77°50'N 21°49'E	38.7	*Mya truncata*	T-9937	9570 ± 165
86-442	2607	77°53'N 21°39'E	30.1	*Macoma calcarea*	TUa-294	8320 ± 75
86-194	2607	77°53'N 21°39'E	18.9	*Macoma* sp.	AAR-1125	9000 ± 90
86-420	2607	77°53'N 21°39'E	17.5	*Mya truncata*	T-9939	9675 ± 50
86-418	2607	77°53'N 21°39'E	15.9	*Mya truncata*	T-9936	9705 ± 135

enced by the cold (−1.8 to 3°C) Polar Spitsbergen Current, which flows southwards parallel with Barentsøya and Edgeøya and continues south of Spitsbergen. In the southern part of Storfjorden the cold water mixes with water masses from the warm Atlantic West Spitsbergen Current (Fig. 1) (see also Elverhøi et al. 1988).

Freemansundet is the strait between Barentsøya and Edgeøya, connecting the Barents Sea in the east with Storfjorden in the west (Fig. 1). The northern part of the strait is especially influenced by meltwater and calving ice from the Freemanbreen glacier, and the mixing of meltwater and seawater in front of the glacier results in high turbidity in this area. Sediment-loaded water was observed flowing parallel to the coast of Barentsøya, either in an easterly or in a westerly direction, depending on the tidal current direction.

The studied sediments in Freemansundet are dominated by mud but contain a varying amount of ice-rafted coarser materials. The coarser materials occur especially in the marginal areas near the coast, while the clays and silts are concentrated in the deepest part of the strait and also close to Freemanbreen. The fine-grained sediments in front of the glacier are probably a result of flocculation in the area where the sediment loaded meltwater mixes with seawater. Several parallel submarine moraine ridges are found in front of the glacier today (Lefauconnier & Hagen 1991).

Foraminiferal assemblages

Four different foraminiferal assemblages (total faunas) have been identified in Freemansundet, the *Elphidium excavatum-Cassidulina reniforme* assemblage, the *Elphidium hallandense* assemblage, the *Cibicides lobatulus* assemblage and the *Elphidium incertum-Haynesina orbiculare* assemblage (Fig. 2).

The Eastern Transect was characterised by two assemblages (Figs. 2 and 3; Table 1). The *Elphidium excavatum-Cassidulina reniforme* assemblage occurred close to Freemanbreen and the *Elphidium hallandense* assemblage was found in the middle part of the sound at some distance from the glacier (see Fig. 2). It is especially noteworthy that the epifaunal species *Trichohyalus bartletti* (see Murray 1991) only occurred as living specimens in sample 2. *Cibicides lobatulus*, however, generally occurred as dead specimens in the material (Table 1), but a special study of the coarser fraction (>1 mm) showed that living individuals of *Cibicides lobatulus* occurred fixed to the gravel.

The southern part of *the Middle Transect* was characterised by an *Elphidium excavatum-Cassidulina reniforme* assemblage similar to that found in the northern part of the Eastern Transect (Figs. 2 and 4; Table 1). The specimen-poor assemblages in the northern part of the transect were grouped with the *Cibicides lobatulus* assemblage as found in the Western Transect (see below).

The Western Transect contained three assemblages: The *Cibicides lobatulus* assemblage on the northern side of the sound, the *Elphidium excavatum-Cassidulina reniforme* assemblage in the middle and the *Elphidium incertum-Haynesina orbiculare* assemblage in the southern side

Table 3. Foraminiferal list for the Freemansundet samples and the Guldalen samples. AB marks the species included in the arctic-boreal group; SH marks those included in the shallow water/low salinity group (see Gudina & Evzerov 1973; Feyling-Hanssen 1980, 1983; Seidenkrantz & Knudsen 1993).

Ammodiscus planus Höglund
Ammotium cassis (Parker)
Astrononion gallowayi Loeblich & Tappan – AB
Astacolus hyalacrulus Loeblich & Tappan
Brizalina pseudopunctata (Höglund) – AB
Buccella frigida (Cushman)
Buccella tenerrima (Brady)
Cassidulina reniforme Nørvang
Cibicides lobatulus (Walker & Jacob) – AB
Cornuspira involvens (Reuss)
Cribrostomoides crassimargo (Norman)
Cribrostomoides jeffreysi (Williamson)
Dentalina pauperata d'Orbigny
Dentalina inornata (Derviex)
Deuterammina astrifica (Rhumbler)
Elphidiella arctica (Parker & Jones) – AB-SH
Elphidium albiumbilicatum (Weiss) – AB-SH
Elphidium asklundi Brotzen – SH
Elphidium bartletti Cushman – SH
Elphidium excavatum (Terquem) forma *clavata* Cushman – SH
Elphidium excavatum (Terquem) forma *selseyensis* (Heron-Allen & Earland) – AB-SH
Elphidium groenlandicum Cushman
Elphidium hallandense Brotzen – SH
Elphidium incertum (Williamson) – AB-SH
Elphidium magellanicum Heron-Allen & Earland – AB
Elphidium spp. – SH
Epistominella vitrea Parker – AB
Fissurina danica Madsen
Fissurina marginata (Montagu)
Fissurina serrata (Schlumberger)
Glandulina laevigata d'Orbigny
Globulina landesi (Hanna & Hanna)
Globulina sp.
Guttulina austriaca d'Orbigny
Guttulina dawsoni Cushman & Ozawa
Guttulina glacialis (Cushman & Ozawa)
Guttulina laevigata d'Orbigny
Guttulina problema (d'Orbigny)
Guttulina yamazakii Cushman & Ozawa
Haynesina nivea (Lafrenz) – SH
Haynesina orbiculare (Brady) – SH
Hippocrepina sp.
Islandiella helenae Feyling-Hanssen & Buzas
Lagena clavata (d'Orbigny)
Lagena mollis Cushman
Lagena semilineata Wright
Lagena spp.
Laryngosigma lactea (Walker & Jacob)
Miliolidae (others)
Miliolinella subrotunda (Montagu)
Nonionellina labradorica (Dawson)
Oolina melo d'Orbigny
Oolina williamsoni (Alcock)
Parafissurina lateralis (Cushman)
Pateoris hauerinoides (Rhumbler)
Pattelina corrugata Williamsoni
Pseudopolymorphina novangliae (Cushman)
Pseudopolymorphina suboblonga Cushman & Ozawa
Pyrgo williamsoni (Silvestri)
Quinqueloculina agglutinata Cushman
Quinqueloculina arctica Cushman

Table 3 — continued.

Quinqueloculina seminulum (Linné)
Quinqueloculina stalkeri Loeblich & Tappan
Rhabdammina linearis Brady
Reophax regularis Höglund
Reophax subfusiformis Earland
Rosalina vilardeboana d'Orbigny - AB
Sigmomorphina undulosa (Terquem)
Silicosigmoilina groenlandica (Cushman)
Spirillina vivipara Ehrenberg
Spiroplectammina biformis (Parker & Jones)
Stainforthia loeblichi (Feyling-Hanssen)
Stainforthia feylingi Knudsen & Seidenkrantz
Textularia bocki Höglund
Textularia contorta Höglund
Textularia earlandi Phleger
Trichohyalus bartletti (Cushman)
Trifarina fluens Todd
Triloculina tricarinata d'Orbigny
Triloculina trigonula (Lamarck)
Tritaxis atlantica (Parker)
Trochammina sp.

(Figs. 2 and 5; Table 1). The epifaunal *Cornuspira involvens* (see Murray 1991) only occurred as living specimens in sample 9.

Discussion of the assemblages

The distribution of the four different Recent assemblages in Freemansundet seems to be determined by the input of meltwater from Freemanbreen, by current velocity and by the substrate. Unfortunately, however, no temperature, salinity or current velocity data were available to support these suggestions.

The proximal glacier environment in the northeast is characterised by the *Elphidium excavatum-Cassidulina reniforme* assemblage, which seems to be associated with muddy bottoms in areas with high turbidity and sediment loaded waters in front of calving glaciers. Similar assemblages have been recorded from other areas with calving glaciers in Svalbard (Aasgaard 1978; Nagy 1965; Elverhøi et al. 1980; Hald et al. 1994).

A distal glacier environment comprising the *Elphidium hallandense* assemblage is recorded at some distance from Freemanbreen in the Eastern Transect. This assemblage may be determined by the distal more stable environment, which is probably influenced by a relatively high current velocity.

The *Cibicides lobatulus* assemblage at the northern end of Middle and Western Transects appears to be determined by shallow waters and a high current velocity (Mackensen 1987; Murray 1991). A similar fauna recorded between the two submarine moraine ridges in the Eastern Transect (Fig. 3) is presumably also determined by a local strong current velocity in this trough.

The *Elphidium incertum-Haynesina orbiculare* assemblage recorded in the southwestern part of Freemansundet is located in shallow waters, and the faunal composition may here be determined by the higher temperature water masses close to Storfjorden.

The distribution of assemblages in Freemansundet thus seems to be determined mainly by local environmental factors. In general, there is no trend from the east to the west in the strait, which could indicate any influence from either the cold water masses of the Barents Sea or the relatively warmer waters of Storfjorden. The only exception is the southwesternmost part of the strait, which seems to contain slightly warmer water elements in its faunas.

Guldalen

Lithology

The lithology of the Quaternary deposits in Guldalen was described in detail by Landvik et al. (1992) and Slettemark (1993), who subdivided

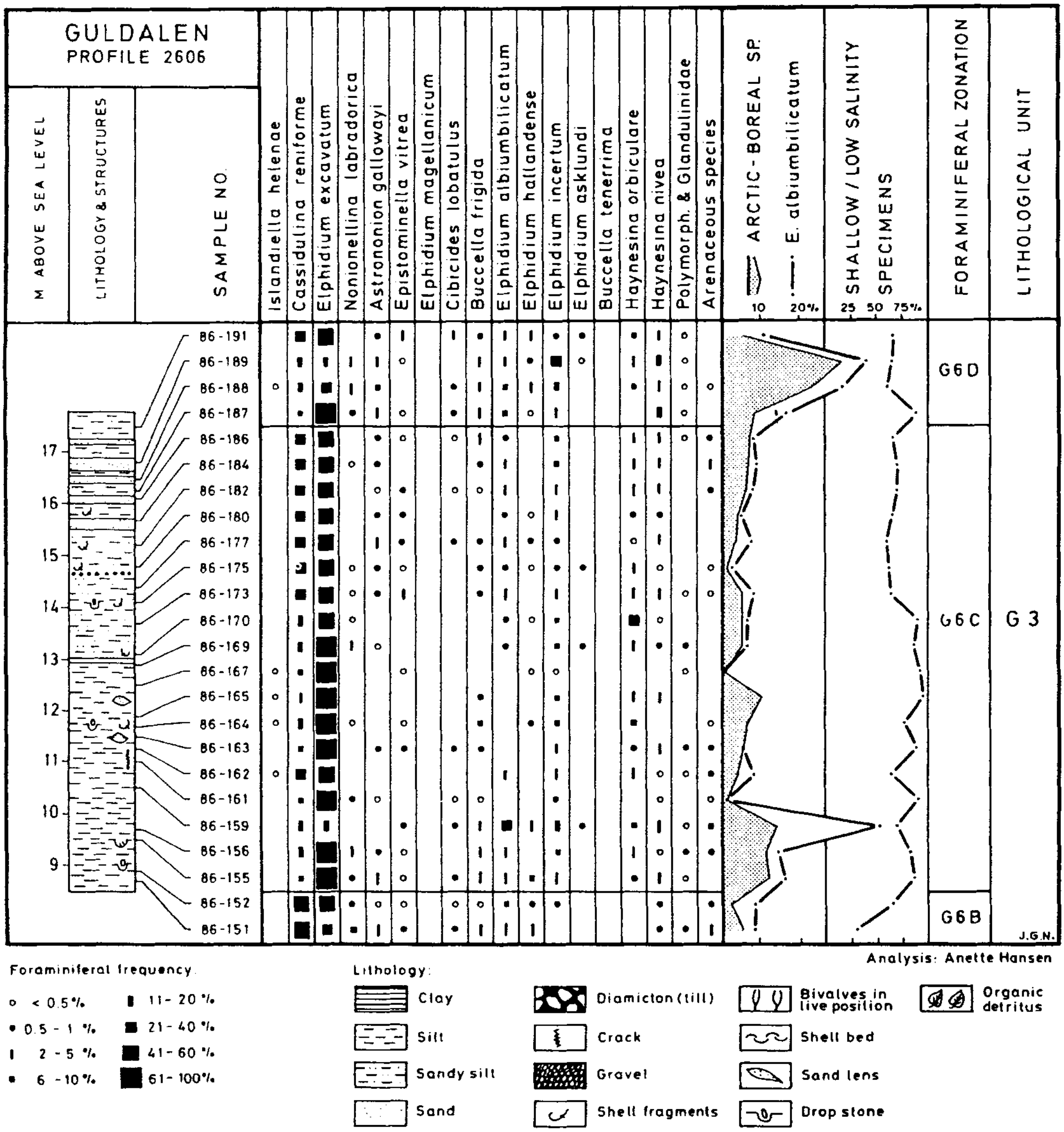

Fig. 7. Percentage range chart of selected foraminiferal species (percentages of the total fauna) and faunal parameters (percentages of arctic-boreal specimens and shallow water/low salinity specimens, see Table 3) from profile 2606 (location, Fig. 1D). The shaded area indicates the arctic-boreal content without *Elphidium albiumbilicatum*, while the solid curve indicates this content with *E. albiumbilicatum* included.

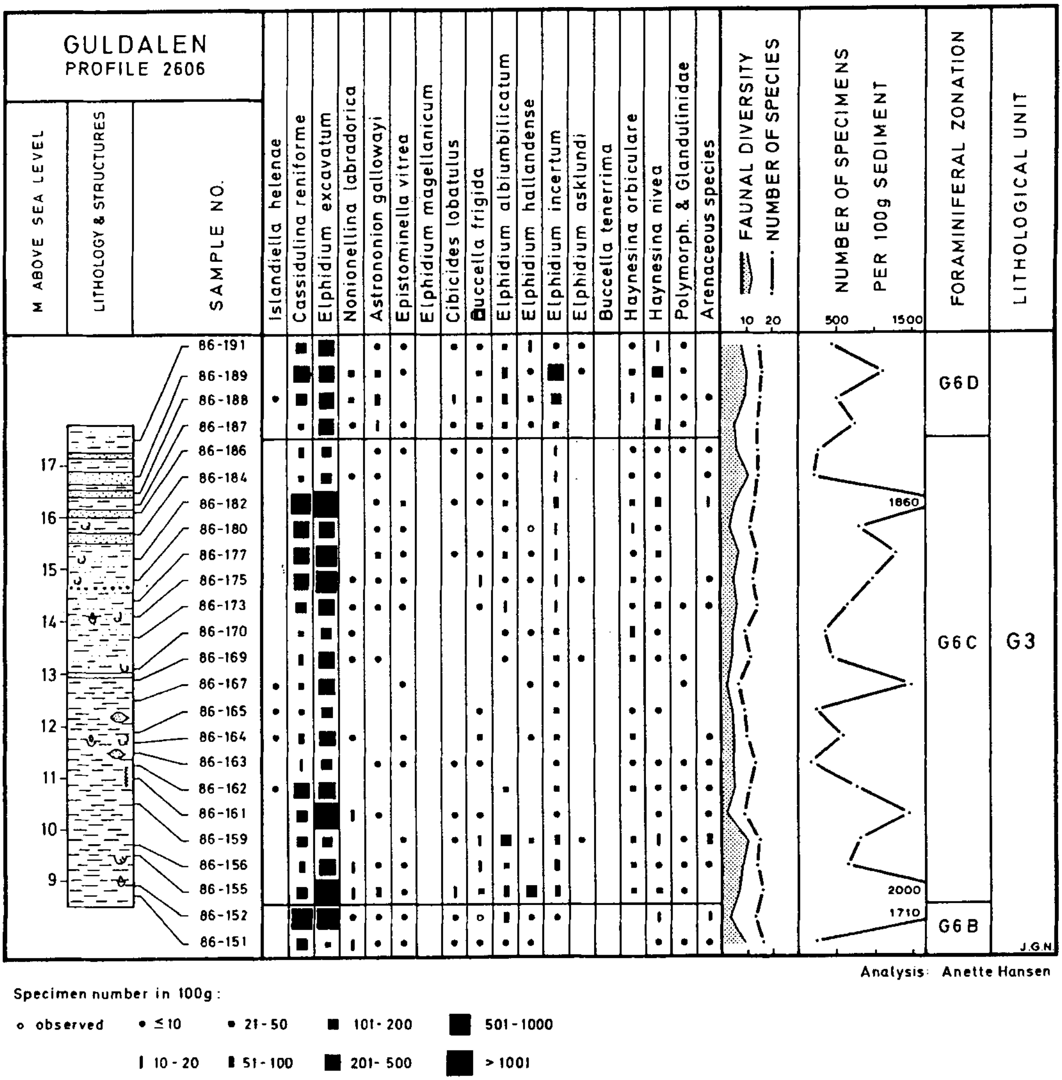

Fig. 8. Abundance range chart of selected foraminiferal species (concentrations per 100 g sediment) and faunal parameters (total number of specimens per 100 g sediment, faunal diversity index and number of species) from profile 2606 (location, Fig. 1D). Legend for lithology, Fig. 7.

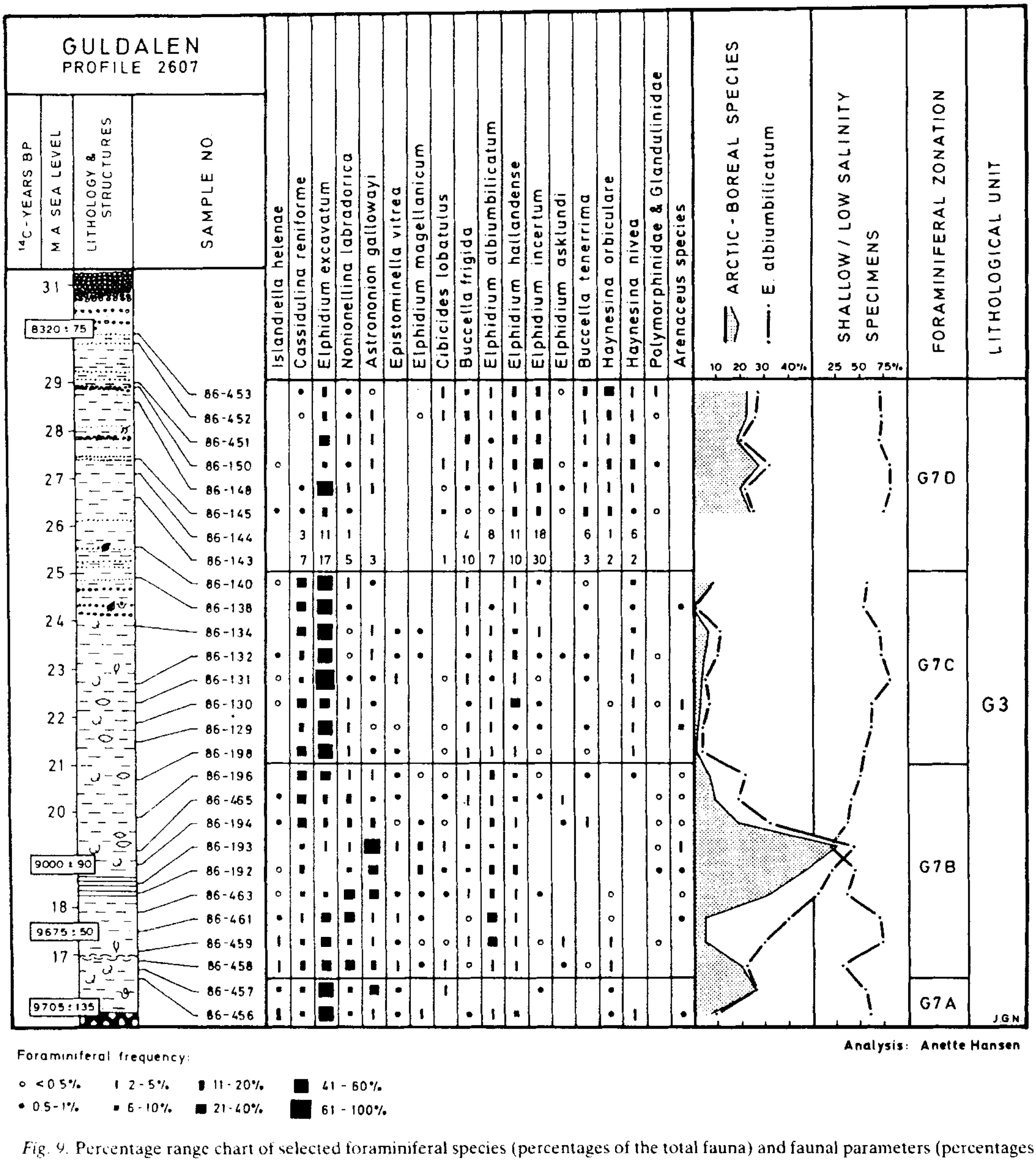

Fig. 9. Percentage range chart of selected foraminiferal species (percentages of the total fauna) and faunal parameters (percentages of arctic-boreal specimens and shallow water/low salinity specimens, see Table 3) from profile 2607 (location, Fig. 1D). The shaded area indicates the arctic-boreal content without *Elphidium albiumbilicatum*, while the solid curve indicates this content with *E. albiumbilicatum* included. Legend for lithology, Fig. 7.

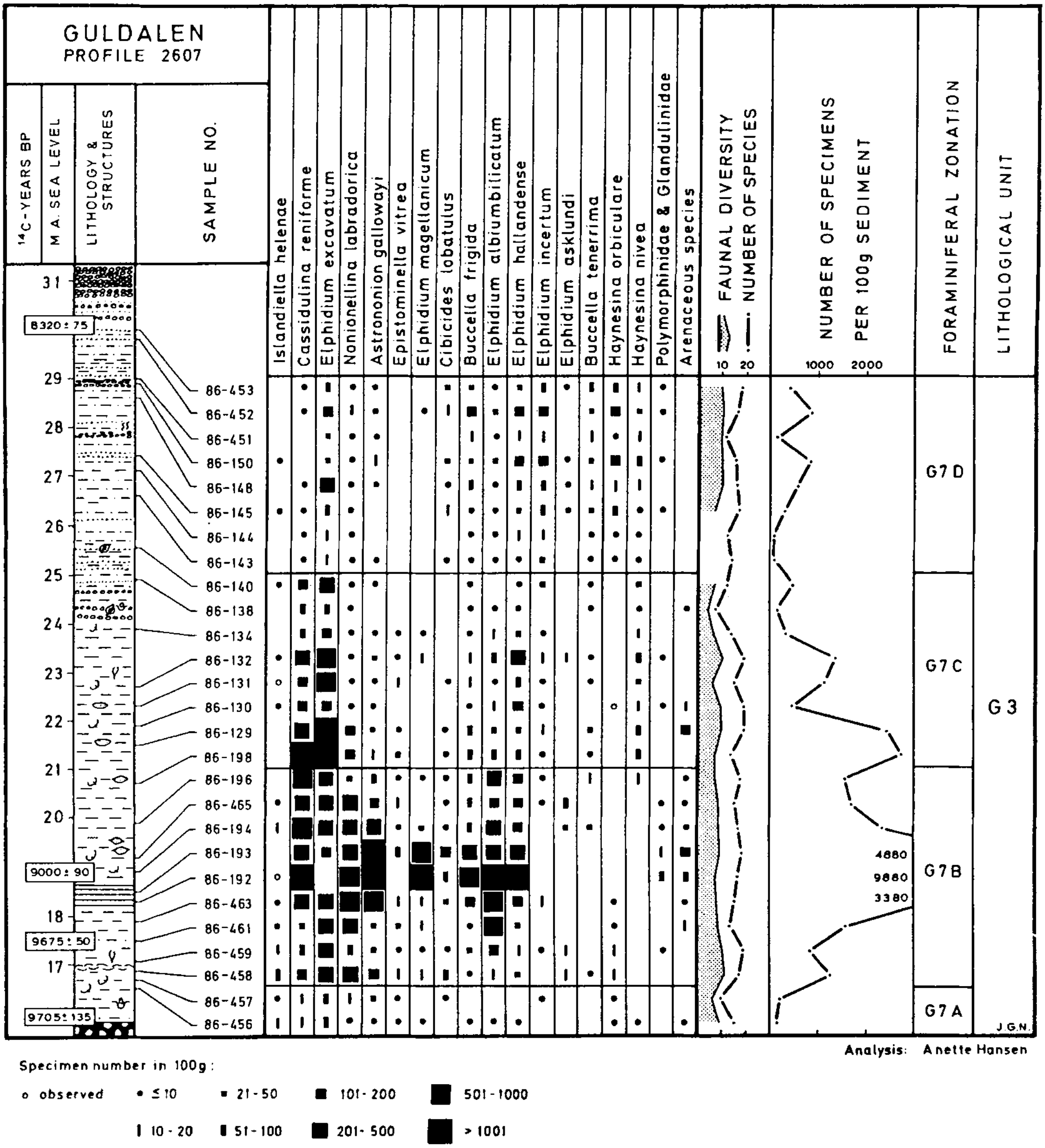

Fig. 10. Abundance range chart of selected foraminiferal species (concentrations per 100 g sediment) and faunal parameters (total number of specimens per 100 g sediment, faunal diversity index and number of species) from profile 2607 (location, Fig. 1D). Legend for lithology, Fig. 7.

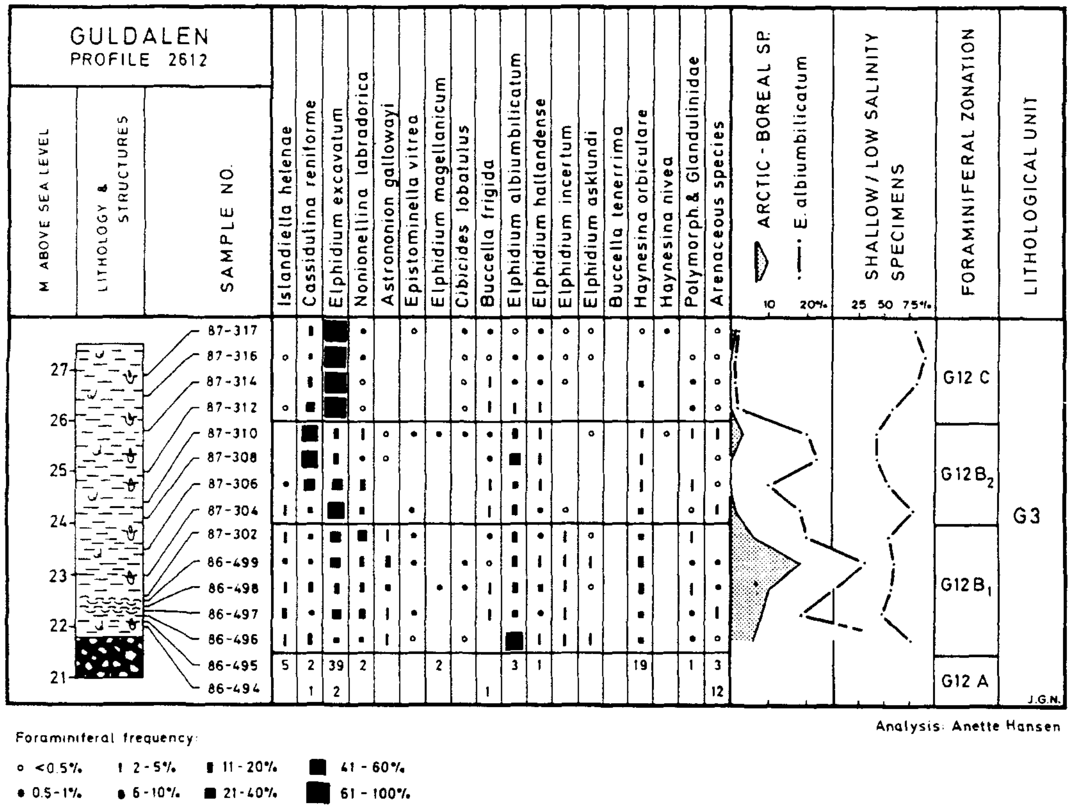

Fig. 11. Percentage range chart of selected foraminiferal species (percentages of the total fauna) and faunal parameters (percentages of arctic-boreal specimens and shallow water/low salinity specimens, see Table 3) from profile 2612 (location, Fig. 1D). The shaded area indicates the arctic-boreal content without *Elphidium albiumbilicatum*, while the solid curve indicates this content with *E. albiumbilicatum* included. Legend for lithology, Fig. 7.

the deposits into four different units, Units G1, G2, G3 and G4 (for descriptions, see Fig. 6). Molluscs, mainly *Mya truncata* Linné but also *Hiatella arctica* (Linné), are present from the base of Unit G3 and occur continuously, characteristically concentrated in a 30 cm thick bed about 1 m above the base, between sites 2607 and 2605. Only scattered mollusc shells are found above this level together with ice-dropped material. The unit coarsens upwards in all the studied sections and contains fine-grained sand laminae and beds of sands towards the top. Unit G4, which consists of sand and gravel, occurs only at profile 2607 (Fig. 6).

The lithology of each of the four studied sections is illustrated in Figs. 7–14.

Foraminiferal zonation and paleoenvironment

The deposits in Guldalen are divided into four foraminiferal assemblage zones, named Zones A, B, C and D. The assemblage characteristics are illustrated on the distribution diagrams of Figs. 7–14.

Zone A, the Elphidium excavatum Zone, has been recorded in profiles 2607, 2612 and 2605 (Zones G7A, G12A and G5A) in the inner part of the valley. *Elphidium excavatum* usually dominated in these low density assemblages with *Cassidulina reniforme* and a few other foraminiferal species as secondary species (Figs. 9–14). Such assemblages reflect extreme glacial marine environments (Hald et al. 1994; Steinsund et al. in press). Similar faunas were found in Freemansundet close to Freemanbreen (Figs. 2 and 3) and seem to be typical in areas close to glaciers where the water is influenced by cold, sediment loaded meltwater (see also Aasgaard 1978; Elverhøi et al. 1980; Nagy 1984; Hald et al. 1994).

Zone A is interpreted to be deposited in a

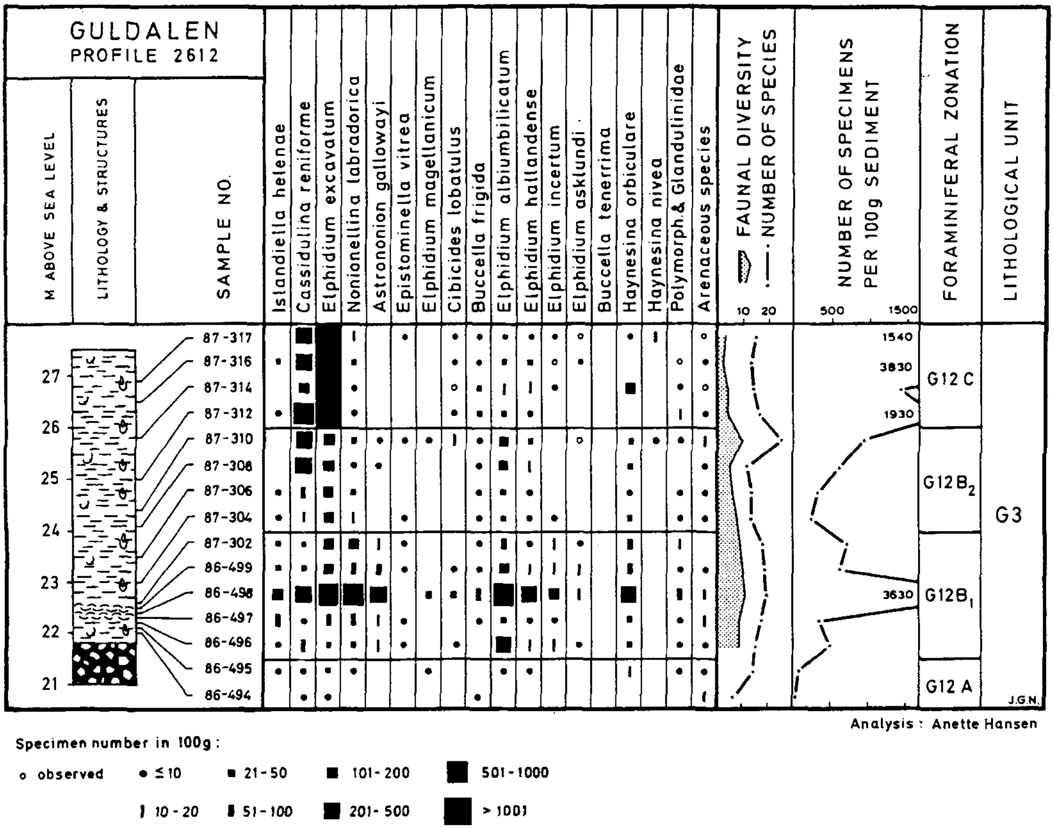

Fig. 12. Abundance range chart of selected foraminiferal species (concentrations per 100 g sediment) and faunal parameters (total number of specimens per 100 g sediment, faunal diversity index and number of species) from profile 2612 (location, Fig. 1D). Legend for lithology, Fig. 7.

glaciomarine fjord environment during and just after the deglaciation of the Guldalen valley.

Zone B, the Astrononion gallowayi-Nonionellina labradorica Zone occurred in all the studied profiles (Zones G6B, G7B, G12B and G5B, Figs. 7–14). The assemblages were rich in specimens and had a high content of *Astrononion gallowayi*, *Cassidulina reniforme*, *Nonionellina labradorica* and *Elphidium albiumbilicatum*, together with *Elphidium excavatum*.

The pronounced increase in the arctic-boreal species group and the decrease in the amount of shallow water/low salinity species in this zone (Figs. 7, 9, 11 and 13) indicate a marked change in environmental condition compared to Zone A. In general, the assemblages indicate a more stable environment with a slightly increased water temperature, higher salinity and relatively deep water.

A comparison of the Zone B assemblages in the Guldalen valley, however, reveals that the assemblages are not similar throughout the valley. Both *Astrononion gallowayi* and *Nonionellina labradorica* are relatively more important in the outer part of the valley (profile 2607, Zone G7B). This presumably indicates deeper water and higher salinity conditions here than in the inner part (profiles 2612 and 2605, Zones G12B and G5B), where *Elphidium excavatum* and *Cassidulina reniforme* were relatively more frequent.

Although *Astrononion gallowayi* and *Nonionellina labradorica* were not very frequent in any of the surface samples from Freemansundet, previous data (Aasgaard 1978; Elverhøi et al. 1980; Lycke et al. 1992; Slinning 1993; Hald et al. 1994; Steinsund et al. in press) relating to these two species in Svalbard gives credence to the conclusions drawn from the fossil faunas in Zone B. *A. gallowayi* was most common in the deeper part of the Western Transect in Freemansundet (Fig.

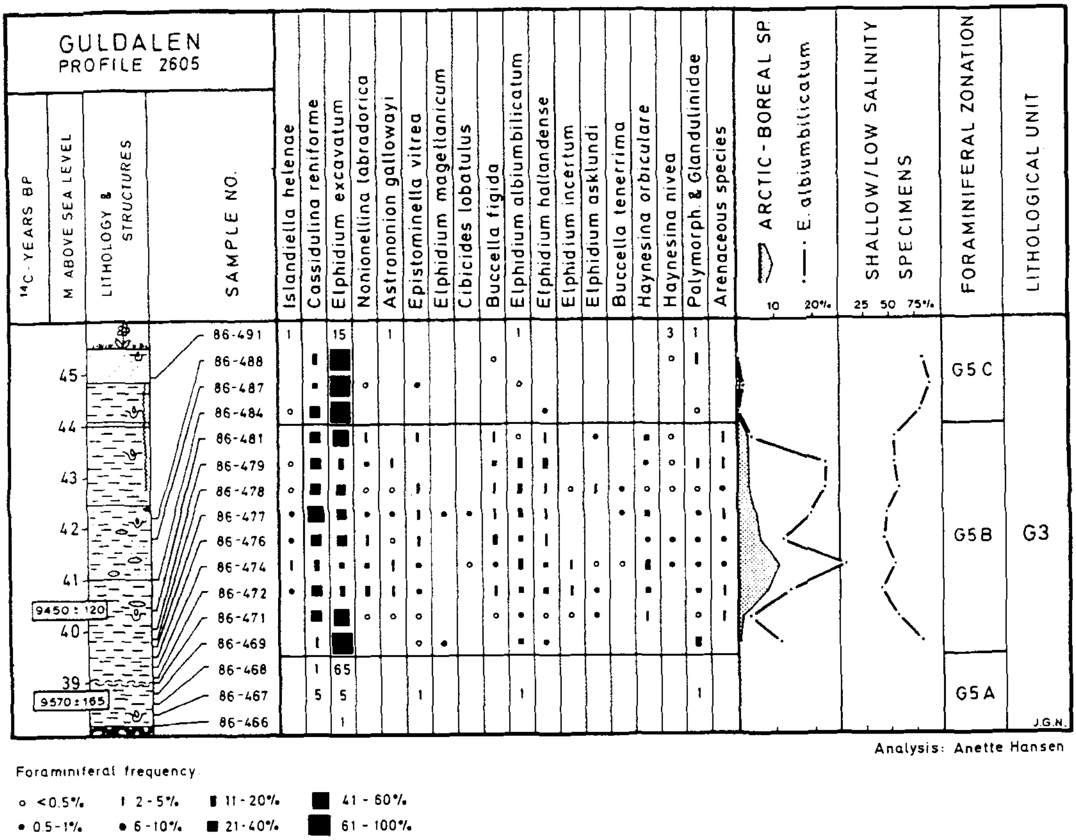

Fig. 13. Percentage range chart of selected foraminiferal species (percentages of the total fauna) and faunal parameters (percentages of arctic-boreal specimens and shallow water/low salinity specimens, see Table 3) from profile 2605 (location, Fig. 1D). The shaded area indicates the arctic-boreal content without *Elphidium albiumbilicatum*, while the solid curve indicates this content with *E. albiumbilicatum* included. Legend for lithology, Fig. 7.

5), but it also occurred close to Freemanbreen (Fig. 3). Previous studies of the present distribution of assemblages around Svalbard, especially in the present fjord systems, however, show that *A. gallowayi* and *N. labradoricum* usually occur together in areas with relatively stable environmental conditions under the influence of Atlantic Water masses.

A very high concentration of both mollusc shells and foraminiferal tests presumably indicates a low sedimentation rate during deposition of Zone B. This interpretation is also supported by the lithological characteristics of the zone (see Landvik et al. 1992). Zone B is interpreted to have been deposited during a cold period, in which glacier stagnation prevented almost any outflow of meltwater with suspended material. This would allow an influx of relatively stable high salinity Atlantic Water into the "Guldalen fjord".

Zone C, the Elphidium excavatum-Cassidulina reniforme Zone, was found in all the four profiles in Guldalen (Zones G6C, G7C, G12C and G5C; Figs. 7–14). There was a marked increase in the relative abundance of *Elphidium excavatum* at the transition from Zone B to Zone C. *Cassidulina reniforme* was always a common species in Zone C, while *Elphidium hallandense* and *Haynesina nivea* were especially common in the outer part of the valley (profiles 2606 and 2607; Figs. 7, 8 and 9, 10). There was a pronounced decrease in absolute abundance and in the content of the arctic-boreal species group and an increase in shallow water/low salinity specimens in Zone C compared to Zone B.

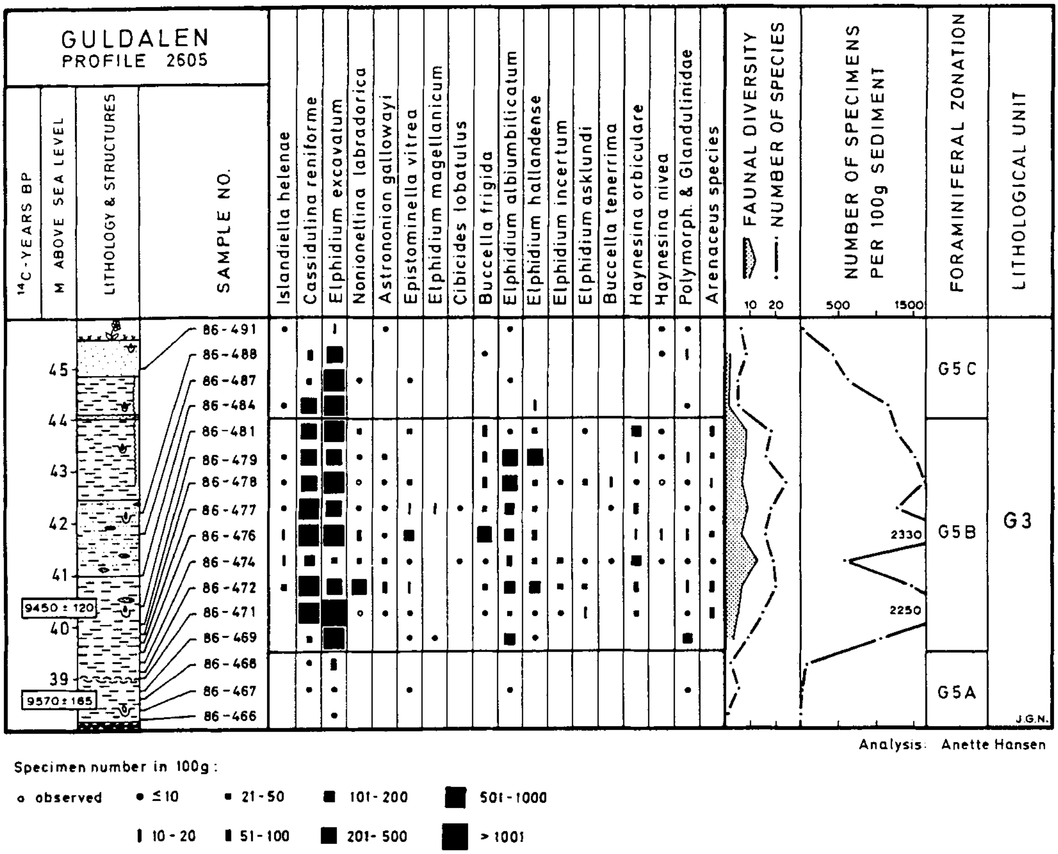

Fig. 14. Abundance range chart of selected foraminiferal species (concentrations per 100 g sediment) and faunal parameters (total number of specimens per 100 g sediment, faunal diversity index and number of species) from profile 2605 (location, Fig. 1D). Legend for lithology, Fig. 7.

The dominance of *E. excavatum* and *C. reniforme* in Zone C indicates glaciomarine conditions, and the faunal distribution along the valley points to a more ice proximal environment in the inner than in the outer part of the "Guldalen fjord". Zone C is thus interpreted to be deposited during a new period of glacier retreat. A lower faunal diversity in Zone C in the inner part of the valley (Figs. 12 and 14) than in its outer part (Figs. 8 and 10) supports this interpretation.

Zone D, the Elphidium incertum Zone, only occurred in the profiles 2606 and 2607 from the outer part of the Guldalen valley (Figs. 7, 8 and 9, 10). A typical feature for the assemblages was the relatively high percentage of *Elphidium excavatum* together with *E. incertum*, *E. hallandense*, *E. albiumbilicatum*, *Haynesina nivea*, *H. orbiculare*, and a few specimens of *Cibicides lobatulus*. There was a relatively high number of the arctic-boreal species group in Zone D, while the number of shallow water/low salinity specimens was about the same as in the upper part of Zone C.

The faunal composition in Zone D thus indicates shallow water conditions with some influence of higher temperature water masses. *Elphidium incertum* usually points to relatively open and well-oxygenated water conditions (e.g. Leslie 1965; Lutze 1965, 1974), and both this species and *E. hallandense* and *H. orbiculare* are often associated with silty to sandy substrate (e.g. Leslie 1965 and Poag 1982, *Elphidium hallandense* referred to by both as *E. subarcticum* Cushman).

The faunal composition in Zone D is relatively similar to the shallow *Elphidium incertum-Haynesina orbiculare* assemblage in the southwestern part of Freemansundet (Figs. 2 and 5), which is suggested to be influenced by higher temperature water masses from Storfjorden.

The Zone D assemblages are interpreted to represent shallow water marine sediments deposited during the final uplift of the Guldalen area. The assemblages reflect a gradually warmer climate and a marine environment close to that found at present in the same area. The area, thus, seems to have been under the influence of the higher temperature Atlantic Water masses from Storfjorden.

Correlation

The Guldalen profiles

A biostratigraphical correlation between the four studied sections in Guldalen is shown in Fig. 15 together with the results of ^{14}C datings from two of the profiles (Table 2). Due to different distances to a melting glacier and to the open water at the mouth of the former fjord, there is some change in the foraminiferal assemblages within each zone from northwest to southeast in Guldalen. This is especially true for assemblage Zones B and C, which clearly indicate that the south-

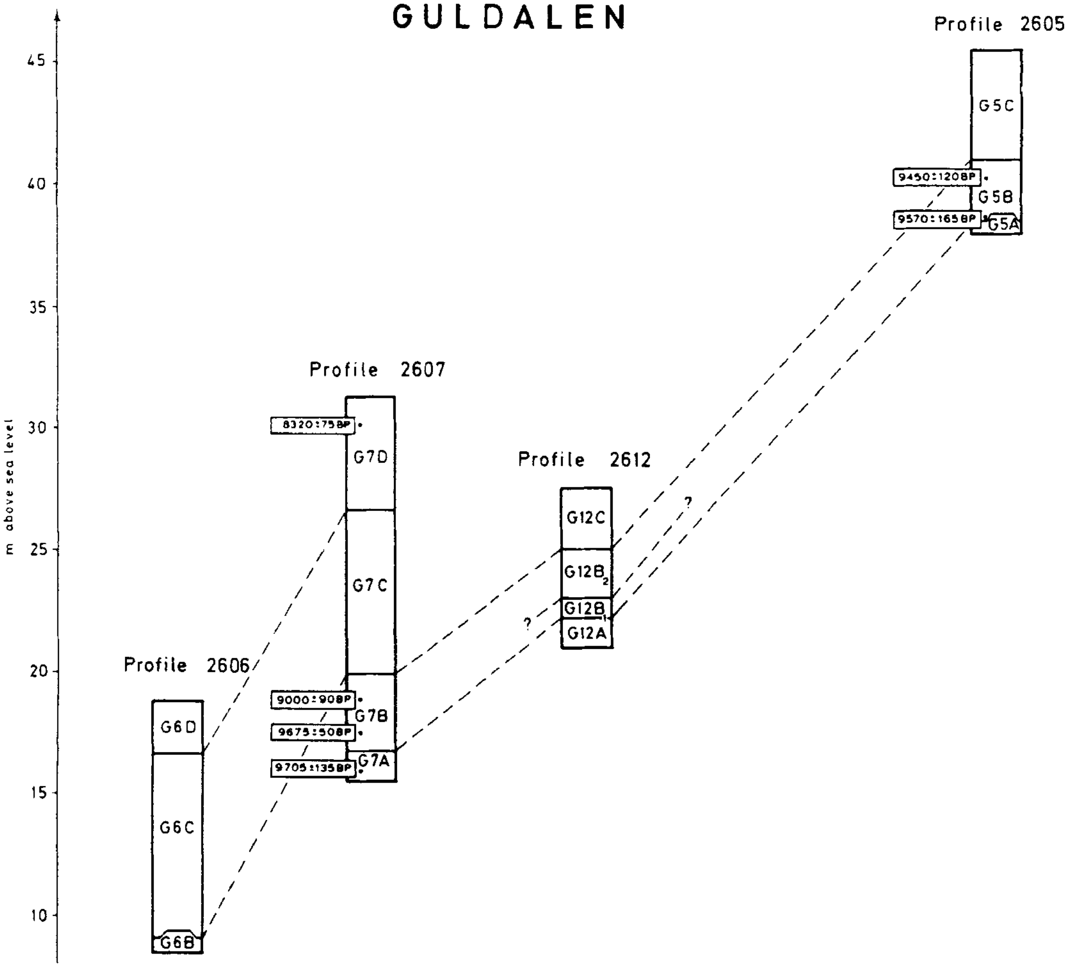

Fig. 15. Cross-correlation between the profiles 2606, 2607, 2612 and 2605 in Guldalen. Foraminiferal zonation and ^{14}C dates are indicated.

eastern part of the valley must have been located closer to the glaciation center than the northwestern part, and that the northwestern part must have been closer to the open water masses of Storfjorden. In addition to this, the ^{14}C datings suggest that the zone boundaries are slightly time transgressive. Zone B thus appears to cover a longer period of time at site 2607 in the outer part of the fjord than at site 2605 in the inner part. A hiatus in the upper part of Zone B at site 2605 cannot be excluded, however. Zone D only occurs in the outermost part of the valley.

Correlation with adjacent areas

The foraminiferal assemblages in Guldalen have been compared with similar faunas described from adjacent areas, in particular with sections from the northern part of Edgeøya, which were described by Nagy (1984). A compiled foraminiferal diagram for the raised glaciomarine and marine sequence in Visdalen (Fig. 1) and Raundalen (northeast of Visdalen) has been compiled by Nagy (1984), and our results are correlated with his results in Fig. 16.

Nagy (1984) registered a glaciomarine *Elphidium excavatum* assemblage at the base of the sections in Visdalen, and the marine transgression was dated to late Younger *Dryas* time, at ca 10,200 BP (Fig. 16). A similar assemblage, which was dated at 10,300 BP, has also been found in Blåfjorddalen in east Edgeøya (Fig. 1) (Landvik et al. 1992). In Guldalen, however, the *Elphidium excavatum* assemblage did not appear until close to 9700 BP, indicating a somewhat later deglaciation in this area.

The *Astrononion gallowayi-Nonionellina labradorica* assemblage zone (Zone B) in Guldalen

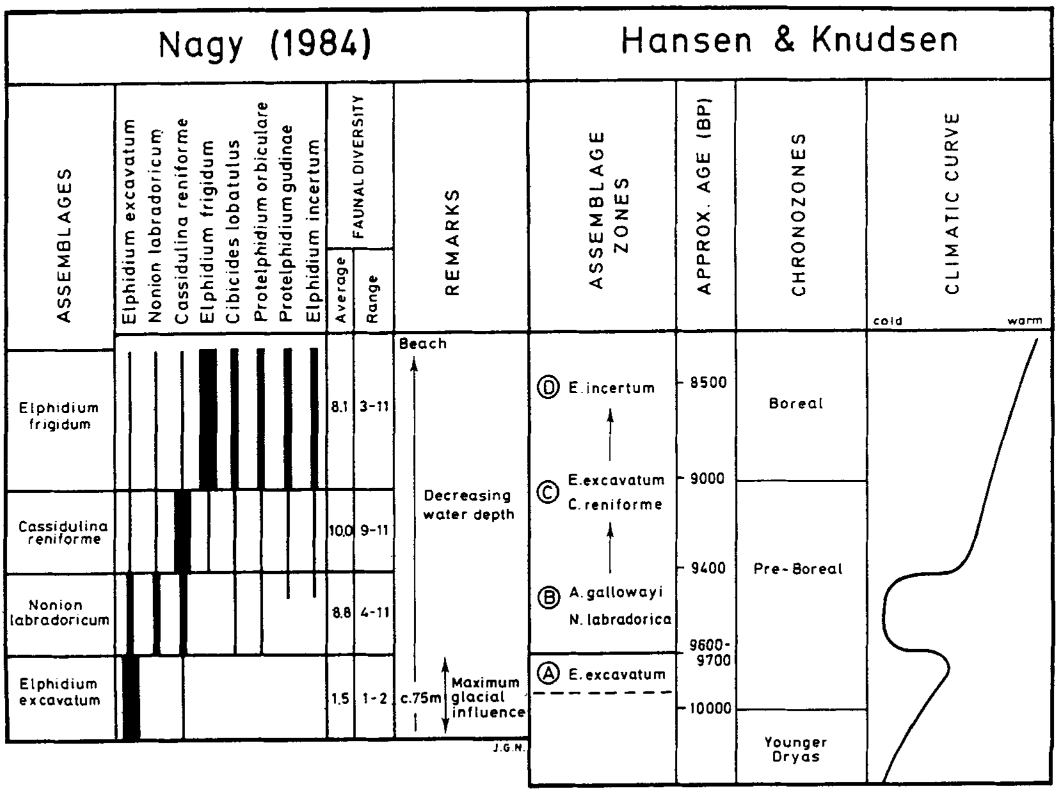

Fig. 16. Stratigraphical correlation between the foraminiferal assemblages of Nagy (1984) and the present results from Guldalen. The climatic development through the Younger Dryas and Early Holocene is suggested on the basis of foraminiferal indications. The climatic curve indicates the air temperature, not the water temperature. Chronozones are used in accordance with Mangerud et al. 1974.

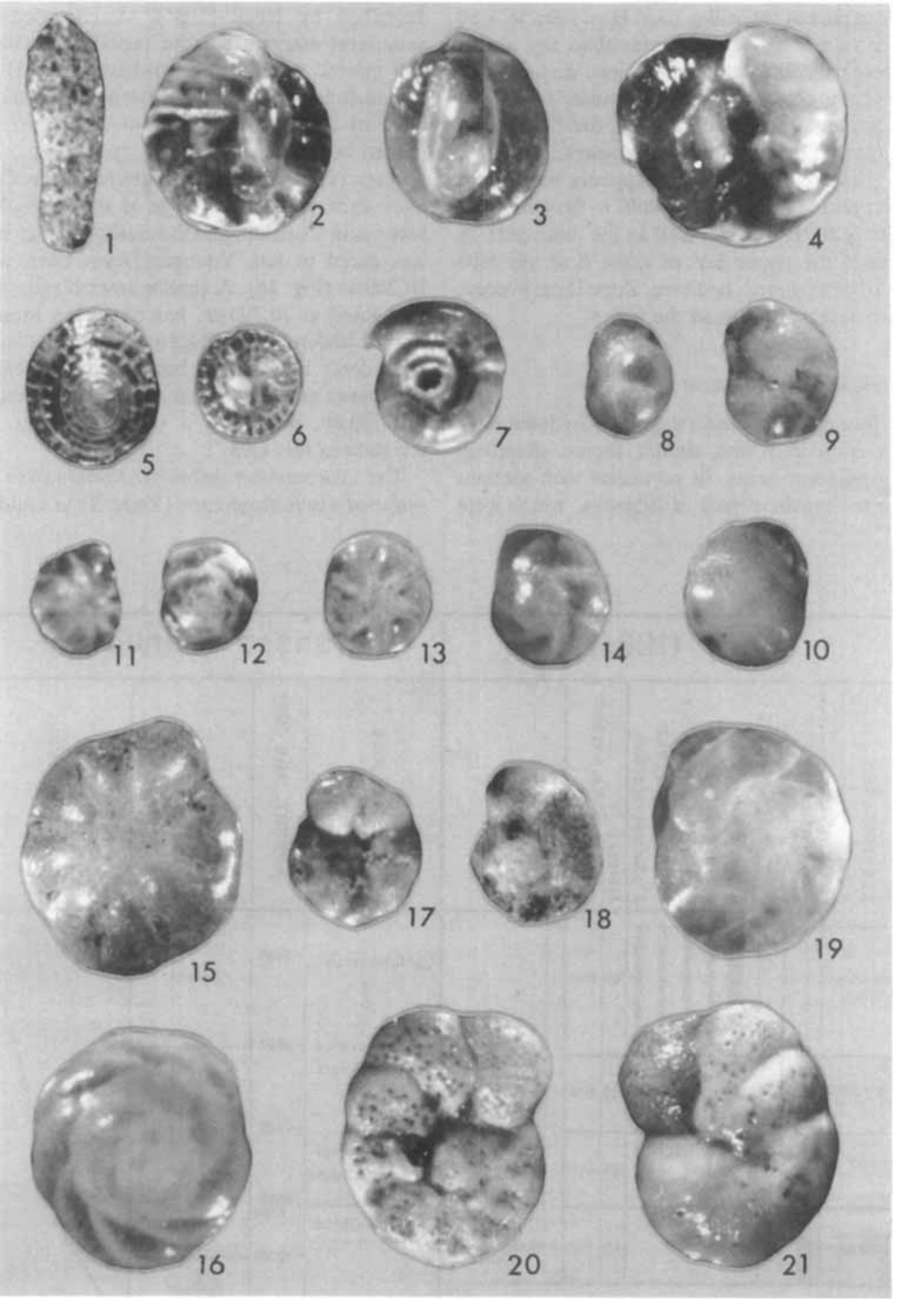

Fig. 17. Selected foraminifera from Freemansundet and Guldalen, Svalbard. Light microscope photographs: 1 *Spiroplectammina biformis* (×90); 2–4 *Pateoris hauerinoides* (nos. 2 and 4 × 75, no. 3 × 90); 5–6 *Patellina corrugata* (×90); 7 *Cornuspira involvens* (×75); 8–10 *Cassidulina reniforme* (×90); 11–12 *Epistominella vitrea* (umbilical side ×110, spiral side ×90); 13–14 *Buccella frigida* (umbilical side and spiral side, both ×90); 15–16 *Buccella tenerrima* (umbilical side and spiral side, both ×90); 17–18 *Rosalina vilardeboana* (umbilical side ×105, spiral side ×85); 19 *Islandiella helenae* (×70); 20–21 *Cibicides lobatulus* (spiral side and umbilical side, both ×75).

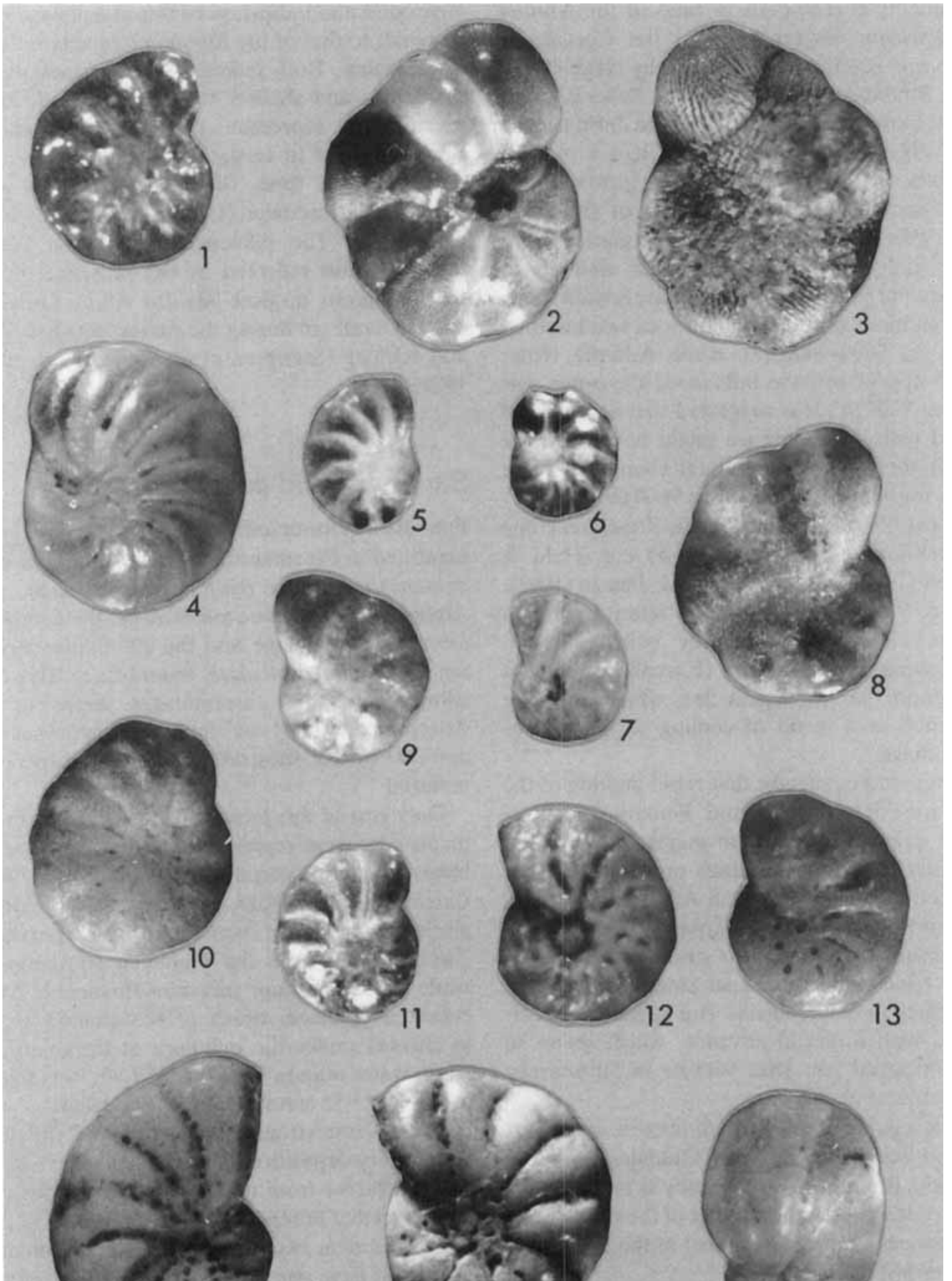

Fig. 18. Selected foraminifera from Freemansundet and Guldalen, Svalbard. Light microscope photographs: 1 *Astrononion gallowayi* (×90); 2–3 *Trichohyalus bartletti* (spiral side and umbilical side, both ×30); 4 *Haynesina orbiculare* (×75); 5–7 *Haynesina nivea* (×105); 8 *Elphidium hallandense* (×60) (this form was separated as *Elphidium frigidum* by Nagy 1984); 9 *Elphidium albiumbilicatum* (×90); 10–12 *Elphidium excavatum*, forma *clavata* (no. 10 × 60, nos. 11–12 × 90); 13 *Elphidium incertum* (×70); 14 *Elphidium bartletti* (×35); 15 *Elphidium asklundi* (×45); 16 *Nonionellina labradorica* (×70).

presumably corresponds in time to the *Nonion labradoricum* assemblage and the *Cassidulina reniforme* assemblage registered by Nagy (1984) from Raundalen (Fig. 16). This zone is interpreted to represent a period of time during which relatively stable Atlantic Water had a marked influence on the environment in the fjord systems. The assemblage in the inner part of Guldalen, which must have been close to the glacier front, is especially characterised by high amounts of *Cassidulina reniforme*. Here relatively stable marine conditions only prevailed for ca two hundred years (ca 9600–9400 BP), while Atlantic Water would appear to have influenced the outer part until ca 9000 BP. It is suggested that a short cold period with stagnating ice might have been the reason for this environmental change to more stable marine conditions at ca 9600 BP.

A possible cold spell within the Pre-Boreal time has previously been reported by e.g. Hald & Vorren (1984) and Koç Karpuz & Jansen (1992). Hald & Vorren (1984) found a relative increase in the amount of sinistrally coiled *Neogloboquadrina pachyderma* (Ehrenberg) at ca 9700 BP in the Norwegian Sea, which might be explained as a result of cooling of the surface water masses.

Other studies suggest that rapid melting of the Svalbard-Barents shelf and Fennoscandia ice-sheets prior to ca 9600 BP might have created a density stratification, which prevented contact between the relatively warm Atlantic Water and the atmosphere (see Koç Karpuz & Jansen 1992). The resulting lowered sea surface temperature might have caused a glacier stagnation or even readvance in Scandinavia. This presumably correlates with a glacial advance, which seems to have occurred just after 9600 BP in Spitsbergen (Salvigsen et al. 1990).

A correlation of the *Elphidium excavatum-Cassidulina reniforme* Zone in Guldalen with the Visdalen/Raundalen stratigraphy is uncertain. It might correspond either to part of the *Cassidulina reniforme* assemblage or to part of the *Elphidium frigidum* assemblage.

The upper part of the marine sequence in Visdalen and Raundalen (Nagy 1984), the *Elphidium frigidum* assemblage, is dominated by *E. frigidum* Cushman (included in *E. hallandense* in the present work), and species such as *Haynesina orbiculare*, *H. nivea* (called *Protelphidium gudinae* Feyling-Hanssen), *Cibicides lobatulus* and *Elphidium incertum* are also frequent. The environmental indication of this assemblage corresponds to that of the *Elphidium incertum* Zone in Guldalen. Both indicate slightly ameliorated conditions and shallow water depths, and they presumably represent the final period of regression due to isostatic rebound in the area during Boreal time. Similar assemblages also occur in Blåfjorddalen (Landvik et al. 1992) from ca 8300 BP. The influence of Atlantic Water masses is also reflected by the presence of the thermophilous mollusc *Mytilus edulis* Linné in eastern Svalbard during the period between 8700 and 5000 BP (Salvigsen et al. 1992; Hjort et al. 1995).

Summary and conclusions

Four distinct foraminiferal assemblages have been identified in Freemansundet, the *Elphidium excavatum-Cassidulina reniforme* assemblage, the *Elphidium hallandense* assemblage, the *Cibicides lobatulus* assemblage and the *Elphidium incertum-Haynesina orbiculare* assemblage. The distribution of these assemblages seems to be determined by local environmental factors such as current velocity, substrate, salinity and suspended material.

Only two of the present faunal types in Freemansundet were represented in the fossil assemblages from Guldalen. The *Elphidium excavatum-Cassidulina assemblage*, which reflects a proximal glacier environment, was found in ice proximal Zones A and C in the Guldalen stratigraphy, while the *Elphidium incertum-Haynesina orbiculare* assemblage, which reflects shallow water in an area under the influence of the relatively warm water masses from Storfjorden, was found in the Zone D assemblages of Guldalen.

The paleoenvironmental setting of the late Quaternary deposits in Guldalen must have been quite different from that in Freemansundet due to the fact that Freemansundet represents an open sound between two islands, while the Guldalen area must have comprised a closed fjord system, which only opened into Storfjorden to the west.

The foraminiferal assemblages in Guldalen revealed a glaciomarine to marine environmental development through Early Holocene time. A marine transgression occurred immediately after the initial deglaciation in the area, which started at ca 9700 BP. After deposition of the glaciomarine *Elphidium excavatum* Zone (Zone A), there are faunal indications of a cold period, in which glacial stagnation allowed relatively stable Atlantic Water masses to enter into the Guldalen fjord (Zone B, the *Astrononion gallowayi-Nonionellina labradorica* Zone). A succeeding period of melting is reflected in the *Elphidium excavatum-Cassidulina reniforme* Zone assemblages (Zone C). Continuous and rapid isostatic uplift in the area is documented by an increasing amount of shallow water foraminifera through Zones C and D, and the assemblages in the *Elphidium incertum* Zone (Zone D) indicate the final regression in the area (around 8300 BP).

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