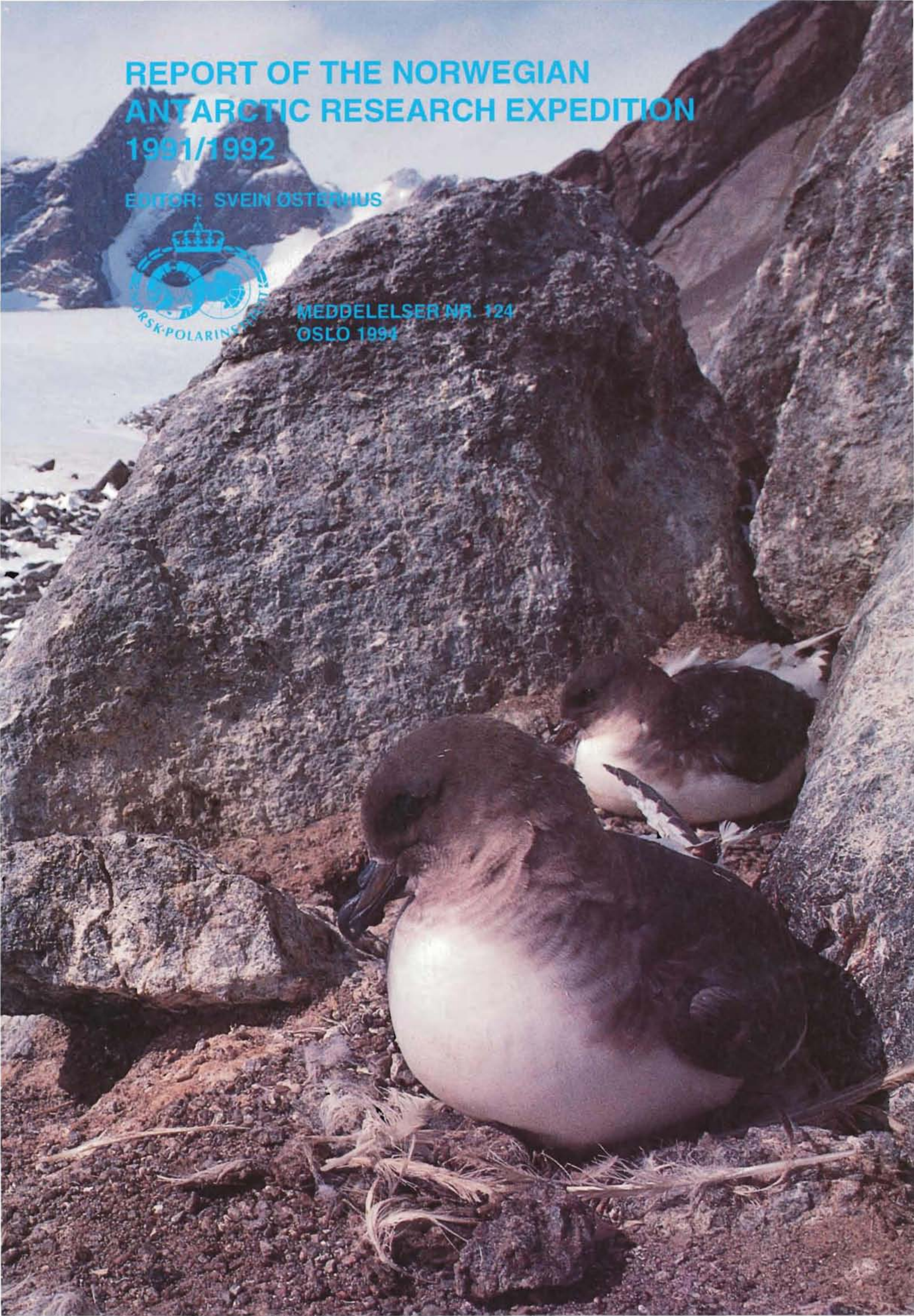

REPORT OF THE NORWEGIAN ANTARCTIC RESEARCH EXPEDITION 1991/1992

EDITOR: SVEIN ØSTERHUS

NORSK POLARINSTITUTT
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CONTENTS

GENERAL REPORT ON THE 1991/92 NARP EXPEDITION

by

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INTRODUCTION

The Norwegian Antarctic Research Expedition (NARE) 1991/92 was part of the Nordic Antarctic Research Programme (NARP) which also includes the Finnish Antarctic Research Programme (FINNARP) and the Swedish Antarctic Research Programme (SWEDARP).

FINNARP was in charge of transportation to and from the Antarctic. The Russian ship Akademik Fedorov was used for transport of equipment and personnel from Montevideo to Dronning Maud Land.

SCIENTIFIC PROGRAMME

Three research programmes were carried out:

Monitoring of seabirds at Svarthamaren:

Svarthamaren is a Site of Special Scientific Interest (SSSI). A long-term research programme on seabirds (Antarctic Petrel, Snow Petrel, and South Polar Skua) has been in operation since NARE 84/85.

Oceanography, Glaciology, and Geology at Fimbulisen:

The melting and freezing on and underneath the ice shelf were investigated, and studies of ocean current and tides underneath the ice shelf were done by instrument moorings, temperature and salinity probes, and water samplers.

Studies of sedimentation below the ice shelf were carried out by means of gravity coring and bottom photography.

Glaciology at Riiser-Larsenisen and Vestfjella:

Studies of melting and freezing underneath the ice shelf were carried out by means of radar. The heat flux around the blue ice area was also investigated.

In addition to the scientific research discussed in this report, construction work and maintenance of the Norwegian research station Troll were also carried out (Kvannli, Nøst, and Østerhus).

LIST OF PARTICIPANTS

Name	*Institute*	*Location*
George Bangjord	NINA	Svarthamaren
Svein-Håkon Lorentsen	NINA	Svarthamaren
Nils Røv	NINA	Svarthamaren
Bent Kvannli	NP	Jutulgryta/Troll
Ole Anders Nøst	UiB, GI	Jutulgryta/Troll
Svein Østerhus	NP	Jutulgryta/Troll
Bjørn Erlingsson	NP	Vestfjella
Yngvar Gjessing	UiB, GI	Vestfjella
Erik Selmer	NTB	Akademik Fedorov

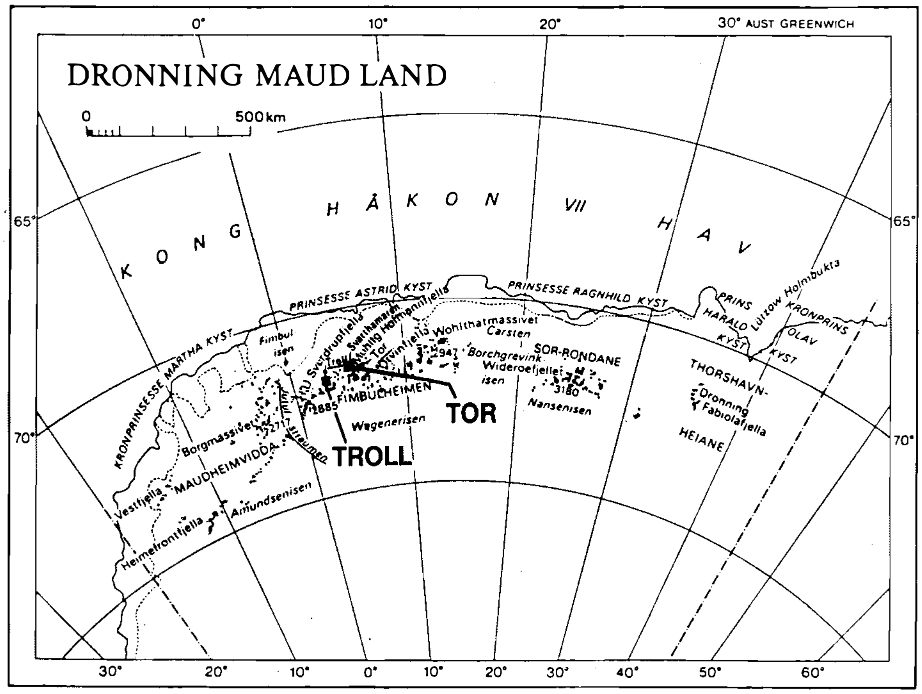
Institutions:

NP	Norwegian Polar Institute
NINA	Norwegian Institute for Nature Research
UiB, GI	University of Bergen, the Geophysical Institute
NTB	Norwegian News Agency

NARRATIVE

The participants of NARE left Norway on 2 November and went on board Akademik Fedorov on 3 November in Montevideo. AKADEMIK FEDOROV left Montevideo on 6 November. The ship sailed via King George Island bringing supplies to the Polish station Arctowski and the Russian station Bellingshausen.

Due to unfavourable ice conditions, AKADEMIK FEDOROV had to sail further to the east than planned. On 24 November we were approximately 150 nautical miles north of Fimbulisen. The ice conditions made it impossible to get any closer. From this position equipment and expedition members going to work at Svarthamaren and Jutulgryta were flown onto the ice shelf by Russian MI-8 helicopters. From there we had to use snowscooters to reach Troll and Svarthamaren.



AKADEMIK FEDOROV sailed on to Rampen by Kvitkuven, Riiser-Larsenisen. Rampen was the place of discharge of FINNARP and SWEDARP, and also Gjessing and Erlingsson. They left the ship on 3 December.

The scientists working at Svarthamaren and Fimbulisen went to Troll by the end of the season. The Russian helicopter fetched them there on 15 February. The group at Vestfjella was fetched on 20 February together with the SWEDARP and FINNARP participants.

AKADEMIK FEDOROV left Riiser-Larsenisen on 23 February and arrived in Montevideo on 5 March.

CONCLUSIONS

The collaboration with FINNARP and SWEDARP was excellent. The stay on board Akademik Fedorov was comfortable, but rather long. Transportation by Russian MI-8 helicopters was acceptable, but there were problems due to difficulties in communicating and lack of safety measures. Using snowscooters from Fimbulisen to Troll and Svarthamaren was time-consuming and laborious, but since the field season was so long, there was time enough to complete all the research programmes satisfactorily.

ACKNOWLEDGEMENTS

We would like to thank the expedition leaders and all the members of FINNARP and SWEDARP for fruitful co-operation and for contributing to an atmosphere of goodwill and friendliness. Special thanks to the Russian Captain and the crew on board Akademik Federov and to the Russian expedition leaders.

SEABIRD STUDIES AT SVARTHAMAREN, DRONNING MAUD LAND

by

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BACKGROUND AND OBJECTIVES

According to the objectives of The Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR), the ecological relationships between harvested and dependent species must be maintained. Nations acceding to the Convention are expected to "compile data on the status of and changes in populations of Antarctic marine living resources and on factors affecting the distribution, abundance and productivity of harvested species and dependent species or populations". It is therefore important to identify and monitor species and parameters likely to be particularly sensitive to changes in environmental conditions and harvesting regimes.

There are large colonies of Antarctic Petrels *(Thalassoica antarctica)*, Snow Petrels *(Pagodroma nivea)* and South Polar Skuas *(Catharacta maccormicki)* at Svarthamaren in Dronning Maud Land (Mehlum et al. 1988; Røv 1990; Røv 1991). Both petrel species live in the pack ice areas around the continent throughout the year. Consequently, any changes occurring in these populations will be due to variation either in food availability or environmental conditions in Antarctica. The South Polar Skua is totally dependent on petrels as food during the breeding season. Therefore bird ecosystems in the interior of Antarctica are extremely suitable for monitoring purposes.

Svarthamaren, Mühlig-Hofmannfjella, Dronning Maud Land (71°53' S, 5°10' E) is a Site of Special Scientific Interest (SSSI), where a long-term monitoring programme of the populations of the Antarctic Petrel and South Polar Skua has been established. Annual investigations are planned for the next ten years. A detailed evaluation of the programme will be carried out after the first five years.

During the NARE 1989/90 expedition, eggs, juveniles and adults of seabirds were collected at Svarthamaren for analysis of organochlorines. The findings thus far clearly indicate evidence of long-range transportations of environmental pollutants and profound biomagnification through food-chains in this area (T. Nygård, unpublished). Therefore, we have also included a monitoring scheme for environmental pollutants in the programme.

The objectives of monitoring and research at Svarthamaren are as follows:

- To document long-term changes in the population dynamics of Antarctic Petrel and South Polar Skua in relation to resource availability.
- To examine whether the demography of the breeding populations on the continent differ from the pattern recorded in seabird populations in other parts of the region.
- To study ecological adaptations among Antarctic Petrel breeding in continental Antarctica.
- To elucidate the transport routes of chlorinated hydrocarbon residues, heavy metals and trace elements through food-chains and the ultimate fate of these compounds.

PRELIMINARY RESULTS

We arrived at Svarthamaren on 1 December, 1991 and left the area on 15 February, 1992. Establishment of the monitoring programme was given the highest priority. However, since our arrival was 1.5 month earlier than on preceeding expeditions to the area, there was ample opportunity to study several aspects of breeding biology which had not been examined before. The field data has not been completely analysed yet although in preliminary form some results are given in the present paper.

The mean minimum temperature during the chick period was 7-16 degrees below zero (mean 11.3, stand. dev. 3.1). Maximum temperatures was 0-10 degrees below zero (mean 4.2, stand. dev. 2.5).

1. Antarctic Petrel

Population census

A 40m x 40m grid system covering all accessible parts of the entire breeding area in the colony at Svarthamaren was established. The mid-point of each square was permanently marked in the field with aluminium poles. Their position was documented by photos (Lorentsen et al. 1993). The number of chicks within a circle

Table 1. **Estimated density and population size in Antarctic Petrel subcolonies**

Sub-colony	No. of plots	Area (1000m²)	Density (chicks/plot)		Population size	
			Mean	Standard deviation	No. of chicks	Standard error
1	48	7.68	4.98	2.74	38 240	3 038
2	113	18.08	5.43	2.88	98 240	4 900

Table 2. **Measurements and weight of breeding Antarctic Petrels and eggs. M=males, F=Females. Egg volumes were calculated as 0.551 x l x b x b/1000, where l=length and b=breadth (Warham 1990). Length measurements are in mm, volume in cubic cm and weight in g.**

		Mean	Stand. deviat.	Min	Max	N
Culmen midline	M	36.6	1.4	33.6	40.0	65
	F	34.3	1.5	30.8	36.9	54
Bill depth	M	11.2	0.5	10.0	12.2	63
	F	10.4	0.6	9.4	11.6	52
Head+bill	M	94.3	2.1	87.9	98.0	63
	F	90.1	1.9	84.4	93.7	52
Wing	M	323	6.1	311	336	63
	F	315	6.5	300	330	52
Weight	M	665	76	495	850	206
	F	633	68	445	765	122
Egg length		70.2	2.88	60.5	78.3	117
Egg breadth		47.8	1.73	38.8	51.3	117
Egg volume		88.5	8.47	50.2	109.3	117
Egg weight		89.3	8.15	70.0	112.5	47

of 10 m² around each point were counted between 17 and 31 January. The statistical procedure for estimating the total size of the breeding population has been described by Anker-Nilssen & Røstad (1993). A minor part of the colony, located situated at a high elevation and partly inaccessible, was not censused and will not be included in future monitoring.

The results are shown in Table 1. The difference between the two subcolonies in mean density is not statistically significant ($t= -1.76$, $p>0.08$). The estimated number of chicks during the census period was 136,480 (SE=5 764). Considering a 28 % egg loss and 83 % hatching success, the results indicate that about 228,000 eggs were laid in the part of the colony covered by the grid system. We assume that the inaccessible part of the colony constitutes around 10 % of the total area. The total breeding population should therefore be 250,000 pairs. The results are consistent with earlier estimates made by Mehlum et al. (1988) and Røv (1991). According to the figures on the number of non-breeding birds, results indicate that about 820,000 individuals were associated with the colony in 1991/92. The estimated number of petrels present at any one time varied from between 360,000 and 480,000.

Demography studies

Four study plots of 9m x 15m were established during the early incubation period in order to study adult mortality and recruitment to the breeding population. Each study plot was divided into 3m x 3m grids and all breeding birds were ringed and sexed by cloacal inspection. The positions of their nests were also recorded. Prior to our departure, breeding success was recorded and chicks were ringed. A total of 948 adults occupying 605 nests (nonbreeders and failed breeders included) and 294 chicks were ringed. Altogether 554 pairs successfully raised a chick and 82 pairs were unsuccessful due to natural causes (landslide or nest destroyed by meltwater). An additional 40 birds in another study plot experienced loss of eggs or young related to our sample collecting for environmental pollutant studies. Differences in the survival rates of these two groups (successful/"failed") will be examined. The position of the study plots and the results of field-work are documented (Lorentsen et al. 1993).

The presence of non-breeding birds within the colony

The attendance pattern of non-breeding nest-holders and non-territorial individuals was studied in ten study plots. The results indicate that 70 % of the nests were occupied by birds which had laid eggs. In late January only 45 % of the nests contained a chick. The other nests were occupied by non-breeding pairs or birds that had lost their eggs or chicks (Fig. 1). Furthermore the results show that 13 % of all individuals in the study plots did not occupy a nestsite. These were probably young birds trying to establish themselves within the colony. Variation in the number of individuals present in the study plots is shown in Fig. 2. According to our observations, both successful breeders and failed breeders attended the nest until chicks became independent in late January. The number of non-breeding birds present in the colony varied during the egg and chick period, but dropped to zero when the attending breeders left their chicks. The low number recorded on January

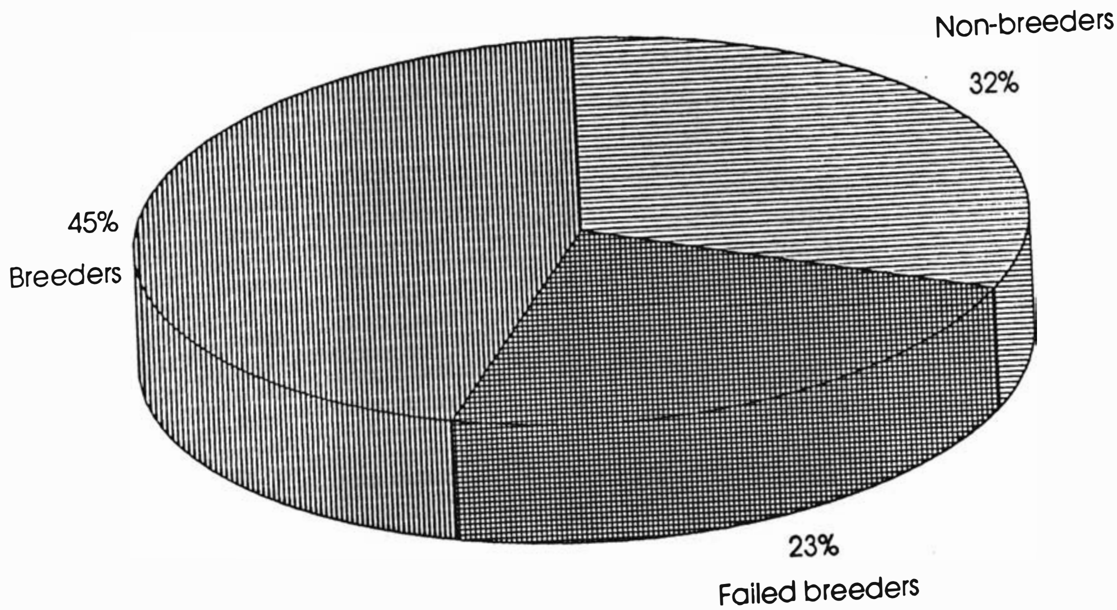

Fig. 1. Status of occupied nest sites in Antarctic Petrel on January 29.

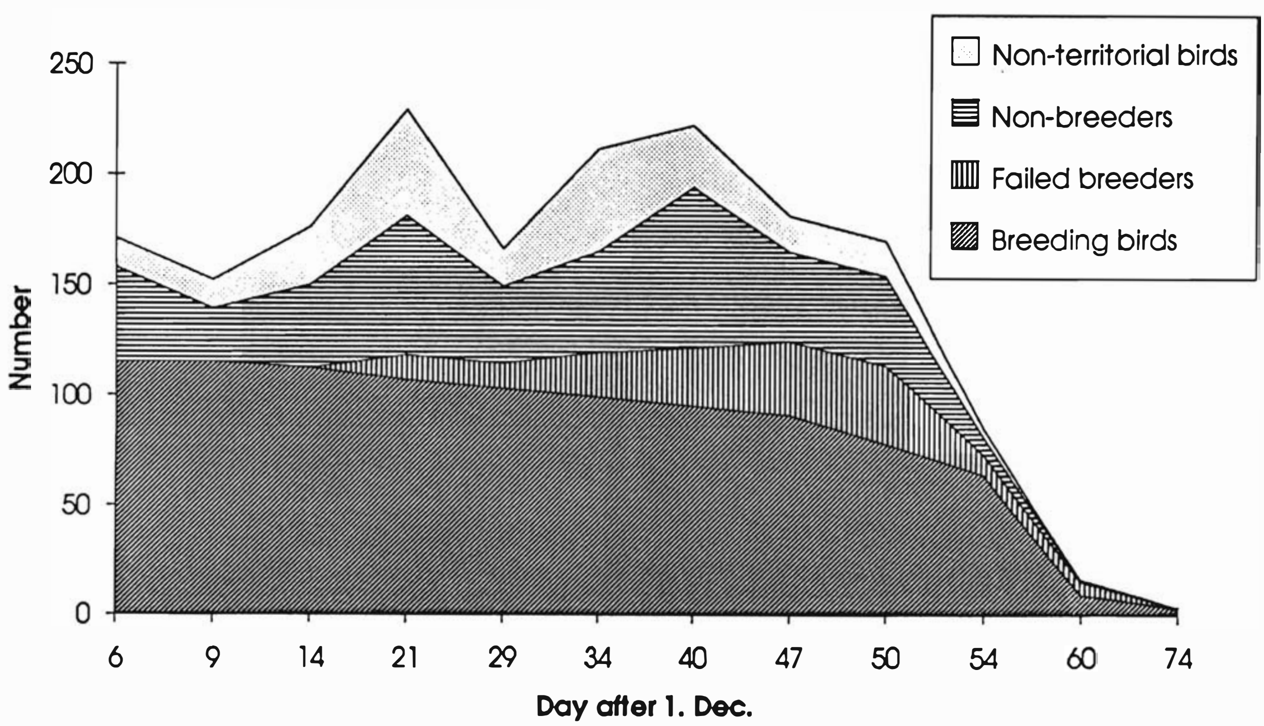

Fig. 2. Presence of birds in Antarctic Petrel study plots.

29, was probably caused by a heavy snow-storm which lasted for several days.

Biometry

During the early incubation period, weight and standard measurements of bill (culmen, midline and minimum depth at the middle), head + bill, and wing were made on breeding adults (Table 2). The birds were sexed by cloacal inspection, in females the cloaca were transversely distended and the epithelium was swollen and featherless. This technique has been widely used with procellariiform seabirds (Warham 1990). The results show that the males are slightly (3-8 %), but significantly larger than the females. By means of discriminant analysis it was possible to sex 91% of the birds correctly on the basis of their body measurements (Lorentsen & Røv 1994). The mean weight of incubating males was significantly higher than that of females (ANOVA, $F=14.6$, $p< 0.001$).

The length (l), breadth (b) and weight of eggs were measured shortly after laying and repeated once a week throughout the incubation period (Table 2).

The daily weight loss during the first part of the incubation period was on the average 0.36 g. Assuming a median laying time in the period November 26-27, the mean egg weight at laying would be 91.5 g, almost the same as reported by Orton (1968).

Phenology, incubation and chick brooding

When we arrived on 1 December, most birds had laid eggs. During the period 2-5 December, 60 nests with eggs were marked and inspected daily. In order to study the division of labour between the sexes in the incubating and brooding shifts, the birds were sexed by cloacal inspection and those which undertook the first shift (the males) were dyed with picric acid.

Forty eggs hatched, the first on 8 January and the last on 18 January. 75 % hatched between 11 and 14 January (median 12-13 January). Assuming a mean incubation period of 47 days (cf. Marchant & Higgings 1990), the data indicate that egg laying took place between 22 November and 2 December (median 26-27 November). One egg that was recorded to be laid on December 2, had a star-shaped fracture after 45 days of incubation and a "pip-hole" one day later. Hatching occurred on 19 December, 49 days after egg-laying.

The first incubation shift was the longest and was undertaken by males. The lengths of incubation and brooding shifts are shown in Table 3. Hatching occurred during shifts no. 4 (62 %) or 5 (38 %). After hatching, chicks were attended by one of the parents for 9-15 days (mean 11 days, n=38). They were left between 21 and 28 January (median 24, n=38), mostly during shift no. 7 or 8. The mean length of the final shift before the chicks were left was only 1.7 days (range 1-3) (Lorentsen & Røv in press).

During incubation shifts, adults lost an average 1.9 % of their weight per day, which means that during the first shift, the males lost 20 - 35 % of their initial weight. Over the total incubation period, adults increased in weight and were heaviest in the shift

Table 3. Duration of incubation and brooding periods in Antarctic Petrel

Shift no.	Sex	Duration			N
		Mean	Range	Stand. dev.	
1	M	16.2	12 - 23	2.8	40
2	F	13.0	9 - 17	1.8	49
3	M	10.8	8 - 13	1.3	46
4	F	7.6	5 - 10	1.0	42
5	M	4.6	3 - 8	1.2	38
6	F	2.9	1 - 4	0.7	38
7	M	2.1	1 - 4	0.8	35
8	F	1.7	1 - 3	0.7	18
9	M	1.0	1 - 1		3

when hatching occurred. Males incubated eggs an average of 8 days more than the females, and attended the chicks one day longer (Lorentsen & Røv in press).

Food and feeding

Thirty-eight chicks were weighed twice a day during their first 30 days of life in order to estimate feeding rate (Jouventin et al. 1985). Furthermore, data will be used to estimate the total amount of food received by the chicks and to relate figures with their growth rate and asymptotic weight.

Food portion weight in the colony was sampled by randomly selecting chicks that were weighed before and after feeding. From 4-11 February, the mean food load brought to the chicks was 149 g (SD=32, n=125). The results indicate that there is no significant annual variation in the weight of the food portions carried to the chicks, although growth rate and asymptotic weight may differ.

The stomach content of 10 adults (before feeding chicks) and 10 chicks (newly fed) will be analysed for food items, dry weight, lipids and energy. The sample consists of 30 day old chicks collected in a study plot where we had recorded egg weight, hatching time, brooding period, growth, feeding rate, and also estimated the total amount of food received. On the basis of the data on food and feeding rate, we will work out an energy budget for the chicks.

Breeding success and chick growth

Four study plots each consisting of 50 nests were established to study egg loss, hatching success and chick mortality. Furthermore, the study on adult attendance also provided data on breeding success. Total egg loss during the incubation period was estimated to be 28 %, and hatching success 83 %. By the time field-work was

was estimated to be 28 %, and hatching success 83 %. By the time field-work was completed (one month after hatching), only 5.6 % of the chicks that hatched in the study plots had died or were predated by Skuas. The relatively high egg mortality could partly be attributed to a period of heavy snowfall and mild weather which resulted in accumulation of water in some of the nests. Haftorn et al. (1991) reported a hatching success of 92.3 % in 1985. The chick mortality was considerably lower in 1991 than that recorded during earlier expeditions. In 1985, chick loss during the first 30 days was 15 % (Haftorn et al. 1991) and in 1990, 16-30 % (Røv 1990).

Chick growth was determined by daily weighing of 38 chicks. Chicks increased in weight until an age of 33 days. The mean asymptotic weight was 670 g, or the same as the adult weight. In 1990, the chicks only reached a mean weight of 504 g (Røv, in press) and in 1985, about 580 g (Haftorn et al. 1991). Results indicate a highly variable chick growth amont Antarctic Petrels, probably caused by variation in food availability. Low mortality and high growth rate of chicks in 1992 indicate good food availablility in that season.

2. Snow Petrel

Biometry

During the incubation period we measured and weighed breeding adults and eggs, using the same procedure as for the Antarctic Petrel. The results are shown in Table 4. Males were significantly larger than females and discriminant analysis indicate that

Table 4. Measures and weight of breeding Snow Petrels and eggs Description see Table 2

		Mean	Stand. dev.	Min	Max	N
Culmen midline	M	20.4	0.9	19.0	21.6	20
	F	19.3	0.5	18.0	20.2	20
Bill depth	M	8.2	0.4	7.7	9.0	20
	F	8.0	0.3	7.4	8.9	20
Head+bill	M	69.0	1.2	67.1	70.8	20
	F	66.4	2.1	62.7	69.5	20
Wing	M	259	5.5	250	269	20
	F	254	6.6	239	263	20
Weight	M	267	25	215	300	20
	F	253	25	210	290	19
Egg length		56.3	2.5	50.7	62.7	52
Egg breadth		39.2	1.2	36.0	42.3	52
Egg volume		47.3	3.5	36.2	53.2	52

it was possible to sex 80 % correctly by the use of standard body measurements (Røv & Lorentsen unpublished). Our results confirm the suggestion by Haftorn et al. (1988) that the Snow Petrels at Svarthamaren belong to the subspecies *nivea* and are among the smallest that have ever been described. Earlier, only 5 sexed birds from Dronning Maud Land have been measured (cf. Marchant & Higgins 1990).

Phenology, incubation and chick brooding

The first eggs were recorded on 4 December, and on 10 December most birds seemed to have laid eggs. In the 22 nests that were inspected daily, hatching occurred during the period January 17-24 (median 20.5) and the chicks were brooded until 22-31 January (median 25.5, n=19). The mean attendance time was 5.2 days (range 3-7, n=19). Assuming an average incubation time of 43 days (Marchant & Higgins 1990), the eggs in the study plot were laid between 5 and 11 December (median 8), in accordance with our observations. Hatching time and length of the attendance period were both the same as recorded in 1990 (Røv 1990).

During the incubation period, 40 breeding Snow Petrels were caught and sexed (sampled outside the study plot). On 22 December and 3 January most incubating birds were males. During the period between these dates most birds were females. On 3 January, 15 nests with eggs were marked and on 11 January a further tennests were marked. In each nest, one of the adults was dyed with picric acid (but not handled or sexed) and the nests were inspected daily. Our observations imply that the males took the first incubation shift and that on 3 January most nests were again incubated by the males on their second shift. Our data suggest that the mean length of the first three incubation shifts was 11 days, the first probably being the longest. The duration of subsequent shifts was generally shorter (Table 5).

Most of the chicks hatched during shift no. 5 (4-6) and were brooded until shift no. 6 (5-7).

Food and feeding

Feeding rate was estimated by daily weighing 18 chicks from the time they were left alone by their parents until 15 February, using the same method as for the Antarctic Petrel. The mean feeding rate for the observation period was 0.59. In 1990 the figure was 0.69 (Røv, in press) implying that chicks were fed more often that year. The weights of food portions were calculated by weighing chicks before and after feeding. The weights of eight portions were 55-98 g (mean 80 g, SD=14). Because of great difficulties in getting sufficient data, we have also estimated the mean weight of food portions on the basis of data from the "growth-group". That method gives an estimated mean food portion weight of 69 g (n=213) which is not significantly different from the former estimate, and is probably more reliable because of the large material. Using the estimated figures above, the daily food delivery to the chicks would be 41 g, which is exactly what was found in 1990 (Røv, press).

Table 5. **Mean duration of the three last incubation/brooding shifts in Snow Petrel**

Shift no.	Sex (?)	Duration			N
		Mean	Range	Stand.dev.	
4	F	8.8	7-13	1.7	14
5	M	4.4	2-7	1.4	22
6	F	2.6	1-4	1.1	11

Breeding success and chick growth

Of 25 incubated eggs, 21 hatched, and of 19 chicks, three died during their first week of life. The others survived until 15 February. The results give a hatching success of 84% and a chick mortality rate of 16 % during the first 26 days of the chick period. In 1990, chick mortality was the same (Røv 1990).

Weight development was studied in 18 chicks (Fig. 3). On 15 February, the nine oldest chicks were 25-27 days old and were probably still increasing in weight. Their mean weight was 341 g, which is 32 % more than the adult weight (cf Table 4) and considerably more than in 1990 (Røv 1990). The results suggest a highly variable

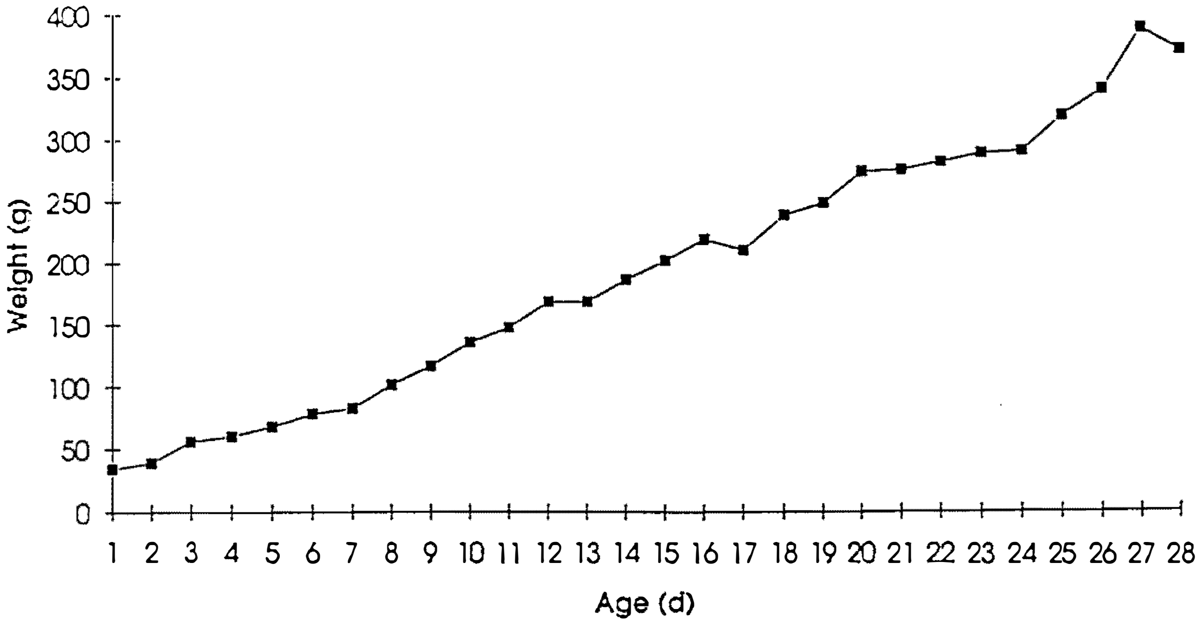

Fig. 3. Mean weight development in Snow Petrel chicks.

growth rate and asymptotic weight, as was also found in the Antarctic Petrel (this study). The higher growth rate recorded in 1992 than in 1990, may be related to higher temperatures in 1992.

3. South Polar Skua

Our main objectives were to make a complete survey of the population in the Svarthamaren area, and to colour-ring the breeding birds in such a way that they can be individually recognized in the field during future expeditions to the area. The work forms the basis for monitoring population development and adult mortality. Furthermore we studied several aspects of the breeding biology of the South Polar Skua.

The main colony is situated on the ice-free areas at the base of the hillside where the Antarctic Petrels breed. We localized all Skua territories at Svarthamaren and in neighbouring areas. A total of 110 territories were recorded, mostly in the main colony. Six nests were found 3-10 km outside the main colony. The nests were numbered and their exact position recorded and marked with bamboo sticks. We ringed 120 breeding Skuas. In addition to territorial birds, 31 non-breeding individuals were observed during a night roost on the glacier.

After hatching the nests in the central part of the colony were inspected every third day. Nests outside this area were examined three or four times during the chick period. Skuas caught in their territories were weighed and measured. Furthermore, data on territory size, breeding phenology, incubation time, egg size, clutch size, hatching and fledging success, and chick growth was collected. Each young was ringed with a steel ring and a plastic ring with a "year-code". Skuas ringed on earlier expeditions, were recaught and individually color-ringed.

4. Studies of environmental pollutants

Eggs, young and adults of petrels and skuas were collected for analysis (Table 6). The eggs and young of Antarctic Petrel were of different ages.

Table 6. **Material collected for analysis of environmental pollutants**

	Eggs	Young	Adults
Antarctic Petrel	30	30	10
Snow Petrel	5	5	5
South Polar Skua	5	4	3

REFERENCES

Anker-Nilssen, T. & Røstad, O. W. 1993: Census and monitoring of Puffins *Fratecula arctica* on Røst, N Norway, 1979-1988. *Ornis Scand. 24,* 1-9

Haftorn, S., Mehlum, F. & Bech, C. 1988: Size variation in the Snow Petrel *Pagodroma nivea. Notornis 35,* 109-116.

Haftorn, S., Bech, C. & Mehlum, F. 1991: Aspects of the breeding biology of the Antarctic Petrel *Thalassoica antarctica* and the krill requirement of the chicks, at Svarthamaren in Mühlig-Hofmanfjella, Dronning Maud Land. *Fauan norv. Ser. C. Cinclus 14,* 7-22.

Jouventin, P., Mougin, J.-L., Stahl, C.-J. & Weimerskirch, H. 1985: Comparative biology of the burrowing Petrels of the Crozet Islands. *Notornis 32,* 157-182.

Lorentsen, S.H., Røv, N. & Bangjord, G. 1993: Documentation of the Antarctic Petrel demography and population monitoring schemes, Svarthamaren, Dronning Maud Land. *NINA, Oppdragsmelding 2450, 71 pp.*

Lorentsen, S.H. & Røv, N. 1994: Sex determination of Antarctic Petrel *Thalassoica antarctica* by discriminant analysis of morphometric characters. *Polar Biology 14,* 143-145.

Lorentsen, S.H. & Røv, N. in press: Incubation and brooding performance of the Antarctic Petrel *Thalassoica antarctica* at Svarthamaren, Dronning Maud Land. *Arbis.*

Marchant, S. & Higgins, P.J. (Coordinating editors) 1990: *Handbook of Australian, New Zealand and Antarctic birds. Vol 1.* Oxford Univ. Press, Oxford.

Mehlum, F., Gjessing, Y., Haftorn, S. & Bech, C. 1988: Census of breeding Antarctic Petrels *Thalassoica antarctica* and physical features of the breeding colony at Svarthamaren, Dronning Maud Land, with notes on breeding Snow Petrels *Pagodroma nivea* and South Polar Skua *Catharacta maccormicki. Polar Research 6,* 1-9.

Orton, M.N. 1968: Notes on Antarctic Petrels. *Emu 67,* 225-229.

Røv, N. 1990: Studies of breeding biology of Antarctic Petrel and Snow Petrel in Mühlig-Hofmanfjella, Dronning Maud Land. *Norsk Polarinst. Medd. nr. 113,* 47-51.

Røv, N. 1991: The density of breeding and non-breeding Antarctic Petrels at Svarthamaren, Dronning Maud Land, 1990. *Fauna norv. Ser. C, Cinclus 14,* 49-53.

Røv, N. in press: Breeding biology of Antarctic and Snow Petrels in Continental Antarctica. A comparative study. *Polar Biology.*

Warham, J. 1990: *The Petrels. Academic Press,* San Diego. 440 pp.

OCEANOGRAPHIC AND GLACIOLOGIC INVESTIGATIONS THROUGH JUTULGRYTA, FIMBULISEN IN THE 1991/92 SEASON

by

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BACKGROUND AND OBJECTIVES

Thinning of Antarctic ice shelves with resulting un-pinning and reduced buttressing of continental ice is potentially the largest contributor to sea level change. Thinning would occur from increased melting of the underside of ice shelves, which could be a result of changed oceanographic conditions caused by climate change.

Various models exist describing sub-ice-shelf melting and freezing related i.a. to a) depression of freezing point and vertical motion of water related to local and regional sub-ice topography, b) sub-ice currents related to bottom topography and tidal and Coriolis forces, c) supercooling of sea water in contact with the ice shelf, and d) heat flow through the ice.

However, practically no observations are available of conditions below the ice shelves, and such data are critically needed to tune and improve on present hypothesis and models.

With the above in mind a long-term programme to investigate conditions underneath Antarctic ice shelves was initiated on the Norwegian Antarctic Research Expedition (NARE) 1989/90. The first stage of this programme was the deployment of sub-ice instruments at Fimbulisen, Dronning Maud Land, to test various concepts and obtain data from a medium size ice shelf. The long-term objective was to deploy such recording instruments underneath the Filchner-Ronne Ice Shelf.

The instrument rig at Fimbulisen was deployed on 10 February 1990 in Jutulgryta (position 71°18.6' S - 0°17.2' E), a fracture area of Jutulisen, located 140 km from the open sea (Fig. 1). The thickest fragments of ice shelf were here 2-300 m thick, but the instrument rig was deployed in a fissure through 11.1 m of solid ice, which was underlain by 27 m of slush. The latter indicated rapid freezing conditions at this site, perhaps mainly caused by advection of supercooled water. The rig contained altogether 39 sensors. (Orheim et al. 1990a, b). Data recovery was planned to be both by transmission over ARGOS, and by a solid-state data recorder. The satellite transmission failed, and the data storage unit was retrieved during NARE 1990/91, which was part of the joint Nordic Antarctic Programme. The following gives a brief summary of field work that season, and gives the first presentation of the recovered data.

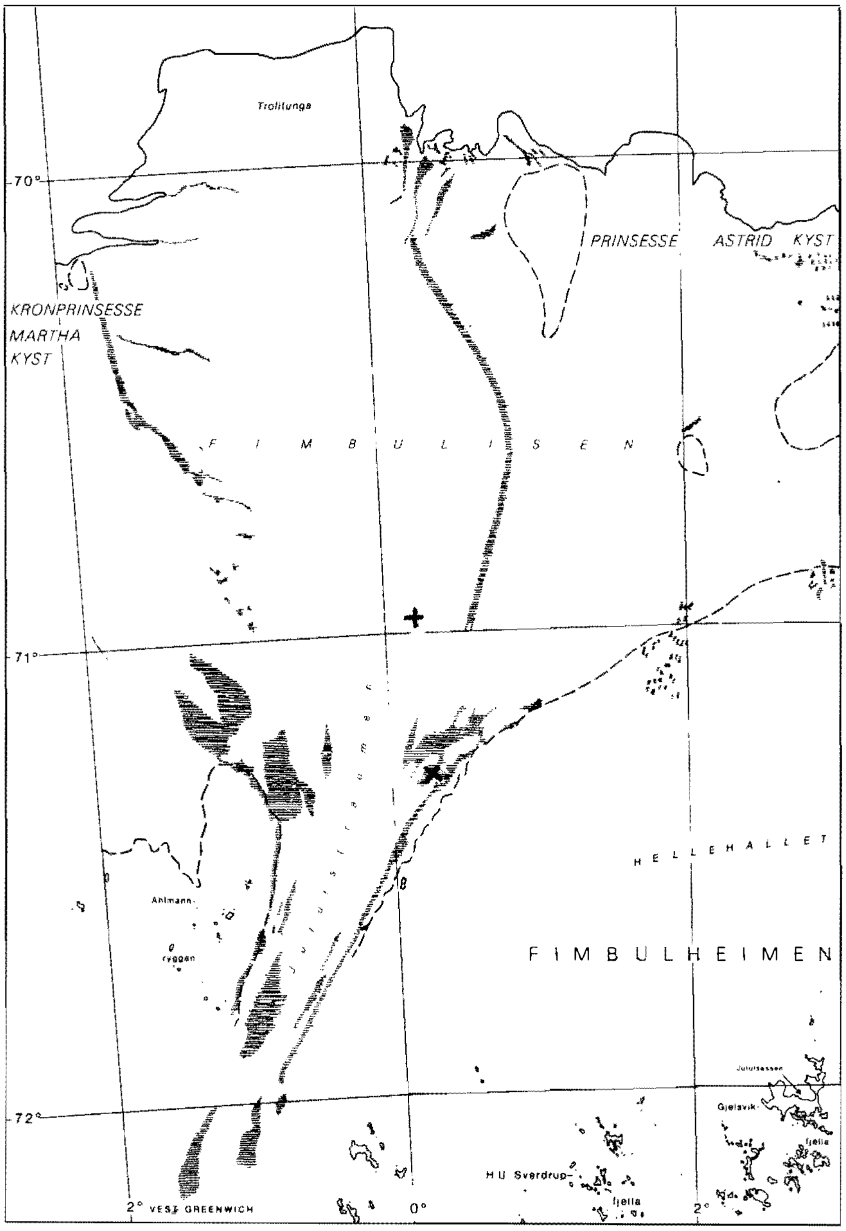


Fig. 1. Location of instruments at Jutulgryta, marked "X", and of 325 m deep temperature measurements, marked "+". Dashed line marks grounded ice, hatching shows crevasse areas.

FIELD WORK

Recovery of instruments left in and under the ice

The participants in the 1991/92 field work were Svein Østerhus and Bent Kvannli from Norsk Polarinstitutt, and Ole Anders Nøst from Geophysical Institute, University of Bergen.

Table 1. Instruments and period of data collection (day, month, year)

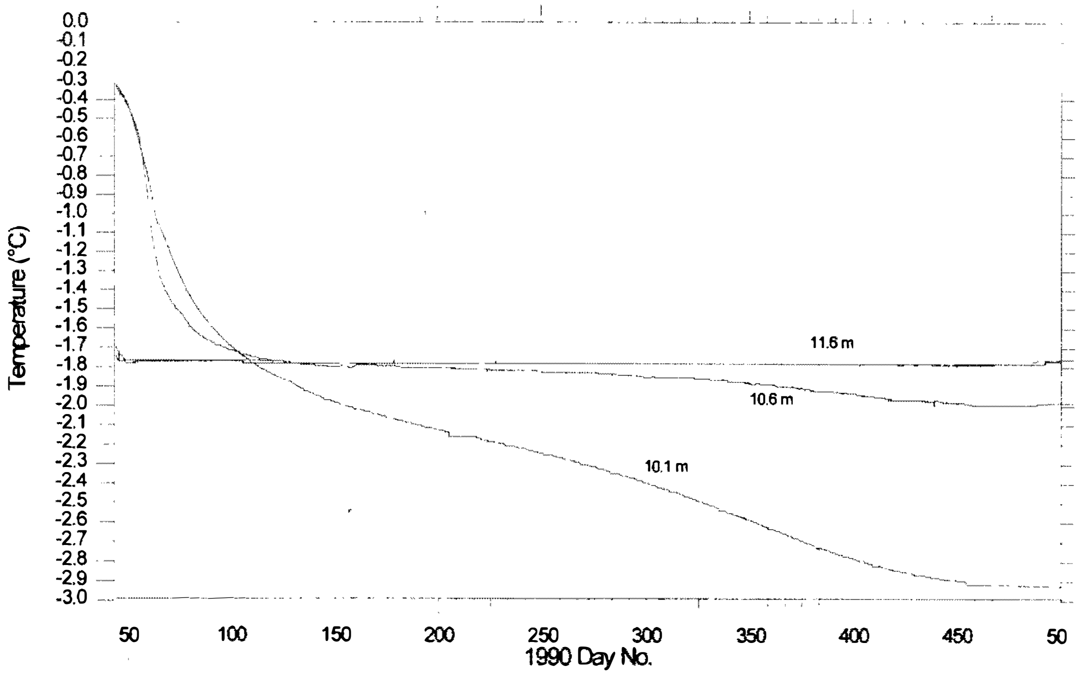
Depth below surface (m)	Instr. no.	Type of sensor	Start	Stop
3.00	8	Temperature	100290	120691
6.00	9	"	100290	120691
10.10	12-8	"	100290	120691
10.60	12-7	"	100290	120691
10.95	12-6	"	100290	120691
11.05	12-5	"	100290	120691
11.10	12-4	"	100290	120691
11.15	12-3	"	100290	120691
11.25	12-2	"	100290	120691
11.60	12-1	"	100290	120691
13.1	0-1	Salinity	100290	120691
13.1	0-2	Temperature	100290	120691
16.1	1-1	Salinity	-	-
16.1	1-2	Temperature	100290	120691
21.1	2-1	Salinity	100290	120691
21.1	2-2	Temperature	100290	120691
26.1	10	"	100290	120691
31.1	3-1	Salinity	100290	120691
31.1	3-2	Temperature	100290	120691
41.1	13-1	Salinity	-	-
41.1	13-2	Temperature	-	-
41.1	13-3	Current dir.	-	-
41.1	13-4	Current speed	-	-
51.1	4-1	Salinity	100290	120691
51.1	4-2	Temperature	100290	120691
11.1	11	"	100290	120691
201.1	14-1	Salinity	100290	210490
201.1	14-2	Temperature	100290	210490
201.1	14-3	Current dir.	100290	210490
201.1	14-4	Current speed	100290	210490
251.1	5-1	Salinity	100290	120691
251.1	5-2	Temperature	100290	120691
301.1	6-1	Salinity	100290	200290
301.1	6-1	Temperature	100290	200290
371.1	15-1	Salinity	100290	210590
371.1	15-2	Temperature	100290	210590
371.1	15-3	Current dir.	100290	170590
371.1	15-4	Current speed	100290	170590
391.1	7-1	Salinity	-	-
391.1	7-2	Temperature	-	-

The instrument string was recovered by melting a hole around the cable. The total thickness of solid ice was about 40 meters, showing that considerable ice had accumulated in the two years after deployment. The cable and instruments situated deeper than 10 meters below surface had been subjected to corrosive attack, but all instruments were in good condition. The cable-end was strongly attacked by corrosion. The cable and instruments below 250 meters were fouled by thin green threads about 10 millimetres long. The data storage unit and other equipment on the surface, and all instruments and sensors in and below the ice shelf, were recovered. All were returned to Norway.

The instrument package was tested just after arrival early in December 1991. The battery voltage was found to be below the minimum operating voltage, and data logging had stopped. The data storage unit was read after return to Norway. The data logging unit had worked properly from the date of deployment (10 February 1990) to 12 June 1991, then the internal watch in the data storage unit stopped. This data storing unit contains some additional months of data. this additional data can be rescued, assuming that the time counter in the data logging unit has worked properly.

The instrument rig consisted of 39 sensors from 16 sensor packages at 30 measuring levels. Temperatures were measured at 15 levels in the ice and 8 levels below, salinity at 10 levels and ocean currents at three depths. Of these, six sensors failed from date of deployment, 10 sensors stopped after a short period, and 23 sensors worked through the whole period (Table 1). The data logging interval was three hours.

Fig. 2 shows the temperatures at 10.1 m, 10.6 m and 11.6 m depth. The temperature at 11.6 m is constant at the freezing point for the surrounding sea water. The temperatures at 10.6 and 10.1 metres are decreasing through the whole period.



Figs. 3 and 4 show data for the period 13 February to 18 April 1990, at 370 m depth. Fig. 3 shows the current strength, in cm/sec. These are generally low, with maximum at just below 8 cm/sec, and are dominated by the diurnal tidal component, and a weaker semi-diurnal component. Note the relatively high speeds in early April. These coincide with advection of relatively warm water, as shown in Fig. 4.

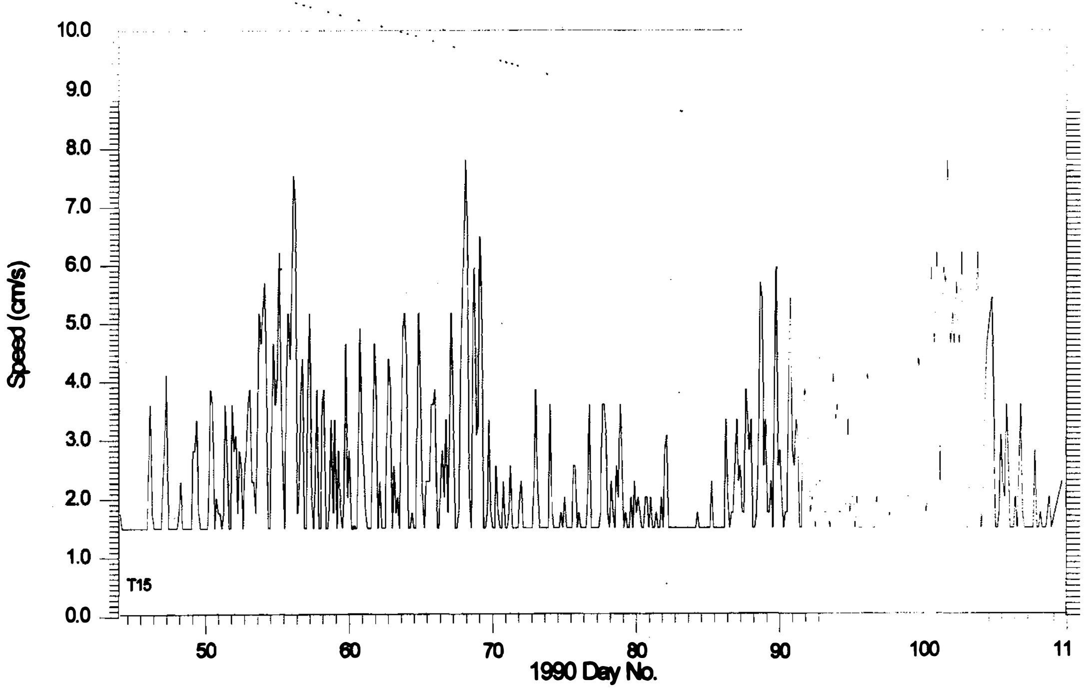


Fig. 3. Current speed at 370 m depth, above a minimum threshold of 1.5 cm/sec.

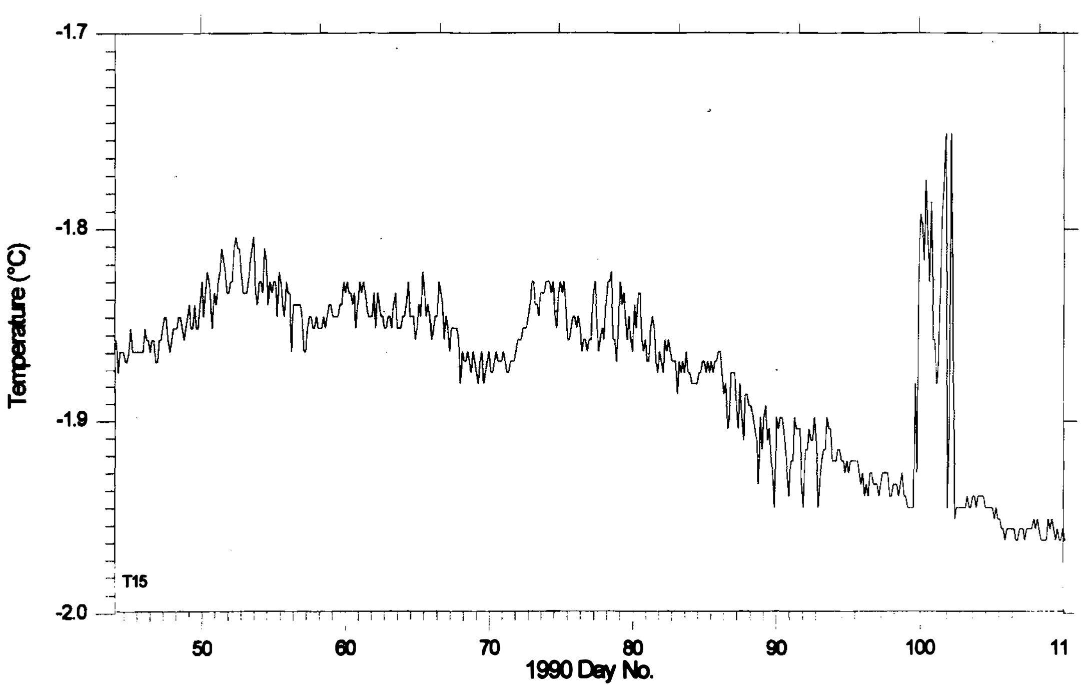


Fig. 4. Temperature at 370 m depth, for same time period as Fig. 3. Data are recorded every three hours. Note the incursion of warmer water in early April.

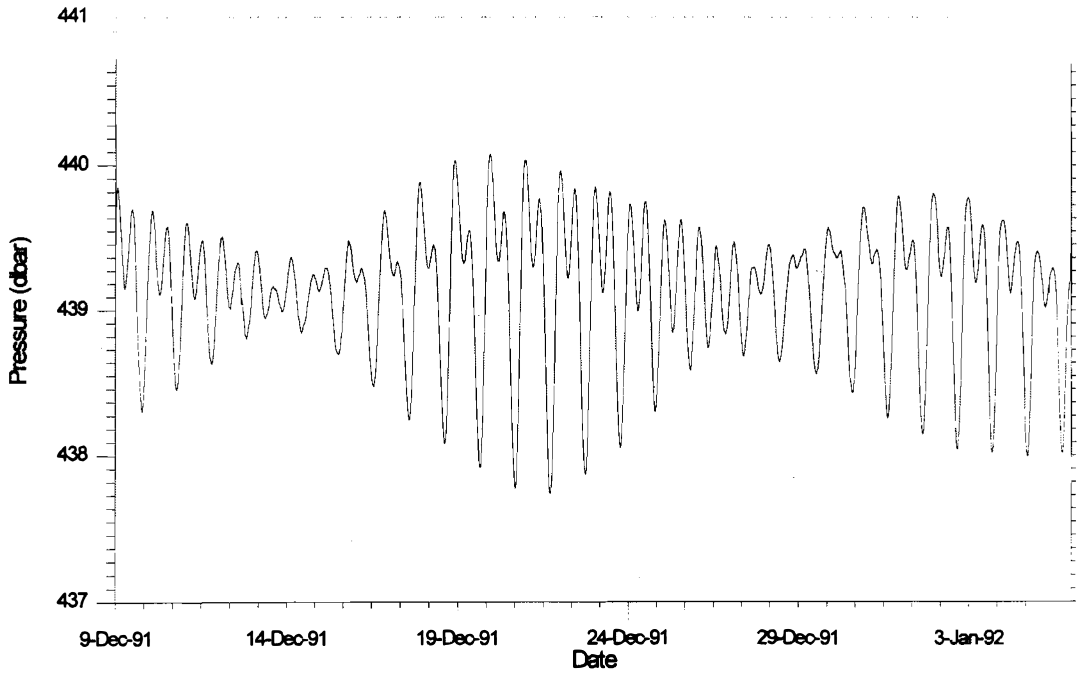


Fig. 5. Tides at Jutulgryta for December 1991/January 1992. The record shows a dominant diurnal, and a weaker semi-diurnal, component.

Tides at Jutulgryta

An Aanderaa Instruments water level recorder (WLR-5) was deployed through a hole at a site where the ice was 27 meters thick. It was lowered to the sea bed by means of a Kevlar line. The water depth was about 400 meters. The water level recorder was recovered after 30 days. Fig. 5 shows the results of these measurements, and indicates tides of up to 2 m amplitude.

Temperature and salinity (CTD-measurements), Jutulgryta.

A mini-CTD from Meerestechnik-Elektronik (ME) was used for termohaline mapping. Altogether 60 CTD casts were taken, all through 29 m thick ice. The water depth was about 400 metres.

Water sampling

Water samples for salt, oxygen isotopes and helium were collected for laboratory analyses at altogether 16 levels.

Temperature measurements in the ice shelf Fimbulisen

A 400-meter deep borehole was drilled through Fimbulisen, at 70°59' S - 0°12' W, during NARE 89/90 (Orheim et al. 1990 a, b). A thermistor string was installed in this hole, with thermistors at depths of 2, 7, 12, 22 and 27 meters depth, and then every 25 m to 327 m below the surface. The surface elevation was 53 meters.

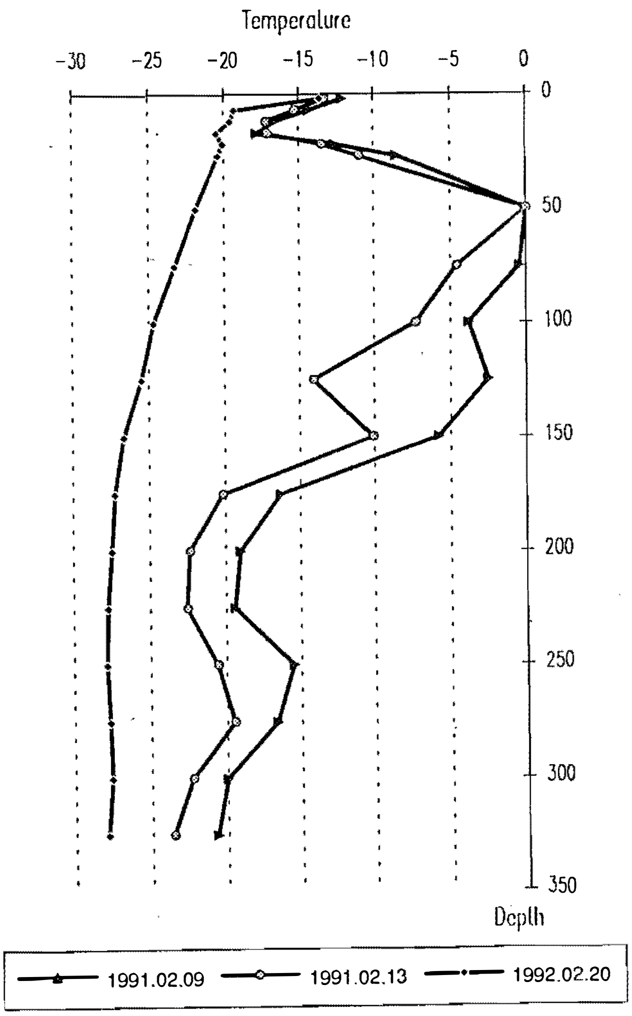


Fig. 6.Temperatures from the surface to 327 m depth in Fimbulisen. The ice shelf was here 399 m thick. Note that the temperatures in the upper part of the hole seem to deviate from presumed pre-drilling temperatures.

The temperatures were remeasured on 18 February 1992, by means of an Ohm-meter. The minimum temperature was -27.9 C (Fig. 6). The temperatures are generally colder than expected for this elevation and latitude, as indicated already by the measurements from 1990. That the temperatures of the bulk of the ice are colder than expected could have several causes, including a) that the main body of the ice has temperatures reflecting that it is inland ice originating at higher elevations, brought down by Jutulstraumen, b) that the mean annual temperatures are lowered because of descent of cold air along Jutulstraumen, and c) that lower (and warmer) ice is melted from the underside of the ice shelf. The upper part of the hole may still be open, which may cause some of the apparant deviations in temperatures from presumed pre-drilling profile.

Additional glaciological work

Two different stake nets were established in Jutulsessen during NARE 89/90 (Orheim et al. 1990a). All stake positions were measured by traditional surveying with theodolite and electronic distance meter in February 1992, together with stake heights.

REFERENCES

Orheim, O., J.O. Hagen, S. Østerhus, & A.C. Sætrang, 1990a: Studies on, and underneath, the ice shelf Fimbulisen. *Norsk Polarinstitutt Meddelelser 113*, 59-73.

Orheim, O., J.O. Hagen, S. Østerhus, & A.C. Sætrang, 1990b: Glaciologic and oceanographic studies on Fimbulisen during NARE 1989/90. *FRISP Report 4*, 120-131.

PROXIMAL SUB ICE-SHELF SEDIMENTATION, JUTULGRYTA, EAST ANTARCTICA

by

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BACKGROUND AND OBJECTIVES

Depositional models for the ice shelf environment found over large parts of the Antarctic continental shelf, indicate that most basal debris is released and deposited relatively close to the grounding line due to basal melting of the inner part of the ice shelf (e.g. Orheim & Elverhøi 1981) (Fig.1). Hence, the present-day sedimentation rates outside the major ice shelves are low (Elverhøi & Roaldset 1983) and the tabular icebergs produced at least from the wide ice shelves, are generally void of debris.

Based on the sparse amount of drill-cores available, sediments deposited from the base of an ice shelf, proximal to the grounding line, are interpreted to comprise a large part of the glacigenic sedimentary section on the continental shelf around Antarctica. Both in Prydz Bay, off the Amery Ice Shelf (Barron, Larsen et al., 1989) and in the Ross Sea (Barrett et al. 1989) large parts of the recovered sections are interpreted to consist of waterlain till. The term "waterlain till" has been used for sediments deposited through a thin column of water, but without any sorting effect from the water. Hence, it resembles a till, but is not deposited directly from the base of the glacier and has therefore not experienced any compaction by the glacier. The term "waterlain till" is debated. Anderson et al. (1980) term the sediments "transitional glacial-marine" sediments. Despite this discussion, the important point is that for large regions of the Antarctic continental shelf, a major part of the sedimentation seems to take place beneath the floating ice shelves.

Because of grounding line fluctuations in response to glacial - interglacial variations, studies of relict sub-ice shelf sediments have been possible. Sampling to study the present-day sedimentary environment beneath an ice shelf, however, has been limited to a few observations under the Ross Ice Shelf (Webb et al. 1979) and under the Novolazarevskiy Ice Shelf (Kolobov & Savatyugin 1980). These were all short

(< 30 cm) gravity cores that contained soft diamicton and silty clays with siliceous microfossils. Anderson (1975) described diamictons both in the Ross and the Weddell Sea, that were interpreted to be deposited in the proximity of a former grounding line. These samples also contained a benthic foraminiferal assemblage believed to be endemic to the sub-ice shelf environment. Hence, there is a potential for finding material datable with accellerator ^{14}C techniques (AMS).

If, on the other hand, depositional models as the one indicated in Fig. 1 do not hold, and the area proves to have low sedimentation rates, biostratigraphic investigations of core material could be used to interpret grounding line fluctuations and the possibility of an open marine environment (without an ice shelf). Miocene ages have been discussed for the sub-ice shelf material cored in the Ross Sea (Webb et al. 1979).

In summary, the sub-ice shelf sedimentary environment has apparently been of great importance to the overall glacigenic sedimentation on the Antarctic continental shelf throughout the glacial period, which most likely lasted since the Lower Oligocene (Hambrey et al. 1991). At the same time, however, this environment remains one of the least studied of all glacigenic sedimentary environments because of its inaccessible nature. The studies in the Jutulgryta area offer an unique opportunity to sample this environment and therby to test models and interpretations based on relict material.

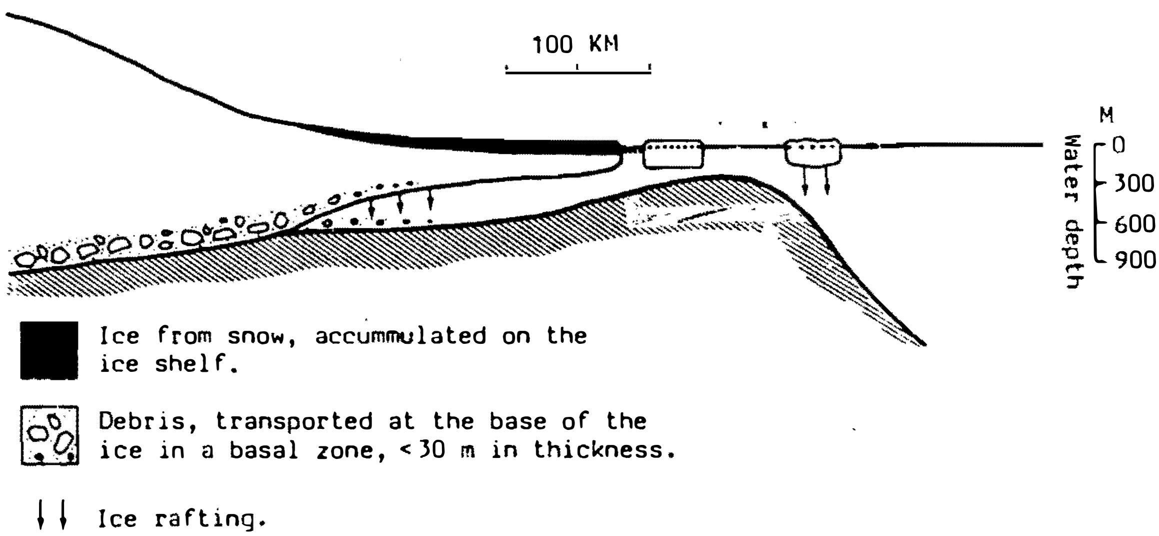

Fig. 1. Schematic section through an ice shelf, showing basal melting and deposition of basal debris near the grounding line. (From Orheim & Elverhøi 1981; Elverhøi & Roaldset 1983).

On the above background, a small coring and sea floor photography program was carried out by the geophysical team in Jutulgryta (Østerhus & Orheim 1994) with the following main objectives:

- To obtain cores of up to 2.4 m length (restricted by equipment) and sea floor photographs from a series of closely spaced locations during the period of occupation of the field camp.
- To investigate the nature of sedimentation in this sub ice-shelf environment relatively close to the grounding line, particularly sediment composition and sedimentation rates.
- To study possible grounding line fluctuations and other paleoclimatic events through biostratigraphy.

COOPERATING SCIENTISTS

Carl Fredrik Forsberg, Norw. Polar Institute	Geochemistry, sedimentology
Anders Elverhøi, Univ. of Oslo	Sedimentology
Jenø Nagy, Elisabeth Alve, Univ. of Oslo	Biostrat., forams.
Amy Dale, Barry Dale, Univ. of Oslo	Palynology

FIELD WORK

The corer used was a Benthos Model 2171 gravity corer with core liner length of 2.4 m and a core diameter of 6.7 cm. Total weight of the corer was 110 kg. The bottom camera system consisted of a Benthos Model 371/381 camera/flash system with a bottom contact switch.

Due to unexpectedly thick and difficult ice conditions in Jutulgryta (Østerhus & Orheim 1994), the corer and camera system were only deployed very few times. The coring resulted in three cores, 37cm, 55 cm and 61 cm, respectively, while only one bottom photograph was obtained. It should be noted, however, that these are the longest sub ice-shelf cores ever recovered from Antarctica, and the first sub ice-shelf sea floor photograph.

In addition to this, a number of water samples were also taken for studies of particulate matter and comparison with the sea floor surface sediments.

Due to the slow ice movement in Jutulgryta, the cores, bottom photograph and water samples are located within a few metres of each other at the same position: 71°18.6' S, 0°17.2' E, and the waterdepth was 400 m (see Østerhus & Orheim 1994).

DATA PROCESSING AND PRELIMINARY RESULTS

The sediment cores were frozen in the field, transported and kept frozen during storage and subsequently thawed before splitting. Hence most primary structures in the cores were disturbed. Two cores are currently being studied, those of 37 cm and 61 cm, respectively. Work carried out on these cores are:

- X-ray photography
- Splitting, photography, visual description and subsampling at 2 cm intervals.
- Grain size distribution
- XRD on the < 63 micron fraction
- Biostratigraphy; foraminifera and dinoflagellates (diatoms will be studied)

The sediment consists of a homogeneous sandy, silty clay with gravel (2-3 mm) and a few scattered pebbles (20-30 mm). The homogeneous structure is verified both by visual description and X-ray. The fossil content (foraminifera and dinoflagellates) seems relatively poor, with the exception of one level at approximately 10 cm core depth, where a peak of the dinoflagellate cyst *Impagidinyum pallidum* give a strong indication of open water conditions. This interval also has the highest content of foraminifera. However, theese consist of very small specimen and we have not been able to pick adequate samples for AMS dating.

The bottom photograph showed a sea floor with clean dropstones in a muddy matrix. The apparently clean surfaces of the dropstones seem to indicate a more vigorous current regime than that recorded during the oceanographic field work (Østerhus & Orheim, 1994).

REFERENCES

Anderson, J.B. 1975: Ecology and distribution of foraminifera in the Weddell Sea of Antarctica. *Micropaleontology, 21*, 69-96.

Andersson, J.B., Kurtz, D.D., Domack, E.W. & Balshaw, K.M. 1980: Glacial and glacial marine sediments of the Antarctic continental shelf. *Journal of Geology, 88*, 399-414.

Barrett, P.J., Hambrey, M.J., Harwood, D.M., Pyne, A.R. & Webb, P.N. 1989: Synthesis. Pp 243-253. *In DSIR Bull., 245.*

Barrett, P.J. (Ed.): Antarctic Cenozoic history from the CIROS-1 drillhole, McMurdo Sound. *DSIR Bull., 245.*

Barron, J., Larsen, B. et al. 1989: *Proc. ODP, Init. Repts.,* 119: College Station, TX (Ocean Drilling Program).

Bucher-Nurminen, K., Ohta, Y., Austrheim, H. & Dallmann, W. 1990: Geological observations in Gjelsvikfjella and Mühlig-Hoffmannfjella. *In* Orheim, O. (Ed.) *Report of the Norwegian Antarctic Research Expedition 1989/90. Norsk Polarinstitutt Meddelelser, 113,* 91-100.

Elverhøi, A. & Roaldset, E. 1983: Glaciomarine sediments and suspended particulate matter, Weddell Sea Shelf, Antarctica. *Polar Research, 1 n.s.*, 1-21.

Hambrey, M.J., Ehrmann, W.U. & Larsen, B. 1991: Cenozoic glacial record of the Prydz Bay continental shelf, East Antarctica. *In* Barron, J., Larsen, B. et al. 1991: *Proc. ODP, Sci. Results,* 119: College Station, TX (Ocean Drilling Program)

Kolobov, D.D. & Savatyugin, L.M. 1980: Bottom sediments under the Novolazarevsiy Ice Shelf. *Polar Geography and Geology, 6,* 267-271.

Ohta, Y., Tørudbakken, B. & Shiraishi, K. in press: Geology of Gjelsvikfjella and Mühlig-Hoffmannfjella, western Dronning Maud Land, East Antarctica. *Polar Research, Vol.*

Orheim, O. & Elverhøi, A. 1981: Model for submarine glacial deposition. *Annals of Glaciology, 2,* 123-128.

Østerhus, S. & Orheim, O. 1994: Oceanographic and glaciological investigations through Jutulgryta, Fimbulisen, in the 1991/92 season. *Norsk Polarinst. Meddelelser 124* (this volume).

Webb, P.N., Ronan, T.E. Jr., Lipps, J.H. & DeLaca, T.E. 1979: Miocene Glaciomarine sediments from beneath the southern Ross Ice Shelf, Antarctica. *Science 203,* 435-437.

CHEMICAL FRACTIONATION OF SEA SALT IN SNOW

by

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BACKGROUND AND OBJECTIVES

In Antarctica the sulphur occurs primarily in three components: SO_4^{2-} in aerosols and SO_2 and H_2S as gas (Junge 1960). In addition sulphur occurs in DMS, DMSO and other organic components. In the coastal areas most of the SO_4^{2-} aerosols are salt particles in sea spray and are produced by bubbles breaking at the sea surface. As the water evaporates a small salt particle with radii (r)<0.5µm is left which is believed to have residence time of several hours or days depending on the atmospheric conditions. Breaking waves produce large particles with radii (r) < 5µm with a normal residence time in the atmosphere of only a few minutes.

The major part of Mg^{2+}, Na^+ and Cl^- content in the atmosphere and in the precipitation in the coastal areas in polar regions are of marine origin. The SO_4^{2-}/Na^+, the SO_4^{2-}/Cl^- and the SO_4^{2-}/Mg^{2+} ratios in sea water by weight are respectively 0.25, 0.13 and 2.0 (Wilson, 1975). If we assume that the contents of Na^+, Cl^- and Mg^{2+} in the atmosphere in coastal areas of Antarctica are of marine origin and the ionic ratios in the marine aerosols are the same as in sea water, the exc. SO_4^{2-} can be calculated. By multiplying the Na^+ content by 0.25, the Cl^- content by 1.4 or the Mg^{2+} content by 2.0 and subtracting this value from the total content of SO_4^{2-}, the excess SO_4^{2-} (content of SO_4^{2-} of non-marine origin) is obtained.

The most important sink mechanisms for atmospheric aerosols and gases are precipitation (scavenging processes), and dry deposition of particles and absorption of gases. The two latter mechanisms affect the surface leading to a higher ion content in the snow layer than in the original precipitation.

The SO_4^{2-}/Na^+, SO_4^{-2}/Cl^- and SO_4^{-2}/Mg^{2+} ratios in deposited snow in the coastal area of Antarctica, west coast of Norway and on Spitsbergen are markedly lower than for sea water (deficit of sulfate with respect to sea water). Precipitation and newly fallen snow in summer in the same area have an excess of sulfate relative to sea water (Gjessing 1984, 1989).

The purpose of this project is a detailed study of the relation between the excess - deficit of sulfate in snow and the distance from the coast in a coastal area.

METHODS AND FIELD WORK

Snow samples were collected every 1 km from the shelf edge and 5 km inland and every 5 km of the next 40 km. Further inland samples were collected every 20 km. At the different locations snow samples were collected from the surface and then from 0.25 m layers from the wall of 1 m deep snow pits. The snow samples were transferred to double polyethylene bags which were sealed and kept frozen during the transport to the laboratory.

After melting in the laboratory, the concentrations of Na^+ and Mg^{2+} were determined by atomic adsorption spectroscopy, the SO_4^{2-} concentration was determined by the Thorin-method after passing an acid cation exchange resin and Cl^- was determined colometrically. The precision of the chemical analyses are better than 5 ng m^{-3} for Mg^{2+} and SO_4^{2-} and better than 15 ng m^{-3} for Cl^- and Na^+.

PRELIMINARY RESULTS AND DISCUSSION

Some of the results are indicated in Fig 1. The maximum of the total concentrations of ions of marine origin is found 2-3 km inland from the shelf edge and as expected further inland the concentrations decrease with the distance from the shelf edge. There exists a close correlation between the ions except for the surface layer which shows only a weak correlation between sulfate and the other ions. The explanation to the comparatively low concentrations near the shelf edge are probably due to wind transport to the sea of the surface snow due to the prevailing catabatic winds.

If the assumption is made that all the ions of Na^+, Cl^- and Mg^{2+} are of marine origin and the ratio between these ions are the same as in sea water, the excess_x SO_4^{2-} can be calculated, where the x index indicates which of the major sea salt ions the calculation is based on. The results are given in Fig. 2. In the surface layer there is an excess of sulfate in the relative to the other major ions in sea water, except for a small deficit some 40 km from the shelf edge.

According to Fig. 2 there is a deficit of SO_4^{2-} relative to Na^+, Cl^- and Mg^{2+} in the layers below (0.05m - 1.0 m depth) 2 km - 20 km from the coast. The deficits of SO_4^{2-} relative to Cl^- and Na^+ are markedly higher than those relative to Mg^{2+}. This indicates that there is a deficit of Mg^{2+} relative to Na^+ and Cl^- in the snow.

More than 30-40 km from the coast there is an excess of SO_4^{2-} which is comparatively constant inland and independent of which of the main ions it is related to.

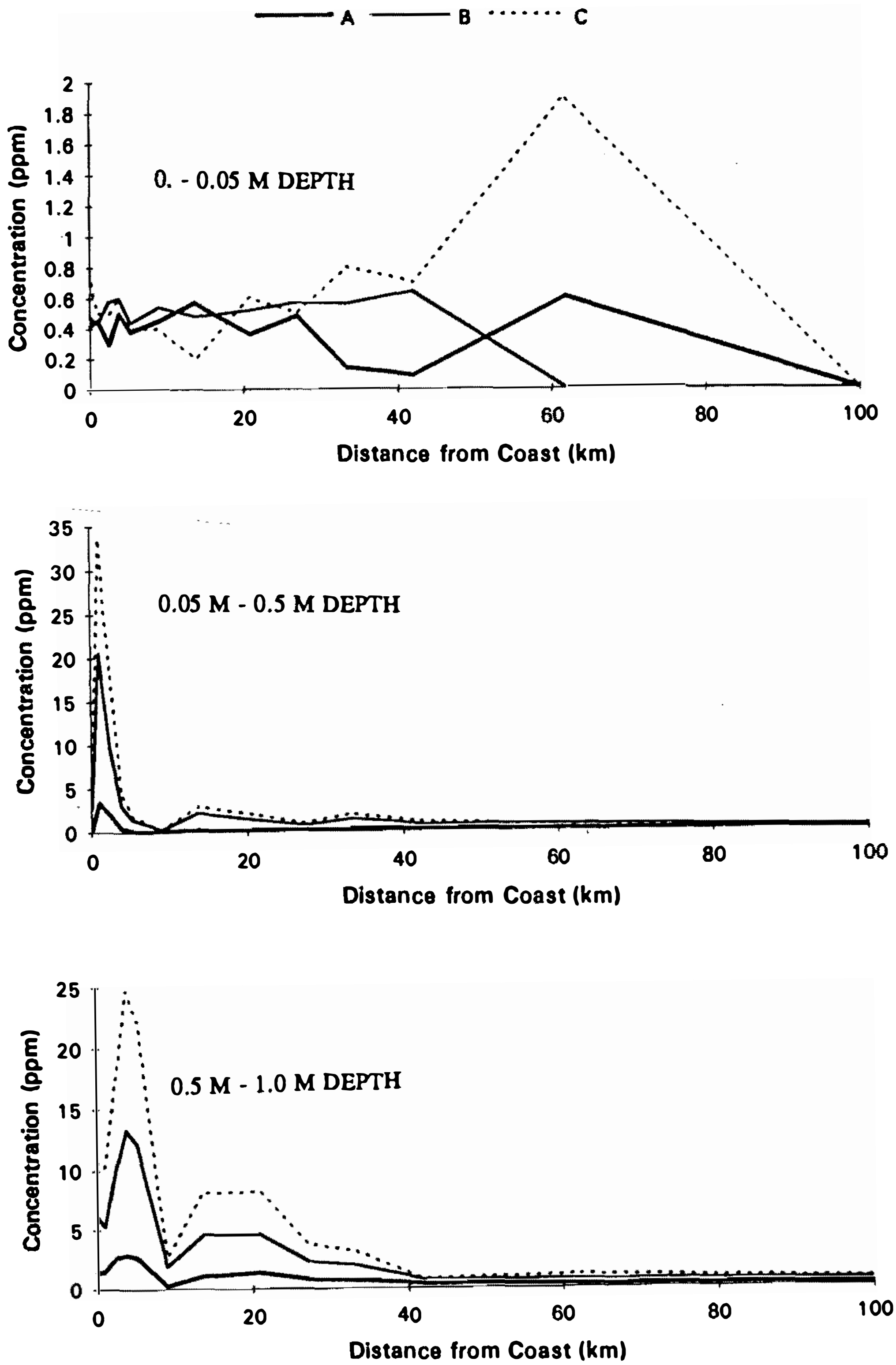

Fig. 1. Concentrations (ppm) in snow of some of the major ions in sea water at Riiser-Larsenisen Iceshelf as a function of the distance to the coast. A : SO_4^{2-}. B : Na^+. C : Cl^-.

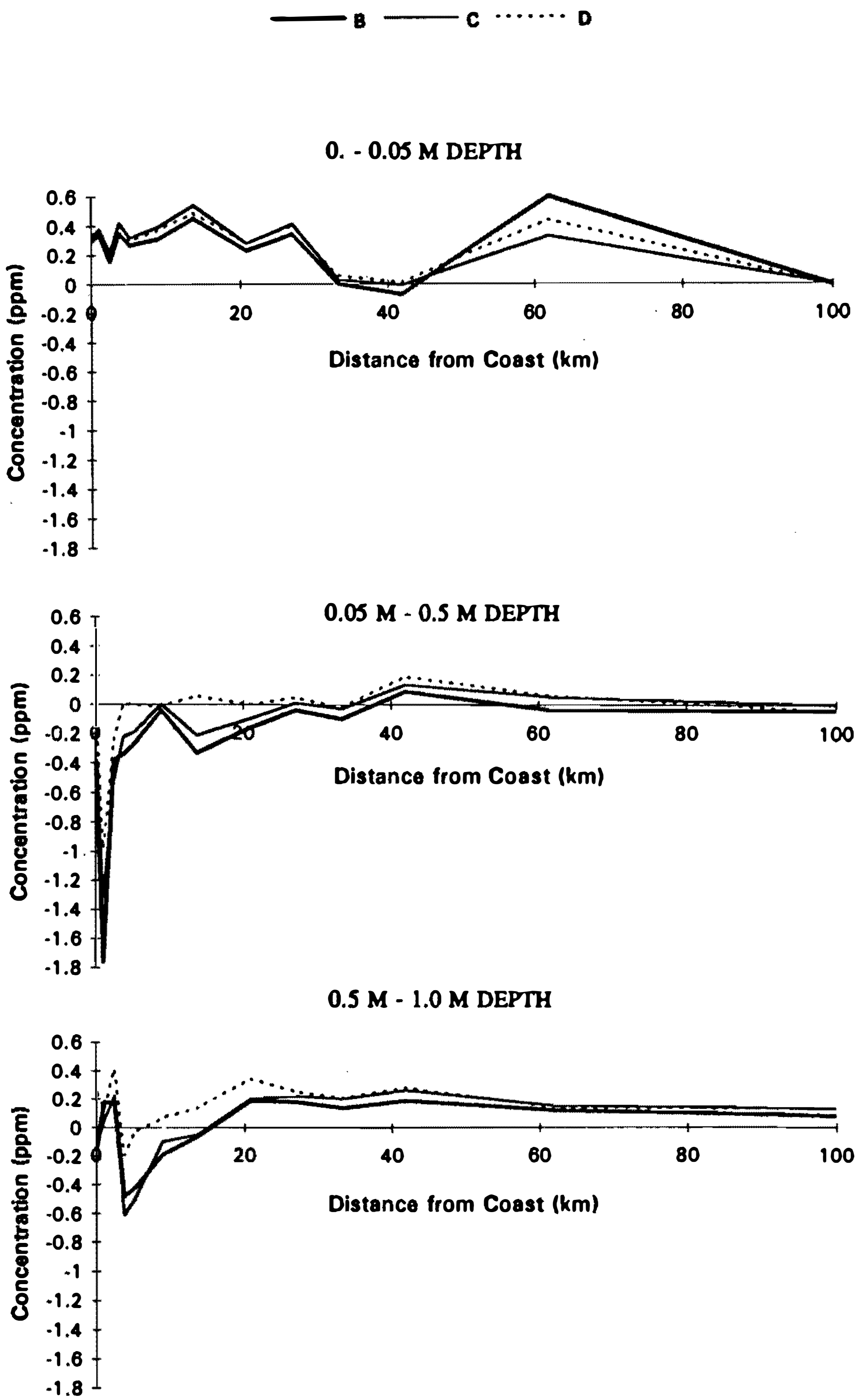

Fig. 2. Concentration (ppm) of $excess_x$ sulfate in snow at Riiser-Larsenisen Iceshelf as a function of the distance from the coast. The index x is referring to which ions that are used for the calculation of excess sulfate. B : Na^+, C : Cl^- , and D : Mg^{2+}.

If we assume that there is no contamination of the samples or any analytical errors and that there is no local anomaly in the ionic ratios of sea water in the area, there are two main possible explanations to the SO_4^{2-} deficit in snow:

1. Sulphur has disappeared from the snow pack by melting or by volatilization to the atmosphere.

2. Dry deposition to the snow surface of aerosols with a low content of sulfate.

Melting may occur in shorter periods producing a thin ice layer on the surface, however, the snow temperatures underneath are below zero, so no melt water leaves the snow pack. Volatilization of sulphur is assumed to take place only at very high temperatures. In a simple experiment in a cold laboratory (Gjessing, 1989), snow samples were ventilated during a 48 hour period with 2 m^3 air that first had passed through an aerosol filter and an SO_4^{2-} absorber. The snow samples were at the same time exposed to UV radiation. Control samples were kept in dark. No sulphur was released from the snowpack.

Sea salt aerosols in the atmosphere are assumed to be produced by small air bubbles bursting the surface film of the water producing small film droplets $r < 1$ µm. Drops of sea water in the atmosphere that are produced by breaking waves which have $r > 5$ µm normally have residence time in the atmosphere of only a a few minutes, however during periods of strong wind the residence time may be longer. If the water evaporates a salt particle is left in the atmosphere.

In polar regions the drop of sea water may freeze rather than evaporate. When sea water starts to freeze there is always a certain amount of brine between the ice plates and in brine pockets. The concentration of this brine will increase as the freezing continues. The chemical processes that occur during the freezing of sea water are less understood than the physical processes. Measurements and changes in the relative composition of salt and brine in sea ice when it is formed under laboratory conditions have been discussed by several authors. Richardson (1976) studied the chemical processes during the freezing of "normal sea water" (Copenhagen sea water). Some of his results are indicated in Fig. 3. He found that $Na_2SO_4 \cdot 10H_2O$ starts to precipitate at -8.2°C, $CaSO_4 \cdot 2H_2O$ at -10°C and $NaCl \cdot 2H_2O$ at -22°C. This leads to a change in the ionic ratios in the brine. According to Richardson's experiment the SO_4^{2-}/Na^+ ratio will decrease from 0.25 at -2°C to respectively 0.146 and 0.021 as the temperature decreases to -10°C and -20°C.

At low temperatures there will exist tensions in the ice leading to cracks in the ice particle. This leads to a separation of brine from the ice particle as indicated in Fig. 3. The mass of this brine is, according to Richardson's experiment (Fig. 3), only a few

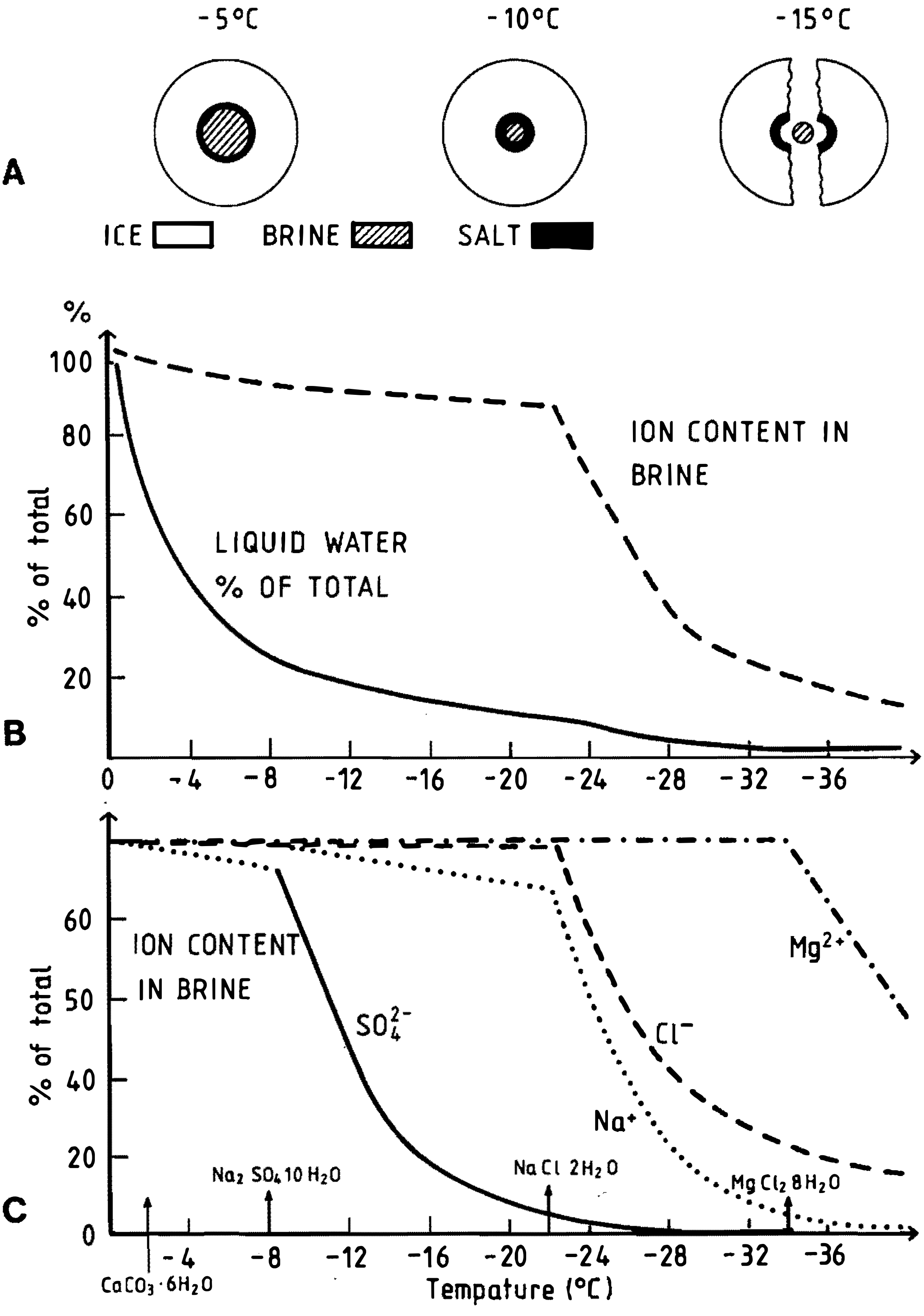

Fig. 3 A., B, C. Ilustration of how the fractionation of sea salt and separation of brine may take place. Phase relation of freezing standard sea water based on laboratory experiments (Richardson 1976).

per cent of the mass of the total ice particle. The residence time in the atmosphere of the brine with a low content of SO_4^{2-} relative to Na^+, Cl^- and Mg^{2+} is therefore long compared to the residence time of the ice particle. The brine may be transported inland before it is deposited on the snow surface while the ice particle will be deposited in sea. Similar prosesses may occur when waves hit the cold ice at the front of the shelf or when new ice is formed on open leads near the shelf. The brine formed will in the next turn be transported inland by the wind.

The data from Antarctica showed that deficit of sulfate was only observed in the coastal area. This indicates that the residence time in the atmosphere of those aerosols with a deficit of sulfate is comparatively low, and therefore indicates that these aerosols are produced by breaking waves rather than bursting bubbles.

REFERENCES

Gjessing, Y. 1984: Marine and non-marine contribution to the chemical composition of snow at the Riiser Larsenisen Ice Shelf in Antarctica. *Atmospheric Environment 18*, 825-30.

Gjessing, Y. 1989: Excess and deficit of sulfate in polar snow. *Atmospheric Environment 23*, 155-160.

Junge, C.E. 1960: Sulphur in the atmosphere. *J. Geophys. Res. 65*, 227-237.

Richardson, C. 1976: Phase relationship in sea ice as a function of temperature. *J. Glaciol. 17*, 507-519.

Wilson, T.R.S. 1975: Salinity and the major elements of sea water. Pp. 365-413 in Riley, T.P. and Shirron, G. (eds.): *Chemical Oceanography 1*. Academic Press, New York.

DETAILED STUDIES OF BOTTOM FREEZING UNDER AN ICESHELF AND MAPPING OF ACCUMULATION BY USE OF MULTI-FREQUENCY PULSE-APERTURE RADAR

by

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BACKGROUND AND OBJECTIVES

Half of the Antarctic area is surrounded by floating ice shelves. The major part of this ice originates from inland Antarctica and from precipitation on the ice shelf. In the inner part of the shelf the ice is partly grounded and partly floating. The shelf ice will interact with the seawater underneath. Freezing or melting processes will take place dependent on the temperature profile of the ice near the ice-water interface and the stabilities of the watermasses underneath.

Results from NARE 1977-78 (Gjessing & Wold 1986) showed that the sum of any disequilibrium of the shelf and bottom freezing was about 3 m of ice per year near the grounding line. Some 10 km downstream from the grounding line this sum was - 1.7 m yr $^{-1}$. Budd et al. (1982) used the same technique and found a secondary area with ice formed by sea water about 150 km from the grounding line.

In Antarctica the summer temperatures most places normally are not high enough for forming ice layers at the snow surfaces, However during special weather conditions thin ice layers can be formed. The depth of these iso-chronous layers, which have marked differences in the dielectric constant, can me mapped by a radar technique. The age of these layers can be determined by the O^{18}/O^{16} ratio from ice cores.

EQUIPMENT AND METHODS

The radar system used is a step frequency radar or a synthetic pulse radar collecting 201 frequencies at equidistant steps over desired bandwith (developed by Environmental Surveillance Technology Program; Hamran et al. 1986). The bandwith is obtained by sampling at discrete frequencies by stepping the frequency domain as a function of time. The radar system has a bandwith 0.1-3000 MHz, but the antennae is the band limiting factor for the sounding equipment. Two types of sounding systems were used: a) a non-resonent dipole antennae (resitively loaded with 1.12 balun, Watts & Wright 1981) operating 5-30 MHz for mapping the total depths. b) An UHF- radar system with Yagi antennae (6 elements of an opening angle of 60°) working at frequencies 140-180 MHz and 320 MHz were used to study the internal structure of the glacier. For the 320 MHz UHF-radar the sampling step frequency was 250 kHz and the range resolution in ice 1.7 m.

The data were stored in a computer, processed and displayed as intensity modulated plots with a linear magnitude scala. Fast Fourier transform was used for processing the data from the time domain making use of the Hanning window (Hamran 1989).

The radar system was operated from sledges pulled by snow-scooter. The sampling of the radar was controlled by a wheel, attached to the sledge, producing triggering pulses to the computer. The positions were obtained from GPS mesurements.

Radio echo soundings were carried out twice with respectively 140-180 MHz and 320 MHz antennaes on the 100 km profile from the grounding line of the ice shelf Riiser-Larsenisen (downstream the nunatak Plogen) to the ice front. In addition soundings of the profile from the grounding line and 50 km down- stream were repeated three times with different antennaes.

Near the blue ice area to the north of Basen the annual layers in snow are supposed to be distinct due to heat advection from the heat island formed by the nunatak. Depth profiles from the blue ice area and some 5 km north (in the direction of the prevailing wind during summer) were recorded with 900 MHz antennaes. These profiles down to some 10 m depth showed marked reflection from layers. Based on the corresponding profiles of O^{18}/O^{16} these layers were interpreted as summer surfaces of the previous years.

Velocities and strain rates of the ice shelf were determined by geodemeter readings between the nunatak Basen and the shelf, and between stakes at time intervals of six weeks.

PRELIMINARY RESULTS

At the grounding line of Riiser-Larsenisen the mean annual velocity of the ice flow is 84 m year^{-1} and the ice thickness 410 m. The maximum ice thickness of 610 m was found 25 km downstream from the grounding line and at the ice edge the total ice thickness was 220m. The strain rate parallel to the flow was of order of magnitude 10^{-3} yr^{-1} .

From the grounding line to the area of maximum ice thickness the signal/depth ratios were decreasing and then some 50 km downstream the signal/depth ratios increased with distance from the grounding line. Further downstream the ratio was comparatively constant. The interpretation of this is absorption due to salt content and brine pockets in the bottom layers of the ice.

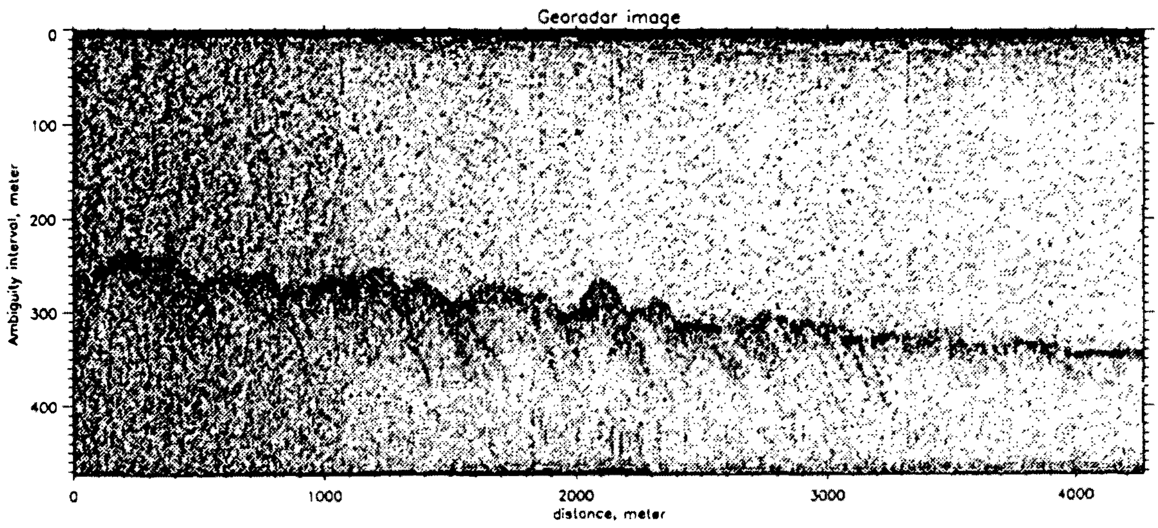
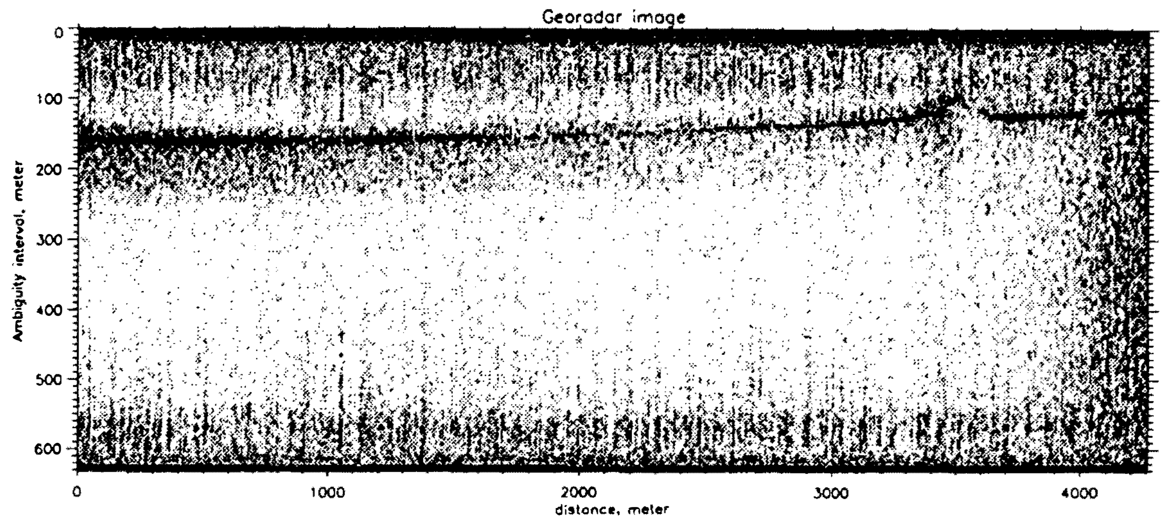
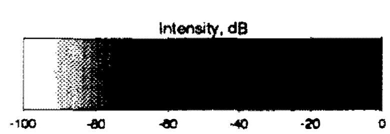


Fig. 1A. Bottom topography of the inner part of the ice shelf Riiser-Larsenisen.





Data filename	repr11 geo
Measurement date	02/16/92
Start time	18 01 27
Start frequency	155.00 MHz
Stop frequency	170.00 MHz
Bandwidth	15.00 MHz
Number of freqs	201
Number of shots	508

Fig. 1B. Bottom profile of the outermost part of the iceshelf.

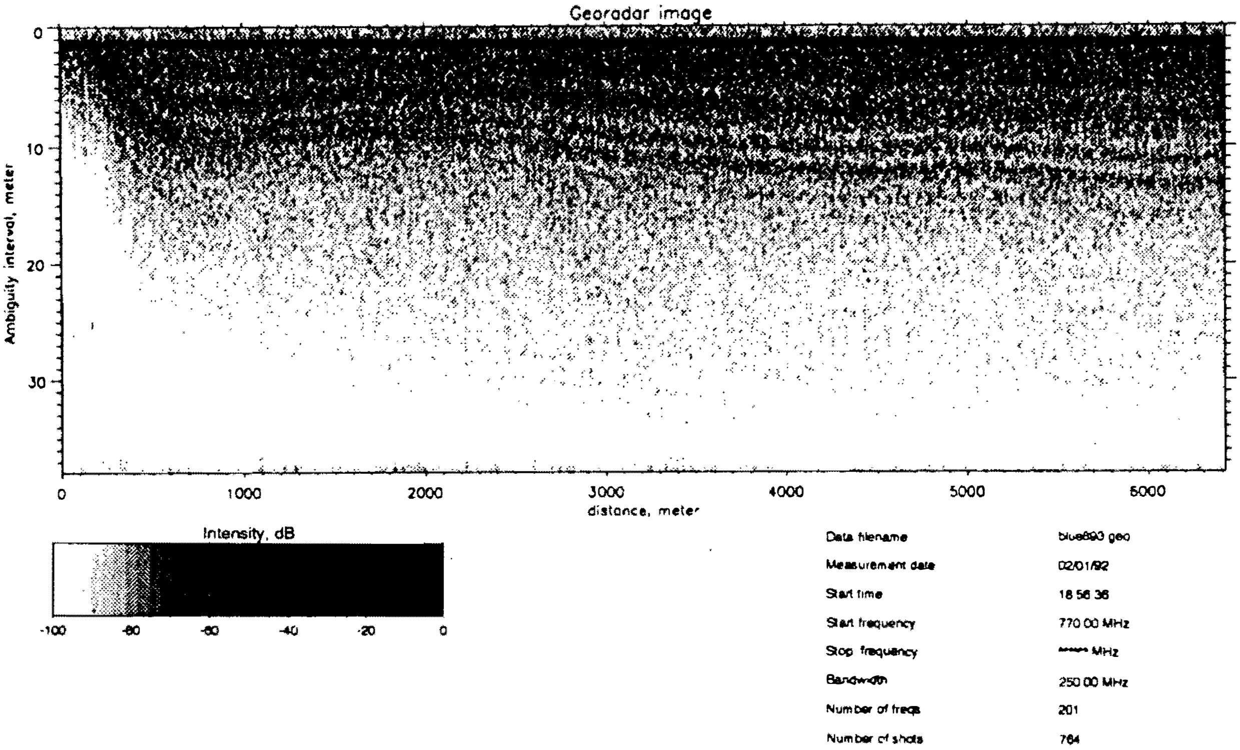


Fig. 2. Snow profile to the north of Basen, starting at the outer border of the blue ice area and directed to the North.

The bottom topography became smoother with distance from the grounding line. An illustration of this is given in fig. 1A which shows a profile of the bottom topography that starts 10 km from the grounding line, and Fig. 1B showing the bottom topography from the outermost part of the shelf. Fig. 1B also shows that some 1 km from the shelf edge the bottom topography indicates that calving of the shelf probably will take place soon. No indications of this could be observed at the snow surface.

Fig. 2 shows the profile starting at the outer part of the blue ice area to the north of Basen. In this profile there is a number of distinct layers in the snow. Based on 3 corresponding profiles of O^{18}/O^{16} ratioes, these layers are interpretated as summer layers. According to fig. 2 the rate of accumulation increased to about 1.5 m of snow 1 km from the blue ice and then remained comparatively constant the next 5 km.

REFERENCES

Budd, W.F., Corry, M.J. & Jacka, T.H. 1982: Results from the Amery ice shelf project. *Ann. of Glaciology 3,* 36-41.

Gjessing, Y. & Wold, B. 1986: Absolute movements, mass balance and snow temperatures of the Riiser-Larsenisen Ice Shelf, Antarctica. *Nor. Polarinst Skr. 187*, 23-31

Hamran S.E. et al. 1986. Hydrogeological Exploration by use of radio wave. *Proc. URSI COMM F 1986. Symp.*, New Hampshire, USA.

Hamran, S.E. 1989: *Geophysical elektromagnetic backscatter tomography. Experimental results from glacier study.* (Ph.D thesis) University of Tromsø. 1 - 126.

Watts, R.D. & Wright, D.L. 1981: System for measuring thickness of temperate and polar ice from the ground and from the air. *J. Glaciol. 27 (97).*