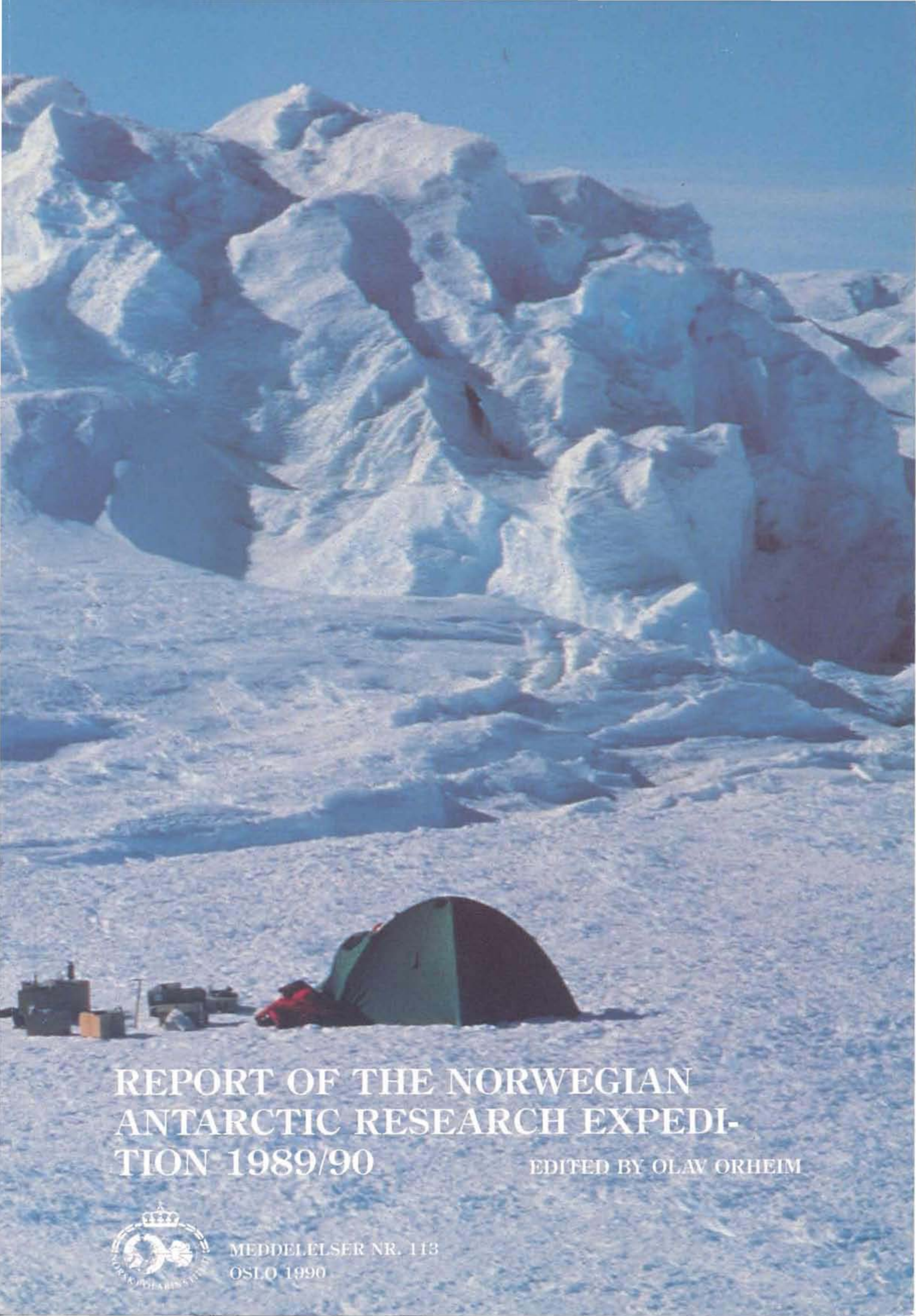

REPORT OF THE NORWEGIAN ANTARCTIC RESEARCH EXPEDITION 1989/90

EDITED BY OLAV ORHEIM

MEDDELELSER NR. 113
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Cover:

Field camp 3 m above sea level at Jutulgryta (71°19'S, 0°18'E).
a rift zone between fast flowing Fimbulisen and grounded ice.
Here the glaciologists installed sub-ice equipment (see article on p. 59).
In the background fractured ice shelf of 30 m elevation.

Photo: Jon Ove Hagen

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PREFACE

This report describes the research conducted on the Norwegian Antarctic Research Expedition (NARE) 1989/90. The expedition involved 34 scientists working in Antarctica during January and February 1990, and the report contains 18 contributions from altogether 33 authors. Responsibility for contents rests with the individual authors, but the reports have been edited for uniformity of style. They generally contain sections on

1) background,
2) objectives,
3) field works and
4) preliminary results.

This report first includes a broad account of the expedition and the building of the station TROLL, followed by an account of the industrial archaeology and biology research at South Georgia.

The next section covers ornithologic, invertebrate, topographic-geodetic, and geologic work done by a 19-person group at TROLL and in the region of Gjelsvikfjella and Mühlig-Hofmannfjella, and glaciological work done at Fimbulisen.

The last part of the report describes the oceanographic, marine biological and marine geological research done from the expedition vessel, K/V ANDENES, in the central and southern parts of the Weddell Sea.

Olav Orheim
Editor

GENERAL REPORT OF THE EXPEDITION

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INTRODUCTION

The Norwegian Antarctic Research Expedition (NARE) 1989/90 comprised the largest number of scientists of any Norwegian antarctic expedition. It consisted of altogether 91 persons: 42 ship crew, 34 scientists including medical personnel, four helicopter crew, four media personnel, three bandwagon crew, two station builders, and two observers.

NARE 89/90 used the 106 m long Norwegian Coast Guard vessel K/V ANDENES. This ice-strengthened vessel was commisioned in 1982, and sailed altogether 23,000 nautical miles until return to Norway (Fig. 1). She left Norway on 29 November 1989, departed Montevideo, Uruguay, on 28 December, arrived Rio de Janeiro, Brazil, on 6 March 1990, and returned to Norway on 1 April. Most of the expedition members, including some of the crew, joined the ship in Montevideo and departed in Rio de Janeiro.

Planning of the expedition started more than a year before departure. Scientific programmes were selected by a seven-person committee appointed by Nasjonal-komiteen for Miljøvernforskning (The National Committee for Environmental Research) and Norsk Polarinstitutt (NP). Finally 16 projects were selected from 37 submitted. At the same time the expedition logistics were planned by Norsk Polarinstitutt together with a group from the Norwegian Coast Guard, and helicopter company and station contractors were selected through bidding processes. NP was assisted by Bjarne Instanes A/S in station planning and contractor selection.

Various modifications were done to ANDENES to make the ship more suitable for conducting the marine science programmes. The ship was outfitted with equipment including four winches with capacity to 4500 m for marine geology and oceanography, an O.R.E. 8 KHz echo sounder, a complete Neil Brown CTD profiler system with back-up, a General Dynamics 12 bottle water sampler Rosette system, and a current profiler.

Equipment to deploy oceanographic rigs included 46 Aanderaa RCM 7/8 currentmeters, 2 Aanderaa WLR water level recorders, and 14 Oceano acoustic releases. Gravity corer, grabs and nets were also onboard for marine geological and biological sampling, and a pressure tank was installed in connection with diving by the biologists.

The expedition carried a Bell 214B and an Ecureuil AS 350 B helicopter, which could lift 3.5 tons and 1.5 tons, and were flown 178 hours and 87 hours respectively. All equipment and personnel had to be flown from the ship to the ice, shelf or the inland areas, and the helicopters were used both for these transport duties and in science support. Their most challenging tasks were several up to 250-km-long flights with underhanging cargo.

Two BV 206 Hägglund bandwagons were used to transport about 100 tons of cargo to Jutulsessen, where a new station named TROLL, was established. The drive from the ice front, where the cargo was unloaded, covered 303 km, and involved crossing crevasses at the hinge zone between ice shelf and inland ice. This drive was done without mishaps five times, so that each bandwagon travelled more than 3000 km. Eight snow toboggans were used in science support. They travelled mostly around 2000 km.

Several techniques were used on land that were new to Norwegian Antarctic Research. The ornithologists measured bird flights by radio transmitters, and invertebrate research included use of high precision electronic balance and osmometer for microsamples of hemolymph. The geodesists brought along five GPS receivers, mostly dual channel, and one that was used from the helicopter. Three new automatic weather stations were established during the season, including one on Bouvetøya with the help of a private Norwegian expedition, and one on Peter I Øy with the help of the USA.

The new permanent station, TROLL was established at 72°00.7'S, 2°32.3'E, at 1290 m elevation. 24 persons worked at and from this location. In addition seven glaciologists were located at camp Fimbul at 70°58.7'S, 0°11.9'E at 53 m elevation, and four ornithologists had their summer camp at Svarthamaren, at 71°53'S, 5°10'E, at 1625 m elevation (Fig. 2).

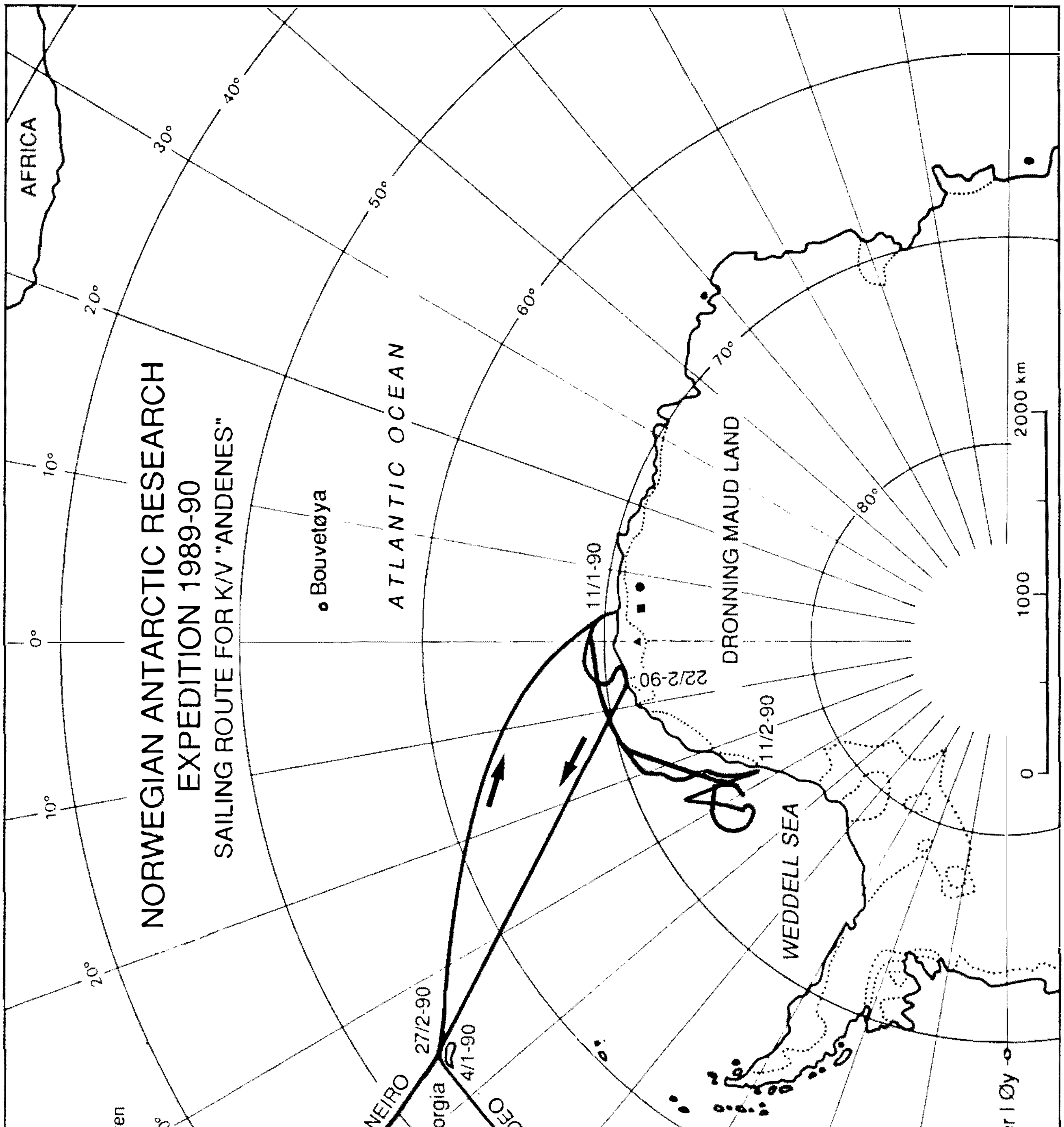

Fig. 1. Sailing route (dotted) and work area (dashed) of the Norwegian Antarctic Research Expedition 1989/90

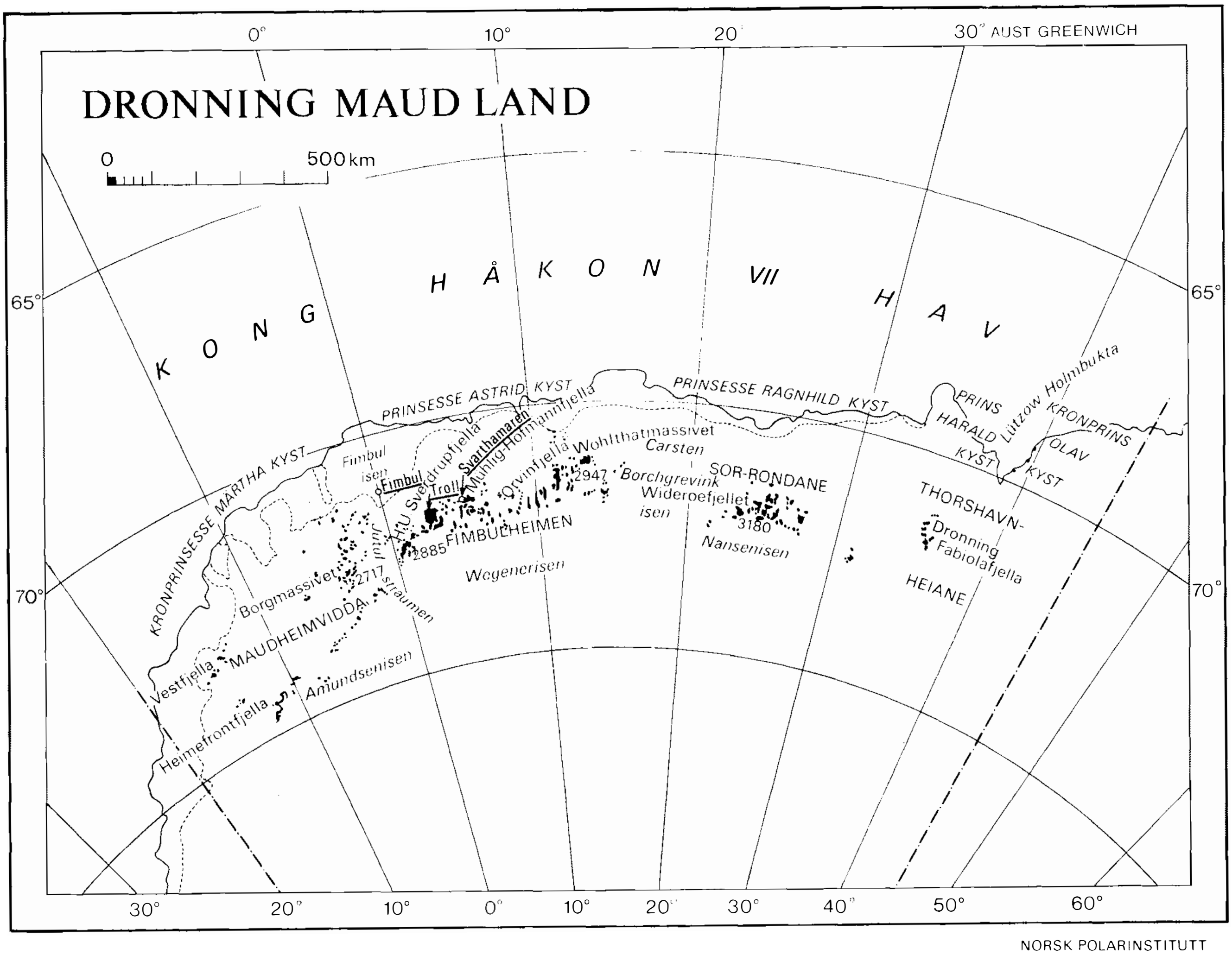

Fig. 2. *Locations (underlined) of the station Troll, and of main camps, Fimbul and Svarthamaren.*

Troll was built on ice-free permafrost-ground in Jutulsessen (Fig. 3), consisting probably mostly of morainic material. It lies on a SW-NE trending pass, i.e. a small saddle, between a high mountain ridge around 2 000 m elevation to the south and a low peak, 100 m higher than the station, to the north. The station consists of two buildings, is designed for winter occupancy, and can accomodate up to eight persons. For the time being it will be occupied in summer only. The establishment of the station is described further in an accompanying article in this volume.

The region of the station is surrounded on three sides by extensive blue-ice areas. Survey was done on a blue-ice area to the east that was suitable for landing by wheeled aircraft (Fig. 4).

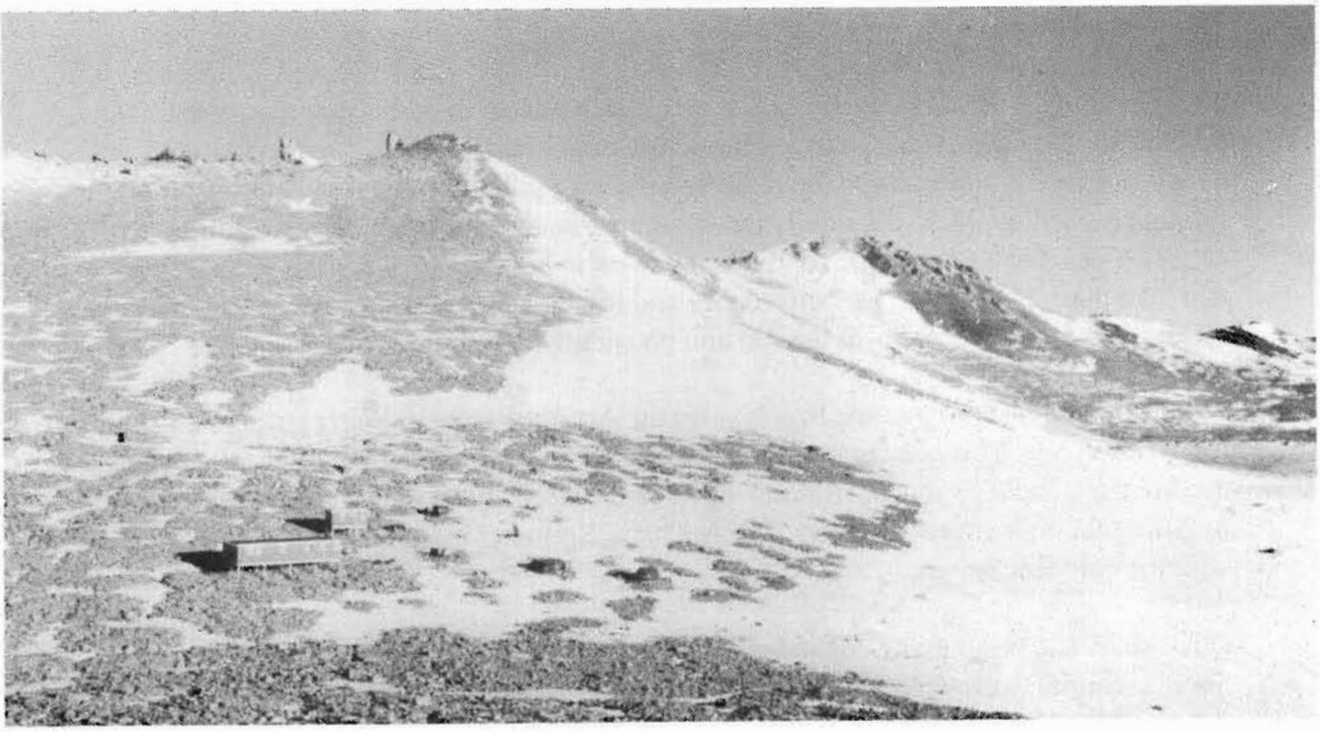

Fig. 3. *Troll. The main building measures 15.3 m x 6.3 m, and contains four bedrooms, one office, a mess hall and work room, kitchen, shower, and toilet. The small building houses the generator and snow melter. Shown are also storage/science buildings, which are transportable.*

Fig. 4. *Aerial photograph of Jutulsessen, taken 5 Jan 1959 from 3 700 m elevation. (Norsk Polarinstitutt Photo No. DML58-59 1301.) Light arrow shows location of Troll, dark arrow shows location of potential air field.*

PROGRAMME AND PARTICIPANTS

The main emphasis of this expedition was research related to global environmental problems, especially climate and sea level. The major research programme measured conditions on the underside of the floating ice shelf Fimbulisen, both by melting a hole through the 397 m thick ice, and by installing instruments for observations during the next two years in a thinner rift zone. The aim was to understand better the processes that take place at the interface between ice and ocean, and how a warmer climate may affect the melting processes of the ice, and potentially cause rise in sea level.

The second largest programme investigated the Antarctic Bottom Water production in the Weddell Sea. This is a current of heavy water that is more than 10 times larger than the Amazon, and it forms the heaviest water in the world oceans and replenishes these by lifting the lighter water masses. The Antarctic Bottom Water is formed in contact with the cold ice shelves.

Other scientific programmes included reindeer research and industrial archeology at South Georgia, marine biology and geology oceanography in the Weddell Sea area, and geology, biology, climatology, geodesy and medical research in central Dronning (Queen) Maud Land. Preliminary results from all these programmes are described in accompanying articles in this volume.

The expedition included the following particpants:

Name	Inst.	Location	Function	
1. Scientists				
Bjørn L. Basberg	UiT	Husvik	Industrial archeology	
Dag Nævestad	"	"	"	
Svein D. Mathiesen	UiTø	"	Biology	Base leader
Tove Aagnes	"	"	"	
Reidar Andersen	NINA	Svarthamaren	Ornithology	
Hans Chr. Pedersen	"	"	"	
Nils Røv	"	"	"	
Bernt Erik Sæther	"	"	"	Base leader
Alex Strømme	UiT	"	Invertebrates	
Hugh F.J. Corr	BAS	Fimbul	Glaciology	
Jon Ove Hagen	NP	"	"	
Mike Kennett	NVE	"	"	
Olav Orheim	NP	"	"	Expedition leader
Arne Sætrang	"	"	"	
Jan Gunnar Winther	NHL	"	"	
Svein Østerhus	NP	"	Oceanography	
Haakon Austrheim	UiO	TROLL	Geology	
Kurt Bucher-Nurminen	"	"	"	
Winfried Dallmann	NP	"	"	

Yoshihide Ohta	NP	TROLL	Geology
Trond Eiken	"	"	Geodesy/topography
Brit Å. Luktvasslimo	"	"	"
Bjørn Lytskjold	"	"	"
Otto Inge Molvær	NUTEC	"	Medical
Fredrik S. Bendiksen	FO	"	"
Per-Ivar Reitehaug	"	"	"
Arne Foldvik	UiB	ANDENES	Oceanogr., leader onboard
Tor Gammelsrød	"	"	"
Nina Nordlund	"	"	"
Kjell M. Nytun	"	"	"
Bjørn Gulliksen	UiTø	"	Marine biology
Cecilie Hellum	UiO	"	"
Ole Jørgen Lønne	UiTø	"	"
Jorunn Sjøholm	UiB	"	Marine geology

2. Other personnel

Jan Erling Haugland	NP	TROLL	Logistics, deputy leader
Georg Johnsrud	"	"	"
Tor Opsahl	FO/HST	"	Surface transport, leader
Bjørn Bakke	"	"	"
Bent Kvannli	"	"	"
Kjell Rivelsrud	Lufttransport	"	Helicopter crew, leader
Dagfinn Robertsen	"	"	"
Tom Lauritzen	"	"	"
John Borge	"	"	"
Birger Amundsen	NRK	TROLL	Radio
Susan Barr	NP	"	Film team
Kikki Engelbrektson	NRK	"	"
Rolf Larsen	NRK	"	"

Captain onboard was Commander Geir A. M. Osen, Norwegian Coastguard.

Institutions

NP	Norwegian Polar Research Institute
UiT	University of Trondheim
UiO	University of Oslo
UiB	University of Bergen
UiTø	University of Tromsø
NRK	Norwegian Broadcasting
NINA	Norwegian Institute for Nature Research
BAS	British Antarctic Survey
NVE	Norwegian Water Resources and Energy Administration
NHL	Norwegian Hydrotechnical Laboratory, SINTEF

NUTEC	Norwegian Underwater Technology Center
FO	Norwegian Defence, Medical Div.
FO/HST	Norwegian Defence, Transport Div.

MAIN EVENTS

After departure from Montevideo on 28 December 1989, the expedition first made a brief call at Stanley, for refuelling and embarkation of a visiting scientist from British Antarctic Survey.

The expedition arrived South Georgia Island on 4 January 1990, and placed four scientists and their equipment at Husvik Harbour. These stayed in the building used in the past by the manager of the whaling station; this was the only building still in fairly good shape. For the next 8 weeks the group had daily contact with the expedition by radio, and they also had periodic contact with the British on the island, in case of emergency.

The expedition arrived to the ice shelf at Prinsesse Astrid Kyst on 11 January, and immediately started offloading cargo at 70^0 10' S, 4^0 40'E. On the following day four ornithologists were in place at Svarthamaren, and site selection for Troll was completed, two persons were left in Jutulsessen for environmental assessment reserach, and a route with minimum of crevasses for the overland transport to TROLL was reconnoitred. The work of flying more than 100 tons of cargo onto the ice shelf was completed by 14 January, and by then the first caravan had started towards TROLL. Altogether 38 persons were embarked ashore, including those who were flown 250 km to TROLL or Svarthamaren.

ANDENES then moved westwards, but the days 15-19 January were spent drifting north of Trolltunga in heavy ice and under overcast weather which prevented flying long distances over the ice shelf. Flying the 130 km to Fimbul commenced on 20 January, and by the next day seven persons were installed here with about 10 tons of equipment. The four helicopter crew plus one logistic person flew from here to Troll, where the helicopter base was located for the remainder of the season (see Fig. 2).

ANDENES conducted marine programmes in the Weddell Sea from 22 January until 18 February. Two Norwegian observers were taken onboard from Finland's R/V ARANDA, and Halley Station was inspected during this period. ANDENES was beset by heavy ice on 2 February, which caused damage to one hull section and chipped a piece off one propeller blade. The hull damage was fixed by underwater welding, but for a while it was feared that propeller vibration would cause problems travelling at higher speeds. This, combined with heavy ice in part of the Weddell Sea, meant that the southern part of the cruise was curtailed. Later experience showed that ANDENES could transit at 14 knots without vibration problems.

TROLL Station was officially opened on 1 February, and on 13 February the glaciologists at Fimbul completed their work and moved to TROLL. All persons from there were flown out to the ice shelf by 17 February.

Flights to ANDENES started on the following day. At that time there was still a 20 nautical-mile-wide belt of fairly heavy ice off the ice shelf. The ornithologists from Svarthamaren were also flown out. Retrograding of cargo, which included all refuse from TROLL, was completed on 19 February, and ANDENES set course westwards, for inspection of the SANAE and Georg von Neumayer stations.

When the station was closed for the winter, the following were left behind:

1 drum petrol
3 drums kerosene
350 man-day rations of food
Field equipment for three mobile parties

ANDENES left the continent on 23 February, and the four at Husvik were taken onboard on 27 February. From there the ship sailed directly to Rio de Janeiro, arriving on 6 March. Here the scientists and some of the ship crew disembarked and flew back to Norway.

RESULTS

Preliminary results of NARE 1989/90 are reported elsewhere in this volume. As a general remark it can be concluded that nearly all programmes on land were completed approximately as planned, while the marine programmes, and especially the oceanography, achieved less than hoped for. The glaciologists drilled 400 m through the ice shelf, and deployed sub-ice instrumentation under thin ice shelf, they conducted radio-echo soundings over Jutulstraumen, and measured the heat- and water balance of the snow at two locations. The ornithologists completed an extensive measuring programme at the Svarthamaren SSSI, which consist of nearly 1 million Antarctic Petrels,

CONCLUSIONS

NARE 1989/90 has demonstrated that it is possible to plan on quite complex logistics using a combination of K/V ANDENES, medium-sized helicopters, bandwagons, and skidoos, and still allow the scientists to have their field season intact. The establishment of Troll was done with a crew of only two builders who received help from the scientists in their spare time, and three drivers. The latter drove altogether a distance of 3000 km to bring the building materials to the site, that is more than the distance from Paris to Moscow. The station was built using a patent that allowed for extremely efficient coupling of the sandwich panels, using no screws or nails, and the successful organization of the transport sequences was critical to maintain the high building speed.

ACKNOWLEDGEMENTS

The execution of this expedition has involved assistance from a number of institutions. Most important we want to thank the Norwegian Coast Guard for the use of ANDENES, and the Norwegian Army for the use of two bandwagons with personnel. Those institutions, mentioned above, that sent participating scientists have given large contributions, generally in the form of lending equipment free of charge, and giving the scientists leave of absence with full pay. We would like to thank especially FINNARP, the Finnish Antarctic Research Programme, for very helpful cooperation in the field.

APPENDIX

Sailing list for K/V ANDENES:

Dep.	Oslo	29 Nov. 1989
Arr.	Montevideo	26 Dec.
Dep.	"	28 "
Arr.	Stanley	31 "
Dep.	"	1 Jan. 1990
Arr/Dep.	Husvik, South Georgia	4 "
Arr.	70°10'S, 4°40'E, land parties ashore	11 "
Marine programmes, Weddell Sea		21 Jan. - 16 Feb.
Arr.	69°55'S, 4°21'E, retrieval land parties	18 Feb.
Arr/Dep.	SANAE	22 "
Arr.	Georg von Neumayer	22 "
Dep.	"	23 "
Arr/Dep.	Husvik	27 "
Arr.	Rio de Janeiro	6 March
Dep.	"	10 "
Arr.	Bergen	1 April

BUILDING OF THE STATION TROLL

Jan Erling Haugland, Expedition Coordinator, Norwegian Polar Research Institute, P. O. Box 158, 1330 Oslo lufthavn, Norway

INTRODUCTION

One of the main objectives for NARE 89/90 was the building of a permanent scientific research station in Dronning Maud Land.

From our knowledge of the region, it was planned to locate the station within Jutulsessen, which contains relatively large ice free areas. However, the exact placement of the station was not decided in advance, but after reconnaissance the site of the station was located at 72°00.7'S, 2°32.3'E.

The station, with this placement, is 220 km from the barrier and 1270 m above sea level. It was placed on a frozen morraine area where snow should not accumulate.

The station has a main building which is 96 m^2 and an annex (generator house) which is 22 m^2. The station is designed and equipped for use by 8 - 10 persons for long periods of stay. Some minor work remains before the station is suitable for year-round use. A greater electrical supply is necessary, among other things.

The building was put up in the course of one month by the expedition participants, without the help of technical experts.

PREPARATIONS

Norway's northern location and Norwegian experience from Svalbard have led to solid expertise in polar technology (building construction, cold weather conditions, etc.).

We selected a well known engineering consultant firm, "Sivilingeniør Bjarne Instanes A/S", to help in planning and preparations. Proposed drawings and specifications were ready early in 1989. Emphasis was placed on planning for a functional design, transport in parts, construction by labor without construction experience, durability and strength. The heating system and insulation were also important.

Knowledge based on experience from areas in Norway and at Svalbard with extreme weather conditions, combined with earlier experience from Antarctica was used as a basis for planning the station.

One of the more demanding tasks was co-ordinating the size of the buildings, our need for room at the station, and the transport capacity we expected. In addition, it was important that the prefabricated parts had a size and weight which could be handled without cranes or machines, and with simple mechanical means.

The use of two helicopters, a Bell 214 1B and an Ecureuil B350 for transport and building, was also planned. Two bandwagons (Hägglund BV 206) were to be used for transport of building materials from the shore landing area to the building site.

CONSTRUCTION PHASE

All equipment was flown onto the ice shelf at 70°10'S, 4°40'E, where a temporary storage depot was established. From here a 303 km long overland route, with minimum of crevasses was found to the station locality.

After two days travel from the landing area, the first load of materials reached the construction site on Jutulsessen, and work on the foundation and building of the generator house could begin. This building was put up in three days, and we could then start on the foundation for the main building. The foundation was made up of aluminum units. Fifteen vertically adjustable main piles (from 70 - 200 cm) were erected in solid ground and cemented or frozen in place, with four bolts through each piles' adjustable ground plates. The fundament frame consisted of triple-insulated horizontal and crosswise H-beams of aluminum. All of these parts of the foundation were stabilized by tension cables.

Floor, wall and roof elements had a standard width of 1.2 m, but were of variable lengths. All were fastened together with premounted bolts. The elements were covered with 0.8 m steel plates which were 20 cm thick and reinforced by four 2" x 6" planks and insulated with polyurethan. The finished result was a rather tightly sealed "package". The main building was raised and all exterior work finished by 1 February 1990.

The interior walls were standard pre-finished units with 10 cm rockwool insulation.

The whole station, with annex, was finished on 17 February 1990 and only minor adjustments remained to be done.

SUMMARY

We look upon the building of TROLL as a very successful venture, even though we realize afterwards that some things could have been done somewhat differently. Size, choice of materials and plans were suitable according to our needs and conditions. The future will reveal whether or not results are as hoped for.

There are a number of persons who should be thanked for making the project successful, and we would like to name here the main contributors:

- Consultant engineering company Siv.ing. Bjarne Instanes A/S
- Fresvik Produkter A/S, which produced the prefabricated elements, and
- Byggkompaniet A/S, the general contractor for prefabrication of the whole station complex.

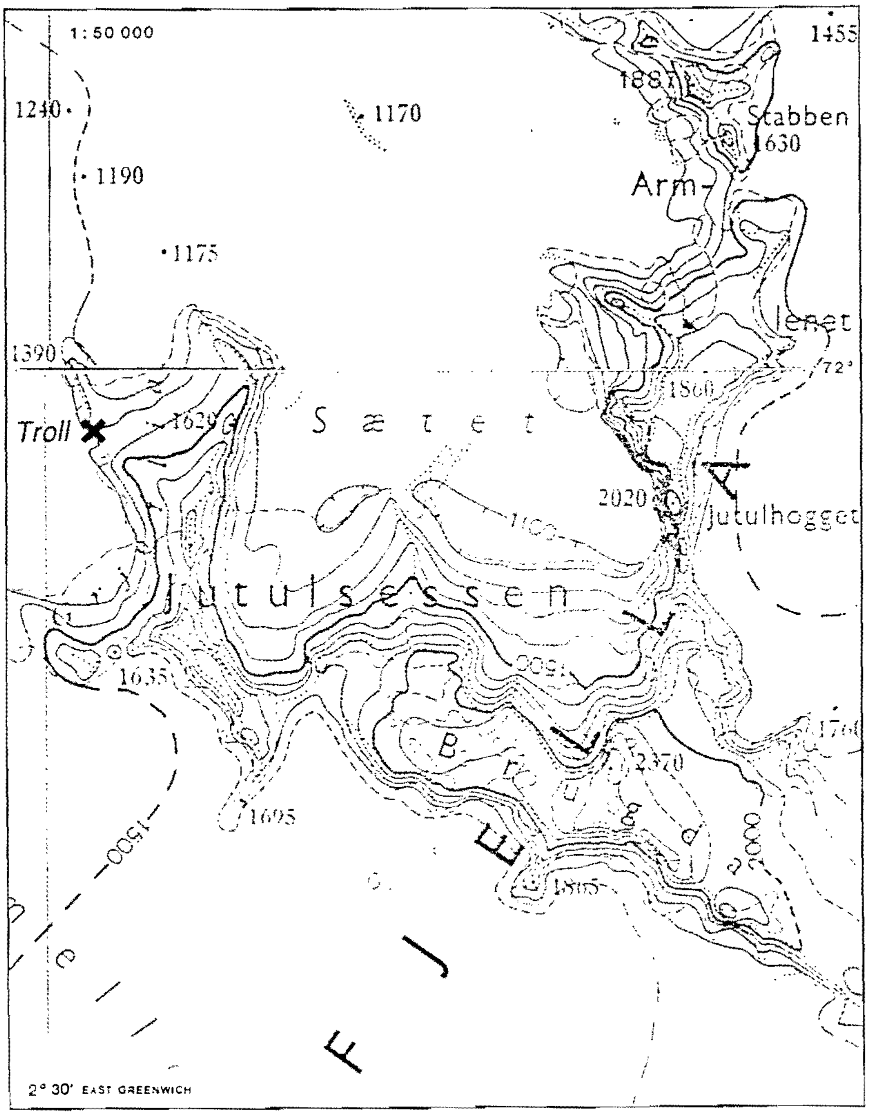

Fig. 1. Jutulsessen, with location of TROLL station.

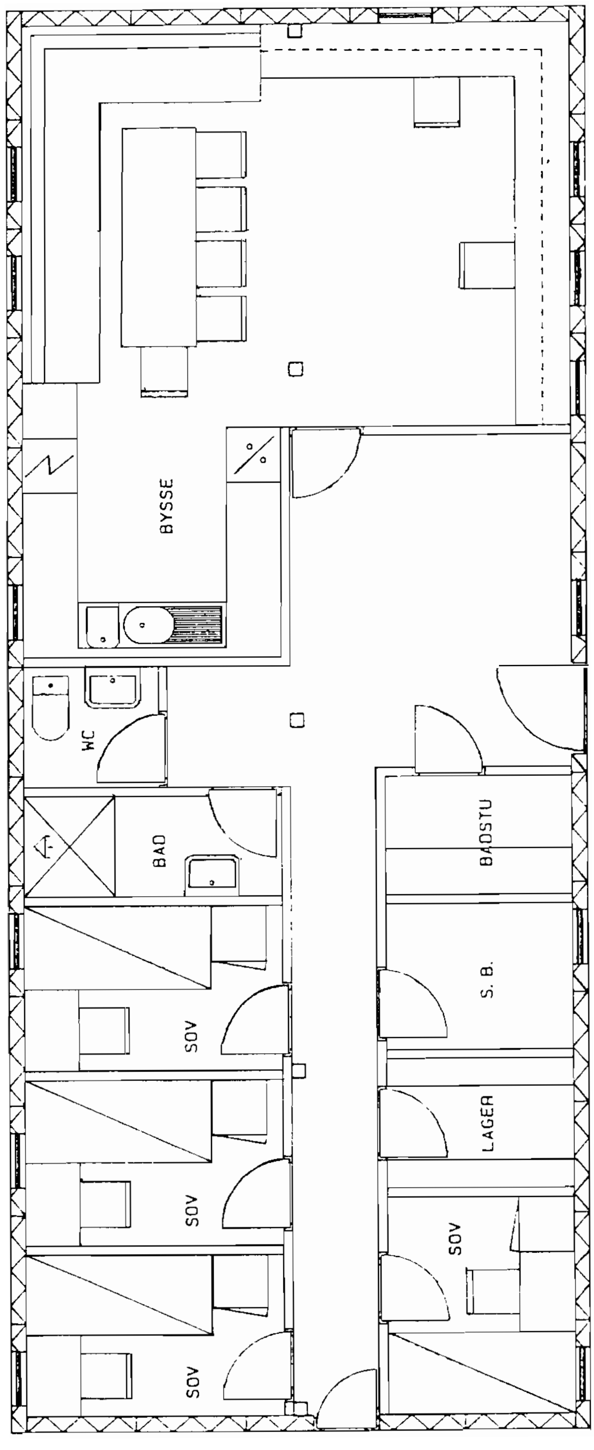

Fig. 2. Plan of research station TROLL

Bysse: Pantry, Sov: Bedroom, Bad: Shower,
Badstu: Sauna, S. B: Office, Lager: Stores

INDUSTRIAL ARCHAEOLOGY AT SOUTH GEORGIA

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BACKGROUND

Altogether there have been six whaling shore stations at South Georgia, South Atlantic Ocean, at different periods between 1904 and 1965. The owners were Argentinian, British and Norwegian companies, while the majority of the whalers always were Norwegian (Tønnessen and Johnsen 1982; Headland 1984). Before the pelagic whaling became the dominant form of whaling - from the late 1920s - South Georgia was the centre of modern Antarctic whaling.

After the close of whaling, the stations have been in a rapid decline and deterioration due to the rough weather, visiting tourists collecting souvenirs and other visitors from ships ravaging the buildings. With the exception of very few buildings, there has been no maintenance whatsoever.

OBJECTIVES

The very bad and deteriorating condition of the stations have been reported by several visitors over the last ten years (Headland 1980, 1986; Shackelton 1982; Sømme 1983). This led to the planning of a systematic survey of the stations before it was too late. The preparations had been going on for several years in cooperation with the Whaling Museum in Sandefjord, Norway. Not until the Norwegian Antarctic Research Expedition (NARE) 1989/90, however, was it possible to undertake the project. NARE offered the necessary financial support and solved the logistic problems.

A detailed survey has been concentrated on the two stations, Husvik Harbour and Stromness Harbour, during a stay based at the "Villa" in Husvik from January 4th to February 27th 1990. The time did not permit working in detail on more than two stations. To undertake this survey has been the main objective of the project.

An additional objective has been to make an assessment of, and make some recommendations for, the future use of the stations at the island. The background for this is a recent British initiative for a museum in Grytviken and also plans for clean-up and salvage operations on several stations. During our stay at South Georgia we made short visits at three stations: Grytviken, Leith Harbour and Prince Olav Harbour. Consequently, five of the six stations at the island have been visited, making at least a limited assessment possible.

PRELIMINARY RESULTS

The survey

The whaling stations at South Georgia were self-contained units, incorporating all the functions of a community of several hundred men. The general lay-out of the stations reflects the complex structure needed for such operations. The stations were used for a period of more than 50 years, with many modifications and new structures adding to the complexity of the buildings and the whole station. Surveying the stations is thus a time-consuming task. To minimize the time needed in the fieldwork, the survey relies in great extent on terrestrial photogrammetric methods, involving the use of a Zeiss metric camera (9x13 cm format), a Hasselblad (6x6 cm), and a theodolite/total station for establishing fix positions for the photogrammetry.

The photogrammetry was done both at Husvik and Stromness from several positions in the hillside, approximately 120 meters above the stations. At Husvik several local photogrammetrical surveys were also done, of the flensing plan, the catcher "Karrakatta" (b. 1912) and surrounding buildings at the slip and the blubber cookery.

Supplementary measurements for the construction of maps of the stations were limited to Husvik, where over 200 positions were measured. For these measurements a database in D-Base 3+ was constructed, and X, Y and Z coordinates calculated. The compilation of maps will be done by the Norwegian Institute of Technology (NTH), Trondheim.

In addition to this survey a photographic documentation of all the sides of buildings and significant installations (except tanks) has been done, using a Hasselblad 500c and a Hasselblad Super Wide C (black and white photographs) and a Nikon FM (24x36mm) (color diapositives). All photographs are logged in a database, stating the number of the structure photographed, the direction in which the photographs were taken, and additional data. It is thus possible to get quick access to the photographic material concerning each structure documented.

There is a total of 35 standing buildings in Husvik. In addition there are oil tanks, the cinema (which is partly collapsed), the foremen's residence (which burned down in 1985), and the remains of the meat freezer. In Stromness the total number of buildings standing is 26. The cinema has collapsed, and all the old cookeries are dilapidated. External measurements of all the buildings of each station have been taken.

The interiors of all buildings in Husvik have been measured and mapped, by sketching each room, showing the layout of functions and machinery. The data are logged in a database, stating the number of square meters, function, machinery (if any), equipment stored, number of beds (if any) and several other data for each room. The database will provide possibilities for statistical analysis and comparisons with other stations, as well as an inventory of equipment left at the station.

In addition each room is photographed, using a Nikon FM, and colour diapositive film. These photographs are also logged in a database, allowing quick access to the material obtained.

All the drawings and maps will be published in separate reports. The extensive photographic material will be catalogued and kept by the Whaling Museum in Sandefjord.

A complete registration of artifacts and machinery has been beyond the scope of the project. A strong selection has been made. The work at this level has been concentrated on the production plant. Although parts of the buildings are collapsed, much machinery is still intact. The workshops are also to a large extent complete, containing items too large and heavy for souvenir-collectors to carry away! Especially Stromness has a rich collection of machinery, due to the fact that the station has been a repair yard for catchers since 1931 when whaling stopped at that station.

A special category of equipment which has been documented in detail, is whale-catcher equipment. At all stations there is a lot of such equipment (harpoon-guns etc.) both stored and thrown away in the many dumps. Being aware of the increased interest in catcher-restoration in Norway, the project has paid special attention to such items.

Assessment and future plans

It is possible to argue that all five stations visited have qualities which make them conservation-worthy. However, this is obviously beyond reality, and the greater part of the buildings should be left to further decline. It is difficult to oppose salvage or clean-up operations except for a limited number of buildings and artifacts.

If the museum-plans are carried further, we recommend that the work, as suggested in the British initiative, should be concentrated at Grytviken. It was the first station to be established. It is the only place at South Georgia with a permanent staff (King Edward Point). The church, the only one on the island, is already being maintained. The same is, to some extent, the case with the catcher Petrel (b. 1928). The general condition of the station is at least not worse than at any of the other stations. Especially Husvik is in a very bad condition because a river is running straight through several buildings.

The production plants at Grytviken and Leith are in better condition than the ones in Husvik and Stromness. In Stromness the plant is, as a matter of fact, dismantled after the transformation to a repair-yard. In our view, the plant (the flensing plan, the lofts, the cookeries, the guano factory) should become an important part of a conservation scheme at Grytviken. The production plants represent the uniqueness of these stations, and are not found anywhere else. A full restoration is probably not realistic, but the buildings at Grytviken should be made safe for visitors.

Some items should also be brought from other sites to Grytviken, enabling the museum to offer a near complete exhibition of the most important machinery in the industry (pressure-, Kværner-, Hartmanncookers, Rose Down plants, separators, guano driers etc.) The libraries at Leith and Stromness should also be moved to Grytviken.

CONCLUDING REMARKS

It may well be asked whether labour and money should be employed in maintaining anything at all at a remote place like South Georgia. Conservation gives meaning first of all if the place is being visited. There will probably never be many visitors to the island, and the level of ambition has to be adjusted to this prospect. But there is an increased tourist activity in the Antarctic in general, and it is likely that South Georgia with its unique nature, animal life and history will face the same increase.

All along since the stations were abandoned, decline and deterioration have met the visitors - and they have themselves contributed to that. The time has now come when the trend should be turned around. It is our hope that visitors in the future may be able to see at least one site which will give them information, and where they by themselves can visit buildings that are safe, and get a feeling of this very special part of our recent industrial history.

The survey which is undertaken at Husvik and Stromness, is also by itself a kind of conservation. The knowledge of how the buildings looked and how they worked will be preserved for the future although the buildings themselves are collapsing or being dismantled. It is our hope that similar very detailed surveys can be undertaken at the other whaling stations at South Georgia.

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Fig. 1. Husvik whaling station, South Georgia. Aerial view from NW. (Photo: Y. Kristiansen/KV Andenes.)

Fig. 2. *Stromness Whaling Station, South Georgia. Aerial view from S. (Photo: Y. Kristiansen/KV Andenes)*

MICROBIAL DIGESTION IN NORWEGIAN REINDEER ON SOUTH GEORGIA

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BACKGROUND AND OBJECTIVES

In 1911 fifteen reindeer (*Rangifer tarandus tarandus*) from Valdres in Norway were introduced to South Georgia (54°-55°S, 35°-38°W) by the Norwegian whaling brothers C. A. Larsen and L. E. Larsen. Another seven animals were introduced into the Busen area of South Georgia in 1925 since the five animals first introduced here in 1911 were killed in a snowslide. The island of South Georgia is 3775 km^2, 60% of the island is covered by glaciers, and only 313 km^2 of the area is available for reindeer. The purpose of the introductions was to provide sport and fresh meat for the Norwegian whaling communities on the island (Headland 1984). By 1976 the reindeer population had increased to about 3000 animals, occurring in three sub-populations, the Barff, Royal Bay, and Busen herd (Leader-Williams 1988). South Georgia has the highest density of reindeer ever reported: 23, 13 and 6 animals per km^2 in the Barff, Royal bay, and Busen herds, respectively (Leader-Williams 1980). Prior to the introduction of reindeer South Georgia harboured no herbivorous mammals.

The flora of South Georgia differs markedly from that encountered by reindeer and caribou in the northern hemisphere. It is poor in species, especially vascular plants, and lacks true shrubs. The vegetation is dominated by coastal tussock grass, *Parodiochola flabellata* , a species of high biomass and productivity. In summer the reindeer graze on *Deschampsia antarctica, Acaena magellanica, Poa annua,* and *Parodiochola flabellata.* In winter the animals eat almost exclusively *P. flabellata,* owing to the fact that lichens, which form a major part of the winter diet of reindeer in Norway, are scarce at South Georgia (Leader-Williams 1988).

The animals' dependence on *P. flabellata,* rather than lichens in winter, demonstrates that reindeer are highly adaptable feeders. To understand how Norwegian reindeer have adapted to a diet consisting almost entirely of vascular plants is of considerable interest, especially in northern Norway were the lichen range is now badly overgrazed.

Reindeer are ruminants and depend on highly specialized microorganisms in the rumen to digest the plants they eat. Lichens have a substantially different chemistry compared to vascular plants, and consequently profound differences in rumen microbial metabolism might be expected in animals fed vascular plants as compared with those eating lichen. In particular, a high intake of vascular plants both summer and winter may lead to selection of highly cellulolytic bacteria in the rumen and cecum, which could increase food utilization. The rumen and cecum of high arctic Svalbard reindeer, have evolved a highly specialized microflora adapted to the animals' high fiber diet (Orpin et al. 1985; Mathiesen et al. 1987).

The aim of this investigation was to compare the digestive physiology of reindeer on South Georgia with reindeer in Norway to find out in particular.

1) if the reindeer on South Georgia have the same composition of rumen microorganisms,
2) if new rumen organisms have developed,
3) if some organisms were lost in the original animals due to transport stress in the original reindeer across the equator,
4) if the utilization of vascular plants is more efficient, and
5) if rumen and cecum volumes are different in the two groups.

METHODS

These investigations were carried out in the Busen area, Strømnes Bay, at South Georgia, from 4 January to 27 February, 1990. Accomodation was provided in the old manager's villa at Husvik Harbour, a previous Norwegian whaling station originally established by A/S Tønsberg Hvalfangeri in 1907.

A field laboratory was estabished in the old radio house, harbouring incubators, water baths, scales, freezers, plant grinder, microscopes and chemicals.

Ten adult female reindeer were shot in the area around the whaling station and in the Olsen valley. A permit to shoot these animals was issued by H.M.Governor of the Falkland Island Dependencies.

Anatomy

The total body weight of each animal was measured immediately after the animals were shot using a Salter 1-100 kg scale. Jaws and front teeth were collected for age determination. Length of the femur was taken as a measurement of body size. Each section of the gastrointestinal tract was emptied and weighed using a Salter 1-25 kg scale and a Metler PC180 1-180 gram electronic scale. The length of esophagus, small-intestine, cecum and colon was measured to 1 cm.

Bacteria

Bacterial investigations were carried out on five animals. Rumen and cecum content were brought to the laboratory within 30 min of the death of the animal in a 39°C preheated thermoflask. The population of strict anaerobic bacteria in fluid and on plant particles in the rumen and cecum were measured using a habitat simulating medium, brought from Norway. The medium contained a basal medium (Orpin et al.1985), supplemented with 0.2% glucose, 0.2% cellobiose, 0.2% starch, 0.2% maltose, and 0. 2% Xylan.

The dominant bacteria which grew in this medium were brought to Norway by air for isolation and characterization at the Department of Arctic Biology, University of Tromsø. Estimations of populations of cellulolytic, proteolytic and lactate utilizing bacteria were carried out both in the rumen and cecum. The basal medium was then supplemented with 1.5% acid swollen cellulose, 0.1% azocasein and 1.4% sodium lactate, respectively, in each medium. Plant particles from the rumen and cecum were fixed in 4% glutaraldehyde in phosfate buffer for electronmicroscopic examination of bacteria which adhere to the plant fibres.

Protozoa

Rumen contents from all animals were filtered through two layers of muslin and the fluid fixed in 4% glutaraldehyde in phosfate buffer for microscopic estimation of the populations of different rumen ciliates.

Fungi

The population of anaerobic rumen and cecum fungi were estimated in a habitat simulating fungi medium (Orpin 1988).

Digestibility of the diet

The extent and rate of digestion in the rumen of selected forage collected in January on South Georgia were measured using a modified in vitro dry matter digestibility method designed originally for field use at Svalbard (Tilley and Terry 1963; S.D. Mathiesen, unpublished results). Standard grasses were included in each set of experiments. The plants tested were: *Parodiochola flabellata, Poa annua, Poa parentsis, Phleum alpinum,* and *Acaena magellanica.* Ground-up grass were digested for 6, 12, 24 and 48 hours using rumen fluid from three animals.

Fermentation

Ruminal and cecal pH was recorded in the intestinal fluid using a Radiometer portable pH-meter to characterize the rate of fermentation. Samples were collected for analysis of volatile fatty acids, acetate, butyrate and propionate (VFA) from five animals. As much as 75% of energy expenditure each day in ruminants is provided as VFAs absorbed across the rumen wall. The rate of VFA production in the rumen and cecum content were estimated by subsequent sampling of the content while it was incubated inside the animal after 5, 20, 30, 60, 120, and 180 min post mortum. VFA samples were diluted in three parts of 60% ethanol and frozen. VFA production per gram of selected forage was measured when 100 mg of *Parodiochola flabellata, Deschampsia antarctica, Phleum alpinum, Acaena magellanica* and *Poa annua* were incubated in 10 ml rumen fluid from three different animals. These experiments will be used to calculate the contribution of different species of diet plants to the daily energy uptake of the reindeer.

Invited projectes

To make maximal use of the animals shot, the following projects were carried out on behalf of other scientists:

A) The cause of mandibular swellings in reindeer on South Georgia.
Jaws from all animals were fixed in 3% glutaraldehyde for analysis by electron-microscopy. In collaboration with Dr. S. Risnes, Norwegian College for Odontology, University of Oslo.

B) Distribution of parasites in the abomasum of reindeer on South Georgia.
Abomasums from ten animals were collected and frozen prior to transport toand analysis in Norway. In collaboration with K.Bye, Directorate of reindeer husbandry, Alta.

C) Determination of radio isotopes (cesium and strontium) and heavy metals in reindeer on South Georgia.
Samples from the heart, kidney, liver, femur, feces and skeletal muscles were collected and frozen for analysis in Norway. In collaboration with Dr. T. Skogland, Norwegian Institute for Nature Research, Trondheim.

D) Determination of chromosomal abberations in cultivated lymphocytes from reindeer on South Georgia.
Lymphocytes were isolated from the blood of reindeer, incubated and subseqently fixed for microscopic analysis in Norway. In collaboration with Dr. K. Røed. Norwegian Veterinary Institute, Oslo.

E) Determination of the family relationship of reindeer on South Georgia, with reindeer herds in Norway using the genetic marker protein transferin.
Plasma blood samples were collected from all animals and frozen. In collaboration with Dr. K. Røed. Norwegian Veterinary Institute, Oslo.

F)

Transfer of tussock Parodiochola flabellata grass to Norway, and investigations of its potential for cultivation.

Six tufts of grass and 0.5 kg seeds were collected and brought back to Norway. In collaboration with I. Skjeldrup, Norwegian Agricultural Council for Science, and The Norwegian State Agricultural Research Stations, Holt Research Station, Tromsø.

G) *Plant species composition in the rumen of reindeer on South Georgia.*
A representative sample was collected from the rumen and fixed in 4% gluturaldehyde. In collaboration with Dr. N. Leader-Williams, Department of Zoology, University of Cambridge, UK.

PRELIMINARY RESULTS

Anatomy

The mean ($\pm$ SD) total body weight of ten female reindeer was 73.8 ± 7.7 kg. Rump fat depth ranged from 1 mm to 28 mm. The mean femur length was 0.275 ± 0.058 m; mean jaw length was 0.237 ± 0.011 m and mean liver weight was 1.37 ± 0.18 kg. Total rumen weight including both tissue and contents in these reindeer was 18.2 % of the total body weight. The mean length of the small intestine was 24.32 ± 4.60 m, and its mean total weight was 3.9 % of the total body weight. The mean length of the cecum in the reindeer on South Georgia was 0.46 ± 0.08 m, and the total weight of this section represented on average 0.9% of total body weight. Mean length of the colon was 11.12 ± 1.3 m and its total weight represented 2.4% of the total body weight.

Bacteria

The viable population of anaerobic bacteria in the rumen fluid ranged from $0.23 \pm 0.14 \times 10^9$ bacteria per ml fluid in one animal to $0.98 \pm 0.64 \times 10^9$ cells per ml in an other (Table 1). The viable bacterial population which adhere to the plant particles ranged, however, from $1.70 \pm 0.51 \times 10^9$ bacteria per gram plant material to $4.82 \pm 1.34 \times 10^9$ cells per gram material (Table 2). Ceca of reindeer on South Georgia contained $1.23 \pm 1.14 \times 10^7$ to $1.90 \pm 0.7 \times 10^7$ bacteria per ml fluid, which was rather less than the in the rumen (Table 3). The number of viable anaerobic bacteria which adhere to the cecal plant particles ranged from $1.70 \pm 1.15 \times 10^7$ cells per gram plant material to $2.78 \pm 2.00 \times 10^7$ cells per gram (Table 4). Anaerobic viable bacteria from rumens and ceca were successfully brought to Norway by air, and five hundred different strains of bacteria have been isolated and purified in an anaerobic chamber at theUniversity of Tromsø. These bacteria will subsequently be characterized.

Protozoa

A variety of different ciliates from rumen fluid were observed by microscopy in all animals. Rumen ciliates are sensitive to nutritional stress. Considering the small number of animals originally introduced from Norway, and the probable heat and nutritional stress they suffered during passage through the tropics, it is surprising to find that the reindeer in the Busen herd on South Georgia contain an apparently normal rumen fauna.

Fungi

The population density of viable anaerobic fungi in rumen fluid was $2.0 \pm 0.81 \times 10^2$ cells per ml, but $1.96 \pm 0.70 \times 10^3$ fungi per gram were found adherent to plant particles. Cecal anaerobic fungi was not detected.

Fermentation

Ruminal PH was on average 6.28 ± 0.15 ($\pm$ SD) 20 min after death, decreasing to 6.06 ± 0.31 after 90 min and further to 5.67 ± 0.10 180 min after the animals were shot. Cecal pH was on average higher; 6.90 ± 0.06 20 min after death of the animals. It decreased to 6.71 and 6.53, respectively, 90 and 180 min after death of the animals.

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Fig 1 . A herd of Norwegian reindeer grazing Tussock grass on South Georgia.

Fig. 2. A herd of Norwegian reindeer grazing between the Gentoo colonies of South Georgia.

TABLE 1

Total number of viable anaerobic bacteria and the number of cellulolytic, proteolytic and lactate utilizing bacteria per ml of rumen fluid in adult female Norwegian reindeer on South Georgia in summer ($x10^9 \pm SD$)

Animal No.	**3**	**7**	**8**	**9**	**10**
Viable bacteria	0,33±0,30	0,34±0,31	0,27±0,14	0,98±0,64	0,23±0,09
Cellulolytic bacteria	-	0,13±0,06	0,14±0,08	0,35±0,19	0,14±0,05
Proteolytic bacteria	-	0,04±0,05	0,02±0,01	0,02±0,01	0,01-
Lactate utilizing bacteria	-	0,17±0,07	0,09±0,05	0,41±0,20	0,09±0,05

- : not measured

TABLE 2

Total number of viable anaerobic bacteria and the number of cellulolytic, proteolytic and lactate utilizing bacteria per gram of rumen plant particles in adult female Norwegian reindeer on South Georgia in summer ($x10^9 \pm SD$)

Animal No.	**3**	**7**	**8**	**9**	**10**
Viable bacteria	4,07±3,08	1,70±0,51	1,70±1,15	4,82±1,34	4,16±1,72
Cellulolytic bacteria	-	1,04±0,34	0,79±0,34	2,10±0,85	1,50±0,40
Proteolytic bacteria	-	0,32±0,16	0,05±0,01	0,05±0,01	0,02±0,01
Lactate utilizing bacteria	-	0,56±0,40	0,66±0,18	1,90±0,49	1,55±0,90

- : not measured

TABLE 3

Total number of viable anaerobic bacteria and the number of cellulolytic, proteolytic and lactate utilizing bacteria per ml of cecum fluid in adult female Norwegian reindeer on South Georgia in summer ($x10^7 \pm SD$)

Animal No.	**3**	**7**	**8**
Viable Bacteria	1,90±1,00	1,23±1,14	1,52±0,79
Cellulolytic bacteria	-	0,99±0,21	0,98±0,78
Proteolytic bacteria	-	0,62±0,34	0,38±0,14
Lactate utilizing bacteria	-	1,03±0,72	0,53±0,56

- : not measured

TABLE 4

Total number of viable anaerobic bacteria and the number of cellulolytic, proteolytic and lactate utilizing bacteria per gram of plant particles in the cecum from the adult female Norwegian reindeer on South Georgia ($x10^7 \pm SD$)

Animal No.	**3**	**7**	**8**
Viable bacteria	1,90±1,00	2,78±2,00	1,70±1,15
Cellulolytic bacteria	-	0,99±0,21	1,08±0,76
Proteolytic bacteria	-	1,56±0,70	0,97±0,46
Lactate utilizing bacteria	-	2,34±0,85	0,76±0,21

- : not measured

STUDIES ON THE FACTORS DETERMINING VARIATION IN THE REPRODUCTIVE SUCCESS OF THE ANTARCTIC PETREL *Thalassoica antarctica* IN SVARTHAMAREN, MÜHLIG-HOFMANNFJELLA

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GENERAL BACKGROUND

Seabirds are in general characterized by a very small clutch size. Most often they lay only one single egg per breeding season. Furthermore, they generally reach the age of maturity at an old age. In several species the females delay the onset of the breeding until their sixth or seventh year (Sæther 1987). In such low-reproducing species, stable populations are obtained by an extremely high survival rate (Sæther 1988, 1989). For instance in the Fulmar *Fulmarus glacialis* only 2-3% of the adults die between the breeding-seasons (Ollason & Dunnet 1988).

Basically, the explanations which have been proposed for the low reproductive rate of seabirds, can be divided into two major hypotheses. Firstly, based on sensitivity analyses of life history models (e.g. Goodman 1974), it has been suggested that seabirds invest only a small part of their available resources into reproduction, because a large investment in reproduction is likely to increase the female's probability of dying. These models show that small changes in the adult survival rate will greatly influence the lifetime reproductive success of a female. Thus, if there is a trade-off between resources available for survival and reproduction, a large improvement in reproductive success must occur in order to balance only a small reduction in adult survival rate.

The second set of hypotheses proposes that the low reproductive rate of seabirds is due to a limited supply of resources during or just before the breeding season. Several mechanisms for such a resource limitation have been suggested. For instance, almost all seabirds have a relatively (for their body size) large egg and use a relatively long time to raise their offspring, compared to other birds of similar size. It has therefore been argued that this suggests that either the resources available for egg-production, or the amount of food the parents can collect during the fledging period, may prevent the production of more than one offspring (Lack 1966, 1968).

The purpose of the present study is to experimentally test the preditions from those two hypotheses. According to the resource limitation hypothesis we would expect that the birds can not increase their reproductive effort as a response to an experimentally induced demand for increased reproductive investment. On the contrary, we would expect that the birds should be able to increase their investment if they are not resource limited during the breeding season.

The Antarctic petrel *Thalassoica antarctica* was chosen as our study object, because previous studies have shown that this is one of the seabirds that uses the shortest period to raise its offspring to independence (Bech et al. 1988), even though it breeds under extreme environmental conditions.

THE BREEDING BIOLOGY OF THE ANTARCTIC PETREL

The first detailed studies of the breeding biology of the Antarctic petrel were made during the Norwegian Antarctic Research Expedition in 1984/85 at the Svarthamaren colony. A brief summary of the results from this expedition is necessary as a background for our studies.

The Svarthamaren colony is situated about 200 km from the open sea (71^{0}53'S, 5^{0}10'E) in Mühlig-Hofmannfjella at an elevation of 1600 m a.s.l. The slopes are covered by small rocks or sand, which make them suitable as nesting sites. In 1985 the size of the colony was estimated at about 207,000 breeding pairs (see Mehlum et al. 1988 for a more detailed description of the colony).

The hatching of the eggs occurs very synchronously. When we arrived at the colony on 12 January approximately 50% of the eggs had hatched. Three or four days later hatching had increased to more than 90%. A similar pattern was found in the previous expedition - hatching occurring almost at the same date (Haftorn et al., pers. comm.).

The chick reaches thermal independence 10-11 days after hatching (Bech et al. 1988). Until then, it must be brooded by one of the parents. The growth rate is very rapid, compared to other species of Procellariformes (Bech et al. 1988). This is related to a very high feeding efficiency of the parents. On the average, a chick received a meal every second day (Mehlum et al. 1987). The mean weight of a meal was approximately 150 g (Mehlum et al. 1987).

The length of the fledging period is not known, because we had to leave Svarthamaren on February 18, before the chicks had reached the fledging stage. The age of the oldest chicks was at that date about 38 days. Based on their feathering pattern, we estimated that it was between seven and ten days before they were able to fly. Thus, we agree with Bech et al. (1988) that a nesting period of 42 days seems too short.

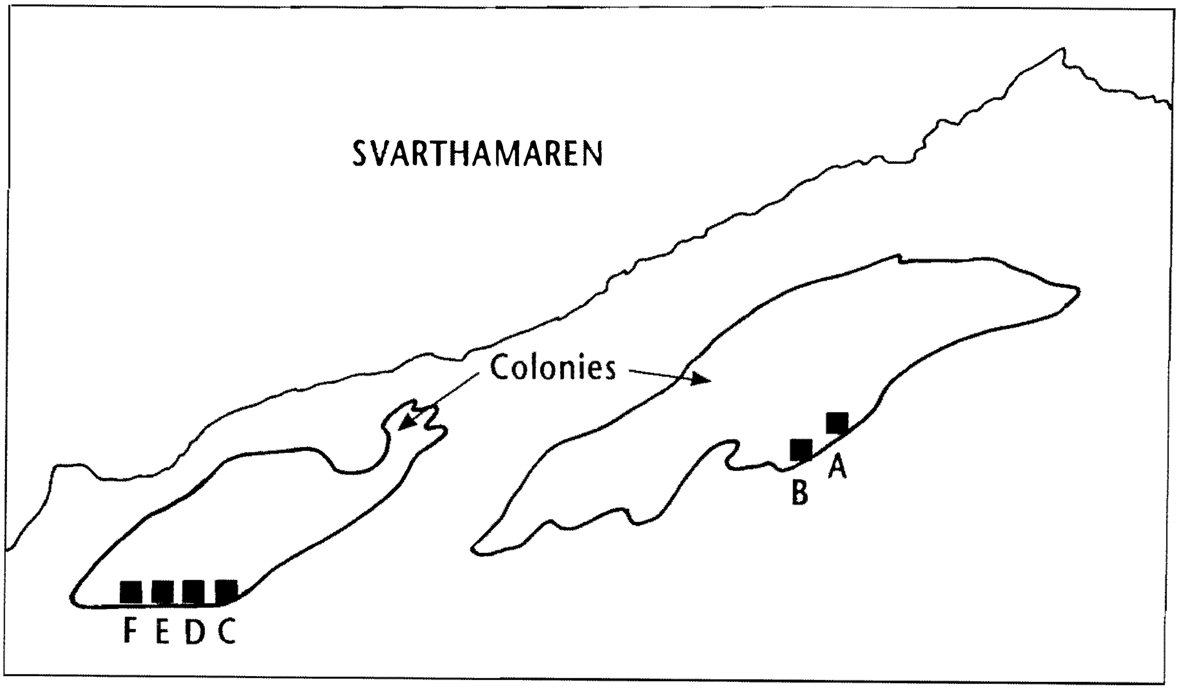

Fig. 1. The location of the study areas in the colony.

Area A denotes the first control group, B the nests used in the Widow experiment, C the site for the Twinning experiment, D the nests included in the "loading" experiment, E the site for the change of juveniles, and F the second control group.

EXPERIMENTAL PROTOCOL

We manipulated the investment necessary for a successful breeding in several ways. The control for these experiments consisted of a group of 67 nests, which were situated in the different parts of the colony as shown in Fig. 1. The chicks in those nests were weighed each day. In addition, the bill-length was measured daily until the age of 15 days. After this date, this measurement was taken every second day. On 14 February wing-length and tarsus-length were measured on the chicks still alive. In addition, wing-length, bill-length and tarsus-length of the parents were measured. The adult present at the nest was weighed as often as possible. During the brooding period this occurred at least daily. These data sets gave us the possibility to examine the effects of body size of the adults on variation in reproductive success.

The following experiments were conducted:

1. Twinning experiment

In ten nests we added an extra egg just prior to hatching. In ten other nests we added an extra chick. Great care was made to have as even-aged and even-sized chicks as possible. The growth rate of the chicks was compared with the control group.

The experiments were also designed to show whether the parents could recognize their own chick.

2. Widow experiment

If the amount of resources available for reproduction is not limited, we would expect that a parent is able to compensate for poor performance of the mate. We tested this hypothesis by removing one adult from 25 nests. This was made both early and late in the nesting period. In this way we would examine whether any compensating investment for the loss of the mate was dependent on the investment in the chick prior to the removal. Furthermore, this experiment also enabled us to test whether any sexual differences exist in the parents' investment into the offspring.

3. The "loading" experiment

The Antarctic petrel in Svarthamaren has to fly at least 200 km to find open water to forage. If body condition is likely to be an important determinant of reproductive success, a greater load to carry over such a long distance is likely to reduce the amount of resources available for investment in the chick (Pennycuick 1989). For instance, if the adult is dependent on a certain amount of resources (e.g. fat) to be able to reach the colony, we assume that more time must be used foraging to compensate for such an increased weight loss. Less food will then be available for the chick. Alternatively, the adult can decrease its body weight, and instead give a proportionate larger part of its available resources to the chick. In this way the growth rate of the chick will not differ from the control groups, whereas the weight loss of the adults during the nesting period will be greater.

In order to obtain such an effect we provided one of the parents with two small rings of lead. Each ring weighed 20 g, so that each individual was given an extral load of 40 g. This amount (less than 10% of the body weight) was assumed only to a lesser degree to infer with the individual's ability to forage. 40 nests were used for this experiment.

The chicks used in this experiment were weighed every four hours at 0600h, 1000h, 1400h, 1800h and 2200h. The nests were watched continuously for 24h-periods. Each time an adult fed a chick it was followed at a distance (20-30m). After having finished the feeding, it was caught by hand or net. Both the adult and chick were then weighed. In this way an estimate of the amount of food given was obtained. Only undisturbed birds were caught.

4. Change of juveniles between nests

Previous studies have shown that the amount of food received by the chicks from their parents differs in relation to their stage in the fledging period (Mehlum et al. 1987). In order to examine whether this is a reflection of the juveniles' demand or a chronological effect of the stage of the nesting period, we placed chicks with large food demands into nests where the parents were expected to give only small amounts of food, and vice versa. If the feeding rate of the parents is an effect of the time in the nesting period, we would expect the growth rate of small chicks in nests of parents which expected a high food demand, to be larger than the control chicks at corresponding stage, whereas the opposite trend should be expected for chicks with a large demand to parents which expect a low feeding rate. On the contrary, if the feeding rate is determined by the demand of the chicks, the parents should adjust their provisioning rate to that found for chicks in the control group at the corressponding stage.

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ASPECTS OF REPRODUCTIVE BEHAVIOUR IN A POPULATION OF SOUTH POLAR SKUA *CATHARACTA MACCORMICKI* IN DRONNING MAUD LAND

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BACKGROUND AND OBJECTIVES

Most South Polar Skua *Catharacta maccormicki* populations studied are found at the coast of the Antarctic continent, often feeding on krill and fish or scavenging on refuse or penguins (Furness 1987). According to Furness (1987) breeding has been documented only in one inland population found in the Theron Mountains, whereas breeding is probable but not well documented in Dronning Maud Land and Byrd Land. However, in 1985 about 50 breeding pairs of South Polar Skua was found at Svarthamaren (71°53'S, 05°10'E), in Mühlig-Hofmannfjella, Dronning Maud Land (Mehlum et al. 1985). At Svarthamaren the South Polar Skua was found breeding in association with colonies of Antarctic Petrel *Thalassoica antarctica* and Snow Petrel *Pagodroma nivea*, and the skuas were totally dependent on the petrels as food.

We stayed at the breeding grounds at Svarthamaren between 12 January and 18 February 1990, with one main objective being to study different aspects of reproductive behaviour in this South Polar Skua population. The questions asked were the following:

1) Do territorial behaviour limit breeding numbers?
2) To what extent do possible replacement birds adopt chicks of widowed birds?
3) Is breeding success correlated with territory size?

In addition several behavioural observations were carried out throughout the whole period.

MATERIAL AND METHODS

Territorial behaviour and breeding success was studied in the South Polar Skua population from 12 January to 18 February 1990. Mapping of 18 territories was carried out through direct observation of territorial behaviour of both birds in a pair towards their neighbours and non-territorial birds. To identify the different territorial birds 14 of them were ringed, 12 with different combinations of colour-rings.

During the period 22 January to 3 February the males were removed from eight different territories. At the time of removal the birds were incubating addled eggs on two territories, had one-two weeks old chicks on three territories, and four weeks or older chicks on three. During the period 3-17 February four males were successively removed from one of the territories. All removed males were weighed, and the length of wing, beak and tarsus measured. The situation in the vacant territories were registered by several daily inspections both with respect to possible replacement males and with respect to survival of chicks.

PRELIMINARY RESULTS

Territorial behaviour and breeding numbers

Altogether 82 breeding pairs of South Polar Skua were found in a narrow belt at the base of the Antarctic Petrel colony. In addition about 80 non-breeding skuas were observed. A great number of these birds were often observed at one club site on the glacier about 300 m from the breeding skuas.

Non-breeding birds were frequently observed searching for vacancies on the occupied area, and were equally frequently observed being attacked and chased away by territorial birds. After the males were removed from eight territories non-breeding birds were observed circling over the territories for long periods. Eventually replacement males settled on five of the territories. The time between removal and replacement varied considerably. The three territories where the widowed birds remained single had all one to two weeks old chicks at the time of removal. In one of the territories with addled eggs, replacement was very rapid. Here four males were removed successively and the third and fourth replacement bird was found to be ringed at Svarthamaren in 1985.

Adoption by replacement males

It was possible to get data on this behaviour only from two territories. The males at these territories behaved quite differently with respect to investment in the chicks of their new mate. One of the males was not observed off the territory at all. Nor was it observed that the female on this territory flew up in the petrel colony to get food for the chicks. Eight days after the replacement male had settled on the territory the youngest chick was found dead and eaten on the territory. Five days later the oldest chick was found dead and eaten, also this one within the territory. It is, however, impossible to say whether the chicks starved to death or were killed by the replacement male. Shortly after the chicks were dead, both the male and the female were observed eating freshly killed Antarctic Petrel chicks on the territory.

On the other territory remains of freshly killed petrel chicks were found continuously. The replacement male was observed bringing petrel chicks to the territory, and immediately after landing he was chased away from the petrel chick by the female. The female then tore the petrel chick into smaller pieces and finally flew to another part of the territory where she fed the chicks.

Territory size and breeding success

Breeding success measured as number of chicks fledged per territory was calculated for 26 territories at the end of the field season (17-18 February). On these territories the mean number of chicks fledged was 1.54.

On the mapped territories the results indicate that breeding success was lower on small than on medium and big territories. It is not clear whether this is caused by a greater proportion of territories with only one egg on small territories compared with medium and big territories, or because small territories have a higher risk of being visited by neighbouring skuas which eat eggs and chicks.

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STUDIES OF BREEDING BIOLOGY OF ANTARCTIC PETREL AND SNOW PETREL IN MÜHLIG-HOFMANNFJELLA, DRONNING MAUD LAND

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BACKGROUND AND OBJECTIVES

During the Norwegian Antarctic Research Expedition 1984/85 a colony of Antarctic Petrels *Thalassoica antarctica* at Svarthamaren was studied by Norwegian scientists (Mehlum et al. 1985). A census was made of the breeding population, and the microclimatic conditions of the colony were studied (Mehlum et al. 1988). Furthermore, studies on the petrels´ adaptation to nesting under extreme conditions were undertaken. Special emphasis was laid on physiological and behavioural studies, but reproductive biology was also studied (Bech et al. 1988a,b; Mehlum et al. 1987; Haftorn et al. unpublished).

The main objectives originally proposed for this project under the 1989/90 expedition were to study the energy flow from marine to terrestrial ecosystems, establish a monitoring system for future surveillance of the Antarctic petrel colony at Svarthamaren, and study the interactions in the predator - prey situation between the Antarctic petrel and the South Polar Skua. However, since the manning of the project was constrained to only one person, some of the aspects of the original plans had to go out. On the other hand I had the opportunity to make some comparative studies of the breeding biology of the Snow Petrel *Pagodroma nivea* which also breed in the area.

FIELD WORK AND PRELIMINARY RESULTS

The Svarthamaren colony is situated at 71°53'S, 5°10'E. An ornithological team of four persons (running two separate projects) established a camp near the colony on 12-13 January just at the time when the hatching of the Antarctic petrel chicks had begun. We left the study area on 17 February.

In the following a short description of the main topics of one of the projects is given. Some of the preliminary results are partly summarized.

1. Timing of breeding in Antarctic and Snow Petrels

The median hatching time of the Antarctic Petrel was 14 January which is one day later than in 1985 as reported by Haftorn et al. (unpublished). The first chicks sitting alone in the nests were observed on 18 January, the same date as in 1985. The mean weight of those chicks was 175 g (range 125-220 g, 10 nests). On 25 January half of the chicks were left alone in the nests, indicating an average brooding period of 11 days, the same as reported by Mehlum et al. (1987).

Most snow petrel chicks hatched on 20 January which is almost the same time as found in the western Dronning Maud Land by Sømme (1977) and Ryan & Watkins (1989). The chicks were brooded 5-6 days.

2. Population censuses

Antarctic Petrel at Svarthamaren

A census was undertaken during 24-25 January using the same methods as described by Mehlum et al. (1988). The total area of the colony will be calculated by means of photogrammetric techniques. Assuming the same total area of the colony as in 1985, the number of live chicks was estimated to be approximately 175,000 during the census period. There was, however, much variation in the density of chicks between the different parts of the colony. Mehlum et al. (1988) estimated the number of "breeding pairs" to be 207,000 in 1985. The figures of the two censuses will be compared more closely in order to demonstrate potential changes in the breeding population.

South Polar Skua at Svarthamaren

The breeding colony was counted on 6 February. The total number of territorial pairs was 82. In addition 83 non-breeding individuals (probably subadult birds) were observed at a roosting site on the ice nearby. The figures indicate a total population of about 250 individuals at Svarthamaren.

Antarctic Petrel at Jutulsessen

The Jutulsessen area in Gjelsvikfjella (72°5'S, 2°40'E) was visited on 2-3 February, and the colonies mentioned by Mehlum et al. (1988) were checked. I investigated one colony and observed two others by binocular; all were of considerable size. Probably 20-50 thousand pairs breed in the Jutulsessen area. In the colony that was visited, the nest density, young production, and timing of breeding seemed to be almost the same as in Svarthamaren.

3. Food and energy studies of the Petrel species

Analysis of prey species

Ten Antarctic Petrel chicks that had just received food were collected for contaminant analysis. The stomach content of these chicks will be analysed. Furthermore a few samples of regurgitated food from live chicks were collected. Stomach pumping of chicks was tried without success.

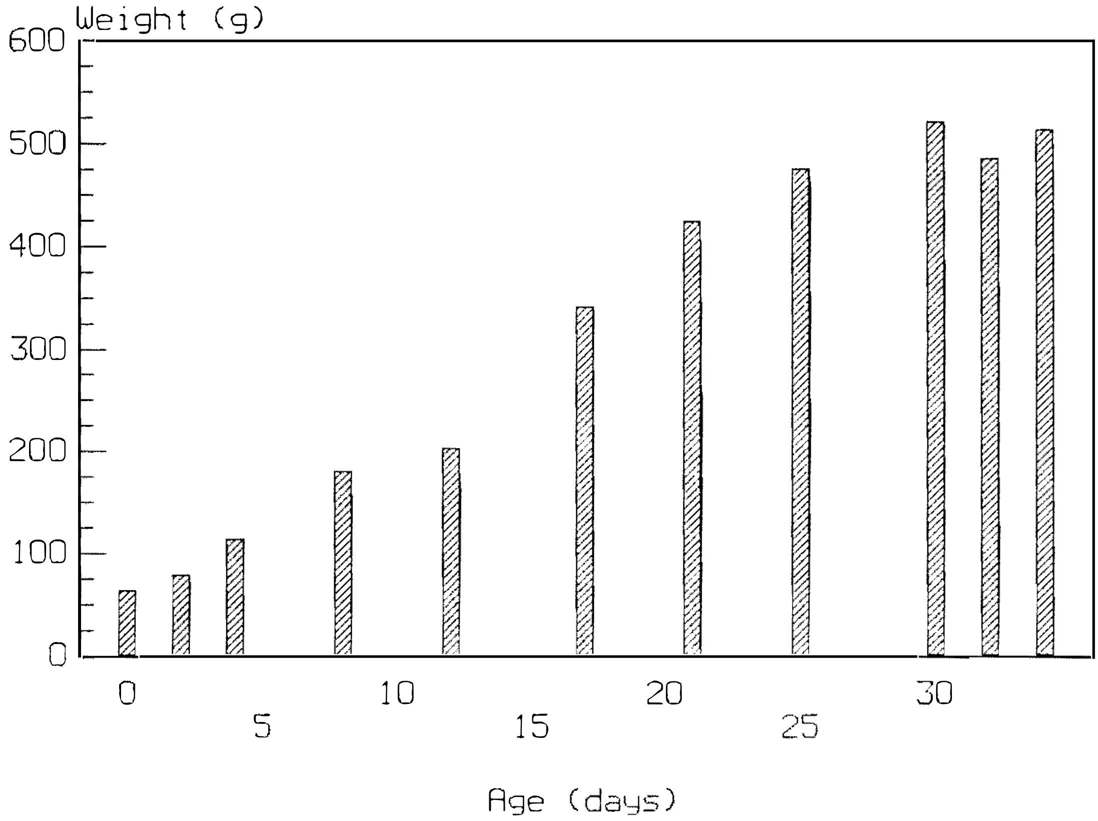

Fig. 1: Mean weight development of Antarctic Petrel chicks

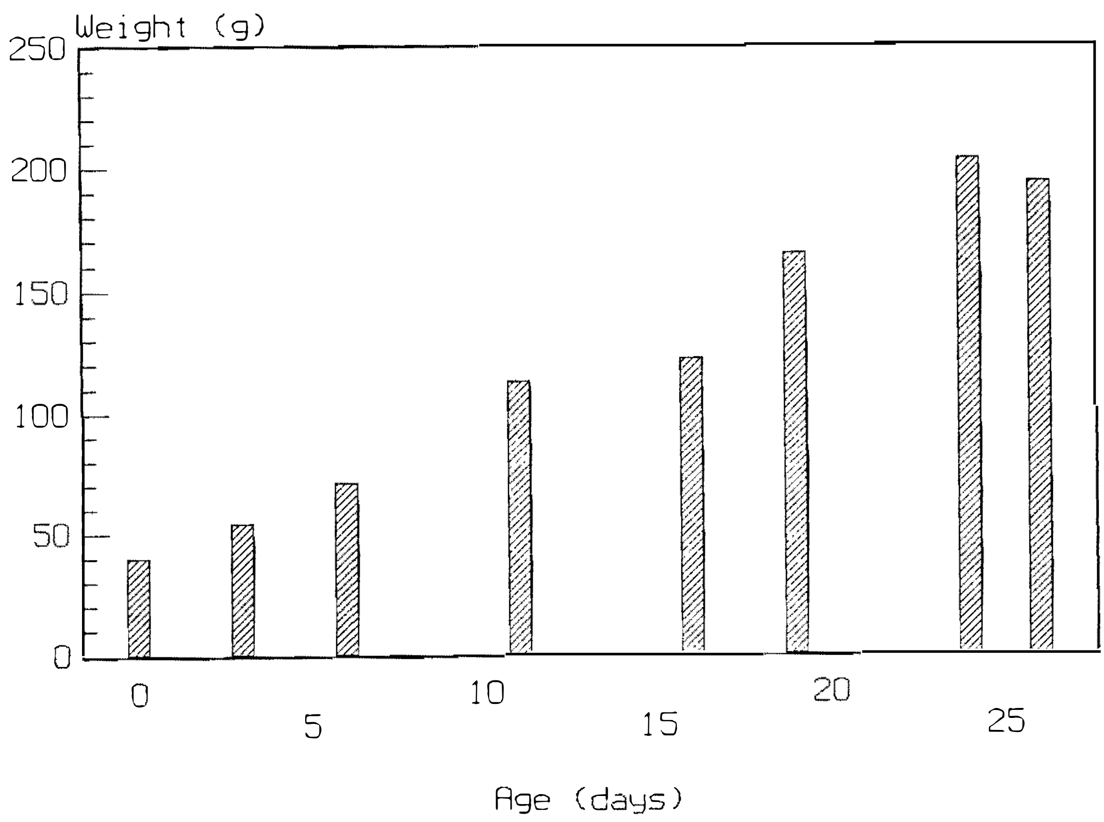

Fig. 2: Mean weight development of Snow Petrel chicks

The energy brought to young

The feeding frequency was estimated by repeated weighing of individual chicks of both species. Also a time-lapse film camera was used in the Antarctic Petrel colony in order to record feeding intervals. The data have not yet been analysed. Recording of food portion weight was done by weighing of chicks before and after feeding. On the average Antarctic and Snow Petrel chicks were fed at intervals of 1.5 and 1.3 days and received about 160 g and 50 g of food each time, respectively.

An analysis of energy content of food in the stomachs of Antarctic Petrel chicks will be undertaken in order to estimate the amount of energy brought to the chicks.

So far the results indicate that one month after hatching, the chicks in the Svart-hamaren Antarctic petrel colony received a total amount of about 17 tons of food each day.

4. Breeding success of Petrels

Mortality of young Antarctic Petrels was estimated by calculating the mean number of chicks in 3x3 meter plots early and late in the study period. During a 30 day period, mortality varied between 16% and 30%. Early in the chick period, about 20% of the occupied nests were empty (but well constructed), or contained dead chicks or eggs. This may indicate a total loss of eggs and chicks of about 45% from egg-layng until the chicks were one month old.

The recorded mortality of Snow Petrel chicks in a study plot (20 nests) was 15% during the first 20 days after hatching.

5. Chick growth of Petrels

The development of chicks with known hatching dates was studied. The results indicate that the young of both species reached the asymptotic weight a few days before we left the study area, probably already on 12 February, after growth periods of 27 days for Antarctic Petrels (Fig. 1), and 23 days for the lesser Snow Petrels (Fig. 2). The mean weights of the chicks of the two species were 500 g and 200 g, representing about 80% and 70% of adult weights. The wings of the young were still growing on 17 February, but the length increase of tarsus and bill had almost finished. Apparently the young Petrels are considerably smaller than the adults when they leave the breeding area.

6. Contaminant analysis

At Svarthamaren the South Polar Skuas exclusively raise their chicks by predating upon the Antarctic Petrel colony. The transport of contaminants in this extremely simple food chain will be studied.

The food of Antarctic Petrel chicks, and eggs and chicks of Petrel and Skua were collected and will be analysed for DDT and derivatives, and PCB´s. The PCB analyses will distinguish between polymers, as they have different half-lives in biological systems, and therefore different potential regarding transport to remote areas.

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ECOPHYSIOLOGICAL ADAPTATIONS IN MITES AND COLLEMBOLANS IN DRONNING MAUD LAND

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BACKGROUND AND OBJECTIVES

The invertebrates of the Antarctic have been the focus of several investigations during the last 20-30 years (see reviews by Block 1984 and Sømme 1985). There are two main reasons for the increasing interest in these organisms. First, many of the species encountered in the Antarctic represent the limit of distribution within their taxa. They are able to endure some of the most extreme environmental conditions on earth, and their ability to adapt has been the object of several studies.

Secondly, Antarctic invertebrates are part of some of the simplest ecosystems known. The study of energy flows in ecosystems of this kind may serve as a model for the understanding of more complicated systems.

The main project of this programme was to study ecophysiological adaptations in mites and collembolans in Dronning Maud Land. Two sub-projects were also carried out: field sampling of blue-green algas, that will be cultivated and studied in Norway, and sampling of algas, lichens and mosses for studies of heavy-metal content.

INVERTEBRATE STUDIES

The present study was carried out in the Jutulsessen area in Dronning Maud Land. In order to map the invertebrate species and density in this area, the period between January 15th and February 5th was spent on field research. The area was examined by turning relatively small stones, and searching on and underneath these stones. The field observations included the geology, the vegetation and microclimate temperature in the area. The sampling of the invertebrates was carried out by the use of an aspirator and 5 ml glasses. The animals were kept either frozen or in 70% ethanol.

A detailed study of the samples will be carried out in the laboratory in Norway. However, three sites were of special interest. Large numbers of the following species were found at the following sites (Fig. 1):

Cryptopygus sverdrupi (collembola), nunatak NW of Stabben (site 1).

Maudheimia wilsoni (oribatid mite), in the proximity of the field station TROLL, Grjotlia (site 2).

Tydeus erebus (prostigmatid mite), at the base of Grjotlia, 2.5 km south of TROLL, (site 3).

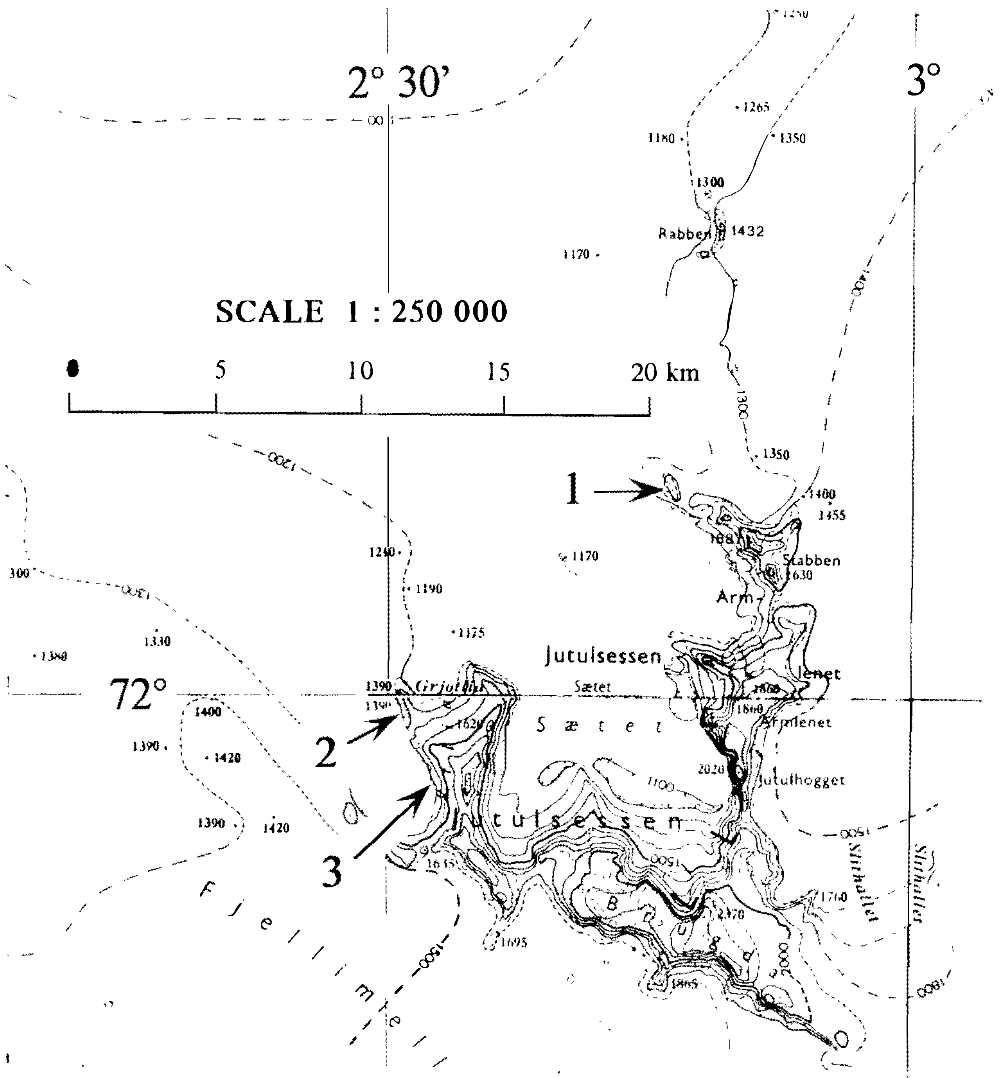

Figure 1: Map of Jutulsessen, Gjelsvikfjella, Dronning Maud Land, Antarctica, with richest sampling areas.

The studies were concentrated on the oribatid mite *M. wilsoni.*

The animals were found underneath a wide variety of stones, as far as geology and size were concerned. However, they appeared to prefer pelitic gneisses with approximate dimensions of 15cm x 15cm x 3cm. All life stages (rests of eggs, larvae, nymphs and adults) were often found on one single stone. The adults seemed to roam about, and were quite active when exposed to high temperatures. The earliest life-stages were often found in clusters, and appeared to be relatively inactive. This distribution pattern indicates that the animals carry out their life cycle, presumably except parts of the adult stage, within a range of a few square centimeters.

This implies that they will have to find their nourishment on the stones or on the substratum directly underneath the stones. It is most likely that they feed on blue-green algas. To examine this, samples were taken from stones and gravel, and brought to Norway for cultivation and further investigations.

The microclimate for the mites were studied. The air temperatures above the ground were rarely above 0°C, however, the animals experienced temperatures up to 20°C for several hours on sunny days (Fig. 2). Even at night, the microhabitat temperature was considerably higher than the air temperature due to heat storage in the ground.

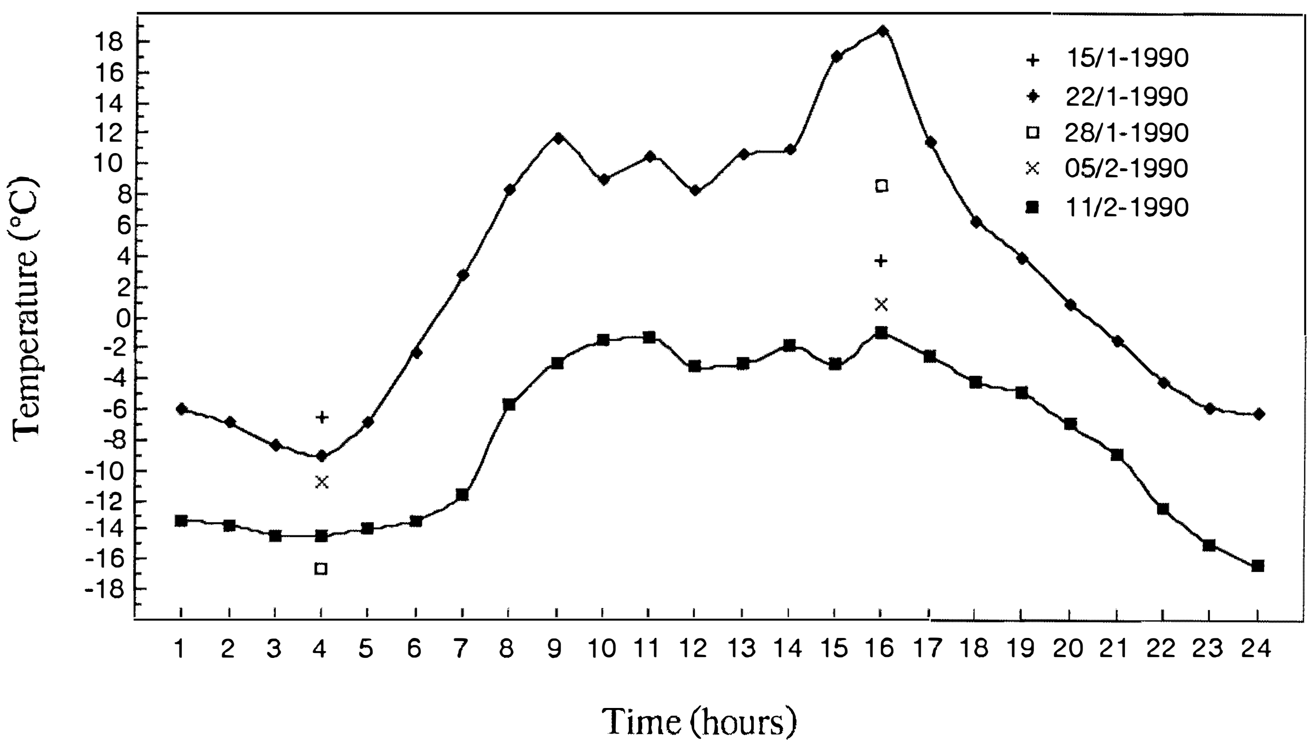

Figure 2: Temperature in a typical microhabitat for the oribatid mite <u>Maudheimia Wilsoni</u> through 24 hrs on two dates (filled symbols) and at 4 am and 4 pm on three additional dates.

The relative air humidity above the ground was quite steady at 60%. The annual precipitation in the area is very low, and there are no glaciers from where melted ice can trickle. The substratum underneath the stones was mostly coarse gravel, that probably will drain water quickly. All these factors make the microhabitat very dry.

PHYSIOLOGICAL EXPERIMENTS

In order to investigate ecophysiological adaptations in *M. wilsoni* , a number of experiments were carried out. Only adult specimens were studied. The animals were sampled in the period February 5th to 12th, and used on the same or on the following day.

All weights were measured on a Chan Electro Balance (0.1 ug to 2500 ug).

Oxygen consumption was measured in Englemann respirometers (Aunaas et al. 1983) at 2, 7, 13 and 20°C. Metabolic rates and Q_{10} values, will be calculated and comparative studies will be carried out on the basis of the measured values.

Osmometric studies (investigations on thermic hysteresis factors and hemolymph osmolality) were carried out on a Clifton Nanolitre Osmometer. However, additional experiments will be executed in the laboratory in Trondheim.

Supercooling points were measured with a thermocouple and a Grant Squirrel Data Logger. Water loss was studied by weighing the animals at certain intervals while kept in a dry atmosphere (by the means of silica gel) at 10°C or 20°C. The fresh and dry weights were also recorded.

The detailed study of the records and measurements has not been completed.

BIOACCUMULATION OF HEAVY METALS

Air-transported heavy metals appear to be one of the most important categories of pollutants in industrialized areas. The fact that they are airborne implies that they may also be transported to areas far from the source, probably also between continents. The Antarctic continent is likely to be one of the least polluted regions in the world, and may offer an opportunity to monitor the natural level of heavy metals in plants and animals, and also to what extent the continent will be affected by air-borne outlets elsewhere.

For this purpose material of the species of mosses, green algae, lichens and collembola from the Svarthamaren and Jutulsessen area were collected. For reference studies, melted water, snow and stones were collected as well. The samples will be brought to the laboratory in Trondheim for analysis. The analysis will focuse on lead, cadmium, copper, zinc, iron and manganese.

COMPARATIVE STUDIES OF BLUE-GREEN ALGAE IN EXTREME ENVIRONMENTS

In cooperation with The Norwegian Institute for Water Research (NIVA), a programme on blue-green algae was carried out.

The algae that lives under the extreme environmental conditions in the Antarctic display interesting physiological adaptations that make it possible for the species to grow and develop in spite of low temperatures and prolonged periods with little light. Extended research is focused on such qualities in these organisms.

The main purpose of this project is to characterize the alga vegetation and do comparative physiological studies with organisms in Norway. It is also interesting to investigate to what extent these organisms take part in the food-web to the mites and collembolans.

12 samples were taken from incrustations from stones, gravel, snow and melted water. Each sample was kept and transported frozen in three medias: growth medium (5% Z8), fix solution (3% formalin), and one without additives. The cultivation and investigation will be carried out in the laboratory in Oslo.

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STUDIES ON, AND UNDERNEATH, THE ICE SHELF FIMBULISEN

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BACKGROUND AND OBJECTIVES

There is increasing evidence of anthropogenically caused global climatic warming, and indications from climatic models that such warming will be largest in the polar areas. Melting and/or increased outflow of the Antarctic ice mass is potentially the largest contributor to raised sea level. Present knowledge indicate that such changes will be primarily driven by melting at the underside of the ice shelves. Thinning of ice shelves implies un-pinning and reduced buttressing which could lead to increased outflow of continental ice and thus contribute to raised sea level.

Theoretical models arrive at quite varying conclusions concerning quantity and sign of sub-ice-shelf melting/freezing. The differences are related to varying weight given to heat flow through the ice, heat transport by currents flowing underneath the ice shelves, the vertical motion of the water related to local and regional ice topography, phenomena related to supercooling of sea water in contact with the cold ice shelf, and tidal mixing. The heat exchange from the ocean depend also on exchange processes (turbulent/molecular). Collection of in situ field data is needed to resolve the validity and relative importance of these ideas.

The objective of this programme was thus to measure and understand the processes taking place underneath an ice shelf. Fimbulisen, which is 130 km wide, was selected because it has a size similar to many of the ice shelves around Antarctica, and because it was centrally located in relation to the logistic plan of NARE 1989/90, allowing maximum field time (Fig. 1). Fimbulisen is the ice shelf continuation of the ice stream Jutulstraumen, which drains an area of 124 000 km^2 (Van Autenboer and Decleir 1978). It has a discharge of 12.5 km^3 a^{-1} (Decleir and Van Autenboer 1982), which makes it one of the large Antarctic ice streams. It flows at ~ 700 m a^{-1} at the grounding line (Orheim and Lucchitta 1987).

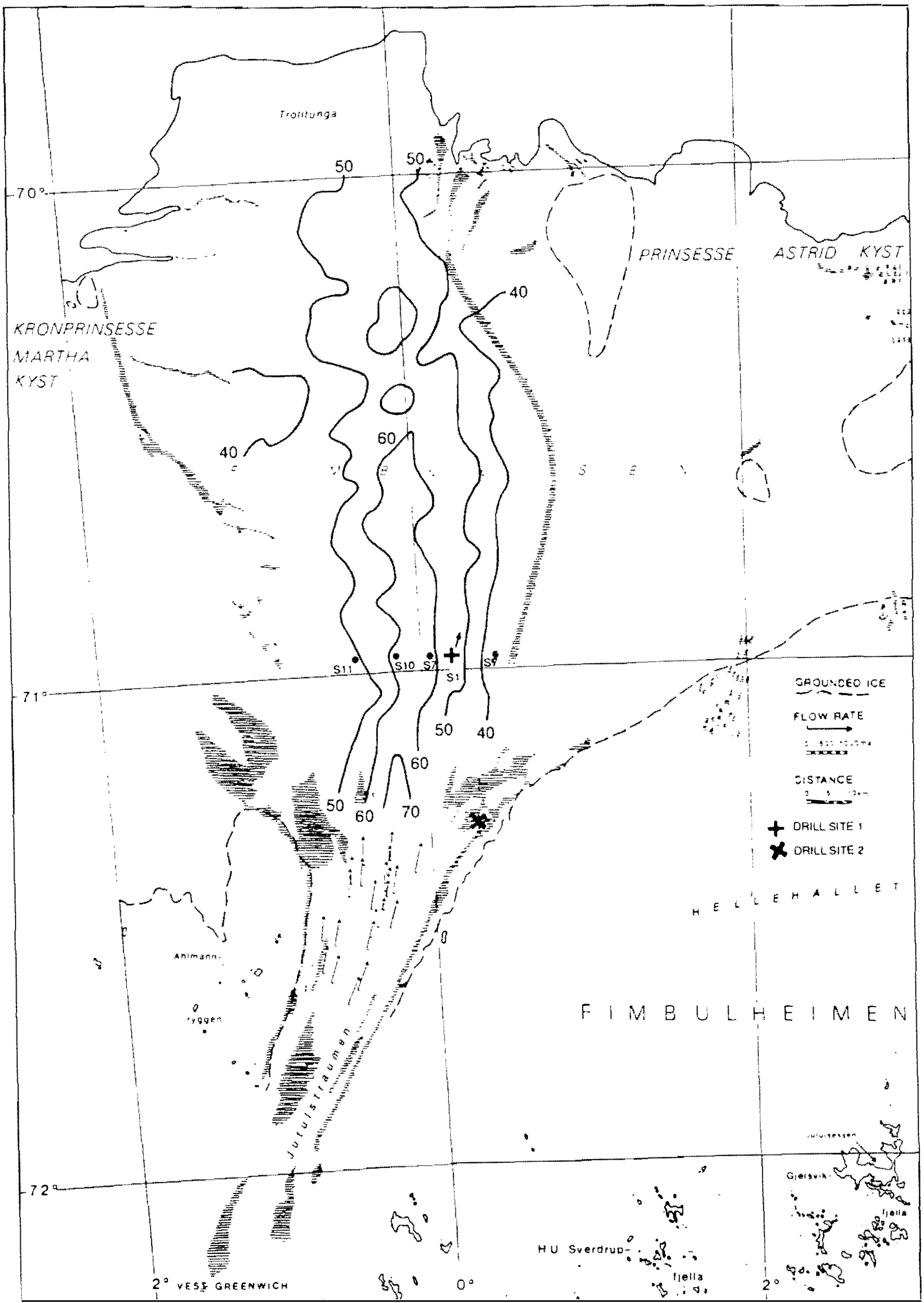

Fig. 1. Fimbulisen and Jutulstraumen, with location of Drill Sites 1 (+) and 2 (x). Arrows show velocity vectors observed from 1975 to 1985 by Landsat (Orheim and Lucchitta 1987), and now at Drill Site 1. Elevations (in m) are from Seasat altimetry in 1978 (Zwally et al. 1987). Jutulsessen, with TROLL Station, is located in lower right of fig.

The programme falls within a key area of Antarctic contribution to the IGBP programme. ICSU/SCAR (1989, p. 14) calls for research to "investigate factors affecting ice-shelf stability including pinning mechanisms in areas of grounded ice and especially basal melting and related ocean characteristics seaward of and beneath the ice shelves."

FIELD WORK

The main field work of this glaciology group was to drill through the inner part of Fimbulisen, conduct under-ice sampling, and deploy sub-ice instrumentation. Installing the instruments required a hole with a 0.2 m working diameter that could be guaranteed for many hours. It was hoped to install the equipment through ~ 400 m ice thickness, but it was recognized already from the planning stage that this would probably strain the available technology/logistics.

Various other glaciologic and oceanographic studies done on the Fimbulisen/ Jutulstraumen ice shelf/ice stream system are also described below.

Investigations of ice and water depths prior to site selection

The drilling plans called for a site of around 400 m ice thickness overlying preferably at least 200 m water. No field surveys were available for the selected area, but ice thicknesses could be estimated using assumed snow and ice densities and elevations available from NP maps and from satellite radar altimetry (Zwally et al. 1987). Prior to final selection of the drill site and deployment of the field camp a party conducted radio echo-soundings (see Kennett 1990, this volume), and seismic measurements. Further such studies were also conducted later in the season, in part to check that there were no sea bed obtrusions in the ice movement direction that could damage the oceanographic instruments during a 2-3 year travel. The studies showed that the pre-selected area had an ice thickness of 400 $\pm$ 5 m and a water depth around 240 m.

The seismic instruments had to be lightweight and easy to use. A 14 Hz center-frequency geophone connected to an analog 2-channel printer running on a car battery via a voltage inverter was selected. Highest voltage resolution on the printer was 1 mV/cm and the highest paperspeed was 250 mm/second. The explosive primer was triggered manually with the trigger signal recorded on the printer. Explosive charges of 0.25 - 4 kg of TNT were used. The depths of the charges were 0-4 m. It was necessary to wait for the geophone to freeze to the ground before shooting, as this made a much better contact between the geophone and the snow surface. The firing cable had a length of 150 m when fully stretched. Totally 15 shots and 20 kg of explosives were fired at 3 different sites and with varying setups. The cold and dry climate made operating the paper printer difficult, but it functioned satisfactorily at slower paper speeds, i.e. 100 mm/s.

An ice thickness of 400 m meant an offset of less than 72 m to avoid the airwave interfering with the seabed-reflection. However, this resulted in too much surface noise, so the offset was increased to 150 m. This made the airwave arrival equivalent to 325 m of water depth. Therefore we could measure depth in the range 0-325 m with good conviction. The p-wave velocity used in the soundings was taken as 3860 m/s for the ice shelf of -27 °C (Robin 1958, Table 14), 1445 m/s for seawater at - 2 °C (Sverdrup et al. 1946, p. 77) and 347 m/s for air (Tipler 1976).

System performance was tested a few kilometers from the shelf edge at the expedition's first depot. Here the water depth was measured by echo sounder in front of the shelf and the ice thickness estimated, using a relationship between freeboard and ice thickness (Orheim 1980). A distinct reflection was observed at the expected arrival time of the seabed reflection, despite disturbing noise from offloading the ship.

FIRST DRILL SITE

The first drill site was selected at position 70° 58.72'S, 0° 11.93'E, at 53 m elevation (Fig. 1). Here the main object was to drill an access hole to the underside of the ice shelf, but the group also conducted other glaciological research.

Hot water drilling

The drill equipment (see Appendix 1), camp gear and fuel weighed 9 tons and took up a packed volume of 30 m^3. It had to be transported to the site, 130 km from the ice front, by helicopters and skidoos. Each drill component was restricted to be so small and light that two persons could lift it.

The drilling equipment had a hot water production of 25 l/min at 100 °C when all three heaters were coupled in series. Drilling started with melting snow to fill the 3000 l reservoir tank and then slow drilling to 50 m. Successive drilling in this interval (0-50 m) gave a water level at 35 m depth and the hole was enlarged to put down the recirculation pump. Drilling continued stepwise at ~ 50 m intervals to 300 m, and then 25 m intervals to the bottom (Fig. 2). After five days a break down in the pressure pump caused the hose to get stuck at 325 m depth. The drilling was continued in the same hole with a new hose, with the expectation that the first hose would be melted out. This did not occur.

The base of the ice shelf was penetrated with 397 m length of hose in the hole, after eight days of drilling. Due to hose stretching this means that the ice thickness was 399 $\pm$ 1 m. The waterlevel in the borehole sank within a minute to 45 m, this accorded with the expected hydrostatic level of fresh water in the hole. Both the radio echo sounding signal and the "feel" of the drill indicate that the base was solid ice, i.e. melting. Further enlargment of the hole was done over the next 5 days. At this time the second drill got stuck at 320 m, probably in the first one, and it was decided to abandon this hole.

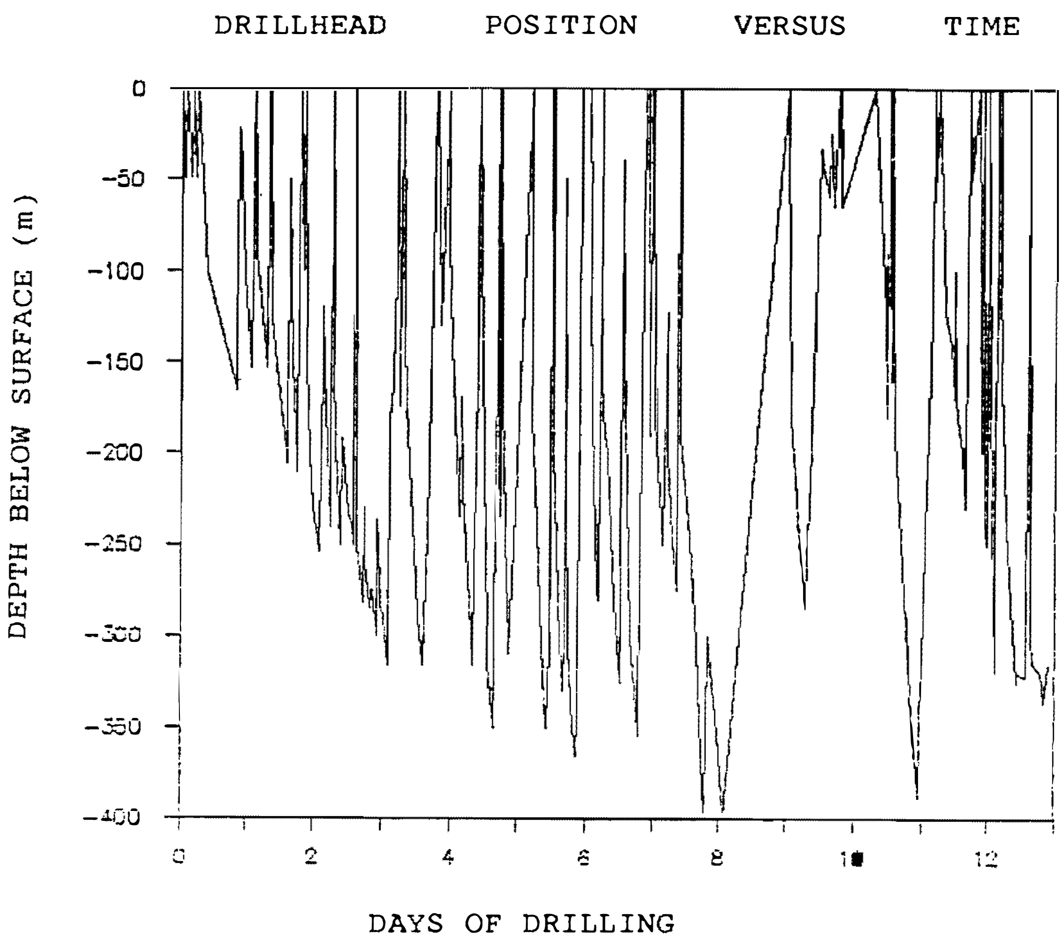

Fig. 2. Drill log from Drill Site 1, showing depth of drillhead during drilling.

The 400 m deep borehole had an estimated volume of ~ 25 m³ when it was left. The diameter at the top was 0.8 m, decreasing downwards to estimated 0.05 m at the base of the ice shelf. Both visual inspection by video camera to 150 m depth, and the different refreezing rates demonstrated by the temperature measurements (Fig. 3), show that the hole diameter varied widely. Changing the borehole volume from snow and ice to more dense water meant that 10 m³ water had to be replaced by melting snow on the surface. Otherwise the recirculation pump operating 40 m down the borehole would run dry before ice shelf penetration. Water lost in the upper ~ 50 m of the hole, i.e. the firn layer, was estimated to an additional 10 m³. A total of 20 m³ of water, equivalent to 60 m³ snow, was thus melted on the surface.

Total jet fuel comsuption was 4 m³, which represents an energy equivalent of 137 GJ. The total amount of water produced was 40 m³ which consumed 16.6 GJ. Heating a 1-m-radius annulus of ice around the borehole to 0^0 C requires 52 GJ; this seems a reasonable maximum estimate for the ice warming. Altogether, this indicates a 50 percent loss of energy in the hot water production, which was as expected.

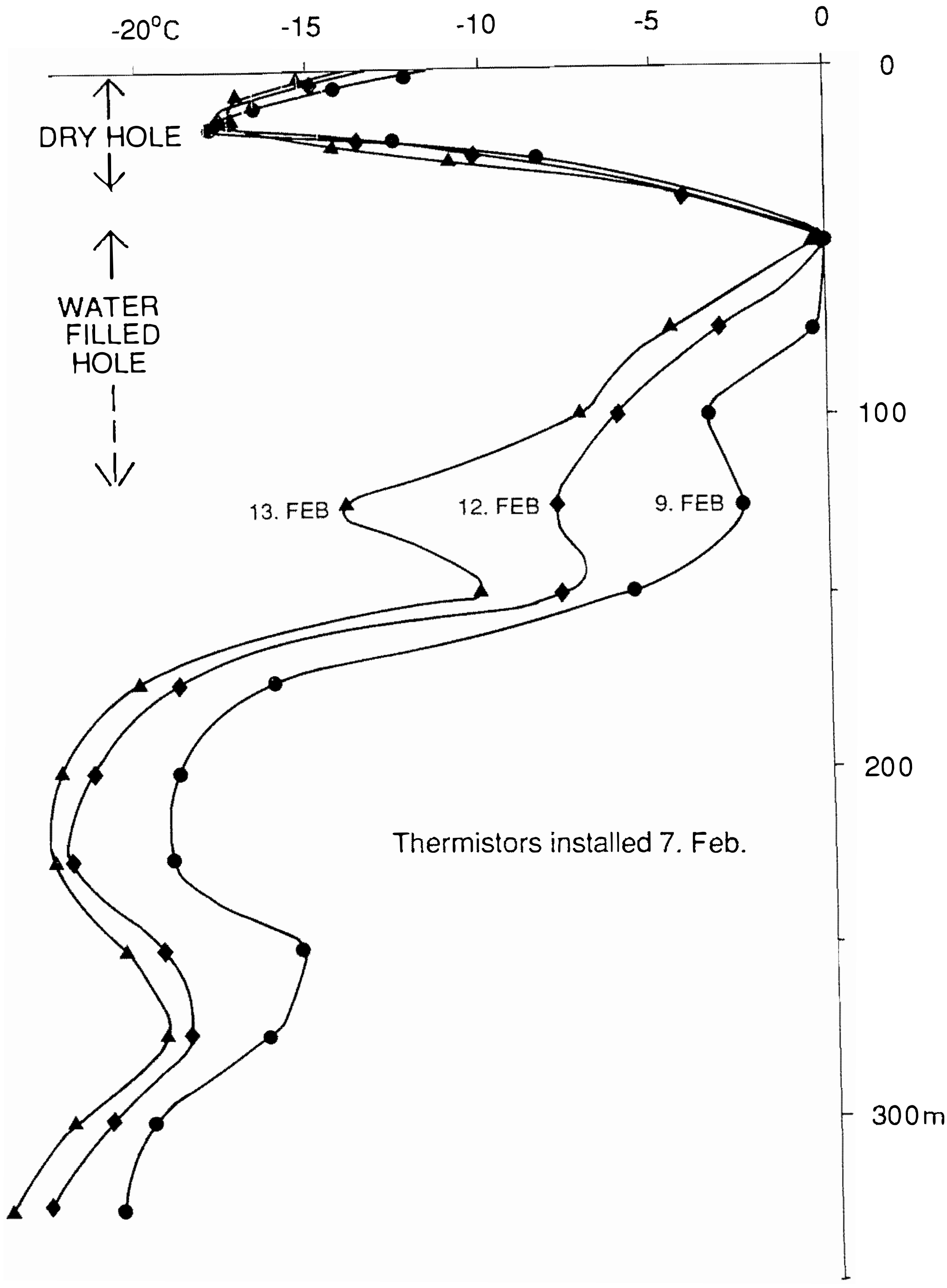

Fig. 3. Temperatures in drill hole during early stages of refreezing. Thermistors were installed on 7 February. The temperatures at depth during this phase of cooling depend primarily upon diameter of hole (related to amount of heat we had transmitted at each depth) and location of thermistors in relation to wall of hole. After six days the thermistor at 52 m depth was clearly still in water.

The drilling operation was done by four people working in shift continously for two weeks. Typical drill rates were 0.5 m/min in the upper 200 m of the hole and at 0.3 m/min in the lower 200 m. The repeated reaming meant that it was absolutely necessary to make a vertical hole. One of the major uncertainties when drilling was whether the drill hung freely or stood at the bottom of the hole. Three times the hose made a knot while within the hole. The drill must have stuck in the wide upper part of the hole while being lowered, and the hose had passed it, so that the drill could thread itself through a loop on the hose.

The drilling equipment had been used for five years in Norway and Svalbard, with surface temperatures down to -20^0 C, which were as cold as we experienced at Fimbulisen. Precautionary measures for surface cold included building a three-sided shelter, and routinely using antifreeze in all critical parts that were stored on the surface. These, and other provisions, proved adequate. However, we had previously only drilled in ice at or near its freezing point, here Fimbulisen provided new challenges.

It was expected that the temperature in the bulk of the ice would be -20^{0}C, based on ice temperature measurements at Norway/SANAE and Maudheim Stations. The temperatures were in reality closer to -30^{0}C (Fig. 3) throughout the bulk of the ice (incidentally implying high melting rates at the base). Making this relatively wide hole in such cold ice showed that refreezing in the hole caused practical difficulties. If any problems arose that stopped the water flow then the hose had to be retrieved rapidly to avoid freezing. Small technical problems with pumps or heaters could thus cause major failures, and we had possibly underestimated the need for back-up units. However, we were so close to success that we believe that with our now-gained experience in cold ice drilling, it should be possible to drill >0.2 m access holes to 400 m depth with this equipment.

Temperature measurements

A thermistor string was installed in the hole, with thermistors at 2, 7, 12, 17, 22, and 27 m depth, and then for every 25 m down to 327 m below the surface. It is not known whether possible blocking of the hole between 320 and 325 m could have hindered the lowest thermistor from reaching 327 m depth, but the measurements (Fig. 3) show that it was probably at least to 320 m depth. The thermistors were of the type Fenwall Uni-curve 192-301CDT-A01. They were all calibrated in a water tank at zero degree. The Ohm-meter that was used made it possible to read the temperature to within $\pm$ 0.05°C.

The temperatures were recorded on three separate days after installation, until the camp was abandonded six days later. The temperatures were then still decreasing throughout the profile (Fig. 3).

Velocity and strain measurements

Surface velocities and strain were measured on eleven stakes in a cross profile at ~ 71° S (Figs. 1, 4), about 60 km from the grounding line and 120 km from the calving front. The width of the fast flowing part of the ice shelf was here about 45 km while Jutulstraumen is slightly above 20 km wide at the grounding line. Radio-echo soundings were carried out in the same cross profile to allow ice flux calculations.

The stake positions were found by GPS measurements. We had three Ashtech XII dual-frequency receivers to our disposal, and measured differentially with one receiver on a fixed point at TROLL, 140 km to the south east. The second receiver was placed on a stake (S1) at the drill camp while the third receiver was moved from stake to stake. We had to measure for 90 to 120 minutes at each stake to get acceptable accuracy of the measured vectors. The measurements had to be carried out in periods when signals were received from minimum four satellites. The time window for this was about four hours twice daily. All stake positions could be determined during one day. The measured vectors have the best accuracy in the x and y coordinate differences, about $\pm$ 2 mm/km, while the altitude (z) is less accurate, about $\pm$ 5-10 mm/km. The GPS receivers were available only for limited periods so the stakes were remeasured after two weeks. However, the accuracy of the positions was such that a measuring interval of two weeks gave adequate precision.

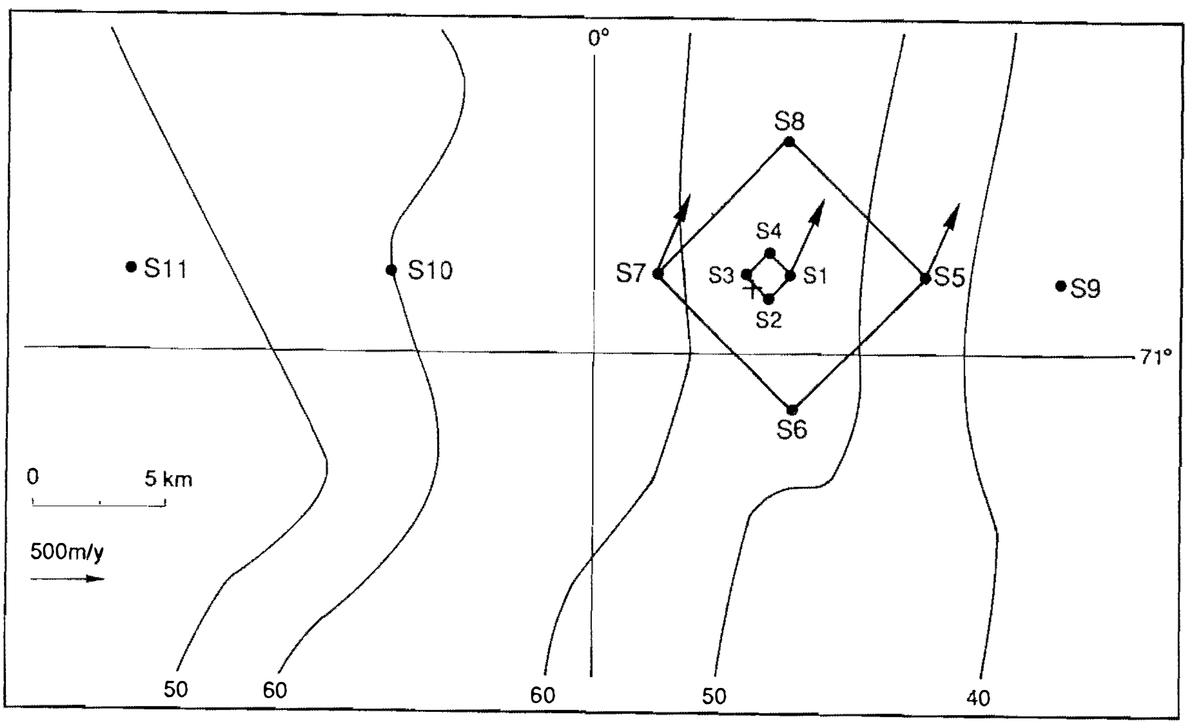

Fig. 4.Stake positions for velocity and strain measurements around Drill Site 1.

Stake S1 at Drill Site 1 moved 31.74 m during the 16-day observation interval. This equals 730 m/year, a number almost identical to the mean of 718 m/year observed further upstream by Orheim and Lucchitta (1987).

Two simple strain nets (Fig. 4)were measured to investigate the ice deformation where it flows out from the relatively narrow gap at the grounding line.

The first strain net consisted of stakes (S5-S8) placed out in 5 km distance to the N, E, S, and W from the center stake (S1) at the drill site. Additional stakes S10 and S11 were placed 15 and 25 km to the west and stake S9 9 km to the east, of S1. The stakes in this net were measured by GPS.

The second strain net (S1-S4) was congruent to the first but with a distance of about one kilometer between each stake. This net was measured by traditional surveying with theodolite and EDM - electronic distance meter.

The distance S1-S10 (about 15 km) increased by 1.8 m during the 16-day measuring interval, e.g. 0.12 m/km. This corresponds to a annual strain of about 2.5 m/km in east-west direction, which is the direction approximately perpendicular to the main ice flow. The distance between S10 and S11 increased only 0.1 m.

The small strain net S1-S4 gave similar results, with strains close to 0.10 m/km during the interval.

The measurements thus show that the main deformation was 10-15 km west and east of S1. The mean transverse strain rate in the central part of the ice stream was $\sim 25\times10^{-4}\ a^{-1}$. The longitudinal strain rate was about 1/10 of the above. This longitudinal strain rate is very close to that observed by Orheim and Lucchitta (1987), while they reported higher transverse strain rates.

SECOND DRILL SITE

The loss of two hoses of around 320 m length required finding thinner ice for sub-ice instrumentation. We therefore investigated Jutulgryta, a shear zone between Fimbulisen and slow-flowing grounded ice. This was located near the grounding line, about 160 km from the ice front, and was surrounded by ice shelf mostly with thicknesses around 200-300 m. (Fig. 1). Here a drill site was selected on a 30-50 m thick "ice island", in position 71° 18.6'S, 0° 17.2'E. Sounding through thin sea ice in a shear crack by the "island" revealed a water depth of 400 m. An access hole was drilled through 38 m thick ice within a few hours. The ice was a mixture of solid ice and freeze-on slush, showing freezing basal conditions. Here the sub-ice equipment was installed.

Instrumentation left in and under the ice

Chr. Michelsens Institute (CMI), Bergen, was contracted to develop the instrument and data recording package, as we had previously worked with CMI producing innovative developments. The basic measuring concept was to obtain accurate recordings of the ice and oceanographic conditions over such a long period that disturbances from melting the hole could be eliminated, and that seasonal variations, if any, could be observed. The equipment was therefore designed to be left, recording data, for over two years. The main equipment constraint was that it should pass through a narrow hole. In the trade-off between making large holes for conventional equipment, or redisigning equipment to smaller diameters, we settled for a maximum equipment diameter of 0.18 m, and a minimum of instrument redesign. Because the equipment would be left unattended we chose well-established technology. Thermistors, which were aged to reduce drift, were chosen even though platinum sensors are more stable with time, becaause the latter are pressure sensitive and also causes some other difficulties. Oceanographic conditions were expected to be fairly stable, so that in the balance between data storage, and sampling period and frequency, a sampling interval of three hours was selected.

The basic concept consist of 39 parameters recorded from 16 sensor packages at 23 measuring levels (Appendix 2). Temperatures are measured at 7 levels in the ice and 16 levels below, salinities at 10 levels and ocean currents at three depths.

The equipment included a rod with eight thermistors cast in polyurethan (instrument No. 12). To this was fixed two stoppers, that were like skis pointing upwards, with tips against the central wire. The stoppers controlled that the 0-level of the thermistor rod was exactly at the ice/water interface, where the in situ melting/freezing rate was to be determined. The stoppers worked as planned.

Accurate location at the interface was necessary to get maximum information on the interface changes. The temperature sensors were to be located at close distances on both sides of the interface. The records are expected to show whether the sensors are in water or ice both by the vertical gradient, and by differing short-term temperature variations. As it happened, we found that the solid ice/water interface at 11.1 m depth was underlain by 27 m of slushy ice interspaced with thick water layers. At this location it is therefore likely that the freezing rate will be determined from combination of several more thermistors. For the purpose of subsequent experiments it was, however, very useful to have here tested successfully this stopping technology.

The instrument design had specified the requirement for on-site decisions on depth of instruments, which led to the choice of inductive couplings for the data transmission to the surface. This was a fortunate design element, as the ice thickness and water depth was different from originally expected, neccessitating some changes of plans.

The deployment required the use of a specially brought tower and winch. The procedure was as follows: A weight was fixed at the centre of 1500 m long cable, and lowered first. One half of the cable was used for suspending the instruments, the other was the return cable for data. Instruments, cramps, and "coasters" were then fixed sucessively as the cables were lowered, with the data cable fixed in special mounts for each instrument. The whole deployment needed four persons working for about four hours.

The control unit calls the sensors sequentially every three hours, and the data are stored in an Aanderaa EEPROM solid state DSU. This has a storage capacity of 262k 10-bit words. In addition the equipment had a temporary DSU with 65k capacity, and a SIPRO HX-12 unit for transmission of selected data over ARGOS. When the equipment was left on 11 February the temporary DSU and ARGOS showed that data was arriving at the surface. Transmission over ARGOS failed thereafter, for unknown reasons. The ARGOS PTT was placed on top of a 7-m high aluminum tower erected 20 m from the hole. The solid state recorded is buried in snow next to the tower, this must be retrieved to recover the data.

Oceanographic observations under Jutulgryta

Several types of equipment were specially constructed for the in- and below-hole studies, such as a 0.15 m diameter video camera, and various oceanographic equipment. The latter included a 0.09 m diameter ME mini-CTD w/sensor for dissolved oxygen, a 0.07 m diameter Sensordata CTD, and various types water bottles.

Five CTD casts were obtained during the period 9-12 February 1990, through 10-m thick ice. Five water samples were also collected for helium, tritium, and oxygen isotope analysis. The temperature and salinity profiles (Fig. 5) show a three-layer structure. The uppermost layer is 40-50 m thick, and is strongly affected by melting, having temperatures close to the freezing point, and low salinity. The next layer, from 50-300 m, show quite stable temperatures and salinities, with slightly supercooled water masses between 50 and 120 m. The lowest temperature, -1.98 ^{0}C, was observed at 225 m. Temperatures and salinities increase below 300 m, probably caused by better connection with the sea water outside the ice-shelf barrier.

The video camera was used for several runs to the sea bed, both to study the ice in the hole, and to search for biological specimens. Some samples of sea bed ooze were also collected by this camera.

Additional glaciological work

Two different stake nets were established in Jutulsessen during a few days stay at the end of the field season. Six stakes was drilled in the blue ice field west of Troll Station. Another six stakes were drilled down on the blue ice field in Jutulsessen east of Troll. All stake positions were measured by traditional surveying with theodolite and electronic distance meter. In addition each stake height above the surface were measured.

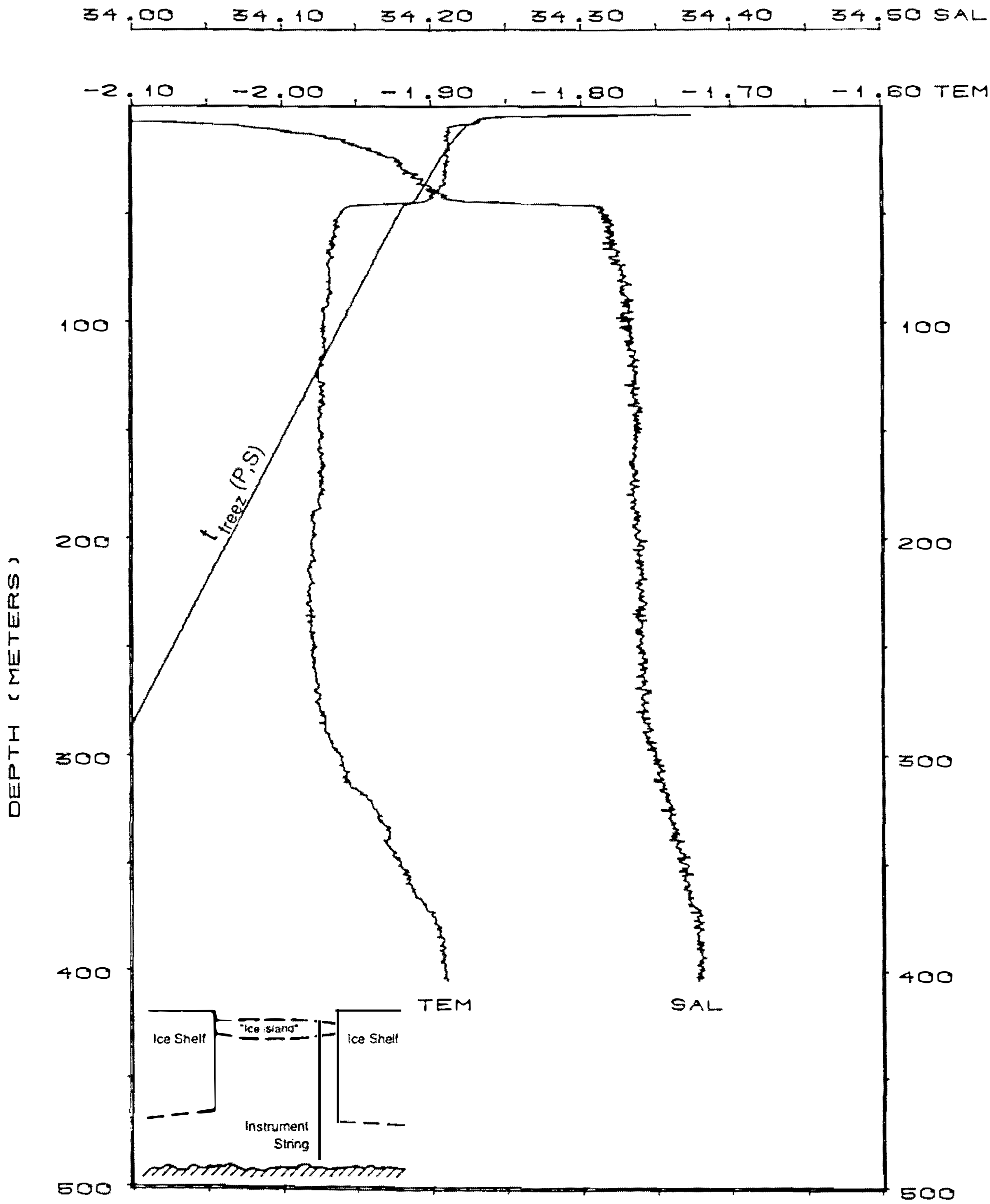

Fig. 5. Temperature and salinity profiles at Jutulgryta, from surface to sea bed. Also shown are freezing point temperatures as a function of salinity and pressure. Note the three-layered structure in the water masses. Lower left shows a sketch (to scale) of the measuring site in relation to surrounding ice shelf.

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APPENDIX 1

EQUIPMENT FOR HOT WATER DRILLING

3 Euroclean Delta Pluss burners, each consuming 5 l Jetfuel/ hour.
1 Honda Euroclean pressure pump, 25 l/min, 100 bar, consuming 4 l/hour
1 Honda Euroclean pressure pump, 15 l/min, 100 bar, consuming 4 l/hour
2 Mase Fox generator, 5 kW 1-phase and 3-phase-generator 220 VAC, consuming each 5 l petrol/hour.
1 Granfoss wellpump, 25 l/min, 60 m height, 0.75 kW 3-phase 220 VAC.
1 Granfoss wellpump, 15 l/min, 60 m height, 0.4 kW 3-phase 220 VAC.
800 m 1/2" Hytrell steel-reinforced hose, work pressure 200 bar.
1 Hose drum for 450 m 1/2" hose, variable speed up/down 0-10 m/min, 0.75 kW 3-phase 220VAC engine.
70 m 1 1/4" wellpump hose.
2 steelpipe drills, outer diameter 0.03 m and 0.05 m.
2 aluminium drills, outer diameter 0.07 m and 0.12 m (made at BAS).
1 aluminium drill, outer diameter 0.20 m.
1 3000 l plastic reservoir tank
Nozzles, couplings, various spare parts.

A working platform and windshield was built of 150 m 2x4" and 4x4" timber, 30 m^2 of plywood, and 100 m^2 tarpolin. Much of the wood was first used as packing cases.

6 tons of jet fuel, 1 ton petrol and 20 l oil was transported to the drill site. The fuel met the specifications for the helicopters, and 1.4 tons were used for helicopter operations.

A fibreglass hut was used as office and dining room, apart from that the camp consisted of standard Norsk Polarinstitutt field equipment.

APPENDIX 2

INSTRUMENTATION DEPLOYED AT JUTULGRYTA, FIMBULISEN ICE SHELF

Surface elvation:	2.8 mø	Thickness of solid ice:	11.1 mø
Ice thickness, including slushy ice:	38 mø	Water depth:	400 mø

Depth below surface (m)	Type of measurement(s)	Instrument No.
3.0	Temperature	8
6.0	"	9
10.10	"	12
10.60	"	12
10.95	"	12
11.05	"	12
11.10	"	12
11.15	"	12
11.25	"	12
11.60	"	12
13.1	temp., salinity	0
16.1	temp.	1
21.1	temp., sal.	2
26.1	temp.	10
31.1	temp., sal.	3
41.1	t., s., current speed, direction	13 (7959)
51.1	t., s.	4
101.1	t.	11
201.1	t., s., cur. speed and dir.	14 (9757)
251.1	t., s.	5
301.1	t., s.	6
371.1	t., s., cur. sp., dir.	15 (9758)
391.1	t., s.	7

All data transmission by inductive coupling.

The sensors have the following specifications:

Temperature:	Fenwall GB32JM19 thermistor, sensitivity 556.3 ohm/°C, Stability 0.05 °C/year, tolerance ± 0.0033 °C/°C. Instruments 8, 9: range -30 - -1 °C, resolution 0.03 °C. Instrument 12: range - 5 - +1 °C, resolution 0.006 °C Other instruments: range -2.4 - +4.1°C, resolution 0.006 °C
Salinity:	Aanderaa 2994 Conductivity cell, resolution 0.1% of fullscale (74 S/cm), precision ± 0.025 S/cm.
Current strength:	Aanderaa RCM-7, modified with savonious rotor for speed, precision ± 1 cm/sec.
Current direction:	Aanderaa RCM 7, modified with magnetic coupled wane constructed to pass through 0.2 m diameter hole, precision ± 5°.

RADIO-ECHO INVESTIGATIONS IN DRONNING MAUD LAND

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INTRODUCTION

Radio-echo measurements have been made over the Fimbulisen ice-shelf and the Jutulstraumen ice-stream, Dronning Maud Land, using a step-FM radar. The data will be used for information on the ice-sea interaction underneath Fimbulisen, and the conditions at the bed of Jutulstraumen, particularly in the grounding-line region. Both are important in assessing the stability of Dronning Maud Land ice with respect to possible climate changes. Data from a total of approximately 2500 km of helicopter profiles and 50 km of ice surface profiles were collected. Only a small fraction of the data has been analysed to date, and the results presented here are preliminary.

EQUIPMENT AND FIELD WORK

The step-FM radar consists of a HP 8753A network analyser with test set and Compaq PC for control of the analyser and data storage. The analyser transmits a continuous wave signal with a frequency which increases in precise steps and measures the amplitude and phase of the received signal at each frequency. The frequency range (within the range 300 kHz to 3 GHz) and number of frequency points (up to 1601) are entered on the analyser keyboard by the user. The received amplitude and phase information is stored and is later fourier-transformed to a time domain signal for interpretation.

Seperate transmit and receive 225-400 MHz panel antennae were used for the helicopter radar measurements, one mounted on each side of the aircraft. The antennae have reasonable gain (ca. 8 dB each) with approximately 50 dB isolation in the helicopter configuration. A power amplifier between the analyser source and transmitter antenna produced 30 W continuous output power. Frequency ranges of 250-280 MHz and 250-300 MHz were chosen for the ice-stream and ice-shelf measurements respectively, and 401 frequency points per shot. The interval between shots was approximately 800 ms, equivalent to 37 m along track at cruising speed.

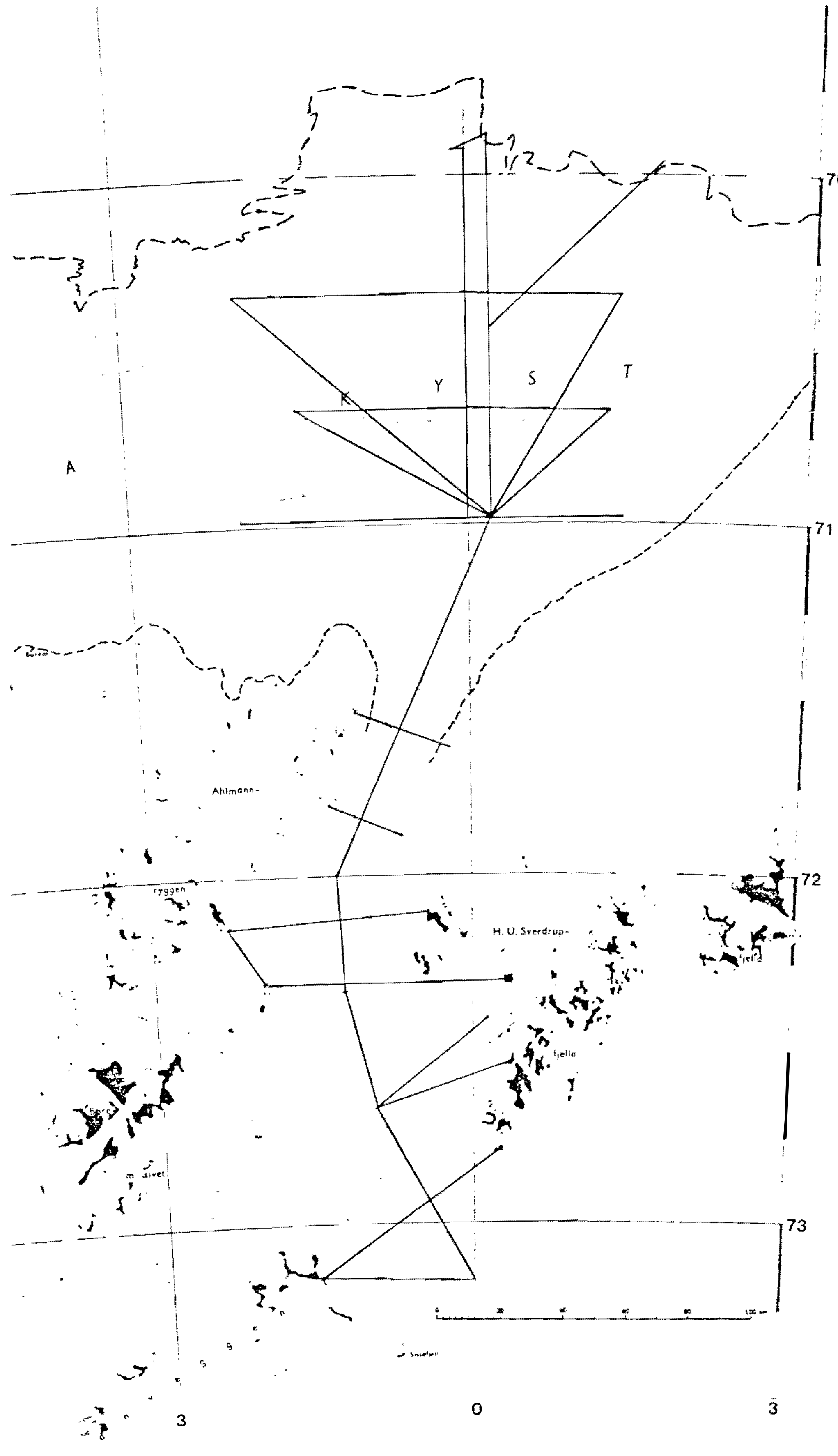

Figure 1: Radar flight lines (heavy lines) over Fimbulisen and Jutulstraumen

The helicopter was specially equipped with a GPS (Global Positioning System) receiver with data logger for navigation. However the receiver ceased to operate at an early stage, and the helicopter's GNS (Global Navigation System, also known as Omega) was used thereafter. Helicopter elevation was logged separately through a digital barometer. Flight lines over Fimbulisen and Jutulstraumen are shown in Figure 1.

A series of high resolution ground based profiles (3-4 m between shots) were also made in the borehole area at 250-300 MHz, 200-400 MHz, 125-175 MHz (folded dipole antennae) and 50-100 MHz (end-fed dipoles).

ICE-SHELF INVESTIGATIONS

The objectives of the ice-shelf measurements were:

1) to map ice-thickness and surface elevation,
2) to delineate regions with a layer of bottom saline ice and measure the thickness of this layer,
3) to map approximate bottom melting rates, and
4) to measure the change of ice shelf thickness directly at specific sites.

The strength of the bottom echo is reduced considerably where a layer of saline ice exists (Neal 1979), and the distribution of saline ice is closely associated with ocean circulation under the shelf. In regions with no saline ice layer the bottom reflection coefficient is constant, thus the strength of the bottom return will depend solely on absorption in the ice. This is a function of ice temperature which is in turn influenced by bottom melting rates. Finally the step-FM radar is capable of measuring precise absolute phase and therefore very small displacements (mm or cm) of a reflector such as that of the shelf bottom due to bottom melting (Nye 1975).

Preliminary results

A preliminary radar estimate of ice thickness at the oceanographic borehole site of 405 ± 10 m was consistent with the 397 m (plus some metres of hose stretching) measured later in the borehole. The bottom echo was generally very clear and typically 30 dB above the background signal, with a sharp leading edge but often complicated tail and typically 0.5 us wide. The ice thickness pattern seems to be consistent with Seasat altimeter measurements of the ice surface altitude and hydrostatic equilibrium, that is thickest in the centre of the fast moving shelf ice from Jutulstraumen and thinning quite rapidly towards the edge shear zones, with little thickness variation along flowlines. Maximum measured ice thickness on the shelf is approximately 600 m.

In some regions the bottom echo is significantly weaker suggesting bottom saline ice. In addition, Two distinct returns are occasionally visible, possibly from the glacier/ saline ice and saline ice/sea water interfaces.

The proposed experiment to measure ice-shelf thinning could not be carried out due to a lack of field time.

ICE-STREAM INVESTIGATIONS

The objectives of the radar measurements on Jutulstraumen were:

1) to map ice thickness and surface elevation,
2) to map the position of the grounding line and the extent of a possible "till delta",
3) to delineate the ice stream boundary laterally and examine the conditions at its bed, and
4) to compare bed topography features to surface features observed in Landsat images (Orheim & Lucchitta 1987, 1988).

In addition, the radar profiles will be examined for englacial layers and polarization differences between grounded and floating ice.

The return from the bed of grounded ice is quite different to that from the bottom of floating ice, principally weaker and exhibiting more fading (strength varying with position). Alley et al. (1987) suggest that on the upstream side of the grounding line at Ice Stream B is a region of thick till deposits. Such a till delta may also exist under Jutulstraumen and might be identifyable in the radar measurements. In addition the fast moving ice-stream ice can be distinguished from the unactivated ice on each side by increased clutter due to crevasses (Bentley et al. 1987). The bed echo can also be examined for information on bed roughness and reflection coefficient, which are expected to be different at the ice-stream bed to that at the bed outside Jutulstraumen due to deformable till and basal water under the ice-stream.

Preliminary results

The echo from the bed of Jutulstraumen is certainly weaker than from the shelf bottom and often difficult to identify in individual shots. The maximum observed ice thickness so far is approximately 800 m. A profile down the centre of Jutulstraumen shows clearly the difference between the smooth shelf bottom echo and the rougher echo from the bed of Jutulstraumen. Bed elevation a few km upstream from the grounding line is very variable. Within one 6 km section of the profile in particular, bed elevation appears to undergo a series of almost sinusoidal variations of period 1-2 km and amplitude up to 300 m. An example radar profile is shown in Figure 2.

Fig. 2. A 15 km section of a radar profile (raw unprocessed data) along the centre of Jutulstraumen and upstream from the grounding line. The total height of the plot corresponds to 13.33 us echo delay, equivalent to 1120 m ice. Arrows indicate (A) the direct signal from transmitter to receiver, (B) the echo from the glacier surface and (C) the bed echo. Interpretation is much clearer in the original colour plots.

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GLACIOLOGICAL AND METEOROLOGICAL MEASUREMENTS IN DRONNING MAUD LAND

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BACKGROUND

Interpretation of digital satellite images demand good understanding of the reflective properties of the snow. The reflection of solar radiation from a snow surface is linked to physical properties of the snow (metamorphism) and meteorological conditions (for example amount, distribution and type of clouds and snowdrift because of wind and the formation of snow dunes). To find the snow albedo during different conditions a broad data base was collected through measurements of radiation, wind, temperature, humidity, heat transfer and several measurements related to metamorphosis of the snow.

A second task of the project was to map the relation between meteorological parameters and the intensity of sublimation/evaporation and snow melt. Estimates of extreme variations in sublimation/evaporation and melting intensity can then be calculated using historical meteorological data.

OBJECTIVES

The objectives of the glaciological and meteorological measurements were:

a) To determine the relationship between different snow types under varying meteorological conditions and their albedo. Such a relationship will be useful input to energy budget models and for interpretation of satellite data, for example Landsat and SPOT.

b) To measure the intensity of snow sublimation/evaporation and melting.

c) To study stratification, physical snow parameters and metamorphism processes in the snow cover.

EQUIPMENT AND FIELD WORK

Meteorological parameters were recorded using two Aanderaa automatic weather stations. Station 1 was placed on the Fimbulisen ice shelf, latitude 70°58'43"S and longitude 0°11'56"E. This station measured average and maximum wind speed, wind direction, air temperature, relative humidity, solar radiation, total radiation and air pressure at 10 minute intervals in the period 1990-01-24 to 1990-02-12. The second station (latitude 72°1'45"S and longitude 2°31'45"E) was set up i Grjotlia, 2.5 km south of the Norwegian station TROLL in Jutulsessen. Station 2 operated from 1990-01-29 to 1990-02-14 and measured wind speed, wind direction, air temperature, relative humidity, solar radiation and total radiation.

Measurements of snow albedo were logged at Fimbulisen approximately 50 m from the meteorological station. A Kipp & Zonen albedometer CM 7 with effective wave length range from 300 nm to 2500 nm was used. Some albedo measurements were made at specific parts of the electromagnetic spectrum using Schott filter glasses. The cut-off wavelengths for the filters correspond to channels in Landsat TM.

Drained containers filled with snow were placed at both meteorological stations. The containers were weighed regularly. To distinguish between intensity of snow melt and sublimation/evaporation, the melt water was collected and weighed separately.

A 2 m vertical pit was dug at the ice shelf edge (latitude 70° 12'9''S and longitude 4°46'16''E). Measurements of density, temperature and free water content were made in addition to studies of stratification. Similar measurements were made in two pits (2 m and 4 m deep) near to meteorological station 1 and in three shallow pits in the surroundings of TROLL.

Snow temperatures at depths 5, 10, 20, 30, 40 and 50 cm were measured at 10 minute intervals (1990-01-24 to 1990-02-12) close to the meteorological station on Fimbulisen.

Measurements of density, temperature and free water content were made in shallow pits at 8 km intervals along a 120 km north-south snow survey on Fimbulisen, from position 69°55'S19"S, 0°6'29"W to 70°58'43", 0°11'56"E.

PRELIMINARY RESULTS

Fig. 1 shows how the snow temperatures at Fimbulisen varied from 1990-01-24 to 1990-02-12. Daily variations in snow temperatures follow the variations in air temperature. There is a trend of decreasing temperatures in the first part of the measurement period. Variations in snow temperatures at $z=30$ cm are delayed and have lower amplitudes compared to the temperatures at $z=5$ cm. On the last night the temperature at $z=5$ cm dropped to -16.5°C with an air temperature of -20.5°C.

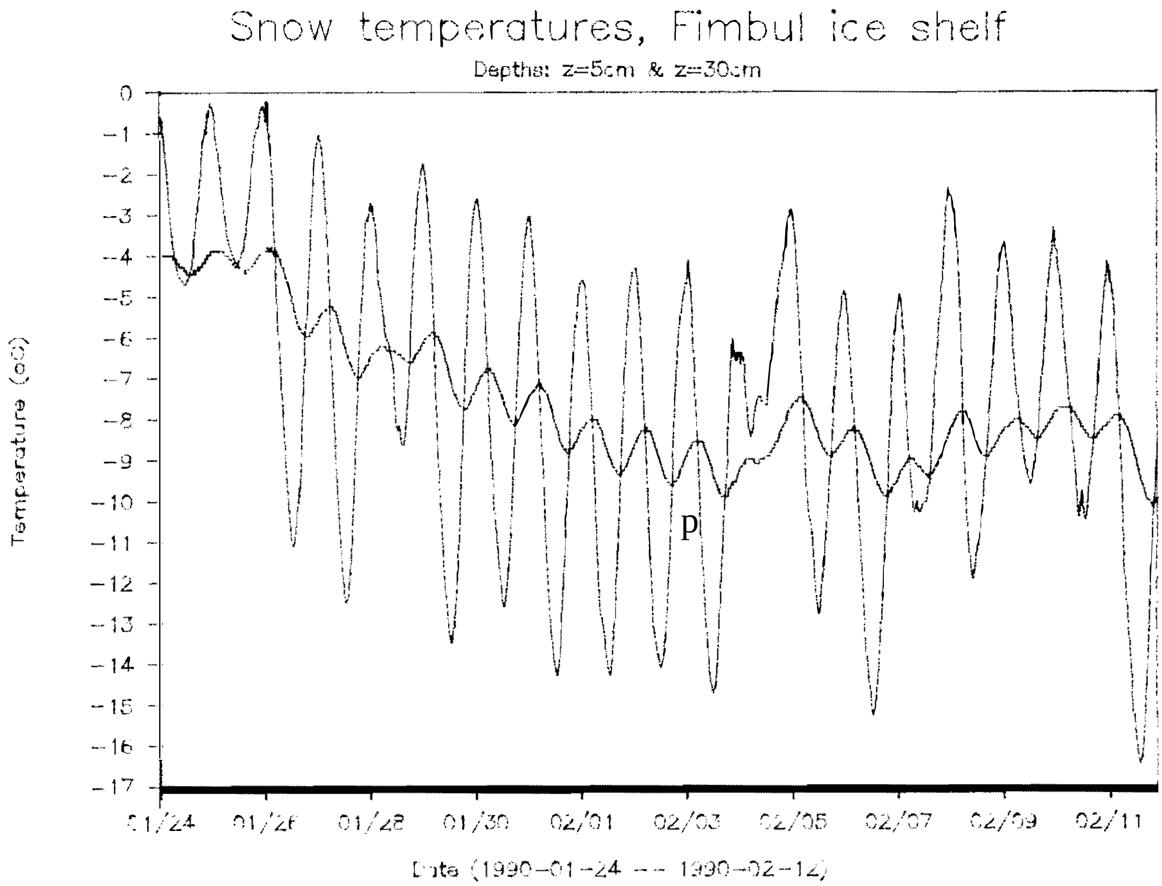


Fig.1. Snow temperatures at depths z=5 cm and z=30 cm, Fimbul Ice Shelf

Fig. 2 shows the temperature and density profile in a 2.0 m deep snow pit at the ice shelf edge, latitude 70°12'9"S and longitude 4°46'16"E. Snow surface temperature was -1°C and decreased to -12°C at 2.0 m. Snow density varied between 0.338 g/cm^3 and 0.546 g/cm^3. A sharp boundary from loose and medium coarse grained snow to hard and coarse grained snow appeared at z=136 cm. Several ice layers with thickness between 2 and 20 mm occurred from z=136 cm to z=178 cm. It is supposed that this part of the pit represents the accumulation during the previous summer (1988/89), which gives an accumulation since then of 598 mm water equivalent.

Only a few results from the snow albedo measurements are processed at the moment. These data show that the average albedo at the Fimbulisen measurement site was 0.86 for clear sky, 0.87 during altostratus conditions and 0.91 under full cloud cover. In general, it can be seen that the thicker the cloud the higher the albedo.

Fig. 3 illustrates the air temperatures at Fimbulisen and at Grjotlia near to Troll.

Station 2 at Grjotlia was located close to areas with exposed rock. Air temperatures above zero are due to absorption and heating of the adjacent rock, and coincide with low wind speed and to some extent the wind direction.

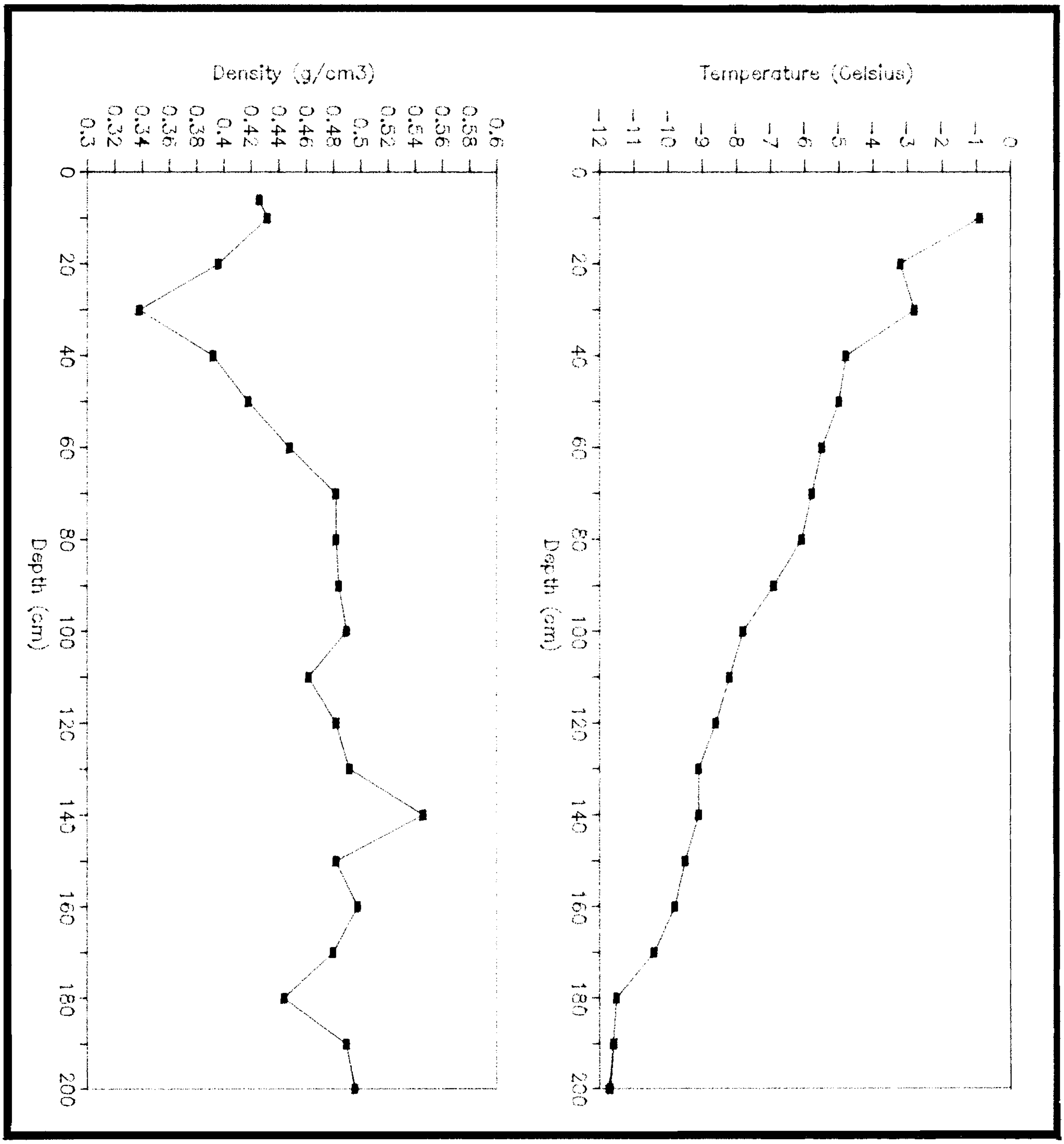
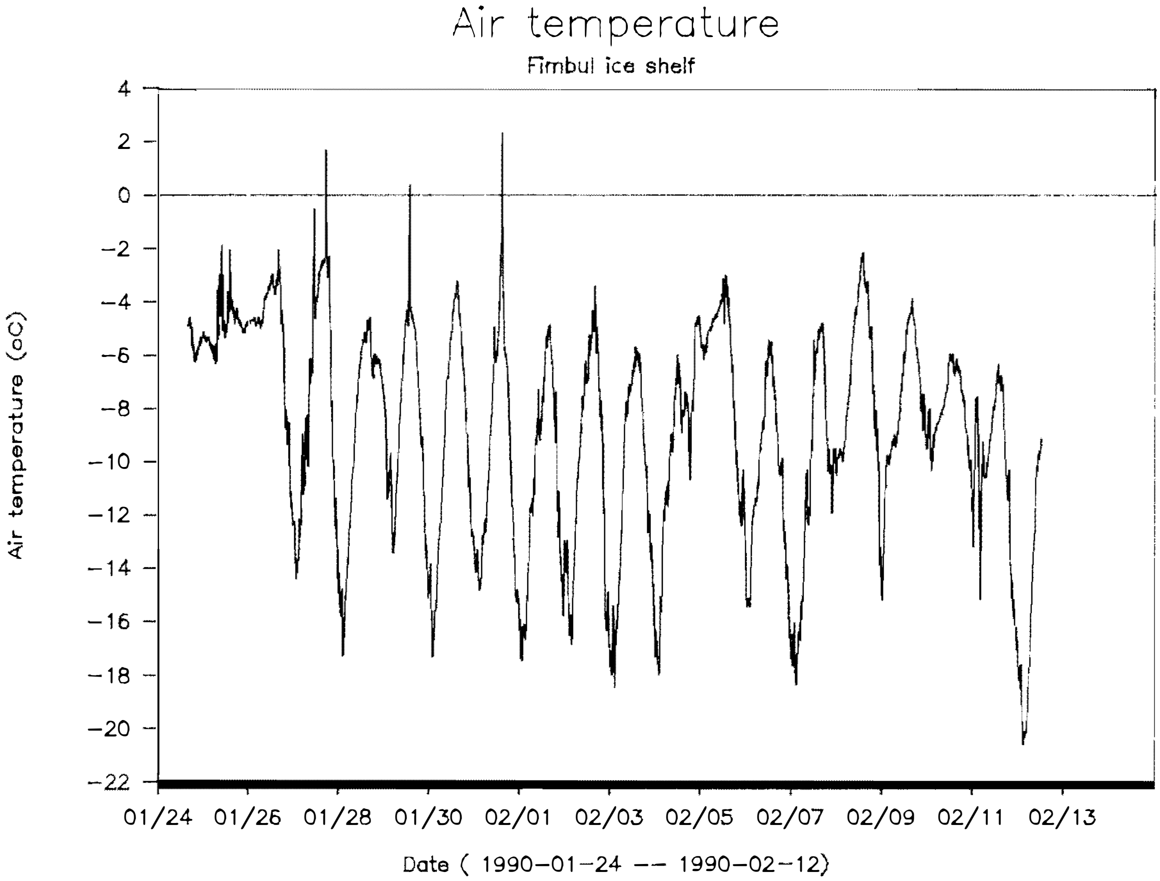


Fig. 2. Temperature and density profile.
Ice shelf edge, position 70°12'9"S, 04°46'16"E



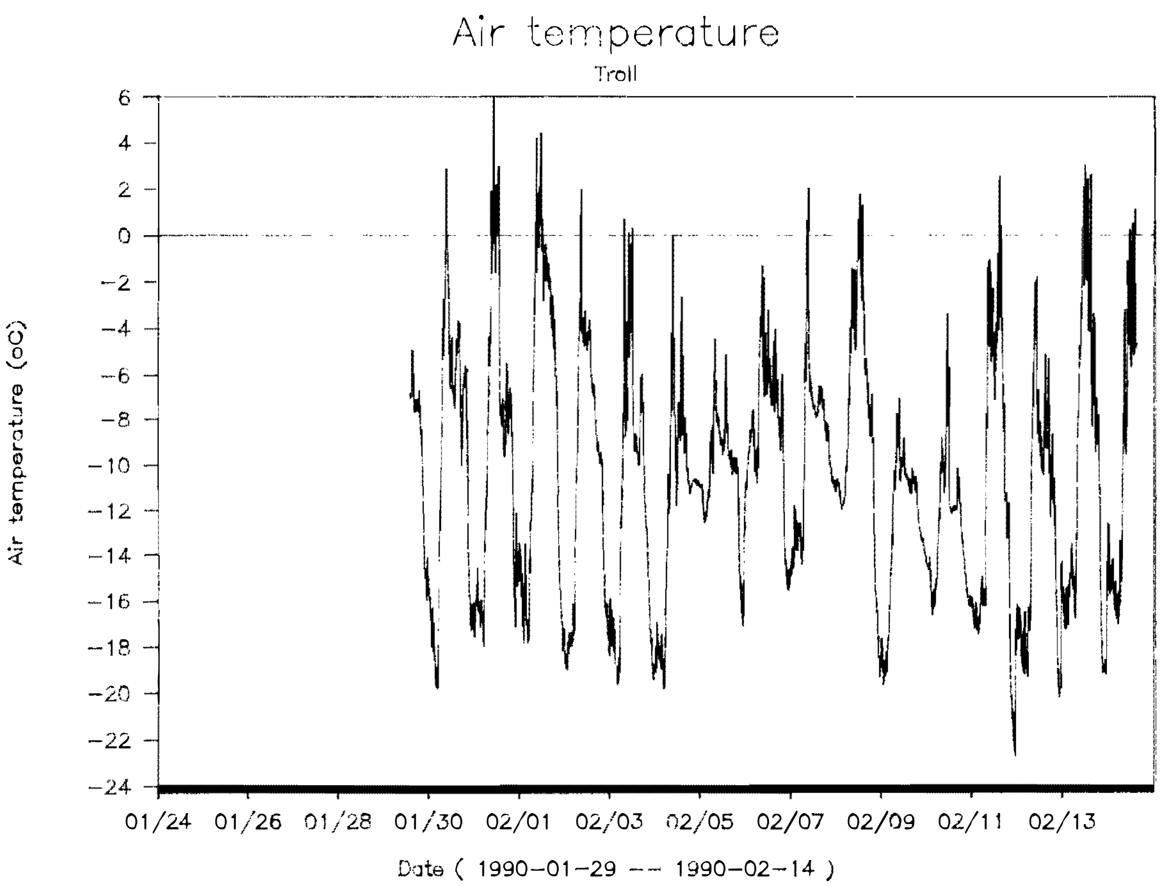


Fig. 3. Air temperatures at Fimbulisen and TROLL.

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CHEMICAL AND GLACIOLOGICAL STUDIES

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BACKGROUND AND OBJECTIVES

I had three main tasks to perform on this expedition:

a) **Obtain accurate surface profiles of specific areas of the ice shelf.**

b) **Collect surface snow samples along a traverse from the ice front.**

c) **Test and evaluate a ground based impulse radar system.**

a)
Using a system that combines position information from a GPS receiver with atmospheric pressure, accurate surface profiles can be easily measured. The pressure transducer has 10 cm resolution while the GPS receiver gives the position to within 30 meters. The resultant surface profiles can then be used as ground truth for satellite altimetry and when combined with radar depth soundings locate areas of the ice shelf that are not in hydrostatic equilibrium.

b)
In each of three recent ice core profiles (from sites Dolleman Island, Gomez Nunatak and Coats Land) it was found that the relative marine ion concentrations differ significantly from their bulk sea water ratios. Similar effects have been observed at other sites (Gjessing 1989). In some cases, considerable positive excesses of an ion are balanced by a negative excess in adjacent sections of the core. The causes are under investigation and one possibility is that the phenomenon may be due to a fractionation process during transport from the ocean to the deposition site. The analysis for marine ions would be done by atomic absorption spectrometry and ion chromatography. This project was devised by Robert Mulvaney, a colleague in the British Antarctic Survey.

c)
Ice radar sounding experiments in various parts of the Arctic and Antarctic have detected echoes from layers within the ice. These layers can have considerable horizontal continuity. It has been suggested that they are the result of deposition or weather induced density variations, and could therefore be isochrones. (Blindow et al. 1987).

The project aim was to test an unproven radar system, then locate and map these internal layers. The relationship between changing ice thickness, position of the internal layers and surface elevation can be used to model the stress regime within the ice.

FIELD WORK AND EQUIPMENT

a)

Unfortunately the pressure transducer ceased to work after only four hours. After repeated attempts to fix the unit the project was abandoned.

b)

A flagged route was established from the ice front depot (S 69°55'33.6", W 00°06'45.9") to the drill site (S 70°58'41.9", E 00°12'03") a distance of 120 km. This provided the ideal opportunity to collect surface snow samples at regular intervals along the traverse. On a return trip from the depot samples were taken every 4 km, giving a total of 30 sites. At each end of the traverse a shallow pit was dug and samples taken from the walls. All samples were obtained by scraping directly into containers. Precautions to avoid contamination included the wearing of disposable polythene gloves and ensuring the sample area was upwind of the party.

c)

The transmitting and receiving dipoles for the impulse radar system were resistively loaded with a centre frequency of 30 MHz. This makes the received echo from a plane reflector 30 ns long. The received waveform was digitized at 200 MHz in burst mode and stacked before displaying and saving to improve the signal to noise ratio.

To cope with the large dynamic range in the received waveform from different reflecting layers within the ice, echos were recorded with different gain settings.

At the drill camp a number of short profiles were achieved along the ice flow line. Profiling speed was 15 km/hr resulting in a completed sounding being recorded every five metres.

PRELIMINARY RESULTS AND CONCLUDING REMARKS

The snow samples are now being analysed by British Antarctic Survey for Na, Mg, Ca, K, Cl, NO, and SO. Plotting the actual values, and the values of the ion ratios, against distance from the coast will show any trends in bulk composition as the aerosol moves inland from the coast.

All radio echo data was recorded on cassettes and is now being processed particularly for horizontal continuity of the reflecting layers. It is hoped to now take this equipment to a bore hole site and then compare the radar returns with detailed chemical analyses of the ice core.

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GEOLOGICAL OBSERVATIONS IN

GJELSVIKFJELLA AND MÜHLIG-HOFMANNFJELLA

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INTRODUCTION

1) General geology

A major large scale structural feature of western Dronning Maud Land is the Jutulstraumen-Pencksøkket Rift Zone (Neethling 1972). This rift separates a Proterozoic platform to the west and a younger east-west trending linear mountain belt with exposed igneous and high-grade metamorphic rocks to the east. The expedition area was located on the eastern side of this rift and covered most of Gjelsvikfjella and western Mühlig-Hofmannfjella.

The mountains and nunataks of Gjelsvikfjella and Mühlig-Hofmannfjella are dominated by granitoid igneous rocks and by metamorphic sequences in upper amphibolite-facies and in granulite-facies. Metasupracrustal rocks are subordinate.

The record of igneous activity is extremely complex and includes large intrusions of charnockite, hydrous granite, quartz-diorite, smaller gabbro intrusions, and a large number of generations of dyke systems ranging in composition from granitic to gabbroic/dioritic. Granitic dykes include several generations of charnockite, aplite, pegmatite and normal granite dyke systems.

Most of the igneous rocks have been modified by subsequent metamorphic episodes and deformation events which interacted with the magmatic activity in a complex way in time and space.

Metamorphism is accompanied by local and regional partial melting in granitic rock compositions where H_2O was available. The studied field area displays spectacular examples of large and small scale subsolidus fluid-rock interaction phenomena.

2) Previous work

The first description of metamorphic rocks of the expedition area was given by Roots (1953). Large scale reconnnaissance mapping was made by Ravich and Soloviev (1966) and a number of radiometric age determinations were carried out on rocks of the area (Ravich & Krylov 1964). A 1:1.5 million scale geological map has been edited by Roots (1969) in the Antarctic Map Folio Series.

Ravich & Krylov (1964) proposed that western Mühlig-Hofmannfjella consist of high-grade metasupracrustals of pre-Riphean age and a granite-granosyenite complex. Their K/Ar and whole rock ages range from 400 to 480 Ma, with a 510 Ma age from Gjelsvikfjella.

The Norwegian Antarctic Research Expedition 1984-85 mapped the main part of Gjelsvikfjella and western Mühlig-Hofmannfjella at the scale of 1:250,000. Geological, petrological, mineral and rock-composition data were presented together with the maps by Ohta et al.(1990). They also presented pressure-temperature estimates for the main tectonothermal event. Their new radiometric age points to a major magmatic event about 500 Ma ago.

3) Objectives of the NARE 1989/90

a) Descriptive regional geology

The maps of Gjelsvikfjella and Mühlig-Hofmannfjella presented by Ohta et al.(1990) are based on distant observations with relatively few field checked localities. It was therefore necessary to improve the density of field checked localities and to verify a number of information based on distant observations. Also some nunatak areas in the southern parts of Mühlig-Hofmannfjella and western parts of Gjelsvikfjella needed to be mapped for the first time. The efforts will result in an improved map at the scale of 1:250,000 and in the accumulation of 1:100,000 scale information from particularly interesting areas (Hoggestabben, Svarthamaren, Jutulsessen).

b) Metamorphic petrology of the gneisses and marbles

Metamorphic mineral assemblages reported by Ohta et al (1990) from various types of gneisses may have a great potential for deciphering parts of the tectonometamorphic history and evolution of the mountain chain. For such petrological studies and modelling of the orogenic process more and better data are required. Small scale field observations and sampling at key localities known from the previous NARE 84/85 (Ohta & Tørudbakken 1985) will be used as a basis for a comprehensive laboratory and modelling program.

c) Petrology of the charnockite complex

The charnockite complex extending to the east from about Hochlinfjella and Hoggestabben in western Mühlig-Hofmannfjella has been previously described by e.g. Ohta et al. (1990). Several interesting assimilation and contact phenomena as well as a multitude of dyke systems have been reported from the boundary zone of the charnockite complex. Charnockites and granulites represent deep crustal material. The nature of the deep continental crust and processes of granulite (charnockite) formation are key research subjects in today's geology. A major research effort on the Svarthamaren Charnockite Complex was, therefore, clearly the major objective of the NARE's 1989/90 geological activities. The field activities were planned to include, besides sample collection, detailed structural and textural data collection at a multitude of localities in western Mühlig-Hofmannfjella.

d) Meteorite search

In the eastern part of Dronning Maud Land a large number of meteorites were found on the internal (southern) side of the mountain range by a number of Japanese expeditions. The finds were made in strong ablation zones in blue ice areas of the inland ice sheet close to the coastal mountains. It was planned to search for meteorites on similar blue ice zones south of Mühlig-Hofmannfjella.

FIELD WORK AND OBSERVATIONS

The areas visited by the geology party during the NARE 1989/90 included large parts of Gjelsvikfjella and of western Mühlig-Hofmannfjella (see Fig. 4 and appendix for detailed route logs and visited localities).

a) Mapping and descriptive regional geology

The collected data and information allow for a substantial improvement of the geological map 1:250,000. A large number of localities and profiles with only distant observations (binocular, helicopter) available have been checked in the field. From some areas (Hoggestabben, Hochlinfjellet, Stabben, Jutulsessen, Svarthamaren) information density has reached the 1:100,000 scale. We have sufficient data to make this scale of geological map sheets with general descriptions of rocks for Gjelsvikfjella and western Mühlig-Hofmannfjella. The considerable local complexity of the geology in Gjelsvikfjella and western Mühlig-Hofmannfjella requires remapping of the entire area at the scale of 1:100,000 by future expeditions in order to supply the basis for further petrology projects.

b) Metamorphic petrology

The metamorphic grade varies between granulite facies and upper amphibolite facies. Field evidence suggest that conditions of metamorphism change locally and episodically between the two regimes as a result of a complex interaction between CO_2-H_2O fluids and the rocks. Fluid-rock interaction involved infiltration of hydrous fluids, partial melting, deformation, local production and consumption of fluids by fluid-rock reactions and magmatic intrusions with associated heat and fluid effects.

Detailed textural and structural data and observations were collected in the field which, together with data from the samples, will allow for petrological modelling of some of the fluid-rock interaction processes. Sufficient material for characterizing the regional metamorphic evolution should be available by now. The expedition area has, however, a great potential for future studies of fundamental rock forming processes at middle to lower crustal levels.

The rock types and observed mineral assemblages in the various lithologies are consistent with estimated maximum pressure and temperature conditions of about 8 ± 1 kbar and 750 ± 50^{0}C.

c) Charnockite complex

As expected, the charnockite complex proved to be a most rewarding, in fact spectacular, subject to study during NARE 1989-90. Much time and effort was invested into the detailed study of contact relationships, inclusion and xenolith patterns, age relationships of a large number of generations of dyke systems, intrusion relationships and subsequent subsolidus modifications of the igneous suites of the Svarthamaren Charnockite Complex (Fig. 1). The collected information, data and samples will enable us to carry out a series of projects on magmatic and metamorphic processes relevant to a large deep-crustal granulite (charnockite) complex in the years to come.

d) Meteorite search

During our second and also, unfortunately, last mapping flight by helicopter one small blue ice field south of Petrellfjellet (western Mühlig-Hofmannfjella) was searched for meteorites from the air, though without success.

SOME PRELIMINARY RESULTS AND CONCLUSIONS

A first discussion of field data on the major research topic of NARE 1989/90, the Svarthamaren Charnockite Complex and the granulite-amphibolite facies relationships is presented below.

Large portions of the western Mühlig-Hofmannfjella are dominated by a massive unfoliated or weakly foliated medium-grained rock type of granitic bulk composition. The granitic rocks display at some places a granulite facies mineralogy (and a distinct

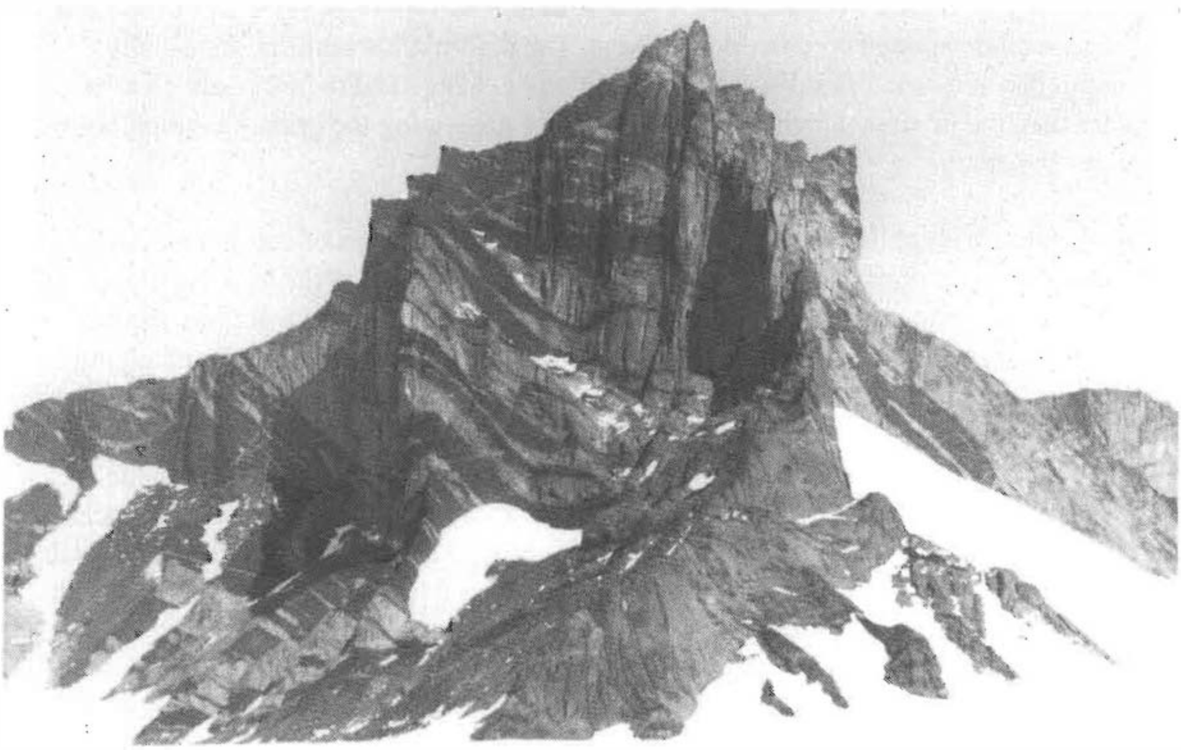

Figure 1. *East wall of Stålstuten (2608 m, 72°4'S, 4°10'E). The height of the wall is about 800 m. The dark bands (dark brown) consist of charnockite (granulite, OPX-granite), the light bands (grey, pink) are made up of biotite-hornblende granite.*

brown weathering colour). At other places it contains a typical amphibolite facies mineralogy. The boundary between the two versions of the same rock is usually sharp, but geometrically very complex. As shown below for the Stålstuten example, one single compact granite mountain may in detail be composed of a very large number of bands of granite with granulite and amphibolite facies mineralogy, respectively.

Excellent examples of granulite-amphibolite facies relationships at the scale of tens to hundreds of meters can be seen in the eastern and northern walls of Stålstuten and in the cliffs of its satellite mountains (Fig. 1). Geologically, the walls are made up of alternate bands of dark brown charnockite and light grey to pink biotite-hornblende granites. The bands are generally parallel to each other and vary in size from less than one meter to more than 100 meters.

The contact between granulite facies charnockite and amphibolite facies granite is generally very sharp and the contact zone is in the order of grain size dimension. The texture, the distribution of mafic minerals and the grain size does not change across the contact surface. The colour change, however, is associated with a change in mineralogy. The brown charnockite contains orthopyroxene and a ternary mesoperthitic feldspar, the pink or grey granite contains biotite and/or hornblende and a two feldspar assemblage (orthoclase-oligoclase). Locally, both rock types display a weak foliation with a well developed crenulation cleavage. The deformation textures are usually continuous across the sharp boundary of the color change and therefore are clearly older than the process which was responsible for generating the granulite-amphibolite facies boundary.

The granulite-amphibolite facies transition is related to a series of continuous dehydration reactions. The nature of these reactions depends on the bulk rock chemistry and the amphibolite-facies mineralogy. All dehydration reactions require heat to proceed, their progress, however, may often be a consequence of a changing chemical potential of H_2O (and possible associated changes in fluid composition) rather than a simple increase in temperature. At a given pressure (or depth in the crust), the equilibrium temperature of all reactions connecting the granulite and amphibolite facies depends strongly on the chemical potential (or activity) of H_2O. Consequently, local small scale variations in the chemical potential of H_2O (in cm og dm scale) may result in an extremely complex amphibolite-granulite facies interface (isograd surface) with complexities on the same scale. The presented field data on the details of the amphibolite-granulite facies boundary are strong evidence that small scale variations in the chemical potential of H_2O (or fluid composition) control the facies transition.

Because the relevant reactions involve H_2O as a volatile component much of the spatial complexity of the reaction front surface (colour change front) is related to the transport properties of the granite and to the mechanisms of fluid transport. Figs. 2 and 3 show two fundamentally different situations for the amphibolite-granulite facies transition. Fig. 2: H_2O is released by the rocks and is channelled out and away from the site of production. The volume of charnockite/granulite (brown rock) increases on the expense of granite. H_2O release from hydrous granite (grey rock) may have been triggered by the influx of CO_2-N_2 fluids or by loss of H_2O caused by local, externally controlled chemical potential gradients for H_2O.

Fig. 3 shows the inverse situation. H_2O is infiltrating granulite along structurally controlled zones and is consumed by the reactions. Brown granulite is turned into grey granite. The brown rock is white-washed (grey-washed) by this process. The hydration H_2O may be imported from dehydrating lower parts of the crust.

There is ample field evidence for the regional importance of the white-wash process. Clear evidence for the hydration of granulites is texturally restricted to fracture systems, late dykes, netveins and xenoliths. However, at many localities it is often unclear whether granulites undergo hydration or hydrous granite is dehydrated, hence the direction of the process at a given locality is ambiguous. This is particularly the case for the majority of the localities with irregular patchy or banded charnockite-granite contacts in massive rock with no apparent inhomogeneities in the form of fractures, shears of lithological boundaries which could have served as fluid pathways. The mechanism for transporting large volumes of H_2O through massive charnockites and granites on a regional scale is not understood at present and will have to be studied in detail.

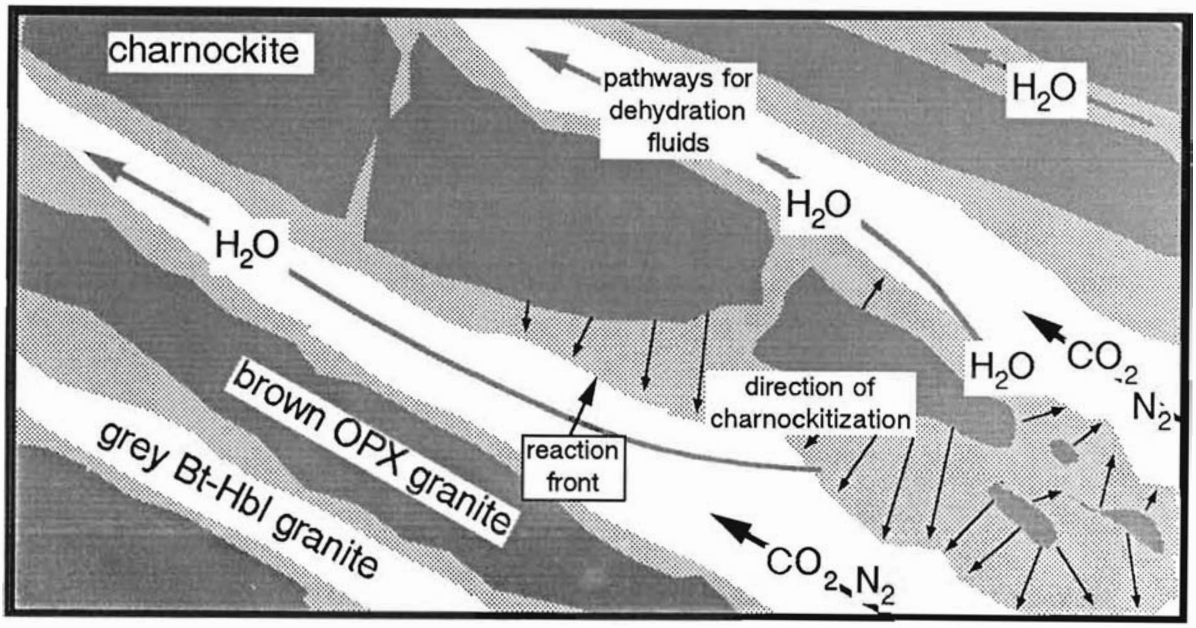

Figure 2. Charnockitization of hydrous biotite-hornblende granite (Bt-Hbl granite) by infiltration of externally derived CO_2 and N_2. and extraction of H_2O. Thickness of charnockite band about 10 m.

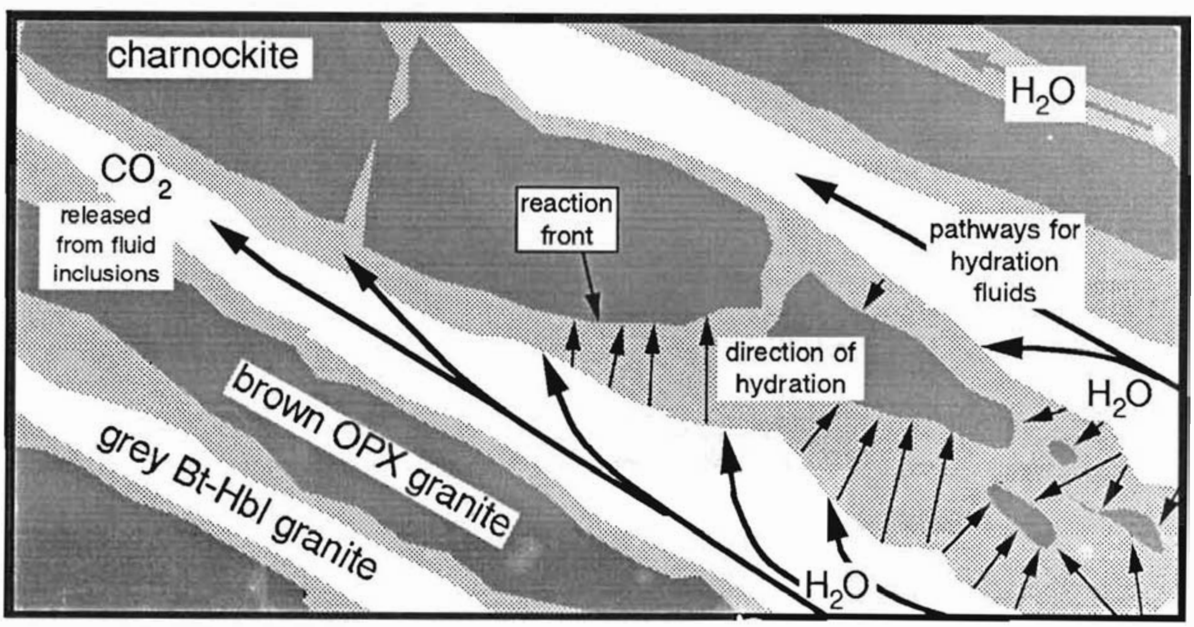

Figure 3. Hydration of brown OPX granite (charnockite) by externally derived hydrous fluids (white wash process). Thickness of charnockite band about 10 m.

It should also be mentioned here that there are at least two different generations of charnockitic rocks. The discussion presented above applies to an early charnockite generation. A late generation of dark brown charnockite is clearly instrusive and separated from the early generation by a period of emplacement of hydrous igneous rocks.

Banded metasupracrustal gneisses occur together with quartzites and marbles at a few localities. These supracrustal rocks will be studied in detail in the laboratory and will provide us with additional information on the condition of the amphibolite-granulite facies transition.

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APPENDIX

Field camps and route logs

The four members of the geological field party left the ice shelf edge on January 13th and established the first camp January 15th, 1990 at the northern edge of Svarthamaren (Mühlig-Hofmannfjella). Field work was carried out in parties of two or four geologists, and areas and localities visited from the field camps are shown on Fig. 4. Field transport was based on snowscooters. Helicopter transport was available for geological surveying during a total of 2.5 hours. The camp was moved from Svarthamaren to Grjotlia (Jutulsessen, Gjelsvikfjella) on January 24th (camp 2). This is the site of the new Norwegian Antarctic Station (TROLL). After 10 field days at Grjotlia the camp was relocated to Porten (north of von Essenskarvet, western Gjelsvikfjella) on February 2nd (camp 3). Finally, a last camp (4) was put up directly under the north wall of Hoggestabben (western Mühlig-Hofmannfjella) by February 7th. After 8 days work around the camp, the party left camp 4 on Februar 16th and returned to the ice shelf barrier on scooters.

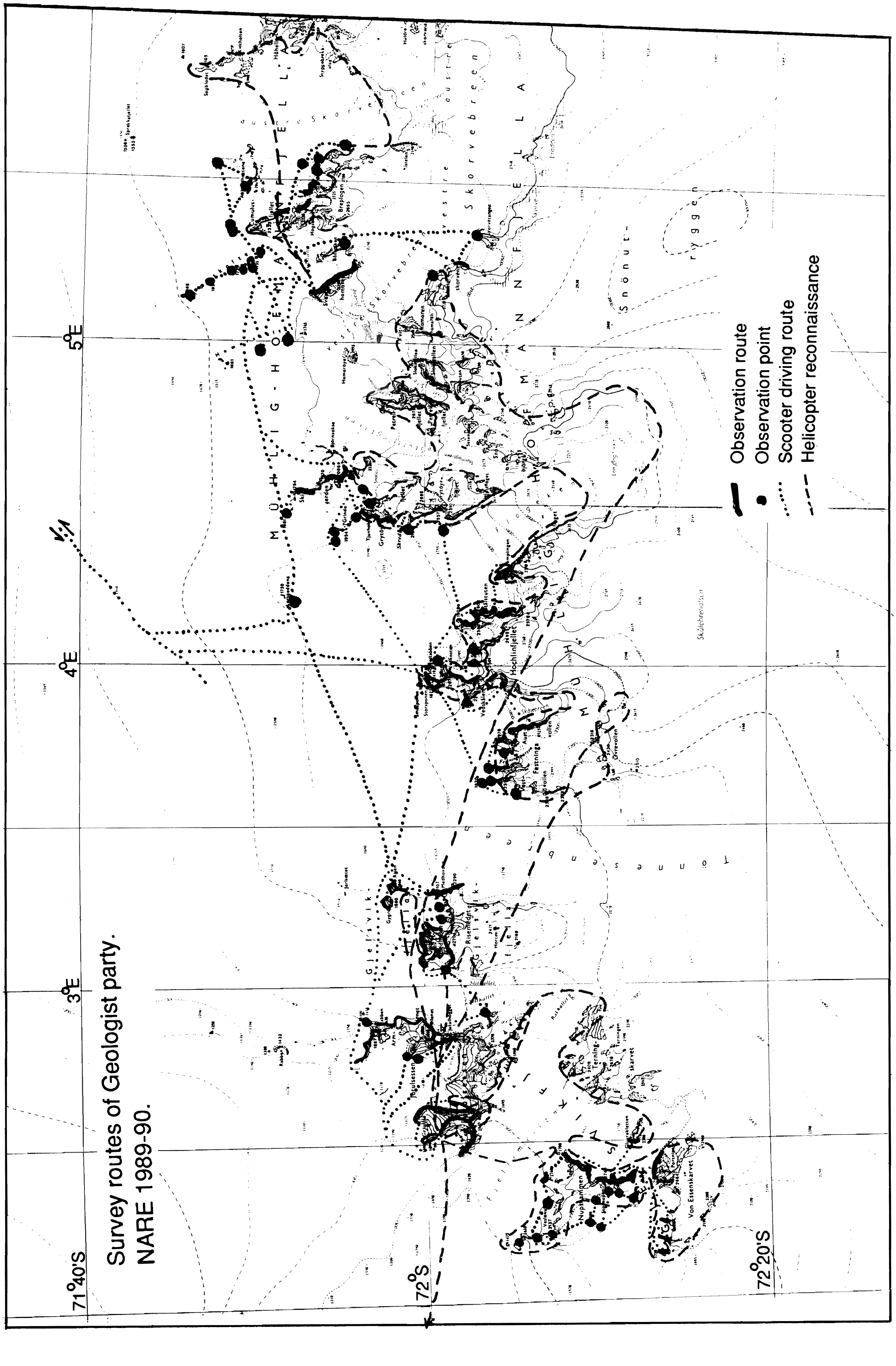

Figure 4. Camp sites, route logs and visited localities.

GEODETIC MEASUREMENTS

IN DRONNING MAUD LAND

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BACKGROUND

One geodesist and one topographer from NP carried out geodetic measurements in the area between Snarbynuten (72°02.4'S - 1°37.3'E) and Svarthamaren (71°53.3'S - 5°09.6'E) on NARE 84/85. The points measured were later used for rectification of satellite images (Landsat TM and MSS). The method for processing the images was developed at the Department of Informatics, University of Oslo. It is described in the thesis of Dag Davidsen (Davidsen 1987). Four maps are at the moment ready for printing based on the measurements carried out on this expedition.

During NARE 89/90 the plan was to extend the measurements westwards from the area covered on the last expedition, possibly covering the mountain area H. U. Sverdrupfjella between longitudes 0° and 2°E with reference points. The area stretches about 90 kilometers in a north-south direction, 70 kilometers east-west, and is rather mountainous. In the northern part the mountains are about 1500 meters high with many smaller nunataks in between, while the southern part has several peaks exceeding 2800 metres.

The trigonometric network in this area is very sparse. It was measured during the Norwegian-British-Swedish Maudheim-expedition 1949 -52. Norway was responsible for the geodetic measurements. The trigonometric net measured, stretching from Ahlmannryggen and Borgmassivet (72°-73°S - 4°W) in the west to Vendeholtet (72°13'S - 1°20'E) in the east, was based on three astronomical stations. In addition, short baselines were measured with steel tapes to determine the scale. The network can not be considered to be very precise, but it was sufficient to compile a set of maps in scale 1:250,000 covering the area. The compilation was performed in the late 1950s and early '60s, and was concentrated to the mountains and nunataks, even if some contour-lines were drawn on the ice.

New technology has made it possible to map areas from satellite images or pictures. Possible sources for compilation are images from the French SPOT-satellite, or pictures from a Russian satellite with the KFA-1000 camera. One stereoscopic pair of SPOT- images covering Jutulsessen with pixel size 10 m, and one stereoscopic pair of pictures scale 1:280,000 covering the central part of H. U. Sverdrupfjella, were available prior to departure.

A glaciological group was to drill through the Fimbulisen ice-shelf during NARE 1989/90. In connection with their work, they required exact velocity and strain rates for the ice. They would establish a network of stakes as soon as they were established on Fimbulisen. They were to put out stakes both in a profile crosswise Jutulstraumen (east-west-direction) and two rectangles with side lengths of 1 km and 7 km. The network was to be measured twice during the season with the best accuracy possible.

The building of the permanent Norwegian research station TROLL in Jutulsessen would give us a natural starting point. It was therefore of interest to establish a reference point here. TROLL and the area around it will be one of the main study areas for future Norwegian expeditions. The existing map of the area is in scale 1:250,000. A more detailed map was especially desired by the geologists. The area is covered with oblique aerial photographs from 1958/59.

OBJECTIVES

The geodetic/topographic program on the expedition had five main objectives:

1. Extend the precise trigonometric network measured during NARE 1984/85 to the west, establishing a network of points measured with high accuracy in the H. U. Sverdrupfjella area. If possible, similiar measurements should be carried out eastwards from Svarthamaren, as far east as possible.

2. Measure points identifiable in satellite images or pictures. The points should be used as fixed points in satellite image rectification or for compilation of maps based on satellite pictures/images.

3. Measure a stake network established by the glaciological group on the Fimbulisen ice-shelf to determine the velocity and strain in the ice. The network should be measured twice, as early and as late in the season as possible.

4. Measure a detailed triangulation net in Jutulsessen with enough control points to map the area at a scale of 1:50,000.

5. Take oblique photographs from helicopter to cover Jutulsessen with photographs for map compilation at a scale of 1:50,000.

EQUIPMENT AND TECHNIQUES

Satellite positioning

With the new techniques used for geodetic positioning, especially GPS, far higher accuracy can be achieved than earlier. For our work we relied on 3 Ashtech XII dual frequency multi-channel GPS receivers. In addition a Magnavox MX1502 transit receiver was operated at TROLL to get an accurate absolute position for a reference point. This point will be the reference point in the computations of the GPS-network.

The Ashtech receivers are "all-in-view" receivers, and collect data from up to twelve satellites. We had a maximum of six satellites visible simultaneously. The receivers were set to log data at ten second epochs. The Ashtech receivers have 1 Mb RAM, storing more than 12 hours of measurements with five satellites and 10 second epochs. Data storage was therefore no problem, but the data had to be transferred daily to a computer. This presented some problems at the start of the season, as there were no heated tents or buildings. We brought two Toshiba T1600 computers for the purpose, their operating temperature should be above +5°C, but with air temperatures constantly below the freezing point we hesitated a little in using them outdoors. However we experienced few problems with the computers even under temperatures below zero.

Processing of the GPS-data was made with Ashtechs own software GPPS (GPS Post Processing System). An IBM PS/2 mod. 70-20 MHz computer was used for processing. Typical time to process one day's data from the three receivers was four hours.

The data from the MX1502 will be processed using the GEODOP software, possibly with precise ephemerides.

The satellites available at the time of our work, gave the necessary constellation of four or more visible satellites in two measuring periods every 24 hours, one 7-hour period during the day and a shorter 5-hour window during the night. We mainly concentrated our measurements to the day-period because of limitations in the daily flying time of the helicopter that we used for transport.

The GPS measurements in H. U. Sverdrupfjella were made with one receiver stationary at the reference point at TROLL, and the two remaining receivers moved to different points in the field. The measurements were laid out as a net of triangles connected to each other with one common side, to give a net suitable for adjustment.

On a typical day we measured at three points in addition to the reference point. We started with one of the two roving receivers at a previously measured point, and the other positioned at a new point. After approximately three hours the first one was moved to a new point where it logged for another three hours. Fig. 1 shows schematically how the measurements were performed.

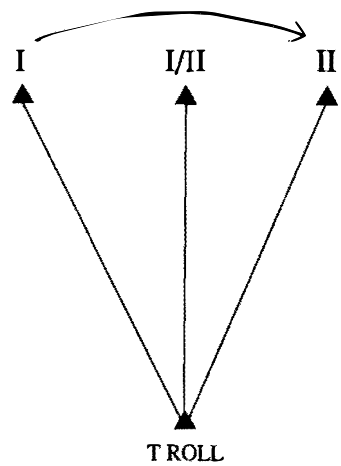

Fig. 1

The velocity and strain measurements on Fimbulisen could also preferably be carried out with GPS, but to get accurate values for the velocity of the ice, one reference station had to be on solid rock as the other points were on the moving ice. The nearest rock outcrop is more than 75 km away from the drilling site. The large distance to the reference receiver could be a serious problem if the measuring conditions for long baselines were poor.

Triangulation

From selected GPS-measuring points, bearing and distance were measured to selected terrain details to fix them as control points. Directions were measured with Wild T2 one-second theodolites, while distances were measured with an infrared electro-optic distancer, Wild DI3000 with 2 ppm accuracy. The same equipment was used for triangulation and trilateration in the network in Jutulsessen.

The control points should be suitable for rectification of Landsat MSS and TM satellite images. These are to be used in combination with the traditional maps in the scale of 1:250,000. The points demand a special selection of terrain objects. Preferably the measured points should be identifiable to one pixel (50x70 m), or at least within a few pixels in the images. The old triangulation points are usually situated at the mountain tops which are very difficult to identify precisely in an image. Instead small nunataks, if possible with the size of one pixel, were to be measured as reference points.

The control points were also to be used as ground control in map compilation from one pair of pictures taken with the Russian KFA-1000 camera. The pictures cover the south-eastern part of H. U. Sverdrupfjella. This gives a stereoscopic model in a scale about 1:280,000 and can be used for map compilation. If an acceptable accuracy can be achived this is a very cost-effective way of mapping remote areas. It is especially advantageous on the large snow-covered areas between the mountains where aerial photographs are difficult to use. The measurements of control points were both to enable map compilation and to estimate the accuracy of point determination and contour lines.

Photographs

A Hasselblad MKWE terrestrial camera was to be used for aerial photographs from a helicopter. Unfortunately this part of the project had to be dropped due to an oil leak in the AS-350 helicopter.

WORK DONE

We had 38 days in the field, of which about 15 were used for transport and building the permanent station TROLL. Five of the remaining 23 days were used mainly for transport between camps. Four days had unfavourable weather. That left us with 14 days for measurements.

In H.U. Sverdrupfjella seven stations were measured with GPS. The points are laid out in a polygon around the mountain group, with one point inside the polygon (Fig. 2). A total of 14 vectors were measured, and six of them were observed more than once. The vectors vary in length from 20,7 to 116 km. Due to weather and helicopter movements the observation periods for the different vectors vary from one hour up to six hours. We intended to remeasure two of the vectors because the accuracies achieved were not acceptable. The oil leak on one of the helicopters prevented this, as it also prevented measuring the line between BREK and KVIT which would have strengthened the net considerably.

In connection with the GPS-measurements a total of twenty fixed points were measured and simultaneously identified in the satellite photographs. Three elevation profiles about 7 km long were measured across the glaciers around Fuglefjellet (FUGL).

The Magnavox MX1502 transit receiver was operated in the reference station at TROLL from 28 January to 14 February.

Fig. 2. GPS-network in H. U. Sverdrupfjella

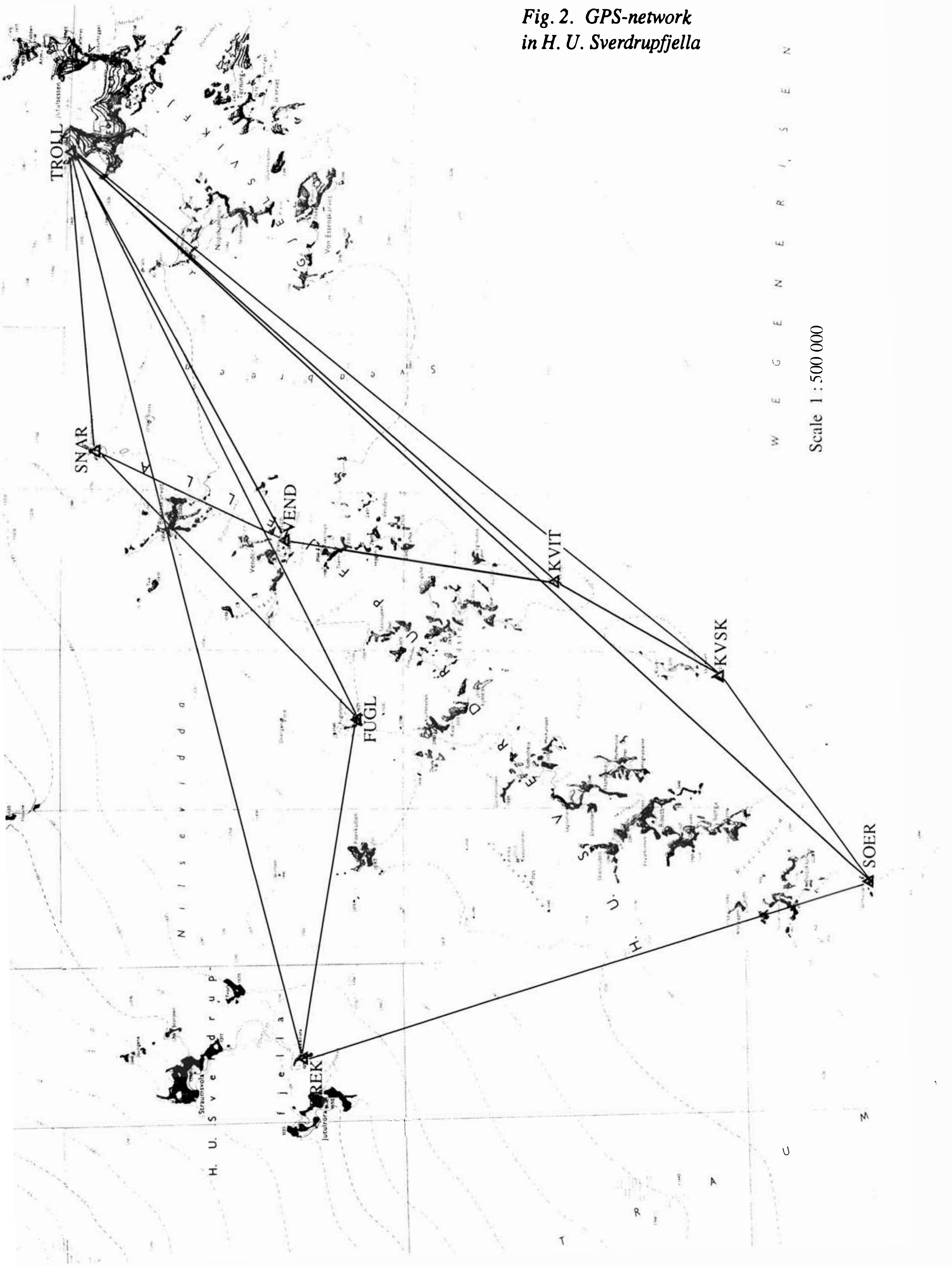

Table 1: Measured vectors

Stations from	To	Approx. length	Measured date
TROLL -	SNAR	31785,8	24,34
	VEND	46885,2	24,25
	KVIT	68985,6	25,30
	KVSK	89335,7	30,31
	SORH	115908,3	31
	BREK	100178,0	31,34
	FUGL	67442,9	34
SNAR	VEND	22052,3	24
VEND	KVIT	29652,1	25
KVIT	KVSK	20674,3	30
KVSK	SORH	27251,4	31
SORH	BREK	64302,7	31
BREK	FUGL	37230,0	34
FUGL	SNAR	39804,0	34

TROLL	RABB	19535,7	23
TROLL	JUTN	11559,7	23
JUTN	RABB	8980,7	23

The stake net (Fig. 3) established by the glaciological group was measured 27-28 January. Four stakes in a rectangle (1-4) with one-kilometer-long sides, were fixed with direction- and distance-measurements with theodolite and distancer. Eight stakes were measured with GPS. One stake (1), near the camp was occupied during all three sessions, while one receiver was moved to the different stakes (5-11) with 1.5 to 2 hours observations at each stake. One receiver logged at the reference point at TROLL in the same period. Even if the main interest is connected to the distance from TROLL to stake 1, giving the velocity of the ice, and the distances from stake 1 to the other stakes indicating strain, it is possible to compute the velocity for all stakes related to TROLL. The very long distance to TROLL, about 142 km, may cause a lower accuracy in the velocity, especially for the stations with the shortest observation period. We could have selected a shorter distance, about 75 km, to the nearest rock, but this introduced logistic problems, and we decided to use the reference at TROLL . The stake network was remeasured in a similiar way 12-13 February, giving 15 days between the two measurements.

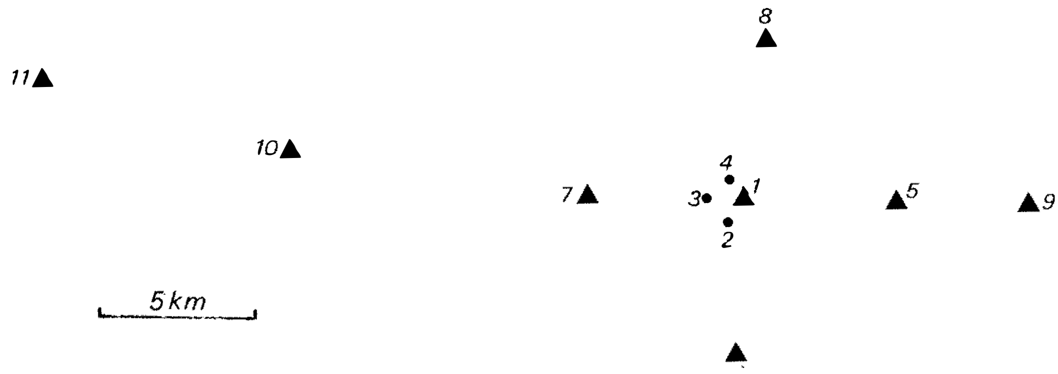

Fig. 3 The stake net

In Jutulsessen trigonometric observations were conducted in nine stations (Fig. 4). A total of nine distances were measured, and two points were measured with GPS for azimuth and scale determination. From the triangulation stations a total of 20 points were fixed for photogrammetric use. They were partly identified in the SPOT satellite images of the area.

This stereoscopic image model is intended for a mapping project similiar to the one mentioned for the KFA-1000 pictures. Fixed points identifiable in the SPOT-model should therefore be measured.

The two triangulation stations, JUTN and RABB (Fig. 4), measured on NARE 1984/85 in the north-eastern part of Jutulsessen, were connected to the new established GPS- and Transit satellite reference points at TROLL with both GPS- and conventional surveying measurements.

PRELIMINARY RESULTS

As the station TROLL became operational with 220 V power supply, we started computing the base lines measured with GPS. We could start the computations on 2 February. The measured baselines were processed during the following days. The preliminary processing is based on an average of the position achived for TROLL from some of the pseudorange positions. This position may contain errors of tens of metres, and the final computation of the transit measurements with the MX1502 should give us a more accurate position. The possible error in the reference position can cause errors of several ppm in the computed vectors. The preliminary computation of the network in H. U. Sverdrupfjella is very promising indicating mean errors of 2-3 ppm on the vectors.

The results of the ice velocity of Fimbulisen are perhaps even more interesting. Both measurements on Fimbulisen were made during three sessions, and a vector can be computed between TROLL and the camp for each session, with some results shown in Table 3. The drift rate calculated from vectors with a time span of 12-14 hours in Table 2 shows an astonishing accordance with the rate based on vectors 382 hours apart.

Table 2: Vectors TROLL - FIMBULISEN

Day	Time	Time diff. (hours)	Vector (m)	Vector diff. (m)	Drift rate (cm/hour)
27	1330		142017,417		
		12.0		0,691	5.76
28	0130		142018,108		
		14.5		0.824	5.68
28	1500		142018,932		
27	1430		142017,611		
		382.0		23,506	6,15
43	1230		142041,117		

The strain measurements in the small rectangle on Fimbulisen gave mean errors of 1.6 mm and 5.4 mm per kilometre. The lower accuracy the second time was probably caused by low temperature and wind, giving difficult observation conditions.

Fig. 4. Triangulation network - Jutulsessen (background Spot-image)

CONCLUDING REMARKS

A final position of the station TROLL, based on the Transit measurements has not yet been computed. The GPS-measurements have, except for one station east of Svarthamaren, been succesfully computed based on a preliminary position of TROLL. The data from the remaining station had to be sent to Ashtech for decoding because of problems during downloading. We hope to get some results from this station too. The GPS-measurements will be recalculated based on TROLL`s final position.

The work with rectification of new Landsat MSS images has started. As a first step, two of the four already processed images will be controlled with the new measurements.

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MEDICAL CONTINGENCY AND BIOMEDICAL RESEARCH

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INTRODUCTION

Antarctica is the most inaccessible, highest, driest, coldest and most windy of all continents. Even in summer extreme weather conditions can be encountered.

One main objective of this expedition was to erect a permanent research station on firm ground in Gjelsvikfjella, Dronning Maud Land, 230 km from the shelf edge. The work should be performed by non-professionals, meaning that many people would have to handle heavy loads and potentially dangerous powered tools with which most of them were unfamiliar.

Altogether 35 persons would be isolated from the rest of the world for five weeks. The main group would vary in size and would be situated in Grjotlia to build the station named TROLL. A group of four would commute between the loading place on the shelf and Grjotlia, transporting heavy goods, provisons and fuel with snow tractors. A group of four geologists would move around in the area, putting up camp for some days at different locations. The seven glaciologists would most of the time be located 142 km from the main camp, while the three geodesists would be away from the main camp for a few days at a time. The two helicopter crew of two each would also be away from Grjotlia for shorter periods, while the four ornithologists would have their permanent camp 93 km from TROLL for the complete five week period. The film team of three would visit different locations for days at a time, as was the case for the radio reporter. The medical team of three would visit the different camps to perform biomedical research on the personnel. A biologist would also travel around to collect specimens, while the expedition coordinator and his aid would be stationary at the main camp, except for brief excursions.

MEDICAL CONTINGENCY

BACKGROUND

Based on the above information it was decided that medical service at a certain level was highly desirable, and professional personnel were recruited from applicants for scientific work during the expedition.

PERSONNEL AND EQUIPMENT

Available for this task were two physicians and one nurse, all male. One of the physicians was a specialist of ear-, nose- and throat diseases (ENT), the other a general practitioner. The nurse had specialized in anaesthesiology. The ENT doctor was provided by the Norwegian Underwater Technology Centre (NUTEC), while the generalist and the nurse came from the Royal Norwegian Army, Medical Corps (RNoA, MC).

Most of the medicines and the medical equipment was provided by the RNoA, MC. Specified lists are available, upon request, from Major Fredrik S. Bendiksen, above address.

A specialized tent-unit for medical treatment, also provided by the RNoA, MC, was erected in the main camp. The out-camps could be reached by the medical team in less than an hour by helicopter, weather permitting.

FIELD WORK

The health condition was generally very good throughout the five weeks ashore. No serious disease occurred and the minor ailments and complaints were few. There were no serious accidents and only a few injuries altogether. A list of treated conditions is shown below. The numbers in parentheses are the number of cases.

Muscle/skeleton:
Fissura antebrachii (1)
Fractura costae (2)
Partial muscle rupture (1)
Patellofemoral pain syndrome (1)
Traction periostitits (1)

Respiratory system:
Bronchial hyperreactivity (1)

Gastrointestinal tract:
Dyspepsia (1)
Hemorrhoids (1)

Dermatology:
Sunburn/eczema solare (3)
Exanthema (2)
Finger fissures (3)
Herpes labialis (2)
Congelatio faciei (2)
Tinea inguinalis (1)
Abscessus inguinalis (1)

Psychiatry:
Neurosis (1)

Ophtalmology:
Conjunctivitis e solare (2)
Corpus alienum (2)

Sundries:
Vulneara incisivus manuum (3)

BIOMEDICAL RESEARCH

The following projects were planned and performed in collaboration between NUTEC, the University of Bergen, the RNoA, MC and the RN Defence Forces Research Institute.

IMMUNOLOGICAL INVESTIGATIONS

BACKGROUND

Much is still unknown regarding our immune defence against infections, in spite of major recent progress in immunological research, especially regarding AIDS. In an urban society our immune system is under constant influence of a multitude of factors that are difficult to control experimentally. However, in small isolated groups there are fewer uncontrollable variables. Accordingly, observed changes can be interpreted more easily.

In a recent review article on infectious disease in Antarctica, it was maintained that the actual immunological changes occurring in a small isolated group in a sterile environment are unknown (Cosman and Brandt-Rauf 1987). A group of data has been gathered, though no coherent picture has emerged as yet. It was concluded that a comprehensive investigation of the responses of the human immune system to relative bioisolation is required. Antarctica was said to be an unequalled natural laboratory for the study of infectious disease.

OBJECTIVES

Our objective was to make use of the rare opportunity of partaking in a research expedition to "the unequalled natural laboratory" of Antarctica for the collection of data on the human immune response to relative bioisolation in a sterile environment.

TECHNIQUES AND FIELD WORK

Serum was collected from 29 of 35 persons belonging to the land party on four different occasions: One month before departure from Norway, on embarkation of the expedition ship in South America, after one month of isolation onshore in Antarctica, and a couple of weeks later, i.e. ten days after embarkation of the expedition ship in the Weddell Sea. At the time of the fourth sampling, some of the subjects had been in contact with persons from a German station in the area.

The crew of the expedition ship and the ship party of scientists counted 54 persons. After some time of isolation in the Weddell Sea two representatives of the Norwegian government embarked from a foreign research vessel in the area. Before the land party embarked, the people onboard the ship had visited a British land station.

A fifth blood sample will be collected one month after arrival in Norway. A record is kept for each person regarding previous and present health status, especially concerning infectious diseases, vaccinations and injections of gamma globuline.

The serum will be kept frozen until the last sample has been collected. It will then be analysed at the Department of Microbiology and Immunology, University of Bergen, and examined for the total concentration of immune globuline classes and subclasses, as well as for complement factors. It will also be examined for content of antibodies against infectious agents, both bacterial and viral.

PRELIMINARY RESULTS

No analysis will be done until the fifth and final sampling is finished, so no results are available yet. We intend to submit the results for publication in English in an indexed medical journal. A report or reprint may be achieved upon request in due time to Dr. Molvær, address above.

DISCUSSION

Immunological studies are being performed also by other parties in Antarctica. We had the opportunity of meeting the party ready for a one year stay in a different station in Dronning Maud Land. One of their projects was to study possible changes in the cellular part of the immune system (activity of T-lymfocytes), while we concentrated on the humoral part of the system. The usefulness of combining such data is obvious.

CONCLUDING REMARKS

The present and other ongoing research projects on immunology in isolated groups in a relatively sterile environment may yield interesting results, valuable in general immunology as well as in aerospace and diving medicine, especially regarding prolonged space travel and deep saturation diving.

DEFENCE AND COPING OF STRESS DURING SHORT TERM ISOLATION IN ANTARCTICA

BACKGROUND

Defence mechanisms and strategies for coping of stress is of general interest in psychology. Compared to urban life ,the sociology of small isolated groups is simple. Accordingly, the interpretation of observed changes in behaviour or strategy should be easier.

During the previous NARE in 1984/85, a pilot project on defence and coping was performed. The preliminary results obtained indicated that more extensive data should be collected. We therefore appreciated the opportunity to continue the collection of data during NARE 89/90. Similar data are being collected by other nations, and the results will be made available to SCAR (Scientific Committee on Antarctic Research) prior to publication in the international professional literature.

OBJECTIVES

Through this project we will try to contribute to the knowledge of which character traits are decisive for successful defence and coping in small isolated groups with well defined tasks. This has a bearing on both efficacy and safety of the group, as well as on the performance of each individual.

TECHNIQUE AND FIELD WORK

Of the 35 persons isolated for 5 weeks onshore in Dronning Maud Land, Antarctica, 20 volunteered to parttake in this investigation. They were presented with a standardized set of questionnaires for the mapping of coping and defence mechanisms related to psychological stress and leadership style. They also filled in symptom questionnaires. In addition they went through a medical examination, including blood samples for the evaluation of the immunological system, sugar metabolism and hormone levels after standardized methods.

Questionnaires were filled in and blood samples drawn prior to the stay onshore, after one month of isolation and 10 days after embarkation of the expedition ship en route to South America.

PRELIMINARY RESULTS

The collected data will be processed in collaboration with the Institute of Physiological Psychology and the Department of Microbiology and Immunology, University of Bergen. No results are available yet. Our impression, though, is that all of the highly motivated test subjects coped well.

DISCUSSION

The test subjects were recruited from the scientists of the expedition. All 35 on the land party were invited, but only 20 (58%) participated. How representative these volunteers are for the whole group is not known.

The test subjects were isolated in different locations in relatively small groups. In addition, the isolation became more efficient than planned, for several reasons:

Certain operations required more fuel than anticipated, resulting in certain restrictions in the use of helicopters for other purposes. White-out and other meteorological conditions sometimes precluded the use of helicopters for planned operations. One of the two heliocopters developed an oil leakage that could not be properly repaired in the field, keeping it grounded during the last week of the expedition. The radio communication between the groups on shore, and between the land party and the expedition ship in the Weddell Sea, was periodically less than optimal, and sometimes failed. The satellite communication system between the land party and the rest of the world did not function at all due to the location (except for two occasions in the very beginning). These unforeseen problems may add to the value of this investigation.

CONCLUDING REMARKS

Our results will be compared with those from similar ongoing research projects conducted by several other nations. Such results may be of interest not only to physiological psychology, but also regarding the selection of personnel for expeditions to remote and isolated areas, and for the selection of crews for extended space travel and for deep saturation diving.

This works is being performed in collaboration with prof. H. Ursin and I. M. Endresen, University of Bergen, R. Værnes and M. Warncke, NUTEC.

COLD ADAPTATION

BACKGROUND

Adaptation to cold stress has been studied extensively on humans and in several animal species. However, data are lacking regarding the effect of relatively short term (weeks) exposure to temperatures common in the area to be visited during the NARE in the Antarctic summer 1989/90.

OBJECTIVES

Norwegian activity in the area will probably increase as a consequense of the permanent research station built during this expedition, especially during the Antarctic summer. Accordingly, we wanted to see if a relatively short exposure to the prevailing conditions could cause adaptation phenomena detectable through relatively simple examinations, and if so, what "strategies" the body resorted to in different individuals.

TECHNIQUE AND FIELD WORK

Ten male subjects were selected randomly from a pool of 15 volunteers on the land party. They were examined onboard the ship on the way to Antarctica and within four days of returning to the ship after a five weeks stay in the field, living in tents.

We had planned to use +5^0 Celsius (C) as ambient test temperature in the ship`s refrigerated store room. Unfortunately, during the experiment on our way to Antarctica a compressor broke down and forced us to resort to the helicopter hangar where the desired temperature prevailed at that time. However, an unpredictable air draught that could not be controlled by us introduced a factor of uncertainty regarding the cooling effect. Accordingly, some caution must be exercised when comparing the data from the hangar with those from the refrigerated room. This introduces some uncertainty in the interpretation of the results.

The test subjects, wearing only swimming trunks or the equivalent, and slippers, were equipped with thermistors as shown in Fig.1 in a thermoneutral room where the pre-test registrations were noted. Generally, a certain unwillingness was present regarding the use of a deep rectal probe. Since no drop was noted in rectal temperature on four occasions, the rest of the measurements were restricted to the skin thermistors. Accellerometer readings from the trapezius and pectoralis muscles were recorded on a Tandberg technical tape recorder to detect the onset, duration and magnitude of shivering.

Expiratory air was collected in Douglas bags on five occasions during each test to allow calculation of the oxygen uptake. The expired air volume was measured using a gas flow metre, and the oxygen concentration of the exhaled air was measured by means of a cervomex oxygen analyser calibrated with pure nitrogen and room air in connection with the gas analyses. The expiratory air was collected for one minute in the thermoneutral room prior to the cold exposure and after 4, 9, 14 and 19 minutes of exposure. The cold exposure lasted for 20 minutes.

Thermistor readings were noted also once a minute throughout the cold exposure.

Blood samples were also drawn from six of the subjects on five occasions during each test: 1/2 hour prior to cold exposure, at the start of the cold exposure, after 10 and 20 minutes of exposure and 1/2 hour after exposure back in the thermoneutral room.

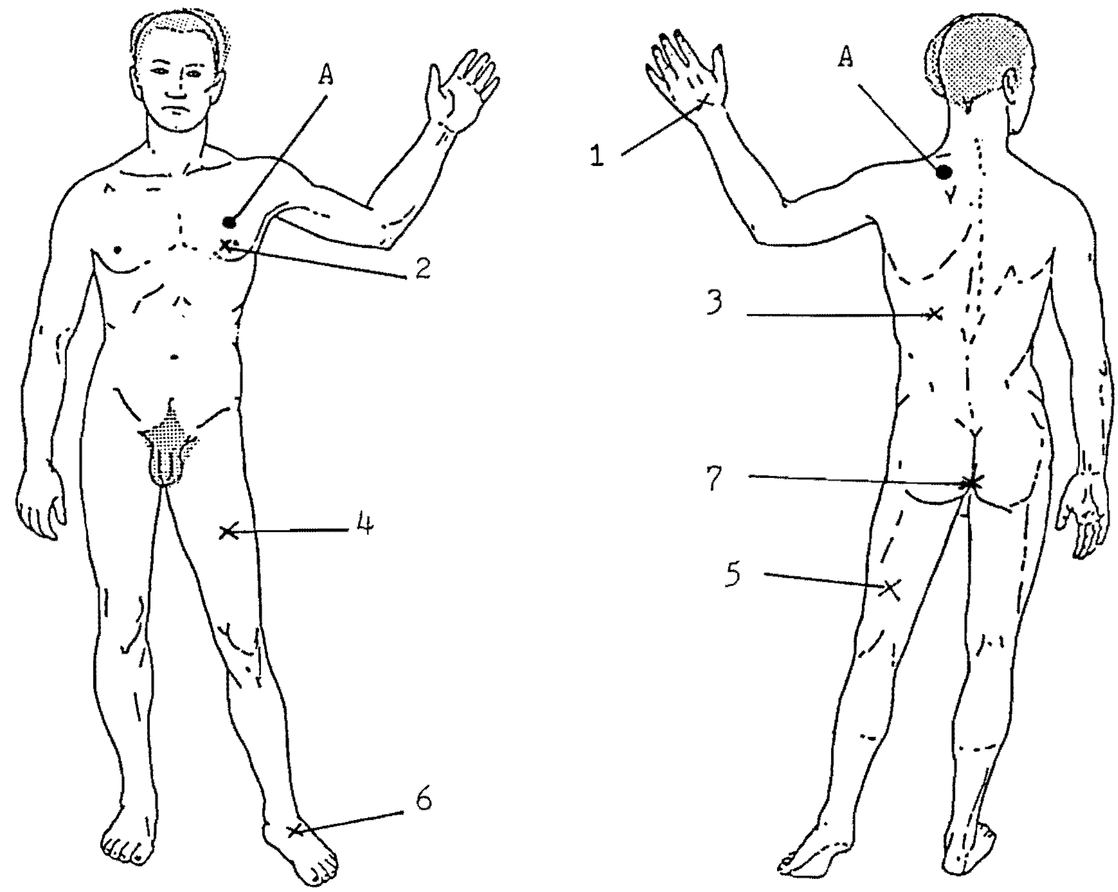

Fig. 1. A: accellerometers. 1-6: skin thermistors. 7: rectal probe.

These serum samples are frozen and will be analyzed for the content of neuro-peptides, free fatty acids, catecholamines and thyroid hormones at the Royal Norwegian Defence Forces' Research Laboratory.

The test subjects' impression of cold during the test, both prior to and after the stay in Antarctica, was also noted. In addition to the test subjects, 19 other persons on the land party were asked for their subjective impression regarding cold adaptation, and their answers are kept on record.

PRELIMINARY RESULTS

No data processing has yet been performed. However, a majority of those asked, 20 of 29 (69%), felt that they tolerated cold better at the end than in the beginning of the five weeks field period. Some had experienced similar changes during previous expeditions to the Arctic or the Antarctic.

DISCUSSION

The number of subjects in this study is small, and we have no control group. Accordingly, no firm conclusions can be expected based solely on this investigation. However, interpreted with caution and compared with data from other investigations, our results will hopefully add to the knowledge in this field.

CONCLUDING REMARKS

The final results from the present investigation will be available upon request through Dr. Molvær, address above, either as a NUTEC Report or as an offprint from an indexed journal.

This work is being performed in collaboration with G. Knudsen and A. Hope, NUTEC, and P. K. Opstad, The Royal Norwegian Defence Forces' Research Laboratory.

COLD FATIGUE AND PERFORMANCE

BACKGROUND

Cold fatigue is a poorly understood phenomenon that may be attributed to mild, prolonged exposure. Relatively little has been done to map the phenomenon, so more data are needed to understand its nature. This is important, since cold fatigue may lead to atypical behaviour, reduced efficacy and unwillingness to work or make decicions. It may also cause irritability, influence on perception and recognition, and affect moral and enthusiasm.

OBJECTIVES

Since we expect Norwegian activity to increase in the area after the permanent station has been erected, we think it is important to find out if the conditions the scientists normally are exposed to in the area will influence on their efficacy and accuracy in data collection and processing.

TECHNIQUE AND FIELD WORK

Twelve volunteers on the land party, 11 male and one female, were equipped with thermistors as illustrated in Fig. 2. However, the rectal probe was accepted by only six (50%) of the subjects. The mounting of thermistors was performed at a reasonably comfortable temperature in a tent heated by a Primus. The pre exposure test on mental performance was conducted in the same tent. The person was then followed for a whole day of field work, and thermistor readings were noted every hour.

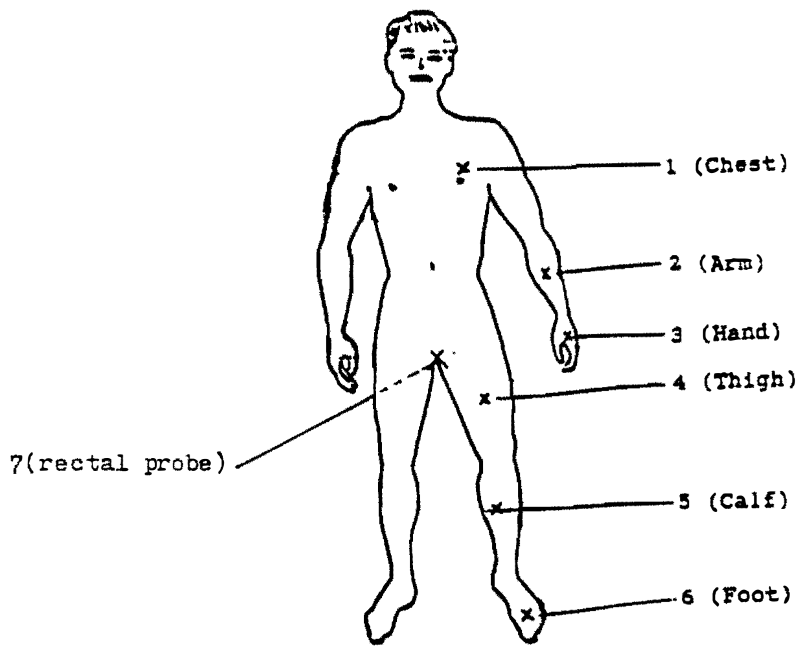

Fig. 2. Location of thermistors.

Ambient temperature, wind data and type of activity, as well as subjective impression of thermal comfort was also noted. We also noted how the subjects were clad and what their own impression of the clothing was.

Immediately on return to camp the mental performance test was repeated, using a different set of forms, though. The test contained elements for different mental skills, such as calculations, reasoning and coordination.

PRELIMINARY RESULTS

The data are not yet processed. Accordingly, no results are available as yet. However, our and the test subjects' impression is that in experienced field workers the conditions encountered did not significantly influence on the quality or quantity of work done.

DISCUSSION

Generally, personnel participating in expeditions like this are creative, energetic and conscientious over-achivers. In none of our subjects were symptoms of cold fatigue obvious. However, this impression may not preclude that such problems could arise in a group less experienced in field work in cold climates.

CONCLUDING REMARKS

The final results from this study will be available upon request through Dr. Molvær, address above, either as a NUTEC Report or as a reprint from an indexed professional journal.

This work is being performed in collaboration with A. Hope and G. Knudsen, NUTEC.

We are indebted to A. Påsche, SINTEF, for valuable advice and for making indispensable equipment for the thermal projects available.

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OBSERVATIONS OF ICE SHELF WATER AT THE SOUTHERN WEDDELL SEA SHELF BREAK

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PARTICIPANTS

Arne Foldvik, Tor Gammelsrød, Nina Nordlund and Kjell Nytun, all from Geophysical Institute, University of Bergen.

BACKGROUND AND OBJECTIVES

The major world ocean basins are filled with cold water at the bottom. These relatively oxygen-rich deep waters are formed in high latitude areas, and the Weddell Sea, Antarctica, is the main source of renewal of such bottom water. Without a steady supply of new water the oxygen would be consumed and most organisms in the deeper layers of the oceans would become extinct.

The most important processes in the formation of the coldest and most heavy bottom water are connected with the Filchner-Ronne Ice Shelf in the southern Weddell Sea (Foldvik & Gammelsrød 1988). This is an enormous floating glacier comparable in area to the North Sea and with typical thickness ranging from 300 m at the seaward edge (the barrier) to more than 1000 m at the southern boundary of the glacial ice-sea interface. In this area we find an interplay between the local climate, freezing of sea ice, melting at the glacial ice-water interface and other natural conditions which are unique for the region and result in the formation of large quantities of extremely cold sea water. During the previous Norwegian Antarctic expeditions, NARE-76/77, NARE-78/79 and NARE-84/85, we discovered that this Ice Shelf Water flowed along the Filchner Depression 500 km northwards towards the shelf break where it overflowed and accelerated down the continental slope like a giant river with transport approximately 10^6 m^3s^{-1} (Foldvik et al. 1985). For comparison, this is roughly ten times the transport of the Amazon River. The Ice Shelf Water flows along the bottom towards the deepest parts of the Weddell Sea continually mixing with the overlying waters. It continues further towards the Atlantic-, Indian- and the Pacific Oceans as

Antarctic Bottom Water. The new bottom water moves under the older water thereby slowly lifting up the water column. After several hundred, perhaps a thousand years, the water at the bottom will be back in the surface layers and may continue the process.

The processes leading to the formation of Ice Shelf Water and subsequently to Antarctic Bottom Water are believed to be very sensitive to climatic variations. For example, with increasing precipitation, the Ice Shelf may move forward and become grounded. This would cut off the production of Ice Shelf Water as we know it today. Similarly, milder winters would provide less freezing of sea-ice and thus less Ice Shelf Water. The related changes in temperature or quantity of bottom water produced could possibly influence the world climate and the global sea-level.

With this background it was decided to focus the physical oceanography programme of NARE 89/90 on a study of the outflowing Ice Shelf Water. In particular it was hoped to gain further understanding of the structure of the flow on the slope and of the mixing processes. We also hoped to improve our knowledge of the chemical parameters of the system.

EQUIPMENT AND TECHNIQUES

Vertical profiles of temperature and salinity were obtained using a Neil Brown CTD sonde and on-line computing facilities. The wire capacity was 4500 m. The CTD was combined with a 12 bottle remotely controlled General Oceanics Rosette for water sampling. Water samples were collected for on-shore laboratory analysis of salinity and of tritium, helium and oxygen isotopes. In order to obtain simultaneous velocity profiles a specially designed Aanderaa Current Meter was attached to the CTD-Rosette rig. This instrument was set to record the temperature, speed and direction of the current every 15 seconds and was operated during the uphaul of the CTD rig.

The University of Bergen long-term monitoring program of the overflowing Ice Shelf Water at the shelf break using moored current meter rigs was continued. One rig was deployed in position S2 (see map, Fig. 1) and equipped with 3 Aanderaa RCM-7 currentmeters at 30 m, 100 m and 200 m above bottom. These instruments record the speed and direction, temperature and conductivity every hour and record the data on tape with sufficient capacity for one year of measurements. The rig was equipped with an Oceano acoustic release. One currentmeter rig deployed by R/V POLARSTERN in 1987 in position S2 with two current meters and one water level recorder was successfully recovered. In addition we deployed and recovered two temporary rigs, one on the shelf break in position S3, and one on the slope in position D.

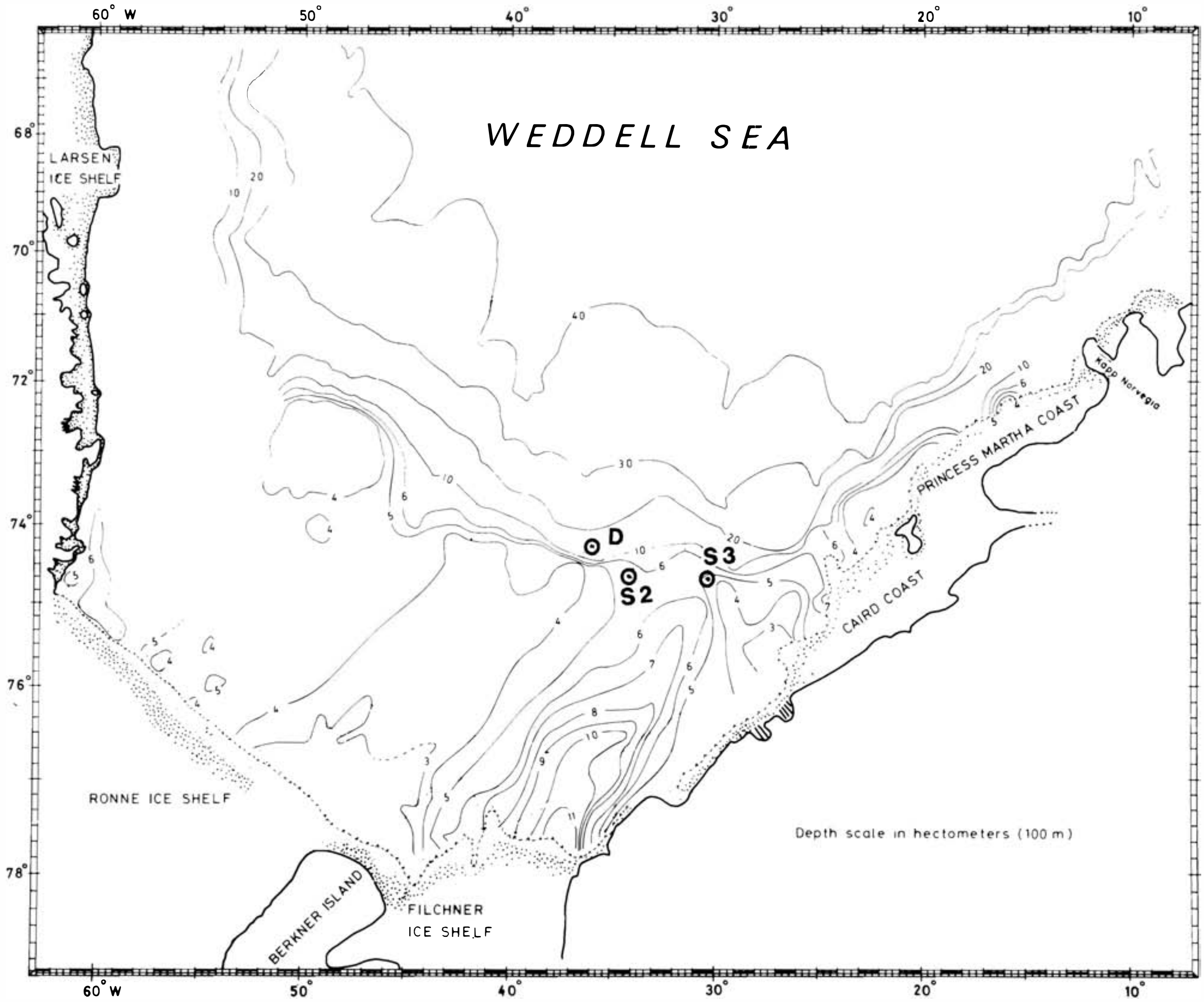

Fig. 1. *The positions of currentmeter stations are shown. The CTD stations are located in the same general area.*

FIELD WORK AND PRELIMINARY RESULTS

This season the ice conditions were difficult with unusually large and thick floes which could not be negotiated. This situation hampered the planned program and led to substantial modifications. For example: of 12 planned temporary current meter rigs we could only deploy two rigs, and those only for a shorter period than planned. Also, it was not possible to reach planned deep CTD stations west of 36°W. However, the most disappointing restriction was that due to damage to the ship by ice, we were not allowed to go south towards the Ronne Barrier, despite this being a region of open water. Thus, we could neither attempt recovery of the currentmeter rig deployed there during NARE 84/85 nor investigate the virtually unknown area west of the Filchner Depression.

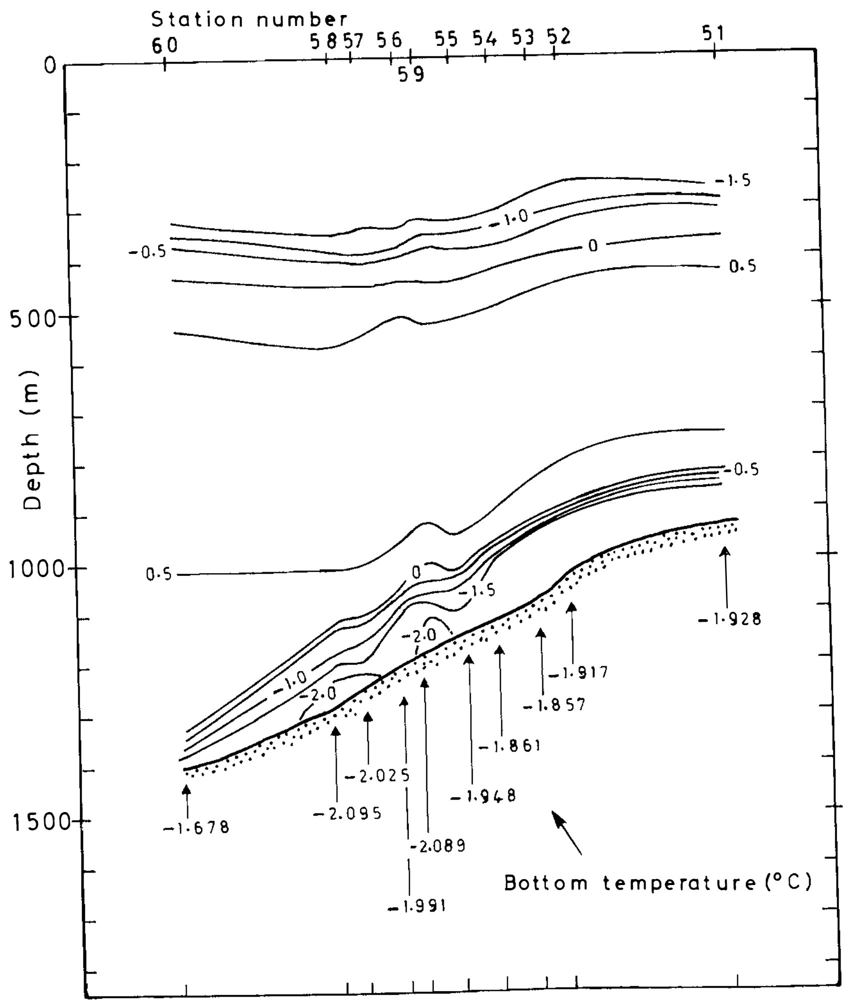

Fig. 2. CTD section at the slope

The CTD work on the shelf break went well and altogether a total of 96 CTD stations were logged. A number of these are actually current profiling stations (jo-jo stations) at a fixed locality near the bottom. About 500 water samples were obtained for chemical analysis.

Fig. 2 shows a section of CTD stations at the slope. At the bottom we find a very cold and shallow plume of Ice Shelf Water with strong gradients towards the overlying warmer water. The minimum temperature in this plume was -2.2°C. Simultaneous current meter measurements indicated maximum velocities of about 50 cm/s. A comparison with current meter records obtained after NARE 84/85 shows that this is a moderately strong plume. CTD station #16 is located on the eastern side of a shallow submarine ridge which turns the current of Ice Shelf Water towards the NNE. Here we recorded -1.65°C at 2200 m depth, possibly the lowest temperature ever recorded at such a large depth.

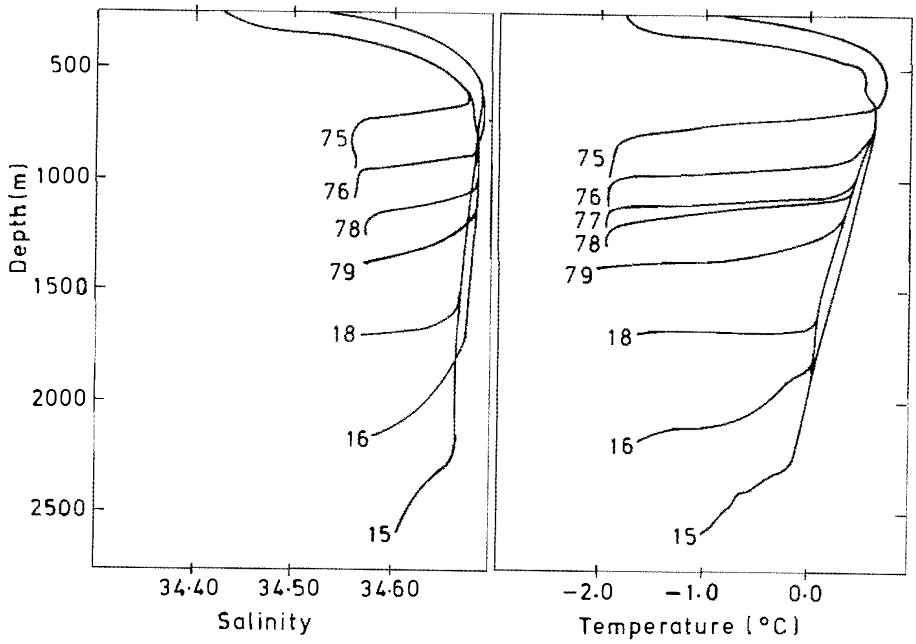

Fig. 3. CTD profiles at the slope

In Fig. 3 we show selected, superimposed CTD profiles at the shelf break. It is noted that the temperature and the salinity stays remarkably constant down to approximately 2000 meter depth. The implication is that very little mixing is taking place in the Ice Shelf Water plume down to these depths. One reason for this reduced mixing is the high compressibility of very cold sea water which makes the density of the plume increase with depth relatively to the surrounding water, and prevents it from attaining geostrophical balance at the slope. The ageostrophic flow allows the plume to utilize potential energy and move at supercritical speeds which eliminates the otherwise strong internal wave mixing at the interface (Foldvik & Gammelsrød 1988).

Two deep CTD sections towards the north and east did not reveal unexpected features. They do not show any sign of cold bottom water whatsoever. This confirms with our model that bottom waters are formed west of 32°W, mainly due to the outflow of Ice Shelf Water.

ACKNOWLEDGEMENT

We wish to acknowledge the professional assistance of officers and crew onboard the ANDENES during the entire cruise. We are especially indebted to Arnstein Andreassen who managed to fix the CTD winch when the motor burned.

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MARINE BIOLOGICAL STUDIES IN THE WEDDELL SEA AND NORTH OF DRONNING MAUD LAND

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BACKGROUND AND OBJECTIVES

Ice Biota

Compared to other oceanic systems, the distinguishing feature of the polar marine system is a thin covering of cold surface water and floating sea ice for at least part of the year. The pack ice, which has a profound influence on the Antarctic ecosystem, covers more than 20 million km^2 in the winter, and recedes to less than 4 million km^2 during spring and summer (Garrison & Siniff 1986).

The sea ice harbours a specialized flora and fauna: the sea ice organisms. It is also generally believed that these sea ice organisms are important links in the transfer of energy from primary production to fish, seabirds and marine mammals in Antartica (Bradford 1978). A food chain is often sketched with at least four trophic levels:

1. Primary production by photosynthetic micro-organisms (mainly ice algae of the group diatoms).

2. Herbivores (mainly foraminiferans, ciliates, amphipods, harpactoid and calanoid copepods and eauphausiids ("krill")).

3. Carnivores I (fish, large amphipods and krill).

4. Large carnivorous predators (seabirds, seals and other marine mammals).

The main object for the marine biology group was to increase the knowledge about the sea ice biota and especially the three first trophic levels.

More specific, the questions we wanted to answer were:

1. Which ice algae and sympagic animals (ice fauna) are most frequent in the sea-ice assemblages north of Dronning Maud Land and in the Weddell Sea?

2. What is the density and biomass of the sympagic fauna?

3. What is the diet of the sympagic fauna?

A central question was also to obtain information about the life strategies of the most conspicuous sympagic organisms, especially if they were autochtoneous (permanent residents in the ice) or allochtoneous (temporal residents) (Melnikov & Kulikov 1989; Gulliksen & Lønne 1989). The large annual variation in ice cover suggests that autochtoneous organisms are lacking in Antarctica (unlike the Arctic), and important questions are therefore why allocthoneous organisms migrate to the ice undersurface where they live when not living in the ice.

Benthos

A rig with current meters deployed by the German research vessel "Polarstern" in February 1987 was planned to be recovered on this expedition. Lead lines to the anchor of such rigs are usually fouled with epifauna. As much oceanographic information was available and the time of submersion was known, it was of interest to study the epifauna on the lead line to the anchor. The locality, 74°39'S, 32°40'W, is a locality with cold bottom water originating from below the Filchner ice shelf.

MATERIALS AND METHODS

Ice Biota

Sampling of ice biota was carried out using conventional Scuba-equipment from the edges of ice floes (Fig. 1). A total of 28 locations were investigated in the Weddell Sea and north of Dronning Maud Land (Table 1).

Ice algae were collected by scraping a plankton net with a mesh size of 25 mm along the underside of the ice-floes and by melting small pieces of coloured ice. Vertical net hauls were also taken in the surrounding water. The samples were preserved in mixture of formaldehyde and acetic acid.

The collection of sympagic organisms was dependent upon the morphology of the ice undersurface. The sampling was done by observation and underwater photography, hand-picking organisms, scraping a plankton net (mesh size 0.35 mm) with a rectangular, 25 cm wide flat top in the opening frame, or by using an especially designed suction sampler to vacuum the undersurface of the ice. Quantitative samples were taken by vacuuming the undersurface of the ice within frames of known size

Fig. 1. Sampling with Scuba-equipment below ice-floes

TABLE 1

Sampling stations, ice biota in Antarctica (NARE 1989/90)

Stn.no.	Sampling Date	Position	
1	10 January	69.26° S	01.38° E
2	12 "	70.10° S	04.40° E
3	12 "	70.10° S	04.40° E
4	13 "	70.10° S	04.40° E
5	16 "	69.42° S	02.38° E
6	17 "	69.38° S	01.50° E
7	18 "	69.39° S	01.37° E
8	19-20 "	69.39° S	01.04° E
9	23 "	69.10° S	00.39° W
10	26 "	74.39° S	30.06° W
11	30 "	72.29° S	33.44° W
12	30 "	72.53° S	34.07° W
13	31 "	73.15° S	34.25° W
14	31 "	74.04° S	35.46° W
15	31 "	74.15° S	35.18° W
16	1 February	74.15° S	35.53° W
17	1 "	74.19° S	35.26° W
18	3 "	74.04° S	35.44° W
19	4 "	74.08° S	34.46° W
20	5 "	74.16° S	34.20° W
21	7 "	74.39° S	32.40° W
22	13 "	75.17° S	25.26° W
23	18 "	69.55° S	04.19° E
24	18 "	69.53° S	04.07° E
25	19 "	69.52° S	03.54° E
26	20 "	69.48° S	04.45° E
27	22 "	70.34° S	07.51° W
28	22 "	70.35° S	07.57° W

(usually 25 x 25 cm). The mesh size used most often in the suction sampler when taking quantitative samples was 0.18 mm, thus sampling the ice meiofauna. Krill and fish were collected with a dip-net mounted on a telescope-pole. Densities of krill were estimated by counting number of individuals within specified areas.

Subsamples of fish, krill and amphipods were collected on locations where these organisms were abundant, for analyses of their diet.

Benthos

The epifauna on parts of the recovered lead line was scraped off with a knife and fixed. In addition, two hauls with a triangular benthic dredge were carried out. The depth was 550 m, and the dredge was hauled along the bottom for 15 minutes in each haul. Most animals in the two hauls were collected. Special attention was put into collecting all species on both the lead line and the dredge-hauls.

PRELIMINARY RESULTS

Ice Biota

More than 70 spp. has been identified from the material of collected ice algae. About 18 spp. were common in most of the samples. Diatoms, dinoflagellates and different types of small flagellates were recorded. Diatoms were most abundant, and the most common species included several species of the genus *Nitzschia (N. cylindrus, N. curta, N. closterium, N. turgiduloides, N. prolongatoides, N. stellata), Chaetoceros neglectum, Chaetoceros dichaeta, Amphiprora sp.,* and *Rhizosolenia alata*. The most abundant autotrophic flagellate in the ice was the Prymnesiophyte, *Phaeocystis pouchetii*.

High concentrations and diversity of algae occurred in the slush-like surface layers near the snow/ice-interface called the infiltration layer. This assemblage consisted of both ice algae and phytoplankton. The most possible mechanism for the formation of this assemblage is infiltration of sea-water with algae when the weight of the snow pushes the upper surface of the ice below the water level (Horner et al. 1988).

There were several types of ice algae-assemblages on the underside of the ice. A net-work of the species *Berkleya rutilans* was recorded at some locations. However, long strands of algae, often dominated by the species *Amphiprora* sp., hanging into the water column from the underside of the ice were more common (Figs. 2, 3), especially early in the cruise.

Smaller amounts of ice algae were recorded in the latter parts of the cruise. Drift of the ice combined with a slightly higher surface temperature may be the main reasons.

Sympagic fauna was recorded on most of the sampling stations, but the material is not analyzed in detail due to lack of laboratory facilities on the ship. Krill, amphipods,

Fig. 2. Strands of ice-algae, mainly Amphiprora sp., from the underside of an ice-floe

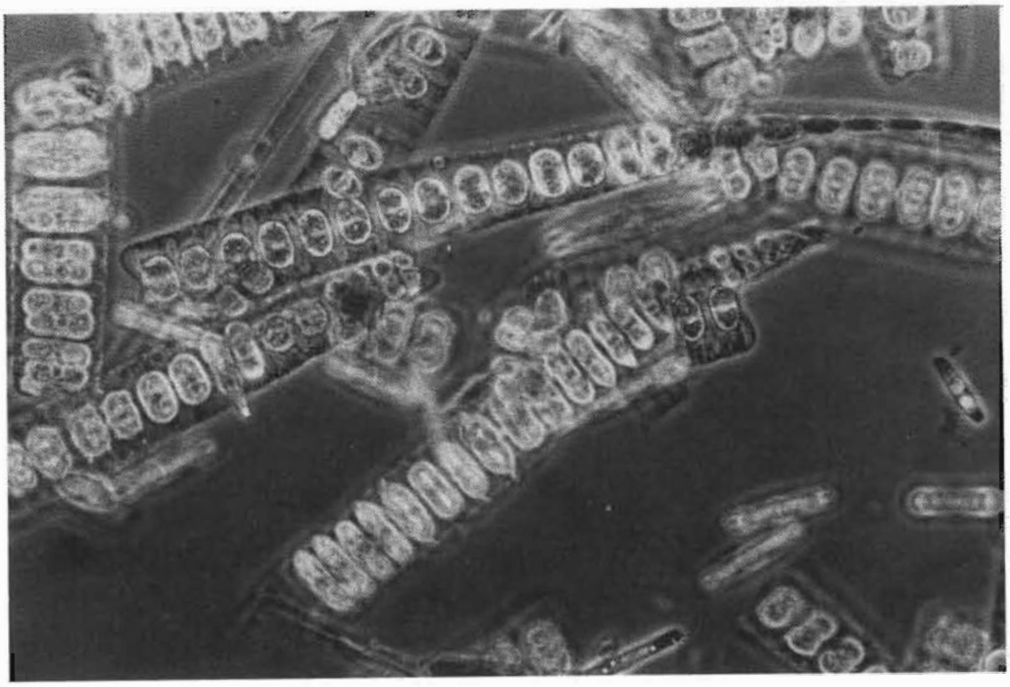

Fig. 3. Amphiprora sp.

Fig. 4. Swarm of krill below an ice-floe

polychaetes and fish were most conspicuous in the sympagic macrofauna. Copepods (harpactoid and cyclopoid), ctenophors and nudibranchs were most conspicuous in the sympagic meiofauna.

Of special interest were the swarms of krill (Fig. 4) occurring under the ice at localities north of Dronning Maud Land. Densities were estimated based upon observation and counting, and the highest mean density at a diving station was approx.70 individuals/m^2. Mean values between 20 and 30 individuals/m^2 were observed at several localities. (Densities had to be estimated based upon observation because these rapid swimming organisms actively avoided the sampling gears used.)

We did not find evidences suggesting that autochtoneous sympagic organisms occur in Antarctica, but this may be due to lack of samples from multiyear ice. Most sympagic organisms recorded are probably allochtoneous with an alternative habitat in the pelagial. Some occurrences may be accidental, but most allochtoneous organisms do probably seek to the underside of the ice, either for food or shelter.

Benthos

The lead line to the anchor of the rig with current meters was heavily fouled with coelenterates, bryozoans and tube-dwelling polychaetes. Motile animals living among these sessile animals were polynoid polychaetes, brittle stars and gephyreans.

The dredge hauls revealed a varied fauna of at least 30 species of macrobenthic organisms living in the area where the current meters were deployed. Conspicuous organisms were sea-urchins, polychaetes, brittle stars, amphipods, poriferans, and crinoids. Species identifications will be carried out later.

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MARINE GEOLOGICAL STUDIES IN THE WEDDELL SEA

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OBJECTIVES AND BACKGROUND

The scientific objectives for the marine programme were based on results from ODP (Ocean Drilling Project) drillings at Leg 119 Prydz Bay and Leg 113 South Atlantic which show that the East Antarctic Ice cover reached the shelf areas approximately 35 million years ago (Eocene/Oligocene time). Despite these new results there are still unresolved questions concerning the stability and variability of the East Antarctic Ice cover. Variations of the West Antarctic Ice sheet are to a large extent unknown, even though mid and late Miocene and Pliocene oxygen isotope enrichments, eustatic sea level lowerings and northward protrusion of the oceanic polar front have been linked with the inception and variation of the Western Antarctic Ice sheet. The main aim of the programme was to see the variations of these ice sheets in a global perspective, and try to link them with climatic changes of global character, especially regarding the Northern Hemisphere. The questions are:

- What factors can bring about glaciations and the causes of the global Cenozoic cooling?
- What factors can destabilize ice sheets?
- How stable is the present situation?
- What factors govern major changes in high southern latitude deep and surface circulation, and major shifts in oceanic fronts?

Based on seismic profiles from NARE 76/77, 78/79 and 84/85 two areas of investigation were chosen: Deutschland Canyon (line 10-77 and 6-85) and Crary Fan (line 8-85) in the Weddell Sea (Table1). Erosion, probably due to strong bottom currents, might have exposed older strata 100-200 metres below the sea floor in the canyon walls. Depending on the degree of coverage of younger (Late Glacial and Recent material) sediments we hoped to get old glacial material extending millions of years back in time.

FIELDWORK

Acoustic equipment:	ORE 3.5 kHz penetration echo sounder
Sampling equipment:	Gravity corer, barrel length 2x3m, diameter 110 cm, weight 800 kg.

Geological sampling was carried out at two locations in the Deutschland Canyon area with five and four stations at each location respectively (Table1, Figs. 2 and 3) yielding 11 cores 20 to 600 cm long. Due to problems with recieving signals from both the echosounder and the pinger unit the sample sites were chosen from locations given by the seismic profiles from NARE 76/77, 78/79 and 84/85. The cores were recovered in slopes with water depths from 3200 to 2700 meters. The third geological station (Crary Fan area) was not reached due to severe ice conditions.

WATER SAMPLING PROGRAM

In addition to the coring programme, a programme was established to sample surface water for oxygen and carbon isotope analysis and nutrient content along a N-S transect from the South Atlantic to the ice margin in the Weddell Sea (Table 2). The purpose of this project was to investigate the oxygen isotopic composition of Southern Ocean surface water to establish the different mixing processes of these waters and to aid in the interpretation of oxygen isotope data from fossil records based on planktonic foraminifers. The carbon isotope analysis will be utilized to study the coupling of carbon isotope composition in surface water with surface water nutrients. This is also aimed at improving our ability to interpret fossil carbon isotope records and to improve the accuracy with which foraminiferal carbon isotopes can be used to predict past nutrient levels and ocean-atmosphere CO_2 exchange. The samples were taken from water buckets with approximately one degree latitude between the sample sites. Oxygen isotope samples were stored at room temperature in air-tight Supelco Serum bottles. Carbon isotope samples were treated with mercury chloride and stored in the same manner as the oxygen isotope samples. Nutrition samples were added 0.2 ml chloroform and stored refrigerated in 0.30 ml screw cap plastic bottles.

PRELIMINARY RESULTS

One core, from the first location, was opened onboard ANDENES. The remaining cores were brought to the University of Bergen for further investigations. The investigations will involve sedimentological studies, chronology, and foraminiferal carbonate studies (if found). Microfossil floras and faunas (diatoms, forams, radiolaria) will be used to infer surface water paleoenvironments. The opened core showed stratified layers, probably turbidite, with some dropstones (ice-rafted material) indicating younger material (Recent). Some of the material at location 1 was very hard, the barrel could penetrate no more than 20 cm of the sediment. This might represent a levee deposits closely connected with the turbidite deposits, indicating strong bottom current activity in the Deutschland Canyon area.

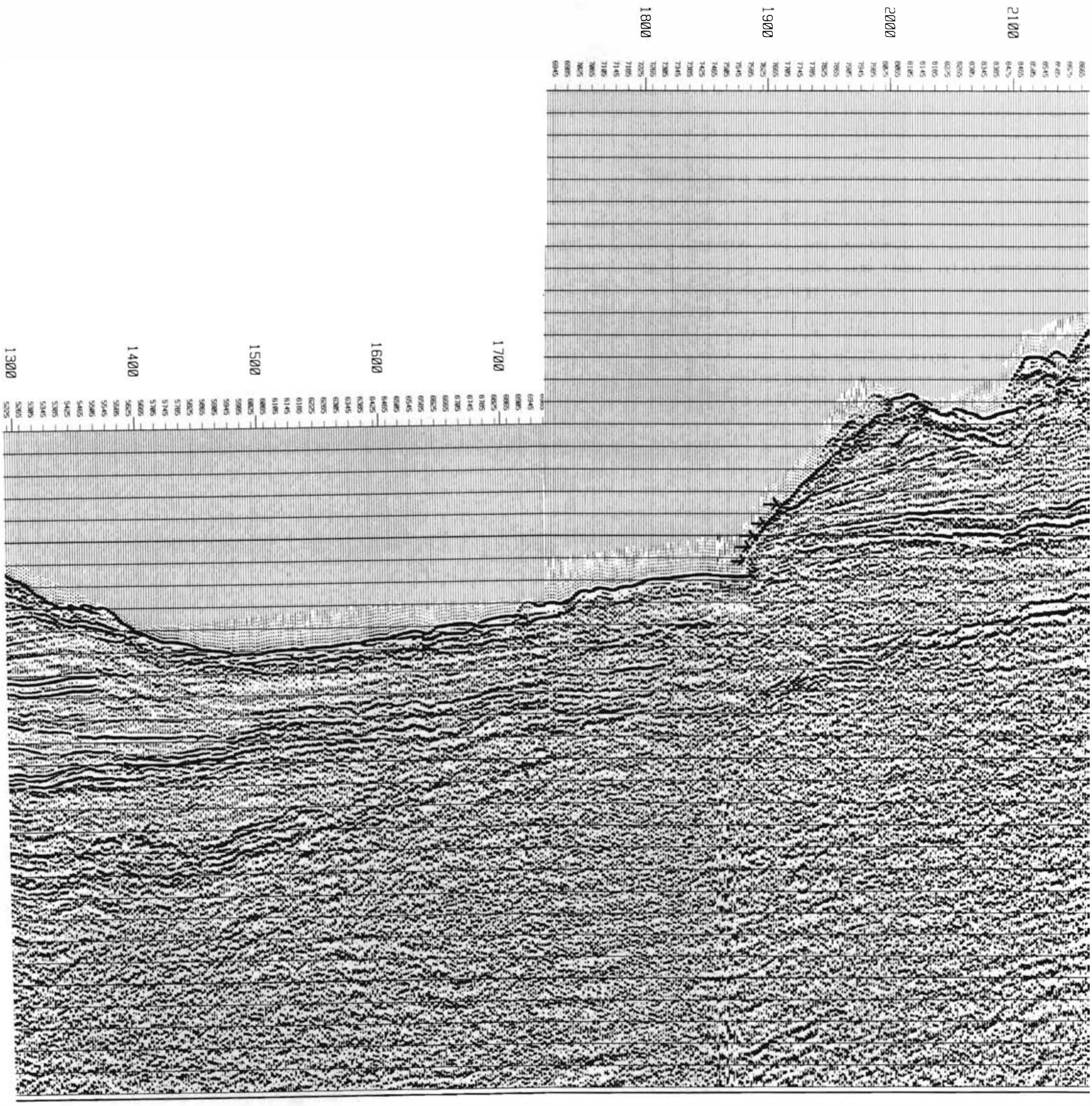

Fig. 1. *A section from seismic line 85-06 (NARE 84/85) in the Deutschland Canyon. Sampling positions shown with arrows.*

Fig. 2. *Preparing the sampling device. A PVC tube is used as lining inside the steel tube for better sediment recovery.*

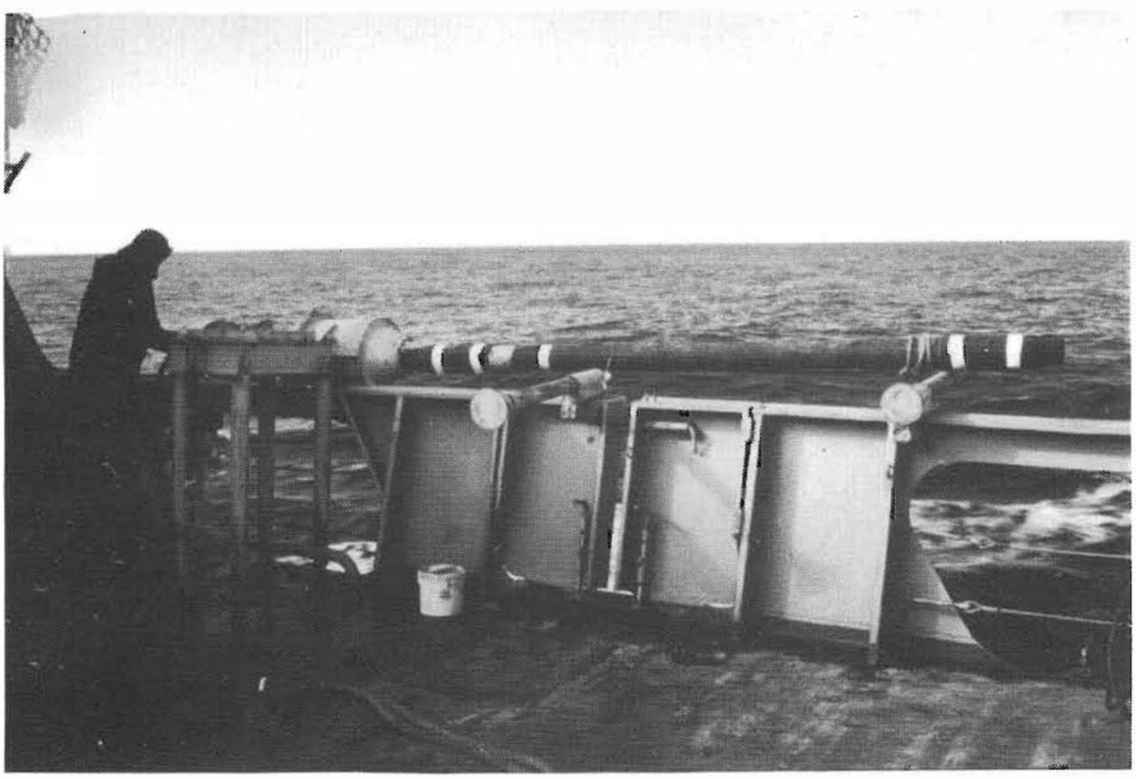

Fig. 3. *Sampling device ready for coring. Barrel length 3 metres.*

Table 1. Geological Sample Stations

Line 6-85

73°49.57'S	25°36.42'W
73°50.47'S	25°38.16'W
73°50.89'S	25°33.84'W
73°51.43'S	25°33.84'W
73°52.19'S	25°31.06'W

Line 10-77

73°28.60'S	23°48.97'W
73°28.44'S	23°48.30'W
73°28.18'S	23°47.63'W
73°27.99'S	23°47.07'W
73°28.00'S	23°47.10'W
73°27.80'S	23°46.60'W

Table 2. Water Samples

51°59.80'S	54°10.16'W
52°47.20'S	46°10.90'W
53°46.56'S	38°22.90'W
54°55.90'S	34°19.90'W
55°46.60'S	31°38.10'W
56°46.20'S	28°51.10'W
57°50.00'S	25°53.90'W
59°51.90'S	18°55.50'W
60°58.40'S	15°37.00'W
61°55.40'S	13°49.50'W
62°55.10'S	11°42.00'W
63°58.20'S	09°44.50'W
64°59.60'S	07°46.20'W
66°42.20'S	04°10.50'W
67°52.60'S	01°40.80'W
69°07.70'S	01°02.80'W
50°01.07'S	37°38.06'W
49°00.97'S	37°53.26'W
47°53.70'S	38°11.80'W
47°05.10'S	38°18.30'W
46°00.80'S	38°38.80'W
45°01.40'S	38°46.40'W
44°00.40'S	39°03.90'W
42°59.70'S	39°15.90'W
42°00.20'S	39°27.50'W
41°01.90'S	39°41.30'W
38°00.00'S	39°46.80'W
35°57.60'S	40°05.00'W
33°51.10'S	40°40.40'W

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