JAN-GUNNAR WINTHER (EDITOR):

REPORT OF THE NORWEGIAN ANTARCTIC RESEARCH EXPEDITION 1996/97

NORSK POLARINSTITUTT

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EDITOR: JAN-GUNNAR WINTHER

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PREFACE

This report describes research carried out on the Norwegian Antarctic Research Expedition (NARE) in 1996/97. Contributions from altogether 57 authors including background, objectives, field work and preliminary results from 15 scientific projects are presented. The work was carried out in the period December 1996 to February 1997.

The first part of the report includes a general introduction describing the logistics, expedition participants, their affiliation together with some highlights from the expedition. Next, aspects concerning the regulations relating to protection of the environment in Antarctica are briefly described. A summary of the initial environmental evaluations (IEE) for the research activities outlined in this report is also presented.

The next section covers industrial archaeology research at South Georgia, studies of seabirds and seals at Bouvetøya, as well as the marine programmes carried out from the research vessel *R/V Polar Queen* including studies of seals, penguins, productivity, physical oceanography and timing of glacial events. This work was mainly conducted in the eastern part of the Weddell Sea and had to some extend to be re-located eastwards due to very difficult sea ice conditions in the Weddell Sea during the 1996/97 austral summer.

The last section presents the terrestic projects including geodesy, geology, population dynamics of seabirds and glaciology. These research projects were partly accomplished by separate field groups and partly by using the TROLL Station as a base.

Tromsø, 15 November 1997

Jan-Gunnar Winther
Editor

Jan Erling Haugland[1]:

GENERAL REPORT OF THE NORWEGIAN ANTARCTIC RESEARCH EXPEDITION (NARE) 1996/97

The Norwegian Antarctic Research Expedition (NARE) 1996/97, was the largest Norwegian Antarctic expedition ever, with regard to the total number of researchers participating. The expedition leadership was as follows:

Expedition leader:	Mr. Jan Erling Haugland, Norwegian Polar Institute
Scientific leader:	Dr. Jan-Gunnar Winther, Norwegian Polar Institute
Cruise leader:	Prof. Arnoldus Schytte Blix, University of Tromsø

The expedition had 101 participants, in addition to the ship's crew of 28:

28	Ship's crew
86	Scientists including medical staff
4	Helicopter crew
2	Media personnel
5	Logistics/ technicians
4	Inspection team including one environmental officer

NARE used the 85 m long Rieber Company owned vessel *R/V Polar Queen.* This ice-strengthened vessel was commissioned in 1995 at Kværner Kleven shipyard, Norway.

The vessel left Norway on 9 November 1996, departed Cape Town with personnel on 4 December 1996, and called on Cape Town again after a journey to Antarctica. She left Cape Town for a second journey on 4 January 1997, arrived in Cape Town again on 28 February 1997, and reached Norway on 26 March 1997. The expedition members and some of the crew joined and left the ship in Cape Town (Fig. 1).

Planning of the expedition started more than a year before departure. Scientific programmes were selected by the National Committee for Polar Research, the Norwegian Research Council. 15 projects were selected from a total project proposal number of 25. At the same time the expedition logistics were planned by the Norwegian Polar Institute. Helicopter and shipping companies were selected through bidding processes and contracts were prepared and signed.

Various modifications were done to the expedition ship, the *R/V Polar Queen,* to make her suitable for the selected scientific programmes. One external drilling tower was welded to the port side and extra winches mounted.

The expedition carried two Ecqureille AS 350 B1/B2 helicopters, with a lifting capacity of approximately 1.1 ton. They were flown 425 hours all together, operating from the vessel as well

1. Norwegian Polar Institute, P.O. Box 505, N-9170 Longyearbyen, Norway

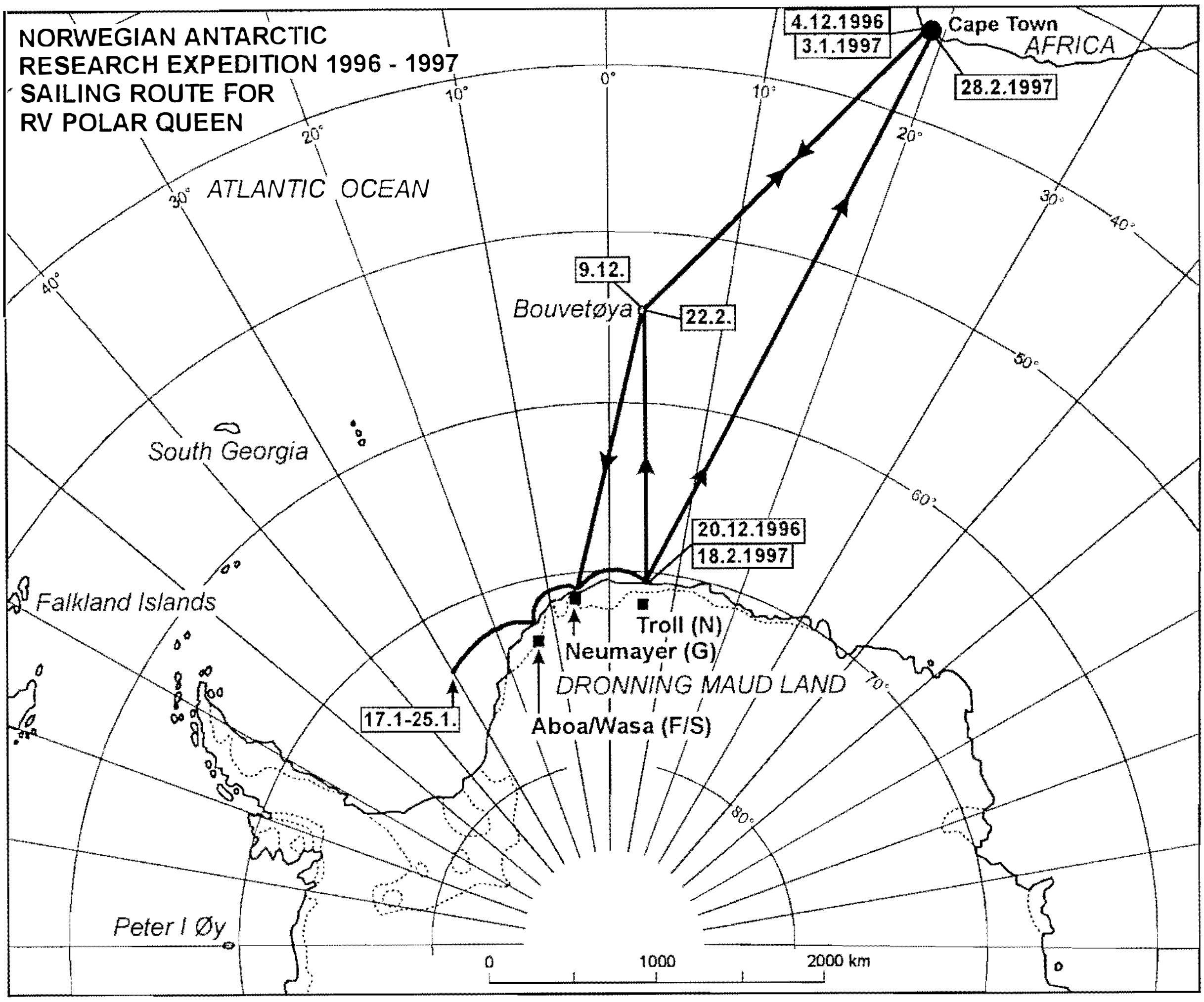

Fig. 1. Sailing route for *R/V Polar Queen*.

as from the inland stations. The helicopters were used for transportation of all equipment and personnel from the ship to the ice shelf or the inland areas, and for science support. Eleven snow machines with sledges were also used for science support. They traveled around 2000 km each.

Three Hägglund BV206 bandwagons were used to transport about 200 tons of cargo to the TROLL Station. The drive from the ice front, where the cargo was unloaded, covered 300 km and involved crossing of the zone between the ice shelf and the inland ice. The drive was done throughout the expedition period without mishaps. In addition, two bandwagons were used during the EPICA-traverse.

Transportation support was given to the Alfred Wegener Institute and the National Science Foundation and support to the science groups during their establishment in the field. A blue ice-field runway was prepared, 50m wide and 1000m long, in the vicinity of TROLL.

In the following some headlines from the scientific projects in NARE 96/97 are presented:

Within the European Project for Ice Coring in Antarctica (*EPICA)* ten European countries plan to obtain two deep ice cores from the Antarctic ice sheet within the next decade. The core drilled at Dome Concordia starting in 1997/98 will provide scientists with one of the longest undisturbed climate archives, extending more than 500 ka. The second core should be characterized by higher accumulation rates with a dominant contribution from the South Atlantic Ocean, to make the link with climate data obtained from the Greenland ice sheet and give us more detailed information about the last glacial cycle. Although it is clear that this core will be drilled somewhere in Dronning Maud Land, which is one of the least explored regions of Antarctica, its exact position is yet to be determined. To this end, a reconnaissance phase has been planned to produce data on accumulation rate, ice depth and dynamics, bedrock and surface topography, snow/ice chemistry and meteorology. This phase will consist of several pre site surveys involving several countries. The Norwegian/Swedish/Dutch ground traverse during NARE 1996/97 was a part of the pre site survey work done within the EPICA programme. The EPICA group on NARE successfully completed their scientific work along a 1100 km traverse route in 22 days, reaching 75° South 15° East at an elevation of 3450 m, a location where the yearly average temperature is about -54°C.

The geodetic programme had four participants, reduced to three during the EPICA traverse as one geodesist participated there. The geodetic work was concentrated on GPS measurements extending the regional control network towards the West and East using up to nine Ashetch Z-XII GPS receivers. One GPS receiver was operated continuously at the TROLL Station in the period 4 January to 16 February. Several smaller tasks were carried out as well, such as tidal and gravity measurements, photogrammetric and satellite image reference points, glacier profiling and stake measurements. Nearly all the planned activity could be performed successfully as efficient helicopter transport was available.

The *R/V Polar Queen* left Cape Town on her second cruise 3 January 1997, stopped at Bouvetøya for oceanographic work, and continued to Dronning Maud Land, Antarctica which was reached on the 12 January. The ship then headed for the Filchner-Ronne ice shelf but was stopped and subsequently stuck in very heavy pack ice northwest of the British Halley Station (74°S, 26°W) from 17 to 25 January. During this period numerous seal sensus surveys were carried out by helicopter, and marine biological and oceanographic work performed. On 26 January the ice temporarily loosened its pressure on the ship, which succeeded in making its way into open water off the Swedish Base Wasa (72°S, 16°W) where deep sea drilling was performed for seven days and sea floor cores for paleoclimatic analyses were obtained. At the same time, seal, penguin and other marine biological studies were done. Subsequently, a comprehensive oceanographic programme aimed at the understanding of the Antarctic coastal currents, was carried out in the eastern Weddell Sea, where biological studies continued until 15 February. At this time, 14 seals, of which two Ross seals, had been instrumented with satellite transmitters, 15 Adelie penguins had been investigated and numerous studies, including under-ice diving for marine algea, had been done. After even more oceanographic work, Swedish and Norwegian land parties were embarked from 14 to 18 February, whereafter the *R/V Polar Queen*, now with 61 scientists onboard, returned to Cape Town on 28 February, only interrupted by a six-hour stop to retrieve three South-African and two Norwegian scientists engaged in cooperative monitoring research on fur seals, chinstrap and macaroni penguins at Bouvetøya. Bouvetøya has recently been established as an environmental monitoring site (CEMP) within the framework of SCAR (Scientific Committee on Antarctic Research). One small station, made of steel, was erected at Nyrøysa, Bouvetøya, and for the first time Inmarsat communication was used as the main connection between the expedition head quarter and the science group.

PARTICIPANTS

In addition to these directly involved in NARE 96/97, the expedition vessel carried a group of eight German scientists on the first leg to Antarctica and three groups consisting of nine persons from Sweden, six from Germany and four from United States on the second leg southwards. The Swedish group was transported back to Cape Town on the last return while the others were taken out by their national programmes.

The participants on NARE 1996/97 are listed in the following:

Name	Institution	Location	Function
1. Scientists			
Bjørn L. Basberg	Sør-Trøndelag College	South Georgia	Industr. Arch. (team leader)
Gustav Rossnes	Riksantikvaren	"	" "
Dag Nævestad	NMM	"	" "
Gisle Løkken	70°N arkitektur a.s.	"	" "
Kjell Isaksen	NP	Bouvetøya	Biology (team leader)
Bruce Dyer	Sea Fish. Research Inst.	"	"
Onno Huyser	UiCT	"	"
Gordon Hofmeyr	UiP	"	"
Alf Næstvold	-	"	"
Arnoldus S. Blix	UiTø	*Polar Queen*	Biology (cruise leader)
Erling S. Nordøy	UiTø	"	"
Monica A. Olsen	UiTø	"	" (team leader)
Else N. Hegseth	UiTø	"	" (team leader)
Cecilie von Quillfeldt	UiTø	"	"
Bjørnar Seim	UiTø	"	"
Ole A. Nøst	NP	"	Oceanography (team leader)
Torleif Lothe	CMR	"	"
Ekkehard Schütt	AWI	"	"
Berit Kuvaas	UiB	"	Geology (team leader)
Nalân Koç	UiB	"	""
Yngve Kristoffersen	UiB	"	"
Allan Persson	Geodrilling a.s.	"	"
Erik Hansen	Geodrilling a.s.	"	"
Heinrich Eggenfellner	SPOT	"	Glaciology (team leader)
Erik Vike	SPOT	"	"
Kåre Pedersen	Telenor	"	"
Jan-Gunnar Winther	NP	TROLL/EPICA	Glaciology(scientific leader)
Trond Eiken	NP	"	"
Michiel van den Broeke	NP	"	"
Raymond Schorno	NWO	"	"
Louk Conrads	IMAU	"	"
Cecilia Richardson	UiS		"
Lars Karlöf	UiS	"	"
Nils Røv	NINA•NIKU	Svarthamaren	Biology (team leader)
Torkild Tveraa	NINA•NIKU	"	"
Ronny Aanes	NINA•NIKU	"	"
Henrik Jensen	-	"	"
Michael Brooke	Dept. Zool. Cambr.	"	"
Dave Keith	-	"	"
Kjetil Melvold	UiO	Jutulstraumen	Glaciology (team leader)
Cecilie Rolstad	NP	"	"
Tron Laumann	-	"	"

(continued)

Name	Institution	Location	Function
Bjørn Barstad	NP	TROLL	Geodesy (team leader)
Randi Finnes	NP	"	"
Ola Øvstedal	-	"	"
Haakon Austrheim	UiO	6° - 8° E	Geology (team leader)
Ane K. Engvik	UiO	"	"
Oscar Paulsson	UiL	"	"
Synnøve Elvevold	-	"	"
Jens-Ove Näslund	UiS	TROLL/Jutulstr.	Glaciology (team leader)
Glen E. Liston	CSU	Jutulgryta	Glaciology (team leader)
Hallgeir Elvehøy	NVE	"	"
Oddbjørn Bruland	SINTEF	"	"

2. Other personnel

Jan Erling Haugland	NP	TROLL	Expedition leader
Jon Bech	UD	*Polar Queen*	Inspection team (leader)
Morten Ruud	JD	"	"
Olav Orheim	NP	"	"
Birgit Njåstad	NP	"	"
Jarl Pedersen	NP	TROLL	Communication
Georg Johnsrud	NP	TROLL/EPICA	Logistics
Stig Onarheim	NP	"	"
Robert Hurlen	NP	"	
Michael Djupsjø	Airlift A/S	TROLL/*Polar Queen*	Helicopter crew (leader)
Ole M. Bjørnhaug	Airlift A/S	"	"
Odd A. Hansen	Airlift A/S	"	"
Håkan Festin	Airlift A/S	"	"
Halvor Bævre	RiTø	TROLL	Expedition doctor
Ole Kristen Harborg	NRK	*Polar Queen*	Film team
Marit Grut	NRK	"	"

INSTITUTIONS

NP	Norwegian Polar Institute
UiO	University of Oslo
UiTø	University of Tromsø
UiB	University of Bergen
UiS	University of Stockholm
UiL	University of Lund
IMAU	Institute for Marine and Atmospheric Research Utrecht
UiP	University of Pretoria
UiCT	University of Cape Town
CSU	Colorado State University
NINA•NIKU	Foundation for Nature Research and Cultural Heritage Research
SINTEF	The Foundation for Scientific and Industrial Research at the Norwegian University of Science and Technology
NVE	Norwegian Water Resources and Energy Administration
NRK	Norwegian Broadcasting
CMR	Christian Michelsen Research
SPOT	Svalbard Polar Travel
NMM	Norwegian Maritime Museum

AWI	Alfred-Wegener-Institute for Polar and Marine Research
NWO	Netherlands Organization for Scientific Research
UD	Norwegian Royal Ministry of Foreign Affairs
JD	Norwegian Ministry of Justice and Police
RiTø	Regionsykehuset i Trondheim

ITINERARY FOR "R/V POLAR QUEEN"

Dep.	Bergen	9 Nov. 1996
Dep.	Cape Town	4 Dec.
Arr.	Bouvetøya	9 Dec.
Arr.	Neumayer Station	14 Dec.
Arr.	70°07'S, 5°20'E, land parties onshore	21 Dec.
Dep.	70°07'S, 5°20'E	23 Dec.
Arr.	Cape Town	30 Dec.
Dep.	Cape Town	3 Jan. 1997
Arr.	Dronning Maud Land	12 Jan.
Marine programmes, Weddell Sea		12 Jan. - 15 Febr.
Arr.	70°07'S, 5°20'E, retrieval land parties	17 Febr.
Dep.	70°07'S, 5°20'E	18 Febr.
Arr./Dep.	Bouvetøya	22 Febr.
Arr.	Cape Town	28 Febr.
Dep.	Cape Town	3 March
Arr.	Bergen	27 March 1997

BIRGIT NJÅSTAD[1]:

ENVIRONMENTAL ASPECTS - NARE 96/97

REGULATIONS RELATING TO PROTECTION OF THE ENVIRONMENT IN ANTARCTICA

In 1995 the Norwegian *Regulations Relating to Protection of the Environment in Antarctica* (Antarctic Regulations) were approved as the Norwegian legal framework for implementing the Environmental Protocol to the Antarctic Treaty (1991). The Antarctic Regulations, which apply to the region south of 60° S, have entailed that new aspects have had to be considered during the planning stage and during the operation of the Norwegian Antarctic Research Expedition 96/97.

The Regulations contain specific provisions regarding the following issues:

- Notice of Activity and Environmental Impact Assessment (Chapter 3)
- Conservation of Flora and Fauna (Chapter 4)
- Management of Pollutants and Waste (Chapters 5 and 6)
- Specially Protected and Specially Managed Areas (Chapter 7)

Notice of Activity and Environmental Impact Assessment

Advanced notice of activities shall be submitted to appropriate authorities one year in advance of the intended start of the activity. The notice shall also include an initial environmental evaluation (IEE). The authorities can order that an activity is to be changed, postponed or completely prohibited if its implementation will or may result in undesirable impacts on the Antarctic environment.

Notice and IEE for logistics

An initial environmental evaluation was prepared for the logistic aspects of the expedition. A thorough description and assessment regarding vessel operation, station operation, transportation, cumulative impacts and alternatives was prepared by the Norwegian Polar Institute. The EIA was evaluated by the Norwegian Ministry of Environment. The expedition was evaluated to have no more than a minor or transitory impact on the Antarctic environment. [Copies of the IEE are available from the Norwegian Polar Institute, 9005 Tromsø, Norway.]

Notice and IEE for research projects

All thirteen Norwegian research projects that took part in NARE 96/97, and which took place south of 60° S, submitted advance notice and IEE as required.[2] None of the projects were considered to have more than a minor or transitory impact.

---

1. Norwegian Polar Institute, 9005 Tromsø, Norway
2. Thus, the South Georgia project and the Bouvetøya project were not considered in accordance with the Antarctic Regulations, as the project areas are located north of 60°S. One project led by Swedish participant was considered in accordance with the Swedish Antarctica Act.

Conservation of Flora and Fauna

Permit is required for taking or catching flora and/or fauna in Antarctica. Five such applications were submitted for the NARE 96/97 projects. None of the activities for which permit was sought were considered to have a harmful effect on the species population or the Antarctic environment in general, and permits were received for all projects. Information about the permits is summarized in Table 1 below.

Table 1. Collection/taking of flora and fauna - Summary of permits received and summary of actual number/amount collected/taken during NARE 96/97

No.	Species	Number/amount applied for	Number/amount taken	Purpose
1.	Phytoplankton	1 l sea water **x** unknown number of localities	120 x 100 ml 550 x 200 ml 18 x 3,5 liter	Measurement of biomass and primary production
	Ice algae	200 ml sea water **x** unknown number of localities	160 x 100 ml 80 x 10 ml	Measurement of biomass and primary production
2.	Antarctic Petrel		1970	Banding
		40	36	Equip. with satellite senders
		50	50	Dietary studies (killed)
	South Polar Skua	None	26	Banding
3.	Crabeater seal	2	2	Pollution/dietary (killed)
	Leopard seal	2	2	Pollution/dietary (killed)
	Ross seal		1	Dead during anaesthetic after two hours of resurrection attempt
	Crabeater seal Leopard seal Ross seal	15 total	10 1 2	Equip. with satellite sender
	Weddell seal	1	1	Dietary studies (killed)
		1	1	Equip with satellite sender
4.	Adelie penguin	15	15	Intestinal studies (killed)
5.	Antarctic Petrel	15 (or 10 + 5 eggs)	10	Genetical analysis
		55 eggs	None	Genetical analysis

Introduction of plant and animal species and micro-organisms can only be done pursuant to permission. Application for such permission was not sought, and to our knowledge no plant, animal or micro-organisms were introduced during the NARE 96/97 expedition.

Management of Pollutants and Waste

The Antarctic Regulations prohibits disposal of waste in the Antarctic, and all waste is to be managed in accordance with a classification system prepared by the Norwegian Polar Institute.

The expeditions waste management was in accordance with the specifications in the Norwegian Polar Institute's waste management strategy ("Waste Management Handbook for NARE 96/97"), and care was taken to find suitable routines for management/disposal, reduction of waste volume, segregation of waste, record keeping and division of responsibility. Only small amounts of waste water and human waste was disposed of in Antarctica during the expedition, this in accordance with specifications made in the environmental impact assessment for the expedition. The waste management strategy is expected to be developed further prior to the next Norwegian Antarctic expedition.

Emission of substances or products which can harm the environment in Antarctica is prohibited. During NARE 96/97 emphasis was put on handling and management of fuel, with special focus on spill prevention, as spilling of fuel is considered the largest potential source of pollution to the Antarctic environment from the NARE operations. Containment systems for fuel depots were introduced, as well as systems for minimizing spills from large fuel transfer operations (e.g. helicopter re-fueling). These systems will be developed even further prior to the next expedition.

SPECIALLY PROTECTED AND SPECIALLY MANAGED AREAS

Permission is required to enter or engage in activity in specially protected areas. Such permits were requested for three projects seeking to enter or engage in activity in Site of Special Scientific Interest No. 23 (Svarthamaren). One of these projects was considered to be in accordance with the protection status of the area (research on the sea bird colonies), while the remaining two were considered to have minimal impact on the protection values of the area. Conditional permits were granted in all cases. Information about the protected areas permits is summarized in Table 2 below.

Table 2. Antarctic Protected Areas - Summary of permits received for activity to take place in protected areas during NARE 96/97

	Protected Area	Purpose of visit	Number of people
1.	SSSI no. 23	Studies of Antarctic Petrel	6
2.	SSSI no. 23	Starting point for project taking place outside area	4
3.	SSSI no. 23	Starting point for project taking place outside area	3

Bouvetøya

Bouvetøya is located north of 60° S, and is therefore outside Antarctica in Treaty terms, and is thus not covered by the Norwegian Antarctic Regulations. This sub-Antarctic island is, however, protected as a nature reserve in accordance with *Regulations relating to the protection of Bouvetøya and surrounding territorial waters as a nature reserve* (Bouvetøya Regulations). It is our intention that in the case of environmental impacts, activity on this island should be considered in the same manner as activity taking place in the Antarctic.

As a consequence, an initial environmental evaluation for the construction of the small research station which was erected on Bouvetøya during NARE 96/97 was prepared and submitted to the Ministry of Environment prior to the expedition. An environmental impact evaluation was also developed for the research project which took place here, and the activity was carried out on the same terms as the other NARE projects.

BJØRN L. BASBERG[1], GISLE LØKKEN[2], DAG NÆVESTAD[3] & GUSTAV ROSSNES[4]:

INDUSTRIAL ARCHAEOLOGY AT LEITH HARBOUR, SOUTH GEORGIA, 1996/97

A Preliminary Report

INTRODUCTION

The former whaling shore station Leith Harbour in Stromness Bay, South Georgia (Falkland Island Dependencies) was surveyed during a four weeks stay in December 1996 and January 1997 by a Norwegian four-man team. This is the third survey within the project on Industrial Archaeology at South Georgia (Hvalfangstminneregistrering på Syd Georgia). Husvik and Stromness Harbours were surveyed in 1989/90, and Grytviken in 1992/93 (for information on these surveys, see Basberg, Nævestad & Rossnes 1996). The project is part of the Norwegian Antarctic Research Expeditions (NARE) and is financed by the the Norwegian Research Council.

The party flew from RAF Brize Norton in England to Mount Pleasant Airport in the Falkland Islands. We sailed with the *HMS Leeds Castle* from Mare Harbour and arrived in Leith Harbour on December 17. We were picked up by RAF *Grey Rover* on January 13 and returned to the Falkland islands on January 17. A container with our equipment was brought from Portsmouth to Leith Harbour and returned on board *HMS Endurance*.

We stayed in a former ware-house at Leith Harbour (the Steward's Store) which had been used by the *HMS Endurance* survey team for two seasons.

OBJECTIVES

The aim of this and the former surveys of the South Georgia whaling stations is to make as detailed documentation as possible of the stations, given personnel and time constraints, by way of measurement, mapping and photographic documentation of interiors and exteriors.

The reason for the surveys has been the gradual deterioration of the buildings. After about thirty years without maintenance and caretaking, many of them are gradually collapsing. The surveys collect and preserve information about this industrial heritage, both the production processes and living conditions, which otherwise gradually would have disappeared.

A SHORT HISTORICAL BACKGROUND

Leith Harbour was one of a total of six whaling shore stations built at South Georgia between 1904 and 1911 (Fig. 1). The construction of Leith began in 1909 and the station was owned and run by Chr. Salvesen & Co. in Leith, Scotland - a company with

1. Sør-Trøndelag College, 7005 Trondheim, Norway.
2. 70°N arkitektur a.s. P.O. Box 1247, 9001 Tromsø, Norway
3. Norwegian Maritime Museum, Bygdøynesveien 37, 0286 Oslo, Norway
4. Riksantikvaren, P.O. Box 8196 Dep., 0034 Oslo, Norway

former whaling experience in northern waters.[1] Although the company was a Scottish one, a major part of the whalers were recruited in Norway - as was the case with the other stations. Leith Harbour whaling station was built on a flat beach in Stromness Bay. However, over the years several snow avalanches hit this location (which had been named "Jericho"), most seriously in 1929, when a substantial part of the station was destroyed and three men were killed. The station was then relocated to its present site, a point stretching from "Jericho" in a south-easterly direction. At this location Leith Harbour gradually grew to become the largest whaling station at South Georgia (and, as a matter of fact, in the world). From 1931 it also incorporated the Stromness station in the next bay which had been a whaling station up until the economic depression and now became a repair yard for Leith Harbour and for Salvesen's pelagic whaling expeditions.

Salvesens' closed down their whaling operation at Leith Harbour in 1961 - at a time when most Norwegian/British whaling in Antarctica came to an end. At South Georgia both Grytviken and Leith were subleased to Japanese whaling companies, but were permanently closed already in December 1964 and December 1965, respectively.

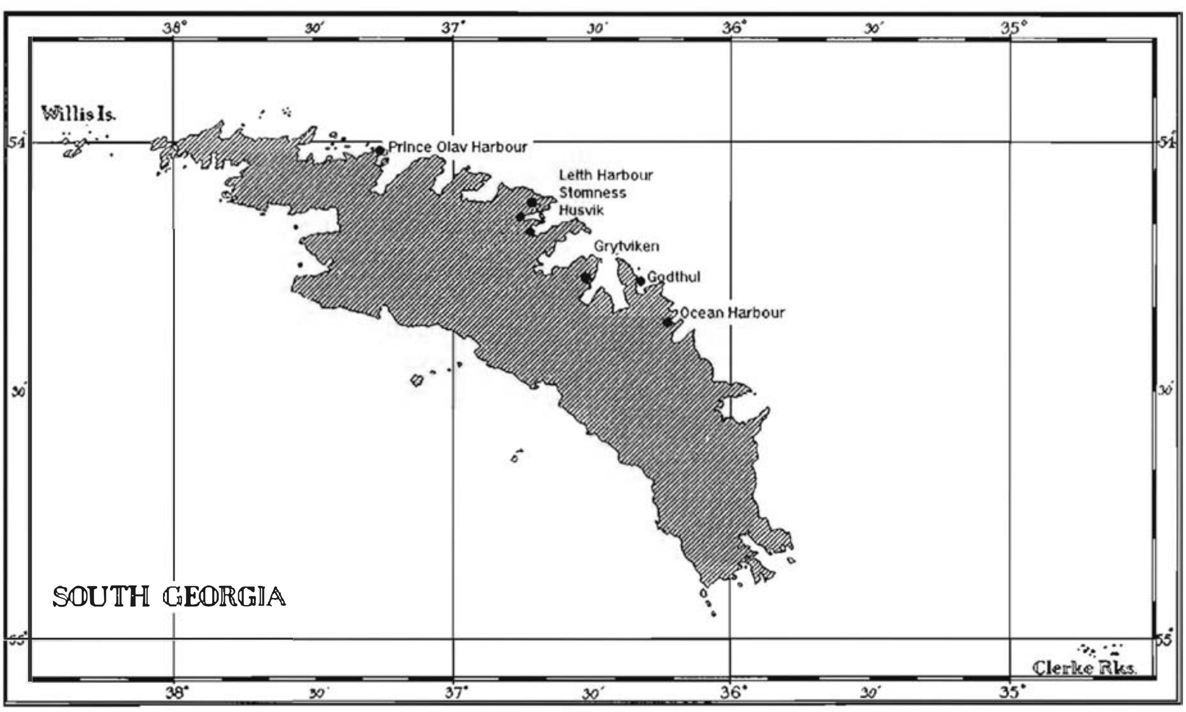

Fig. 1. Whaling stations in South Georgia. Godthul was only an anchorage for floating factory ships (Map after S. Kemp and A.G. Bennet: On the distribution and movements of whales on South Georgia and South Shetland whaling grounds. Discovery Reports, Vol. 6, 1932.)

1. The history of the company is examined in Vamplew (1973). A description of whaling and the whaling stations at South Georgia may be found in Headland (1984), and more in detail in the comprehensive Tønnessen & Johnsen (1982).

Fig. 2. Leith Harbour viewed from the South (Photo: G. Rossnes)

A caretaker remained in Leith Harbour until January 1966. After that year the station has been without supervision and the decline was rapid, due to weather and sadly enough, visitors of several kinds. In the 1970s Eastern European fishermen paid frequent visits to South Georgia and literally vandalised many buildings. Furthermore, the Argentine scrap merchant Constantin Davidoff put a mark on Leith Harbour, removing numerous machines from workshops and emptying many stores. Everything was piled up at the Catcher Pier, but was not loaded. After the 1982 conflict, British military servicemen have unfortunately contributed to the deterioration. Leith Harbour actually appears to have been vandalised more than any of the other stations.

SURVEY METHODS AND RESULTS

The overall methods of the Leith Harbour survey followed the pattern of our former South Georgia surveys. Consequently, the data collected are comparable. The main elements in the survey are the following:

Station map

Leith Harbour was surveyed in 1954 by J. Brown who made an overall map. This was revised several times throughout the 1950s as buildings were erected, dismantled or functions were changed. Consequently, a map exists showing the station at the time when it was left. It shows the layout of the station and indicates the main functions of every building and other structures. Maps made by R.K. Headland (the latest version revised in 1991, prepared by R.I. Lewis Smith) is based on this map. We have used the revised 1954 map as a starting point. Our own survey and measurements show that this map is fairly accurate. Some corrections have been made, and we have compiled a revised map. We have also added to the map the main pipelines running through the plant in order to show the main links from oil storage and transportation of whale products through the various refining and extraction processes.

Building plans
Every building has been measured and drawn to scales 1:100, 1:125 or 1:200 depending on its size. The drawings will be completed using a CAD-system, and published in a separate report. The building plans show the functions of every single room on every floor, with the interior (machinery, equipment, main furniture, beds etc.) indicated (see one example in Fig. 3). More emphasis than in the former surveys has been put on surveying the production processes in detail and correct scale, and show the line of production. We have identified and drawn up altogether 99 structures including 673 rooms or units (this does not include tanks).

Sections of the production process
In addition to the building plans (horizontal) for every floor, we have selected two of the most complicated production processes (the Rose-Downs plant and the whale meal [guano] plant) and made sections (vertical) of the main elements in the processes. The drawings do not show the processes in every detail, but are simplified to a degree which both gives a fairly correct impression and at the same time is simple enough to be of some teaching value. Leith Harbour is the only station where we have undertaken such a survey, but the production processes were similar to some extent from one station to the other, and the drawings should therefore be of general interest and be possible to use in interviews with former whalers. The sections will be published together with the other drawings.

Room-database
Every identifiable room is numbered and stored in a database (FileMaker) showing the size of the room (sq.m), inventories, machinery, nos. of beds (if any), name and function. An edited version of the database will be included in the publication of the maps, in the same way as for the other surveyed stations. We have surveyed - and the database includes - information on the mentioned 673 (plus) units, totalling 30.917 (plus) sq.m. This includes the flensing plan, but not units like tanks, piers and vessels.

Exterior photographs
Every building has been photographed in b/w (6x6 Hasselblad) and colour diapostive (Kodachrome 25) showing horizontal and vertical scales. Most buildings are photographed from all sides in separate exposures. Some minor buildings (sheds, pumphouses) are photographed from one or two positions, showing at least two sides of the building. Altogether 290 exterior photographs have been taken.

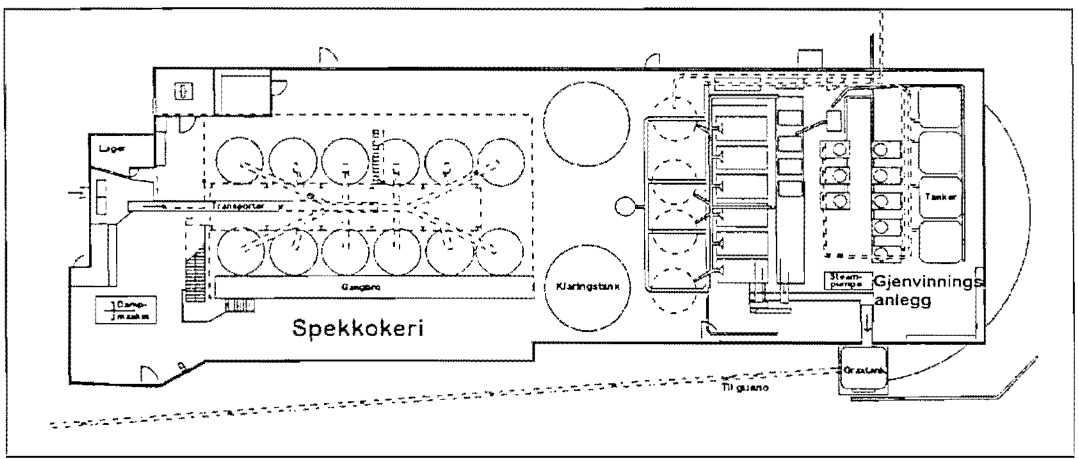

Fig. 3. The Blubber Cookery/Spekkokeri and the Recovery Plant/Gjenvinningsanlegg (Drawing: G. Løkken)

Interior photographs
The aim has been, as was the case for the earlier surveys, to photograph every single room from at least one position. However, this aim had to be modified somewhat in Leith Harbour. One reason had to do with the time constraints involved. Secondly, it became apparent that many bedrooms in the large barracks were almost identical. In addition, they were almost without exception in a very bad state where furniture had been removed and replaced after the whaling station was abandoned. We therefore concentrated on selecting "representative" rooms of every barrack which contained as much information as possible on how they originally might have looked. Furthermore, some completely empty store-rooms (in the cold store etc.) are not photographed. Rooms in the manufacturing plant containing important machinery or equipment in the production process are, on the other hand, photographed in more detail, showing the stages in the processes in a series of photographs from a single room/plant. Special emphasis was placed on the documentation of the whale meal plant, the Rose-Downs plant and the Hartmann plant. Altogether we have taken 520 interior photos in colour diapositive (Kodachrome 25 and 64) and 30 in b/w (6x6).

Photo-database and storage
The photographic reference logs - both for exterior and interior photographs - are stored in a database (FileMaker) where every photograph is numbered, and there is information on the direction of the photograph and information on what is seen on the photograph. An edited version of the photo-database will be published in a separate report, as was the case with the other stations. The photo-collection will be deposited together with the collection from the other stations, with the Com. Chr. Christensen's Whaling Museum in Sandefjord, Norway.

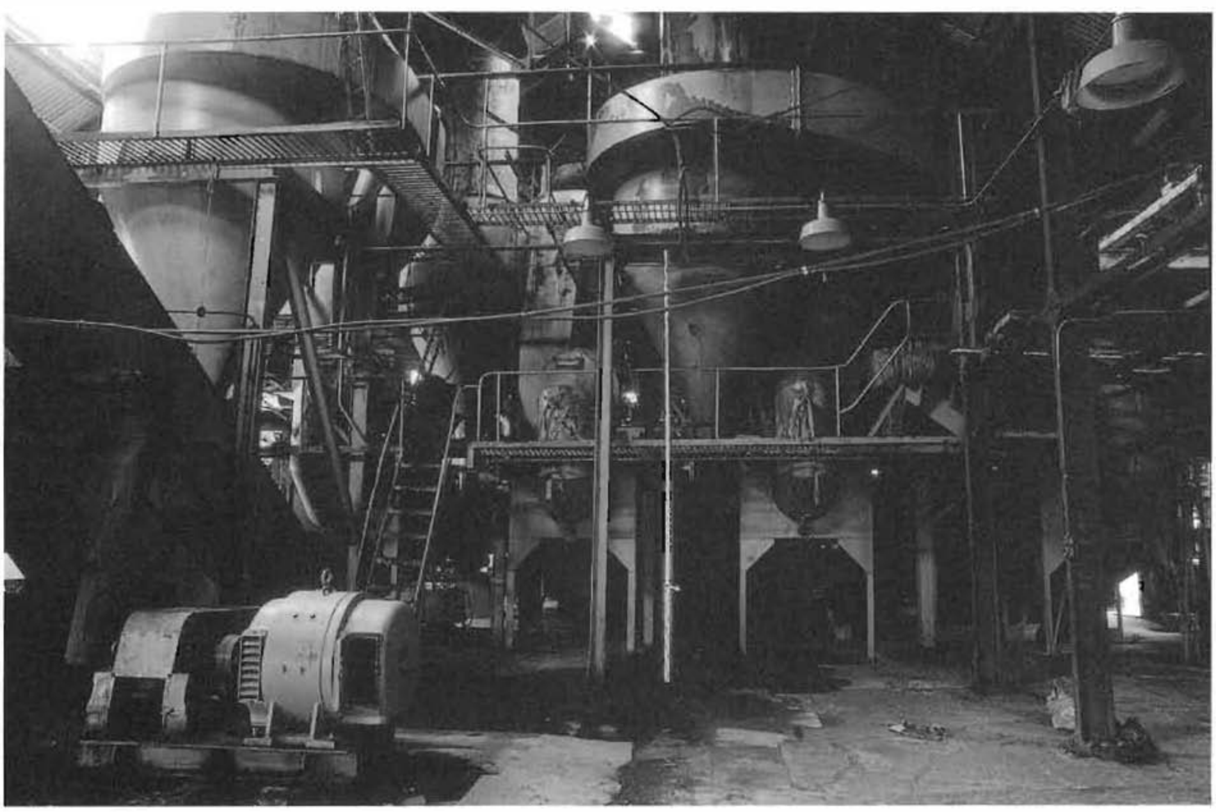

Fig. 4. Detail from the Whale Meat Plant («Guano Plant»), Leith Harbour (Photo: G. Rossnes)

THE CULTURAL HERITAGE OF LEITH HARBOUR - CONSERVATION ASPECTS

The aim of the Industrial Archaeology Project is primarily to survey the stations. Especially since the South Georgia Whaling Museum was established in Grytviken in 1990, and there is an interest in conserving equipment and artefacts by this - and also by other - museums, we have considered it as one of our tasks to point out items of specific historical interest.

There are now few very valuable and unique artefacts left in Leith Harbour which are not represented in the Grytviken museum or other museums. Many valuable items have also been removed over the years since the whaling station was abandoned, and their fate is unknown.

We would like to put emphasis on the following items which we consider of special interest:

- In the production plant, we will focus on the *Hartmann-plant.* The Hartmann horizontal rotating cookers were very important on the shore stations as well as on board floating factories in the 1920s. The four remaining cookers at Leith Harbour are by now probably unique. The cookers are obviously too large to be removed, and the South Georgia Whaling Museum should be encouraged to maintain and secure the buildings which contain these cookers.
- The *radio and radar workshop* also contains unique equipment; complete radio, radar and asdic apparatus with a significant historical value. This building should also be secured, and some items should be considered for removal to Grytviken. They may become a valuable asset for the museum.
- The two *graveyards* do also represent significant historical and of course emotional value. They are both (especially the small old graveyard) in a bad state and need renovation.
- The *library* in Leith Harbour in the Hillside barrack is very derelict, and the books still in reasonable condition have fortunately been removed in part to Grytviken and in part to a store room in the Steward's Store. The store room should, however, not be their permanent storage, and the whole library should be considered for removal to Grytviken.

CONCLUDING REMARKS

The survey of Leith Harbour completes the survey of the four largest stations which were all in operation until the early 1960s.The conditions of the stations are poor, and most buildings are gradually collapsing. Grytviken is an exception, where some buildings are maintained as a part of the museum. A substantial part of the buildings in all stations are, however, still in a state which make a reconstruction of the original functions, and make measurements and exact plans possible. The photographic documentation has a more varied quality in terms of the extent to which the past may be recollected from them. Especially the living quarters (many bed-rooms, messes, recreational areas) are very derelict and only to a limited extent do they resemble how they looked like when the whalers were around. A survey would of course have obtained a better result if it had been undertaken twenty years ago. We started late, but, bearing in mind the obvious limitations, not too late to obtain a result which will preserve valuable knowledge of the stations which otherwise would have been lost. The substantial material which has been collected may also hopefully generate future research into economic, technological and social aspects of our recent whaling history.

There are another two former whaling stations at South Georgia which we have not surveyed yet; Ocean Harbour and Prince Olav Harbour. While there is very little left of the former, Prince Olav has several houses and parts of the processing plant left. Being abandoned already in 1931, it is very different from Grytviken and the three stations in Stromness Bay. It is smaller, and not much is left. Of the few whaling stations in the Southern Ocean which have not been operated since the interwar years (Deception Island in the South Shetlands, Kerguelen, Western Australia), Prince Olav is now the most "complete", and should be considered surveyed if logistics and financial conditions make it possible.

ACKNOWLEDGEMENTS
The survey has been fully financed by the Norwegian Research Council (Norges forskningsråd), and has been a project within the Norwegian Antarctic Research Expedition. Practical planning and support in Norway has been taken care of by the Norwegian Polar Institute (Norsk Polarinstitutt).

The logistics has been fully provided by British institutions, as was also the case with the Grytviken survey in 1992/93. The undertaking of the project has been recommended by the Commissioner of the South Georgia and the South Sandwich Islands. The Foreign and Commonwealth Office, South Atlantic and Antarctic Division, accepted our request for help to carry a container with our equipment from Portsmouth to Leith Harbour and back onboard *HMS Endurance*. The Falkland Islands Government, London Office, arranged airfares for the party from RAF Brize Norton to Mount Pleasant in the Falkland Islands onboard RAF *Tristar*. The British Forces Falkland Islands arranged passage to and from Leith Harbour on board *HMS Leeds Castle* and RFA *Grey Rover*. Finally, the project has closely co-operated with the South Georgia Whaling Museum and its director Robert Burton, and with Robert K. Headland at Scott Polar Research Institute at the University of Cambridge. From both we received valuable help in the planning phase of the project. We will finally mention the Upland Goose Hotel in Stanley which kindly provided the team with a Christmas Pudding and four crackers which made our stay in Leith Harbour even more pleasant. We are extremely grateful for this support, without which the project could not have been undertaken.

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STUDIES OF SEABIRDS AND SEALS AT BOUVETØYA 1996/97

INTRODUCTION

The early history of harvesting of biological resources in the Antarctic was dominated by over-exploitation. Several species of baleen whales and fur seals were especially targeted. The *Convention on the Conservation of Antarctic Marine Living Resources* (CCAMLR) was established in 1980 to control the harvest of marine living resources in the Antarctic. The increasing interest in krill fisheries (mainly *Euphausia superba*) at that time was of particular concern. Krill is a key species in the Antarctic marine ecosystem and many species of penguins, seals and whales rely on a high availability of krill for food. A significant harvest of krill by humans may thus have negative effects on species preying on krill.

To obtain information on the harvest of both krill and fish, and the effects of this harvest on other species in the ecosystem, the *CCAMLR Ecosystem Monitoring Program* (CEMP) was instituted. Monitoring of several species of seabirds and seals that prey predominantly on krill are important parts of the CEMP-program today. Several aspects of the biology of these species that are thought to be sensitive to changes in the availability of food are included in the program. Monitoring programs following standard CCAMLR methods have been implemented by a number of Antarctic Treaty states at sites throughout the treaty area.

Bouvetøya is the only land within a considerable portion of the South Atlantic. Large numbers of seabirds and seals aggregate on the island to breed during summer. The dynamics of these populations have been little studied. To gain more information concerning penguins and fur seals and to be able to assess the effects of future krill fisheries in the ocean around the island, the Norwegian Ministry of the Environment decided to start a CEMP monitoring program at Bouvetøya in the 1996/97 field season. The responsibility for carrying out the monitoring program was given to the Norwegian Polar Institute.

The expedition ship *R/V Polar Queen* arrived at Bouvetøya on 9 December 1996. The five members of the expedition to the island were Bruce M. Dyer, Onno Huyser (both South Africa), Greg Hofmeyr (Norway/South Africa), Kjell Isaksen and Alf Næstvold (both Norway). The *Polar Queen* returned to Bouvetøya on 22 February 1997 to collect the team. A more thorough presentation of the monitoring program at Bouvetøya and preliminary results from the 1996/97 season can be found in Isaksen et al. (1997a, b).

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OBJECTIVES

The objective of the project was to establish a monitoring program (CEMP) for penguins and fur seals on Bouvetøya. This was to be the first of a number of seasons during which populations on the island would be monitored. In addition to the CEMP program other work on seabirds and seals was to be carried out.

A research station was to be built at the study site to accommodate the researchers working on the monitoring program.

STUDY AREA

Bouvetøya is a small (10x7 km), isolated island in the South Atlantic (54°25'S, 3°20'E). It is of volcanic origin, situated on the Mid-Atlantic Ridge. Most of the island (93%) has permanent ice cover (Orheim 1981), but some ice-free areas exist along the coast, especially in the western parts of the island (Fig. 1). The wildlife on the island is concentrated in these areas.

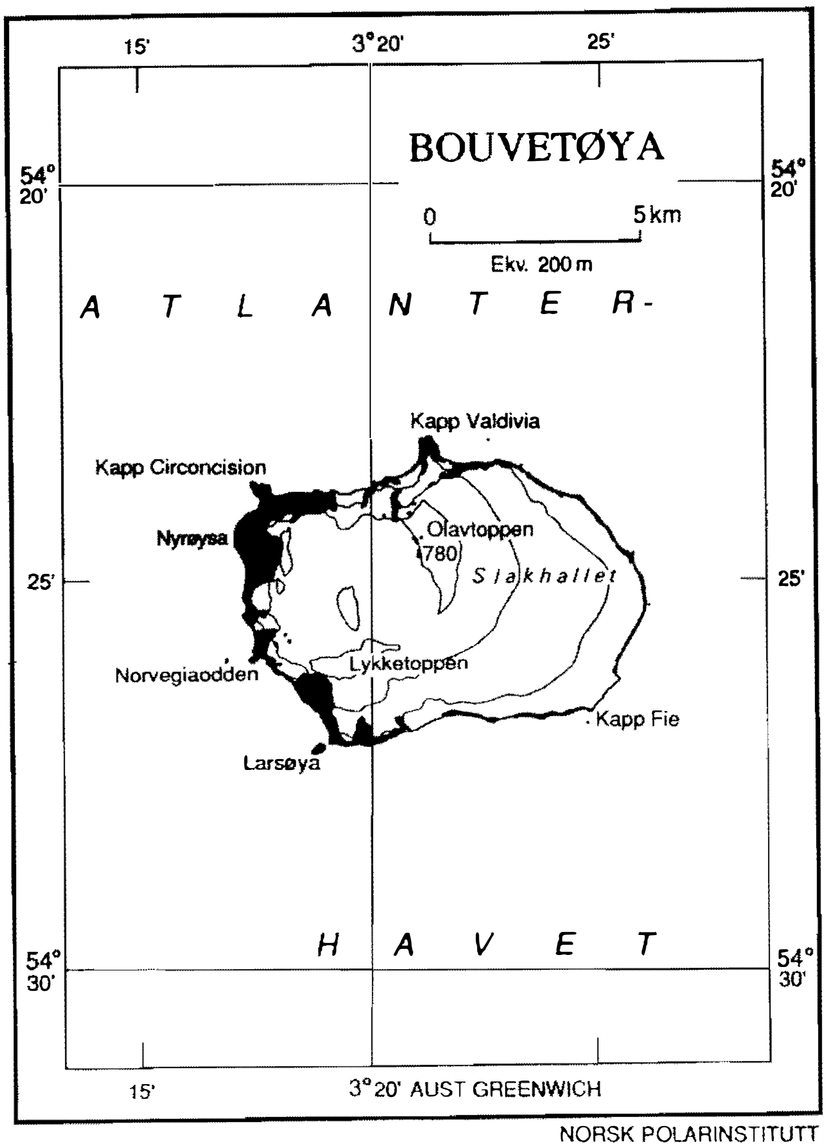

Fig. 1. Map of Bouvetøya with the study site, Nyrøysa, indicated on the western coast of the island.

Twelve species of seabirds have thus far been recorded breeding on the island. Among the most numerous are Chinstrap Penguins (*Pygoscelis antarctica*), Macaroni Penguins (*Eudyptes chrysolophus*), Southern Fulmars (*Fulmarus glacialoides*), Cape Petrels (*Daption capense*), Black-bellied Storm-petrels (*Fregetta tropica*), Antarctic Prions (*Pachyptila desolata*) and Brown Skuas (*Catharacta antarctica*). Antarctic Fur Seals (*Arctocephalus gazella*) maintain a large breeding population on the island. Southern Elephant Seals (*Mirounga leonina*) are common on some beaches of the island during summer moult, but it is not known whether they breed on the island at present. Few studies, apart from a number of counts of birds and seals made during earlier visits to the island, have been completed.

A large landslide between 1955 and 1958 formed a new area of relatively flat land on the western side of the island (Prestvik & Winsnes 1981). The new beach, Westwindstranda, together with the plateau Nyrøysa, comprise almost the only relatively flat, ice-free areas on Bouvetøya. Westwindstranda/Nyrøysa also provides the only suitable camp site on the island (Fig. 2). Westwindstranda and Nyrøysa were quickly colonised by penguins and fur seals, and these areas now constitute suitable sites for studying these species.

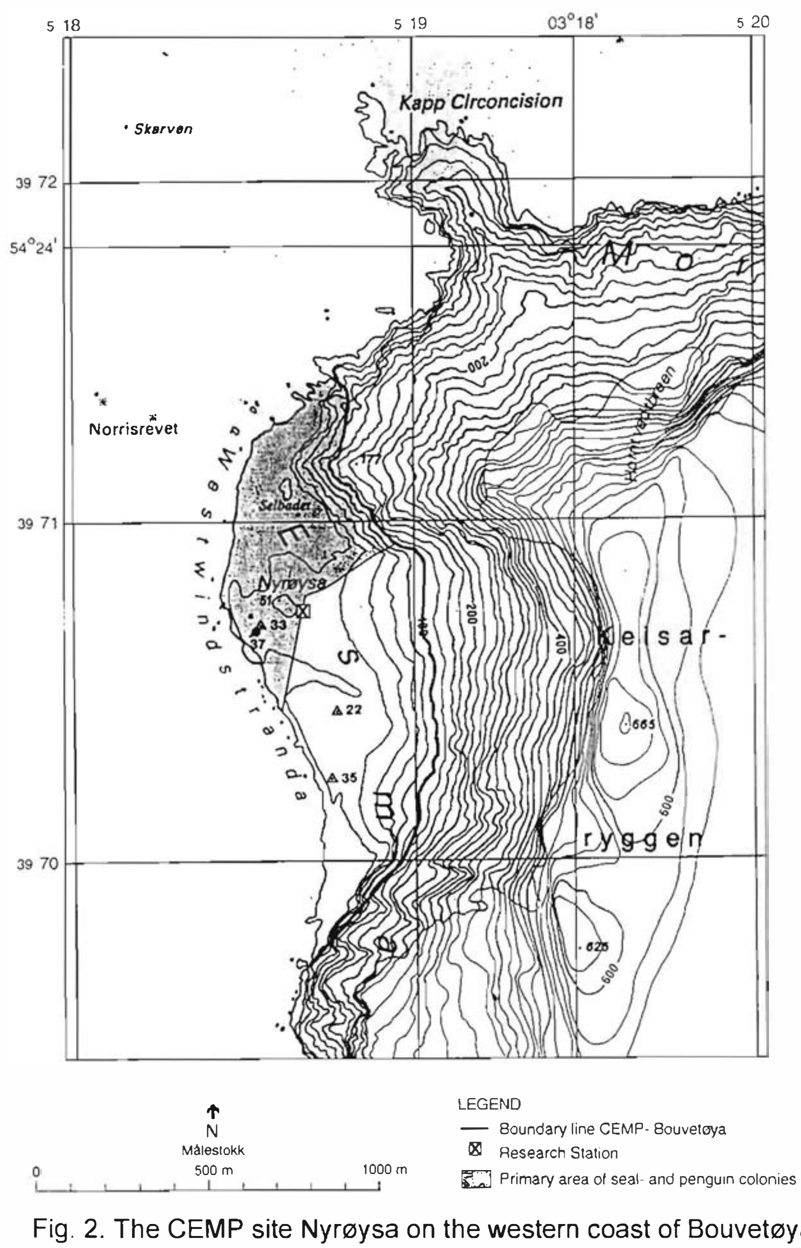

Fig. 2. The CEMP site Nyrøysa on the western coast of Bouvetøya.

ERECTION OF THE FIELD STATION

After the arrival of the R/V *Polar Queen* at Bouvetøya on 9 December 1996, a group of people were transported to Nyrøysa by helicopter to find the best site to erect the field station. This was duly selected 60 m from the coastline and close to a small hill. The main penguin colonies and seal breeding areas on Nyrøysa were situated nearby, on the other side of the hill. These areas were therefore out of sight of the station and well protected from noise and other direct disturbance from the station area.

The work on the main lodging unit started early the next day when all equipment was transported to Nyrøysa. The completed hut consists of seven prefabricated sections of steel mounted on a frame with eight legs. It measures three by nine meters and has a total weight of six tons. It contains beds for four persons, a small office section with two desks, and a kitchen section. A smaller container for a generator was placed at some distance from the main hut. A 10 kW diesel generator supplies electricity for lighting, heating, office equipment and a deep freezer for storing scientific samples. Communication with the rest of the world was established by satellite (phone, telefax and e-mail) as well as with HF-radio. In addition to the main hut, tents were erected to provide space for storage of equipment and additional room for working and sleeping.

The purpose of the station will be to provide accommodation and working facilities for personnel engaged in CEMP-related work. It accommodated five people and served its purpose very well during the 2½ month stay in 1996/97.

FIELD WORK AND PRELIMINARY RESULTS

The first period on the island after arrival on 10 December was devoted to carrying out practical work required to set up the station, after which the scientific work started. The field work was terminated on 22 February 1997 when the ship returned to pick up the expedition members.

Standard methods have been developed by CCAMLR to be used at all sites participating in the CEMP-program (CCAMLR 1992). The monitoring program at Bouvetøya follows these methods. For Chinstrap and Macaroni Penguins the program involves monitoring six different biological parameters, whereas only two are monitored for Antarctic Fur Seals.

CEMP-work on penguins

Breeding population size (CEMP Standard Method A3)

The breeding colonies of Chinstrap and Macaroni Penguins at Nyrøysa were sectioned into separate plots. For each plot the number of incubated nests, the number of occupied (but not incubated) nests, and the total number of birds were counted separately at least three times. The monitoring included all breeding penguins at Nyrøysa, but none in other areas of the island.

The resulting numbers were considerably lower than previous counts from the late 1970s to the early 1990s (Haftorn et al. 1981, Watkins 1981, Bakken 1991), especially for Chinstrap Penguins.

Age-specific annual survival and recruitment (A4)

A relatively small number of Chinstrap (54 breeding adults and 50 chicks) and Macaroni Penguins (100 breeding adults and 50 chicks) were banded with flipper bands for a long-term study of individual survival. Few individuals were banded due to uncertainty about the suitability of the flipper bands.

Duration of foraging trips (A5)

VHF radio transmitters (Advanced Telemetry Systems) were attached to 40 Chinstrap and 40 Macaroni Penguins with chicks. The transmitters were attached to the backs of the birds with fast-setting epoxy. The presence of these penguins in the breeding colony at Nyrøysa was monitored by a VHF-receiver/data-logger system (RX-900, Televilt Int.) during parts of January and February 1997 at 10–30 minute intervals.

A preliminary analysis of some of the data shows that Chinstrap Penguins making foraging trips departed from the colony in the morning and generally returned in the evening the same day. Macaroni Penguins made foraging trips of longer duration, often lasting more than 24 h. This was especially so for the first major foraging trip made by male Macaroni Penguins during the chick-rearing period; these trips lasted for several days.

Breeding success (A6)

The number of chicks and adults in the colonies at Nyrøysa was counted in the period 4–7 February. At least three separate counts were made in the same plots that were used to determine breeding population size. The breeding success of the Macaroni Penguins seemed to be very low in the northern parts of the colony, probably due to interactions with fur seals, whereas the breeding success of the Chinstrap Penguins generally seemed to be high.

Chick diet (A8)

Food samples from two Chinstrap and five Macaroni Penguin adults were collected every five days during the chick period. The low number of Chinstrap Penguins sampled was due to the low number of breeding pairs of this species on Nyrøysa. The food was sampled by stomach pumping (Wilson 1984) adults when they arrived at the colony from the sea to feed their chicks. All samples were collected between 1800 and 1930 h 'local time' (GMT+1h). Samples were preserved in alcohol (Chinstrap Penguins) or frozen (Macaroni Penguins).

The Chinstrap Penguins had taken almost exclusively *E. superba* as prey. Macaroni Penguins on the other hand fed mostly on fish, with *E. superba* constituting an important part of the diet for some birds in some periods.

Breeding chronology (A9)

The timing of important breeding events (*e.g.* egg-laying and hatching) may vary from year to year depending on snow melt, ice conditions and other environmental factors. Information on the timing of breeding is important for interpreting the results of other monitoring parameters, for instance breeding population size.

About 50 Chinstrap Penguin and 100 Macaroni Penguin nests were marked and checked every other day. The presence of eggs or young was noted for each nest, as well as whether the chicks were guarded by an adult or not. The mean hatching dates of both Chinstrap and Macaroni Penguins were at the very end of December. The Macaroni Penguins generally hatched later and were more synchronous than the Chinstrap Penguins.

CEMP-work on Antarctic Fur Seals

Duration of adult female foraging/attendance cycles (C1)

Forty-five adult females, seen to be suckling pups, were captured, either with a choker pole or hoop net (David & Meyer 1990). VHF radio transmitters (Advanced Telemetry Systems) were attached midway between the shoulders of each animal with fast-setting epoxy. The seals were then tagged with flipper tags and released. The presence of the instrumented females on shore was recorded by the automatic VHF-receiver/data-logger system (RX-900, Televilt Int.) over 39 days from 12 January to 19 February. The station searched for each frequency at 10–30 minute intervals. The data from 36 VHF transmitters yielded the durations of 223 complete foraging trips and 223 complete shore attendance periods.

Pup growth (C2)

Two methods were used: (1) Pups (77 ind.) were caught, marked and weighed at birth. Throughout the season, animals from this group were opportunistically recaptured and re-weighed. (2) Random samples of 100 pups each were weighed at 30, 60 and 74 days after mean pupping date. Mean weights for each sex were calculated using both methods. The results obtained from the two procedures for measuring pup growth rates differ. Procedure 1 is usually the more accurate of the two as it requires repeated sampling of individual pups, whereas procedure 2 does not. In the case of the Bouvetøya study, however, its accuracy was compromised because of the timing of birth of the sampled pups; they were born at the end of the season. Timing does not impact on procedure 2 as the samples of pups are weighed on specific dates.

Additional projects

In addition to the monitoring program other work on seabirds and seals was carried out during the stay on the island. Some of this work is listed below.

General registration of the wildlife on the island

Records were kept of sightings of less common birds and mammals. Antarctic Prion and Wilson's Storm-Petrel (*Oceanites oceanicus*) were confirmed breeding on the island for the first time (see Bakken 1991 for breeding of unidentified prions). Subantarctic Fur Seal (*A. tropicalis)* was recorded on the island for the first time. Humpback Whale (*Megaptera novaeangliae*), Wandering Albatross (*Diomedea exulans*), and Light-mantled Sooty Albatross (*Phoebetria palpebrata*) were regularly seen from Nyrøysa. Several King Penguins (*Aptenodytes patagonicus*) stayed at Westwindstranda to moult.

Breeding biology of seabirds

Investigations of breeding biology of Southern Fulmars, Cape Petrels, Black-bellied Storm-Petrels and Brown Skuas were carried out. For all species a number of nests were monitored and hatching dates, chick growth, breeding success and causes of failure recorded. See Huyser et al. (1997) for results of the work on Cape Petrels.

Seabird and fur seal diets

Stomach samples were collected from breeding Southern Fulmars, Cape Petrels, Antarctic Prions and Black-bellied Storm-Petrels for analysis of prey composition. Diets from Southern Fulmars and Cape Petrels were sampled from adults, using a modified water-offloading technique similar to that used on penguins, when they returned to feed their chicks. Following CEMP procedures five samples were collected every five days over the chick-rearing period for Cape Petrels. Only five diet samples were obtained from Southern Fulmars due to the low number of accessible nests and few pairs still breeding at that stage. Diets from Antarctic Prions and Black-bellied Storm-Petrels were obtained from birds caught in mist nets. They were induced to regurgitate and the samples collected and frozen. Krill (*E. superba*) was an important part of the diets of all these species, with other prey (fish and other euphausiids) less important.

Pellets from Brown Skuas were collected for analysis of predation rates, and for analysis of ingestion of plastic particles by Black-bellied Storm-Petrels.

Ninety Antarctic Fur Seal scats were collected. Most of the scats contained krill and 17 yielded the remains of fish, as yet unidentified. Two scats contained feathers (possibly from penguins).

Diving behaviour of penguins
Two types of devices were used to study the foraging behaviour of penguins. Time-depth recorders (Wildlife Computers Mk5-type microprocessor-conTROLLed TDR) were fitted to 4 Chinstrap and 4 Macaroni Penguins rearing chicks. The instruments weighed 50 g and were glued onto the lower back of the penguins with fast-setting epoxy. Depth and temperature were sampled every five seconds. The instruments were removed from the penguins to download the data after 5 to 14 days. The depth resolution of the instruments was 2 m. Only dives deeper than 4 m were included in the analysis in order to exclude travelling dives (cf. Bengtson et al. 1993).

Data-logger time-depth-recorders (TDRs) manufactured by Driesen and Kern (Kiel, Germany) were fitted to both Chinstrap and Macaroni Penguins. The data loggers were set to record water/air temperature, light intensity, depth, swim speed and three-dimensional compass readings with 16-bit resolution every five seconds for up to 10 days. A total of 18 complete foraging trips from eight female Macaroni Penguins were logged, and four incomplete foraging trips from two Chinstrap Penguins.

Preliminary results from the first type of devices show that Macaroni Penguins generally made deeper dives and dives of longer duration than Chinstrap Penguins. This is probably a consequence of the different diets of the two species.

Diving behaviour of fur seals
Wildlife Computers (Redmond, USA) Mk5-type microprocessor-conTROLLed Time-Depth Recorders were deployed on three adult female Antarctic Fur Seals nursing pups between 8 January and 12 February 1997. The animals were caught and restrained using a hoop net and the TDR applied directly to the fur midway between the shoulders using a fast-setting epoxy. The animals were then tagged and released after ten minutes. Data was downloaded onto a computer either in the field while restraining the animal with the hoop net or after removal of the device from the animal. The TDR sampled depth at five second intervals, and temperature and light level at 60 second intervals. Only dives that achieved a depth of five metres or more were analysed.

Diving behaviour of the three study animals was recorded over 12, 14 and 21 days, giving a total of 47 days of data. During this time 8003 dives of a depth of five or more metres were recorded from 13 complete and two partial foraging trips.

Ringing and tagging
Antarctic Prions, Black-bellied Storm-Petrels (adults) and Brown Skuas (adults and chicks) were captured and ringed for estimation of survival rates. Recaptures of Antarctic Prions will be used to estimate local population size at Nyrøysa.

In total, 193 adult female, one subadult and 478 pup Antarctic Fur Seals were tagged to provide supplementary data on attendance patterns and as part of a long-term project on survival rates and dispersal.

Morphometric analysis
Extensive morphological measurements (body mass, wing length, tarsus length, head length and several measurements of bill morphology) were taken from a sample of the birds captured for ringing.

Measurements of eggs of all species of seabirds accessible on Nyrøysa were taken.

One Southern Elephant Seal skull and approximately 80 Antarctic Fur Seal skulls were collected for morphometric analysis.

Collection of material for analysis of genetics and pollutants
Fifty-one blood samples were obtained from several species of seabirds. The species sampled were Chinstrap Penguin, Macaroni Penguin, Southern Fulmar, Cape Petrel, Antarctic Prion, Wilson's Storm-Petrel, Black-bellied Storm-Petrel and Brown Skua. Blood samples were also taken from Antarctic Fur Seals. In addition, genetic material in the form of biopsy samples from fur seals, and skin samples from Southern Elephant Seals were taken.

Milk and blood samples from nursing adult female Antarctic Fur Seals, and blood samples from their pups, were taken for studies on pollutants.

Estimation of pup production
A mark-recapture experiment was conducted to determine the number of Antarctic Fur Seal pups on Nyrøysa. A total of 1 669 pups distributed evenly throughout the colony were marked with paint, and the proportion of marked and unmarked pups recorded at two later counts in the colony.

Counts of Southern Elephant Seals
Weekly counts of Southern Elephant Seals were completed. The maximum number hauled out (on the 6 January) was 171 adult females, 71 sub-adult males, 1 sub-adult female, 101 sub-adults of undetermined sex, and 6 yearlings.

Recordings of vocalisations
Vocalisations of Antarctic Fur Seal adult males, and adult female-pup pairs, were recorded for comparison with other populations. Recordings were also made of calls of several seabird species.

Marine debris
Surveys of beached marine debris were conducted according to guidelines approved by CCAMLR. In addition, records were kept of seals (and seabirds) entangled in man-made material (such as nets).

Collection of seaweed
Seaweed washed up on the beach was collected to investigate which species of seaweed and seaweed epiphytes are found around the island.

CONCLUSION

The field work at Bouvetøya was very successful. The planned work on the monitoring project on penguins and fur seals were completed, as well as most of the additional work that was planned. The field station was successfully erected during the first days of the stay at the island, and the logistics at the station also functioned very well.

The island proved to be a promising site for further studies of seabirds and seals.

ACKNOWLEDGEMENTS

The project is headed by the Norwegian Polar Institute in collaboration with the FitzPatrick Institute of African Ornithology, University of Cape Town, South Africa. We are deeply indebted to V. Bakken, I. Gjertz and F. Mehlum at the Norwegian Polar Institute for planning the field work. We would also like to thank J. Cooper and P. Ryan of the FitzPatrick Institute for their help in planning the field work, and M. N. Bester and I. Boyd for their invaluable advice concerning the work on fur seals.

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ERLING S. NORDØY[1] & ARNOLDUS SCHYTTE BLIX[1]:

STUDIES OF SEALS IN THE WEDDELL SEA AND KING HAAKON VII SEA

ABSTRACT

During the period January 4 to February 28, 1997, as part of the NARE 1996/97 expedition on board *R/V Polar Queen* to the Weddell Sea, a total of ten crabeater seals, two Ross seals, one leopard seal and one Weddell seal were tagged with satellite-linked dive recorders (SLDR's) to follow their distibution and dive behaviour. Aerial surveys were moreover performed to count numbers of pack ice seals in relation to pack ice, distribution, coverage and consistancy. Finally, five seals of different species were killed for physiological studies of the digestive system in relation to dive behaviour.

BACKGROUND OF PROJECT

In *Perspectives for Norwegian Antarctic Research* (Perspektiver for norsk antarktis-forskning) marine ecology is identified as one of the two most important research priorities for future Norwegian activities in Antarctica. Moreover, the need to understand effects of changes in prey abundance on the population dynamics of birds and mammals, which seasonally occupy the pack ice and primarily prey on krill, is particularly emphasised.

In this context, knowledge of both abundance, annual distribution and food consumption of crabeater seals (*Lobodon carcinophagus*), numbering in the order of 15 million individuals in Antarctic waters is of paramount importance since this most abundant of all pinniped species is supposed to prey heavily on krill. Assuming that this is true, it would imply an annual consumption of 40 million metric tons of krill by this species alone. Adding to this figure an annual krill consumption by at least one million minke whales of something in the order of 30 million tons implies that the understanding of energy fluxes and ecosystem dynamics requires knowledge of krill consumption by seals and whales in general, and how this is partitioned regionally and seasonally, in particular.

Assessment of the ecological role of the crabeater seal depends to a large extent on knowledge of population size, annual distribution of the population and their choice of prey at different times of the year. From these parameters food consumption can then be estimated on the basis of known physiological factors. The study is part of an international five-year research programme (Antarctic Pack Ice Seals (APIS)) concerning Antarctic pack ice seals as indicators of environmental changes and contributors to carbon and energy flux in the southern ocean (Anon. 1993). The programme is currently coordinated by the SCAR Group of Specialist on Seals, and was adopted at the XXIII SCAR (1994) meeting as priority research programme.

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Until recently, there only existed three published reports on crabeater seal stomach contents from February-October from a limited number of animals (Øritsland 1977; Lowry et al. 1988; Green & Williams 1986), and one study of crabeater seal diving behaviour in mid-March by use of short-range radio transmitters (Bengtson & Stewart 1992). Due to both logistical and exponentially increasing ethical constraints it is unlikely that adequate information on the diet of crabeater seals in the future can be obtained by traditional stomach content analysis. We have therefore made use of modern satellite telemetry which can provide both location and dive depth and duration data, subsequently to be related to prey abundance based on resource surveys, or already accumulated data on prey distribution and behaviour.

During the 1992/93 season on the Norwegian Antarctic Research Expedition to the waters off the coast of Dronning Maud Land eigh crabeater seals were tagged with Wildlife Computers 0.5 Watt satellite-linked dive recorders (SLDR's) to study seasonal changes in distribution and diving behaviour. The average life-time of the tags in this study was 77 days (32-110 days), except for one which was lost after only eight days. Information from a total of about 82,500 dives during the months February-June was obtained, showing that crabeater seals mainly feed in the upper water layers (< 50 m) during this period. This study moreover showed that crabeater seals are distributed within the deep pack-ice also when winter returns in these waters, in contrary to earlier perception. Analysis of movement patterns also suggested some correlation with bottom topography, in particular with local sea mounts within the Weddell Sea (Nordøy et al. 1993; 1994; 1995). During the 1992/93 expedition stomach and faecal samples were also obtained from a number crabeater seals for studies of energy assimilation from the food, an important parameter when calculating food consumption of crabeater seals. This study indicated that about 84% of the energy in Antarctic krill (*Euphausia superba*) is available for absorption (Mårtensson et al. 1993; 1994; 1994).

Tracking studies of crabeater seals were further pursued during the 1994/95 season, on the USCGC *Polar Star* research cruise around the Antarctic continent. The main purpose of this cruise was to assess the size of the crabeater seal population by ship and aerial surveys, as well as conduct further satellite transmitter tagging of this species to obtain information on habitat use, seasonal movements, haulout-patterns and diving behaviour (Bengtson et al. 1995). During this cruise a total of nine crabeater seals were tagged off the Queen Mary Coast, Prytz Bay, and in the Weddell Sea.

PURPOSE OF CURRENT PROJECT

1. Distribution and dive behaviour between February and January

The main purpose of the project is to collect additional information on the distribution and dive behaviour of crabeater seals by use of SLDR's, in particular from June till January, from which period very little information exists. This information, together with data on energy utilization of prey and other known physiological factors, will be used to estimate the annual food consumption of crabeater seals in the southern pack ice.

2. Seasonal changes in krill distribution

Currently, traditional methods such as net sampling and acoustics have clear limitations for evaluating krill distribution, particularly throughout the long winter season. The dive data from the 1993 expedition suggests that the major prey item of crabeater seals is krill, at least during autumn and early winter. We propose that the seasonal distribution of crabeater seals can be used as a indirect measure of krill distribution. The transmitters are equipped with temperature sensors which record sea water temperature at the different dive depths of crabeater seals, which may indicate water temperature preferences of krill. Thus another purpose of using satellite transmitters on crabeater seals is to increase our understanding of krill distribution and which physical factors that may influence it.

3. Abundance of seals in the pack ice

Another purpose of the project was to perform aerial surveys in the pack ice of the Weddell Sea and King Haakon VII Sea to count seals as part of the SCAR/APIS (Antarctic Pack Ice Seals) programme. Population estimates in relation to pack ice distribution, coverage and ice type are important input parameters when calculating the total food consumption of pack ice seals.

4. Physiological studies

Another objective was to do comparative studies of the digestive system of Antarctic seal species in order to relate the anatomy of the digestive system with the dive behaviour in order to test the hypothesis that species which have a well developed diving capacity (long dive durations) compensate for low blood flow to the digestive system during long dives, by having larger intestinal surface area.

5. Pilot studies of Weddell, Ross and leopard seals

A last objective was to perform initial tagging of Weddell, leopard and Ross seals with satellite transmitters to develop methods for handling and anaesthesia of these seal species, as well as doing pilot studies of their distribution and dive behaviour.

STUDIES PERFORMED

Aerial surveys

In the period 19.1 - 18.2 1997 a total of 14 hours of aerial surveys to count seals by use of helicopter was performed. A total distance of 1638 km was covered during these surveys. The preliminary results from these surveys are indicated in Table 1 and suggests a high density of pack ice seals in general, but quite surprising, also a very high density of crabeater seals (*Lobodon carcinophagus*), in particular, within heavy pack ice in the Weddell Sea. This observation ought to have impact on the design of future international (APIS) surveys in Antarctica during the 1998/99 season.

Table 1. Preliminary results from aerial surveys during NARE 96/97. Number of different species of seals observed (crabeater, Weddell, leopard, Ross and southern elephant seal (*Mirounga leonina*)), unidentified seals and total density of seals along the transect line.

Transect no.	Survey type	Date	Position start of survey	Begin time	End time	Distance (km)	Crab-eater	Weddell	Leo-pard	Ross	S.ele-phant	Unid.	Total no. of seals	Seals /km
1	Aerial	19.1.97	74° 16' S 25° 52'W	1018	1147	329	228		1				229	0.69
2	"	20.1.97	74° 25' S 26° 32'W	1008	1047	113	112						112	1.00
3	"	20.1.97	74° 25' S 26° 32'W	1118	1150	100	151						151	1.52
4	"	26.1.97	74° 00' S 24° 00'W	1400	1523	253	327						327	1.29
5	"	28.1.97	71° 47' S 19° 18'W	0827	0947	208	122			1			123	0.59
6	"	28.1.97	72° 02' S 18° 20'W	1155	1320	275	331	2	7	1		15	356	1.30
7	"	31.1.97	72° 25' S 16° 55'W	1249	1254	10	4	2					6	0.60
8	"	01.2.97	72° 20' S 15° 57'W	1314	1453	280	171	112		5		31	319	1.14
9	"	17.2.97	70° 06' S 04° 07'E	1557	1757	316	270	11	2			6	289	0.91
10	"	18.2.97	70° 02' S 05° 53'E	1120	1224	135	31	15	5	1	1	6	59	0.44
Σ				11 t	05 min	2019	1747	142	15	8	1	58	1972	

Tagging with satellite transmitters

A total of ten crabeater seals, one Weddell seal (*Leptonychotes weddelli*), two Ross seals (*Ommatophoca rossii*), and one leopard seal (*Hydrurga leptonyx*), were tagged with satellite transmitters, the latter two species for the first time in history. Data for position and size/sex are presented in Table 2. In early May 1997 four crabeater seal and one Ross seal transmitter are still active and transmitting information daily about movements, dive depths, dive duration and water temperatures at different dive depths.

Physiological studies

In agreement with a given permit two crabeater seals, one leopard seal and one Weddell seal were killed. One Ross seal died from anaesthesia (during a satellite tagging procedure) dispite considerable efforts to resuscitate the seal. Material from all seals is conserved for comparative studies of the digestive physiology of seals in relation to diet and dive behaviour.

Table 2. Data on seals tagged with SLDR's during the cruise with the *R/V Polar Queen* off Dronning Maud Land and in the Weddell Sea, January 4 - February 28, 1997 (NARE 96/97). The table shows the date and position of relase of the animals, the species, the total body length (snout to tip of tail) and sex.

Tag no.	Date	Time	Position	Species	Length (m)	Sex
14436	06.02.97	1200	73°49'S 23°05'W	Crabeater	2.02	F
14437	06.02.97	1645	73°49'S 23°05'W	Crabeater	2.35	M
14438	06.02.97	1750	73°49'S 23°05'W	Crabeater	1.90	M
14439	06.02.97	2245	73°40'S 22°41'W	Crabeater	2.50	F
14440	07.02.97	1140	73°44'S 24°29'W	Crabeater	2.45	F
14441	07.02.97	1325	73°43'S 24°18'W	Crabeater	2.37	F
14442	07.02.97	1715	73°51'S 23°45'W	Crabeater	2.19	M
14443	12.02.97	1100	72°12'S 16°11'W	Crabeater	1.88	M
14444	12.02.97	1400	72°12'S 15°53'W	Crabeater	1.96	M
14445	12.02.97	1730	72°25'S 17°03'W	Crabeater	2.17	M
17610	12.02.97	1900	72°32'S 16°35'W	Weddell	2.77	F
17606	13.02.97	1350	71°59'S 17°32'W	Ross	2.10	M
9871	16.02.97	1525	69°33'S 00°26'W	Leopard	2.22	M
9870	18.02.97	1330	69°25'S 07°24'E	Ross	2.23	F

Table 3. Data on seals killed for different physiological studies during NARE 96/97. The table shows the date of capture, sex, body weight (BW), body length (BL) and weight of different internal organs.

Species	Date	Sex	BW (kg)	BL (cm)	Heart (kg)	Lungs (kg)	Liver (kg)	Spleen (kg)	Kidneys (kg)
Crabeater	03.02.97	M	181	222	1.1	2.1	3.1	0.5	1.2
Crabeater	04.02.97	F	122	194	0.8	1.4	3.0	0.2	1.0
Leopard	10.02.97	M	178	2.47	1.1	2.2	6.7	0.5	1.8
Leopard	10.02.97	F	469	3.05	2.1	4.2	9.1	2.0	2.1
Weddell	12.02.97	F	314	2.65	1.3	3.7	6.2	2.7	1.3

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MONICA ALTERSKJÆR OLSEN[1] & SVEIN DISCH MATHIESEN[2] :

ANATOMY AND MICROBIOLOGY OF THE DIGESTIVE TRACT OF THE ADELIE PENGUIN

ABSTRACT

The krill-eating adelie penguin is one of the most abundant species of penguins, breeding in large colonies on the Antarctic coast. The current study was conducted to gain information on anatomy and function of the digestive tract of these birds, and also to investigate the effect of dietary acrylic acid on the intestinal microflora. The adelie penguin had a relatively long oesophagus but no crop, a stomach that was divided into a glandular proventriculus and a muscular gizzard. The gizzard in many of the adelie penguins investigated contained grit (small stones) which probably help to churn the food. The surface lining of the proventriculus was acidic, indicating that HCl is secreted in this initial stomach compartment. The small intestine of these birds measured 4.5-6.3 x body length (n=5), the colon was about 3.3 cm long, and they had rudimentary, paired cecae. Low concentrations of bacteria were found in the mucous lining of the small intestine, which might be explained by the antibacterial effect of the acrylic acid. The small size of the colon indicates that the relative contribution of this compartment to the total digestion of the prey is small. Median numbers of viable bacteria in the contents of the colon inoculated in a culture medium containing chitin for 96 h ranged between 2.35×10^5 - 8.75×10^6/ml in the birds examined (n=3). Identification of the bacterial isolates from the intestine of the adelie penguin and microanatomical studies of the different compartments of the digestive tract is currently in progress.

INTRODUCTION

The adelie penguin (*Pygoscelis adeliae*) breeds on the Antarctic coast and associated islands. It is, with the Emperor penguin (*Aptendytes forsteri*), the most southerly breeding penguin. Information on structural and functional features of their digestive system is important in understanding their ability to utilise the prey, and hence, how they cover their energy needs for maintenance, growth and reproduction. Data on the gastrointestinal tract of penguins are, however, scarce (Reid 1835; Jackson & Place 1990; Jackson 1992), and in the present work we therefore intended to describe the gross and micro anatomy of the gastrointestinal (GI) system of the adelie penguin on which functional assumptions can be made.

Low concentrations of aerobic bacterial populations and even sterility of the digestive tract of penguins have been reported (Soucek & Mushin 1970; Lésel & Menet 1977), although Sieburth (1959a) found two adelie penguins devoid of aerobic bacteria to have small but detectable anaerobic bacterial populations present in the intestine. The phenomena of sterile intestines is suggested to be caused by the antimicrobial properties of the acrylic acid secreted by alga (Sieburth 1959b; Sieburth 1960; Sieburth 1961), which are ingested by krill, an important dietary component of the adelie penguin (Emison 1968; Paulin 1975; Watanuki et al. 1994). The microbiological techniques have improved since the 1970ies. Hence, we wanted to enumerate the

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total population of anaerobic bacteria on the small intestinal mucosa and of the contents of the small intestine.

The exoskeleton of the krill contains chitin and the adelie penguin seems able to digest 25-35% of this substrate (Staley & Herwig 1993). The birds are thought to produce chitin-degrading enzymes which are secreted into the small intestine from the pancreas (Stemmler et al. 1984). Moreover, bacteria isolated from the colon contents of the adelie penguin have been shown to have the ability to brake down chitin (Stemmler et al. 1984). In the current study we also wanted to isolate and characterise the chitinolytic bacterial strains from the colon of these birds.

MATERIALS AND METHODS

Animals

A total of fifteen adelie penguins were killed and examined during the Norwegian Antarctic Research Expedition 1996/97; in addition one adelie and one emperor penguin harvested on the Norwegian Antarctic Scientific Expedition 1992/93 are included in this data set.

The animals were harvested in the Weddell and Haakon VII Sea between 70°S 9°W and 74°S 25°W in January and February. They were killed with an overdose of pentobarbital (50 mg/ml) (Nycomed Pharma AS) or by one lethal blow to the head. Body mass and body length were recorded prior to sampling.

Gross anatomy

The tissue wet weight of each part of the digestive tract was weighed to the nearest 0.1 g and the length measured to the nearest mm. The proventriculus was regarded to be the portion of the gastric region covered with secretary cells. The gizzard was considered to be the part of the gastric region between the proventriculus and pyloric sphincter. For both proventriculus and gizzard, maximal length and width (opened) were used to estimate planar surface area. The length of each intestinal part was measured with the segment fully extended but not stretched. Width of each section of the oesophagus and intestine was measured on opened segments at the proximal, mid- and distal sections. Planar surface area was estimated from the product of length and mean width.

Microanatomy

Small tissue samples from each part of the GI system was fixed in 10% formalin with phosphate buffer (pH 7.3, 317 mosm) for routine histology of the GI mucosa, and in McDowells phosphatebuffer (pH 7.3, 322 mosm) for transmission electron microscopical (TEM) examinations of the tissue.

pH

The pH of the contents and the mucosa of each section of the digestive tract were measured using a portable pH meter (PHM 201, Radiometer Copenhagen®) and a combined pH electrode (pHC2005 and pHC2441, Radiometer Copenhagen®) immediately after the death of the birds.

Intestinal bacteriology

The anaerobic bacterial population of the small intestinal mucosa and the contents of the small and large intestines of the penguins were enumerated and isolated by use of strict anaerobic methods (Sørmo et al. 1994; Olsen et al. 1994). The initial part of the small intestine (the duodenum) was removed and the small intestine was divided in two equally long sections comprising the proximal and distal part, which were ligated in both ends. The two parts were then cut in 10 cm sections which were opened by cutting longitudinally and put directly into 500 ml anaerobic buffer (M8) were they were washed vigorously. Samples (2.5 ml) of the mucosa, including the epithelium, were scraped off randomly selected segments under sterile conditions with a scalpel inside a tent maintained with an atmosphere of CO_2. Each sample was homogenised in 22.5 g M8 buffer containing 0.1% methylcellulose (Kudo et al. 1987) in a Polytron PT 10OD homogenizer (Kinematica, GMD, Luzern, Switzerland). The tissue suspensions from the proximal and distal small intestine were diluted serially in ten fold steps in M8 buffer, and made viable by inoculating 1 ml from each dilution in quadruplicate in Hungate tubes containing M8V and MRS and incubated at 39°C. Colonies of viable anaerobic and aerobic bacteria were counted and results presented as number of bacteria per ml wet weight of mucosa. Contents from the middle of the small intestine and from the colon were diluted serially in ten fold steps in M8 buffer, and made viable by inoculating 1 ml from each dilution in quadruplicate in Hungate tubes containing M8V and MRS, and M8CH, respectively, and incubated at 39°C. M8 anaerobic buffer (Olsen et al. 1994) formed the basis of the anaerobic medium (M8V) (Orpin et al. 1985) and the M8CH containing 0.5% collodial chitin (Olsen et al. 1994) as sole source of carbohydrate. A solution of vitamins (0.1 ml per 10 ml medium) (Roché et al. 1973) was sterile filtered through a Millex®-GS single use filter unit (0.22 μm) (Millipore S. A., Molsheim, France) and added to both the M8V and the M8CH medium before use. An aerobic M.R.S. Broth medium (Code CM359) with addition of 2% (w/v) agar was used to select for lactobacilli. Small sections (0.5x0.5 cm) of the small intestine were fixed in McDowells phosohate buffer (pH 7.3, 322 mosm) and prepared for TEM (Sørmo et al. 1994) to study the bacterial population adherent to the mucosa of the small intestine.

The culture tubes were kept at 4°C and the isolation of the bacterial strains were initiated immediately after arrival to Tromsø. Bacterial colonies were picked from their original culture tubes using sterile glass Pasteur pipettes under strict anaerobic conditions for strains growing on M8V and M8CH, and under aerobic conditions for strains growing on M.R.S. medium according to Olsen et al. 1994b.

RESULTS

Animals

Mean (±SD) body mass and body length of the adelie penguins investigated were 4957 ± 1203 g (n=15) and 55.1 ± 1.9 cm (n=15), respectively. The emperor penguin (n=1) examined weighed 18000 g and had a total body length of 105.0 cm.

Gross anatomy

Both the adelie and the emperor penguin had a relatively long oesophaguses (Table 1) but no crop like that found in many other birds such as the ptarmigan. The lining of the oesophagus was white with longitudinal foldings. The stomach was divided into a glandular compartment (the proventriculus) and a muscular compartment (the gizzard). In several of the birds examined the gizzard contained stones which probably support churning the prey. The intestine measured between 252 and 360 cm (4.5-6.3 x body length) in five adelie penguins examined and is small compared to 629 cm (6 x body length) in the emperor penguin (Table 1). The ceca were situated at the junction between the small intestine and the colon, they were paired and rudimentary (Table 1). The colon was very short and the wet mass of the colon comprised only 1.71% and

0.94% of the total GI-tract wet mass in adelie and emperor penguin, respectively (Table 1).

Table 1. Gross anatomy of the oesophagus and gastrointestinal tract of penguins.

	Adelie penguin (n=1)	Emperor penguin (n=1)	Rockhopper penguin[1]
Body mass	6500	18000	2000
Wet mass (g)			
Oesophagus	22.1	83.0	n.d.
Proventriculus	18.6	64.0	15.3
Gizzard	23.9	68.0	14.4
Small intestine	99.4	279.0	45.6
Ceca	1.0	2.3	n.d.
Colon	2.48	4.7	1.3
Total[2]	145.4	501.0	76.6
Length (cm)			
Oesophagus	19.0	47.5	n.d.
Proventriculus	12.5	13.0	5.5
Gizzard	6.0	9.8	7.5
Small intestine	338.0	629.0	465.8
Ceca	1.7 & 1.9	2.9 & 2.85	1.6 and 1.3
Colon	3.3	9.1	9.6
Total[2]	359.8	660.9	488.4
Planar surface area (length x width, cm²)			
Oesophagus	67.45	205.7	n.d.
Proventriculus	100.0	130.0	55.0
Gizzard	40.8	127.4	71.3
Small intestine	771.8	1805.2	372.6
Ceca	2.0 & 2.3	5.5 and 4.9	1.9 and 0.5
Colon	7.8	22.8	10.6
Total[2]	924.7	2095.8	511.9

1. Data from Jackson & Place (1990).
2. Not including oesophagus. Totals for length exclude the ceca. n.d. = not determined

Microanatomy

The microanatomy of the various compartments of the GI-tract of the adelie penguin is currently under examination.

pH

The surface pH (mean values for three adelie penguins) of the oesophagus decreased from 5.10 in the upper part of the oesophagus to 4.31 in the lower part. The proventriculus surface pH ranged from 2.90 to 3.92, while in the gizzard it ranged between 2.53 and 3.39. The pH of the contents of the proventriculus ranged between 4.08 and 4.52 and of the gizzard between 3.66 and 3.86 in two birds examined. The surface pH of the small intestine was slightly acidic, ranging from 6.81 in the duodenum to 6.79 at the end of the intestine in the one bird examined. The mean surface pH of the caecum and colon were 6.52 and 6.48, respectively, measured in two birds.

INTESTINAL BACTERIOLOGY

Small intestinal mucosa

Median viable numbers of bacteria in the mucosa of the small intestine of the adelie penguins (n=3) examined were low, ranging between 500 and 10500 per ml mucosa in the proximal part of the small intestine and between 450 and 97500 per ml in the distal part after using the M8V medium. A total of 266 colonies were selected from the culture tubes and streaked on M8V for isolation, many of these original colonies gave 2-3 different strains on isolation, but of the original colonies 69.9% were viable on isolation. A total of 256 bacterial strains have been isolated from the proximal and distal part of the small intestinal mucosa, of which 55% were facultatively anaerobic. Using an aerobic MRS medium to select for lactobacillus spp. gave viable number of bacteria ranging from 150 to 9000 cells per ml in the proximal small intestinal mucosa and 60-160000 cells per ml in the distal small intestinal mucosa of the adelie penguin (n=3). Only 31% of the colonies picked (n=198) were viable on isolation. The bacterial isolates from M8V and MRS are now being characterised in our laboratories in Tromsø.

Small intestinal contents

Median numbers of viable bacteria in the contents of the small intestine ranged between 5000 and 7500 / ml on M8V and 2100 and 105,000/ml on MRS in the two penguins examined. Only 32% of the colonies (n=72) picked from M8V were viable on isolation, while non of the colonies (n=72) picked from MRS were viable on isolation.

Colon contents

Median numbers of viable bacteria in the contents of the colon inoculated in M8CH medium ranged between 235,000 and 8,750,000 / ml after 96 h incubation in the birds examined (n=3). A total number of 131 bacterial strains were isolated from the M8CH medium, all of which were strict anaerobes.

DISCUSSION

Preliminary results of this study indicate that the adelie penguin has a relatively simple digestive tract consisting of a long oesophagus, a proventriculus, a gizzard, a small intestine, short paired ceca, and a short colon. According to Prévost & Vilter (1962) the emperor penguin secretes oesophageal milk rich in proteins (59%) and containing 28% lipids and 8% carbohydrates, which is fed by the fasting male to the young chicken if the mother is delayed on her return from sea. We do not know if the adelies produce this type of milk in their oesophagus. Both the adelie and the emperor penguins lack the crop, but the wet mass of the oesophagus comprise equal amounts (13.2% and 14.2%) of their total digestive tract (including the oesophagus) (Table 1).

The stomach was divided into a proventriculus with an acidic lining and contents, and a gizzard containing grit. The grit may be important to assist churning rough components in the food, like the chitinous exoscelleton of the krill.

The small intestine measured 4.5-6.3 x body length in adelie penguins examined compared to 6 x body length in the emperor penguin (Table 1) and 7 x body length in the king penguin (*Aptenodytes patagonicus*) (Reid 1835). The small intestine of the herbivorous adult male willow grouse (644 g) killed in winter in Finnish Lapland measured 129.7 cm (intestinal length/body mass: 201) (Puilliainen 1976), compared to only 338 cm in an adelie penguin (intestinal length / body mass: 0.052) (Table 1). For comparison, the small intestine measured 20.5 m and 21 m in two monogastric krill-eating crabeater seals investigated (intestinal length/body mass: 0.17 and 0.12) (Mårtensson, unpubl. data). Jackson (1992) found a clear relationship between mean retention time of digesta and the length of the intestine in penguins and other seabirds. She also argues that a greater gut surface area in penguins compared to flying seabirds may be an adaptation enabling penguins to meet the relatively high energy cost of swimming. The relationship between the planary surface area of the intestine and the body mass (kg) was 201, 223 and 155 in rockhopper (*Eudyptes chrysocome*), gentoo (*Pygoscelis papua*) and king penguin respectively, compared to much lower values in both the adelie (120) and the emperor penguin (102) resembling that of the sooty albatross (*Phoebetria fusca*) (116) (Jackson, 1992) (Table 1). The small relative size of both the ceca and the colon (Table 1) indicate reduced importance of these compartments in the digestion of penguins, although chitinolytic bacteria have been isolated from the colon contents of adelie penguins (Stemmler et al. 1984). Microanatomical studies still remain to be done in order to describe the function of each compartment of the digestive tract of the adelie penguin. Low concentrations of anaerobic bacteria in the mucosa of the small intestine of the adelie penguin, is most probably a result of the antibacterial component acrylic acid found in the prey. The intestinal bacterial population is now being characterised in our laboratories in Tromsø.

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ELSE NØST HEGSETH[1], CECILIE HELLUM VON QUILLFELDT[1] & BJØRNAR SEIM[1] :

PRODUCTIVITY IN THE SOUTHERN WEDDELL SEA IN THE AUSTRAL SUMMER

INTRODUCTION

Today, Antarctica is recognised as a mosaic of productive systems (Tréguer & Jaques 1992), and phytoplankton distribution has been shown to have a great impact on the structure of the upper level pelagic food webs (Ainley et al. 1991). The Weddell Sea is an important area for primary production in the Antarctica, belonging mainly to the seasonal ice zone (SIZ). The western part is ice-covered all year, while the eastern part is normally ice-free in summer, with large coastal polynyas opening up in spring. Phytoplankton blooms in neritic areas are generally more dominated by diatoms than oceanic stations; here the populations have been found to be more flagellate-dominated during summer (Nötig et al. 1991a). Ice edge blooms during melting season in spring have been found in the western part (Fryxell & Kendrick 1988), but not in the eastern (Scharek et al. 1994), probably linked to different hydrographic conditions.

Ice algae have been found inside the ice in summer in the pack ice zone (Ackley et al. 1979; Nötig et al. 1991b; Syvertsen & Kristiansen 1993; Fritsen et al. 1994), and in the south also in thick layers under the fast ice due to formation of ice crystals in the deep raising through the water, and accumulating algae inside on its way to the surface (Eicken 1992). This may cause major blooms in the open water as well, «superblooms» (El-Sayed 1971; Sakshaug 1989; Smetacek et al. 1992). Hence the Weddell Sea has several productive zones, the southern part probably being the most productive in years when the water is open.

OBJECTIVES

Originally, the main objective of the project was to study the productive system of the southern Weddell Sea, both in open water and in the ice. However, when entering the Weddell Sea in January, it became clear that it would not be possible this austral summer. The ice cover was exceptionally in its extension, and almost no open water was observed. Two attempts to go south ended at 74°30' S, from there on the ice was too thick to proceed. The project had to be changed, and according to what was possible to do, work was concentrated on the following objectives based on a new plan: *Distribution and development of phytoplankton and ice algae in an ice-covered area of the eastern Weddell Sea during summer.*

- Will a phytoplankton bloom develop in an extremely short summer?
- What is the extension and duration of the bloom?
- Which are the most important conTROLLing factors for bloom initiation?

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- What is the chemical composition of the particulate matter, including phytoplankton? What is the effect of summer UV radiation on the phytoplankton primary production?
- What is the concentration of ice algae in the area?
- Is the species distribution different in different parts of the area, and which are the important factors conTROLLing the distribution?
- Does ice algae seed the phytoplankton bloom?
- Does the krill feed on ice algae during summer?
- What is the chemical composition of the ice algae, included the content of stable isotopes and organic pollutants (PCB, toxaphene)?

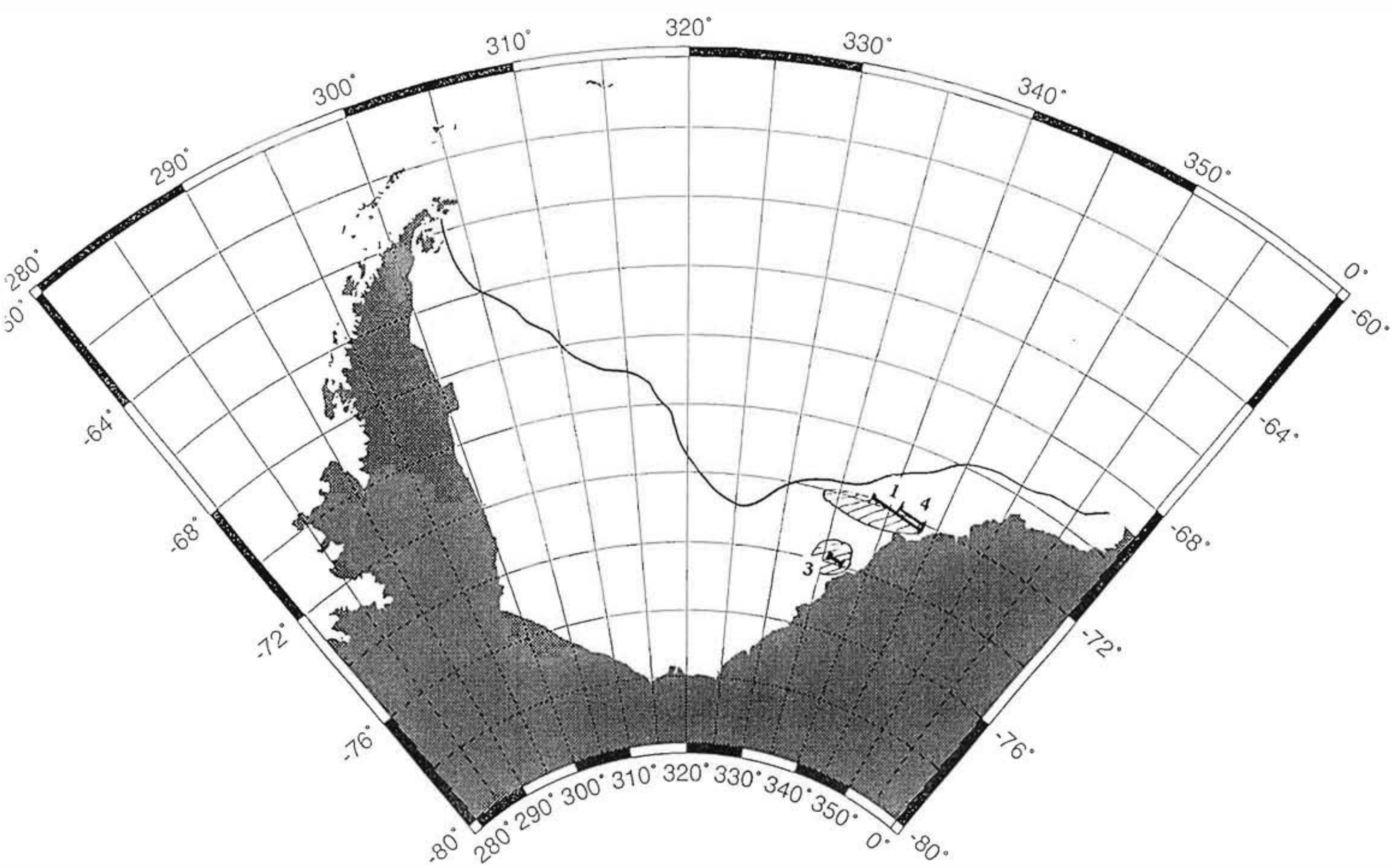

Fig. 1. Map of the Weddell Sea, showing position of transects for phytoplankton sampling and areas (shaded) for ice algal sampling.

STUDY AREA

The study area covered the coast of Dronning Maud Land to 5° E, and the north-eastern part of the Weddell Sea (Fig. 1) between 74°30' and 71° S, and 26° and 16°30' W, which is the area between the western side of the Antarctic Coastal Current and the ice barrier. The extension of the area was limited by the ability of the ship to move in the heavy pack ice.

MATERIAL AND METHODS

Incoming radiation [PAR (400-700 nm) and 4 wavelengths in the UV part (308, 320, 340, 380 nm) of the spectrum] was measured during the cruise period by a PUV500 irradiance meter (Biospherical Instruments) mounted on deck. At several open water stations underwater irradiance (same wavelengths) was measured down to 80 m by the instrument's underwater sensor. Measurements also included natural fluorescence.

Phytoplankton was sampled both quantitatively from water bottles (Rosette sampler on a Neill Brown CTD) and qualitatively from net samples (25 μm mesh size). Biomass distribution was obtained by a fluorescence sensor mounted on a small CTD (Multipar, Meerestechnik Elektronik), and 12 sampling depths were adjusted to the biomass profile to give an optimal coverage down to 100 or 150 m. On every station chlorophyll was measured in total samples and in the size fraction below 20μm in parallels. In the latter case, water was sieved through a 20 μm net before filtration. Samples were measured fluorometrically in a Turner Designs fluorometer, using methanol as extracting solvent (Holm-Hansen et al. 1965). On several stations samples were taken for cell numbers and identification (formaldehyde preserved) and for nutrient measurements. Additionally, samples for particulate matter (particulate organic carbon, nitrogen, phosphorus and biogenic silica) were taken at some stations. Samples other than for chlorophyll measurements were brought home for later analysis.

Incubations for production measurements were performed on deck with water samples from 0 and 10 m to test a possible effect of UV radiation on the primary production, measured as ^{14}C uptake. Phytoplankton was incubated in 50 ml tubes of quarts (stops none of the radiation), quarts with mylar film (stops UV-B) and quarts with pyrex shields (stops all UV radiation) and exposed to natural incoming radiation for 6 hours during daytime.

Ice algae were sampled by diving, either by a hand-held small corer, or by an electric suction sampler (Lønne 1988). Diving was performed in leads, and samples were taken from the surrounding ice-floes. Additional light measurements were performed on sampling sites using a hand-held irradiance meter (QSI-140, Biospherical Instruments) measuring into the ice where the algae samples had been removed. Salinity and temperature in the leads were measured by a small salinoterm (YSI 30). The algae were usually incorporated in ice. Ice cores were melted slowly over night in darkness and at low temperature. The next day samples were taken for analyses of chlorophyll, particulate organic carbon, nitrogen, and phosphorus, biogenic silica and cell numbers. At some stations samples for stable isotopes and organic pollutants (PCB, toxaphene) were collected. On several occasions krill were sampled from the under-side of the ice or from caves in the ice for identification, age determination and gut content investigations, usually by a hand-held net or a suction sampler.

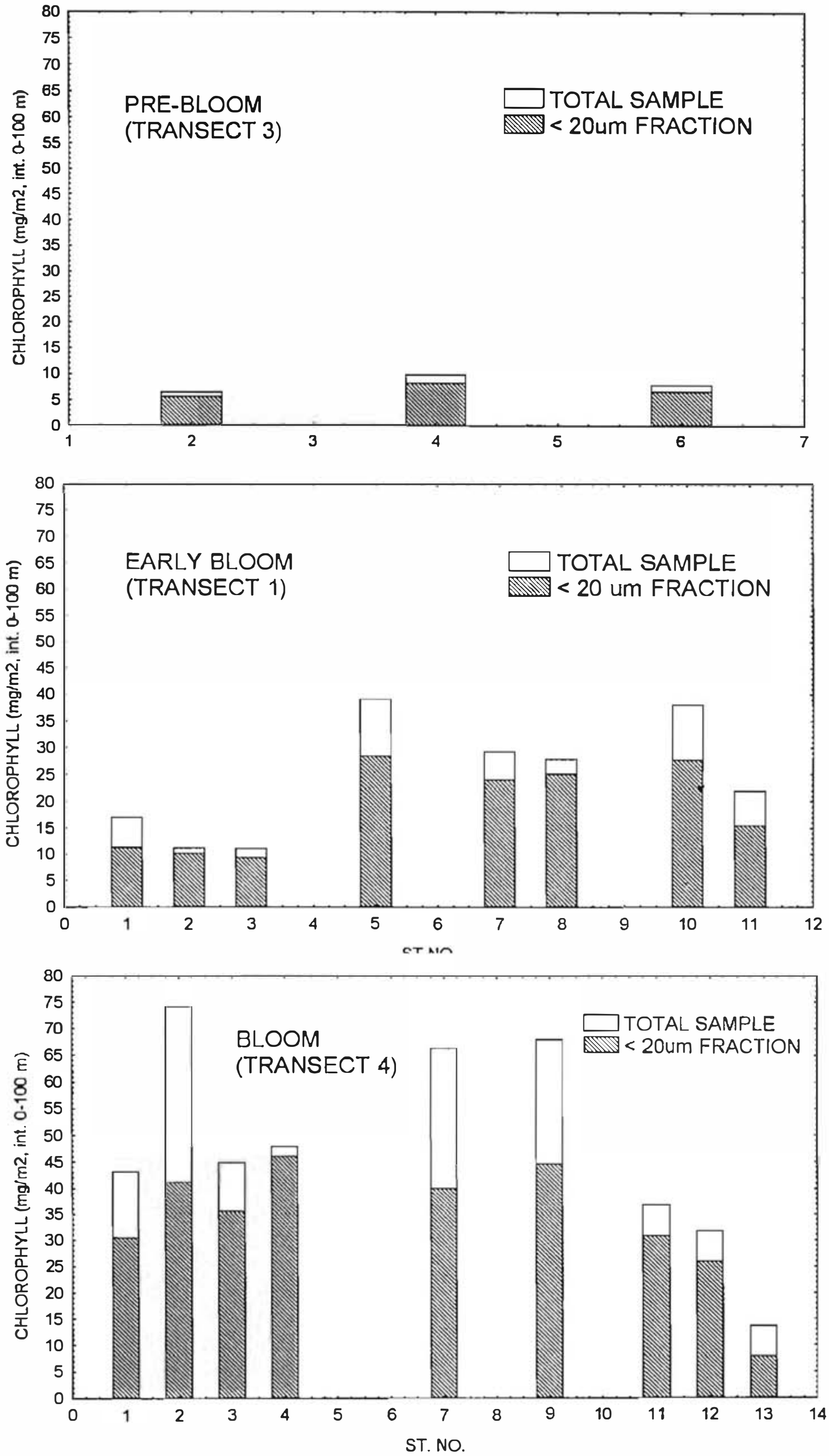

Fig. 2. Values of integrated chlorophyll (mg m^{-2}, 0-50 m) during a prebloom (transect 3), early bloom (transect 1) and bloom (transect 4) situation. Bars show chlorophyll of total samples and of the < 20 μm fraction. Station 1 is at the western end of the transects, Station 9/14 are at the eastern end.

PRELIMINARY RESULTS

Phytoplankton

Five transects were performed along with the CTD-samplings (Fig. 1), with a total number of 45 stations. In addition, 20 stations of net sampling were performed. The first transect in the end of January was taken at 72°30' S in an area with some open water, and showed that the phytoplankton was distributed mainly over the slope and the shelf, and less over deep water. The next transect was taken further south at 74°30' S, but here the phytoplankton biomass was extremely low (0.03-0.04 μg chlorophyll l^{-1}, integrated 4-5 mg m^{-2}). This area had been ice-covered all summer, according to ice maps. We moved back north again to the position where the first transect was made and carried out two new transects, now in mid February. Since our first sampling a bloom had developed. Biomass had increased to a maximum of 1.5 μg l^{-1}, and integrated chlorophyll was up to 55-60 mg m^{-2}. Compared to a spring bloom on the northern hemisphere these are low values, but in Antarctica it is recognised as a bloom. Thus we encountered a development from late winter (pre-bloom) to spring (bloom) conditions during the time we were there (Fig. 2).

The phytoplankton biomass was mainly concentrated in the upper 40-50 m. Light penetrated down to 80 m, while the euphotic zone was about 35 m before the bloom, decreasing to only 20 m during the bloom (Fig. 3) From the shape of the natural fluorescence profiles, we could see that the production maximum coincided well with the biomass maximum (Fig. 3).

The phytoplankton was completely dominated by small species with cell size less than 20 μm (Fig. 2). On all stations and at all depths this fraction made up 55-95% of the chlorophyll biomass, and on average in a non-bloom situation 80% was nano-plankton, slightly lower in a bloom (65%). Diatoms were predominant in the net samples (small cells pass through the net), and the species composition was in most cases comparable to the diatom flora in the ice (Table 2), although there was a relative increase of other species like *Chaetoceros dichaeta, Corethron criophilum, Fragilariopsis kerguelensis, F. pseudonana, Proboscia alata* and *Rhizosolenia hebetata* f. *semispina.*

Ice algae

Ice algae was mainly sampled in two areas (Fig. 1) in a total of 80 samples. Brown ice was observed almost everywhere when floes were broken and turned over by the ship, and in leads lots of brown slush and lumps were floating. At the beginning of the cruise, along the coast of Dronning Maud Land, infiltration layers (between snow and ice on top of ice floes) were observed. Later on, however, when entering the Weddell Sea, the ice flora was mainly concentrated to internal bands from 0.5 to 3 m depth inside the ice, or on all sides of underwater ridges where it sometimes could be collected by suction pump. The chlorophyll concentration of the bands varied between 0.65 and 29 mg m^{-2}, but most of the concentrations were in the range of 5 to 10 mg m^{-2} (Table 1).

Samples were also taken from the lower part of the ice barrier where ice algae formed a 2 m thick layer in some areas, like a littoral zone. This layer was covered by water on high tide, but visible on low tide. Biomass of this layer was comparable to the average band concentration (Table 1).

Krill were creeping around on the ice underside, particularly in January/early February. Later in February most of it had disappeared. The krill population was mainly dominated by young stages.

Table 1. Average chlorophyll concentrations (mg m^{-2}) of ice algae in various biotopes in the eastern Weddell Sea during summer, 1997.

Biotope	**Chlorophyll concentration (mg m^{-2})**
Internal bands	10.3
Infiltration layer	13.8
Barrier	5.3
Pressure ridges	3.2

The species composition in the ice barrier algae differed somewhat from the rest of the sampling area in the north by being dominated by an unknown diatom species (Table 2). The most dominant species in all Weddell Sea ice were the diatoms *Fragilariopsis cylindrus* and *F. curta*, while in melt ponds the plankton population was dominated by the haptophyte *Phaeocystis antarctica*, and small brown threads in the ice consisted of the diatom *Berkeleya adelienses.* The total number of algal species recorded so far is 80, mainly diatoms.

Table 2. Dominating species in ice algal samples from various assemblages of the eastern Weddel Sea pack ice in the austral summer 1997

Type of ice	**Assemblage**	**Dominating species**
Pack ice, south	Band assemblage	*Fragilariopsis cylindrus, F. curta, Pseudonitzschia subcurvata, Cylindrotheca closterium*
Pack ice, south	Meltpool assemblage	*Phaeocystis antarctica*
Pack ice, north	Infiltration assemblage	*F.curta, Nitzschia sp., Stellarina microtrias, Nitzschia taeniformis, Phaeocystis antarctica*
Pack ice, north	Band assemblage	*F.curta, Nitzschia sp., Odontella weissflogii, S. microtrias, Entomoneis sp.*
Fast ice, north	Band assemblage	*F.curta, Pleurosigma antarctica, O. weissflogii, Nitzschia taeniformis, N.stellata*
Barrier, north	Band assemblage	*Navicula/Fragilaria sp.*

CONCLUSIONS

The productive season in the open water of the eastern Weddell Sea in the summer of 1997 was short and limited to a small area. In the northern part ice maps showed no opening until the beginning of February, but small areas were ice-free at the end of January during our first transect. An early bloom situation (Fig. 2) showed that the ice-cover must have been open, at least partly, for some time. Further south no phytoplankton growth had taken place,

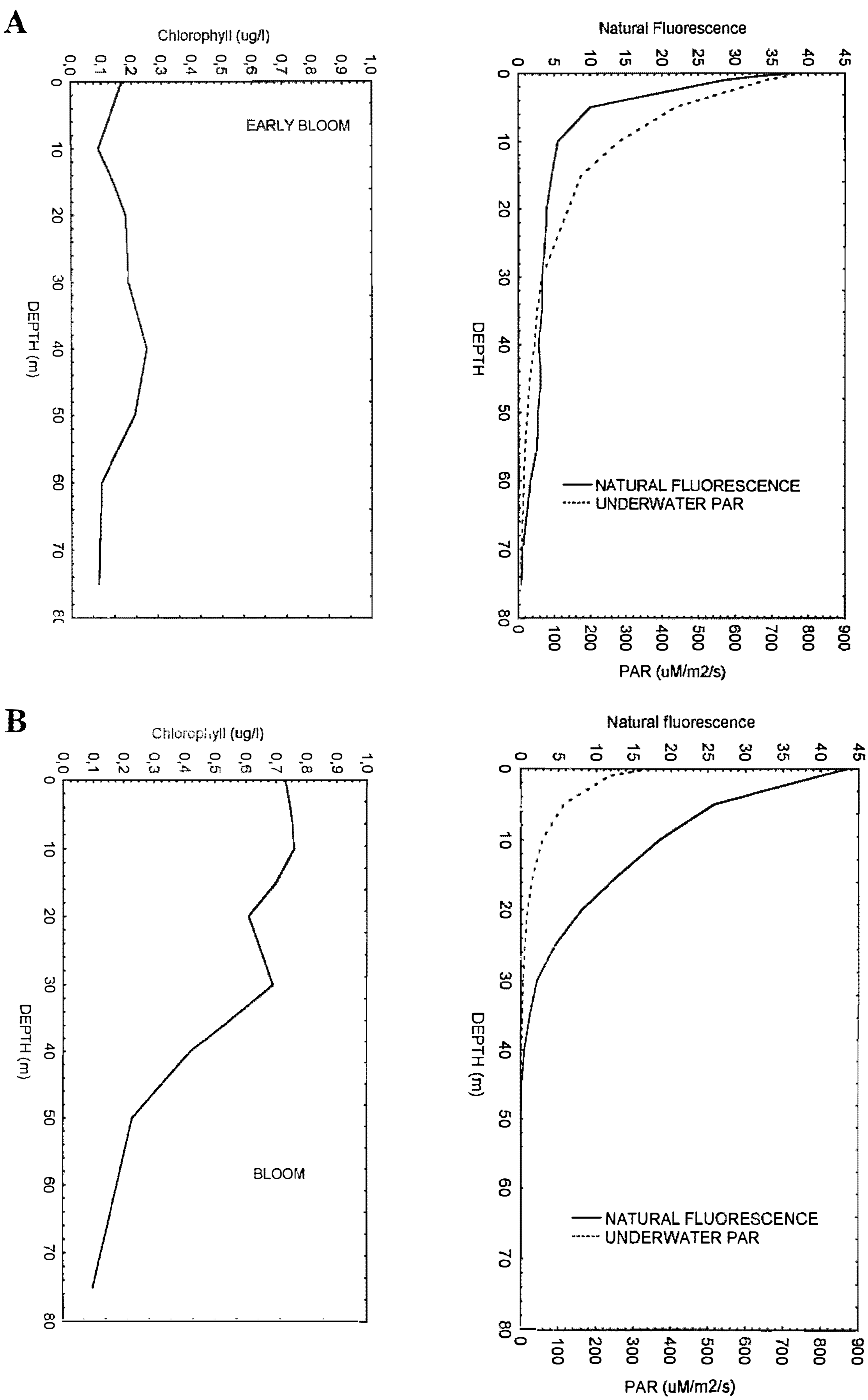

Fig. 3. Biomass (chlorophyll, $\mu g\ l^{-1}$, left), production [from natural fluorescence] and underwater irradiance [PAR, $\mu M\ m^{-2}\ s^{-1}$ (P), right] from A) early bloom and B) bloom.

indicating complete ice cover most of the time before we arrived. Two weeks after the first transect at our northern position, a bloom had developed. It is not possible to decide how far it was from peaking, but the dominance of the < 20μm fraction indicates that it had not yet reached its full potential, and that, given enough time, diatoms may have been taking over. When we left in the middle of February, however, freezing had started in open water, and the ice would probably close the area within a short time. At best, the open water productive season would last a month in the limited open areas north of 73° S, and considerably shorter further south.

The low number of diatoms in the water may be an explanation for the fact that the infiltration layer was almost missing in the Weddell Sea. The ice algal vegetation of the internal bands in the ice was most probably a result of growth of cells frozen into the ice the previous season, resuming growth when light became sufficient in spring. During the ship's first leg in December to the coast of Dronning Maud Land, much brown ice was observed, indicating start of the growth season well ahead of that. This means that the growth season in the ice probably lasted four months, maybe longer, as growth may have continued well into March, and could have started as early as October.

The summer of 1997 was exceptional in the Weddell Sea by having extreme amounts of ice and correspondingly small areas of open water, all of short duration. Hence, the primary production this year was to a large degree restricted by the ice. This may favour the young krill population which is known to feed on ice algae, but the effect on the ecosystem still remains to be seen (Knox 1994),.

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OLE ANDERS NØST[1] & TORLEIF LOTHE[2] :

THE ANTARCTIC COASTAL CURRENT - PHYSICAL OCEANOGRAPHIC RESULTS FROM NARE 1996/97

INTRODUCTION

Since the work of Deacon (1937) it has been known that the main source of bottom water is in the southern Weddell Sea. Dense High Salinity Shelf Water (HSSW) formed on the southern Weddell Sea continental shelf sinks down the continental slope and mixes with the Warm Deep Water (WDW, temperature above 0.5 and salinity above 34.70 psu) to form Antarctic Bottom Water (AABW). The mean circulation is along the coast from east to west. During the westward flow the water masses are influenced by brine release during sea ice formation in the coastal polynyas, and by dilution and cooling by interaction with the ice shelves. The Low Salinity Shelf Water (LSSW, temperature near freezing and salinity between 34.3 and 34.4 psu) is formed along the coast of Dronning Maud Land and advected into the southern Weddell Sea by the westward flow of the Antarctic Coastal Current. Thus, the Antarctic Coastal Current is feeding the southern continental shelf with source water masses to the dense water formation processes. The coastal current also plays an important role in continental shelf-deep ocean exchange processes as it separates the shelf water masses from the WDW when flowing along the shelf edge of the southern continental shelf (Gill 1973).

The Antarctic Coastal Current can be seen as a deepening of the pycnocline from around 150 meters depth in the central Weddell Sea to about 500 meters above the continental slope (Sverdrup 1953; Fahrbach et al. 1992; 1994). Sverdrup (1953) suggested that this deepening of the pycnocline was due to an onshore component of the Ekman transport driven by the mean wind conditions in the region. Fahrbach et al. (1994) concludes that the deepening of the pycnocline is mainly due to haline convection in coastal polynyas. In the coastal polynyas the heat flux to the atmosphere averages about 400 W m^2 during the winter period (Markus et al. 1997), and this heat loss is balanced by latent heat release during sea ice formation and/or the heat flux associated with the upwelling of WDW. During sea ice formation in the coastal polynyas, brine is released to the upper water masses. This destabilises the water column and causes vertical convective mixing, which mixes WDW up into the mixed layer. Fahrbach et al. (1994) concludes that about one third of the heat from the upwelled WDW is causing glacial melting. This glacial melting balances the input of salt caused by sea ice formation and the result of this process is a deepening of the pyconcline and the formation of LSSW.

Fahrbach et al. (1992) made measurements of current speed in the coastal current using moored current meters. Their results show annual mean current speeds ranging from 10 to 20 cm s^{-1}. They also report variations on a time scale of 5 to 15 days superimposed on significant annual and interannual variations of the currents. Variation of the current compare well with variations observed in the wind field at Georg von Neumayer Station.

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On NARE 96/97 we made hydrographic measurements within the coastal current. CTD sections across the coastal current with station spacing down to 1 nautical mile where obtained, and two drifting buoys with underhanging temperature and salinity strings where deployed near Halley Bay.

OBJECTIVES
The objectives of this project are:

- To identify and understand the driving forces of the Antarctic Coastal current.
- To identify and understand processes important for the melting of glacial ice.
- To estimate the transport of the coastal current into the southern Weddell Sea continental shelf.

STUDY AREA
Fig. 1 shows the study area with buoy drift tracks and CTD stations marked.

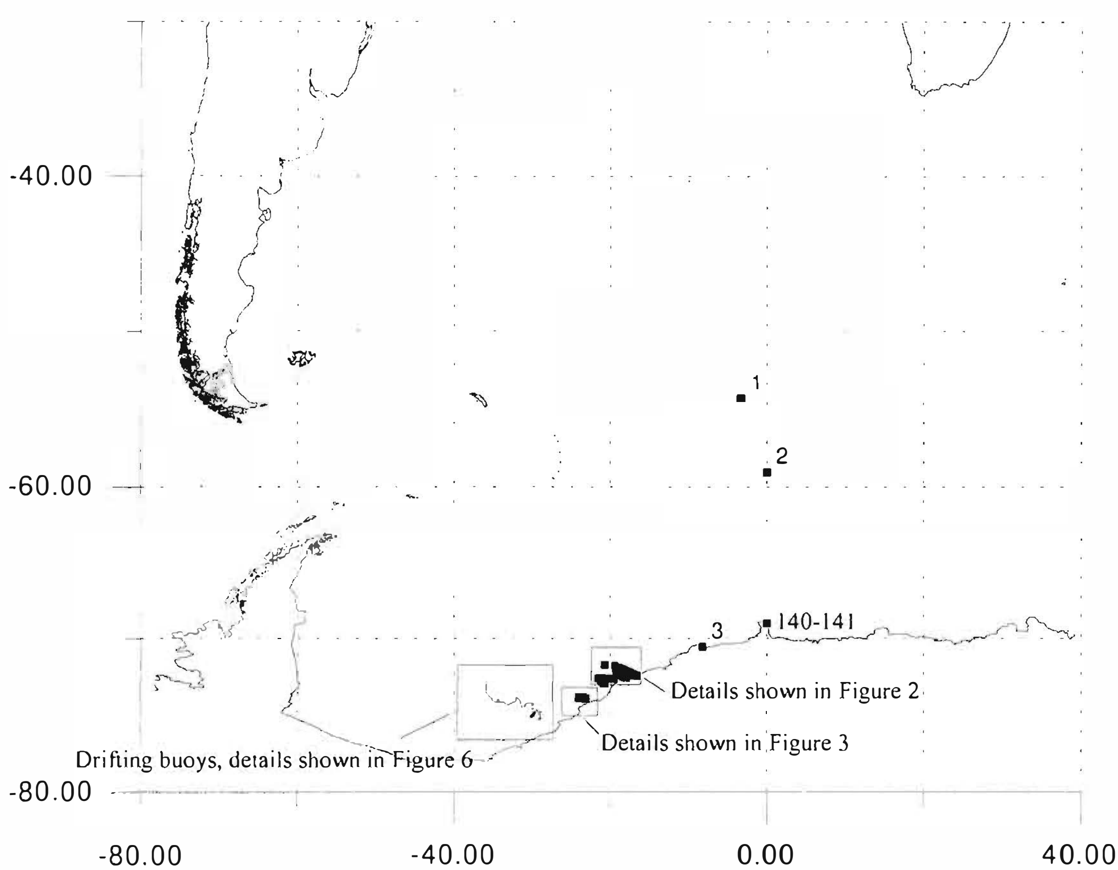

Fig. 1. Map showing all the CTD-stations and locations of drifting buoys. Details are shown in Figs. 2, 3, and 6.

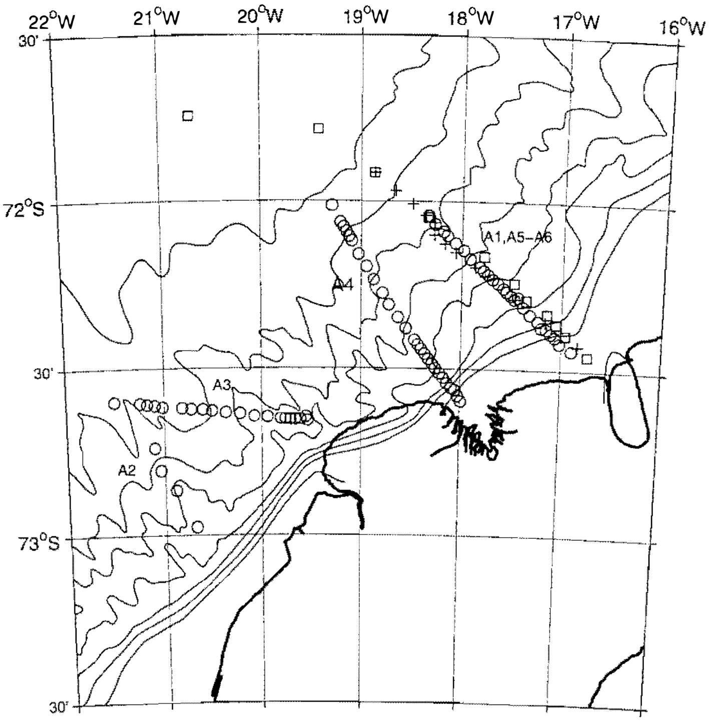

Fig. 2a. Sections A1 to A6 drawn as a function of latitude (y-axis) and longitude (x-axis). A2-A4 and A6 are marked with circles. A5 is marked with plus signs, and A1 is marked with squares. Details of A1, A5 and A6 are shown in Fig. 2b.

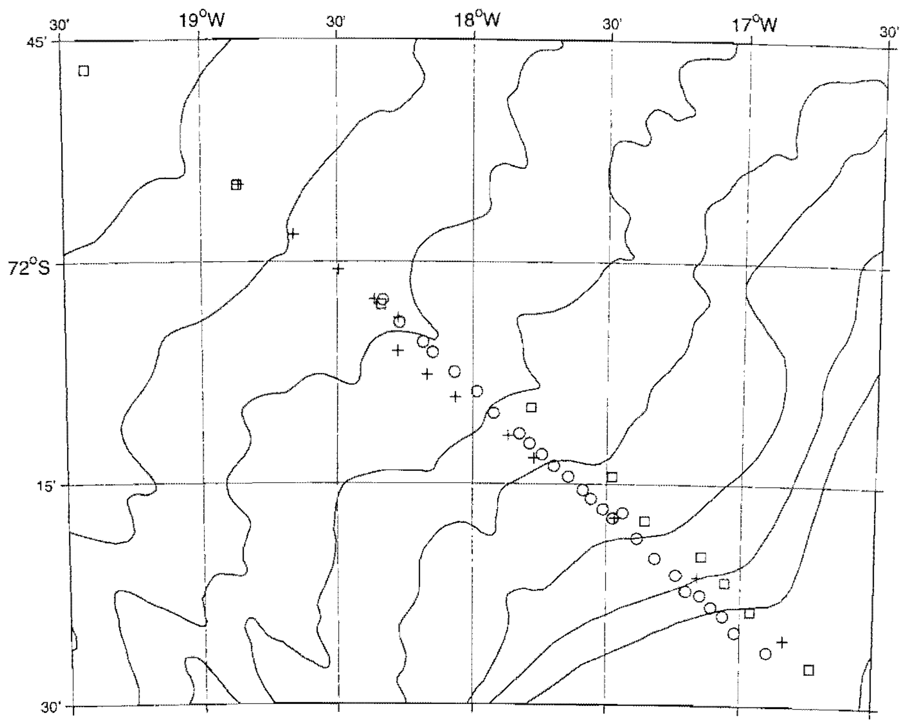

Fig. 2b. Sections A5 and A6 drawn as function of latitude (y-axis) and longitude (x-axis). A1 is marked with squares, A5 with plus signs, and A6 with circles.

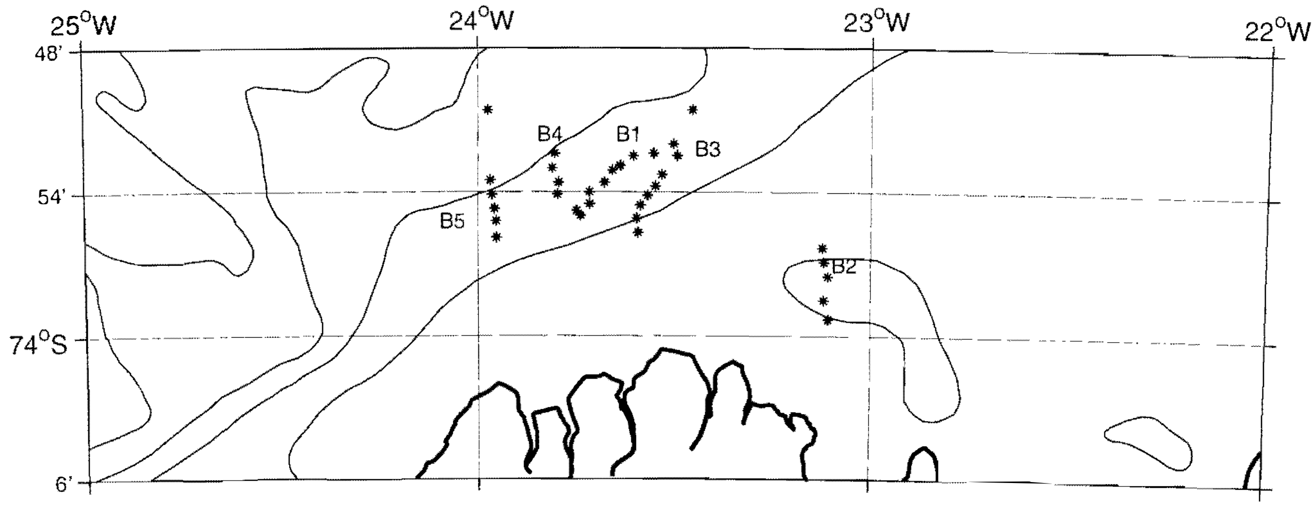

Fig. 3. Sections B1 to B5 drawn as a function of latitude (y-axis) and longitude (x-axis).

METHODS AND INSTRUMENTATION

CTD-sections: A total of 141 CTD station were obtained at the cruise. Stations number 1, 2, 140 and 141 are measurements at the positions of the recovered and deployed AWI (Alfred Wegener Institute) moorings. Station 3 is a test station outside the Neumayer station, and stations 15 and 16 are obtained upon request from the marine biologists. The rest of the CTD measurements were sections normal to the coast.

The accuracy of the CTD data are +/-6 dbar for the pressure, +/- 0.005 °C for the temperature and +/- 0.006 psu for the salinity.

The station numbers and positions of these sections are shown in Table 1. The sections A1-A6 cover the stretch from the coast and across the coastal current. Sections A3, A4 and A6 have station spacings down to 1 nautical mile (nm) in frontal and continental slope regions, while sections A1 and A5 have lower spatial resolution. Sections B1-B5 are from 3 to 5 nautical miles (nm) long, are all starting a few metres from the ice shelf front, and have station spacings around 0.5 nm.

Drifting buoys: Two drifting buoys with underhanging temperature and salinity strings were deployed at positions 75°30'S, 30°00'W and 75°00'S, 30•00'W on 24 January 1997. These positions are on the continental shelf outside Halley Bay (see Fig. 1), which is the region where coastal current waters is transported into the southern Weddell Sea. Three weeks after deploying, the buoys had both drifted about 20 nm northeastwards.

Moorings: In addition to performing CTD measurements and deploying drifting buoys, we also deployed three and recovered four moorings for the Alfred Wegener Institute (AWI). These moorings are not part of the Antarctic Coastal Current project. The mooring positions are:

- (54°20.6'S, 03°17.0'W) Recovered
- (59°01.9'S, 0°01.3'W) Deployed and recovered
- (69°24.2'S, 0°00'W) Deployed and recovered
- (69°00'S, 00°00'W) Deployed and recovered

Table 1. Positions and numbering of CTD sections

CTD-stations	Section name	Starting position	Ending position
4-14	A1	71°44.5'S, 20°41.7'W	72°27,4'S, 16°44.1'W
50-54	A2	72°58.6'S, 20°41.0'W	72°36.0'S, 21°30.6'W
54-73	A3	72°36.0'S, 21°30.6'W	72°39.5'S, 19°31.8'W
74-100	A4	72°35.8'S, 17°59.7'W	72°00.9'S, 19°17.3'W
101-113	A5	71°54.8'S, 18°51.7'W	72°25.5'S, 16°50.3'W
114-139	A6	72°02.6'S, 18°20.0'W	72°26.4'S, 16°53.4'W
17-25	B1	73°55.0'S, 23°44.4'W	73°52.0'S, 23°30.2'W
26-30	B2	73°59.3'S, 23°06.4'W	73°56.3'S, 23°07.4'W
31-38	B3	73°55.7'S, 23°35.3'W	73°50.6'S, 23°27.3'W
39-43	B4	73°54.8'S, 23°45.0'W	73°52.4'S, 23°48.3'W
44-49	B5	73°55.9'S, 23°57.2'W	73°50.6'S, 23°58.5'W

PRELIMINARY RESULTS

CTD sections

As an example of the sections across the coastal current section A6 is shown in Fig. 4. Typical features of the coastal current seen in this section is the pronounced deepening of the pycnocline about 50 km from the coast. The highest baroclinic velocities are associated with the front which is about 15 km wide.

Fig. 5 shows section B1 which represents the fine resolution sections perpendicular to the ice shelf front. Near the bottom we can clearly see the Warm Deep Water penetrating beneath the ice shelf. Signs of upwelling can be seen near the ice shelf front, but it is not known if this is driven by melting at the ice front or other mechanisms.

Drifting buoys

The data from the drifting buoys have still not been analysed. Fig. 6 shows the drift tracks of the two buoys from the 24 January to 6 June.

CONCLUSION

During NARE 1996/97 we collected high resolution temperature and salinity data sections across the Antarctic Coastal Current at several locations. This is the first step in reaching the objectives listed above. We are now developing a model of the coastal current which will help us to understand the mechanisms important for driving the coastal current and melting glacial ice. With this model we may also estimate the transport of the coastal current.

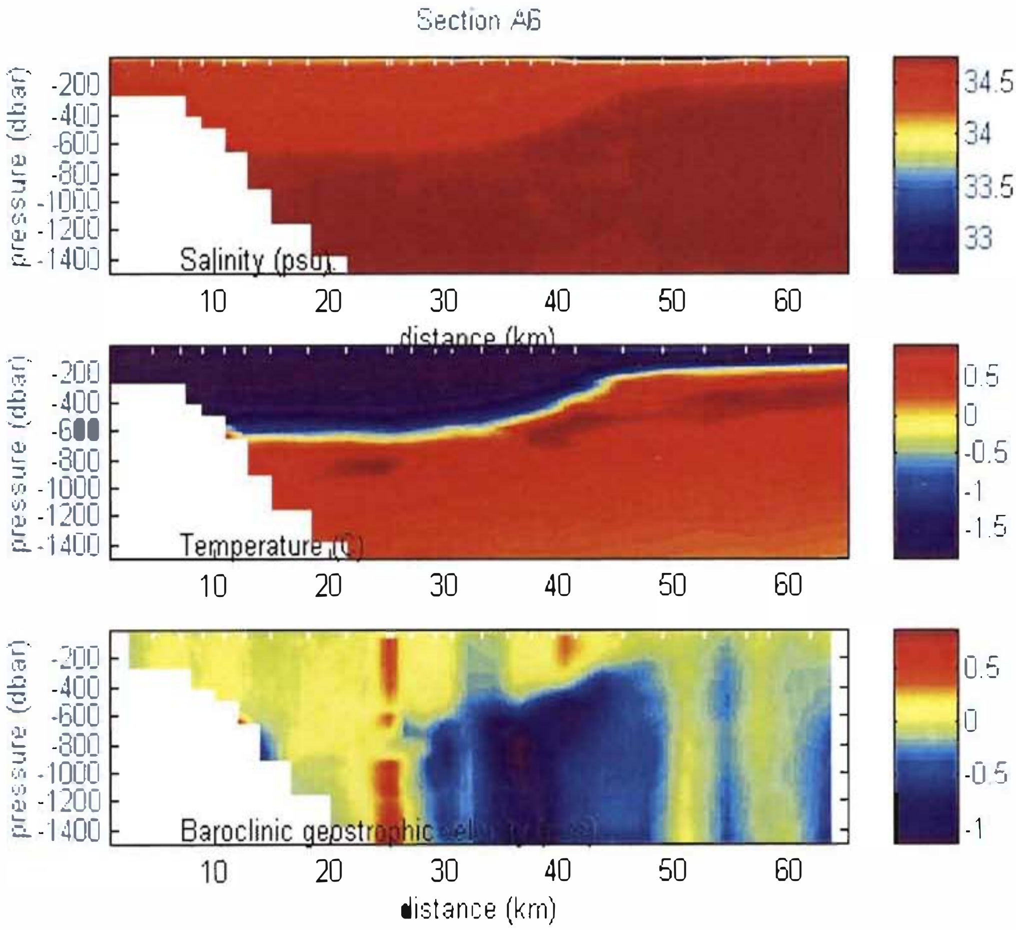

Fig. 4. Section A6 crosses the coastal current. Note the deepening of the pycnocline as seen about 50 km from the coast.

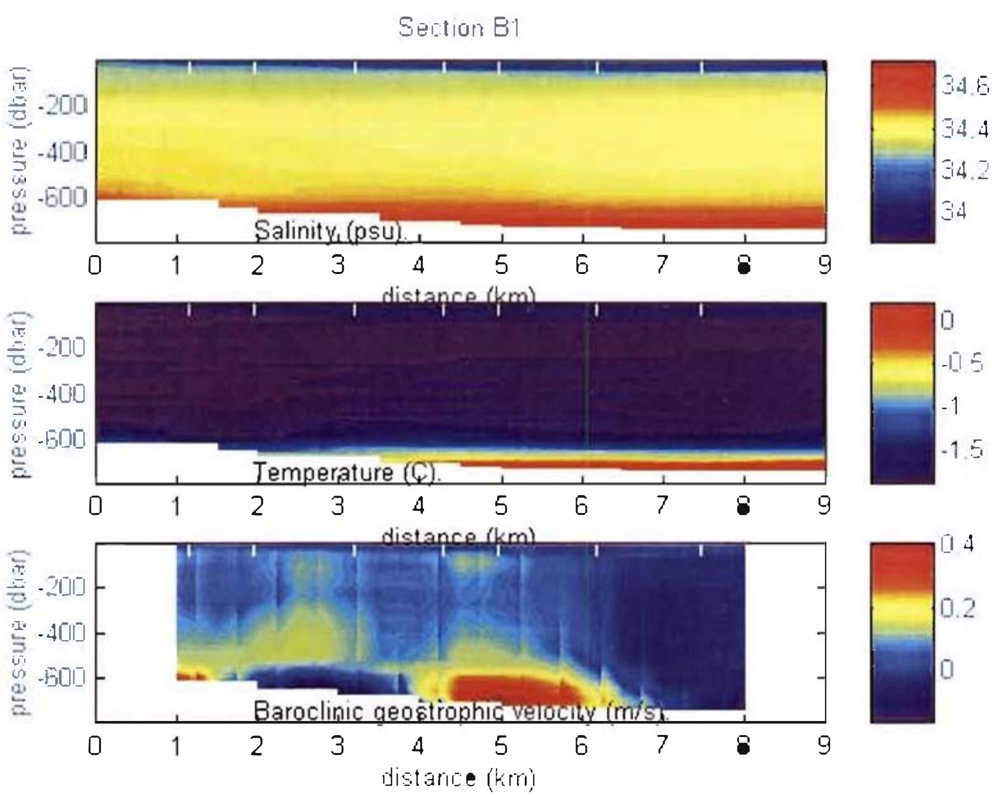

Fig. 5. Section B1 represents fine resolution sections perpendicular to the ice shelf front. Note the WDW close to the bottom.

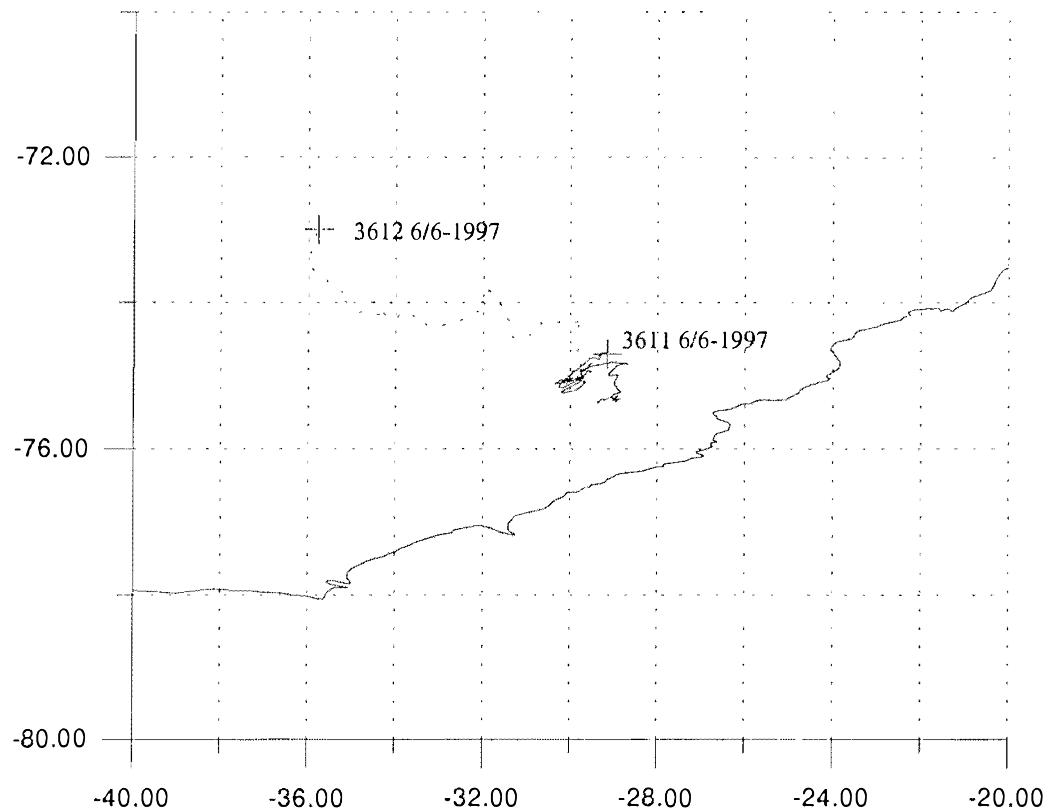

Fig. 6. Drift tracks of buoys 3611 and 3612 plotted as a function of latitude (y-axis) and longitude (x-axis).

ACKNOWLEDGEMENTS

We want to give special thanks to Ekkehard Schütt for very valuable help on board the *Polar Queen*. Thanks are also due to the crew and everybody participating in the marine programme for giving us a pleasant time on board the *R/V Polar Queen*.

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NALÂN KOÇ[1], BERIT KUVAAS[2] , YNGVE KRISTOFFERSEN[2], ERIK HANSEN[3] & ALLAN PERSSON[3] :

TIMING OF GLACIAL EVENTS IN ANTARCTICA
- diamond drilling into the glaciomarine sequence of the Weddell Sea continental shelf

INTRODUCTION

The climatic evolution of the Earth during the Cenozoic largely reflects a trend towards lower temperatures and cryospheric development of the polar regions, initially in Antarctica and later in the Northern Hemisphere. An understanding of the climatic, paleoceanographic and cryospheric evolution of Antarctica is crucial to a broader understanding of global long-term climatic and oceanographic change and assist in our understanding of modern oceanographic and climatic processes (Kennett & Barker 1990).

One of the major scientific problems in recent years and the main objective of four Ocean Drilling Programme (ODP) legs (113, 114, 119, 120) has been the evolution of the cryosphere of Antarctica and the surrounding oceans. Several scientists have attempted to document the variations in the volume of the Antarctic Ice Sheet indirectly, from the oxygen isotope ratios observed in shells of benthic foraminifera in deep sea sediments and investigation of the occurrence of ice-rafted debris (Hodell et al. 1991; Muller et al. 1991; Shackleton & Kennett 1975).

The glacial sediments on the continental shelf of Weddell Sea provide direct evidence for the position of the Antarctic Ice Sheet through time. Transport of sediment to the continental slope and rise is highly cyclic. During periods of maximum glaciation, the grounding line of the ice sheet expanded across the Weddell Sea continental shelf and reached the shelf break (Kuvaas & Kristoffersen 1991). Hence, the sediments are partly eroded, and large volumes of glacial sediments were deposited directly to the shelf break/upper slope. During interglacials sediments are deposited at the grounding line of the ice sheet on the shelf. Hemipelagic sedimentation of biosiliceous ooze and calcareous material takes place in the open water areas.

Although the southern Weddell Sea is one of the most inaccessible areas around Antarctica because of nearly permanent heavy pack ice coverage, considerable amounts of seismic profiles have been acquired during Norwegian and German expeditions to this area. There is not a single stratigraphic tie point available for calibration of the glacial sequences in the area older than the last glacial maximum at 20 ka.

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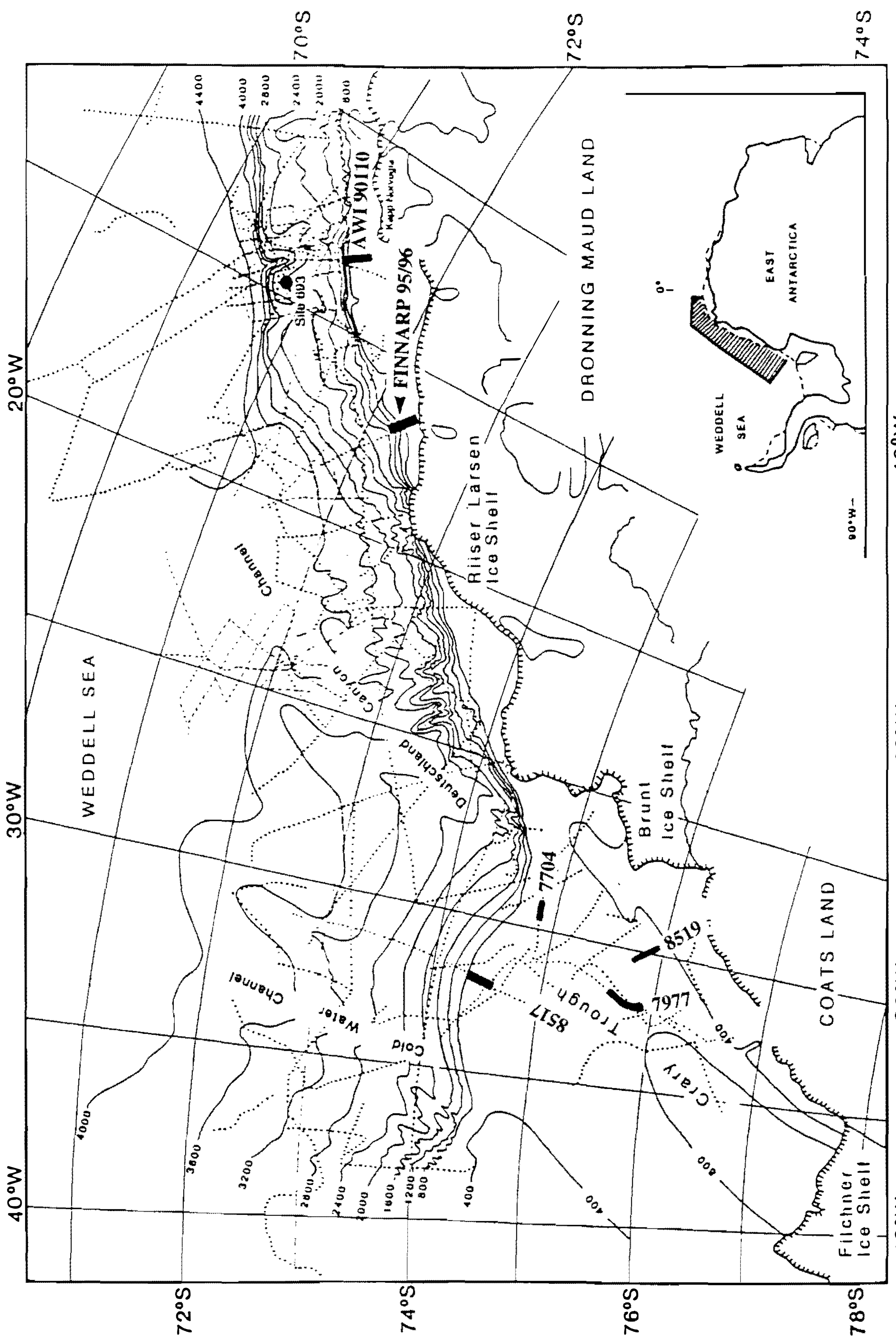

Fig. 1. Location of Crary Trough and originally proposed drill sites along seimic profiles in the Weddell Sea.

Biostratigraphic and magnetostratigraphic control are crucial for interpreting the timing of glacial events. Siliceous microfossils are the most important group of fossils present in the shelf sediments of Antarctica since the early Tertiary and therefore offer great opportunity for dating the timing of Antarctic glaciations.

OBJECTIVE

The main objective of the original project proposal was to study the chronology and variations in the extent of the Antarctic ice sheet along the Dronning Maud Land from sediments deposited on the continental shelf.

STUDY AREA

The primary target area was the Crary Trough (Fig. 1). The convergent ice flow pattern amplifies changes in the glacial history of the catchment area, and the signal is expected to be recorded as changes in the erosional/depositional environment on the adjacent shelf and slope. We, therefore, considered profile NARE 85-17, located along the axis of the Crary Trough to contain the most detailed record of the glacial events along the margin of the southern Weddell Sea. However, the heavy sea ice cover during the cruise period made access to the area impossible.

We alternatively drilled in the Kvitkuven area. A hole was drilled at this area during the FINNARP 95/96 cruise and a detailed seismic study was carried out (Fig. 2). These seismic profiles, together with the current ice conditions, were taken into consideration to choose the drill sites. Drilling at three different sites were attempted (Sites 1, 2 and 3) (Figs. 2, 3 and 4). Site 1, Holes A-C were located by the shelf ice near Kvitkuven. Sites 2 and 3 were located further out on the shelf in more open water conditions.

Site 1
Hole A: 72°30.335´S, 16°32.059´W water depth: 218 m
Hole B: 72°30.330´S, 16°31.800´W water depth: 214 m
Hole C: 72°30.330´S, 16°32.100´W water depth: 218 m

Site 2
Hole A: 72°26.980´S, 16°34.610´W water depth: 282 m

Site 3
Hole A: 72°25.930´S, 16°31.760´W water depth: 224 m

METHODS

The drilling operation was carried out by GEO DRILLING a/s, Namsos, an experienced land wire line drilling contractor.

The drill rig was a DB 1200 which can handle 1200 m of drill string with a core diameter of 43 mm. The weight of the rig was 7 tons plus the weight of the drill string of about 1.5 tons. The weight of the whole drill rig was rested on the ship's deck and the pipe went into the water 20-30 cm from the port side of the vessel. First an outer pipe (76 mm inner diameter) was lowered and suspended from the drill rig to serve as a riser. The riser was secured by the winch wire of the *Polar Queen* attached to a bottom frame, and clamped to the wire at regular intervals. This was to provide support for the drill string in the water column during rotation. It also served as a safety measure against accidental loss of equipment. A drill

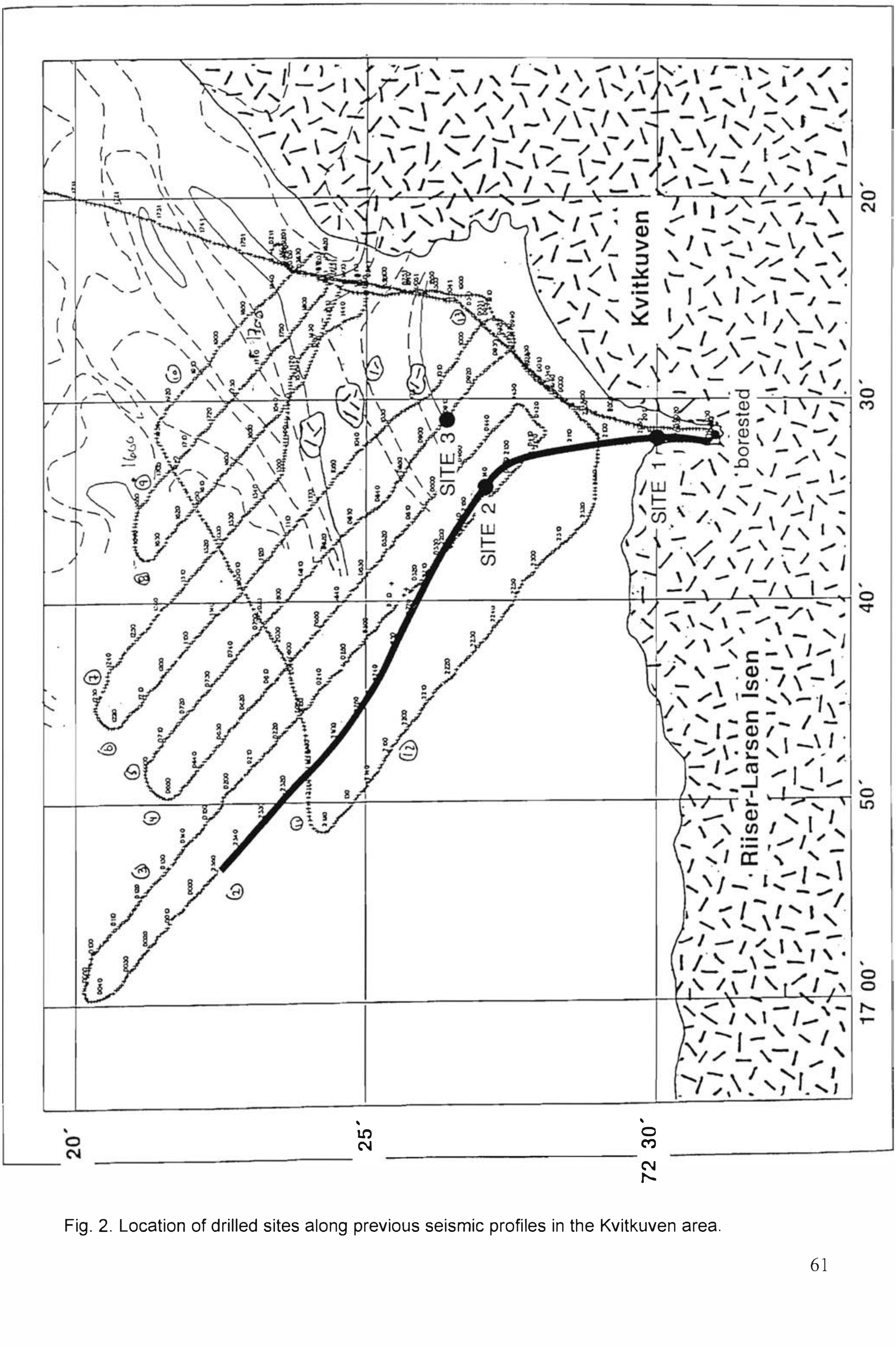

Fig. 2. Location of drilled sites along previous seismic profiles in the Kvitkuven area.

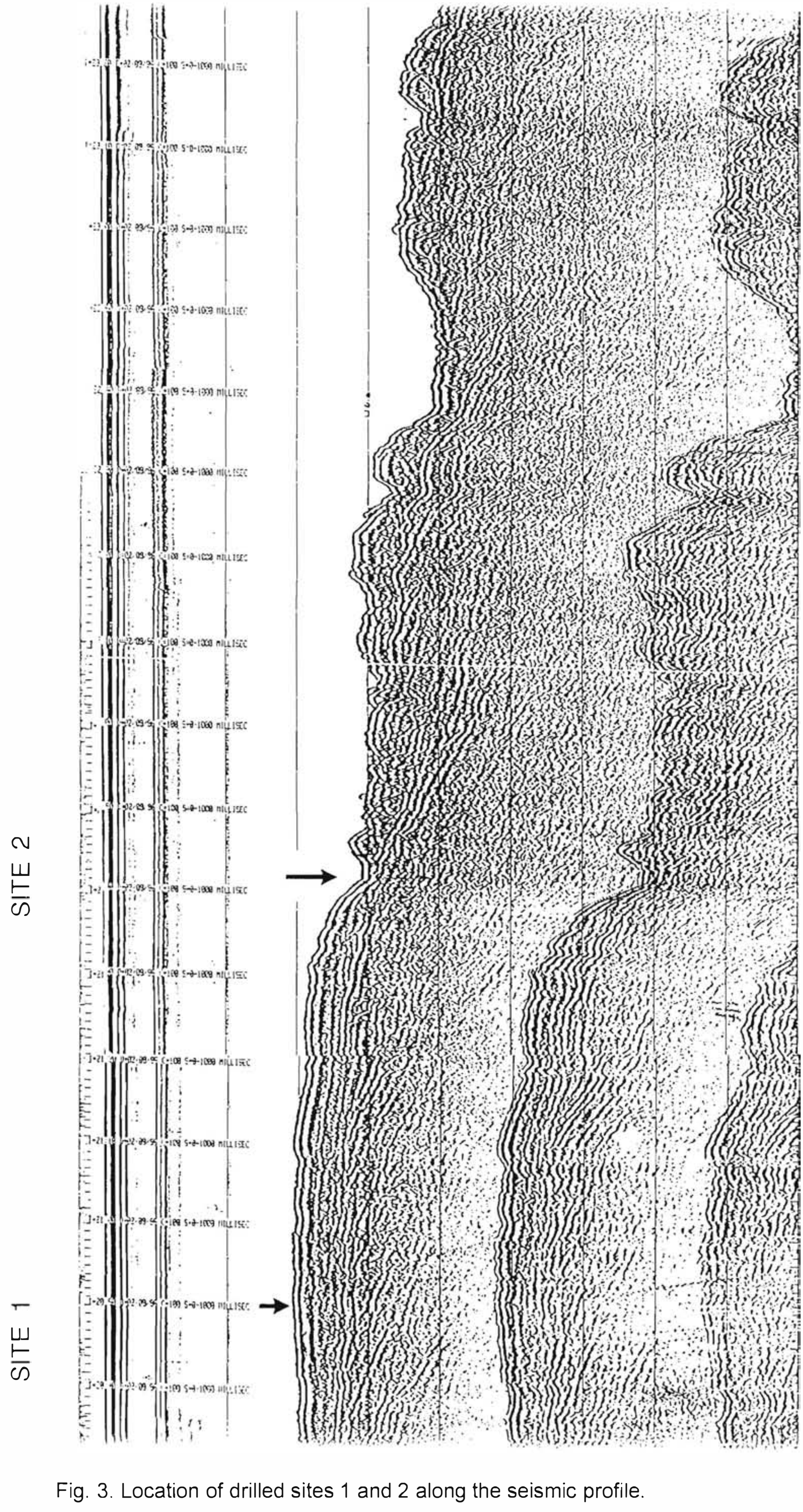

Fig. 3. Location of drilled sites 1 and 2 along the seismic profile.

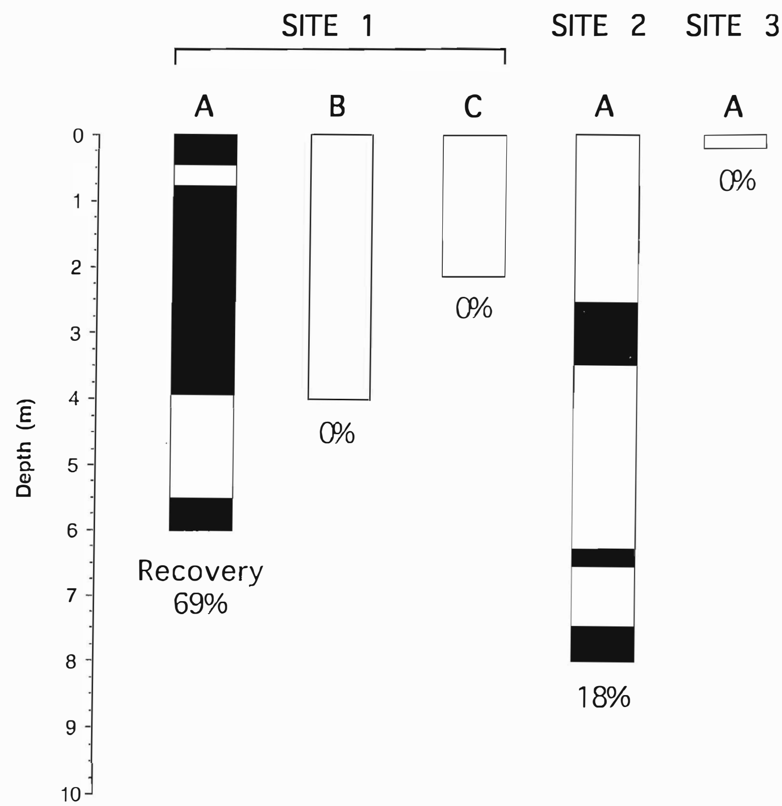

Fig. 4. Drlling and recovery results from each site.

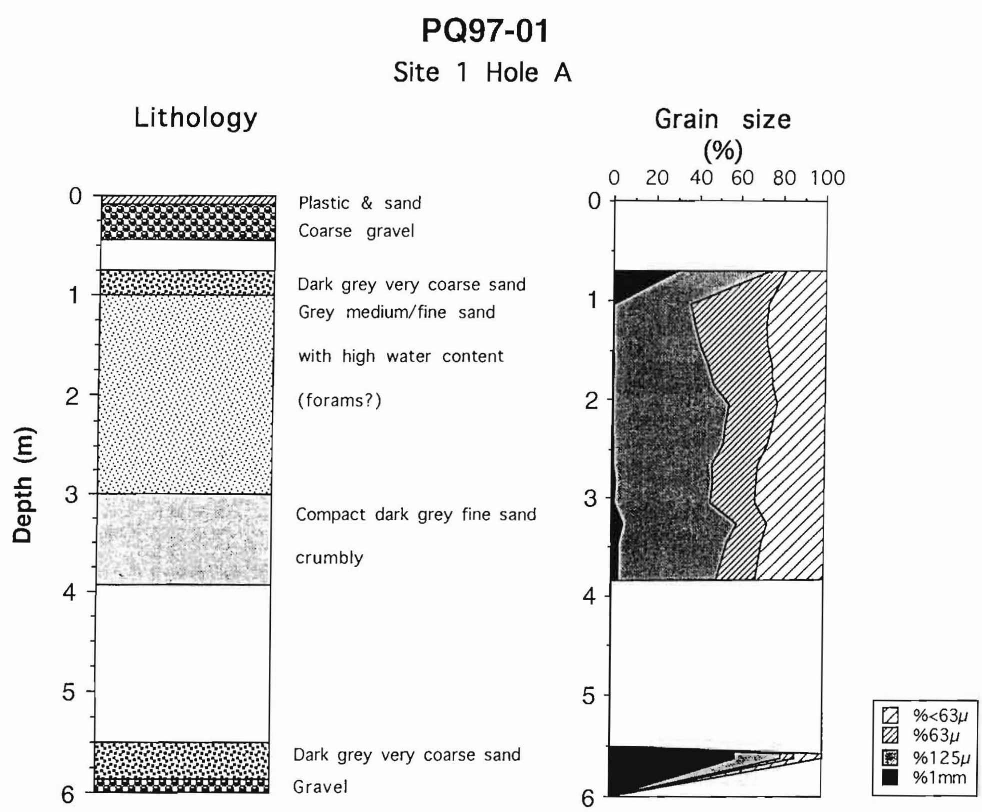

Fig. 5. Lithological description and grain size analysis of Core PQ97-01.

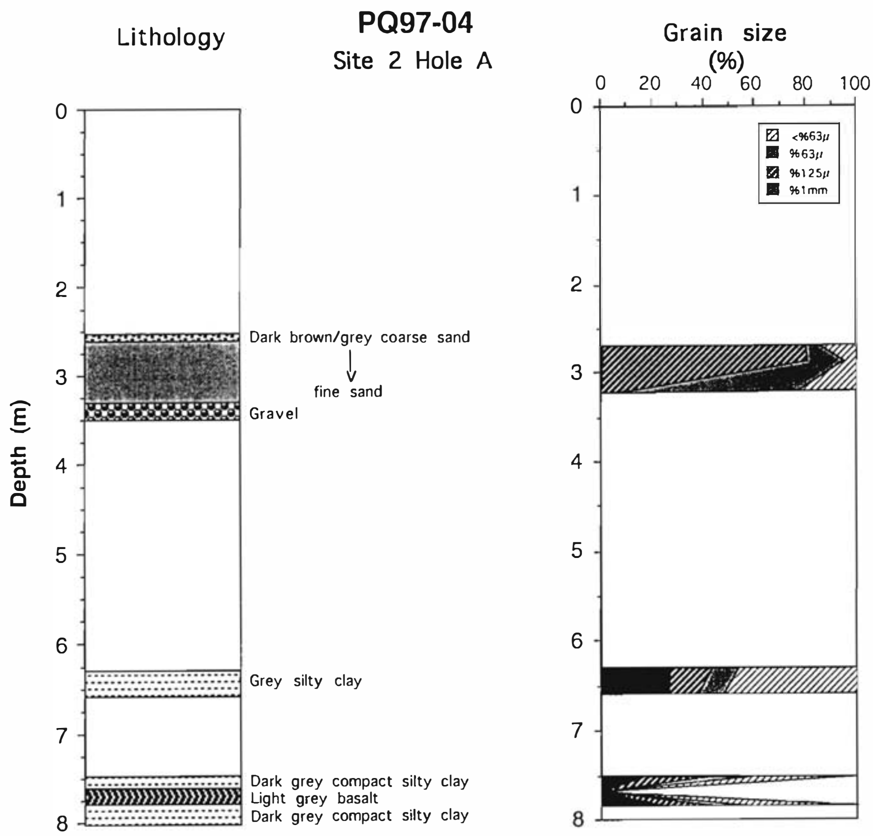

Fig. 6. Lithological description and grain size analysis of Core PQ97-04.

string of outer diameter 56 mm was lowered inside the riser. The sediment core was retained by an inner 3 m long core barrel and brought to the surface by a wire line system whenever the drill bit had advanced 3 m. A prototype removable ice protection for the drill string was constructed.

PRELIMINARY RESULTS

A total of five holes were drilled at three different sites (Fig. 4). At site 1 Hole A we drilled 6 m with a sediment recovery of 69%. The sediments at this hole consisted of gravel and fine and coarse sand (Fig. 5). On board smear slide studies have indicated the presence of rare heavily fragmented diatoms in these sediments. Two further holes were attempted at this site, 4 m and 2.2 m respectively, without any sediment recovery.

At Site 2 we drilled 8 m with a sediment recovery of 18 %. The sediments at this hole consisted mostly of fine sand and silty clay (Fig. 6). During on board smear slide studies some diatoms of Quaternary age (*Eucampia antarctica*, *Nitzschia donahuensis*, *Nitzschia curta*) have been observed in the fine sand and silty clay intervals. Further detailed sedimentological and micropaleontological investigations of these sediments will be conducted later.

At Site 3, after the riser and drill string had been deployed under mostly open water conditions, a heavy ice field moved in at 2-3 knots under winds up to 40 knots. For the smaller ice floes, the ship was able to meet them with the starboard side and thereby shield the drill string. But the ship had to meet the large floes head on in order to break them. In this situation the riser hooked on to a floe and the drill string broke. A fishing tool was successful, but a second impact by a larger floe brutally terminated the operation. Two hundred meters of drill pipe was lost.

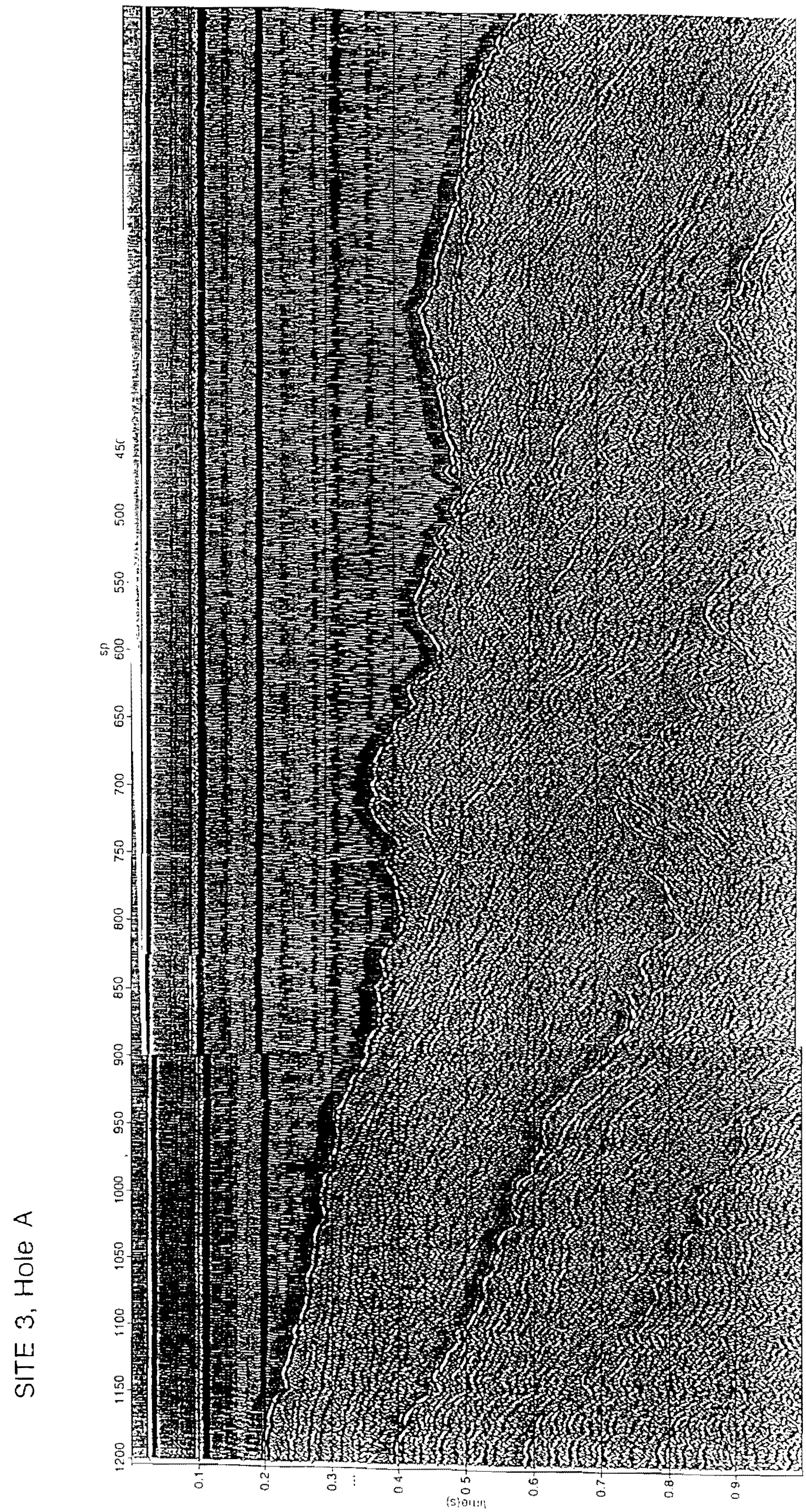

Fig. 7. Location of site 3 along the seismic profile AN96005.

CONCLUSIONS

In spite of very difficult ice conditions and some technical problems related to the drilling operation, we have recovered 6 meters of sediment from the Antarctic continental shelf. Preliminary on board studies show that these sediments contain some diatoms of Quaternary age.

Future advances in sampling of glacial sediments on the Antarctic continental shelf have to come from shallow drilling. A new riser concept was successfully deployed, which makes it possible to operate in shelf water depths with a light wire line drill rig. However, drilling into, and recovering diamicton represented considerable problems with repeated loss of circulation. These problems render drilling in diamicton a much slower process (Hole 1A: 6 m penetration in 14 hours; Hole 2A: 8,5 m penetration in 24 hours) than anticipated. Future shallow drilling in this environment will require a more efficient rig and improved skills in recovering tills.

ACKNOWLEDGEMENTS

We appreciate the professional assistance of the crew of the *R/V Polar Queen* and the leadership of A. S. Blix. We are grateful to Heinrich Eggenfellner, Torleif Lothe, Ole Anders Nøst, Kåre Pedersen, Eckart Schütt and Erik Vike for their participation in the drilling operation. This project was supported by the Norwegian Science Foundation (NFR).

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BJØRN BARSTAD[1], TROND EIKEN[1], RANDI FINNES[1] & OLA ØVSTEDAL[2]

GEODETIC MEASUREMENTS IN DRONNING MAUD LAND

BACKGROUND

Since the series of Norwegian Antarctic Research Expeditions (NARE) 1984 (Eiken & Svendsen 1985) systematic work has been carried out in order to establish a precise and coherent geodetic network in Dronning Maud Land. The network is supposed to serve as a basis for future mapping and for measurements in connection with scientific projects.

From the central part of the mountains in Dronning Maud Land the net has gradually been extended both to the west and to the east (Eiken et al. 1990). After NARE 1992-93 a network of 28 points covering the mountain areas from 4° West to 7° East was established. On NARE 1993-94 new networks in Heimefrontfjella and Vestfjella (9° to 16° West) were established and tied together (Barstad & Luktvasslimo 1996). This network was connected to the SCAR GPS campaign point at Basen, established by the Swedish Antarctic Research Programme in 1991-92.

As a supplement to the existing topographic maps at scale 1:250,000 covering Dronning Maud Land a series of satellite image maps at the same scale has been produced. At the present seven maps of central Dronning Maud Land have been published. The satellite images contain a large amount of information on the ice covered areas thus making the transport planning and field work easier.

The heights of the mountains in Dronning Maud Land are based on barometric levelling of selected reference points. Most of the survey control stations have been fixed with trigonometric levelling from these. In order to improve the basic height network a connection to a sea level reference should be made. Tidal measurements in Jutulgryta (S 71°20', E 0°20') during NARE 1991-92 (Østerhus & Orheim 1994) and some measurements between sea level and the reference point at TROLL during NARE 1992-93 have laid the foundation for the final effort for completing the sea level transfer.

On NARE 1992-93 Jutulsessen - the mountain area around the Norwegian research station TROLL - was photographed from helicopter in order to compile a map at scale 1:50,000 but due to poor weather conditions the photography proved not satisfactory. In the meantime the German *Institut für Angewandte Geodäsie* has performed vertical photography of this area (scale 1:30,000) as well as of large parts of Mühlig-Hofmannfjella thus enabling mapping at larger scales both in Jutulsessen and in Svarthamaren (SSSI No. 23).

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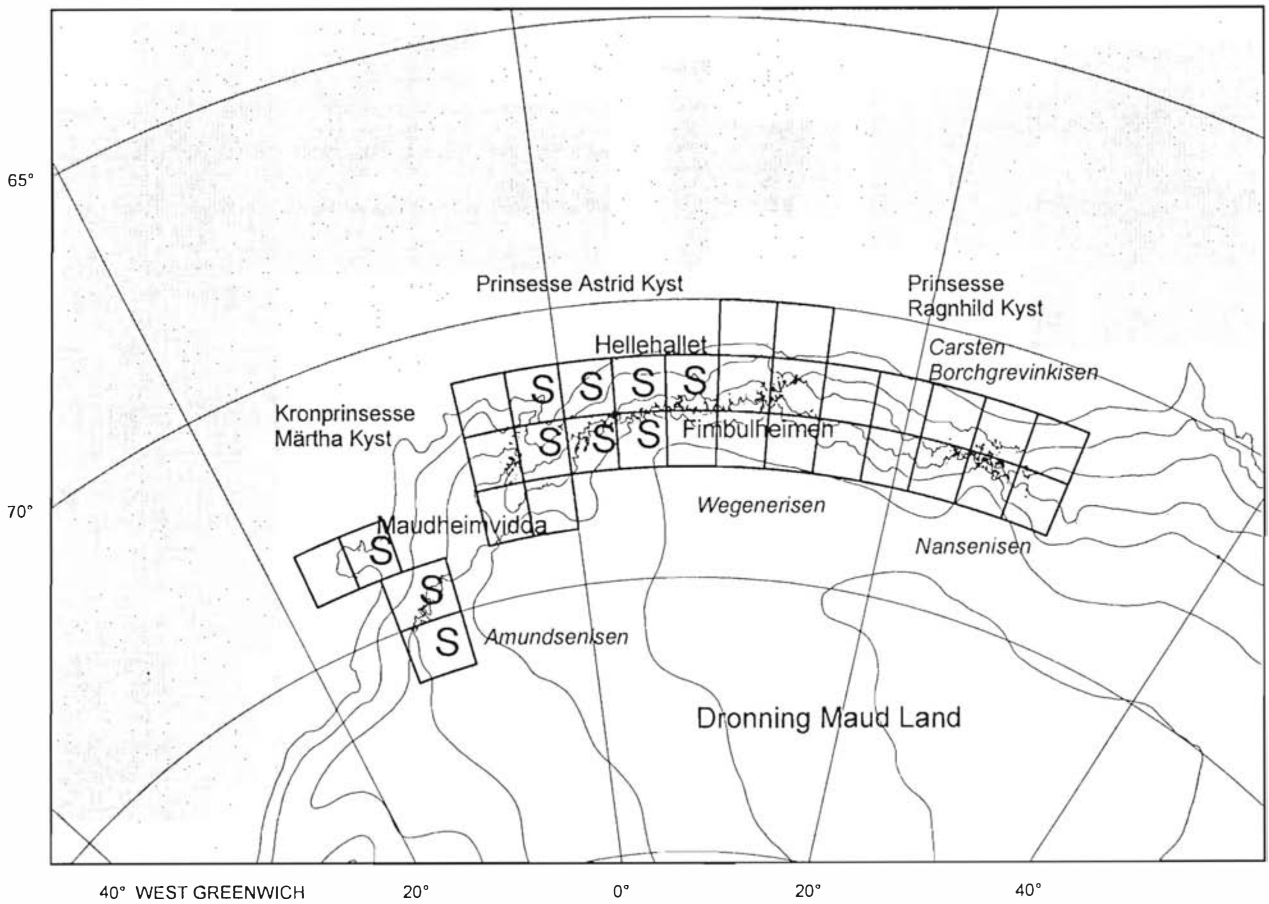


Fig. 1. Norsk Polarinstitutt's map series 1:250,000 in Dronning Maud Land. S indicates that both a satellite image map and a topographic map is available.

Glaciological studies of the Jutulstraumen ice stream (1° West) have been going on for several seasons in order to determine its mass balance and dynamics. Geodetic support has been given to the projects in order to determine quantities such as ice flow velocity and deformation rates. On NARE 1996-97 extensive radar flights and elevation profiles along the flow direction requiring geodetic support were planned.

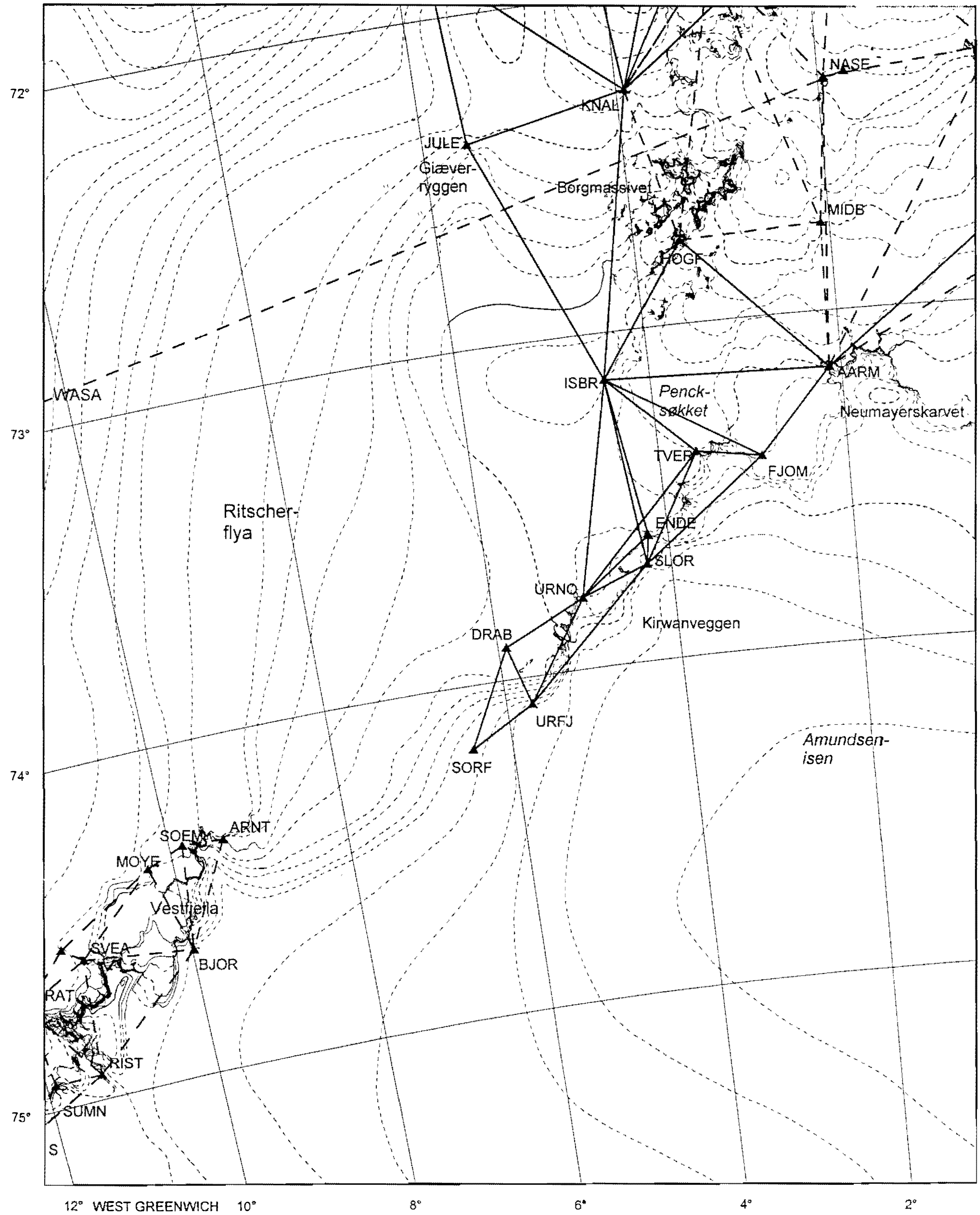
The SCAR (Scientific Committee on Antarctic Research) Working Group on Geodesy has launched several GPS observation campaigns in recent years in connection with the ongoing GIANT Programme (Geodetic Infrastructure for ANTarctica). Incorporating the geodetic reference point at TROLL in the SCAR network would enable us to tie the geodetic network in Dronning Maud Land to the high precision geodetic network of Antarctica.

OBJECTIVES

The geodetic/topographic programme on NARE 1996-97 had six main objectives.

Higher order precise geodetic reference network

The geodetic network should be extended to the northern- and westernmost mountains of Giæverryggen (at 71° 20' S, 6° W), to the south-west through Kirwanveggen and eventually tied up to the network of Heimefrontfjella/Vestfjella at 74° 30' S, 10° W. To the east it should be extended as far as possible, preferably to 12 - 15° E. In order to connect the network to points of the SCAR GPS campaigns, measurements should also be

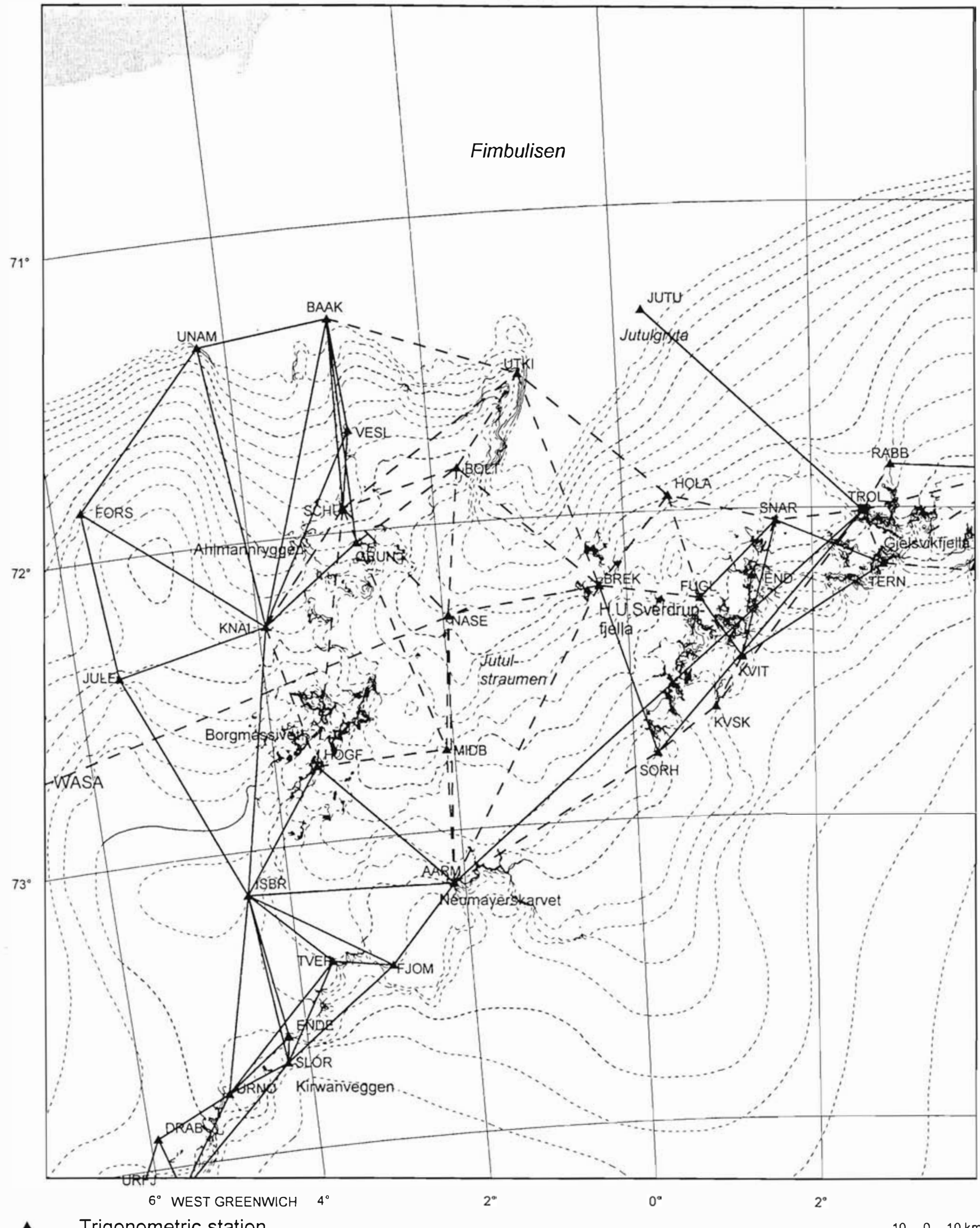


▲ Trigonometric station

– – Trigonometric net established on previous NARE-expeditions

—— Trigonometric net established on NARE9697

Fig. 2. The western trigonometric net, Dronning Maud Land.

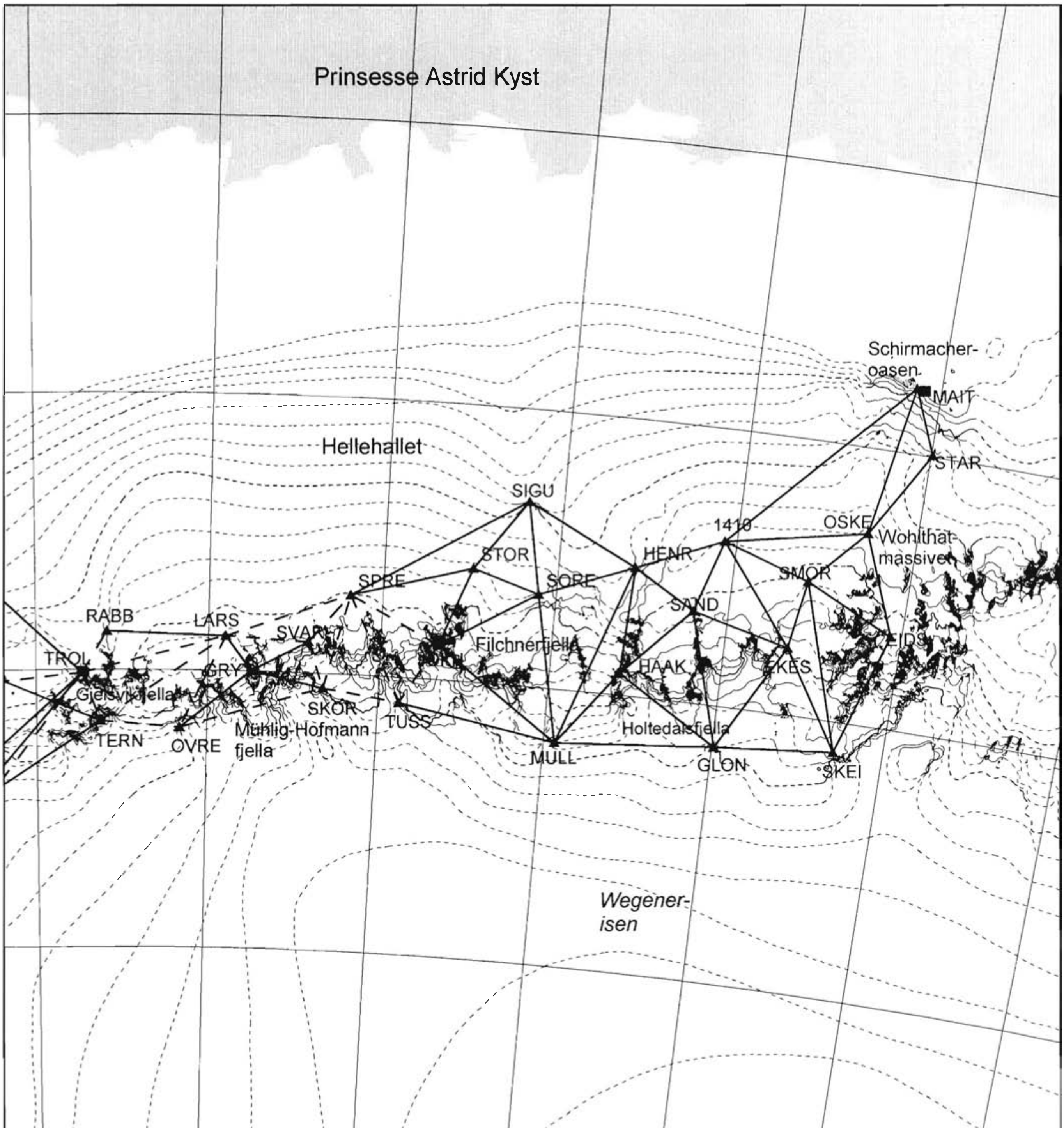


▲ Trigonometric station

– – Trigonometric net established on previous NARE-expeditions

—— Trigonometric net established on NARE9697

Fig. 3. The central trigonometric net, Dronning Maud Land.



▲ Trigonometric station

– – – Trigonometric net established on previous NARE-expeditions

——— Trigonometric net established on NARE9697

Fig. 4. The eastern trigonometric net, Dronning Maud Land.

carried out at the fixed point at Grunehogna - established by the South African National Antarctic Programme, and one of the points at Schirmacheroasen - established by the German Antarctic Programme.

Ground control for satellite image rectification
Reference points should be measured in the same areas as the geodetic network to enable the rectification of satellite images for seven new satellite image maps in the western area (E6 - E8, F5 - F8) and six new maps in the eastern area (K5 - K6, L5 - L6, M5 - M6).

Tidal measurements - geoid height determination
An automatic tide gauge should be deployed in the sea at Jutulgryta to record tide variations as long as possible during the expedition period. Height difference observations between open water and grounded ice as well as on a traverse between grounded ice and the geodetic reference point at the TROLL Station should be carried out. A gravimetric profile should be measured along the traverse including some sites around the fixed point. Gravity measurements and GPS derived ellipsoidal heights can determine the change in geoid height along the profile. Finally, simultaneous observations of vertical angles should be carried out for the determination of the deflection of the vertical around the reference point .

Special maps
Ground control points should be measured in the Jutulsessen area (near the TROLL Station) and in the area around Svarthamaren (SSSI no. 23) to enable the compilation of maps at larger scales (1:10,000 - 1:50,000) from aerial photography.

Support for glaciological programmes in Jutulstraumen and in Jutulsessen
Stakes across the grounding line of Jutulsessen ice stream should be measured twice during the expedition period in order to determine the ice flow rate of the area.

Furthermore, the position of a 'coffee-can' should be determined very precisely in order to predict the emergence velocity in the central part of the ice flow. Two height profiles to both sides of the center line of the ice flow should be measured and positioning of a radar flight along the profiles should be carried out. As reference for local kinematic profiling on the stream a GPS receiver should be run at TROLL on request. Finally, stakes on the blue ice area in Jutulsessen should be re-measured.

SCAR EPOCH GPS-campaign
A GPS receiver should be run continuously at the TROLL Station geodetic reference point during the SCAR EPOCH 97 GPS campaign.

WORK ACCOMPLISHED

Transportation was carried out with helicopters. According to the programme two helicopters should be available for about three weeks. However, because of bad weather one of the helicopters was grounded at the South-African base SANAE 3 for a longer period, and hence the main part of the work was carried out using only one. Due to the long flying distances fuel depots were put out in Kirwanveggen and in Henriksenskjera (at 9° East). Weather conditions were quite good and 23 out of 54 days were efficient working days. Out of these, three days were used for supporting the glaciological programme.

The work was mainly carried out as planned except for the connection between the Heimefrontfjella/Vestfjella geodetic network and the new network in Kirwanveggen. Due to the extreme distance to fuel and base facilities, it was impossible to accomplish the work in this area with only one helicopter available.

Geodetic network measurements
The measurements were laid out as vectors in a network of triangles. 5-6 Ashtech Z-XII dual frequency geodetic GPS receivers were used simultaneously. Each site were occupied for at least two hours with data log interval at 15 seconds. Due to the long distances to the working area no more than 1-2 sessions per day were possible. Aluminium markers were put down at all new points.

To the west the network was extended with three new points in Giæverryggen: Johnsbrotet, Førstefjell and Juletoppane. Furthermore, a new point at Isbrynet south of Borgmassivet was established. In Kirwanveggen eight new points were established: Tverregga, Fjomet, Enden, Sløret, Urnosa, Drabanten, Urfjellgavlen and Sørfløya.

To the east, 16 new points were established/included: Storkvarvsteinen, Sigurdsvodene, Sørensenskjera, Müllerkammen, Henriksenskjera, Nupsskarvet, Sandnesstaven, Nunatak H. 1410, Glopenesranen, Ekesteinen, Smørstabben, Skeidsberget, Eidshaugane, Oskeladden, Starheimtind and Maitri. At Oskeladden a German GAP-95 point was sited and at Maitri *the Survey of India Control Point* just north of the main base building was sited. The point at Maitri was sited instead of one of the GAP95 points at the former Forster Station due to lack of point descriptions. Unfortunately, the point at Maitri is not included in any SCAR EPOCH-campaign.

Some densification of the existing network was also carried out: a new point was established at Grytøyrfjellet in Mühlig-Hofmannfjella and some additional vectors were measured in Gjelsvikfjella/H.U. Sverdrupfjella.

Ground control for satellite image rectification
The points of the geodetic network will serve as ground control for the rectification. Unfortunately only a few satellite images were available for the areas of interest. Identification in situ for most of the points were not possible. All points, however, were thoroughly documented for later identification when the images eventually are acquired.

Tidal measurements - geoid height determination
An Aanderaa automatic pressure tide gauge was deployed at the sea floor in Jutulgryta for a period of 36 days. Unfortunately, the receiver was not stable at the bottom throughout the period. The unstable tide gauge and an erroneous data recording resulted in only a few days of recorded measurements. The recorded data will, however, enable a connection to the sea level. The mean sea level can be computed from the harmonic constants found in 1991 by Østerhus (Østerhus & Orheim 1994). Furthermore, an elevation profile consisting of five points between the geodetic reference point at TROLL and Jutulgryta was measured. The tide variation was measured between grounded ice and ice floating on open water using both GPS observations and simultaneous vertical angle observations along with distance measurements, the latter performed with Wild T2 theodolites and a Geodimeter 6000 EDM. A Lacoste-Romberg relative gravimeter was used for measuring gravity along two c. 100 km long parallel profiles between Jutulgryta and TROLL with ten points in each. The gravity was also measured in eight points of the geodetic network of Jutulsessen/Gjelsvikfjella as well. Finally, simultaneous vertical angles were measured at five points of the local network for detection of the deflection of

the vertical. The gravity profiles as well as simultaneous vertical angles were measured with the purpose to give the best possible estimate of the geoid between TROLL and the tidal station in Jutulgryta.

Special maps
Six new ground control points in Jutulsessen and eight points around Svarthamaren suited as basis for block triangulation were measured using kinematic GPS methods. The control points were identified and marked in the German aerial photos.

During a short stay at Bouvetøya at the end of the cruise the opportunity was taken to photograph the area of Nyrøysa. A Hasselblad NKWE camera, handheld in a helicopter, was used for the purpose. A few ground control points were measured to support a local mapping of the area. During the stay a GPS receiver occupied one of the trigonometrical stations on the island. The data have been used to compute a new WGS84 position for the point using reference data from IGS stations. The point has former WGS72 coordinates fixed from NNNS TRANSIT measurements 1979.

Support for glaciological programmes
Four flow rate stakes at the grounding line of Jutulstraumen were measured twice with a time span of 26 days. A 'coffee-can' (steel plate just beneath the snow surface) was also measured. The track of the radar flights along the stream as well as 18 profile points were measured using kinematic GPS methods. In Jutulsessen, 11 flow rate stakes were measured using theodolite/EDM and real time kinematic GPS methods. On request from a glaciology/hydrology project at Jutulgryta, GPS observation support was given in order to make a topographic surface model of the area.

SCAR EPOCH GPS-campaign / GPS reference receiver
An Ashtech Z-XII GPS receiver was operated at 24-hour sessions for the period 20 January to 10 February. This receiver also served as reference for other projects using GPS; the EPICA traverse and glaciological radio echo sounding on Jutulstraumen and Fimbulisen.

CONCLUDING REMARKS

The mountains of Central- and Western Dronning Maud Land are now covered with a precision geodetic network. The network is tied up to the SCAR EPOCH stations.

The processing of the GPS measurements has so far been successful, and computed baselines have acceptable solutions. The data collected at TROLL during the SCAR campaign have been delivered to the Technische Universität Dresden for processing. The gravity measurements have not been computed yet. The reading of the tidal measurement tape showed that part of the data was lost.

ACKNOWLEDGEMENTS

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HÅKON AUSTRHEIM[1], SYNNØVE ELVEVOLD[2], ANE K. ENGVIK[1] & OSKAR PAULSSON[3]:

GEOLOGICAL OBSERVATIONS IN GJELSVIKFJELLA, MÜHLIG-HOFMANNFJELLA AND WESTERN ORVINFJELLA DURING NARE 96/97

INTRODUCTION

Geological setting

The investigated area is a part of the East Antarctic shield, which is characterized by the predominance of Precambrian metamorphic and igneous rocks (Paech 1995). Previous work (Ohta et al. 1990; Bucher-Nürminen et al. 1990; Bucher-Nürminen & Ohta 1993) in the western part of the area visited has shown that the mountains and nunataks of Gjelsvikfjella and Western Mühlig-Hofmannfjella (Fig. 1) are dominated by granitoid igneous rocks and metamorphic sequences in upper amphibolite and granulite facies. Mapping to the east of the investigated area by Soviet, German and Indian groups have revealed large charnockite and anorthosite bodies. Noteably the Lodchnikov charnockite intrusion extend between 6° and 10° E and the Eliseev anorthosite intrusion occur as a circular intrusion in the Wohlthat massif.

Age dating in the area is sparse but ages around 400-500 Ma are reported by Ravich & Krylov (1964) and Ohta et al. (1990). Based on radiometric ages from Jutulsessen (Gjelsvikfjella), Moyes (1993) suggested that the area underwent polyphase deformation and metamorphism at 1150 Ma during the Kibaran orogeny. Ages around 500 Ma were interpreted to reflect the Ross or Pan African orogeny which were said to cause open folding of the Jutulsessen gneiss.

Bucher-Nürminen & Ohta (1993) found that the cordierite bearing rocks of Western Mühlig-Hofmannfjella equilibrated at 650°C and 4 kbars while associated orthopyroxene bearing granulites revealed temperature of 750°C and pressures of about 8 kbars. Thus we are dealing with rocks of lower and middle crustal inheritance. The timing of the metamorphism are not at present known, but based on the few existing radiometric ages from the area, Bucher-Nürminen & Ohta (1993) proposed two alternatives: The granulite facies metamorphism is Proterozoic in age and the P-T conditions recorded by the cordierite bearing rocks reflect retrograde metamorphism during a thermal event related to Paleozoic (500 Ma) intrusions in the area. Alternatively the metamorphism (collision orogeny) and the intrusions all occurred in Paleozoic time.

Objectives

The main objective of our work is to map the area of least coverage from 6° to 8° E to join up with the mapping of the Indian and German groups. Further the objective is to obtain a better understanding of the crust forming processes and geological history of the area.

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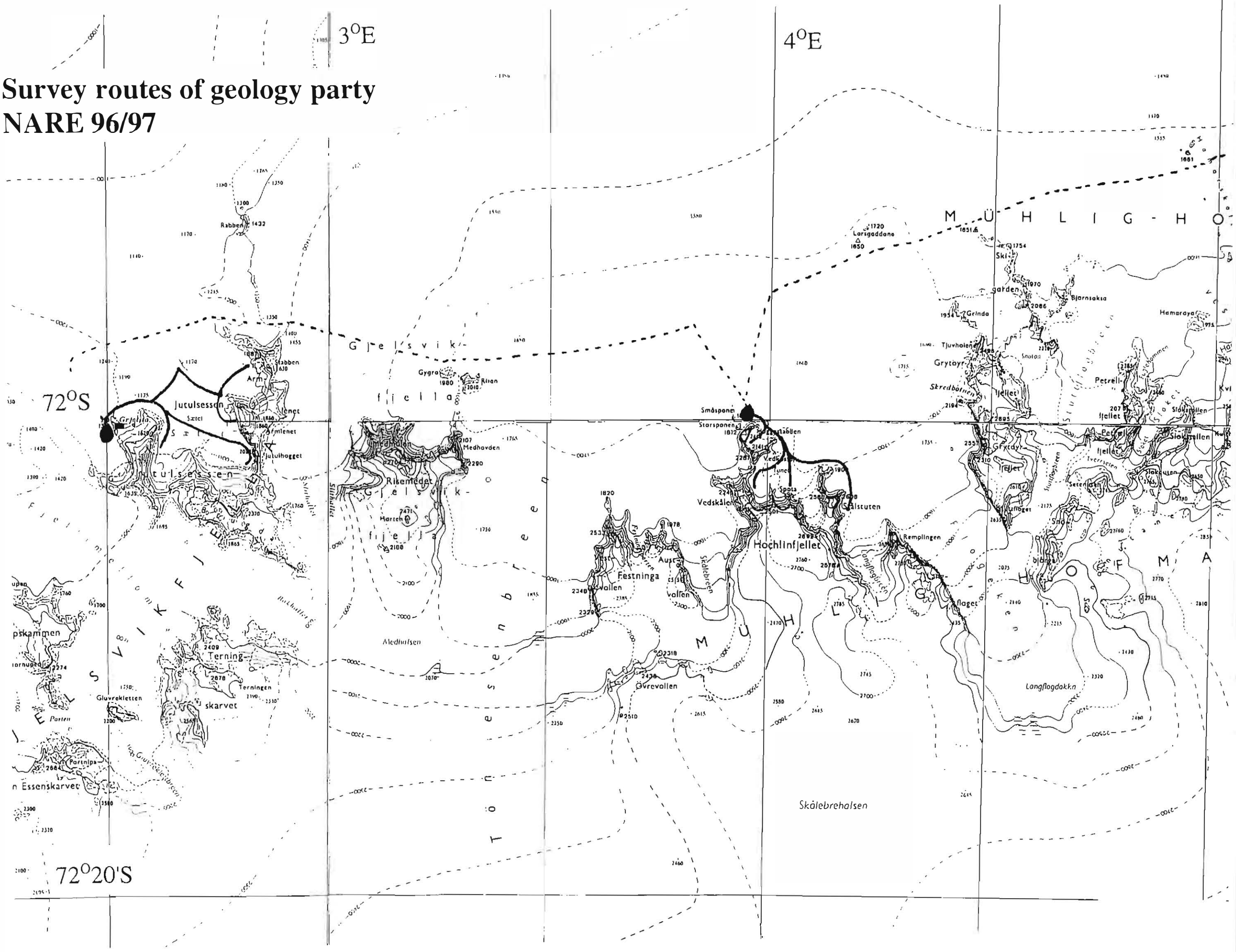
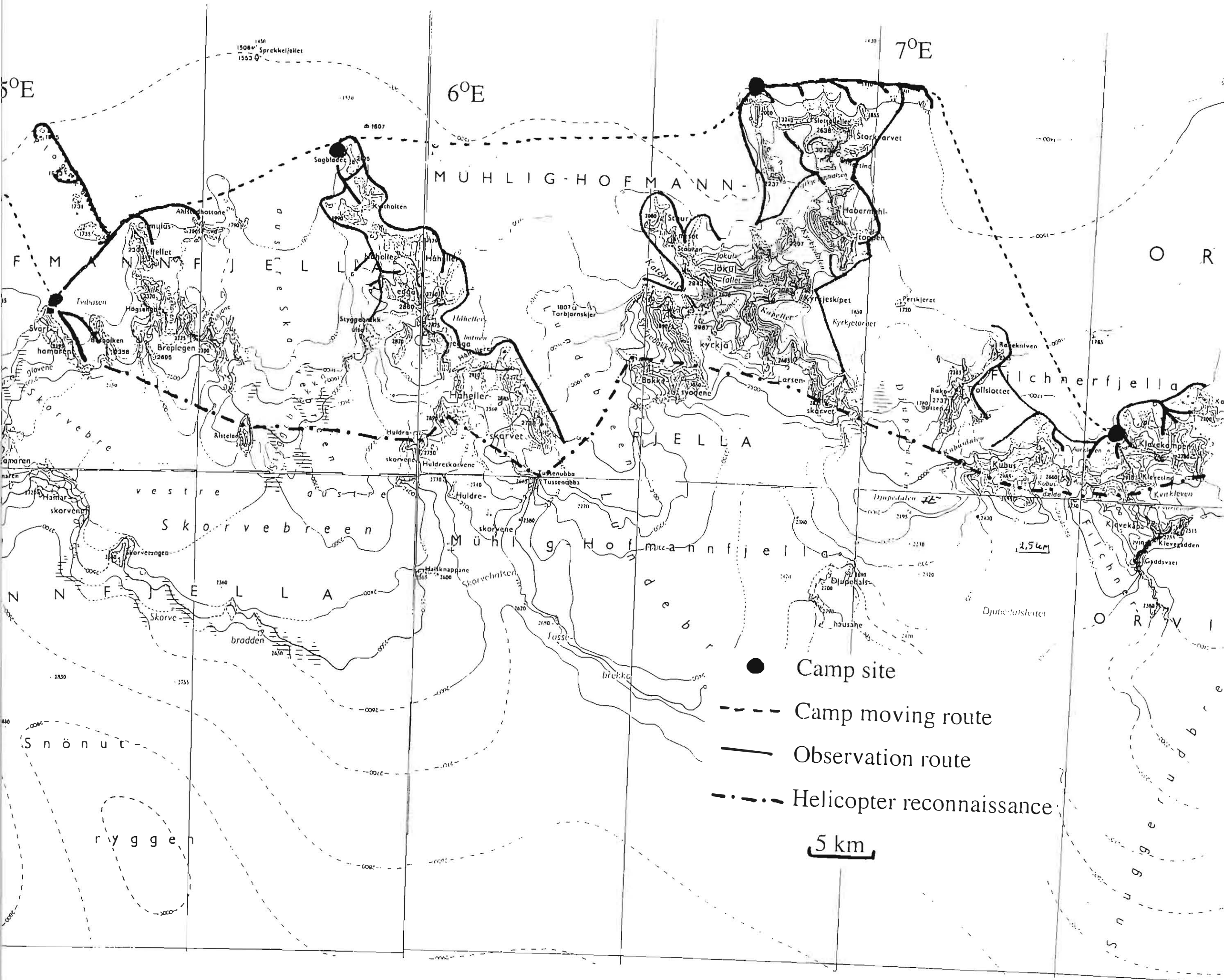


Fig. 1. Map showing camp sites and the areas visited.

Geochronology is a major tool in such work and sampling for this purpose was given priority. Previous work in the western part of the area has shown excellent field examples of fluid rock interactions, a petrological problem presently of high interest in earth sciences. Sampling, mapping and illustrating this phenomena were major issues during the expedition.

Studied areas and methods

The mapping was done at a scale of 1:100,000 out from four campsites in the east (Svarthamaren, Sagbladet, Jaren and Aurkleven, Fig. 1) during six weeks. From the camp in Svarthamaren we visited Plogskaftet, Cumulusfjellet, Båsbolken and the inner part of Svarthamaren. From Sagbladet we had access to the Håheller massif. Jaren was the base for investigating the Jøkulkyrkja and Gessnertind area and from Aurkleven we reached the NE part of Trollslottet and the north side of Kubusfjellet and Klevekampen. West of Svarthamaren we camped at Hoggestabben for a week and finally we worked two days in the Jutulsessen area, when staying at Troll. We were allowed one half day of helicopter support which were used to visit the inner part of the area not accessible with snowscooters. We collected structural data and about 500 rock species.
For detailed petrological problems we used a drill to obtain relevant samples.



SOME PRELIMINARY RESULTS AND CONCLUSIONS

Like in most high grade metamorphic terrains, the crust in the studied area is formed and modified through an interplay of metamorphic and magmatic processes. The metamorphism may be superimposed on the igneous rocks, but also the metamorphic process may grade into magmatic processes through partial melting, and eventually the metamorphic rock may take on an igneous appearance. Abundant assimilation of wall rocks occur as pultons are formed. Transport of material through fluid migration (metasomatism) is also active in modifying mineralogy and composition of the rock. Field relationships illustrate that all these processes have been active in the formation of the crust in the investigated area and giving rise to rocks of thrue igneous origin as well as high grade metamorphic rocks as granulites and amphibolites. In addition rocks in the boarder land between magmatic and metamorphic are present. The complex history of some igneous rocks is also evidenced by the Sr isotopes analysis (Ohta et al. 1990) showing that the charnockites of Svarthamaren and gabbros of Jutulsessen have elevated initial $^{87}Sr/^{86}Sr$ ratio requiring an abundant component of older crust. During our mapping we have attempted to distinguish between rock of pure magmatic origin, true metamorphic rocks and rocks formed during interaction of metamorphic and magmatic processes.

Fig. 2. Granitoid zenoliths of gneissic and magmatic origin in coarse-grained syenite from the diatreem like body in the northern part of Håheller massif. Photographed part of the cliff is approximately 100 m high.

Similar to the western parts of Mühlig-Hofmannfjella, visited by NARE 84/85 and 89/90, the rocks encountered to the east of Svarthamaren (Håhelleren, Jøkulkyrkja-Gessnertind and the northern part of TROLLslottet) are dominated by coarse grained magmatic rocks of granitoid composition. High grade metamorphic rocks are subordinate to the intrusive rocks but are found in a number of places. Notably Klevekampen, Kubusfjellet and southern part of TROLLslottet are made up of granulite facies migmatitic rock and banded gneisses of granitoid composition.

A complex intrusive history can be outlined. In a nunatak east of Håhelleren, four intrusive phases were mapped within an area of 100 m². In places the intrusive rocks carries abundant xenoliths of both magmatic and gneissic origin. Such xenolith rich rocks form plug-like bodies that tend to be resistant to weathering and stand up as nunataks. A diatreem like body with abundant xenoliths in the northern part of Håheller massif was mapped and sampled in detail (Fig. 2). The most prominent igneous rock in the area is a coarse grained to pegmatitic fayalite-syenite making up the northern part of Svarthamaren and extending through Cumulusfjellet, Sagbladet, Kvitholten, Jøkulkyrkja to Jaren and

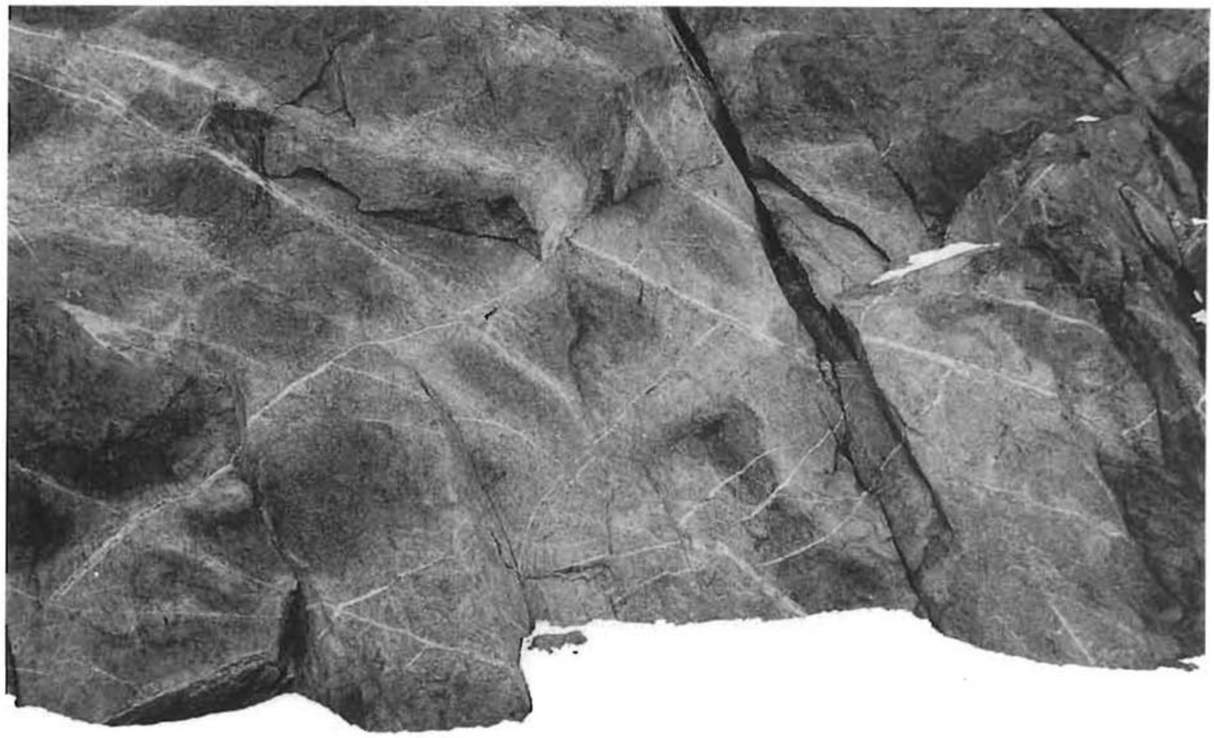


Fig. 3. Dark coarse grained syenite with whitening zones at Rakekniven. Mineral fillings and pegmatite can be seen in the central part of the whitening zones. Photographed part approximately 30 m wide.

Gessnertind area. It may be a continuation of The Lodochnikov charnockite intrusion, in which case this intrusion is at least 200 km long. The fayalite-syenite is late in the intrusive history and is found to intrude an orthopyroxene bearing granite (charnockite proper). An intrusive breccia with block of granite up to several metres across surrounded by fayalite-syenite is formed at the boarder between these rocks. This breccia makes up the nunataks of Alstadhottane and east side of Cumulusfjellet. A rock sample collected by the topographers at Sigurdsvodane showed to be coarse grained anorthosite, which indicate that anorthosites may be present also west of the Wolthat massif.

Intrusive relationship between the fayalite-syenite and an orthopyroxene bearing granite (charnockite) can also be seen in Håhelleren. The charnockite can be shown to have a complex history and be traced back to a gneissic precursor. In its most igneous looking form the granite has euhedral feldspar with a strong preferred orientation and carries in addition quartz and two pyroxenes together. The charnockite has composite veins which is locally pegmatitic. These veins often have a whitish colour that can be used to distinguish the charnockite at distance. The charnockite is seen to have developed from a preexisting gneissic material. Preliminary geochemical data from the intrusive suite collected by NARE 89/90 show that the igneous rocks of the area have extremely high Fe/Mg ratios which is reflected in almost pure Fe-end member pyroxenes and olivine. Further the rocks are found to carry abundant REE and Th, U-bearing minerals like allanite and chevkenite. The field examination of the rock visited this year suggest that this characteristics continues to the east as abundant allanite were recorded at many outcrops.

The fluid rock interaction process described by Bucher-Nürminen et al. (1990) are found to effects intrusive as well as metamorphic rocks in the areas mapped by NARE 96/97.

Fig. 4. Large scale folding of banded and migmatitic gneisses from Aurkleven, Klevekampen.

Detailed mapping of whitening zones at Rakekniven (Fig. 3) demonstrated that the decolorization occurred along three major sets of fractures. All fractures contain mineral fillings/pegmatites suggesting an open system behavior also with elements other than water. As stated by Bucher-Nürminen et al. (1990) the fluid may have been derived from devolatizing xenoliths as these were heated by the magma. Also late magmatic fluids may have been active. We have collected samples over a number of such decolorizing zones to be able to better describe the hydration and dehydration reactions taking place. In particular we collected a number of samples over a meter thick whitening zone cutting the granulite facies migmatite at Kubusfjellet.

STRUCTURES

The mapped area from Svarthameren through Håheller massif, Jøkulkyrkja, Gessnertind area and northern part of TROLLslottet dominated by coarse-grained magmatic rocks of granitoid composition show locally syn-magmatic and late-tectonic brittle structures. Syn-magmatic foliation present in some of the syenitic and granitic bodies, is defined of orientation of K-feldspar crystals, lenses of oriented xenoliths, restites of older material and a local foliation defined by concentration of mafic minerals along bands.

Kubusfjellet, Klevekampen and the southern part of TROLLslottet composed of banded gneisses and migmatitic granulites is foliated, locally with a strong lineation. An older foliation is preserved in competent mafic lenses tectonically enclosed in the banded gneisses. Shearbands, both normal and reverse, are frequently observed in the migmatitic gneisses. They show both sinistral and dextral movement. Spectacular large scale folding is visible along the north edge of Klevekampen and Kubusfjellet as both open and tight folds with about E-W-trending fold axis (Fig. 4). On a smaller scale, isoclinal folds are also observed internally in the foliation. Extensional ductile to brittle shear zones with up to 10 m offset cut the banding of the gneisses. The shear zones is both dextral and sinistral which indicate respectively top-SW and -NE movement. The faults and shear zones result in rotated fault blocks and the more ductile shear zones show often a listric appearance. The structures of gneisses in Filchnerfjella is cut by the syenite intrusion at TROLLslottet, and can be a window to the old tectonic Precambrian history of the area. The structures of the gneisses is complex and more detailed fieldwork is needed to outline the complete structural picture and to conclude a tectonic history of the area.

Late tectonic brittle structures, which have a marked influence on the topography, cut through the rocks of the mapped area. They include large brittle faults, clearly visible in the mountain side as well as smaller dextral and sinistral brittle to ductile faults with some centimetres of fault breccia and which offset markers with up to tens of metres.

FUTURE WORK IN THE AREA

Geological mapping and age dating

Only a few percent of the crust in Dronning Maud Land is available by exposures and only part of this has been studied in details by geologists. In spite of this large scale tectonic models and correlations has been produced and orogenies postulated. The fundament for outlining any geological history and plate tectonic model is a geological map of the region. At present only part of the exposed areas are covered by detailed geological maps. Radiometric age dating is a must for developing geological history of Precambrian rocks and the few radiometric ages available can not give confidence to any correlation and plate tectonic reconstruction for the area.

Environmental research and bedrock

Extensive projects are presently launched in Antarctica with the aim to outline present and past climate variations. This is done through ice studies and how the ice excavate and form the topography. The composition and the structure (foliated contra massive) of the rocks are obvious important input factors in such models. Heat producing elements in crust is of importance for the rheological behavior of the ice cap and for the general heat budget. At present we only have a few geochemical data available for the area.

The need of geophysical investigations

In light of the few exposures the only way to obtain a better knowledge of the crustal composition and structure in the area is through geophysical experiments. Such experiments are resource consuming and can probably only be carried out in collaboration with other nations working in the area (Sweden, Germany, India). If such experiments are successful they can provide a picture of the crustal structure over the whole area. When correlated by exposed rocks it may also be possible to identify the rock types hidden by the ice.

The record of the bedrock at land in the sediments at sea

Alternatively information of the bedrock on land can be obtained from sediments cored in the sea. This however require a knowledge of the deposition history and the source area of the sediments. Such investigation can bring information regarding heat producing elements like Th and U. These elements are hosted by monazite which is resistance to weathering processes and often found as detrital grains in sediments. Monazite is also a suitable mineral for age dating of the source rock and a study like this would provide valuable information with respect to rock types and geological history on land.

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TORKILD TVERAA[1], NILS RØV[2], RONNY AANES[2] & HENRIK JENSEN[3]:

SEABIRD RESEARCH AT SVARTHAMAREN DURING NARE 1996-1997

BACKGROUND

As an adaptation to an environment where the food is patchy and sparsely distributed (Ashmole 1971), seabirds such as the Procellariiformes have an extreme life history strategy. They are characterised by single-chick broods, low chick growth, deferred maturity, a long lifespan and forage over large areas (Prince et al. 1992; Weimerskirch et al. 1993). Hence, Procellariiform seabirds are an important part of the marine ecosystem (Siegfried et al. 1985), because changes in adult survival and breeding success of populations will tend to reflect changes over long temporal and large spatial scales (Croxall et al. 1988; Croxall & Prince 1991). Monitoring of seabird populations is therefore of great interest within the Convention for the Conservation of the Antarctic Marine Living Resources (CCAMLR).

During the last decades, ecologists have put considerable effort into studies of many species within a wide number of taxa in order to understand how reproductive effort may affect adult survival rates as reviewed in Stearns (1992) and Roff (1992). According to life history theory, investment in current reproduction may reduce an individual's prospects of reproducing in the future (through reduced survival or fecundity), the cost of reproduction hypothesis (Williams 1966; Charnov & Krebs 1974). In long-lived species, such as seabirds, reduced future reproductive output will have large negative impact on lifetime reproductive success (Charlesworth 1980; Wooller et al. 1992). The future reproductive costs of current reproduction may be assessed through changes in parental body condition (Drent & Daan 1980; Weimerskirch 1995; Daan et al. 1996). Accordingly, recent studies of the Antarctic petrels (*Thalassoica antarctica)* breeding at Svarthamaren (Lorentsen 1996; Sæther et al. 1997) as well as other seabirds (Chaurand & Weimerskirch 1994b; Weimerskirch et al. 1994; Erikstad et al. 1997) have shown that parents in good body condition provide more food for their chicks than parents in poor body condition. Moreover, Sæther et al. (1997) found that the body condition of breeding Antarctic petrels may also be of importance for their breeding success in a year with poor breeding conditions. They therefore suggested that parental body condition may be an important factor which may outweigh some of the stochastic variation in breeding conditions.

Due to the size of the colony and the behaviour of the Antarctic petrel, the population breeding at Svarthamaren offers a good opportunity to provide data on population trends, which is of importance for CCAMLR, and, moreover, functions as a unique laboratory for experimental studies of how seabirds are adapted to the marine ecosystem. Through experiments we have examined how parental body condition may influence on the parents foraging behaviour, chick provisioning and future reproductive output. By combining population monitoring with experiments, we can understand how parental body condition

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may outweigh the effect of environmental stochasticity on reproductive success and hence be an important factor regulating seabird populations.

OBJECTIVES

The purpose of the seabird research at Svarthamaren was:

- to continue the monitoring of the breeding biology and demographic parameters of the Antarctic petrel,
- by means of satellite tracking examine how individual differences in quality and reproductive investment are related to foraging behaviour, and
- experimentally to examine how parental body condition may affect reproductive success and reproductive costs.

In this way, we continued the monitoring of the Antarctic petrel colony at Svarthamaren, identified important feeding areas and, moreover, examined how parental body condition may affect breeding success and mortality. Such studies are of particular interest within the CCAMLR programme and is needed in order to understand how the Antarctic petrel is adapted to the Antarctic environment.

FIELD WORK

During NARE 1996/97, the biological team consisted of four persons working on the Antarctic petrel project funded by the Research Council of Norway (project leader Bernt-Erik Sæther) whereas two persons, one from England, and one South Africa, did behavioural studies on the South Polar Skua (*Catharacta maccormicki*). These people were; Ronny Aanes, Nils Røv (team leader) and Torkild Tveraa from The Norwegian Institute for Nature Research, Henrik Jensen from the Norwegian University of Science and Technology, Michael Brooke from the University of Cambridge (UK), and Dave Keith (SA). Røv was responsible for the field work on population monitoring of petrels whereas Aanes, Jensen, and Tveraa were responsible for the experimental work on life history strategies on petrels. The project on the South Polar Skua by Brooke & Keith will be reported elsewhere. The field work was carried out from the 21 December 1996 to 15 February 1997 at Svarthamaren (71°53'S, 5°10'E) in Mühlig-Hofmannfjella, Dronning Maud Land.

PRELIMINARY RESULTS

Population monitoring

Adult survival

A large number of breeding Antarctic petrels were banded during the austral summer of 1991/92 (about 1500 individuals) and 1992/93 (about 1000 individuals). This banding programme was conducted in four study plots (9 x 15 m) in different parts of the colony (Lorentsen et al. 1993). By this procedure the average annual survival rate can be estimated through the use of capture-recapture methods (Burnham et al. 1987; Lebreton et al. 1992; 1993). Such a large sample of marked birds gives the possibility to detect even very small changes in adult survival rates. Preliminary results suggest that the adult survival rate is c. 96% and constant over years. However, these results may be biased since the survival is only estimated over six-year period.

The study plots 1, 2 and 4 have been checked three times yearly since 1991/92 with the exception of 1995/96 when there was no Nordic expediton. During 1996/97, 867 breeders and ringed non-breeders were controlled in these study plots. The number of conTROLLed and ringed birds are given in Table 1. On the basis of these data, we will estimate the annual survival rate of adult Antarctic Petrels.

Breeding numbers of antarctic petrel

In 1991/92 grid systems of 40 x 40 m that covered the accessible parts of the colony were established, and the mid-points of each square were all marked (Lorentsen et al. 1993). In order to collect data on chick production, all nests within a circle of 10 m^2 around each mid-point, has been checked for the presence (or absence) of chicks during the previous expeditions. A statistic method for estimating the size of the breeding population by using this method is used (Anker-Nilssen & Røstad 1993).

The population census results indicate that the number of adult birds that breed vary considerably, and that in some years only a small fraction of the birds produce eggs. In 1995 an unusually low number of breeding pairs were recorded in the colony, while in 1997 the breeding number was "normal". The results of the population censuses since establishment of the study plots are given in Table 2, while in Fig. 1, the population figures are compared to earlier census results (Mehlum et al. 1988; Røv 1991). We have calculated the breeding frequency of individual birds within the demography study plots 1

Table 1. Number of breeding Antarctic Petrels controlled in the study plots 1, 2 and 4, since the establishment of the study plots in 1991/92. Each year, all unringed breeders were ringed, the number of which are shown in the table together with the number of active nests.

	1991/92	1992/93	1993/94	1994/95	1996/97
Controlled	576	620	896	174	499
Ringed	576	197	210	19	119
Nests	315	347	468	94	278

Table 2. Number of nests with chicks recorded in the study plots in 1992-1997, and estimated number of breeding pairs in the colony.

Year	Mean	S.E. Mean	Std. Mean	Min-Max	Sum	N	Total Number	S.E Number
1992	4.24	0.23	3.31	0-13	853	201	136,480	7397
1993	2.94	0.29	2.80	0-13	546	186	94 ,405	6753
1994	5.54	0.29	4.16	0-16	1114	201	178,240	9859
1995	1.72	0.12	1.75	0-7	341	198	55,387	3859
1997	4.07	0.25	3.52	0-17	813	200	130,730	8005

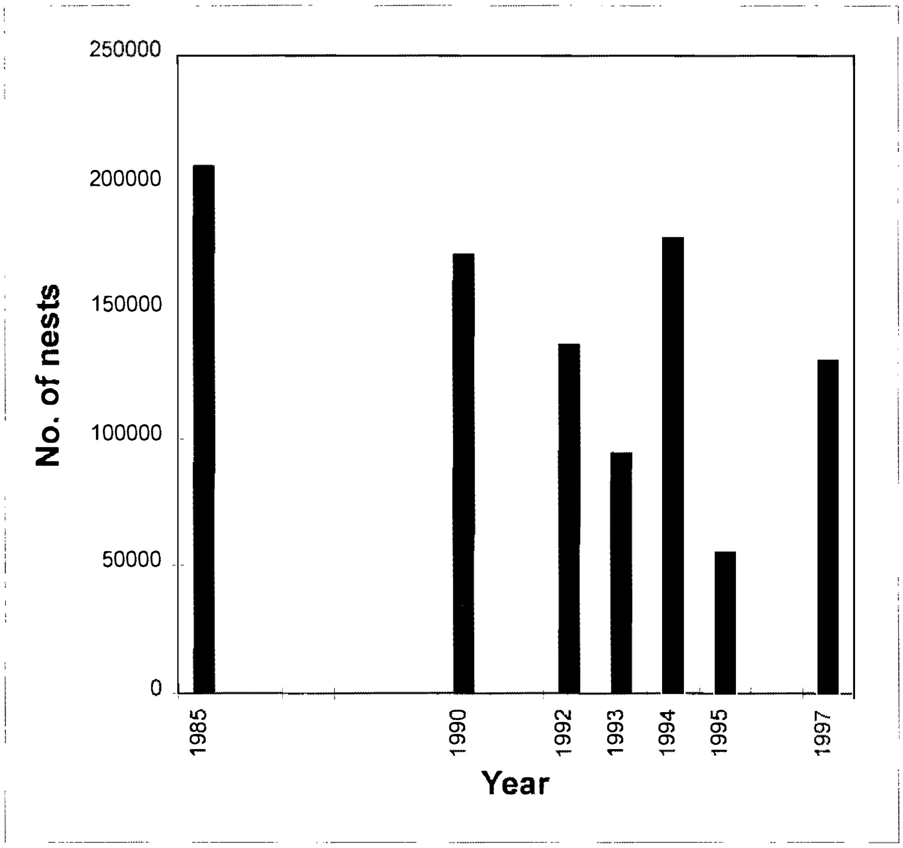

Fig. 1. Estimated number of breeding Antarctic Petrel pairs during the four breeding seasons (1992/93, 1993/94, 1994/95 and 1996/97), compared to population estimates from 1985 (Mehlum 1988) and 1990 (Røv 1991).

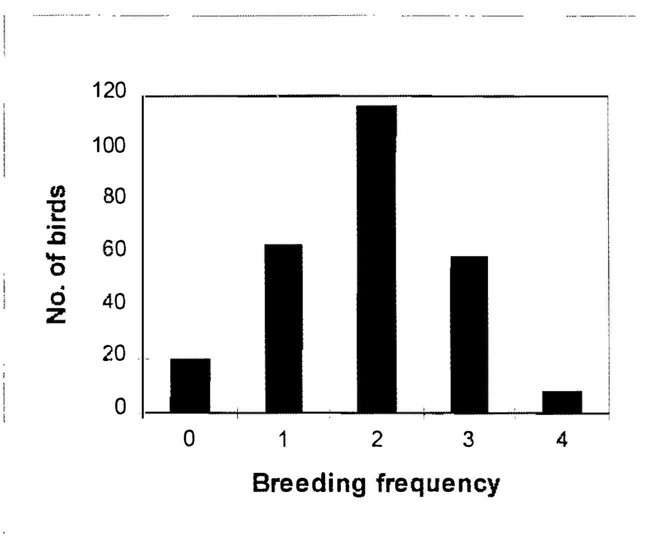

Fig. 2. Distribution of breeding frequency of 267 Antarctic Petrels during the four breeding seasons (1992/93, 1993/94, 1994/95 and 1996/97).

and 2 for the seasons 1992/93, 1993/94, 1994/95 and 1996/97. However, we have not been able correct for birds that have lost their eggs before we arrived at the study site. Accordingly the real breeding frequency is assumed to be slightly higher than the one calculated. The material consists of a total of 267 individuals that were ringed as breeders in 1991/92 and recaptured in 1996/97. Each year between 12% and 80 % of those birds were recorded breeding. During four breeding seasons, most individuals have been breeding twice (Fig. 2). Average annual breeding frequency was 0.47 (SE=0.014). A correlation analysis show that almost 90 % of the annual variation in the number of breeding pairs in the colony can be explained by variation in breeding frequency (Fig. 3).

Hatching time
The first chick was observed in the colony on 5 January. In the study plot of 50 nests, the first egg hatched on 7 January and the hatching period lasted for eleven days. However, 82% of the eggs hatched during 11 - 14 January, with 12 January as the median hatching date (Fig. 4). This is the same as has been recorded on earlier years.

Chick growth and survival
A study plot with 52 Antarctic Petrel nests were inspected daily until all eggs had hatched. The chicks were measured (lengths of bill, head + bill, tarsus and wing) and weighed every third day until they were 30 days old. To study survival of eggs and chicks, the number of active nests within the demography study plots were recorded in late December, at the time of hatching (8-9 January), after independence of the young (19-20 January) and about 30 days after hatching (11 February). Two-hundred-and- fifty eggs hatched. Of these 12% were lost during their first 30 days of life.

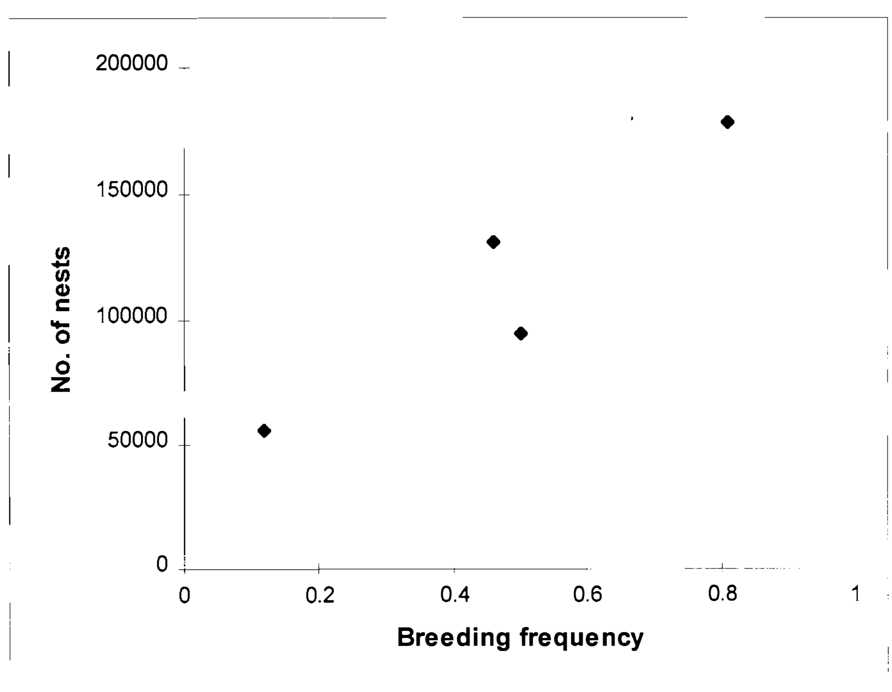

Fig. 3. Relationship between breeding populations size of Antarctic Petrels and breeding frequency ($r = 0.94$, $p = 0.062$, $n = 4$).

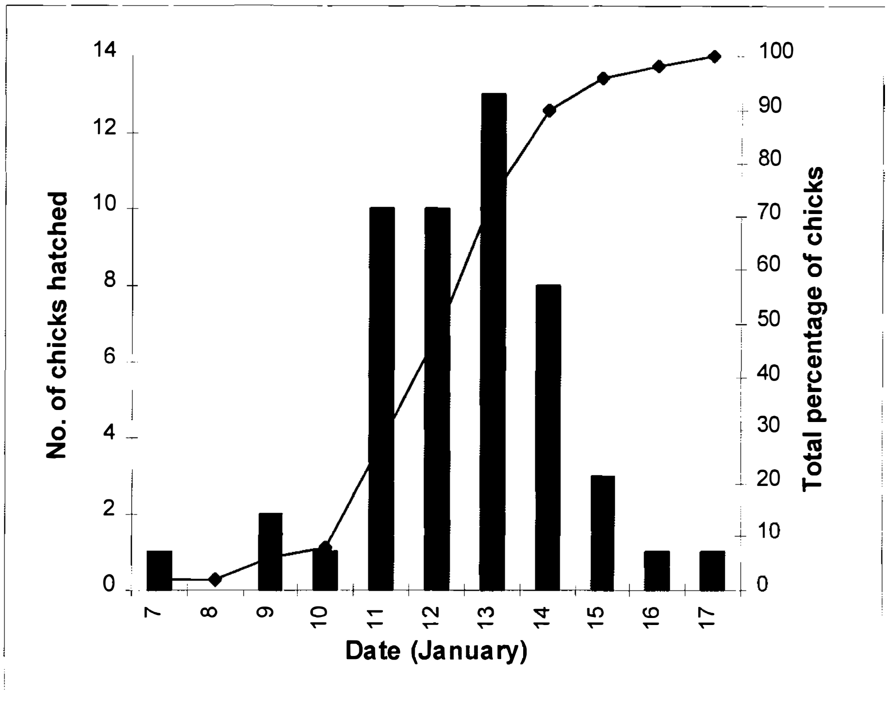

Fig. 4. Hatching date of 50 Antarctic Petrel eggs. Columns show frequency distribution, and line show cumulative percentage of hatched eggs.

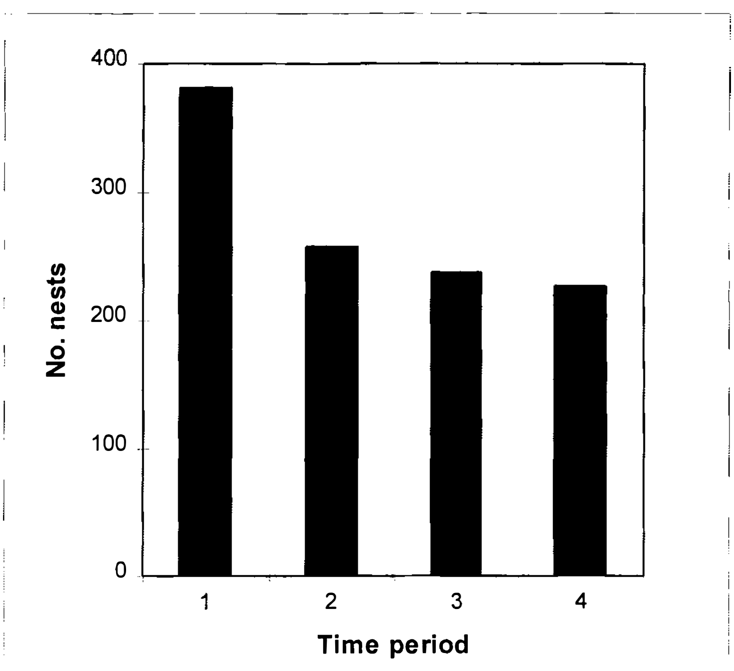

Fig. 5. Loss of Antarctic Petrel eggs and chicks during the study period. The figure shows number of nests with eggs or chicks in the study plot during the following periods:

1. During incubation in late December.
2. At the time of hatching (8-9 January).
3. At the end of the time when the chicks are attended by the parents (19-20 January).
4. Approx. 30 days after hatching (11 February).

Within the demography study plots, 381 nests with eggs were recorded during the later part of December. Of these, 32% were lost before the time of hatching (Fig. 5). The most probable reason for this is meltwater in the nests after heavy snowfall early in the season. 88% of the chicks survived until an age of about 30 days (Fig. 5). With 130 thousand chicks in the colony shortly after hatching, the results indicate a daily loss of about 500 chicks during the first 30 days. At that time about 250 adult South Polar Skuas (breeding and non-breeding birds) were feeding on Petrel chicks. On the basis of the above considerations, a maximum of two chicks per day would be available to each of the Skuas during that part of the season. Most Skuas had large chicks at that time.

The body mass of the chicks increased until they reached almost 600 g at an age of 30 days (Fig. 6). The results indicate a normal food situation compared to earlier years.

Food delivery of antarctic and snow petrels
During 3-9 January, 46 Antarctic Petrel chicks and 23 Snow Petrel chicks were weighed two times daily in order to estimate feeding frequency. During the same period 50 food portion weights of Antarctic Petrel chicks were recorded by weighing the chicks before and after feeding. The chicks were sampled at random at different parts of the colony. These data will be used to compare the size of the meals delivered to the chicks with results from previous years.

The results from the five-year study on population monitoring was presented for the CCAMLR Working Group on Ecosystem Monitoring and Management in July 1997.

Satellite tracking and foraging success
A lot of evidence shows that there exist a large individual variation in the contribution of offspring to the next generation (Clutton-Brock 1988; Newton 1989), and recent studies of seabird have shown that the body condition (body mass corrected for body size) of the

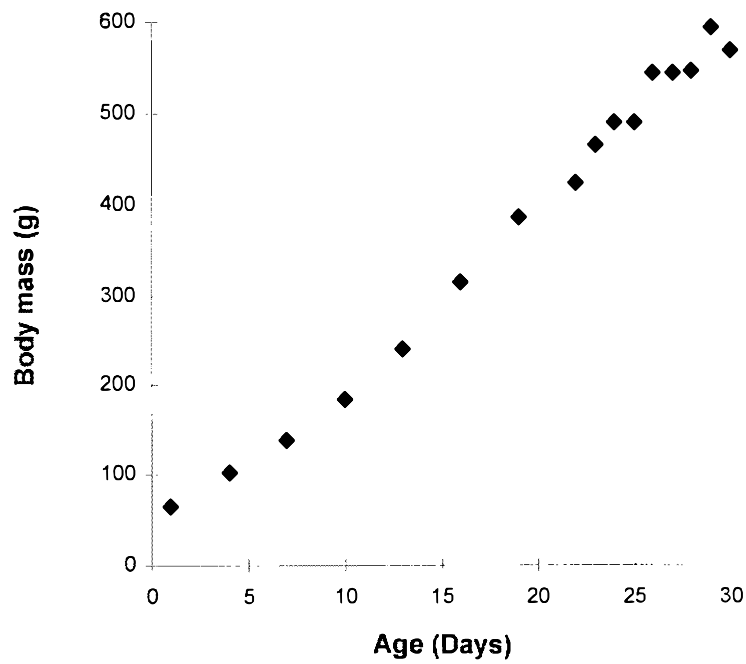

Fig. 6. Growth of Antarctic petrel chicks. Mean weight of 47-50 chicks are shown.

parents may greatly influence on the parents ability to reproduce in any one year (Chastel et al. 1995a, b). Moreover, individual variation parental body condition may be an important factor regulating the reproductive decisions in seabirds (Chaurand & Weimerskirch 1994a, b; Weimerskirch 1995; Weimerskirch et al. 1994, 1995; Lorentsen 1996; Erikstad et al. 1997; Sæther et al. 1997; Tveraa et al. 1997). For instance, Lorentsen (1996) found that Antarctic petrels at Svarthamaren that were in good body condition delivered larger meals to their chick and consequently produced larger chicks than parents in poor body condition. Apparently, parents in good body condition are able to outweigh some of the negative effect of environmental stochasticity on reproductive success (Sæther et al. 1997). However, the direct relationship between parental body condition and foraging success is only poorly understood.

The purpose of the present study was to examine what areas the Antarctic petrel use for foraging during the chick rearing period, and whether individual differences in body condition and foraging success is related to foraging behaviour and foraging areas. To answer these questions, we attached 36 small satellite transmitters to the back of breeding birds at the end of the guarding period, i.e. when the parents leave their chick alone.

To profound the effect of body condition, we randomly selected 18 males from the lower and 18 males from the upper quartile from a sample of 92 males according to their body condition at hatching. We then measured the body mass of these chicks twice a day (from 0800-1100 and 1900-2200) in order to estimate the size of the meals delivered. We also collected sub-samples of the food delivered to the chick. To examine the effect of the satellite transmitters on the frequency, the size, and the content of the meals delivered, we also collected these data on control birds (males without satellite transmitters).

Causes and consequences of variation in reproductive success

According to life history theory, the current reproductive effort should be balanced according to the costs for future reproductive output in order to maximise lifetime reproductive success (Stearns 1992; Roff 1992). Seabirds are characterised by low annual fecundity and high adult survival rates. In such species, small reductions in adult survival rates may have large negative impact on the lifetime reproductive success (Wooller et al. 1992). Such species should therefore not jeopardise their future reproductive output due to increased investment in the current breeding attempt.

In order to examine how parental effort may affect adult survival, we experimentally increased the parents costs of current reproduction by adding lead weights to the legs of one group of birds using the same procedure as Sæther et al. (1993) and Tveraa et al. (1997). Another group were used as controls. We then studied the relationship between treatment and parental body condition, and foraging success in terms of the sizes of the meals delivered by these parents, and also by the growth rates of their chicks. The lead weights added to these birds were removed after about three weeks.

The relationship between parental body condition, treatment, and future reproductive success will be examined by examination of the breeding success in the next breeding season (1997/98) and the return rate to the 1997/98 breeding season.

Regulation food provisioning

Procellariiform seabird species are characterised with delayed maturity, low fecundity and long lifespan (e.g. Croxall & Rothery 1991). This life history strategy is assumed to be an adaptation to the stochastic marine environment (Ashmole 1971), where the resources are patchy and sparsely distributed (Heinemann et al. 1989). Due to the long distances to the foraging areas and the patchy distribution of their prey species, procellariiformes such as the Antarctic petrel typically feed their chick with large meals at long time intervals which may last for several days (Fisher 1967). For these reasons, procellariiform species have been suggested to have a fixed investment in their chick. I.e. they feed their chick according to an intrinsic rhythm, but independent upon their chick's need. On the other hand, other seabird species (Bertram et al. 1996; Erikstad et al. 1997) and passerines (e.g. Wright & Cuthill 1989, 1990) have shown that the parents regulate their investment both according to their own body condition, the value of their brood and their chick's need. Such a mechanism will be greatly profitable in a stochastic environment (cf. Erikstad et al. 1997). Accordingly, recent studies of the Antarctic petrel have shown that parents in good body condition provide more food for their chicks (Lorentsen 1996), and Sæther et al. (1997) have shown that parental body condition may be an important factor which may outweigh some of the negative effect of stochastic environmental processes.

In order to test how the parental body condition and the chick's need may influence in the provisioning to the chick, we swapped chicks of different size between parents in poor and good body condition.

Preliminary results suggest that the Antarctic petrel, contrary to previous suggestions have flexible investment and regulate their investment both according to their own body condition and their chick's need (Tveraa et al. unpublished)

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EPICA DRONNING MAUD LAND PRE SITE SURVEY 1996/97

INTRODUCTION

Within the European Project for Ice Coring in Antarctica (EPICA) it is planned to obtain two deep ice cores from the Antarctic ice sheet within the next decade. The first one will be drilled at Dome Concordia (Dome C), starting in the 1997/98 season, and should provide scientists with one of the longest undisturbed climate archives, extending more than 500 ka. The second core site should be characterised by higher accumulation rates with a dominant contribution of precipitation from the South Atlantic Ocean (the 'Atlantic signal'), to make the link with climate data obtained from the Greenland ice sheet and obtain more detailed information of the last glacial cycle. Although it is clear that this core will be drilled somewhere in Dronning Maud Land (DML), which is one of the least explored regions of Antarctica, its exact position is yet to be determined. To this end, a reconnaissance phase has been planned to produce data on accumulation rate, ice depth and dynamics, bedrock and surface topography, snow/ice chemistry and meteorology. This phase will consist of several pre site surveys, the first one of which started in the field season 1995/96 with an extensive German airborne radio-echo sounding campaign, yielding valuable information on ice thickness, surface and bedrock topography over a large area. The Norwegian/Swedish/Dutch ground traverse during the last field season 1996/97, is another part of the pre site survey work done within the EPICA programme. This report describes in somewhat more detail the activities during that traverse, as well as some preliminary scientific results.

THE TRAVERSE

The *EPICA DML pre site survey 1996/97* was part of the Norwegian Antarctic Research Expedition (NARE) and involved ten persons: two scientists from The Netherlands, two scientists from Sweden and six persons from Norway, of which three logistic personnel and three scientists. Fig. 1 shows the traverse area, including the routes from the unloading place on the ice shelf to TROLL Station (72°01'S, 2°32'E, 1298 m a.s.l.) and from TROLL Station onto the plateau via the glacier Slithallet. Before the start of the traverse, small groups operated on snow machines in the area north of TROLL as well as along the route between the station and the main depot on the plateau, doing the planned scientific work at sites A, B and C. Before these groups started out, a helicopter reconnaissance was flown over all these routes as well as over the planned traverse route as far as 7°E, covering approximately one-third of the route towards the projected endpoint of the traverse (75°S, 15°E). In the same period, snow- and ice depth radar were operated from tracked vehicles on supply trips between TROLL Station and the unloading place on the ice shelf.

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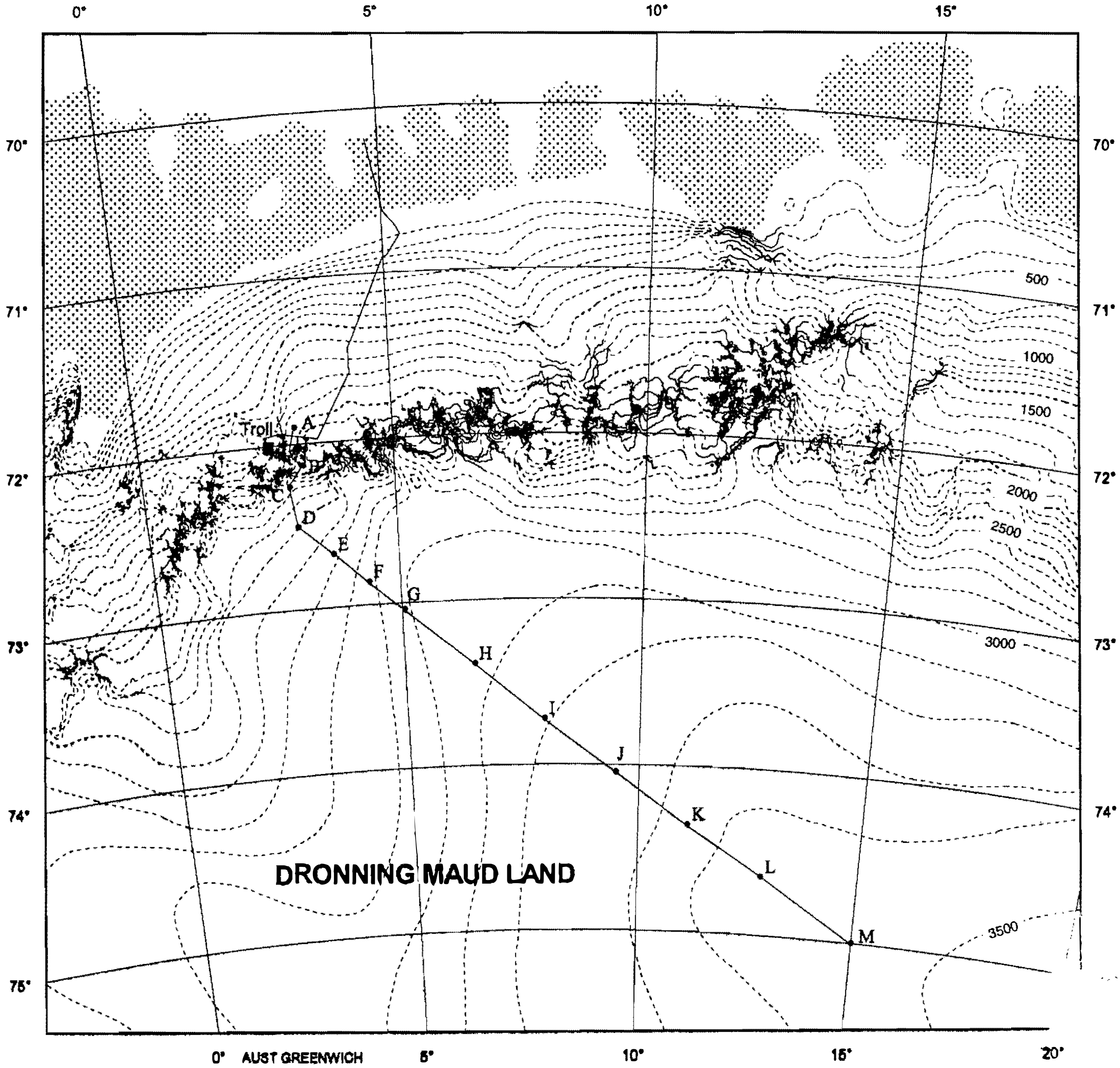

Fig. 1. Topographic map of the working area, showing the routes between the unloading location at the ice shelf and TROLL, and subsequent routes onto the plateau. Letters correspond to locations in Tables 1 and 2.

The actual traverse started out from TROLL Station(1298 m a.s.l.) on January 16 1997, towards the main fuel depot that had been established by helicopter some 25 km south of TROLL (site C) at an altitude of approximately 2400 m a.s.l. Before departure from Norway, Landsat TM images of the area south of TROLL Station had been carefully studied in order to identify crevasses, which laid the basis for the final route between TROLL Station and site D. After site D, the traverse route followed a south-easterly course along the ice ridge leading towards Dome Fuji. Table 1 presents the progress of the traverse during the subsequent three weeks, and defines the position of camps and some of the locations where scientific work was done (sites C to M). A complete listing of these sites can be found in Table 2.

Table 1. Traverse itinerary.

Date (1997)	Travel dist. (km)	Camp location	Elevation (m a.s.l.)	Site	Other information
16-17 Jan.	68	72°15'S, 02°53'E	2400	C	Traverse main depot, loading. Crevasses 3-4 km on both sides of the route between C and D.
18 Jan.	88	72°52'S, 04°21'E	2840	F	
19 Jan.	52	73°10'S, 05°34'E	-	-	
20 Jan.	38	73°23'S, 06°28'E	3074	H	
21 Jan.	60	73°43'S, 07°56'E	3174	I	
22 Jan.	40	73°56'S, 08°58'E	-	-	Delayed start due to white-out
23 Jan.	80	74°21'S, 11°06'E	3341	K	
24 Jan.	60	74°39'S, 12°47'E	3406	L	
25-28 Jan.	76	75°00'S, 15°00'E	3453	M	Traverse turning point
29 Jan.	76	74°39'S, 12°47'E	3406	L	
30 Jan.	60	74°21'S, 11°06'E	3341	K	
31 Jan.	60	74°03'S, 09°30'E	3268	J	
1 Feb.	60	73°43'S, 07°56'E	3174	I	
2 Feb.	80	73°15'S, 05°53'E	-	-	
3 Feb.	70	72°52'S, 04°21'E	2840	F	
4-5 Feb.	88	72°15'S, 02°53'E	2400	C	Traverse main depot, visit D2
6 Feb.	68	72°01'S, 2°32'E	1298	-	TROLL Station

The traverse team travelled with two Hägglunds 206 tracked vehicles, used to pull equipment and supply sledges, and four Polaris Wide Track snow machines. On the sledges pulled by the tracked vehicles stood one large hut (10 m^2) that was used for cooking, eating and relaxing, and a small hut (6 m^2) that housed temperature-sensitive equipment and was equipped with two beds. Eight expedition members slept in a large Weatherhaven tent and in a Scott-Amundsen tent. More details on logistics can be found under *Logistics.*

On normal travel days, the traverse team split up in three groups: after break-up of camp, usually between 10 and 11 am, two snow machines with three persons left directly for the next location, thereby marking a safe route for the Hägglunds (marking the route with flags every fifth km). Two persons on the remaining snow machines zigzagged between points situated 5 km on each site of the main route to perform kinematic GPS measurements. For safety reasons, the two scooter parties met at each crossing point, i.e. every 10 km. After arrival at the camp site, the two scooter parties would establish camp and perform drillings and pit studies before the slower tracked vehicles arrived. Usually five persons travelled with the Hägglunds, carrying out radar and meteorological measurements.

The turning point of the traverse, located at 75°S, 15°E at an elevation of approximately 3450 m a.s.l., was reached on January 25. After a stay of three days at the turning point, the traverse team started back northwards along the same track, and reached the site of the main depot on February 4. During the traverse, weather conditions had generally been favourable, with good visibility and low wind speeds. On the way in, bad visibility had held up the traverse team for only half a day. On the way out, strong winds (12-15 m s^{-1}) caused bad visibility and drifting snow on February 3. In spite of the high altitude and the advanced season (temperatures at the high plateau ranged between -30 and -45°C) all equipment functioned properly and no serious delays were encountered. Total travel distance from TROLL Station and back was 1122 km, and the average distance covered on travel days was 66 km. Fig. 2 schematically shows the traverse route and locations of the various glaciological, meteorological and GPS-related activities.

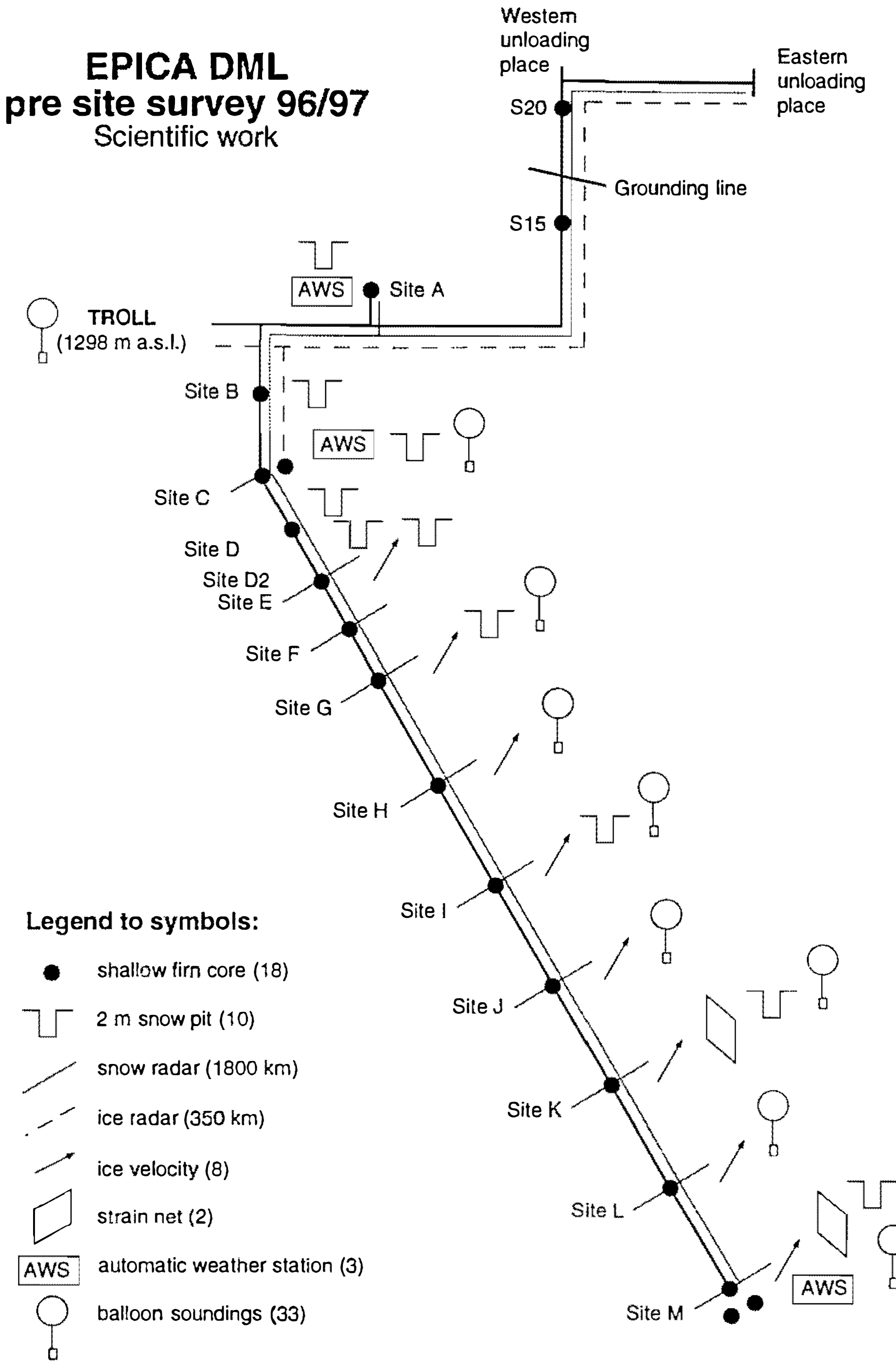

Fig. 2. Schematic outline of travel routes and scientific work. Numbers in brackets in legend indicate totals.

SHALLOW FIRN CORES

Aims

Shallow firn cores are widely used in mass balance and climate research (e.g. Peel & Mulvaney 1992; Isaksson et al. 1996). Most of the shallow (10-20 m) firn cores that were drilled during the traverse will be analysed to obtain local accumulation rates, which are both of general interest and serve to calibrate the snow radar signal (see Section 5: Snow radar). It is anticipated that a 20 meter firn core represents 100-200 years of accumulation on the plateau but considerably less (about 20-30 years) in the coastal area. In both cases, however, the records reach back to volcanic and bomb horizons, enabling the dating of certain levels and hence the assessment of integrated accumulation figures. Volcanic eruptions and bomb horizons can be found by means of electroconductivity measurements (ECM, Hammer 1980) and analysis of ß-activity along the core segments. In addition, oxygen isotope ratios ($\delta^{18}O$) along the core gives information on the yearly accumulation rates, and serves as a check on the other dating methods, although the yearly cycle in low-accumulation areas is often not very distinct.

Three 20 m cores as well as surface snow samples from every drilling site were taken for chemical analysis (^{10}Be, Uppsala University, site C; Halogenated hydrocarbons, Linköping University, site M; Ionic composition, Stockholm University, site MM). Researchers at Linköping University will investigate the presence and origin of triflouro-, monochloro-, dichloro- and trichloroacetate in precipitation. The results for the snow samples could definitively confirm or disprove the existence of a substantial natural source of haloacetates in precipitation. Firn samples will be analysed to compare concentrations in the precipitation of today and of pre-industrial origin. If possible, they will also be used in an on-going study on the chemical character and origin of absorbable organic halogens (*AOX*) in precipitation. From the ionic composition (Stockholm University) we obtain information on seasonal variability of climate and environment 100-200 years back in time. Temporal variations show us which compounds were forming the aerosol (i.e. how the ions were combined), whether the aerosol was acidic or alkaline and in which state the compounds were deposited (as gases or in aerosol form).

Methods and equipment

The firn cores were drilled with a PICO drill system, consisting of a 3 inch core barrel, 1 and 2 m long extensions and a upper part that connects the system of extensions to an electrical drill. At temperatures below -35°C it was found that the polyester of the drilling extensions became brittle, so that using it for extended periods at these temperatures would result in damage. We started out with a 220V/650 W Hilti drilling machine, which generally generates enough rotation power (50 Nm) to drill down to 20 m depth in dry firn.

In the field, we used a Honda 1 kW generator to power the drilling system, the output current alternating at 60 Hz. However, when powered by a much stronger Hatz (2.5 kW) generator, the Hilti was heated up too much, resulting in internal short-circuiting. After that we switched to a 36V/350W Hilti drilling machine, connected to a converter (220 to 24 V). When powered with 36 V, it was found that the internal safety slip of this machine prevented effective operation. The lower rotation power of this machine (app. 25 Nm) forced us to hand-drill at depths greater than 10 m. A 10 m firn core took three persons typically 3-4 hours to drill and pack, whereas the drilling and packing of a 20 m firn core consumed an entire working day with up to 6 people in the drilling team. Usually the snow in the upper layer was poorly sintered, and therefore density was measured in a pit and snow samples taken with 5 cm interval (except at site A). Individual core pieces were measured and weighed, then packed in plastic and sealed. It was found that, due to the low temperatures, operating the balance with an external power supply was preferable to batteries. The sealing device, a Sealboy 235 SA, worked well even under very cold conditions.

Table 2. Information on shallow firn cores, snow pits and 10 m temperatures. N.a. means 'not available'. If borehole depth is less than 10 m, temperature was measured at the lowest possible level.

Site	Location	Elevation (m a.s.l.)	Shallow firn core (m)	2 m snow pit	T_{10m} (°C)
S20	70°14'26"S, 04°48'41"E [(1)]	48 [(1)]	20.1	no	-18.3
S15	71°11'32"S, 04°35'51"E [(1)]	800 [(1)]	15.1	no	-21.3
A	71°54'00"S, 03°05'00"E [(1)]	1420 [(1)]	13.3	yes	n.a.
B	72°08'01"S, 03°10'31"E	2044	11.8	yes	-29.4
C	72°15'04"S, 02°53'28"E	2400	12.3; 17.2	yes	-31.7
D	72°30'00"S, 03°00'00"E	2610	11.9	yes	-36.5
D2	72°35'51"S, 03°21'17"E [(1)]	2750 [(1)]	no	yes	no
E	72°40'42"S, 03°39'46"E	2751	10.1	yes	-37.6 [(2)]
F	72°51'41"S, 04°21'05"E	2840	10.0	no	-40.4
G	73°02'26"S, 05°02'39"E	2929	10.2	yes	-41.0 [(2)]
H	73°23'11"S, 06°27'38"E	3074	9.8	no	-44.9
I	73°43'27"S, 07°56'26"E	3174	10.3	yes	-47.0
J	74°02'41"S, 09°29'30"E	3268	10.2	no	-48.8 [(2)]
K	74°21'16"S, 11°06'13"E	3341	9.9	yes	-50.5
L	74°38'50"S, 12°47'27"E	3406	9.0	no	-52.0
M	74°59'59"S, 15°00'06"E	3453	19.9; 20.0	no	-54.2
MM	App. 1 km SE of M	-	20.1	yes	-54.2

(1) no DGPS measurements available
(2) no overnight measurement

Fieldwork and preliminary results

Table 2 shows details of the shallow firn core programme. As a preliminary result, we show the mean density of the first 10 m of the snow pack as a function of 10 m temperature in Fig. 3. If we disregard the two drillings north of TROLL (S15 and S20), where annual mean temperatures exceed -25°C and regular melting occurs during summer, the average density of the first 10 m appears to be a linear function of annual mean temperature, with an approximate slope of 4 kg m^{-3} $°C^{-1}$. Figure 4 shows uncorrected ECM measurements performed on the core drilled at site E. A preliminary dating suggests that eruption of Agung at Bali (1963) can be traced back as a level of elevated acidity at about 6.5 m depth. In combination with the density data of the overlying layer, this would suggest a yearly accumulation of 94 mm w.e. per year at this location, which is not unreasonable. *(NB! Later β-analysis of core E shows that the yearly accumulation is 56 mm w.e. - editor's comment.)*

SNOW SAMPLING IN PITS

Aims

The snow samples collected during the traverse will be used for ion concentration analysis and oxygen isotope studies. The ions and isotopes that will be analysed are Natrium (Na^+), Potassium (K^+), Nitrate (NH_4^+), Magnesium (Mg^{2+}), Calcium (Ca^{2+}), Chloride (Cl^-), Nitrate (NO_3^-), Sulphate (SO_4^{2-}), Methanesulfonate ($CH_3SO_3^-$) and oxygen isotopes ($\delta^{18}O$). The spatial variability of the deposition of major components of atmospheric aerosol (seen as ions in the snow) reveal where the influencing sources are located. The calculated scale heights for different ions indicate where in the atmosphere they were transported (regional marine compounds in lower layers, long-range transport compounds at higher levels of the atmosphere). The deposition patterns along transport paths (showing a decrease with distance) are connected to deposition processes in the present climate.

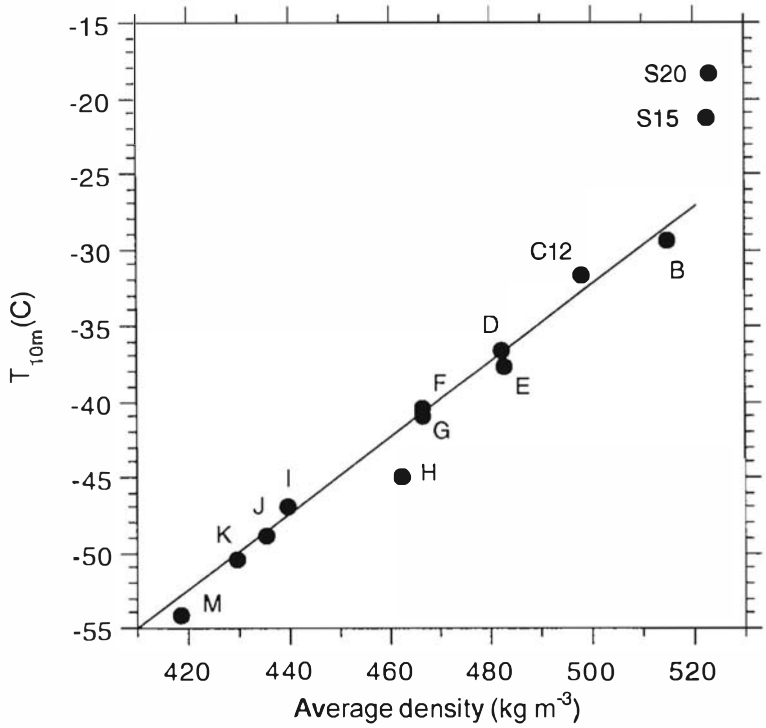

Fig. 3. Mean density of the uppermost 10 m of firn vs. temperature at 10 m depth.

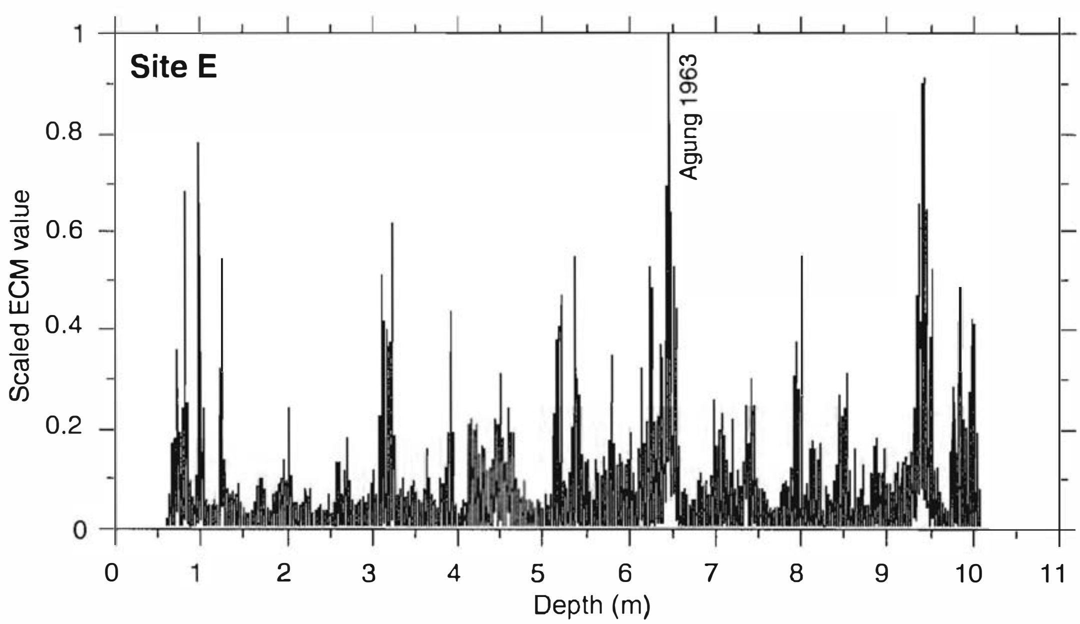

Fig. 4. Raw ECM data of core E. The probable location of a layer with elevated acidity values owing to the eruption of Agung (Bali, 1963) is indicated.

Methods and equipment
To make sure the samples were taken without contamination from local sources, sampling was performed in three stages: first the main pit was dug using normal shovels and clothing. Then the upwind wall for sampling was prepared after which the sampling itself took place. These last two stages were performed in clean suits and with clean equipment. All tools used for sampling are made of polyethylene, and were thoroughly washed with double-deionized water (resistivity > 18 MΩ) from a Milli-Q system. Samples were collected in pre-cleaned (double-deionized water) 60 ml polypropylene Nalgene bottles.

Fieldwork and preliminary results
During the traverse a total number of 10 snow pits was dug, all 2 m deep (Table 2), and sampled at 2 cm intervals. Each pit was situated 100 - 150 m upwind of any local contamination source such as Hägglunds, snow machines and generators. The upwind wall was used for sampling and all spoils were dumped in the downwind direction in order to avoid direct contamination. All samples were transported in isolated boxes to Stockholm. After the sampling, density was measured with a resolution of 5 cm.

he first three pits at sites A, B and C, were sampled according to the technique used during the Swedish ITASE traverse 1993/94, which means collecting the samples from top to bottom. In order to get better data quality, a new sampling routine was used on the remaining sites. Here, instead of sampling from top to bottom, the sampling started from a depth of 180 cm and samples were collected every 2 cm up to the surface. By doing so, it was avoided that snow from higher levels fell down on the remaining sampling surface, thereby contaminating it.

SNOW RADAR

Aims
Snow accumulation is a mass balance parameter that is characterised by large variations over the ice sheet surface. When an initially even snow cover is exposed to wind, the snow may be redistributed in a pattern with a very high spatial variability. Surface topography has a strong impact on the wind systems and thus also on the snow accumulation pattern. The highest spatial variability in snow accumulation can therefore be expected in areas with an undulating surface topography. The snow cover may be redistributed also in areas with a flat surface resulting in sastrugi fields. When locating a suitable drill site for the EPICA deep core it is important to find a place characterised by a low spatial variability in snow accumulation. Otherwise the climatic information obtained from the core may not be representative for the area and difficult to interpret. High resolution snow radar soundings give an opportunity to obtain information on the present snow cover distribution along continuous profiles. This two-dimensional information is an important complement to the traditional point studies of snow accumulation, such as stake measurements, pit studies and firn- and ice core analyses.

The information obtained from snow radar soundings is also important in a more general context, namely the mass balance of the Antarctic ice sheet. The ice sheet mass balance is a matter of great concern in discussions and predictions of ice sheet response to climatic change. The present-day mass balance is not well established. The main reason for this is that large parts of the Antarctic continent are still unknown, with a lack of field data on mass balance parameters. The data available on snow accumulation consists primarily of point measurements concentrated to the easily accessible regions near the coast. In calculations of the ice sheet mass balance the snow accumulation has to be estimated for very large parts of the ice sheet, which introduces significant uncertainties. Continuous snow radar registrations along profiles give information on the spatial variability in snow accumulation to make reliable estimates of accumulation rates over large areas.

The principal aim of this study is to map the spatial variations of snow accumulation. A continuous snow radar profile has been recorded extending from the ice shelf to the polar plateau at 3450 m a.s.l. At coring locations, the radar registrations will be used to determine the spatial representativity of the cores with respect to snow accumulation. The relations between spatial variability in accumulation and physical parameters such as surface slope and topography, altitude, distance from mountain ranges and open sea will be analysed. The investigated region will be divided into areas with characteristic spatial variability in snow accumulation.

Methods and equipment

The snow radar registrations reveal subsurface stratigraphy of the snow pack along the profile (Fig. 5a). The snow layers are assumed to represent time horizons, i.e. one layer has been formed during a specific occasion or limited period of time. In the processing of the data the principle is to follow a specific reference layer throughout the registrations along the travel route in order to register the variations in snow layer depth. In order to obtain the annual average accumulation rate along the route, the snow layer will be dated through correlation to firn core analyses. The radar profiles were positioned by GPS measurements using a logging interval of 15 s, corresponding to a horizontal distance of 35-40 m. The GPS data will be corrected differentially against a reference station that was operational at TROLL Station. The distance between adjacent sounding points was set to 5 m, giving a very high spatial resolution of the data.

The depth of the reference layer is calculated by using density data from firn cores that were retrieved along the travel route. Snow depth is transformed into water equivalents using density data from the firn cores. When calculating the depth of the reference layer, it is necessary to make a geometric correction for the non-vertical ray path related to antenna separation. However, refraction effects in the snow pack may be neglected. The above described method has been reported by Richardson et al. (1997). The radar has previously been used for studies of spatial variability in snow accumulation along a 1040 km long profile located approximately 10° further west in Dronning Maud Land (Richardson, 1995). The snow radar used is a synthetic pulse stepped frequency carrier wave radar, described in Hamran and Aarholt (1993) and Hamran et al. (1995). The system is based on a HP Network Analyser (8753B), transmitting a sequence of 201 frequencies evenly distributed over an adjustable bandwidth (maximum range 0.3-3.0 GHz). The radar is conTROLLed by a 486 computer. Two different frequency ranges were applied using two types of antennae (Table 3). A dual-frequency GPS, P-code (Ashtec Z XII) was used for positioning the radar registrations. The radar was installed in one of the Hägglunds with the antennae mounted on a steel frame on the outside of the vehicle.

Fieldwork and preliminary results

Radar soundings were performed continuously along the trail from the shelf edge at the eastern unloading place (70° 08'S, 05°16'E) to TROLL Station, and from TROLL to the EPICA traverse turning point on the polar plateau (75°S, 15°E, Fig. 2). All sections were sounded using both antennae type A and B (Figs. 5a, b). On the polar plateau, transverse profiles with length ranging between 1 and 10 km were recorded at a number of sites (Table 4), in order to determine the geographical representativity of accumulation data derived from firn cores.

Although the radar data are not yet processed, some preliminary results can be given. On the polar plateau, good results were obtained from the shallow radar sounding down to 12 m depth. There appears to be a snow layer which is possible to trace along the traverse route on the plateau. The lower frequency antennae gave less good results. Layering within the upper 50 m snow pack was recorded in some areas, but seems to be absent in general. Detailed post processing may help to reveal layering in these data. In the coastal area good results were

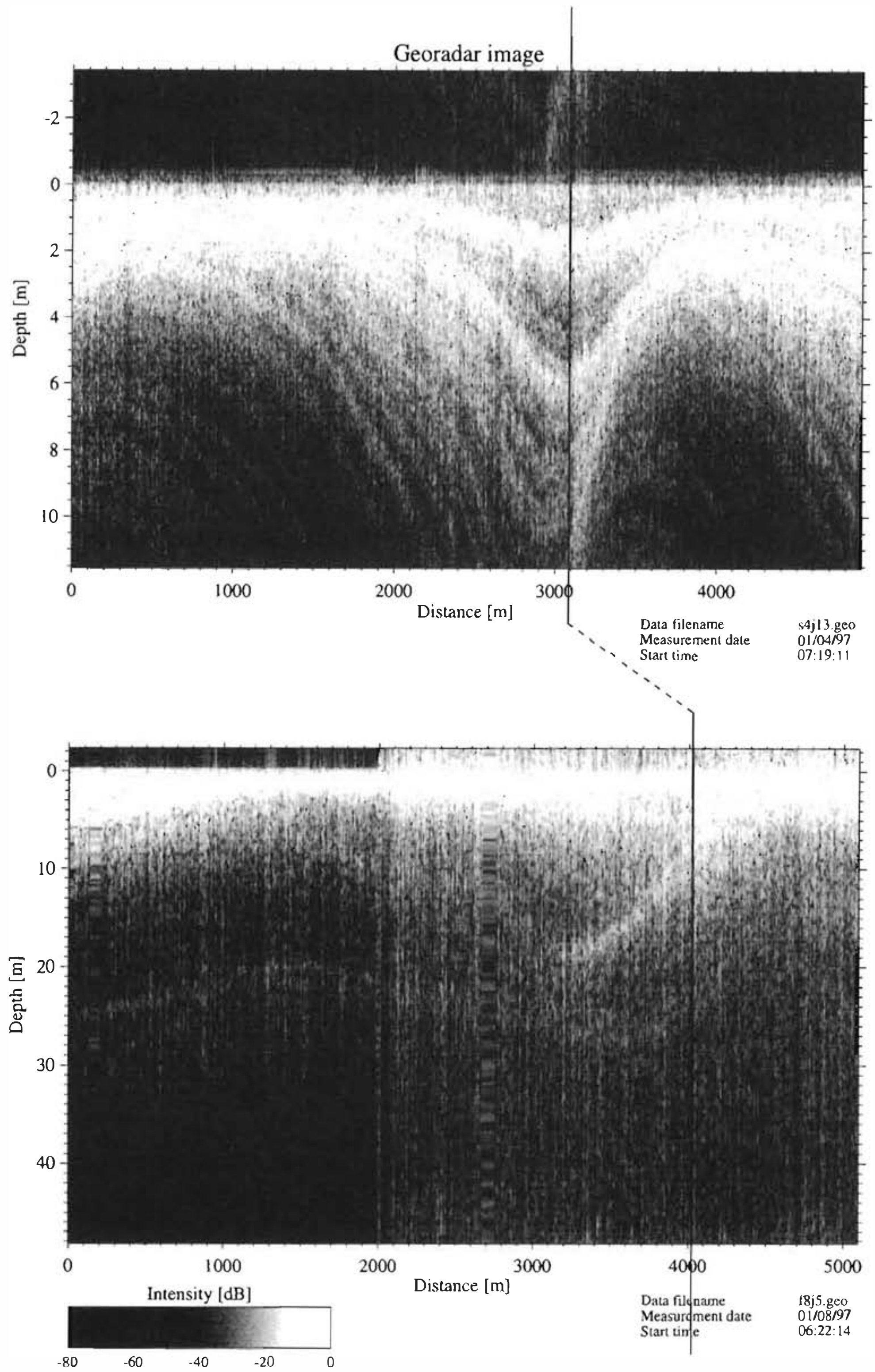

Fig. 5. Radar registrations retrieved along the same profile (70°45'S, 05°19'E - 70°47'S, 05°17'E), using different frequency ranges. Fig. 5a (upper panel) shows the stratigraphy within the upper 12 m of the snow pack (antenna A). Fig. 5b (lower panel) reveals the layering within the upper 50 m (antenna B). The location of the registrations is not perfectly matching, and we have inserted vertical lines to indicate shots taken at the same position. Note that the snow layer geometry is dislocated at greater depth, indicating a shift in the accumulation pattern over longer time periods.

Table 3. Data on snow radar antennae and radar characteristics.

Antenna type	Notation	Frequency range (MHz)	Penetration depth (m)
A	AEL APN-106AA	800-2300	12
B	Allgon 7125.04.05.00	750-1050	50

Table 4. Length of transverse radar profiles recorded at various drill sites.

Site	Total length of perpendicular profil	Comments
C	1 km	
D	-	unsafe area
E	2.5 km towards SW	unsafe area to NE
F to L	5 km	
M	10 km	

obtained using both antenna types, revealing clear layering in the snow pack at shallow depths (down to 12 m) as well as at larger depths (down to 50 m).

In the beginning of the season (4-7 January 1997) it was found that the registrations recorded around noon were of a poor quality, impaired with strong surface reflections and indistinct snow layering. This problem was probably generated by the relatively high air temperatures and associated melting at the snow surface. At the high frequencies used (800 - 2300 MHz) the radar is very sensitive to liquid water, which causes a strong reflection and makes it difficult to penetrate through the surface. The snow radar soundings were repeated along the same trail at lower temperatures in the end of the season (14-16 February), this time with good results. We also found that the high frequency antennae (A) caused disturbances of the navigation c/a-code GPS receiver (Garmin 120) and to some extent also of the logging p-code GPS receiver. Efforts to separate the radar and GPS antennae as far as possible and using metal shields did not reduce the disturbances to an acceptable level. The Trimble Navigator GPS receiver was not disturbed by the high frequency radar signal.

Calibration tests of the snow radar were made at site A, where steel reflectors were pushed into the snow pack at two different depths, 205 cm and 155 cm. The reflectors were marked by four bamboo stakes along a 2-3 m line. The reflectors and bamboo stakes were left at site A, and the reflector depths may be re-surveyed by manual probing.The tests were performed in warm weather around noon (possible surface melting) on 6 January 1997 and at colder temperature (no surface melting) on 9 February 1997.

The ground based snow radar soundings will be compared to ERS-2 data in order to test the possibilities to determine spatial variability in snow accumulation from satellite images. The ERS-2 takes registrations at 5.3 GHz, and the images have a spatial ground resolution of approximately 25×25 m. Four corner reflectors were placed out at EPICA site C at (72°15'07"S, 02°53'39"E; 72°15'35"S, 02°52'34"E; 72°15'39"S, 02°52'39"E; 72°15'07"S, 02°53'24"E), with inclination 27° and horizontal direction 199°S. The ERS-2 passage was on 2 February. The radar soundings were performed in a gridnet on 5 February, and by that time the surface was covered with recently fallen snow. Photographs and notes on the snow surface characteristics were taken at corner reflector positions.

ICE DEPTH RADAR

Aims

An ice depth radar was brought to map ice thickness variations and internal layering along the traverse. The radar was kindly lent to us by the British Antarctic Survey (BAS) in Cambridge. Data on ice thickness is necessary when calculating the mass balance, ice flow patterns and bedrock topography. In addition, the ice depth measurements may tell us whether there are cold- or temperate conditions at the ice sheet base.

Methods and equipment

The radar is based on three units: a BAS 60 MHz valve transmitter, a 60 MHz log receiver and a Tektronix 520 oscilloscope. Antennas used were of Yagi type. The system has been developed by H. Corr at BAS.

Fieldwork and preliminary results

Ice depth soundings were taken continuously along the trail from the shelf edge at the eastern unloading location to TROLL Station. Depth soundings were also performed along the initial part of the EPICA traverse on the polar plateau (Fig. 2). Unfortunately, the radar did not work properly and the maximum penetration depth recorded was about 1000 m. The functioning of various system components was tested in the field, but no failing part was found. However, bottom reflections were obtained along the trail from the shelf edge and approximately 100 km inland towards TROLL Station(Fig. 6). We interpreted the location of the grounding line from the occurrence of basal crevasses. The crevasse density increased from a travel distance of 64 km until the 70 km point, and further inland no basal crevasses occurred. Along some sections north of TROLL Station, internal layers were recorded at shallow depth (less than 220 m). Bottom reflections were registered nearby the mountain range Mühlig-Hoffmannfjella, where the maximum ice depth was less, about 600 m. The ice thickness beneath the glacier Slithallet is shown in Fig. 7. No bed reflections or internal layering was registered on the polar plateau except nearby the mountain range. We tried to modify the radar system in order to improve the possibilities to pick up internal layers on the expense of bed reflections, but without success.

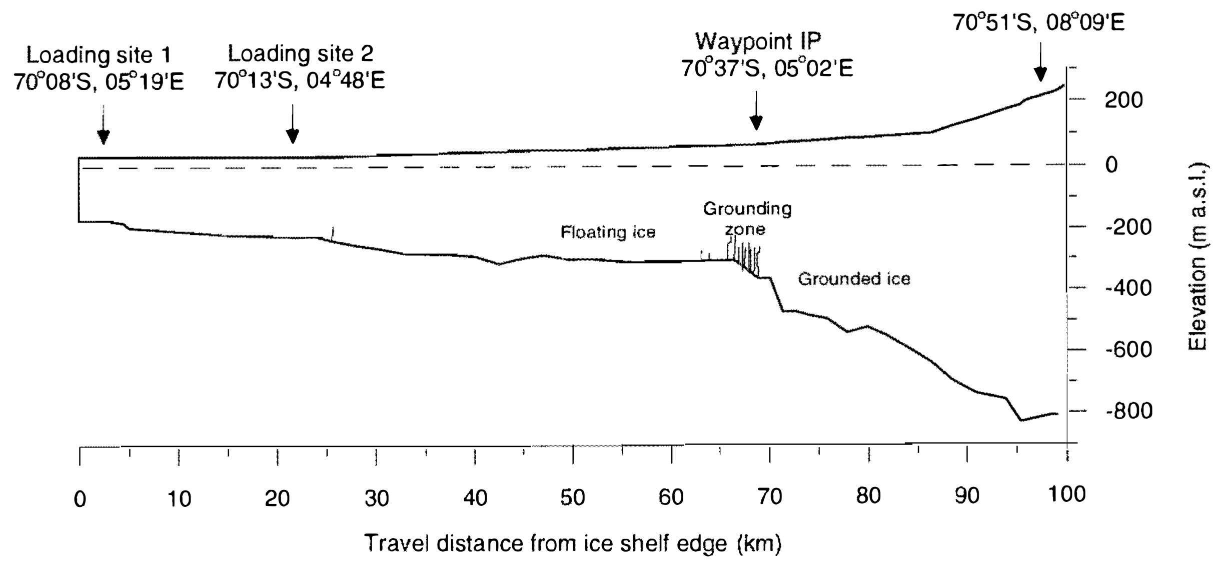

Fig. 6. Ice thickness profile of the ice shelf and grounding zone. Basal crevasses are indicated.

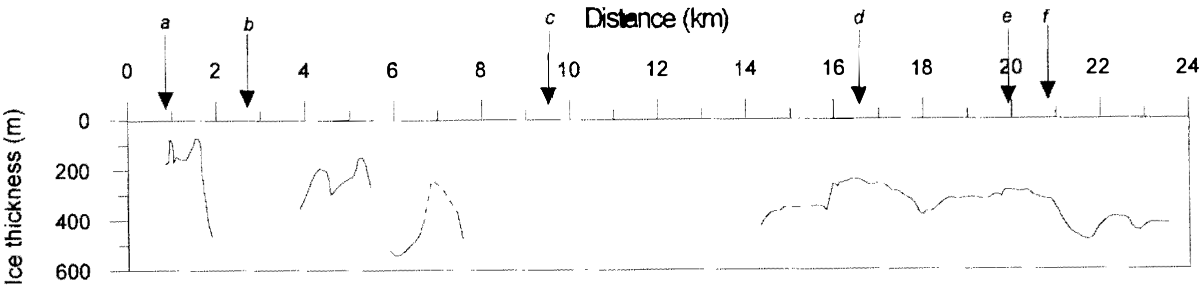

Fig. 7. Ice thickness profile from N to S along Slithallet, Mühlig-Hoffmanfjella. Positions: a) 71°56' S, 02°54' E; b) 71°57' S, 02°55' E; c) 72°01' S, 02°57' E; d) 72°05' S, 02°58' E; e) 72°06' S, 03°00' E; f) 72°07' S, 03°04' E.

Fortunately, the German airborne radio-echo sounding programme collected data on ice depth by flying parallel to the tracks of the traverse.

METEOROLOGY

Aims

The meteorological activities during the traverse were focused on the erection of 3 Automatic Weather Stations (AWS) and the launching of a series of meteorological balloons. These data will hopefully learn us more on moisture transport mechanisms from the coastal areas towards the East Antarctic plateau. Western DML is one of the least explored areas in the world, and the AWS data therefore also serve a general climatological interest. It is well known that synoptic disturbances that migrate eastwards along the coast of Antarctica do not penetrate far inland, and that the moisture content of the atmosphere decreases quickly further inland: by situating the AWS at different distances from the coast, moisture and heat transport processes can be studied in more detail. The moisture transport towards Antarctica takes place mainly in the free atmosphere (Fortuin & Oerlemans 1992), whereas the layers closest to the surface experience flow towards the coast. Especially at the high Antarctic plateau, an important part of the accumulation takes place through deposition of ice crystals in the lowest layers of the atmosphere. With the employment of meteorological balloons the structure of this part and upper parts of the atmosphere can be mapped, and the main processes identified.

Methods and equipment

The AWS are designed by the technical staff of IMAU, and are of the same type as those employed previously in Greenland, Iceland and Antarctica (Berkner Island). The stations are dug in the snow in such a way that only the mast, sensor arms and 4 guying cables are above the snow, the sensors initially being 3 m above the surface. Temperature, humidity, wind speed and direction, radiation and snow height are measured with Aanderaa sensors. Two stations (those situated at sites A and M) are equipped with a thermistor string with temperature sensors of the type Pt 100. At these stations, firn temperatures are measured at 0.25, 0.5, 1, 2, 4, 8 and 16 m depth. Sampling interval is 2 minutes, and with every passing of a polar orbiting satellite, the measurements of a 6 h period are transmitted to the Netherlands via the ARGOS satellite communication system. The stations operate on a set of Lithium batteries that can power the station for about three years.

Table 5. Specifications of the Vaisala RS80-18G sonde.

Measured variable	Range	Reproducibility[1]
Pressure	1060 to 3 hPa	0.5 hPa
Temperature	+60 to -90 °C	0.2 °C up to 50 hPa
Humidity	0 to 100 %	< 3 %
Wind vector	0 to 180 m s^{-1}	0.5 - 0.2 m s^{-1}

[1]Data based on WMO International Radiosonde Comparison Phase I, II and III (WMO TD-195 and 451)

Table 6. Installation details of Automatic Weather Stations (AWS).

	Site A	Site C	Site M
Station no.	AWS-1	AWS-3	AWS-2
Connection date	31 Dec. 1996	3 Jan. 1997	28 Jan. 1997
Connection time (GMT)	11:50 GMT	13:00 GMT	14:50 GMT
cm of snow covering data logger	32	28	28
Position relative to drill site	6.4 m at 240°	-	6 m at 110°
Max. depth thermistor string	13 m	-	16 m
Data transmission to Utrecht ?	yes	no	yes

For the balloon sounding system, a standard Vaisala MW 12 rawinsonde set was used to follow the 200 g He-filled balloons that carry up the sonde (Vaisala RS80-18G). This system is also used at many national meteorological services. The rawinsonde set collects upper air pressure, temperature, humidity, wind speed and direction with great precision, and automatically processes them into ASCII files. The MW12 system consists of a basic unit and software configuration, but with different options for wind finding. The system includes a Rawinsonde set, an UHF receiver and telemetry antenna, a PTU data processor, a data recorder with 2 DD diskette drives and a printer. Used probably for the first time in Antarctica, and certainly in Dronning Maud Land, is the newly developed GPS-based wind-finding. The special sonde contains a codeless, 8-channel digital GPS receiver with down transmission of the GPS data with 1200-baud FSK modulation and a wind vector update of 2 Hz. The wind computation is performed by the ground station.

The measuring accuracy is twice as good as previous systems based on OMEGA or LORAN-C ground navigation. This GPS system is invaluable for Antarctic operations, as the older ground navigation systems are not reliable south of 73°S. Measurement specifications of the sonde are given in Table 5.

Field work and preliminary results

Before the start of the traverse, the three AWS were tested at TROLL Station to see if any damage had occurred during transport. During intercomparison tests in Cabauw (The Netherlands) all internal systems had functioned well. During testing at TROLL Station, however, the transmission of AWS-3 malfunctioned (probably due to problems in the ARGOS transmitter), and it was decided to place that station at site C. The internal datalogger is capable of storing data locally for at least two years. Because this site is relatively easily accessible from TROLL Station, we hope that the station can be repaired and the raw data collected within the next two years. Balloon sounding tests were carried out at TROLL Station. For comparison purposes, two soundings were performed at approximately the same time as at Neumayer station. A handhold tethered balloon system was also tested, using a kevlar cable. This system worked to an altitude of about 250 meters above ground level. After return to TROLL Station three more balloons were launched.

During the traverse, three to four times during each day, clouds, snowdrift, pressure, temperature, relative humidity, wind and position were recorded in a logbook. The weather on the high plateau was generally fairly good. Most of the time Cirrus *(Ci),* Altocumulus (*Ac*) and Altostratus (*As*) clouds were observed between 0/8 and 4/8 only. Half a day was counted as whiteout. Most of the time there was little wind, typically between 1 and 3 m s^{-1}, blowing from a north-easterly direction. A wind speed of 8 m s^{-1} was recorded at the turning point, in combination with a temperature around -40°C. During the traverse, temperatures ranged between -13 and -45°C. Two AWS were successfully placed along the traverse at sites C and M, whereas the third AWS was erected at site A (Table 6).

It was planned to take regular balloon soundings during clear weather. Moreover, during at least one full day period four soundings were to be taken in order to cover the different solar radiation balances at the surface. Table 7 shows that both objectives were fully met by successfully launching 33 balloons between 20 January and 5 February 1997. Most soundings were performed during good weather, but at the end of the traverse some balloons were released during clouded conditions with snowdrift. In Fig. 8 we present some preliminary results of the balloon soundings. Temperature, wind speed and a polar diagram giving the main changes of wind with height, are shown for three different sites and corresponding launching elevation of the surface. Further studies of this kind of profiles, weather maps and data of the AWS hopefully will give clues on the Atlantic influence ('Atlantic signal') in this part of Dronning Maud Land.

Table 7. Overview of balloon soundings during the traverse

Date	Time (GMT)	Location	Weather type
20 Jan.	22:15	site H	clearing up after whiteout, drifting snow
21 Jan.	23:00	site I	6/8 *As* clouds, good visibility
22 Jan.	22:00	73°56'S 08°58'E	1/8 *As* after whiteout
23 Jan.	07:00, 22:30	73°56'S 08°58'E, site K	sunny, 2/8 *Ci*
24 Jan.	10:00, 22:45	site K, site L	sunny, in evening 6/8 *Ac*
26 Jan.	15:30, 22:30	site M	sunny, some *Ac/As* clouds
27 Jan.	03:30, 09:30, 15:30, 21:30	site M	sun shining through 6/8 *As/Ci*
28 Jan.	03:30, 09:30, 16:00, 21:30	site M	7/8 *As*, some drift snow
29 Jan.	03:30	site M	6/8 *As*, sunny
30 Jan.	00:00, 18:30	site L, site K	mostly sunny, few high clouds 2/8 *As*
31 Jan.	07:00, 21:00	site K, site J	sunny, more cloud in evening 7/8 *As*
1 Feb.	07:15, 13:30, 19:00	site J, 73°50'S, 08°30'E, site I	sun shining through 7/8 *As*
2 Feb.	07:00, 20:45	site I, 73°14'S 05°53' E	sunny, 2/8 *Ac*
3 Feb.	14:00	73°02'S 05°06'E	drift snow, clouded 7/8 *St/As*
4 Feb.	21:45	site C	drift snow 6/8 *As*, clearing up
5 Feb.	07:00, 13:00, 17:45, 00:15	site C	sunny with high cloud 6/8 *As/Ci*

SURFACE TOPOGRAPHY, ICE VELOCITY AND ICE DEFORMATION

Aims

Continuous kinematic GPS measurements were performed along the driven track and in a corridor 5 kilometres to each side of the track to determine surface elevation. This will enable us to compile a terrain model of the surface topography in a narrow band along the track. Because ice velocity is expected to be low, reliable measurements of this quantity are obtained through precise positioning of stakes, and re-measurement after some years.A set of stakes (three on each location, one on the track and two 5 km on each side) was set out every 60 km (at drilling

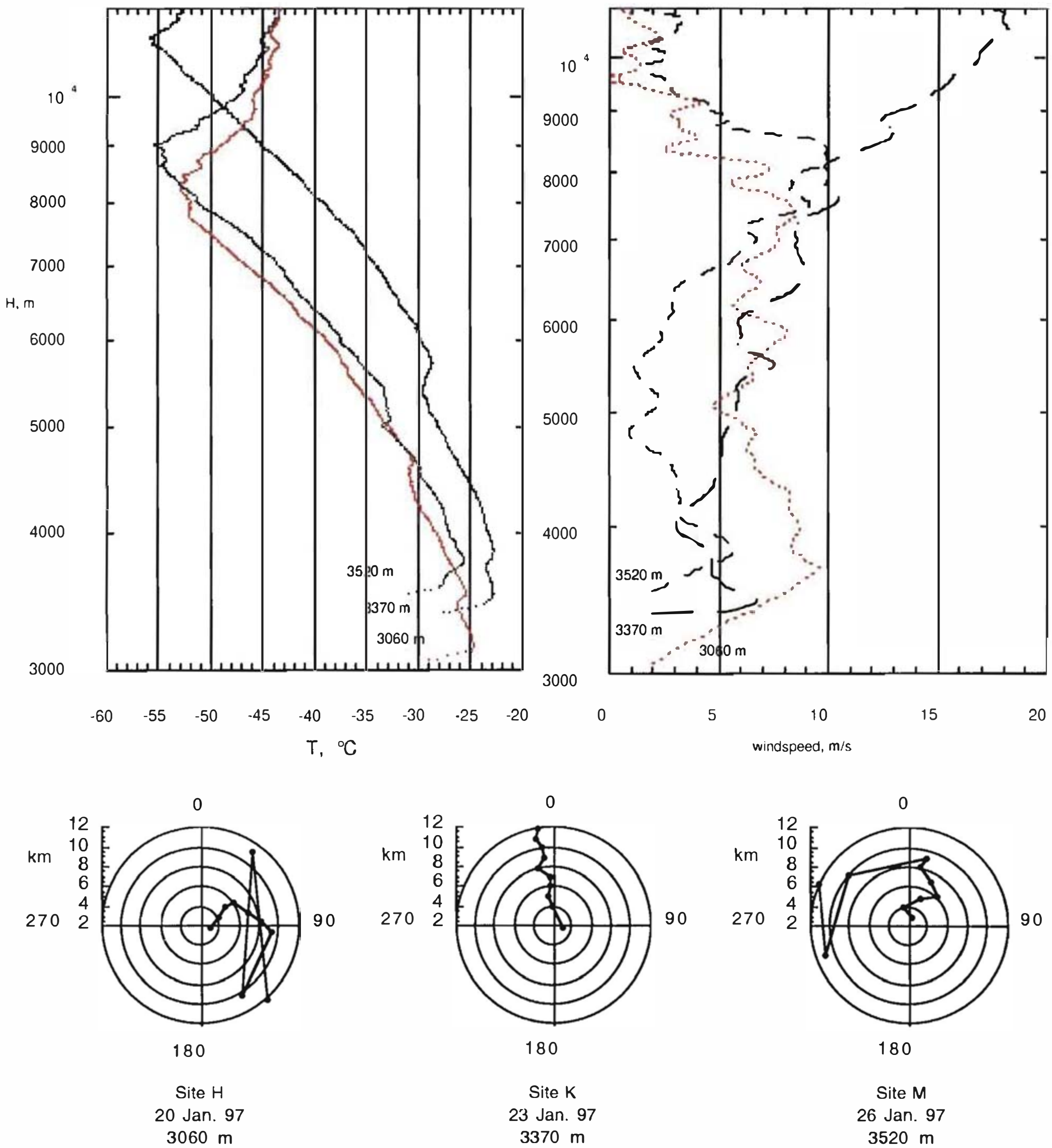

Fig. 8. Temperature and wind speed profiles and polar graphs of wind direction (showing changes with height) obtained around 22:30 GMT on the plateau. Measurements at site K are distinctly different from those at sites H and M: winds are from the north throughout the troposphere (approximately the first ten kilometres of the atmosphere) and temperatures significantly higher, resulting in a elevated position of the tropopause. Also note the temperature inversion close to the surface, a typical night-time phenomenon during the Antarctic summer but a permanent feature during the winter (Van den Broeke and Bintanja, 1995).

sites) and measured as static GPS. Ice in motion will undergo some degree of deformation, and a precisely positioned strain network can show strain at the sub centimetre level when re-measured. Because re-measurement of the EPICA strain nets are planned within some years, accuracy at the cm level can be obtained.

Methods and equipment

Measurements were performed with Ashtech Z-XII dual frequency GPS receivers. The Z-tracking of the Ashtech receivers gives very good phase measurements on both the frequencies used, with very few cycle slips, and are as such well suited for continuous kinematic GPS measurements. A total of four GPS receivers was brought on the traverse, together with the necessary equipment for downloading and processing data. One receiver was continuously operating at TROLL Station to provide a set of reference positions. GPS data collected for surface profiling and static stake measurements will be processed relative to the TROLL Station receiver. This will give long distances between the reference station and the measuring units in the field, especially at the end of the traverse, which is unfavourable for the accuracy. However, it was the nearest and only possible reference station in operation.

Surface profiling was performed with one receiver permanently recording on one of the Hägglund vehicles along the main track, while one receiver was operated on a sledge towed by a snow machine. The snow machine crossed the main track under a 45 degree angle and operated within a 5 km wide corridor centred around the main track. Positions were logged every 15 seconds, yielding a resolution higher than 100 m along the main track, and 100-150 m along the crossing track. For ice velocity measurements data were recorded for some hours at each stake, with longer periods used (3-6 hours) at the southernmost points where the distance to the reference station were largest. The two strain networks (sites K and M) consisted of nine stakes in a 2 by 2 km square. Locations were fixed with two stakes occupied with static reference receivers, while one receiver was moved around to the remaining seven stakes, thus giving two vectors for each stake. All the stakes were visited twice in the measuring session of about three hours.

Fieldwork and preliminary results

On the inward trip, the Hägglund with GPS receivers was also equipped with the snow radar. Preliminary checks of the data showed that parts of the measurements were very noisy, with some data gaps as well. On the return trip the other Hägglund was also equipped with a receiver, which improved the situation. The data that have been processed so far indicate that a position error (one sigma) better than 0.25 metres can be achieved for most of the time. The estimated accuracy is probably too optimistic for the absolute altitude, but is expected to be representative for the epoch-to-epoch accuracy, or the relative accuracy of heights along the profile.

The stake positions for ice velocity have so far been calculated using the Ashtech PRISM software package for static GPS processing. The PRISM software is probably not ideal to get the best accuracy for the very long baselines, and a final processing is planned with other software. The preliminary results for each group of stakes has been corrected using a least squares adjustment relative to TROLL Station, giving results at the 0.1-0.3 m level for the southernmost points. Future processing will probably give results around 0.1 m or better for all velocity stakes. The strain nets have been processed using the PNAV kinematic GPS software from Ashtech, and the resulting vectors between stakes have been adjusted. The results are close to what could be expected, i.e. with adjusted relative accuracy of 3-5 ppm horizontally and somewhat better vertically. The better results for vertical positions can be explained from the small movements of the top of each stake between occupations, which mainly influences the horizontal position.

OTHER WORK

10 m temperature

In each borehole 10 m temperature was measured with an ordinary thermistor cable. The seasonal cycle of temperature at this depth is reduced to 5% of the surface value. Therefore the 10 m temperature is a reasonably reliable measure for the yearly averaged surface temperature (Loewe, 1970). However, one should be careful when performing these measurements, because a significant period, preferably 10-20 hours (Seppälä, 1992) is needed for air in the borehole to settle down, the frictional heat of the drilling to dissipate away and the cable and sensor to reach thermal equilibrium with their environment. During the traverse, it was usually possible to leave the sensor in the borehole overnight, after which the reading was stable. Results of these temperature measurements are summarised in Table 2.

Fig. 9 shows 0 m potential temperature, (corrected for height differences) together with the surface elevation as a function of the distance from the coast (assumed to be at 70°S). The maximum in potential temperature that occurs at the steepest part of the topography illustrates the influence of strong winds. These winds prohibit the formation of strong surface inversions and hence cause the surface temperatures to be higher. Strong winds, high temperatures and low relative humidity are probably responsible for the existence of blue ice areas in Dronning Maud Land, and the present data will for instance enable us to make a physical interpretation of temperature gradients observed between the AWS that were erected along the traverse route (see under *Meteorology*).

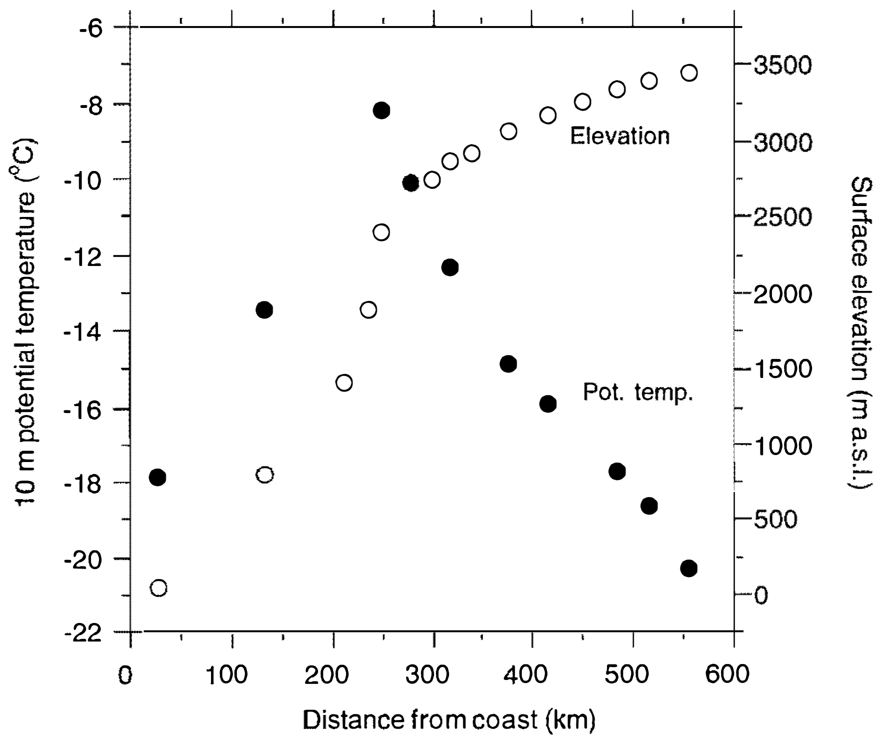

Fig. 9. Potential temperature versus elevation. Potential temperature is the temperature which a parcel of air would have if it were transported to sea level without heat exchange with the surroundings.

Spectral albedo
Snow and ice reflect solar radiation very efficiently such that little of the incoming solar radiation is absorbed at the surface in polar regions. Even so, small changes in surface reflectance can affect the earth-atmosphere energy balance (Warren and Wiscombe, 1985). Thus, it is important to monitor and calculate the variability of the albedo of snow and ice. Accurate calculations of the energy exchange between snow and ice surfaces and the surrounding air mass can then be carried out.

The reflectance of snow and glacier ice shows a clear dependence on wavelength. Typically, the fraction of radiation reflected from fresh snow remains high in the visible region while a distinct drop occurs in the near-infrared region of the electromagnetic spectrum. Satellites like Landsat TM (Thematic Mapper), NOAA AVHRR (Advanced Very High Resolution Radiometer), and SPOT (Système Probatoire pour l'Observation de la Terre) carry sensors that record surface reflectance within the visible and infrared wavelength regions. Consequently, satellite remote sensing enables studies to be made of surface characteristics such as topography, temperature, grain size variations, melting areas, and snow and glacier ice facies (Orheim & Lucchitta 1988; Winther 1993).

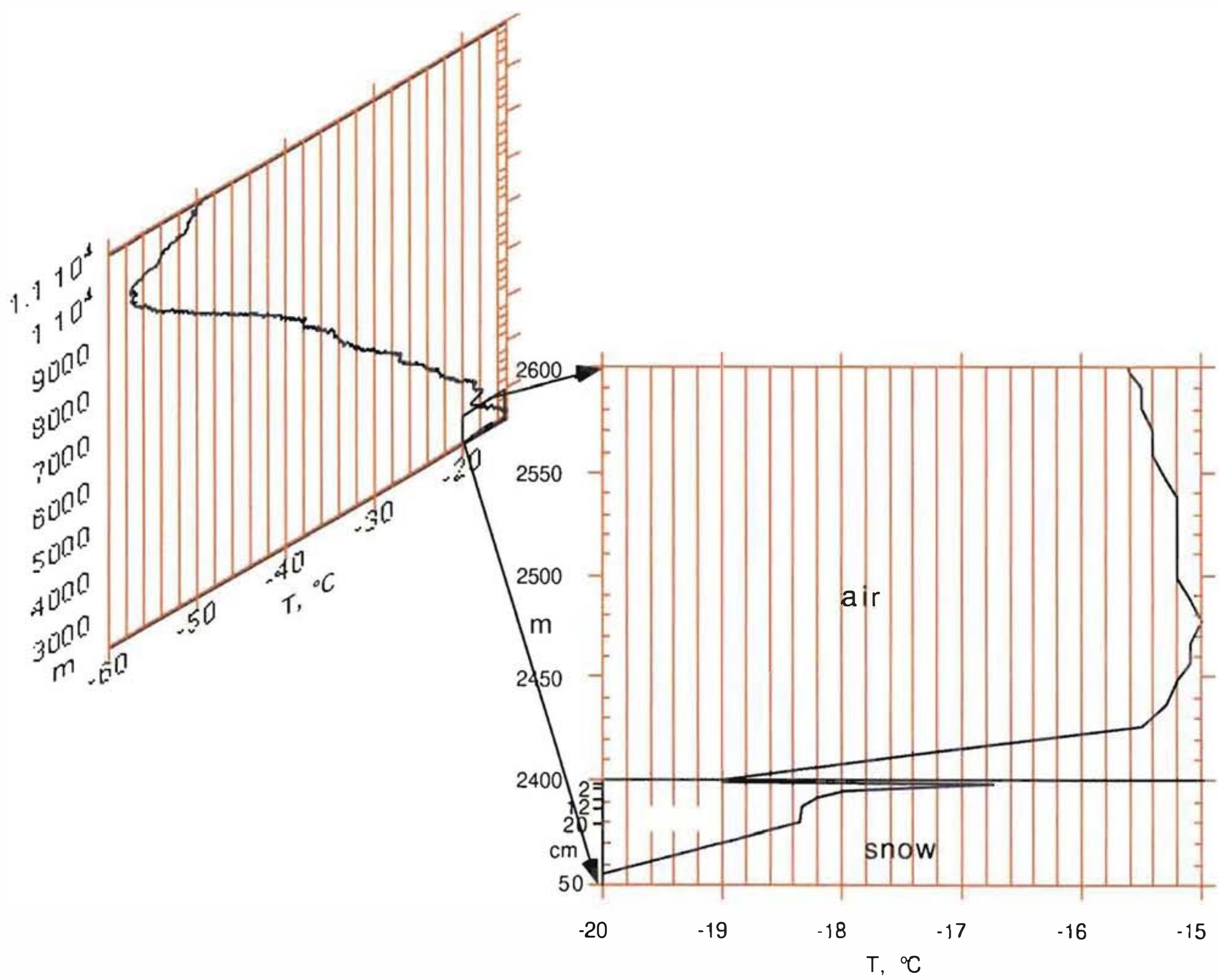

Fig. 10. Air and snow temperature measurements on 5 February 1997 at site C, 08:00 GMT.

A FieldSpec radiometer was used to measure spectral albedo of snow surfaces both as ground truth measurements and for more basic studies of the variability of surface albedo at the polar plateau. Measurements were taken at sites A, B, C, M and around the TROLL Station. Several measurements were taken at each location. The spectral measurements were supported by weather observations and the sampling of snow at different depths for later analysis of physical parameters like crystal size, shape and perimeter. The spectral reflectance data are presently being processed.

Snow pit temperatures

For heat balance studies it is interesting to know the snow temperatures very precisely. At several places snow temperatures were measured at depths of 10 and 20 cm, and in a snow pit at site C temperatures at various depths up to 2 meter were measured every 4 hours during 24 h. Figure 10 shows a first result. Air and snow pit temperature measurements are combined to show the steep temperature gradients in both air and snow close to the air-snow interface.

Coffee cans

Coffee cans are markers that have been fixed at a certain depth in the firn pack (Hulbe & Whillans 1994). A steel wire that is connected to the marker protrudes above the snow, and the absolute height of a point on this wire is measured with GPS with mm accuracy. By re-measuring several years later, the vertical displacement of the wire (and thus the marker) represents the sum of accumulation, densification of the firn pack between the surface and the marker and the vertical velocity of the ice. If the accumulation and densification are known (e.g. by shallow firn cores) and the vertical velocity component of the ice is estimated from the surface slope, the remaining vertical displacement will then reveal if the ice sheet is growing or shrinking. To reveal non-linearity of log-density with depth, at least three coffee cans should be installed within several meters distance. Five coffee cans were installed, three at site C (at depths of 17.5, 12.2 and 6.6 m) and one each at sites H (9.8 m) and K (9.9 m).

Accumulation stakes

A total of as much as 63 aluminium stakes (5 m long, diameter 32 mm, thickness 3.2 mm) was put out along the route, both from the shelf to TROLL Station and on the plateau. Most of these stakes serve primarily as GPS reference points for ice velocity and ice deformation. Two stakes were placed close to each drilling location to determine the local accumulation independently from the firn cores.

LOGISTICS

Vehicles

Two Hägglund tracked vehicles were used during the traverse. The same vehicles were also used on NARE 92/93 and have been stored at the TROLL and TOR stations in DML since then. The two vehicles were equipped with a flatbed on the rear chassis for carrying loads. In addition one vehicle had a hydraulic crane and a snow plough, and the other a snow melting system (borrowed from Swedish Polar Research Secretariat), in which water was produced by circulating cooling water of the engine through the melter. Both Hägglunds were powered by a Mercedes Benz 6-cylinder turbo-charged diesel engine with a high altitude converter. HF and VHF radio and GPS were installed in the cabins. Fuel used for the engines was Jet-A1 mixed with 0.5% pro-long. Normally, the fuel consumption was 25-30 litres per 10 km, the speed with loads on the way south being 5-8 km h^{-1}. With light loads and downhill the speed increased to 12-15 km h^{-1}. When outdoor temperatures were below -25°C, the engines ran continuously on idle. Two short stops were necessary because of technical problems, namely a broken fan belt and a broken drive axle. Except for these minor problems the vehicles ran very well and needed only ordinary maintenance. Two four-runner sledges with sizes 6.1x2.4 metres were pulled by the Hägglunds. The maximum load we had on each sledge was about 8000 kg, while the weight of the sledge itself is 1350 kg.

We used four new snow machines type Polaris Widetrack LX, with water-cooled 500 cc engines, low/high forward, reverse gears and handwarmers. Two of the snow machines were equipped with GPS. Fuel consumption was 2-3 litres per 10 km. The snow machines, each with one sledge, were mainly used by the drilling and GPS teams and for reconnaissance and marking of the route. Each snow machine group was always equipped with VHF radios, emergency beacon, tent, sleeping bags, food as well as equipment necessary for reconnaissance and, if necessary, rescue in crevassed areas.

Power supply
The traverse team needed 220 volts for scientific use. The main generator was a Hatz diesel 1D41Z/24 V with electric start, producing 4.5 kW. As a spare generator we had a smaller Hatz diesel E673 R36 of 3 kW. Both generators used Jet-A1 for fuel. The drilling group also made use of a portable generator, a Honda EX 1 kW.

Communication
Each day at 20 GMT the traverse team contacted TROLL Station. On the traverse we had three systems for ordinary communication and one emergency system:

- A portable Inmarsat system from ABB with voice and e-mail system, powered by 12-36 V or 220 V. This system worked excellently during the entire traverse.
- Each Hägglund was equipped with a Icom IC-735 HF radio (100 W) and an automatic antenna tuner. A dipole antenna was used for communication with TROLL Station. About 50% of the time we were standby for TROLL Station. We had successful contacts with TROLL Station around 80% of the time (at 20 GMT).
- VHF was used for internal communication (between snow machine parties and the Hägglunds and between the two Hägglunds). In the Hägglunds and dwelling hut we used Icom VT 200 radios (25 W) with 2 m long antennas, while the snow machine parties used hand-held Icom F30 LT radios (5 W).
- The traverse team carried three satellite-based emergency beacons, one on the tracked vehicle group and one on each of the snow machine teams.

Accommodation
As cooking/dining/working facilities we brought two wooden huts. The largest hut measured 4 x 2.5 m and weighed approximately 1000 kg. This hut was mainly used for cooking and eating. For cooking we used propane gas (about 30 kg propane for three weeks). For heating we had a Jet-A1 stove with a maximum capacity of 3 kW (fuel consumption 7-10 litres per day). An electric 1 kW stove was brought as spare. A VHF base station was mounted in this hut. The other hut measured 2.5 x 2.3 metres with a weight of 750 kg. This one was used for working and storage of temperature-sensitive scientific equipment. The Inmarsat system was placed in this hut, which was also equipped with two beds.

For sleeping we had one large Weatherhaven Endurance tent, comfortable for 6 persons. It was light (approximately 40 kg) and easy to put up. On the plateau, night temperatures were well below -40°C, but with good sleeping equipment including light-weight beds, therm-a-rest mattresses and woollen blankets, the low temperatures generally created no problems.

ACKNOWLEDGEMENTS

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MASS BALANCE AND DYNAMICS ON JUTULSTRAUMEN ICE STREAM, NARE 1996/97

BACKGROUND

The mass balance of Antarctica is one of the most uncertain factors in discussion about future climatic change and sea level rise (Meier 1990). Mass balance data is lacking from great areas of the Antarctic continent. The mass balance is measured by comparing input with output. The mass input is mainly snow accumulation over the entire surface while the mass output is mainly by calving. Under the ice shelf it can be some mass input by bottom freezing or some mass output by melting at the ice/ocean interface. The melting/freezing processes under the Fimbulisen ice shelf is studied in a project started during the Norwegian Antarctic Expedition in 1989/90 (NARE 1989/90) (Orheim et al. 1990). This project mainly concentrates on the surface mass balance parameters on Jutulstraumen ice stream (Fig. 1). The project started during the Norwegian Antarctic Research Expedition in 1992/93 (NARE 1992/93) (Hagen & Melvold in press) and continued during NARE 1993/94 (Melvold et al. 1996) and this field season. Jutulstraumen with its shelf area Fimbulisen drains parts of Amundsenisen and Wegenerisen, an area of 124 000 km². The maximum speed is 720 m a^{-1} at the grounding line and decrease to about 420 m a^{-1} 40-50 km south of the grounding line, and the discharge is about 12.0 Gt. a^{-1} (Høydal 1996). Jutulstraumen is one of the larger ice streams in Antarctica and it is the largest outlet glacier between 15°W and 20°E (Van Autenboer & Decleir 1978).

OBJECTIVES

The objective of this programme is to perform a mass balance study on the Jutulstraumen ice stream with its shelf area Fimbulisen and parts of the catchment area up to about 2700 m a.s.l. through the following investigations:

1. Accumulation rate measurements.

The project will mainly cover the mass input by measuring the a) present and b) the last twenty-thirty years' annual snow accumulation in different parts of the drainage area, and c) monitoring the future accumulation rate. On the ice shelf sub-surface processes (accumulation or freezing) have to be considered in the mass budget. This will be done by analysing radio-echo soundings for different frequency ranges as in combination with strain measurements, ice thickness and surface accumulation data (Hamran et al., unpublished).

2. Ice flux

Ice flux will be calculated using: a) the measured ice surface velocity in combination with radio-echo sounding data to investigate ice flux in different parts of the ice stream, and b) monitoring of ice flux changes.

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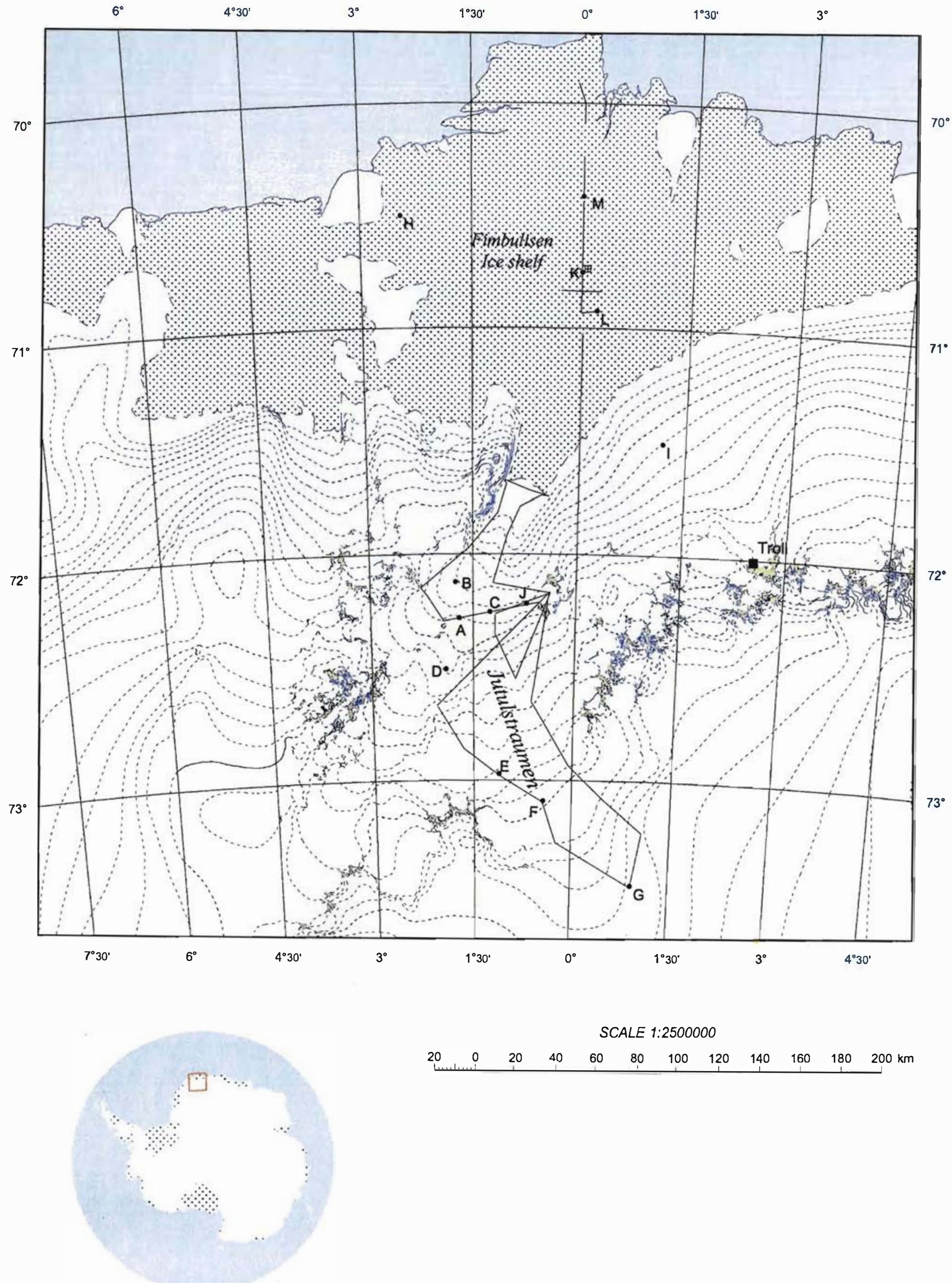

Fig. 1. Jutulstraumen and Fimbulisen with location of stakes and shallow core drill sites and radio-echo lines.

FIELD WORK AND PRELIMINARY RESULTS

The field work was carried out between the 1 January and 14 February 1997 by three persons. The work was concentrated on four tasks:

1. stake readings for measuring accumulation and velocity during the last three years;
2. shallow ice core drillings;
3. radio-echo soundings; and
4. strain rate measurements on the Fimbulisen ice shelf.

Velocity and accumulation measurements

Accumulation and velocity stakes drilled down during NARE 1993/94 in profile 1 and at core locations E, F, and G were remeasured during this field season. Both stake heights (for deduction of the accumulation rate) and positions (for deduction of the velocity) were measured. The positions were found using the kimematic GPS-method. One or more receivers were placed stationary at a fix point, while the other was moved to the stake. At each stake the portable receiver was placed for more than 10 epochs. The measurement was done when more than five satellites were visible. Ashtech Z12 dual frequency GPS-receivers were used.

To obtain the surface velocity across the grounding line of Jutulstraumen four stakes were drilled down about 5 km apart along the grounding line. These stakes were measured twice during the field season by use of Ashtech Z12 two-frequency GPS-receivers. All the GPS data were partly collected and processed by the topographic team from Norsk Polarinstitutt. From the stakes' position a maximum surface velocity of about 720 m a^{-1} was found at the grounding line. This result agrees well with the maximum flow rate of 744 m a^{-1}, measured by Orheim & Lucchitta (1987) on repeated satellite images from the same area.

The accumulation rate was calculated using the change in stake heights between 1994 and 1997 and the mean snow density measured in three pits during NARE 1992/93. Preliminary results show large span in the accumulation rate varying from about 50 mm to 450 mm water eq. a^{-1} and no clear pattern.

Shallow core drilling

Four shallow cores were drilled (J, K, L and M) (Fig. 1). Core J (18.4 m deep) was drilled about 10 km west of Jutulrøra and 10 km east of core C from the 1992/93 season and will be used to investigate local variations in accumulation across Jutulstraumen. Core K, L, and M were drilled about 20-30 km apart along the central part of the Fimbulisen ice shelf. Core L (10.3 m deep) was drilled close to the accumulation tower put out in the 1989/90 season at position 70°56'S and 0°13'E. Core K (30.1 m deep) was drilled at position 70°45'S and 0°1'E close to the strain net and core M (6.2 m deep) at position 70°25'S and 0°1'W.

We used a PICO (Polar Ice Core Office, Lincoln, Nebraska) light-weight coring auger, with a diameter of 3" (7.69 cm). A portable electric threader was used as a drill connected to the PICO. An 18 m deep core could be drilled in one day by three persons. The length and weight of each core section (10-40 cm) were measured, before they were packed and labelled in plastic tubes, and brought frozen to Norway. The density at different depths was calculated (Fig. 2).

Twenty-four hours after drilling the temperature was measured in the K borehole every 5 m. We used at termistor string with Fenwall Unicurve 192-301 CDT-A01 termistors. The Ohm-meter used made it possible to read/calculate temperatures within ±0.05° C.

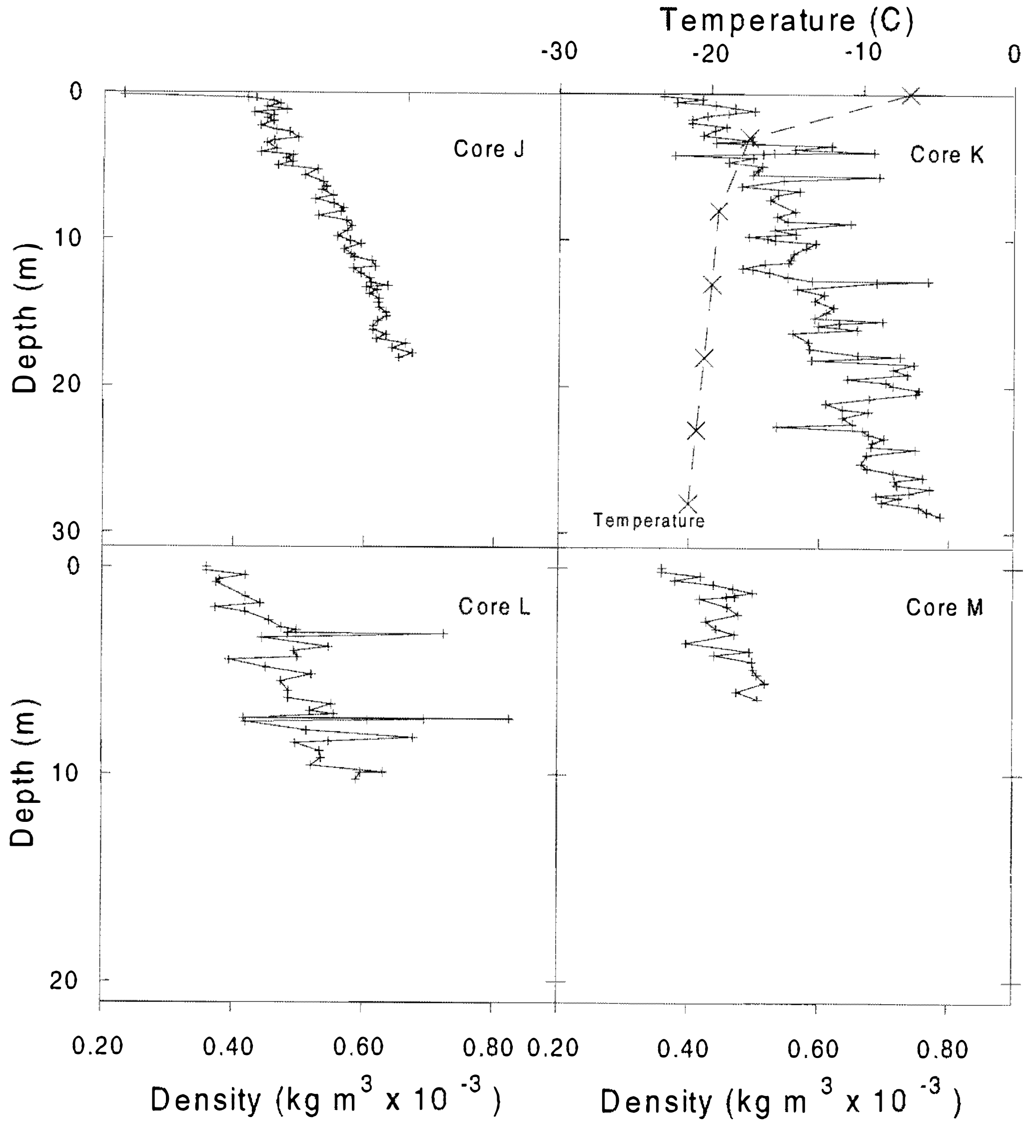

Fig. 2. Density and temperature in the core drill holes, J, K, L and M.

The cores will be analysed for stable oxygen isotopes ($\delta^{18}O$), β-activity, ^{137}Cs, and electrical conductivity for identification of annual layers. These methods are similar to those used elsewhere in Antarctica (Clausen et al. 1979; Orheim et al. 1986; Isaksson 1994).

Radio-echo sounding and surface elevation

As a part of our programme about 700 km of radio-echo soundings and surface elevation from helicopter were measured along the Jutulstraumen ice stream. The GPS survey was carried out with assistance from the topographic team from the Norwegian Polar Institute (see Barstad et al. this issue) and the radio-echo soundings with assistance from Jens Ove Näslund (see Näslund this issue). On the Fimbulisen ice shelf 500 km high resolution ground based radio-echo sounding profiles were made simultaneously with surface elevation measurements. The surface elevation was measured by both GPS-receivers and with a digital barometer. Both flight lines on Jutulstraumen and ground based lines on Fimbulisen are shown in Fig. 1.

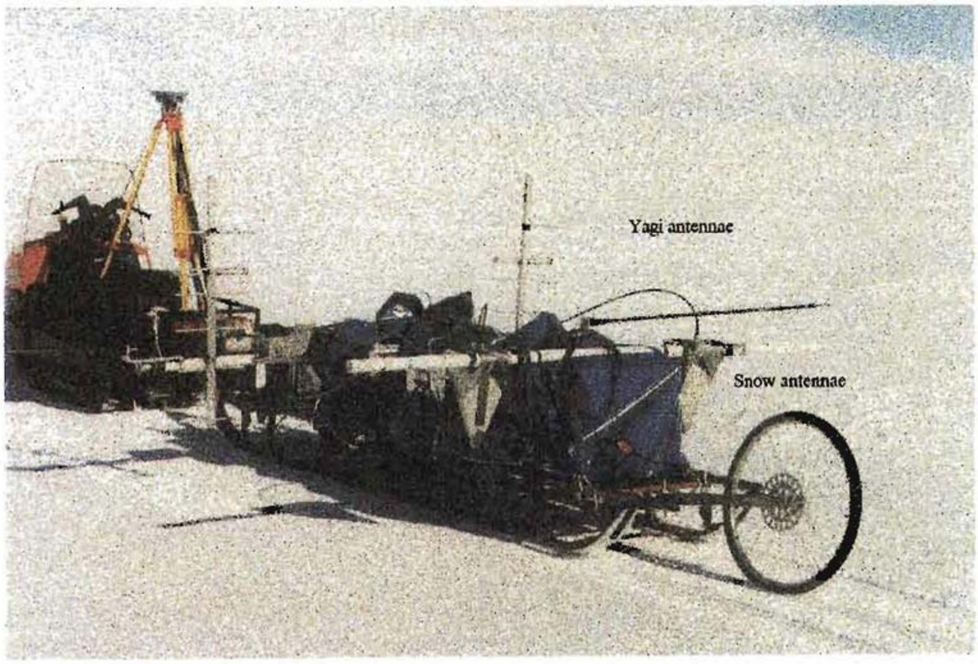

Fig. 3. Ground base radar system with, GPS receivers and digital barometer and radar operated from a sledge tracking a snow scooter. Fibre-glass road with yagi antennas is shown on the picture.

On the ice shelf, the radar system, GPS receivers, and the digital barometer were operated from a sledge tracking a snow machine. The radar antennas were mounted transversally on a fibre-glass road (Fig. 3). The radio-echo data were sampled equidistantly every 3.3 to 6.6 metres, triggered by a wheel giving pulses to a digital data acquisition system where both the radar shot and the time of the shot were stored. The log interval for the GPS data was twenty seconds and approximately one second for the digital barometer data.

The radar system used was a range gated synthetic pulse system (Hamran & Aarholt 1993; Hamran et al. 1995). The frequency range of the system is from 0.1 MHz to 3 GHz and the number of frequency points used was 201 per shot. The following four types of frequency bands and three different types of antennas were used for the ice shelf work: 30-55 MHz, 80-105 MHz broad-band, end-fed resistively loaded dipole antennas, 330-355 MHz six-elements yagi antennas and 600-1350 MHz yagi antennas (snow radar). The three first frequencies were used to delineate areas of different geophysical processes at the interface between ice and sea water such as sub-glacial melting or freezing areas. The last frequency was used to investigate the pattern of snow accumulation along the Fimbulisen ice shelf. These data have not been analysed to date.

The barometer system used was a digiquartz, precision pressure instrument, Model 760 (from Paroscientific, Inc) with a range of 11.5-16 PSIA. The pressure data were logged and stored in a computer.

Ashtech Dimension single frequency GPS-receivers were used for work on the ice shelf.

Strain measurements

On 22 January a strain net was set out and measured in the central part of Fimbulisen (at a position of about 70°45' S and 0°1' E) about 80 km from the grounding line and 100 km from the calving front. The strain net was located close to a topographical height. The stakes were arranged in a 3 x 3 rectangular strain net. The distance between the stakes was about 1.5 km. The stakes in the strain net were remeasured on 8 February. Surface accumulation and ice thickness were also measured along the line in the strain net to allow calculation of the contribution from under-shelf melting or freezing.

The stake position was only measured for one of the stakes in the strain net by GPS measurements with the TROLL Station as a reference station. The other stakes were measured only relative to this stake by traditional surveying with a Wild T2 theodolite and a Wild DI 3000 electronic distance meter (EDM). Preliminary results show that maximum strain rate is in a north-west to south-east direction and it is about 14×10^{-4} a^{-1}.

Information from NARE 1989/90 concerning velocity (Orheim et al. 1990) and radio-echo-sounding (Kennett 1990) in other parts of the Fimbulisen can be used for ice flux calculations and give additional information about the balance of Fimbulisen.

FUTURE WORK

The project will be continued on later Nordic Antarctic Research Expeditions if possible. Our results so far show large variations in accumulation both in time and space. Additional core drillings and radio-echo soundings (snow radar) are necessary for further investigation of these phenomena.

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JENS-OVE NÄSLUND[1]:

AIRBORNE RADAR SOUNDINGS OF ICE DEPTH, GPS MEASUREMENTS OF ICE VELOCITY AND STUDIES OF LANDFORM EVOLUTION IN CENTRAL DRONNING MAUD LAND EAST ANTARCTICA

The glaciological work conducted with TROLL as base during the NARE 96/97 expedition is divided into three parts, both geographically and scientifically. The first part deals with radar soundings of ice thickness and GPS measurements of ice velocity along the Jelbartisen/Fimbulisen grounding zone. The second part describes ice depth soundings in the Jutulstraumen ice stream. The third part concerns bed topography and long-term landform evolution of the Jutulsessen area, Gjelsvikfjella, close to the TROLL Station.

ICE THICKNESS AND ICE VELOCITY ALONG THE JELBARTISEN/FIMBULISEN GROUNDING ZONE BETWEEN LONGITUDES 6.5° W and 5° E.

Introduction

During the past 100-200 years global sea level has been rising at an estimated rate of 1.5-2.0 mm/yr. The sea level rise is of concern for the world's population as a whole, and it is therefore a key issue in global change research. There are three processes that presumably are causing this sea level rise: (1) a thermal expansion of the oceans due to a warming climate, (2) an increased melting of temperate glaciers and ice caps, and (3) an imbalance in the Greenland and Antarctic ice sheets. The contribution of the Antarctic ice sheet is the largest uncertainty in the analysis of the sea level rise.

Imbalances in the ice sheets are studied by measuring their mass balance, that is the difference between the mass gain (accumulation) and the mass loss (ablation) of the ice sheet. If the mass balance is negative, the ice sheet is loosing mass because the ice discharge exceeds the surface snow accumulation. This situation gives a net transfer of mass from the ice sheet to the oceans, and thus contributes to a rising sea level.

For Antarctica the mass loss is due to calving of icebergs, melting of ice underneath the floating ice shelves, and surface melting with runoff. The two first terms are by far the most important. Unfortunately, they are also very difficult to measure. Surface melting occurs only near the coast and this term is much smaller. Available data on Antarctic mass balance are not even good enough to say whether the ice sheet has a positive or negative mass balance, although they do suggest that it is negative.

One way of measuring the ice sheet mass loss is to calculate the ice flux across the grounding zone, i.e. the border between the grounded portion of the ice sheet and the floating ice shelf. This method eliminates various problems that otherwise would occur for example when trying to estimate ice shelf calving- and melting rates. When

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studying mass balance with the purpose to find out the ice sheet contribution to sea level change, mass flux calculation is an appropriate method. It can exclude the ice shelves, since melting and calving of floating ice does not affect sea level. In relation to sea level change, the mass flux method should be applied to the Antarctic ice sheet as whole. This may be done by studying the accumulation rate over the entire grounded portion of the ice sheet together with measurements of ice thickness and the ice velocities at the grounding zone along the ice sheet perimeter. In order to get velocity data from around the whole ice sheet remote sensing techniques must be applied. These can be calibrated by ground truth measurements of ice velocity at specific sites by GPS measurements.

In 1993 a task group on "Antarctic ice sheet mass balance and sea level contribution" (ISMASS) was established by SCAR/GoS/GLOCHANT. The first goal set for ISMASS was to make a better determination of the mass balance of the grounded portion of the Antarctic ice sheet. The reasons for setting this as a primary goal were, in addition to the facts mentioned earlier, that the subject was not receiving much attention in the national programmes of SCAR (Scientific Committee on Antarctic Research) countries, although it is a project well suited for a co-ordinated effort among SCAR programmes.

Field area and programme

Partly for the ISMASS programme, radar soundings of ice thickness and bed topography were made by helicopter along the Jelbartisen/Fimbulisen grounding zone, western-central Dronning Maud Land during the 1996/97 field season. GPS measurements of ice velocity were carried out along the same line. The work was conducted within the Swedish part of NARE 1996/97.

The radar soundings were performed along a route prepared in advance. Waypoints had been extracted from maps (Table 1), producing a route along the grounding zone, 1-2 km upstream the ice shelf (Fig. 1). The route passes several ice divides[1] and outlet glaciers/ice streams[2], from west to east: Giæverryggen[1], Schyttbreen[2], Båkenesdokka[2], Ahlmannryggen[1], Jutul-straumen[2] and Hellehallet[2]. In order to fly this route, extra helicopter fuel was supplied by the South-African Sanae IV station at Vesleskarvet. In addition to the radar measurements along the grounding zone, ice depth was also sounded along all transportation routes to and from TROLL, Sanae IV and a fuel depot at Straumsvola (Fig. 1).

Table 1. Route for radar soundings along the Jelbartisen/Fimbulisengrounding zone.

Waypoint	Latitude	Longitude
Glasiologbukta 2	71° 20' 00" S	06° 37' 00" W
Glasiologbukta 1	71° 27' 40" S	06° 00' 00" W
Johnsbrotet (300 m a.s.l.)	71° 20' 50" S	04° 17' 00" W
Robertskollen (300 m a.s.l.)	71° 28' 40" S	03° 19' 00" W
waypoint 7	71° 20' 00" S	03° 17' 00" W
Båken (250 m a.s.l.)	71° 18' 10" S	02° 56' 00" W
Krylvika 2	71° 30' 10" S	02° 08' 00" W
Krylvika 1	71° 28' 25" S	01° 36' 00" W
TROLLkjelneset	71° 17' 42" S	01° 04' 00" E
Straumsida 2	71° 25' 25" S	00° 52' 00" E
Jutulgryta camp	71° 24' S	00° 31' E
Hellehallet 3	71° 00' 00" S	02° 17' 00" E
Hellehallet 2	70° 53' 30" S	03° 49' 30" E
Hellehallet 1	70° 43' 34" S	04° 52' 37" E

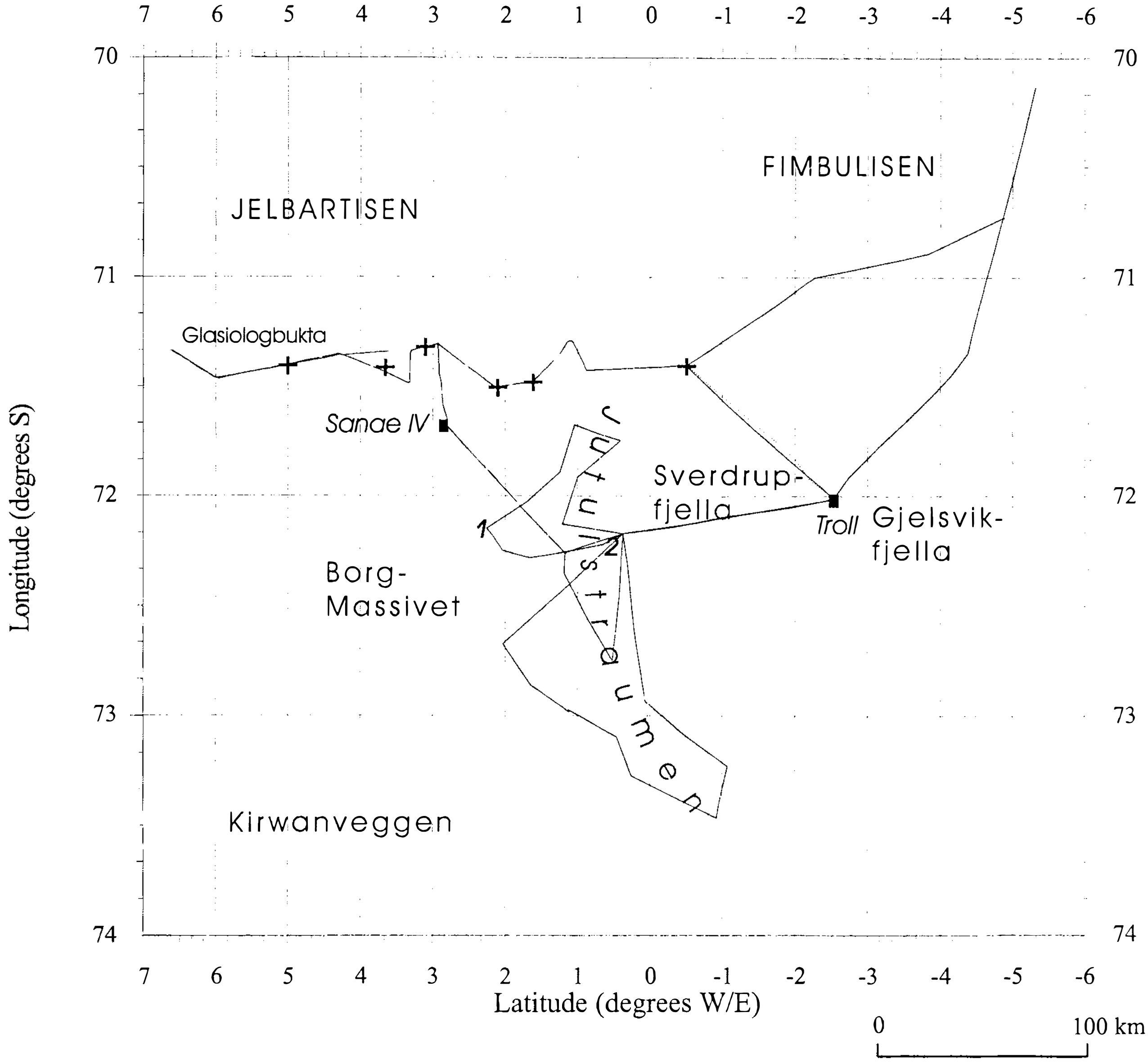

Fig. 1. Locations of all airborne radar profiles sounded during NARE 1996/97, except the ones sounded in Jutulsessen (see Fig. 3). The locations of the stakes put out for ice velocity measurements are marked by crosses.

Methods

Radar soundings

The radar equipment used was a synthetic pulse continuous-wave (cw) radar, developed and lent for the expedition by Environmental Surveillance Technology Programme in Lillestrøm, Norway (Hamran & Aarholt 1993). It is based upon a Hewlett-Packard Network Analyser 8753A which produces, transmits and receives the radar signal. It is a step-frequency radar using 201 frequencies evenly distributed over an adjustable bandwidth. The start and stop frequencies can be set between 300 kHz and 3 GHz, making it a truly multi-purposes radar. In Antarctica it has previously been utilised for depth measurements of cold ice (c.f. Näslund et al. 1991; Holmlund 1993; Holmlund & Näslund 1994; Näslund 1997) and for snow distribution studies (Richardson et al. 1997). In Scandinavia it has also been used on temperate glaciers for measurements of ice depth, ice temperature and snow distribution.

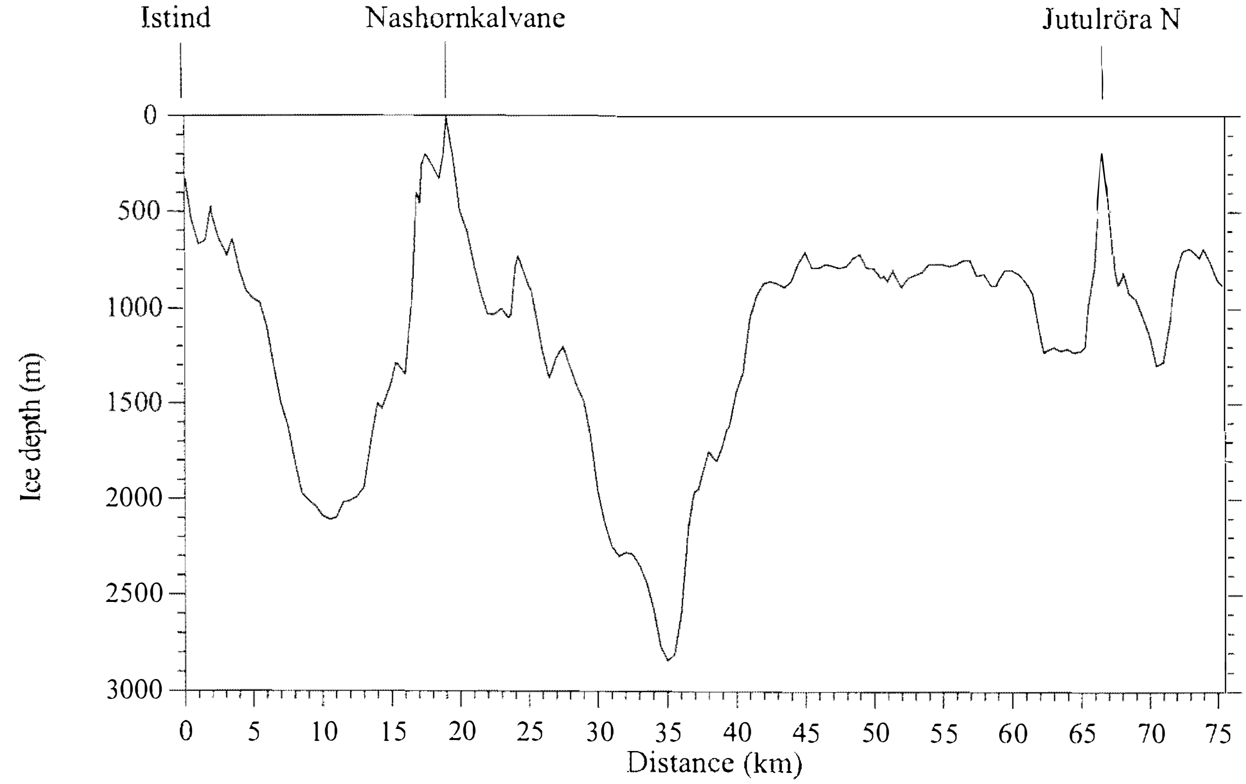

Fig. 2. The southern cross profile of Jutulstraumen, sounded from Istind, via Nashornkalvane to Jutulrøra. The maximum ice depth recorded during the fieldwork, 2800 m, was sounded in the trough west of Nashornkalvane. The processing and plot of these data are preliminary. The finally processed data will be published elsewhere by K. Melvold, Geografisk Institutt, University of Oslo.

In the present study the band width was varied between 5 (157-162 MHz) and 8 MHz (156-164 MHz), corresponding to 3400 and 2100 meters as the maximum ice depths possible to measure. The sampling interval varied between 0.4 and 0.6 seconds, depending on the flying speed and the location. The helicopter flew at an approximate altitude of 100 (-150) feet, at a speed of 80-100 knots. Depending on sampling rate, this gave a ice depth recording each 15-30 m. The radar was placed on the floor behind the pilot in an Ecureuil helicopter. Three amplifiers were used on the transmitter in order to penetrate deep ice, especially for soundings in the Jutulstraumen ice stream (see Section 2). The output signal had a power of 70-150 W, depending on the frequencies used. The antennas were of a dipole type with a centre frequency of 158 MHz. They were mounted externally on the helicopter, on a metal frame made especially for this purpose. A laptop computer was used for conTROLLing the radar and for data storage. Power supply for the radar, amplifiers and computer was taken from the helicopter generator, via two 250 W 24V DC/220V AC inverters.

West of Jutulgryta the radar profile was positioned by dual-frequency GPS measurements made by an Ashtech Z-12 geodetic GPS receiver mounted in the helicopter. The GPS was logging at a 15 seconds interval. Differential corrections of these data towards a reference station at TROLL were subsequently made, which gave an accuracy within a few metres in the positioning of the radar profiles. East of Jutulgryta positioning of the profiles was done by readings from a Garmin 100 c/a code GPS receiver, giving an accuracy of ±150 m.

GPS measurements

Five stakes were put out for ice velocity measurements in the grounding zone west of Jutulstraumen ice stream towards Glasiologbukta (Table 2), along the same route that was sounded for ice thickness. In order to get the ice velocity, the stakes were positioned by differential GPS measurements at two occasions during the field period. At the first occasion, on January 1, two Trimble 4000ST single frequency geodetic GPS receivers were used. One was placed as reference station on the nunataks Valken (240 m a.s.l.) and Robertskollen (370 m a.s.l.). The receiver was placed over fixed points, marked by a cross cut in solid rock. The cross was subsequently painted white and covered by a small cairn. The second receiver was placed over the stakes, logging at ten-second intervals for 45-60 minutes over each stake. On the second occasion, on February 5, seven dual frequency Ashtech Z-12 geodetic GPS receivers were used at the same fixed points as well as at the stakes.

Another stake located close to Jutulgryta, put out and used by the geodetic team from Norsk Polarinstitutt, was also measured more than once during the field period. By kind permission, also these data could be used for determining ice velocities at the grounding zone. The Ashtech Z-12 GPS receivers were here used over the stake and as reference station at the TROLL Station.

Table 2. Data on stakes, reference stations and calculated preliminary annual ice velocities. Horizontal and vertical datum is WGS-84. The altitude refers to the snow surface.

Stake number or ref. station	location name	stake height (m) Jan 1 97	position Jan 1 1997	altitude (m above WGS-84)	location of reference station	baseline-distance to ref. stn. (m) Jan 1
Ref. stn. Valken (240)	Valken (240)	-	71° 29' 43.982" S 01° 58' 58.651" W fixed-point	249.020	-	-
1181	Ahlmann -ryggen	1.34	71° 28' 30.102" S 01° 36' 05.150" W	150.2	Valken (240)	13 720.72
1182	Ahlmann -ryggen	1.22	71° 28' 35.083" S 02° 14' 10.857" W	183.3	Valken (240)	9 234.78
Ref. stn. Roberts-kollen (370)	Roberts-kollen (370)	-	71° 27' 07.125" S 03° 18' 48.138" W fixed-point	367.393	-	-
1184	Båkenes -dokka	1.34	71° 19' 08.360" S 03° 04' 55.873" W	108.5	Roberts-kollen (370)	16 975.59
1172	Schytt-breen	1.31	71° 24' 52.883" S 03° 37' 57.055" W	140.3	Roberts-kollen (370)	12 087.65
1185	Giæver-ryggen	1.35	71° 23' 53.291" S 05° 01' 12.578" W	312.1	Roberts-kollen (370)	61 003.51
ref. stn. TROLL	TROLL	-	72° 00' 43.331" S 02° 32' 17.144" E fixed-point	1313.000	-	-
5-1191	Jutulgryta	-			TROLL	

Preliminary results

Radar soundings of ice depth

Continuous ice depth data were collected on January 11 and 12 along the grounding zone along a 493 km profile. The profile stretches from the innermost part of Glasiologbukta at 71° 19' 58" S, 06° 36' 53" W at Jelbartisen to position 70° 43' 34" S, 04° 52' 37" E on the Fimbulisen ice shelf (Fig. 1). Radar data were of good quality along the whole profile. The differential GPS data retrieved for positioning of the profiles also provide good enough altitude recordings to reconstruct the upper ice surface along the profile, with the biggest error being the varying flying altitude. The altitude profile may be used when processing the radar data.

GPS measurements of ice velocity

Positioning of the stakes west of Jutulstraumen were done on January 1 and February 5 1997. The Jutulgryta stake was positioned on January 1 and February 2. The locations of the stakes are seen in Fig. 1. Table 1 presents data on stakes and reference stations. The coordinates of the two reference stations and the stakes are corrected towards the coordinates of a reference station logging at TROLL (72° 00' 3.33096" S, 02° 32' 17.14375" E, ellip. height 1,313,000 m). Preliminary results gave ice velocities between 60 and 340 m/year at the six locations. The precision in each positioning is estimated to 1 ppm. All stakes, except perhaps stake 1184 at Båkenesdokka, are probably placed on grounded ice. Additional data on snow accumulation and even more accurate velocity determinations would be achieved if the stakes were revisited and measured, preferably from the same reference fixed points, during a coming expedition. The GPS ice velocity data will be used to calibrate coming velocity measurements made by remote sensing techniques. The ice depth and ice velocity data will finally be used to calculate the mass flux across the grounding zone along this part of the Antarctic coastline.

ICE THICKNESS OF THE JUTULSTRAUMEN ICE STRAM AS MEASURED BY AIRBORNE 158 MHz CW-RADAR SOUNDINGS

Introduction

A study on mass balance and ice dynamics have been running on the Jutulstraumen ice stream, central Dronning Maud Land, since 1992/93 (Høydal in press; Melvold et al. 1996; 1997). Recently a force-budget model study has also been initiated in the Jutulstraumen drainage area (Melvold et al. 1997). For both these projects information on ice depth is crucial. Previous radar soundings of the Jutulstraumen ice stream have not been successful in this sense. However, seismic data indicate that the maximum ice depth in a cross-section of the profile is 2700 m. The aim of the present field work was to get continuous high resolution radar data along two transverses and two longitudinal profiles in the ice stream, mainly for the above mentioned two projects.

Methods and programme

The equipment used was the same cw radar as described in Section 1. Because of the expected large ice depth, the bandwidth was permanently set to 5 MHz (157-162 MHz), corresponding to a maximum recordable ice depth of 3400 metres. The soundings in the ice stream had the Straumsvola fuel depot as base. The speed of the helicopter varied between 70 and 100 knots, and the flying altitude was 100 (-150) feet.

The positioning of the radar profiles was co-ordinated with the measurement of two longitudinal ice surface elevation profiles for the force budget model study. For this purpose a dual frequency Ashtech Z-12 geodetic GPS receiver was logging in the helicopter at one-second intervals during the entire flight. Differential post processing of these GPS data towards reference stations placed beside the ice stream will provide sub-meter precision in the positioning of the helicopter and the radar profiles. The GPS positioning was run by the Norsk Polarinstitutt topographic team.

Preliminary results

Two cross profiles for the mass balance project and two longitudinal profiles for the force budget model study was sounded in the Jutulstraumen ice stream on January 10 -11 (Fig. 1). For the cross profiles, the sampling interval was set to 0.4 second, giving a depth recording approximately each 20 m. The northern cross profile, sounded from Hellehallet to Straumsida, was 23.5 km long and situated approximately at the ice stream grounding zone. The southern cross profile, 75 km long, was measured from Istind to the northern part of Nashornkalvane and further on to the northernmost part of Jutulrøra. In addition two more cross profiles are possible to extract from the soundings made for the longitudinal profiles.

For the longitudinal radar profiles the sampling interval varied between 0.8 and 1.0 second, giving an ice depth recording each 40-50 m. The longitudinal profiles were sounded along the same route as the longitudinal surface elevation profiles measured by GPS. As a general rule, a new radar profile was started from each of the 16 locations where surface elevation was measured. The southernmost part of the ice stream sounded by radar was at latitude 73° 27' 50" S, 00° 55' 12" E. The northernmost part was at latitude 71° 40' 26" S, 01° 02'30" W (Fig. 1). The Straumsvola fuel depot was visited two times during the soundings in the ice stream, providing additional radar profiles.

The results of the airborne radar soundings in the Jutulstraumen ice stream are generally good. The data from both cross profiles are of good quality, so also the majority of the data from the longitudinal profiles. As a preliminary result, the bed was recorded in about 80-85% of all profiles sounded in the Jutulstraumen ice stream. Detailed post-processing will probably increase this number. The signal from the bed is lost at the southernmost parts of the longitudinal profiles. This is probably not only due to the great ice depth, but also to dry-bed conditions. Deeper parts were sounded with a good result along the southern cross profile. Internal layers are recorded at many places, especially in the upper parts of the ice stream. In this area, the internal layers may be used when interpreting the ice thickness/bed topography where bed signals are weak.

A radar plot of a part of the southern cross profile is seen in Fig. 2. A deep trough with a maximum ice thickness of 2100 m is found between Istind and Nashornkalvane. Here, the bed is about 1200 m below sea level. In the first part of the profile between Nashornkalvane and northern Jutulrøra the deepest section of the cross profile is found, having a maximum ice depth of 2800 m (Fig. 2). This is in agreement with the seismic data. At the deepest part the bed is approximately 1900 m below sea level. Further towards Jutulrøra a distinct plateau appears, having a height relief of less than 200 m. The plateau is located at sea level, within a few hundred metres. West of the plateau the ice depth increases again as a small valley with a more or less horizontal valley floor is passed. One possible interpretation of this flat valley floor is that it is caused by sub-glacial sediments filling the deepest part of the valley. This would be in line with observations, by radar, of a subglacial valley presumably filled with sediment, located

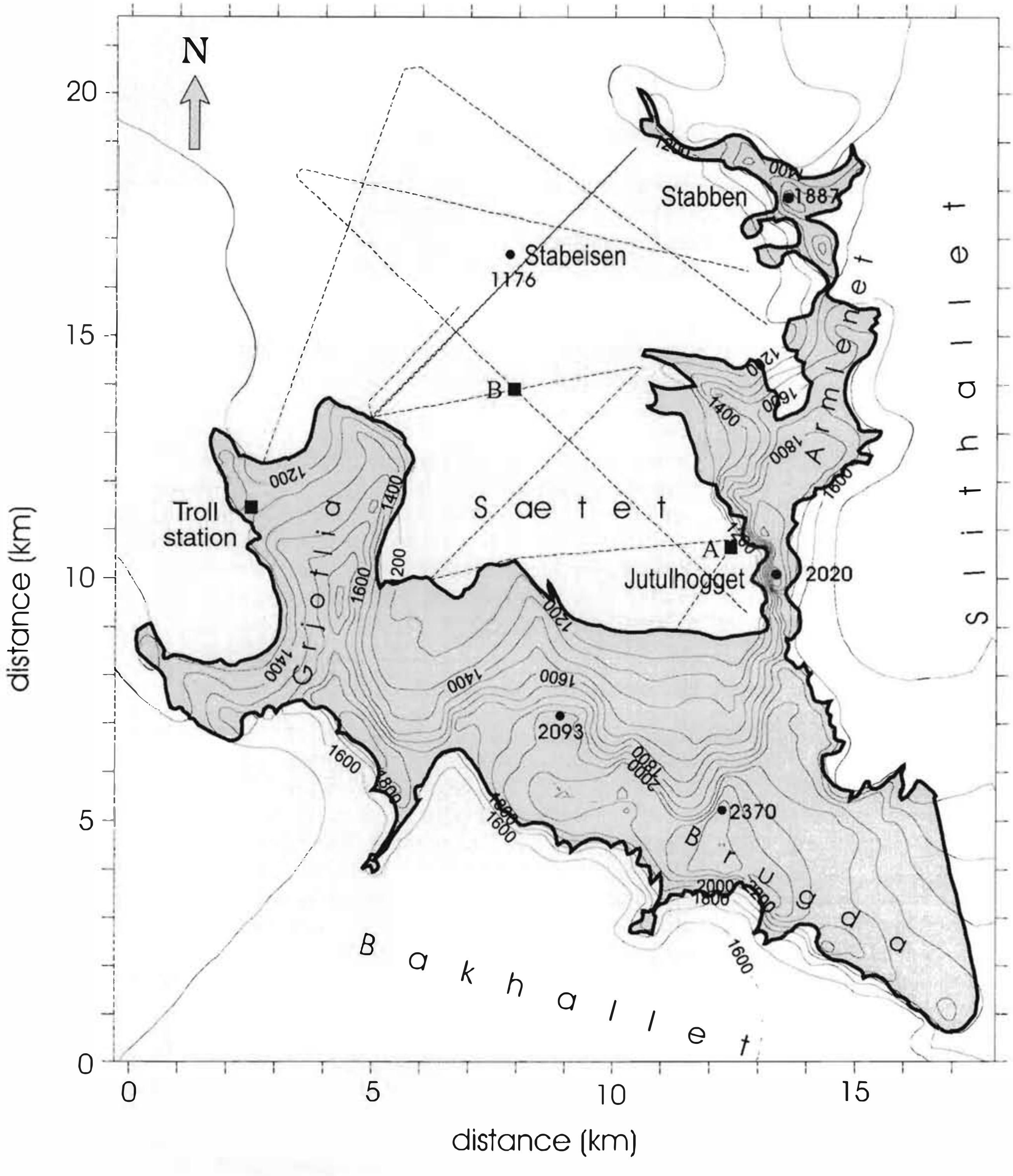

Fig. 3. Locations of radar profiles sounded in Jutulsessen. A and B denote where a preliminary amount of erosion of the palaeoplateau has been calculated, from a reconstructed palaeosurface and from radar data on ice thickness (see text).

beneath the Amundsenisen polar plateau close to Heimefrontfjella, 400 km towards SW (Näslund 1997). The total length of radar profiles sounded in the Jutulstraumen ice stream was 809 km.

ICE THICKNESS, BED TOPOGRAPHY AND LANDFORM EVOLUTION AT JUTULSESSEN, GJELSVIKFJELLA, CENTRAL DRONNING MAUD LAND

Introduction

Mapping of landforms may be used for increasing our understanding of long-term landscape- and glacial history, a history poorly known for the Antarctic continent. A project on landform

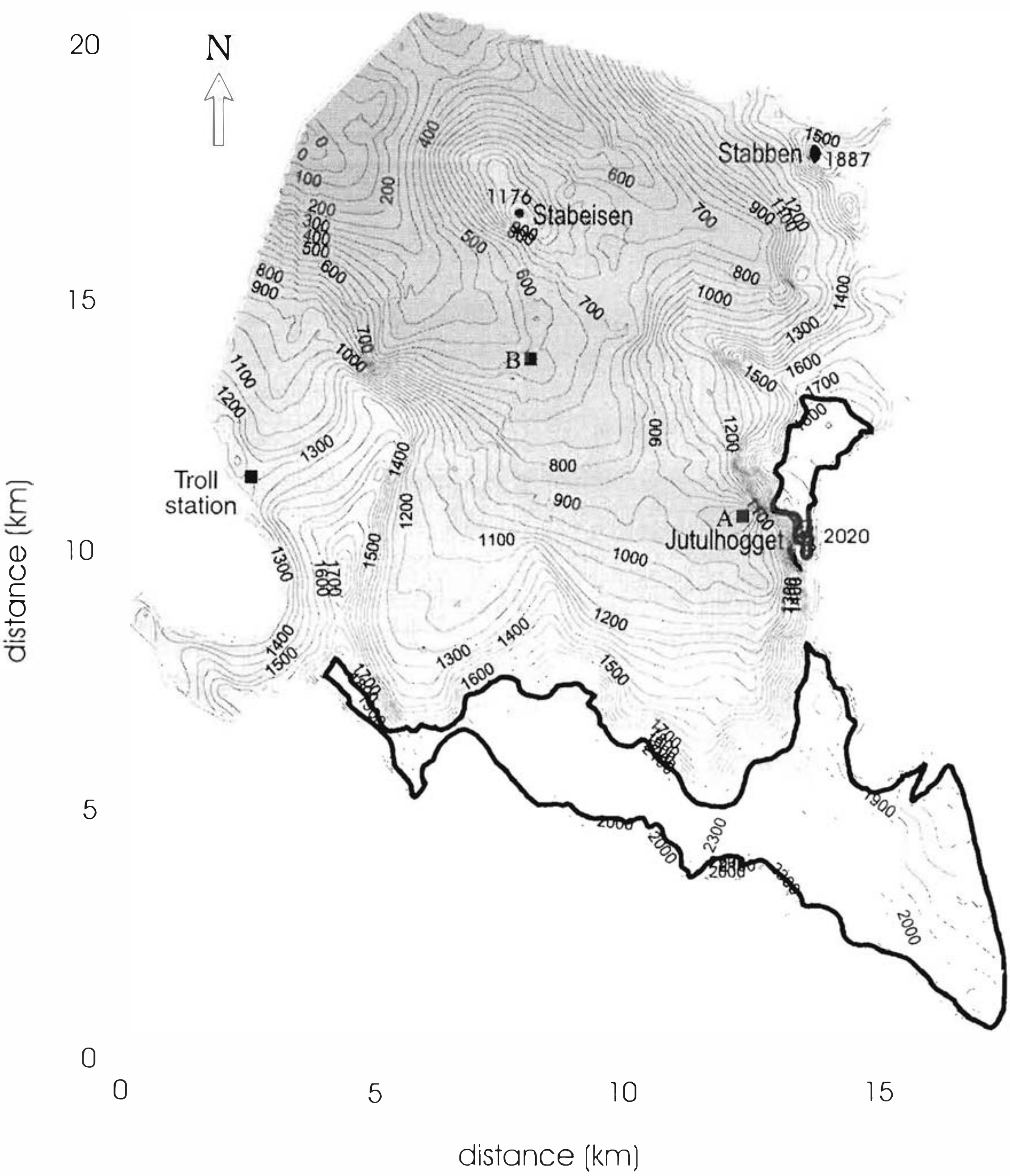

Fig. 4. The pre-glacial surface at Jutulsessen, as mapped in aerial photographs, is marked by a bold line.

evolution and glacial history has been running in the Vestfjella-Heimefrontfjella-Amundsen-isen area, western Dronning Maud Land since 1991/92 (Holmlund & Näslund 1994; Näslund 1997). In order to do a similar study further east in Dronning Maud Land, investigations on landform evolution and glacial history of the Jutulsessen area were made during NARE 96/97. The study included mapping of gross-morphology by radar soundings of bed topography and by landform mapping in aerial photographs. Furthermore, bedrock samples were collected for cosmogenic exposure dating.

Methods

Landform mapping by radar soundings

In order to get data on ice thickness and sub-glacial valley topography, radar soundings were performed by helicopter in Jutulsessen on January 10. The radar equipment was the same as described in Section 1. The bandwidth used was 5 MHz and the sampling interval was 0.4 second. Navigation was done by visual location of features easily recognisable in the Jutulsessen map (scale 1:100,000, Norsk Polarinstitutt). The locations of the radar profiles are seen in Fig. 3.

Landform mapping in aerial photographs

Mapping of large scale bedrock landforms at Jutulsessen were made in aerial photographs (approximate scale 1:30,000). The photographs were taken 27 January 1996 by Institute für Angewandte Geodäsie und Fotogrammetrie, Frankfurt. The mapping was done with a Wild field stereoscope (TSP1). Mapped landforms were transferred to the Jutulsessen map (scale 1:100,000). At certain locations the mapped landforms were conTROLLed in field by helicopter and by foot.

Cosmogenic dating

Three bedrock samples and two rock samples from boulders embedded in till were collected in Jutulsessen. Additional bedrock samples were collected from the nunatak peaks of Valken (240 m a.s.l.) and Robertskollen (370m a.s.l.), located at the grounding zone. By cosmogenic dating of the samples, a tentative exposure age of the sampled surfaces will be obtained, aiding in the discussion on landform development and glacial history.

Preliminary results

Two types of large scale bedrock landforms are found within the Jutulsessen area. One is a distinct high altitude surface situated at the highest positions of the nunatak. The surface was mapped in detail in the aerial photographs (Fig. 4). It has a very low relief and a gently undulating topography, in sharp contrast to its surroundings. A more or less flat upper surface is found on other nunataks in Mühlig-Hoffmannfjella as well. At Jutulsessen, the high altitude surface is situated at elevations between 1800 and 2300 m. It is mainly found at the southern part of the nunatak, but smaller fragments of the surface are also found at the northern part. From the field observations and the studies of aerial photographs it is obvious that the flat high altitude surfaces we find today previously have been part of a larger continuous surface.

The second striking large scale landform of Jutulsessen is the high vertical walls, forming the sides of the two large valleys that dominate the central parts of Jutulsessen. This area, called Sætet, is today semi-filled with blue-ice. The most pronounced wall is the 800 m high vertical cliff of Jutulhogget (2020 m). These vertical walls and the

Fig. 5. The mountain peak of Stabben. The flat upper surface constitutes a small remnant of the palaeosurface also found elsewhere in the region.

intervening valleys must have been formed by strong erosion, dissecting the high altitude plateau. The plateau thus must pre-date the valleys that are cut into it.

The bedrock geology of Jutulsessen is dominated by metamorphic rocks, probably of a Proterozoic origin (Ohta 1993). In the areas of the flat high altitude surfaces and in the sub-aerial sides of the valleys the bedrock mainly consists of migmatite, with some layered gneiss. The flat surface is thus not caused by a basaltic plateau or by sedimentary rocks. It is more probable that the high altitude surfaces found on Jutulsessen are remnants of an old denudation plateau of a pre-glacial origin. At Jutulsessen, the most spectacular remnant of this paleo plateau is the flat top of the isolated mountain peak Stabben (1887 m), raising 700 m above today's ice sheet (Fig. 5).

By using the topographical information of the plateau remnants, it is to some extent possible to reconstruct the pre-glacial plateau over the Jutulsessen area. The morphology of the present valleys in Jutulsessen will be reconstructed from the ice depth data obtained by the radar soundings. By taking the difference in altitude between the reconstructed plateau and the valley floor beneath the blue ice, it is possible to get a figure on how much the bedrock surface have been lowered by erosion since the plateau started to disintegrate. A preliminary figure on erosion have been calculated for location A and B in Fig. 3, amounting to 1200 ±200 m and 900 ±300 m, respectively.

OVERALL CONCLUSION ON FIELD WORK

The radar system used for ice depth soundings from helicopter performed well. Minor problems did occur, but they were adjusted and did not affect the programme. In total, 2217 km of airborne radar soundings were made, divided as follows: grounding zone 493 km (Jelbartisen 71° 19' 58" S, 06° 36' 53" W to Fimbulisen 70° 43' 34" S, 04° 52' 37" E), Jutulstraumen ice stream 809 km, Jutulsessen 92 km, and additional flights between field areas and the TROLL Station 823 km. The majority of the radar soundings provided results of a high quality. GPS measurements of ice movement were made at six locations along the same grounding zone profile as the radar soundings. Bedrock samples for cosmogenic exposure dating were collected in the Jutulsessen area, Gjelsvikfjella, and from nunataks along the grounding zone between the Jutulstraumen ice stream and Glasiologbukta.

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JAN-GUNNAR WINTHER[1], GLEN E. LISTON[2], ODDBJØRN BRULAND[3], HALLGEIR ELVEHØY[4] & KNUT SAND[5]:

STUDIES AND MONITORING OF CLIMATE-SENSITIVE MELT AREAS IN JUTULGRYTA

INTRODUCTION

The majority of the Antarctic landscape is comprised of large snow-accumulation areas where surface melting is non-existent under current climatic conditions. There are some regions, however, where local melting will occur during the short summer season. For example, the South Shetland Islands have drainage systems associated with snow melt (Birnie & Gordon 1980), and the Dry Valleys region experiences the summer melting of snow, glaciers, and lakes (Chinn 1993). In addition, melting can occur near the coastal boundaries of the Antarctic ice shelves. In many areas, melting is also present in regions close to nunataks, due to strong absorption of solar radiation at rock surfaces and in surrounding blue-ice areas which have much lower albedo than the snow cover in the region (Orheim & Lucchitta 1990). The melt features studied as part of this project, however, are located on the land ice mass in Dronning Maud Land, tens of kilometers away from the closest nunatak and about 130 kilometers from the nearest ice shelf edge.

The melting phenomena in the Jutulgryta area of Dronning Maud Land was first surveyed during the Norwegian Antarctic Research Expedition in February 1990 (NARE 1989/90), and later studied using a Landsat Thematic Mapper (TM) image recorded on 12 February 1990 (Winther 1993). Then, during NARE 1993/94, the area was revisited for a period of four weeks (Bøggild et al. 1995; Winther et al. 1996). The field research programme implemented during NARE 1996/97 builds upon and extends the observations carried out during the NARE 1993/94 field season.

The Jutulgryta area commonly experiences sub-surface melting, during periods when the air and surface temperatures are below freezing. This sub-surface melting can be explained largely by the interactions between the snow-ice-water matrix and the near-surface radiation balance. The surface is cooled by outgoing longwave radiation, while the shortwave solar radiation penetrates the surface layers and warms and melts the ice below. The melt-water produced in this area drains within the ice and accumulates in lakes which drain both from distinct discharge channels and through the ice below. Nearly all of the observable melting activity occurs 10-15 cm below the frozen upper surfaces. Even the lakes, which are approximately 1 m deep, have approximately 10 cm of ice on them throughout the summer months. Because of the threshold melting conditions found in this region, changes in melt-related features of this area are expected to be strongly related to changes in atmospheric forcing or climate.

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OBJECTIVES

The overall objective of this research project is to improve our understanding of accumulation- and melt-related features in the lakes, blue-ice, and snow areas in Jutulgryta, near the Jutulstraumen ice stream in Dronning Maud Land. In addition, we expect our studies to provide a more complete picture of the climatically-significant interactions between the snow, ice, water, and atmosphere in this area. The programme includes the collection of glaciological, hydrological, and meteorological data for use in developing a method by which to monitor melting variations in the coastal regions of Dronning Maud Land, Antarctica. To obtain this objective we are employing a combination of field observations, remote sensing techniques, and physically-based numerical energy- and mass-balance modelling.

The melt features that have been identified in Dronning Maud Land are expected to be quite sensitive to variations in local and regional air temperatures and energy balances. Because of this sensitivity, an understanding of the extent and characteristics of these melt features as they change with time can be particularly valuable as a climate change indicator. As part of our effort to understand these melt-related phenomena, we are:

1. using a field programme to study how these melt features originate and evolve in time, and to map their areal distributions;
2. implementing a physically-based numerical modelling programme to determine their sensitivity to changes in atmospheric forcing; and
3. implementing a remote sensing programme to monitor interannual variability within the system.

STUDY AREA

This project focuses on an isolated basin located at S 71° 24' 05", E 0° 29' 59", and covering a domain of 5 by 6 kilometers (Fig. 1). The topography of the region is characterised by gently rolling hills having distances from ridges to valleys of approximately 1 to 2 kilometers, with ridge to valley heights of approximately 100 meters. The area is dominated by easterly winds (Takahashi et al. 1988), and the combination of these winds and the ice-surface topography leads to snow accumulations of up to 15 meters on lee slopes. These snow accumulations lie on top of blue-ice that extends to a depth of

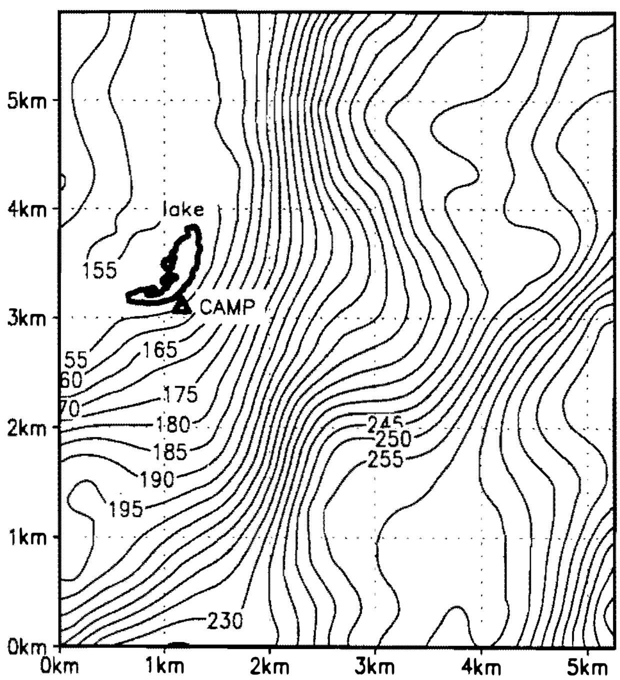

Fig. 1. Location and surface topography of the NARE 1996/97 study area in Jutulgryta, Dronning Maud Land, Antarctica.

approximately 500 meters. The snow-covered area comprises about 30% of the region. The study domain includes an isolated basin which contains a lake and an associated near-surface drainage outlet. The lake elevation is approximately 150 meters.

METHODS/INSTRUMENTATION

The following observations were carried out as part of the Jutulgryta NARE 1996/97 field programme.

Hydrologic characteristics

The mapping and positioning of topography; lake, snow, and blue-ice boundaries; observation sites and transects; and lake drainage channels, were performed using a Differential Global Positioning System (DGPS), with a horizontal accuracy of approximately 1 to 2 metres. Topographic mapping of the 5 by 6 kilometer domain was performed using a high-resolution DGPS (accuracy of 1 cm in x, y, and z).

Lake-water depths and lake-ice thickness observations were made to allow the mapping of the spatial distribution and the temporal evolution of the these variables. In addition, ice was removed from 1-metre sections of the lake surface and the regrowth of the lake ice was measured from its initial formation until it reached equilibrium with the atmospheric forcing.

Tracer experiments were implemented to track water transport within the lake, blue-ice, and snow areas. These measurements were designed to provide information regarding within-basin water fluxes. In addition, lake-channel discharge was measured twice daily throughout the field season.

Snow/ice pits were dug (up to 2.25 metres deep) to determine the temporal evolution and spatial distribution of stratigraphy, density, dielectric constant, hardness, grain-size distribution and character, surface roughness, and depth to blue-ice.

Using a georadar, the three-dimensional characteristics of the lake, blue-ice, and snow areas, and their associated liquid-water characteristics and flows, were analysed and mapped. Field observations (such as snow pits and sub-surface water transport surveys) were designed specifically to provide validation for these remote sensing radar measurements.

Stakes put out during NARE 1993/94 were remeasured using DGPS, to determine glacier movement during the past three years.

Surface Energy Balance and Meteorological Characteristics

Continuous and comprehensive meteorological tower observations were conducted throughout the field season. The station measures air temperature, relative humidity, wind speed and direction, air pressure, and solar and net incoming and outgoing radiation every ten minutes at two levels, one and three metres. These climatic data provide valuable information regarding the linkages between the atmospheric forcing and the observed snow- and ice-melt features.

Solar radiation measurements were conducted within (below the surface of) the lake, snow, and blue-ice areas, and are considered crucial to our understanding of how the solar radiation penetrates the ice and snow surfaces and leads to the sub-surface melting that is so prevalent in this area. Spectral reflective properties of the snow, blue-ice, and lake-ice surfaces were recorded using a portable spectroradiometer (252 bands, 370-1110 nm). These measurements were taken under both clear and cloudy skies.

Vertical temperature profiles were measured in three areas: snow, blue-ice, and in the lake and the ice below the lake. Temperatures were measured at the following levels below the surface (cm): 5, 15, 25, 50, 75, 100, 125, 150, 200 (lake only), 250, 550 (snow and blue ice only). In addition, the air temperature was measured at each of these sites, and these data recorded hourly.

Methodologies to Study Sensitivities of Melt-Related Features to Variations in Atmospheric Forcing

During the field programme, reflective markers were installed as part of a RADARSAT and ERS remote sensing image/data collection effort. The resulting images will be used, in conjunction with the field observations, to relate observed melt-related features to features found on the satellite images. This analysis will be combined with past and future remote sensing products to provide information regarding trends in the extent and character of the melt patterns.

The field data collected as part of this programme are sufficient to aid in the development and validation of physically-based numerical models which are capable of evaluating the sensitivity of the observed melt-related features to variations in atmospheric forcing, or climate. The models being developed as part of this project include:

1. a blowing and drifting snow transport model which will determine the preferred locations of the snow-covered areas within the domain;
2. a lake energy balance model which will evolve the lake water and associated ice cover throughout the spring (initial growth), summer (equilibrium), and fall (freeze-up) seasons; and
3. a snow- and ice-melt energy balance model which will simulate the evolution of the sub--surface melting.

PRELIMINARY RESULTS

Our combined field data and numerical modelling efforts allow the description of many aspects of the seasonal evolution of the snow, blue-ice, and lake features that are common throughout the Jutulgryta region. The snow and blue-ice areas exist due to the interactions between the surface topography and the winter winds. Easterly winds remove snow from the east-facing slopes and deposit it on the west-facing slopes. Consequently, the west-facing slopes develop relatively deep snow deposits; deep enough that they do not melt completely down to the blue ice during the summer melt season. In contrast, the relatively thin snow cover over the east-facing blue-ice areas melt free of the previous winter's snow quite early in the summer. This melt of winter snow from the surface of the blue-ice areas is enhanced by the penetration of radiation within the coarse-grained (leading to a minimal scattering of solar radiation) blue-ice existing below the relatively thin snow cover.

To describe the sub-surface melting, complete energy-balance modelling is required. The meteorological data collected as part of the field effort directly supports this modelling work. This model must take advantage of the influence of snow and ice grain size and packing (by using the density) on the penetration of solar radiative energy. Clearly, the extinction of solar radiation as it penetrates the snow and ice cover, and its wavelength dependence must be accounted for, since so much of the melting is occurring well below the surface. This also suggests that any such modelling effort will require an appropriate coupling of the surface energy fluxes with the conductive energy flux occurring below the surface.

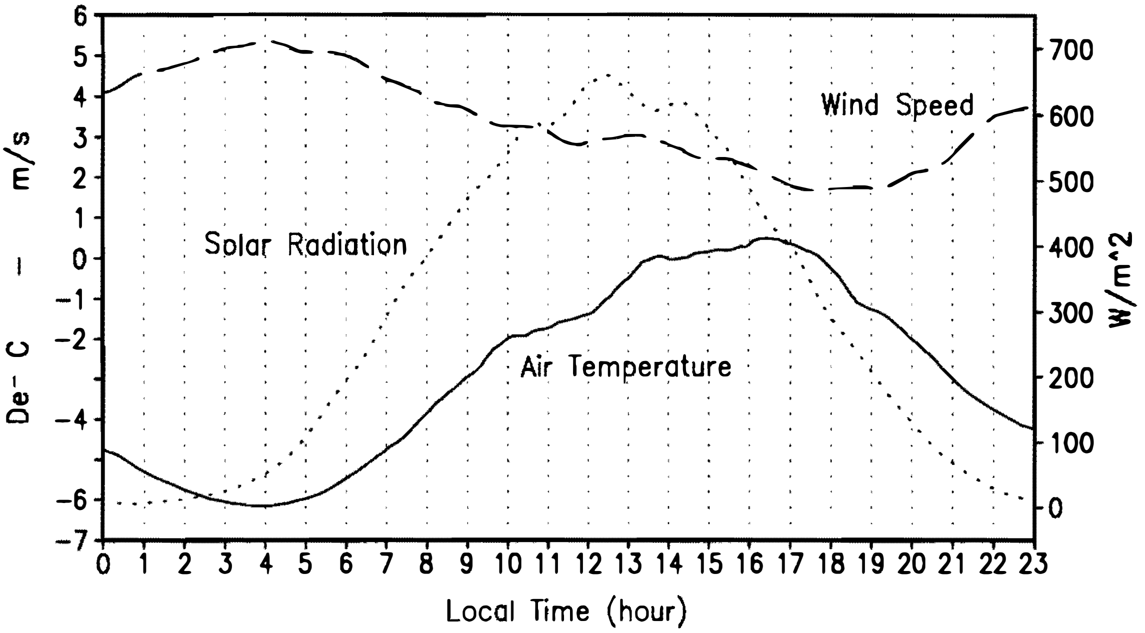

Fig. 2. Average daily cycle of incoming solar radiation, wind speed, and airtemperature at Jutulgryta during the NARE 1996/97 field season.

The local meteorological conditions which are characteristic of this area contribute greatly to the observed phenomena. High incoming solar radiation, coupled with low daytime wind speeds and relatively high air temperatures, contribute to the conditions found above and below the ice surfaces. Fig. 2 illustrates the strong interrelationships between the incoming solar radiation, air temperature, and wind speed. The night-time katabatic wind increase with decreasing temperature is an obvious meteorological feature of this region.

The radar data collected as part of this programme have been found to provide a valuable contribution to the development and understanding of the hydrologic characteristics of this area. By filling in the spatial gaps within our observational programme, the radar has allowed a more complete, often-times three-dimensional, mapping of the features of interest.

This area is characterised by a complex drainage system. In the snow areas, melting at the surface is refrozen as it percolates down through the snow pack, and as such, that melt water rarely reaches the sub-surface and lake drainage systems which remove water from the basin. In contrast to this, the melt produced in the blue-ice areas drains through the near-surface ice matrix (within the top meter) and eventually finds its way into the lake below. If there exists a blue-ice area above a snow area, then the melt water from the blue ice travels along the internal snow/blue-ice boundary until it emerges at the lower end of the snow area. In addition to the more classical drainage out of the obvious lake discharge channel, tracer measurements suggest that water also drains from under the lake, likely through crevasse-related fissures in the glacier ice.

CONCLUSIONS

In Jutulgryta, Antarctica, sub-surface melting during the summer season is a common occurrence, and is confined to the blue-ice areas of this region. This sub-surface melting is the result of solar radiation penetration and absorption within the ice, and longwave radiative cooling at the surface. Since the melting commonly occurs several centimeters below the surface, the melting goes largely unnoticed and requires a below-surface investigation to establish its presence.

The conditions required for melting to take place in Jutulgryta are expected to be marginal, and quite sensitive to variations in local and regional air temperature and energy balance. A slight increase in air temperature may result in more classical surface melting, whereas a cooling may disable the sub-surface melting. Our modelling efforts are expected to enable us to quantify the boundaries at which such melt would be expected to become enhanced or closed down completely. Because of the anticipated sensitivity to the atmospheric forcing, an understanding of the physical processes and mechanisms, and the ability to describe the extent and characteristics of the melt features as they change with time, are expected to be particularly valuable contributions to the development of methods to detect and assess the impact of climatic variations in Antarctica.

ACKNOWLEDGEMENTS

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MONICA KRISTENSEN SOLÅS[1] & HEINRICH EGGENFELLNER[1]:

CHANGING MASS BALANCE OF THE FILCHNER ICE SHELF DUE TO CLIMATE VARIATIONS

ABSTRACT
The Filchner Ice Shelf Project, part of the Aurora Programme, is a study of changes in the mass balance of the Filchner Ice Shelf due to climate-induced changes in the environment. Field investigations have previously been conducted in the seasons 1991/92, 1992/93 and 1993/94. During the first season, in 1991, the Base Blåenga was established and a network of three automatic climate stations and about 50 glaciological stakes were established on the Bailey Ice Stream and on the Filchner Ice Shelf. The stake network was partially re-measured during the next two field seasons. The automatic stations were visited each year and another two stations were deployed. The investigation area covers approximately 30,000 km^2.

BACKGROUND
Presently, climate-induced variations in the mass balance of the Antarctic Ice Sheet is one of the major topics of interest in Antarctic glaciology. However, one obstacle of studying this topic is the magnitude of the continent itself, as well as defining reasonable limits for an area of investigations. The Filchner Ice Shelf, bordered by the coast line, Berkner Island, mountains, and five large ice streams, forms a system which can be studied separately from the surrounding region. Many features in this area suggest that the Filchner-Ronne Ice Shelf is sensitive to climatic change. There is evidence of extensive basal melting at the inner margins, which again can be coupled to the current system under the shelf and the formation of supercooled Antarctic bottom water. This is particularly important when considering the global ocean circulation, since the formation of deep, cold water under the ice shelves is one of the driving mechanisms for the large scale ocean currents. Infrequent calving of giant icebergs from the front of the shelf east of Berkner Island may be related to instabilities in the flow of ice from the catchment areas. Irregularities in the ice flow are present around ice rises and rumples. Other phenomena, such as crevasse patterns parallel to the ice flow may be due to instabilities induced by regional climate variations.

Ice velocities and strain rates in the ice shelves can be assumed to be independent of depth and conditions vary slowly over distances that are large compared to the thickness of the ice. Theoretical models therefore provide good approximations to the behaviour of real ice shelves. Input data relating to the present day mass balance are, however, necessary. These data are:

- Ice inflow/balance fluxes from the five surrounding glacier systems: Bailey, Slessor, Recovery, Support Force, and Foundation Ice Streams.
- Snow accumulation (inside the ice flux boundaries).
- Ice thickness.
- Bottom freezing/melting and ice front dynamics.

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The last type of data is not directly available and has to be derived assuming that isostatic anomalies in the ice shelf surface height is due to saline ice formation or melting at the bottom, and applying the continuity equation for downstream ice flow. The three first types of data are collected within the Filchner Ice Shelf Project.

OBJECTIVE

The aim of the Filchner Ice Shelf Project is to study changes in the mass balance and dynamics of the Filchner Ice Shelf and the surrounding ice streams induced by climate changes. Investigations consist of long-term monitoring of changes in weather and climate parameters, measurements of annual variations in snow accumulation, ice dynamics (ice velocities and ice thickness). Numerical models of ice shelf dynamics will be used to collate the data and to put forward prognoses of development of the ice shelf given different scenarios for regional climate change.

FIELD WORK IN 1996/97

The field work in the 1996/97 season was to concentrate on maintenance of the automatic weather stations and remeasuring of the glaciological stake network (positions and snow accumulation).

A Trimble 4000 Land Surveyor reference GPS station was to be established on Theron mountains with one person to operate the station, while two persons were to travel to the automatic weather stations along the stake lines, measuring positions and logging snow accumulation along the route.

The field work was expected to take two-three weeks depending upon travelling conditions.

Due to very heavy sea ice conditions in the southern Weddell Sea, the expedition ship did not get close enough to Blåenga. Thus, the field party could not be deployed. No effort was spared by the expedition leaders to help the field party, but a number of other options for getting the expedition members into the area also failed. Thus, the work planned for the season of 1996/97 had to be postponed to another field season - hopefully to NARE 1997/98. The expedition members used the time on board the ship helping with the accomplishment of other projects.

After several years of functioning, the automatic weather stations are now in extreme need of new sensors, and general maintenance of the different parts of the stations. It is hoped that all data loggers will be changed to extended storage type loggers at a later date.

Participants: Siv. ing. Heinrich Eggenfellner (field assistant, data analysis), Kåre Pedersen (field assistant), and Erik Vike (field assistant).