INLAND WATERS BRANCH
DEPARTMENT OF ENERGY, MINES AND RESOURCES

Ice Studies in the Department of Energy, Mines and Resources - 1969

REPORT SERIES No.7

CANADA

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INLAND WATERS BRANCH
DEPARTMENT OF ENERGY, MINES AND RESOURCES
OTTAWA, CANADA, 1969

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FOREWORD

This report presents the ice studies currently sponsored by the Department of Energy, Mines and Resources. The first part is a general introduction to the ice studies and their relationship to the functional objectives of the Department, the organization of the Department and the groups engaged in the studies. The second part of the report is a catalogue of current projects.

I am indebted to many individuals in the various branches for providing information for this report. Their assistance has been invaluable.

O.H. Løken,
Head,
Glaciology Subdivision.

August 1969

INTRODUCTION

The Government Organization Act of 1966 which established the Department of Energy, Mines and Resources states that the Minister shall be responsible for coordinating, promoting and recommending national policies and programs with respect to energy, mines and minerals, water and other resources. As part of its functional responsibilities, the Department sponsors several ice studies. This is natural since ice and snow form an integral part of the Canadian environment, and knowledge of the occurrence, behaviour and characteristics of snow and ice is required for effective management of water resources and exploitation of other resources. Ice which covers most of our coastal waters for periods ranging from a few days per year along our south coasts to 12 months a year in the Arctic Archipelago, is a hindrance to navigation. Shipping on the inland waterways is similarly hampered. Some 200,000 square kilometers of the country is permanently covered by glaciers; a large proportion of the northern part of the country is underlain by frozen ground throughout the year and during the winter most of the country is blanketed in snow. The snow and ice-cover has a profound influence on the heat balance of the earth's surface and when it melts in the spring and summer, stream levels often rise above flood stage, causing extensive damage.

The ice studies are mainly concentrated in three agencies: the Inland Waters Branch which is responsible for water resources; the Polar Continental Shelf Project which has a major responsibility for logistics and coordination of investigations in the northernmost part of the country including the adjacent continental shelf and ocean; and the Marine Sciences Branch which is responsible for oceanographic research. The organization chart on page 8 shows the Sectors and Branches of the Department while the groups and individuals involved in ice studies are shown on page 9. The two principal groups are the Glaciology Subdivision, Inland Waters Branch and the Frozen Sea Research Group, Marine Sciences Branch.

To a lesser degree, activities of a number of other Branches involve direct or incidental investigations of ice. For example, the Geological Survey of Canada has projects dealing with ground ice as a major factor in governing the geomorphological processes in the Arctic, and the Mines and the Mineral Resources branches are concerned with ground ice as a complicating factor in Arctic mining operations. Also, metallurgists in the Mines Branch are interested in the solid state properties of ice. The Dominion Observatory Branch needs to know the ice thickness in order to reduce gravimetric measurements over glacierized areas, and the Surveys and Mapping Branch is repeatedly called upon to compile and print special maps required for glaciological research in other Branches.

The field of scientific research is indeed a continuum and any attempt to separate one field from another invariably involves arbitrary decisions, some of which may be rendered invalid or unreasonable by future

scientific advances. The decision as to which projects to include in this report is thus to some extent arbitrary, but the report is intended to cover projects for which ice or snow is the focus of interest. The Surveys and Mapping Branch, for example, has no particular project in ice research but compiles high quality maps requested by other Branches; these maps are listed on page 10. That Branch also prints all the glacier maps and sea ice distribution maps produced by other Branches, for example, the Inland Waters Branch and Polar Continental Shelf Project.

Current map compilations include the maps of the Steele Glacier to show its development during the recent surge. This event led to the establishment of a Working Group to coordinate the Departmental studies of Steele Glacier. The group has members from the Polar Continental Shelf Project, Surveys and Mapping Branch and the Inland Waters Branch, and is an excellent example of how the resources of several agencies may be pooled to reach certain sub-objectives. Many of the ice studies involve such cooperation.

Only projects where the Department is the main sponsor have been included in this report; several projects where the Department cooperates actively with other agencies have been omitted. The Ice Drift Project in the Gulf of St. Lawrence where the Department, the Defence Research Board and McGill University participate is one of those left out.

ICE STUDIES

This report provides a description of ice studies presently undertaken by the Department. In the catalogue beginning on page 11, the projects are grouped according to the nature of the project rather than according to sponsoring organizations. Within each group the sequence of the projects is arbitrary. For easy reference, each project is given a number in the upper left hand corner.

The ice studies may be divided into three groups, namely those related to:

1. Land-based ice.
2. Floating ice.
3. Ice as a material.

The first two groups closely reflect the Department's objectives in the water resources field and in hydrographic surveys. The third group contains projects in support of the first two groups.

Because the projects are sponsored by different Branches and because the degree to which activities are broken down into separate projects is not uniform, the number of projects in each group is not a true indicator of the emphasis the Department puts on each type of studies. Furthermore, the resources (funds and manpower) which are committed to the different projects vary greatly from one to the other.

1. Land-based Ice

These projects relate mainly to glaciers and their climatological regime, but include also the snow-cover in alpine areas and the meltwater it yields, i.e., the ice as a water resource. Studies of the distribution

and fluctuations of existing glaciers and of glacier flow are also included.

The projects are divided into three sub-groups:

1.1 The role of glaciers in the hydrologic cycle.
1.2 Glacier dynamics.
1.3 Glacier Inventory.

1.1 The Role of Glaciers in the Hydrologic Cycle - fundamental to this role is the study of the heat, mass and water balance of selected glacier basins for the purpose of evaluating glaciers as a water resource. There are currently 12 long-term studies, 6 in the Arctic and 6 in the Cordillera, in order to study this relationship under varying climatic conditions. Most of these studies are integral parts of the glaciological program under the International Hydrological Decade program which the Department contributes extensively to.

Of particular interest is the role of glacier meltwater in the regime of the main rivers in the glacierized parts of the country (Project No. 10). Although glaciers cover only a small part of many drainage basins, they are hydrologically significant because they continue to release meltwater throughout the summer when other sources, e.g., the snow cover, have disappeared. The significance of this sustained late summer yield is readily understood in irrigation areas.

The relationship between climatic parameters and glacier melt is investigated in this context and so is the movement of meltwater through the glacier. Of particular interest is an experimental plot in preparation near Ottawa for the study of moisture flux through a snowpack and across its upper and lower boundaries.

These studies will provide new information that may subsequently result in more effective water management. A recent report on Canada's Water Resources,[1] stressed the importance of such improved techniques because efficiency improvements of only 1 to 2 per cent in the operation of existing installations can result in greatly increased benefits. In hydro power developments where water use is non-consumptive, improved management techniques will always result in increased benefits with no downstream water losses.

Long-term glacier fluctuations are important because if the glaciers gradually melt away, their value in sustaining downstream discharge during lengthy dry periods would be lost, a factor which must be considered in watershed planning. There have been a few attempts to 'manage' glaciers by manipulating the energy balance in order to increase or decrease the melt. Methods to induce melt must be used with caution, however, because some glaciers may disappear forever with unknown feedback effects on the local climate.

The energy, mass and water balance studies are made in remote mountain areas where weather and environmental information has been scarce. These projects thus add substantially to the knowledge of the high mountain environment. Of particular interest is snow hydrology, because snow is the major source of runoff from most of the mountainous parts of Canada, and with

[1] Bruce, J.P. and Maasland, D.E.L.: Water Resources Research in Canada. Science Council of Canada Special Study No. 5, 1968.

the rapidly increasing demand for water,[2] it is imperative that we should obtain more detailed information on alpine or snow hydrology. Several diversion schemes have been proposed for the Cordillera region and, although heated controversies surround this topic,[3] there is agreement that a more accurate assessment of water resources of the region is urgently needed.

1.2 Glacier Dynamics - the six studies in this group are closely related to the former group, but the emphasis is on the overall behaviour of glaciers rather than on the mass balance alone. On Meighen Island Ice Cap, the bore-hole deformation is used to deduce the flow law of ice; on the Penny and Barnes ice caps, the overall response of the ice caps are studied. Problems of glacier flow and conditions at the ice-rock interface are of particular interest in the Arctic where mineral exploration and even exploitation may develop under or near glaciers.

A problem of particular interest is the surging glaciers which may advance several kilometers in a few months. The need for understanding this process is obvious as mining operations and other forms of economic activities extend further into the glacierized regions of the country. An interesting example of this is the study made for the Granduc Mining Company in British Columbia to predict the future behaviour of a glacier situated close to a multi-million dollar concentrator site.[4] The potential economic value of this approach is obvious.

Theories about glacier flow and the physical behaviour of glaciers can best be studied on ice masses with a simple outline, lying on an almost flat surface, such as the locations of the Barnes and Meighen ice caps which are studied in detail.

1.3 Glacier Inventory - the aim of the Glacier Inventory is to establish the amount of water stored in Canadian glaciers. The inventory is an International Hydrological Decade project being carried out according to an internationally accepted system. Through the inventory, a vast amount of standardized and compatible data will become available for analysis on a global basis. The data will be stored on tape and punch cards for machine processing. The data may be sorted on a drainage basin basis thus facilitating quick reference for hydrologic purposes. Canadian glaciologists were instrumental in developing a manual for this inventory.

As an extension of the inventory, a 'Glacier Atlas' of Canada will be produced as a further development in the 1:1,000,000 glacier map series which was the first step in developing the inventory.

Various Departmental projects involving the Geological Survey of Canada, Inland Waters Branch, Observatories Branch, and the Polar Continental Shelf Project consist of research on ground ice as a thermal phenomenon or as an agent influencing landforms, stratigraphy, slope stability, hydrology, etc. Project 39 has been selected as the one most directly involved in ice studies.

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[2] See e.g., Cass Beggs, D.: Water as a Basic Resource, in Resources for Tomorrow. Queen's Printers 1961.

[3] See e.g., papers by: McNaughton, A.G.L. and Moss, F.E., in Water Resources of Canada, Royal Society of Canada 1967.

[4] Untersteiner, H. and Nye, J.F.: Computation of the possible future behaviour of Berendon Glacier, Canada. Journal of Glaciology, v. 7, no. 50, 1968.

2. Floating Ice

Sea ice, lake ice and river ice are common features of the winter environment in southern Canada and they occur throughout the year in the Arctic. Wherever present, ice hinders shipping, influences the energy and moisture balance of the waterbody and exerts considerable pressure on shorelines, river banks and structures such as docks or towers for oil rigs. On the other hand, ice-covers provide readily available landing strips for ski-equipped aircraft, roadways for tractor trains and other transports, and operational platforms for oceanographic and limnological research stations. River ice changes the flow regime of a stream and may do so in a very dramatic way when ice jams form. During formation and decay of ice the stability and circulation pattern of the waterbody is changed, thus influencing the distribution of nutrients and pollutants.

The projects in this group can be further subdivided in two:

2.1 Distribution and movement.
2.2 Growth of ice-covers.

2.1 Distribution and Movement - the major study in this group is the study of the distribution and movement of sea ice within the Arctic Archipelago and the adjacent Arctic Ocean (Project No. 39). Little is known of the ice conditions in these areas and the need for this knowledge is rising rapidly with the recent mineral and oil exploration in the Arctic. This need has been further emphasized in a recent study made in the United States.[5] The forthcoming voyage of the tanker "Manhattan" later this year dramatizes this need for sea ice information since exploitation of mineral resources in the north is closely linked to the availability of marine transport. Moreover, the Arctic Ocean is the source of some of the ice that drifts south along the eastern Arctic coast and knowledge of ice movement in the Arctic Ocean is thus essential for the sea ice forecasting farther south. The Department of Transport provides these operational forecasts, but the aim of Project No. 39 is to obtain basic knowledge that can be translated into forecasting techniques for the benefit of mariners.

The Sea Ice Atlas (Project No. 45) will be continuously updated with new supplements issued each year.

The drift of icebergs is analogous to the drift of sea ice, but they originate from glaciers. Project No. 17 will include a study of the rate of iceberg production of one of Canada's most productive ice caps. This project also emphasizes the relationship between sea ice distribution and glacier variation. In the future it may become desirable to modify some of the narrow channels in the Arctic Archipelago as a means of manipulating the sea ice distribution in Canadian Arctic. How will this influence the glaciers and the climate in general on the adjacent islands? Studies of this problem are required.

2.2 Growth of Ice-Covers - this group emphasizes the processes involved in the growth of ice-covers. A recent study stresses the fundamental importance of the original ice - the primary ice - on lakes and rivers, as this initial ice and the conditions under which it formed to a large extent determine the physical properties of the ice cover that subsequently

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[5] Glaciology Panel, National Academy of Sciences - National Research Council: Glaciology in the Arctic, 12 pp. 1967.

develops.[6] Project No. 54 investigates this relationship with the aim of adapting the results to operational ice forecasting.

The other projects in this group relate to sea ice with particular emphasis on the processes along the ice - water interface and in the waterbody below. When sea water freezes, the salinity increases at the interface; some of the brine is enclosed in the ice, but most of it is expelled. The brine within the ice influences its mechanical properties which is clearly related to its effect on structures including oil rigs, icebreakers and other ships. The expelled brine causes convective circulation in the underlying water, thus influencing the distribution of salts and other minerals, including undesirable pollutants. So far the convective circulation pattern has been studied in connection with sea ice, but there are similar problems in physical limnology.

3. Ice as a Material

Studies of the basic properties of ice are best done under laboratory conditions where experiments can be made on specially grown and relatively simple, single crystals of ice under carefully controlled conditions. The experiments can later be extended to samples of the more complex polycrystalline ice usually found in nature, and the results applied to solve practical problems.

Current projects deal with the occurrence of defects in crystals, a phenomenon of great importance to the mechanical properties of ice. It also enhances the understanding of the solid state behaviour of ice. The molecular structure of ice is of great interest since it shows a simple and easily investigated, yet fundamental form of hydrogen bonding.

Impurities may substantially change the mechanical properties, in ice samples, a fact which is being investigated. In the future, it may be possible to introduce selected "pollutants" to create ice with desirable mechanical properties. This could develop to a great potential benefit for icebreaking and as a tool to protect water conveyance structures against ice pressure. The study of 'doped ice' and its properties is only one line of investigation into the basic structure and the properties of ice. Such studies are fundamental for our understanding of how ice interacts with its natural environment, for example, the effect that ice formation on lakes and rivers has on the pollution level in the waterbody.

The creep characteristics of various types of lake and river ice are investigated in order to allow prediction of ice-cover characteristics on the basis of its genesis.

Laboratory studies of ice permit investigations to be made under a greater variety of temperature and pressure conditions than those occurring in classical field situations. Such 'artificial' conditions had previously been of primarily scientific interest, but with the suggested occurrence of

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[6] Michel, B., and Ramseier, R.O., 1969. Classification of River and Lake Ice Based on its Genesis, Structure and Texture. University of Laval, Faculty of Sciences, Department of Civil Engineering, Ice Mechanic Section, Report S-15, 57 pp.

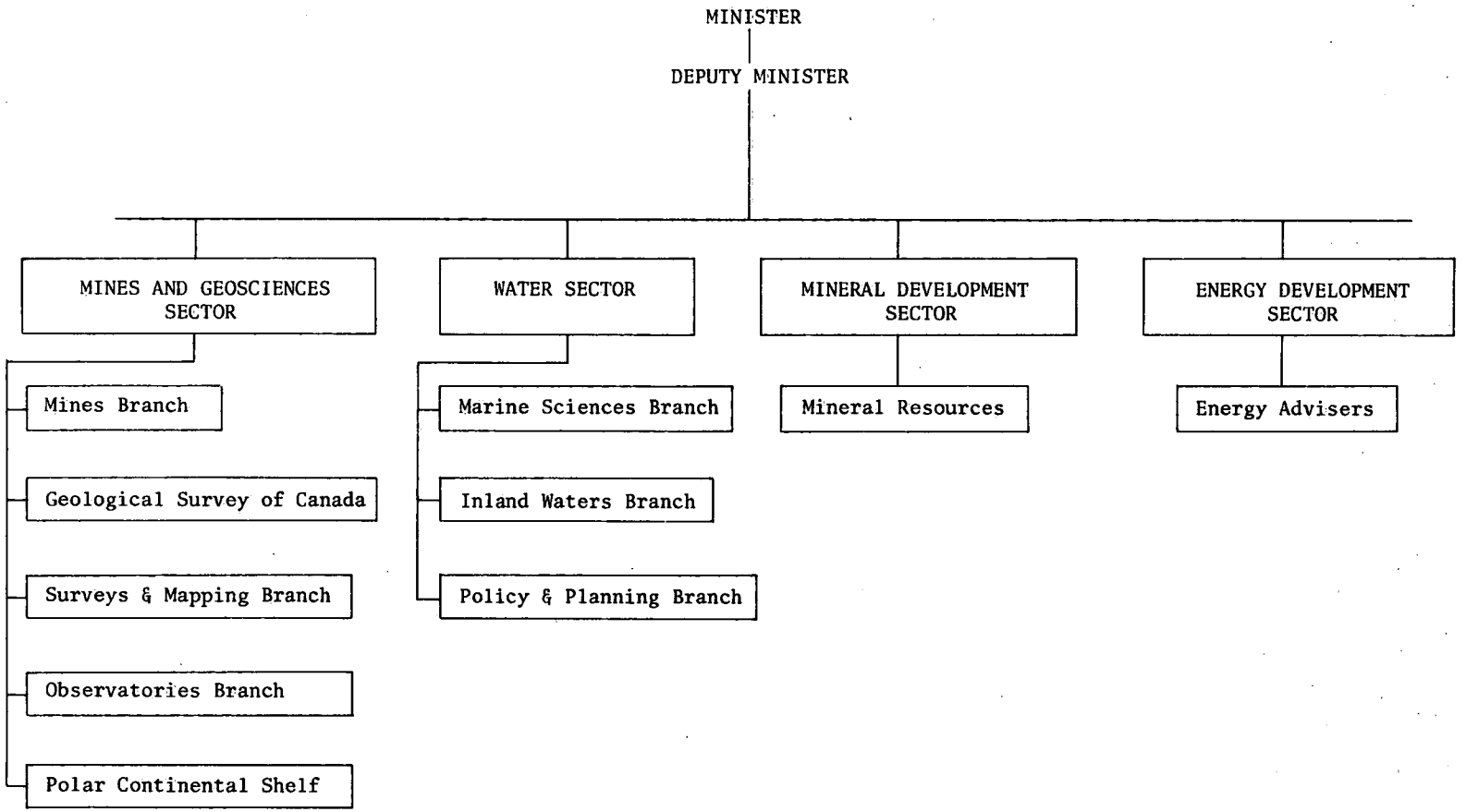
ice caps on the planet Venus,[7] man may soon have to cope with ice under conditions which are far removed from those known on the earth's surface.

In the laboratory, tests are performed on ice samples collected from glaciers or other freshwater ice in the field. Optical, crystallographic, electrical and other properties of the samples are studied. An understanding of the electrical properties of ice is of particular value when electromagnetic prospecting methods are employed in glacierized areas.

[7] Libby, W.F.: Ice caps on Venus? Science, v. 159, November, 1968.

ORGANIZATION CHART DEPARTMENT OF ENERGY, MINES AND RESOURCES

SECTORS AND BRANCHES



PERSONNEL ENGAGED IN ICE RESEARCH

WATER SECTOR

GLACIOLOGY SUBDIVISION (INLAND WATERS BRANCH)

Head - O.H. Løken
Secretary - Mrs. L.I. Logan

Cordillera Section

STANLEY, A.D.	Beck, T.M.H.	Bellaar-Spruyt, T.
Derikx, L.	Henoch, W.E.S.	Mokievsky-Zubok, O.

Arctic Section

HOLDSWORTH, G.	Arnold, K.C.	Christian, D.
Embacher, U.	Fogarasi, S.	Terroux, A.C.D.

Ice Science Section

JONES, S.J.	Barnett, G.	Cross, J.D.
Fisher, D.	Nakamura, T.[1]	Ramseier, R.O.

Glacier Inventory Section

OMMANNEY, S.	Strome, M.

WATER SCIENCE SUBDIVISION (INLAND WATERS BRANCH)

Goodman, R.

WATER SURVEY OF CANADA (INLAND WATERS BRANCH)

Reid, I.A.	Shastal, J.

FROZEN SEA RESEARCH GROUP (MARINE SCIENCES BRANCH)

Head - E.L. Lewis
Secretary - Mrs. M.H. Murkin

Elliott, J.A.	Lake, R.A.	Sudar, R.	Walker, E.R.

MINES AND GEOSCIENCES SECTOR

POLAR CONTINENTAL SHELF PROJECT

Paterson, W.S.B.	Colby, L.R.	Hermann, P.
Koerner, R.	Peister, K.R.	

GRAVITY DIVISION (DOMINION OBSERVATORIES)

Weber, J.R.

[1]Postdoctoral Fellow

GLACIER MAP COMPILATIONS BY TOPOGRAPHIC SURVEY

(Surveys and Mapping Branch)

Name of Map	Scale	Year of Compilation
Athabasca Glacier, Alta.	1:4,800	1962
Meighen Ice Cap, N.W.T.	1:25,000	1965
Decade (Inugsuin) Glacier, N.W.T.	1:10,000	1965
Place Glacier, B.C.	1:10,000	1966
Sentinel Glacier, B.C.	1:10,000	1966
Steele Glacier, Yukon	1:50,000	1966
Steele Glacier, Yukon	1:25,000	1966-67
Centennial Range, Yukon	1:125,000	1967
Ram River Glacier, Alta.	1:10,000	1967
Woolsey Glacier, B.C.	1:10,000	1967
Peyto Glacier, Alta.	1:10,000	1967
Fox Glacier, Yukon	1:10,000	1968
Summit Lake, B.C.	1:10,000	1968
Salmon Glacier, B.C.	1:25,000	1968
Berendon Glacier, B.C.	1:10,000	1969

CURRENT PROJECTS CATALOGUE

1. Land-Based Ice

A. PROJECT 1 - Mass and Water Balance Measurements at Place Glacier (G-67-1)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division)

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: O. Mokievsky-Zubok.

E. OBJECTIVES: Place Glacier is one of five glacier basins in a transect across the Canadian Cordillera selected for long-term investigations to determine the role of glaciers in the hydrologic cycle by:

1. Measuring accumulation and ablation
2. Recording meltwater discharge and meteorological data and
3. Relating glacier variations to recent climatic trends.

The glacier belongs to the world-wide network of glacier basins selected for detailed mass, water and energy balance measurements under the International Hydrological Decade (IHD) program.

F. LOCATION: Coast Mountains (50° 18' N, 122° 48' W) 120 km north of Vancouver, B.C.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Ground control for compiling a topographic map (scale 1:10,000) was established from 1965 aerial photographs. Glaciological, hydrological and climatological observations have been made each summer since 1965.

2. References:
Østrem, G., 1966. Mass balance studies on glaciers in Western Canada. Geog. Bull., v. 8, no. 1, pp. 81-107.

Inland Waters Branch, 1967. Coloured Relief Map of Place Glacier at a scale of 1:10,000.

Mokievsky-Zubok, O., 1969. Mass and water balance, and meteorological observations at Place Glacier - 1967-1968, (in preparation).

H. WORK IN PROGRESS: Period of field work May-September annually.

1. Determination of winter balance in late May and continuous measurement of ablation throughout the summer at more than 40 locations on the glacier surface. These locations are surveyed annually to determine surface movement.
2. Determination of daily discharge of meltwater stream by continuous monitoring of stage during the summer period.
3. Maintenance of meteorological records consistent with recommendations by the IHD Committee on mass, water and energy balance studies.

Instrumentation consists of short-term recorders installed at 1850 m a.s.l., including:

Thermohygrograph Automatic precipitation gauge

I. FUTURE WORK:

1. Installation of long-term meteorological recorders for all-year operation.
2. Construction of a stream gauging station to record stage throughout the year. The stream channel has been surveyed and a suitable site selected.

A. PROJECT 2 - Discharge Components of a Meltwater Stream from Drainage Basin of Sentinel Glacier (G-67-2)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division)

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: O. Mokievsky-Zubok.

E. OBJECTIVES: Sentinel Glacier is one of five glacier basins in a transect across the Canadian Cordillera selected for long-term investigations to determine the role of glaciers in the hydrologic cycle by:

1. Evaluating existing techniques of measuring changes in glacier volume and by establishing criteria for direct comparison of these methods - surface measurement on stakes, terrestrial photogrammetry and hydrologic methods.
2. Developing a method of identifying the glacier meltwater component in a stream which includes runoff from unglacierized areas.

The glacier belongs to the world-wide network of glacier basins selected for detailed mass, water and energy balance measurements under the IHD program.

F. LOCATION: Coast Mountains (49° 50' N, 122° 55' W) 70 km north of Vancouver, B.C.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Stereoscopic terrestrial photographic surveys for mapping part of the glacier were carried out in 1964, 1966 and 1968 by the Water Survey of Canada (see Project G-67-16).

   Ground control for compiling a map of the whole glacier (scale 1:10,000) was established from 1965 aerial photography. Standard glaciological measurements of mass balance and hydrological and meteorological observations were obtained each summer in 1966, 1967 and 1968.

2. Reference:
   Mokievsky-Zubok, O., 1969. Mass, water balance and meteorological observations at Sentinel Glacier for 1967-1968 (in preparation).

H. WORK IN PROGRESS:

1. Surface measurements along longitudinal and transverse profiles are being made to establish the winter balance in late May, and measurements at 33 locations on the glaciers surface are being made to define summer balance and ablation.

2. Meltwater discharge is being measured within the main meltwater channel using a Stevens A-35 stage recorder located at 1500 m. a.s.l. The rating curve is re-established each year.
3. Meteorological observations are taken for the periods May-October. Instrumentation consists of short-term recorders installed at 1540 m a.s.l., including:

Thermohygrograph	Solarimeter
Totalizing Anemometer	Simple Precipitation Gauge
Sunshine Recorder	

Seven precipitation gauges have been located throughout the basin and a thermohygrograph set at 1900 m a.s.l.

I. FUTURE WORK:

1. Continuation of all glaciological, hydrological and meteorological observations.
2. Installation of long-term meteorological recorders for all-year operation.
3. Study of hydrology and sediment transport of the meltwater stream.
4. Continuation of photogrammetry in 1970.

A. PROJECT 3 - Mass and Water Balance Measurements at Woolsey Glacier (G-67-3)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division)

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: A.D. Stanley.

E. OBJECTIVES: Woolsey Glacier is one of five glacier basins in a transect across the Canadian Cordillera selected for long-term investigations to determine the role of glaciers in the hydrologic cycle by:

1. Measuring accumulation and ablation.
2. Recording meltwater discharge and meteorological data, and
3. Relating glacier variations to recent climatic trends.

The glacier belongs to the world-wide network of glacier basins selected for detailed mass, water and energy balance measurements under the IHD program.

F. LOCATION: Selkirk Mountains (50° 00' N, 118° 13' W) 15 km northeast of Revelstoke, B.C.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Ground control for compiling a topographic map (scale 1:10,000) was established from 1965 aerial photography. Glaciological, hydrological and climatological observations have been made each summer since 1965.

2. References:
Østrem, G., 1966. Mass balance studies on glaciers in Western Canada, 1965. Geog. Bull., v. 8, no. 1, pp. 81-107.

Inland Waters Branch, 1968. Coloured Relief Map of Woolsey Glacier at a scale of 1:10,000.

Stanley, A.D., 1969. Mass, water balance and meteorological observations at Woolsey Glacier for 1967-1968, (in preparation).

H. WORK IN PROGRESS:

1. Measurement of winter balance in May-June and continuous study of ablation throughout the summer at more than 37 locations on the glacier surface. These locations are surveyed annually to determine glacier movement.

2. Determination of daily discharge of the meltwater stream at the lake outflow during the period June-October using a Stevens A-35 recorder.

3. Maintenance of meteorological records June-October. Instrumentation consists of short-term recorders installed at 1990 m a.s.l., including:

    Thermohygrograph
    Simple Rain Gauge
    Sunshine Recorder

I. FUTURE WORK:

1. Installation of long-term meteorological recorders.
2. Continuation of mass balance and water balance measurements until 1974.

A. PROJECT 4 - Mass and Water Balance Measurements at Peyto Glacier (G-67-4)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division)

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: A.D. Stanley.

E. OBJECTIVES: Peyto Glacier is one of five glacier basins in a transect across the Canadian Cordillera selected for long-term investigations to determine the role of glaciers in the hydrologic cycle by:

1. Measuring accumulation and ablation.
2. Recording meltwater discharge and meteorological data, and
3. Relating glacier variations to recent climatic trends.

The glacier belongs to the world-wide network of glacier basins selected for detailed mass, water and energy balance measurements under the IHD program.

F. LOCATION: Rocky Mountains (51° 40' N, 116° 34' W) 45 km northwest of Lake Louise, Alberta.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Preparation of a base map (scale 1:10,000) from aerial photographs taken in August 1966. Standard surface measurements of glacier mass balance have been obtained each summer since 1965 and measurement of stream discharge, since 1966. Meteorological observations were obtained during summer months.

2. References:

Østrem, G., 1966. Mass balance studies on glaciers in Western Canada, 1965. Geog. Bull., v. 8, no. 1, pp. 81-107.

Sedgwick, K., 1966. Geomorphology and Mass Budget of Peyto Glacier, Alberta. M.A. Thesis, McMaster University.

Terroux, D., 1969. Mass, water balance and meteorological observations at Peyto Glacier - 1967-1968, (in preparation).

H. WORK IN PROGRESS:

1. Determination of winter balance in late May and continuous measurement of summer balance and ablation throughout the summer at more than 38 locations on the glacier surface. These locations are surveyed annually to determine surface movement.
2. Determination of meltwater discharge by continuous monitoring of stage and measurement of flow using a fluorometric technique.

3. Maintenance of meteorological records consistent with recommendations of the IHD Committee on mass, water and energy balance studies. Instrumentation consists of short-term recorders installed each summer at 1900 m a.s.l., including:

Thermohygrograph	Sunshine Recorder
Barograph	Solarimeter
Anemometer	Rain Gauge

Other instruments include seven precipitation gauges throughout the basin and a Stevens A-35 recorder in the meltwater channel.

I. FUTURE WORK:

1. Continuation of all glaciological, hydrological and meteorological observations and calculation of mass and water balance.
2. Installation of long-term meteorological recorders for all-year operation.

A. PROJECT 5 - Mass and Water Balance Measurements at Ram River Glacier (G-67-5)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division)

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: A.D. Stanley.

E. OBJECTIVES: Ram River Glacier is one of five glacier basins in a transect across the Canadian Cordillera selected for long-term investigations to determine the role of glaciers in the hydrologic cycle by:

1. Measuring accumulation and ablation.
2. Recording meltwater discharge and meteorological data, and
3. Relating glacier variations to recent climatic trends.

The glacier belongs to the world-wide network of glacier basins selected for detailed mass, water and energy balance measurements under the IHD program.

F. LOCATION: Rocky Mountains (51° 51' N, 116° 12' W) 45 km north of Lake Louise, Alta.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Ground control for compiling a topographic map (scale 1:10,000) was established from 1965 aerial photography. Glaciological, hydrological and climatological observations have been made each summer since 1965.

2. References:
Inland Waters Branch, 1967. Coloured Relief Map of Ram Glacier, published at a scale of 1:10,000.

Østrem, G., 1966. Mass balance studies on glaciers in Western Canada, 1965. Geog. Bull., v. 8, no. 1, pp. 81-107.

Terroux, D., 1969. Mass, water balance and meteorological observations at Ram River Glacier - 1967-1968, (in preparation).

H. WORK IN PROGRESS:

1. Determination of winter balance in late May and continuous measurement of ablation throughout the summer at more than 20 locations on the glacier surface. These locations are surveyed annually to determine surface movement.
2. Determination of the discharge of the meltwater stream for period June-late September using a Stevens A-35 recorder.

3. Maintenance of meteorological records for period June-late September. Instrumentation consists of short-term recorders installed at 2550 m a.s.l., including:

Thermohygrograph	Small precipitation gauges
Automatic precipitation gauge	throughout the basin

I. FUTURE WORK:

1. Installation of long-term meteorological recorder for all-year operation.
2. Continuation of all glaciological, hydrological and meteorological observations and the calculation of mass and water balance until 1974.

A. PROJECT 6 - Glaciological Investigations in the Area of Berendon Glacier (G-67-6)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division)

C. COOPERATING AGENCY: Granduc Operating Company Ltd.

D. PRINCIPAL INVESTIGATOR: A.D. Stanley.

E. OBJECTIVES: The Berendon Glacier was selected for long-term investigations to complement existing IHD programs to determine the role of glaciers in the hydrologic cycle. Incorporated in the overall program are a number of specific objectives:

1. Evaluation of an existing theory that predicts the behaviour of glaciers from the simple parameters of mass balance, surface movement and ice depth data.
2. Determination of a simple model that will require only a minimum of annual observations to predict changes in surface velocity and terminus position that may be hazardous to large-scale mining operation.
3. To contribute to the existing IHD network of glacier studies. Berendon Glacier forms part of the N-S chain of glacier basins that extends from Alaska to South America.

F. LOCATION: Coast Mountains (56° 15' N, 130° 10' W) 35 km north of Stewart, B.C.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: In 1956-1957, an expedition to the Salmon Glacier area to make seismic, gravimetric, glaciological and photogrammetric studie was undertaken by the National Research Council and the University of Toronto. Since 1960, the Granduc Mining Company has been active in the area and, since 1965, under the supervision of Dr. W.H. Mathews of the University of British Columbia, some velocity data has become available for the Berendon, North Leduc and Frank Mackie glaciers.

   Studies by the Cordillera Section began in late 1967 and included surface measurements of the mass balance, daily discharge measurements of the stream below the lake and meteorological observatio from late May to early October.

H. WORK IN PROGRESS:

1. Compilation of a base map (scale 1:10,000) based on aerial photography taken in 1968.
2. Standard glaciological surface measurements are being made to determine the winter accumulation in mid-May and observations of ablation throughout the summer at more than 40 locations.

3. To survey each location for glacier movement, a series of five permanent stations were established about the glacier in 1967, and six more in 1968.
4. A stream gauge was installed in August 1967 and rating curves and stage records obtained during the summer in 1967 and 1968.
5. Meteorological parameters were obtained during the summer at two sites near the glacier terminus and from two mountain and ridge sites in the summer of 1968. Instrumentation consists of short-term recorders installed at 630 m a.s.l., in the summer months including:

Thermohygrograph	Totalizing Anemometer
Barograph	Sunshine Recorder
Simple Precipitation Gauges	

At three locations in the basin one precipitation gauge and three thermohygrographs.

I. FUTURE WORK:

1. Installation of year-round meteorological stations at the glacier terminus.
2. Measurement of glacier depths for selected longitudinal and transverse profiles using a radio-echo sounder.
3. Establishment of a more extensive network of stakes to cover all parts of the glacier.
4. A comprehensive survey of winter snow accumulation at the start of the melt season.

A. PROJECT 7 - Decade Glacier Studies (G-67-13)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division)

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: U.H.O. Embacher.

E. OBJECTIVES: To study the mass, water and energy balance of a small well defined glacier basin in an Arctic environment, in order to determine the role of glaciers in the hydrologic cycle by:

1. Measuring accumulation and ablation.
2. Recording meltwater discharge and meteorological data and
3. Relating glacier variations to recent climatic trends.

The glacier belongs to the world-wide network of glacier basins selected for detailed mass, water and energy balance measurements under the International Hydrological Decade program.

F. LOCATION: Central Baffin Island (69° 38' N, 69° 48' W), 70 km. southwest of Clyde River, N.W. T.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Winter accumulation measurements in May-June of each year since 1965. Summer discharge of meltwater stream measured each year since 1965. During summer of 1965, 1966, 1967 and 1968, meteorological records were kept at campsite, 960 m a.s.l., instrumentation included:

Thermohygrograph	Rain gauge
Anemometer	Barograph

The same instruments were installed at the river gauging site (80 m a.s.l.).

Stakes have been surveyed for movement studies and three profiles were leveled across the glacier to determine changes in surface elevation.

2. References:

Løken, O.H., 1965, 1966, 1967. Field Reports, Central Baffin Island. Department of Energy, Mines and Resources.

Østrem, G., Bridge, C.S. and Rannie, W.F., 1967. Glacio-Hydrology, Discharge and Sediment Transport in the Decade Glacier Area, Baffin Island, N.W.T. Geog. Annaler, v. 49, pp. 268-282.

Decade Glacier, 1965. Base Map (scale 1:10,000) compiled by Surveys and Mapping Branch.

H. WORK IN PROGRESS: Continuation of all glaciological, hydrological and meteorological observations.

I. FUTURE WORK:

1. Installation of long-term meteorological recorders for all year operation.
2. Detailed study of formation of superimposed ice.

A. PROJECT 8 - Per Ardua Glacier Studies (G-67-14)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division)

C. COOPERATING AGENCY: Defence Research Board.

D. PRINCIPAL INVESTIGATOR: U.H.O. Embacher.

E. OBJECTIVES: To investigate the mass and energy balance of a small, well-defined glacier in a high-Arctic environment and study the role of glaciers in the hydrologic cycle by:

1. Measuring accumulation and ablation.
2. Relating glacier variations to recent climatic trends.

The mass balance data are related to surface movement determined each year by terrestrial photogrammetry.

F. LOCATION: At head of Tanquary Fiord, Ellesmere Island (76° 35' W, 81° 32' N) 240 km northeast of Eureka, N.W.T.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Glacier was originally selected by Geophysics Section, Defence Research Board and field work was started in 1964 but taken over by the Glaciology Subdivision in 1968 as an International Hydrological Decade project.

2. Reference:
Hattersley-Smith, G., 1964, 1967. Operation Tanquary preliminary report, D.R.B., D.I.R. PHYS. R.(G) Hazen, pp. 22-25.

H. WORK IN PROGRESS: Continuation of mass balance and movement studies.

I. FUTURE WORK:

1. Installation of instrumentation for summer discharge measurements.
2. Installation of long period recording equipment.
3. Investigation of detailed studies of snow and firn metamorphosis in a high Arctic environment.
4. Measurement of glacier thickness.

A. PROJECT 9 - Parametric Hydrology Peyto Glacier Basin (G-68-4)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division)

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: L. Derikx.

E. OBJECTIVES: To establish a simple, flexible and adequate mathematical prediction model for the runoff of the glacier by determining quantitative and generally applicable relationships between meteorological parameters and runoff.

F. LOCATION: Rocky Mountains (51° 40' N, 116° 34' W), 45 km northwest of Lake Louise, Alta.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Streamflow data have been obtained for Peyto stream since 1966 and meteorological observations have been maintained each summer since 1965 (Project G-67-4). Instrumentation includes thermohygrograph, anemometer, sunshine recorder at 1900 m a.s.l. and a number of precipitation gauges installed on the surface of Peyto Glacier.
2. Office: Establishment of a preliminary mathematical simulation model for glacier discharge. Appropriate physically based melt formulae have been derived. The concept of groundwater system analogue has been tested.
3. Reference:
Derikx, L., 1969. Glacier Discharge Simulation. Paper presented at Symposium of American Water Resources Association, Banff, Alberta.

H. WORK IN PROGRESS:

1. Detailed analysis of physical processes on the snow pack and the glacier.
2. Improvement of the melt formulae and the model.
3. Distribution of incoming shortwave radiation on the glacier surface as controlled by slope, aspect and shadows from surrounding mountains.

I. FUTURE WORK:

1. Development of computer programs to determine sensitivity of the model and transferability to other glaciers.
2. Installation of additional instruments to more accurately measure energy balance.
3. Related to this project and concurrent with it: Determination of relationships between mass balance observations on the glacier at different locations, the physical characteristics of the surface at these locations and the meteorologic variables.

A. PROJECT 10 - Glacier Meltwater Contribution to the Flow of the North Saskatchewan River (G-69-3)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division).

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATORS: H.S. Loijens (on contract)
(O.H. Løken, Supervisor)

E. OBJECTIVES: To develop a parametric hydrologic model for the quantitative assessment of the glacier meltwater contribution to the flow of the North Saskatchewan River at Saskatchewan Crossing.

F. LOCATION: North Saskatchewan River headwaters (52° 45' N, 117° 40' W) Banff National Park, Alta.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Part-year (mainly May-September) streamflow data from gauging stations No. 5DA-6 (North Saskatchewan River) and No. 5DA-7 (Mistaya River). Summer season records of varying periods from 1950.

   Streamflow data Peyto Creek from 1966. Since 1968 recording gauge (Project G-67-4).

   Meteorological data for summer period from Peyto Glacier since 1965 (Project G-67-4).

   Snow accumulation during winter 1968-1969 in Mistaya River drainage basin determined from snow courses arranged in profiles from valley bottom to above the timberline.

2. Reference:
   Collier, E.P., 1957. Glacier variation and trends in runoff in the Canadian Cordillera. I.A.S.H. General Assembly, Toronto, pp. 344-357.

H. WORK IN PROGRESS:

1. Evaluation and analysis of published and unpublished data.
2. Evaluation of project requirements and availability of instruments.

I. FUTURE WORK:

1. Inventory of perennial ice in the basin (Project G-67-15).
2. Analysis of snow melt, glacier melt and groundwater flow of the Mistaya River. Installation of additional meteorological instruments and of a streamflow gauging station on Silverhorn Creek (non-glacierized basin).
3. Analysis of streamflow data of the North Saskatchewan River above the confluence with Mistaya River.
4. Development of model for glacier melt contribution to the flow of the North Saskatchewan River at Saskatchewan Crossing.

A. PROJECT 11 - Determination of Ice Ablation By Terrestrial Photogrammety (G-67-16)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH (Hydrologic Sciences Division)

C. COOPERATING AGENCY: McGill University.

D. PRINCIPAL INVESTIGATOR: K.C. Arnold.

E. OBJECTIVES: To measure ice ablation by photogrammetric methods which have an accuracy of approximately ± 10 cm in order to:

1. Examine criteria by which ablation stakes should be distributed over a surface with respect to parameters that influence ablation, with special reference to albedo.
2. Develop an economic data gathering system.
3. Examine some criteria by which benchmark glaciers may be selected, with special reference to those in Arctic Canada.

F. LOCATION: White Glacier, Axel Heiberg Island (79° 28' N, 90° 45' W), N.W.T.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Terrestrial photography of Peyto Glacier, Alberta, in 1966, 1967 and 1968.

   Terrestrial photography of Per Ardua Glacier, Ellesmere Island, 1964, (Faig, University of New Brunswick), 1966, (September), 1967, (June and September), and 1968, (close of season).

   Meighen Ice Cap, aerial photography, 1960, and photogrammetric baseline established near north tongue, 1968.

2. References:

Arnold, K.C., 1966. The glaciological maps of Meighen Island, N.W.T. Canadian Journal of Earth Sciences, v. 3, no. 6, pp. 903-908.

Arnold, K.C., 1968. Determination of changes of surface height, 1957-1967, of the Gilman Glacier, Northern Ellesmere Island, Canada. M.Sc. thesis, McGill University, 74 p.

Weber, J.R., Sandstrom and Arnold, K.C., 1960. Geophysical surveys on Gilman Glacier, Northern Ellesmere Island, N.W.T. I.A.S.H., Publication 54, pp. 500-511.

H. WORK IN PROGRESS:

1. Terrestrial photogrammetry is presently used, but other techniques of remote sensing, e.g., aerial photography, may be used later.
2. Search of the literature for similar studies and establishment of a conceptual model.

3. A detailed field program to test the technique has been developed and was carried out on White Glacier, Axel Heiberg during the 1969 summer. The lower part of the glacier, below 500 m, was photographed three times in conjunction with standard ablation measurements on stakes and ice velocity data obtained by members of the Axel Heiberg Expedition. The ablation values in 1969 were below normal, and this, together with the relatively smaller mass flux typical of Arctic glaciers, should make this a critical test case.

I. FUTURE WORK:

1. Extension of the methods developed in the accumulation areas of glaciers and ice caps, where stereo-perception is more difficult, will be attempted.
2. Alternative methods of data collection in the accumulation areas of glaciers will be examined.
3. Adaption of the techniques developed to include air photogrammetry.

A. PROJECT 12 - Measurement of the Average Annual Loss of Ice by Melting of a Glacier

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH - (Water Survey of Canada)
POLAR CONTINENTAL SHELF PROJECT.

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATORS: I.A. Reid, W.S.B. Paterson.

E. OBJECTIVES: To study methods of determining the contribution of melted glacier ice to streamflow, other than by mass balance measurements.

F. LOCATION: Athabasca Glacier, Alberta (52° 12' N, 117° 15' W).

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Since 1948, surveys of the changes in the glacier and of the flow of the outlet stream by the Water Survey of Canada together with research by many persons on the flow and thickness changes of the glacier tongue, have provided information for checking the validity of the methods.

2. References:
Reid, I.A., and Paterson, W.S.B., 1969. A simple method of measuring the average amount of water produced annually by melting of ice on a glacier. Paper presented at Symposium of Hydrology of Glaciers, Cambridge.

H. WORK IN PROGRESS: Analysis of (1) the relationship of the amount of ice flowing through the glacier cross-section at the equilibrium line (equal to annual ablation in a steady state glacier) to the horizontal component of surface velocity; and (2) the relationship of the vertical component of velocity in the ablation area to the annual loss of ice.

This work has now been completed.

A. PROJECT 13 - Drainage Beneath the Salmon Glacier-Hydrologic Studies, Summit Lake (G-67-19)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH (Hydrologic Sciences Division)

C. COOPERATING AGENCY: U.S. Water Resources Group, Alaska.

D. PRINCIPAL INVESTIGATOR: D. Fisher.

E. OBJECTIVES:

1. To determine the causes of sudden and catastrophic emptying (Jokulhaup) of glacier dammed lakes using Summit Lake as an example.
2. To determine what action should be taken to prevent catastrophic discharges, and with a view to reducing the danger of flooding and accompanying risk of loss of life in addition to extensive economic damage such as happened downvalley from Summit Lake in 1961 and 1965.

F. LOCATION: Salmon Glacier, B.C. (56° 12' N, 130° 04' W).

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Three rows of movement stakes on the Salmon Glacier were surveyed to detect any anomalous glacier movement associated with the discharge in mid-Setpember 1967.

   Detailed observation of Summit Lake were made to determine rate of discharge beneath Salmon Glacier during the Jokulhaup.

   During the summer of 1968, a fluorescent dye method was used to determine if there was a continual leak under Salmon Glacier, and to estimate the size of any such leak.

   Aerial photography of the partly emptied lake was flown during summer 1968 to give an accurate value of the volume of the lake.

2. Reference:
   Fisher, D., 1969. Subglacial Leakage of Summit Lake, British Columbia, presented at Symposium on the Hydrology of Glaciers, Cambridge, England.

H. WORK IN PROGRESS: Further tests with fluorescent dye will be made in 1969 at a stage when the lake is filling.

I. FUTURE WORK: Evaluation of data and writing of report.

A. PROJECT 14 - Resistivity Measurements to Detect Melt Water (WS-68-6)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH (Hydrologic Sciences Division)

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: R.H. Goodman.

E. OBJECTIVES: To determine the distribution and movement of meltwater through a glacier.

F. LOCATION: Peyto Glacier, Alberta.

G. PREVIOUS WORK ON THIS PROJECT: Probes were mounted during 1968 in a hexagonal pattern at three sites on Peyto Glacier.

H. WORK IN PROGRESS: Resistance measurements indicate a resistance of greater than 10^7 ohm-cm. The present equipment cannot measure greater resistance.

I. FUTURE WORK:

1. A new high resistance measuring system will have to be developed.
2. A continuous recording magnetic tape logging facility has been ordered.

A. PROJECT 15 - Moisture Flux in the Snow Pack - Soil System (G-69-8 & GW-69-2)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division)

C. COOPERATING AGENCY: Department of Fisheries & Forestry (Central Experimental Forest)

D. PRINCIPAL INVESTIGATORS: L. Derikx and R. Harlan.

E. OBJECTIVES: To study the moisture flux in the snow pack - soil system during the period of snow cover, and to develop a physical model of the processes involved.

F. LOCATION: Mer Bleue, near Ottawa, Ont.

G. PREVIOUS WORK ON THIS PROJECT: None.

H. WORK IN PROGRESS: Planning and installation of instrumentation before winter of 1969-70.

A. PROJECT 16 - Baffin Island Climatology (G-67-12)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH (Hydrologic Sciences Division)

C. COOPERATING AGENCIES: Geological Survey of Canada and University of Colorado.

D. PRINCIPAL INVESTIGATOR: S. Fogarasi.

E. OBJECTIVES: To develop a physical model that will relate the mass balance parameters of local glaciers to the atmospheric circulation over Baffin Island and thus establish an important link in the hydrologic cycle by:

1. Studying the relationship between the atmospheric circulation types and their related precipitation and water balance patterns and of the structure of the upper atmosphere.
2. Studying in detail the typical days in the 1968 summer when precipitation fell over the Baffin Island.

F. LOCATION: Ottawa, Ont.

G. PREVIOUS WORK ON THIS PROJECT:

1. Office: Detailed studies of the distribution and flux of atmospheric moisture have been made for the period 1961-1965.

2. References:
Barry, R.G., 1966. Meteorological aspects of the glacial history of Labrador-Ungava with special reference to atmospheric vapour transport. Geog. Bull., v. 8, no. 4, pp. 319-340.

Barry, R.G., 1967. North-Central Baffin Island Field Report 1967, Inland Waters Branch, Report Series no. 2, pp. 103-135.

Barry, R.G., 1967. Seasonal location of the Arctic front over North America. Geog. Bull., v. 9, no. 2, pp. 79-95.

Barry, R.G. and Fogarasi, S., 1968. Climatological Studies, Baffin Island, Inland Waters Branch, Technical Bulletin No. 13, 106 pp.

H. WORK IN PROGRESS:

1. Horizontal moisture flux, divergence and total vertical velocity is calculated for several levels of the atmosphere on typical days per weather type when precipitation falls. The orographic effect and the role of friction in the lower boundary layer will be isolated to determine its role in the precipitation and circulation.

2. Atmospheric water balance components, precipitation and evaporation will be estimated over unaccessible areas along a grid-point network.
3. Computer processing of weather type classification for period 1961-1965 and preparation of report.

I. FUTURE WORK:

1. New weather stations on and near the Barnes Ice Cap will be equipped with automatic recorders, thus allowing all-year operation for more detailed observations to be recorded.
2. Analysis for the 1961-1965 period will be extended to cover the period when mass balance observations are made in order to study the glacier climate relationship.
3. Results of the climatological studies will be related to mass balance observations in order to develop a physically based model.
4. Atmospheric energy budget for the 1961-1965 period will be studied on a synoptic scale.

A. PROJECT 17 - Glacier Climate Relationship on the Devon Island Ice Cap (G-69-4)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH (Hydrologic Sciences Division)

C. COOPERATING AGENCIES: Arctic Institute of North America, McGill University and Polar Continental Shelf Project.

D. PRINCIPAL INVESTIGATOR: O.H. Løken - work done under contract with A.I.N.A.

E. OBJECTIVES: To study the relationship between glacier variation and meso-scale synoptic weather patterns over the area. Particular emphasis is given to the contrasts between the southeast and northwest sides of the ice cap.

F. LOCATION: Devon Island Ice Cap (82° W, 75° N), Devon Island, N.W.T.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Reconnaissance field work done in 1968; previous to that glaciological studies had been done intermittently since 1961 by several investigators sponsored by the Arctic Institute of North America.

2. References:

Braithwaite, R.J., 1969. Glacier Climate Studies on the Devon Island Ice Cap, N.W.T., 1968. Report for Department of Energy, Mines & Resources, 17 p.

Koerner, R.M., 1966. Snow accumulation on the Devon Island Ice Cap, N.W.T., Canada. Journal of Glaciology, v. 6, no. 45, pp. 383-392.

Koerner, R.M., 1966. Mass balance of the Devon Island Ice Cap, N.W.T., Canada. Thesis submitted for the degree of Ph.D., University of London. Also submitted as reports to the Arctic Institute of North America and the Defence Research Board of Canada.

Koerner, R.M. Some observations on the superimposition of ice on the Devon Island Ice Cap, N.W.T., Canada. Geografiska Annaler (in press).

Koerner, R.M. Notes entitled 'The Devon Island Expedition', in Arctic, v. 14, no. 4, 1961; v. 16, no. 1, 1963; v. 19, no. 2, 1966; v. 20, no. 1, 1967; v. 22, no. 2, 1969.

H. WORK IN PROGRESS:

1. Mass balance is being measured at stakes on southeast and northwest sides of ice cap.

2. Meteorological data is being collected from two sites, one on top of the ice cap, and the other on the southeast slope.

FUTURE WORK:

1. Continuation of field observations for three more years.
2. Installation of long-term meteorological recorders for all-year operation.
3. Relating mass balance parameters to the shifting sea ice distribution on the adjacent ocean.
4. Measuring flow rates of outlet glaciers in order to assess the rate of iceberg production from the ice cap.

A. PROJECT 18 - Energy Balance and Meteorology of Meighen Icecap

B. PRINCIPAL AGENCY: Polar Continental Shelf Project.

C. COOPERATING AGENCIES: McGill University (Prof. S. Orvig); National Research Council and Department of Transport (Meteorological Branch).

D. PRINCIPAL INVESTIGATOR: Beatrice Barge.

E. OBJECTIVES: To study the energy balance and meso-scale meteorology of a small arctic ice cap and the surrounding area, and to relate this to the seasonal and longer-term changes in the ice cap.

F. LOCATION: Meighen Island, N.W.T. (80° N., 99° W).

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Weather observations have been made on Meighen Icecap each summer from 1959 to 1962, and mass balance measurements annually from 1959-60.

   A micro- and meso-climatological study of the effects of the ice and land surfaces on the temperature of the lower layers of the atmosphere was made in 1961 and 1962, using data collected around the margins of the ice cap.

   The temperature profile from the borehole and the fabric analysis of the core have provided information on the heat content and long-term temperature trend of the ice cap.

   Field observations on this project were started in 1968. Two meteorological stations were established, and three-hourly synoptic observations taken from early June to early September.

2. References:
   Stebelsky, I.A., 1962. A micro-climatological study in the Canadian Arctic. B.A. Thesis, University of Toronto.

   Arnold, K.C. 1965. Aspects of the glaciology of Meighen Island, Northwest Territories, Canada, Journal of Glaciology, vol. 5, no. 40, pp. 399-410.

   MacKay, D.K. and Arnold, K.C., 1965. Access to Meighen Island, N.W.T., Arctic, vol. 18, no. 3, pp. 193-198.

H. WORK IN PROGRESS: Meteorological observations are continuing. Three-hourly synoptic observations are being taken at a station near the summit of the ice cap (241 m a.s.l.) and also on ice-free land north of the ice cap (78 m a.s.l.), with subsidiary radiation and micro-meteorological observations at other locations.

I. FUTURE WORK: The project will continue through the 1970 season. The work done to date indicates the desirability of including upper-air measurements, and obtaining data in the winter by means of automatic equipment; provision for these will be made for 1970 if possible.

A. PROJECT 19 - Mass Balance and Flow of the Melville Island Ice Caps.

B. PRINCIPAL AGENCY: Polar Continental Shelf Project.

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATORS: W.S.B. Paterson, F.P. Hunt.

E. OBJECTIVES: To measure the mass balance and study the ice flow of four small ice caps on Melville Island, the westernmost glaciers in the Canadian Arctic Islands.

F. LOCATION: Melville Island, N.W.T. (Lat. 75° 30' N., Long. 115° W.)

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Mass balance measurements have been made each year since 1963 (Paterson).

   Ground surveys for detailed topographic control and for determining ice movement were made in 1963 and 1966 (F.P. Hunt).

   A detailed gravity survey allowing estimation of ice thickness was carried out in 1963 (Spector).

2. References:
   The investigations and mass balance measurements have been summarized annually since 1962 in the Canadian Geophysical Bulletin vol. 15, pp. 100-101; vol. 16, p. 120; vol. 17, pp. 130-131; vol. 18, p. 139; vol. 19, p.148; vol. 20, p.185; vol. 21, p.219.

   Spector, A. A gravity survey of the Melville Island Ice Caps, Journal of Glaciology, vol. 45, pp. 393-400.

H. WORK IN PROGRESS: Mass balance measurements are continuing. Low-level aerial photography, with ground control targets at surveyed positions to allow detailed photogrammetric interpretation of the gently sloping surface is planned for 1969. This work has been prepared for but has not been possible in each of the past three summers because of the amount of snow on the ice caps throughout the summer.

I. FUTURE WORK: The study is continuing.

A. PROJECT 20 - Mass balance and ice flow in the Meighen Ice Cap.

B. PRINCIPAL AGENCY: Polar Continental Shelf Project.

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: W.S.B. Paterson.

E. OBJECTIVES: To study the mass balance, ice flow, temperature and history of a small arctic ice cap.

F. LOCATION: Meighen Island, N.W.T. (80° N., 99° W.).

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Accumulation and ablation have been measured annually since 1959.

   Surveys for mapping purposes and for determining ice movement were made in 1959, 1960, 1961, and 1964.

   A gravity survey to determine ice thickness was carried out in 1959 and 1960.

   Preliminary seismic reflection studies to determine the ice-rock surface were undertaken in 1960.

   A botanical study made in 1960 of the ice-free land around the margins of the ice cap provided information on the history of the ice cap.

   Low-level aerial photography of the ice cap was taken by the Royal Canadian Air Force in 1960, and topographic maps of Meighen Ice Cap (scale 1:25,000) and Meighen Island (scale 1:50,000) were produced by the Surveys and Mapping Branch.

   A borehole, with complete core, was drilled through the ice cap at its thickest point in 1965, and temperature and closure measurements have been obtained in the hole since that time.

2. References:
   Mass balance measurements are published annually in the Canadian Geophysical Bulletin, as follows:

Vol. 13 (1960) pp. 88-90	Vol. 17 (1964) p. 131
Vol. 14 (1961) pp. 96-97	Vol. 18 (1965) p. 139
Vol. 15 (1962) p. 101	Vol. 19 (1966) pp. 148-149
Vol. 16 (1963) p. 120	Vol. 20 (1967) p. 186
	Vol. 21 (1968) pp. 219-220

Savile, D.B.O. 1961. The botany of the northwestern Queen Elizabeth Islands, Canadian Journal of Botany, vol. 39, no. 4, pp. 909-942.

Arnold, K.C. 1965. Aspects of the glaciology of Meighen Island, Northwest Territories, Canada. Journal of Glaciology, vol. 5, no. 40, pp. 399-410.

Arnold, K.C. 1966. The Glaciological maps of Meighen Island, N.W.T., Canadian Journal of Earth Sciences, vol. 3, no. 6, pp. 903-904.

Paterson, W.S.B. 1968. A temperature profile through the Meighen Ice Cap, Arctic Canada. International Association of Scientific Hydrology, Publication 79, pp. 440-449.

Paterson, W.S.B., 1969. Accumulation and ablation on the Meighen Ice Cap, Arctic Canada, Journal of Glaciology (in press).

Surveys and Mapping Branch, 1965. Maps, Meighen Island North half and Meighen Island South half, scale 1:50,000; and Meighen Ice Cap, scale 1:25,000.

H. WORK IN PROGRESS: Mass balance measurements, measurements of the temperature profile in the borehole, and closure of the borehole continue. In 1969 the borehole was still open to the bottom to admit the temperature measuring equipment, but the lower part had closed sufficiently through flowage to prevent closure-measuring instruments from penetrating to the bottom.

I. FUTURE WORK: The study is continuing, with the ultimate objective of determining the flow law of ice in the temperature range of this ice cap.

A. PROJECT 21 - Barnes Ice Cap Studies (G-67-11)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division).

C. COOPERATING AGENCY: Surveys and Mapping Branch.

D. PRINCIPAL INVESTIGATOR: G. Holdsworth.

E. OBJECTIVES: Measurements will be continued on the Barnes Ice Cap as part of a long-term survey begun in 1962 by Løken (1965, 1966 and 1967). Local investigations at and near the margins of the ice cap will be made to study the mode of flow of the marginal ice and the processes occurring there. Later, deeper information will be obtained by drilling.

F. LOCATION: Baffin Island, N.W.T. (73°W, 70°N).

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: The first glaciological investigations of the Barnes Ice Cap were made by the Arctic Institute Expedition in 1950 (Baird 1950). In 1962, studies of mass balance, glacier meteorology, the hydrology of a meltwater stream and terminal moraines were started on the northern part of the ice cap. Present program is an expansion of the original program to cover the whole ice cap and to give increased emphasis to glaciological aspects.

2. References:

Anonymous, 1967. Hydrology of the Lewis Glacier, Geog. Bull., v. 9, no. 3, pp. 232-261.

Baird, P.D., 1950. Baffin Island Expedition 1950, a preliminary report, Arctic, v. 3, no. 3, pp. 131-149.

Church, M., 1967. Observations of turbulent diffusion in a natural channel. Canadian Journal of Earth Sciences, v. 4, no. 5, pp. 855, 872.

Løken, O.H., 1965, 1966 and 1967. Field Reports, Central Baffin Island, Department of Energy, Mines and Resources.

Løken, O.H., and Andrews, J.T., 1966. Glaciology and Chronology of Fluctuations of the Ice Margin at the South End of the Barnes Ice Cap, Baffin Island, N.W.T., Geog. Bull., v. 8, no. 4, pp. 341-349.

Løken, O.H., and Sagar, R.B., 1968. Mass Balance Observations on the Barnes Ice Cap, Baffin Island, Canada. International Association of Scientific Hydrology General Assembly, Bern, 1967. Publication no. 79, pp. 282-291.

H. WORK IN PROGRESS:

1. Annual mass balance is measured at more than 200 stakes in May-June of each year.
2. The surface form of the ice cap is studied on the basis of detailed topographical maps.
3. Ice depth measurements are made by radio-echo sounding techniques.
4. Surface movement and surface strain rate are measured on the southern part of the ice cap. Surface movement is related to the characteristics of the ice margin. Factors controlling the type of margin and hence the marginal mode of flow are to be elucidated. One or two localities to begin with will undergo intensive study.
5. Temperatures at 10 m. depth in the ice cap are measured by quartz thermometer.
6. Glacier-climate relationships are investigated under the Baffin Island Climatology project.

I. FUTURE WORK:

1. Drill hole through the ice cap is planned for summer 1970 and associated core and bore hole investigations will start when the hole is completed.
2. Studies of shear moraines by trenching through the moraines and drilling are being expanded to study structure and temperature of the ice cap behind the moraines.
3. Internal temperature distribution is to be studied in additional deep and shallow drill holes.
4. Accumulation of data (temperature, deformation) to enable generalized flow laws to be determined for the ice cap.
5. Investigation of surface instabilities including crevasses and undulations near the margins of the ice cap.

A. PROJECT 22 - Penny Ice Cap Studies.

B. PRINCIPAL AGENCY: Observatories Branch.

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: J.R. Weber.

E. OBJECTIVES: To study the long term variations of the Penny Ice Cap by observing, at intervals from three to five years, thickness changes, surface flow, and mass balance parameters along a NE - SW profile across the crest of the icecap. The ice thickness change is determined by deriving the change in surface elevation from the observed change in gravity.

F. LOCATION: Penny Ice Cap, Baffin Island, near 67° 15' N, 66° W.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: In 1962, stakes were permanently drilled into the ice across the crest of the ice cap and referenced to rock markers on both sides of the ice cap. Gravity differences between the stakes and a rock outcrop were measured. These measurements were repeated in 1965 and 1966, and an observed decrease in gravity corresponded closely to the observed increase in surface elevation, thus confirming the validity of the gravimetric method for determining elevation changes.

2. References:
Weber, J.R., 1967. A gravimetric determination of the vertical ice movement of the Penny Ice Cap, Baffin Island. Paper presented at the meeting of the I.U.G.G. in Berne, Switzerland.

Weber, J.R., and Andrieux, P., 1969. Radar Soundings on the Penny Ice Cap, Baffin Island. Journal of Glaciology (in press).

H. WORK IN PROGRESS: None in 1969.

I. FUTURE WORK: Resurvey of the stakes to determine relative movement, change in elevation as measured by gravimetric means, and mass balance parameters will be made at intervals of several years. The next resurvey is planned for 1970.

A. PROJECT 23 - Computer Modeling of Glacier Flow (WS-69-1).

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division).

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: R.H. Goodman.

E. OBJECTIVES: To predict glacier flow on the basis of laboratory-measured values of the mechanical properties of ice.

F. LOCATION: Ottawa, Ontario.

G. PREVIOUS WORK ON THIS PROJECT:

Reference:
Campbell, W.J. and Rasmussen, L.A. Heuristic Numerical Model for 3-dimensional time dependent glacial flow. Canadian Journal of Earth Sciences (in press).

H. WORK IN PROGRESS:

1. Initial differential equations have been studied and the Navier-Stokes equation analysed.
2. Suitable characteristic boundary conditions have been considered.

I. FUTURE WORK: Computer programs for numerical evaluation of the equation will be developed and then applied to a real glacier.

A. PROJECT 24 - The Mechanics of Flow of a Temperate Glacier

B. PRINCIPAL AGENCY: Polar Continental Shelf Project.

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: W.S.B. Paterson.

E. OBJECTIVES: To analyse the physical nature of flow of a glacier near its pressure-melting point.

F. LOCATION: Athabasca Glacier, Alberta, (52° 12' N., 117° 15' W).

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: This study of the surface and internal movement of Athabasca glacier has been underway since 1959. Temperature measurements at depth, and gravity and seismic surveys of the glacier bed, have contributed additional data.

2. References:

Paterson, W.S.B., and Savage, J.C. 1963. Geometry and movement of the Athabasca Glacier. Journal of Geophysical Research, vol. 68, no. 15, pp. 4513-4520.

Paterson, W.S.B., and Savage, J.C. 1963. Measurements on the Athabasca Glacier relating to the flow law of ice. Journal of Geophysical Research, vol. 68, no. 15, pp. 4537-4543.

Paterson, W.S.B. 1964. Variations in velocity of Athabasca Glacier with time. Journal of Glaciology, vol. 5, no. 39, pp. 277-285.

Meier, M.F. 1965. Comments on Paterson's paper 'Variations in velocity of Athabasca Glacier with time'. Journal of Glaciology vol. 5, no. 41, pp. 761-762 (see also reply by Paterson, Journal of Glaciology, vol. 5, no. 42, pp. 875-876).

Paterson, W.S.B. The sliding velocity of Athabasca Glacier. Journal of Glaciology (in press).

Paterson, W.S.B. 1969. The Physics of Glaciers. Permagon Press, Oxford, 245 pp. (to be released in August 1969).

H. WORK IN PROGRESS: The quantitative physical relationships between the flow of the glacier and its physical and geometrical characteristics are being analysed, using the field observations now available.

I. FUTURE WORK: The mathematical and theoretical analysis is continuing.

A. PROJECT 25 - Temperature-Depth Relations in Athabasca Glacier.

B. PRINCIPAL AGENCY: Polar Continental Shelf Project.

C. COOPERATING AGENCY: University of Toronto, (Department of Physics).

D. PRINCIPAL INVESTIGATOR: W.S.B. Paterson.

E. OBJECTIVES: To measure the variation of temperature with depth in a near-temperate glacier, (i.e. with temperature near the pressure-melting point).

F. LOCATION: Athabasca Glacier, Alberta (52° 12' N., 117° 15' W).

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: This study has obtained measurements of temperature in boreholes in the Athabasca glacier since 1960 (first useful temperature data 1961).

2. References:
Paterson, W.S.B., and Savage, J.C. 1963. Measurements on the Athabasca Glacier relating to the flow law of ice. Journal of Geophysical Research, vol. 68, no. 15, pp. 4537-4543.

Savage, J. C., and Paterson, W.S.B. 1963. Borehole measurements in the Athabasca Glacier, Journal of Geophysical Research, vol. 68, no. 15, pp. 4521-4536.

Paterson, W.S.B., and Savage, J.C. Excess Pressure observed in a water-filled cavity in Athabasca Glacier. Journal of Glaciology (in press).

H. WORK IN PROGRESS: The temperature in boreholes in the glacier tongue is being measured, completing ten years of observation of the temperature distribution in three dimensions.

I. FUTURE WORK: A decision as to whether the temperature measurements should be continued after 1969 will be made after the present data have been analysed.

A. PROJECT 26 - Investigation of Surface Instabilities on Glaciers (G-69-11)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division).

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: G. Holdsworth.

E. OBJECTIVES: To plot the distribution and geometry of surface instabilities on selected glaciers, as expressed by crevasses and compression waves, and relate these to the flow of the ice mass in response to particular stress conditions. The relationship between surface instabilities and general glacier instabilities will be investigated.

F. LOCATIONS: Selected parts of Barnes Ice Cap and other glaciers on Baffin Island, N.W.T.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Studies of crevasses as separate structures have been made and it is contended that many reports of surface waves have been misinterpreted, as they are not connected with instability conditions.

2. References:
Holdsworth, G., 1969. Primary Transverse Crevasses, Journal of Glaciology, v. 8, no. 53, pp. 107-129.

Holdsworth, G., Surface instability of ice and compression wave formation (in press).

H. WORK IN PROGRESS: Field work (August 1969) will provide a basis for a preliminary report. Other work will be done photogrammetrically at a later date.

I. FUTURE WORK: Detailed measurements at selected points on several glaciers will be made. On the basis of photo-scanning, additional glaciers will be selected for study in order to investigate further theories relating to glacier instabilities.

A. PROJECT 27 - Glacier Surges (G-67-7).

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division).

C. COOPERATING AGENCY: Surveys and Mapping Branch; Polar Continental Shelf Project; Icefield Ranges Research Project, (Arctic Institute and American Geological Society).

D. PRINCIPAL INVESTIGATOR: A. D. Stanley.

E. OBJECTIVES: To obtain information on glacier surges from maps, air photos, description of surges, etc. to evaluate existing theories as to their causes.

F. LOCATION: Ottawa, and Steele and 'Fox' glaciers, Icefield Ranges, Yukon.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: An extensive photographic record of Steele Glacier is available due to the effort of Dr. W. Wood, Icefield Ranges Research Project, Working Group on Steele Glacier and others who have worked in the area since the 1920's.

   In the summers of 1967 and 1968, the Glaciology Subdivision measured the meltwater discharge of the glacier basin. 'Fox' Glacier is considered to be in a pre-surge condition.

2. Office: Participation in the Working Group established to coordinate map requirements.

3. References:
   Faber, T., 1969. 'Fox' Glacier basin, Yukon Territory, Canada. Results of the 1968 hydrological field work. Paper presented at the Symposium on Hydrology of Glaciers, Cambridge, England.

   Stanley, A.D., 1969. Observations of the Surge of Steele Glacier, Yukon Territory, Canada. Canadian Journal of Earth Sciences (in press).

H. WORK IN PROGRESS: Preparation of reports on the development of surface features during a glacier surge.

I. FUTURE WORK:

1. In cooperation with other groups - to obtain further information on the final stages of the surge - including aerial photographs and surface measurements.
2. Measurement of ice depths along the longitudinal profile, using a radio echo sounding unit.
3. Measurement of the stream discharge from the Fox Glacier basin during the 'anticipated' surge.

A. PROJECT 28 - The Cause and Mechanics of Glacier Surges.

B. PRINCIPAL AGENCY: Polar Continental Shelf Project.

C. COOPERATING AGENCY: Working Group on Steele Glacier.

D. PRINCIPAL INVESTIGATOR: W.S.B. Paterson.

E. OBJECTIVES: To study the movement of a glacier prior to and during a surge; to relate this to temperature distribution, ice fabric, and conditions of the bed.

F. LOCATION: Steele Glacier, Yukon (61° 15' N., 140° 10' W.); Otto Fiord Glacier (81° 20' N., 84° W.) and, as opportunity arises, other glaciers subject to surging.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Studies of Athabasca, Meighen and other glaciers have provided information on the physics of flow of non-surging glaciers under a range of physical and geometrical conditions. These studies provide an essential background to the investigations of surges.

   The maps resulting from the activities of the Working Group on Steele Glacier should provide three-dimensional changes in a glacier during a surge, the first data of sufficient accuracy to allow quantitative calculations of the energy and mass transfers involved in surging.

2. References:

Paterson, W.S.B. 1964. Variations in velocity of Athabasca Glacier with time. Journal of Glaciology, vol. 5, no. 39, pp. 277-285.

Paterson, W.S.B. 1968. A temperature profile through the Meighen Ice Cap, Arctic Canada. International Association of Scientific Hydrology, Publication 79, pp. 440-449.

Paterson, W.S.B. 1968. Glacier Surges. Canadian Alpine Journal, vol. 51, pp. 220-223.

Paterson, W.S.B. 1969. The Physics of Glaciers. Permagon Press, Oxford, 245 pp. (to be released August 1969).

H. WORK IN PROGRESS:

1. The maps of Steele Glacier are being compiled and checked for accuracy in connection with volumetric studies.

2. Under way is a theoretical analysis of the mechanism by which a glacier slides over its bed, and of the way in which water is stored and flows within and beneath a glacier.

I. FUTURE WORK:

1. Temperature measurements and fabric analyses at different depths will be made in recently surged glaciers, preferably in a surged glacier whose bed is above the pressure melting point but also in one whose bed is below the pressure melting point.

2. Direct measurements of the roughness of the glacier bed will be attempted.

A. PROJECT 29 - Mapping the 1965-68 Surge of Steele Glacier.

B. PRINCIPAL AGENCY: Departmental Working Group on Steele Glacier (Comprising Surveys and Mapping Branch, Polar Continental Shelf Project, Inland Waters Branch, and reporting to the Working Group on Steele Glacier of the NRC Sub-Committee on Glaciers).

C. COOPERATING AGENCIES: Icefield Ranges Research Project (AINA-AGS); National Research Council (Sub-Committee on Glaciers); Defence Research Board, Army Survey Establishment, R.C.E.; Water Survey of Canada.

D. PRINCIPAL INVESTIGATOR: W.S.B. Paterson (as Chairman of both Working Groups).

E. OBJECTIVES: To determine the map requirements of various researchers engaged in study or analysis of the 1965-68 surge of Steele Glacier; to prepare a plan for photography, ground control, compilation and cartography of the maps that will best meet those requirements; and to arrange for and oversee the necessary surveys, photogrammetry, and map production.

F. LOCATION: Ottawa, with field operations as required at Steele Glacier, Yukon, (61° 15' N., 140° 10' W.).

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Surveys of Steele Glacier with topographic control and terrestrial photography have been made at intervals since 1935, and give a useful record of the pre-surge behaviour of the glacier. Many of the control points used in the early surveys can be used as references for present and future maps.

   Aerial photographs of the glacier taken in 1951 and 1959 show the pre-surge condition; those obtained in 1964 show the initiation of the surge.

   Under this project, complete vertical photography was taken in August 1966, September 1966, and August 1967. Oblique aerial photography of selected parts of the glacier was taken at roughly monthly intervals during the 1966-67 winter and in spring 1968. Ground control points were established and surveyed in 1967.

   The surge ended in 1968.

2. References:
   Paterson, W.S.B., 1966. Test of contour accuracy on a photogrammetric map of Athabasca glacier. Can. Journal of Earth Sciences, vol. 3, no. 6, pp. 909-915.

Roots, E.F. 1967. Yukon Centennial Projects - a variety of survey problems. Canadian Surveyor, vol. 21, no. 3, pp. 250-259.

Surveys and Mapping Branch. The following maps showing Steele Glacier have been produced under this project:

Date map produced	Date of glacier condition	Scale	Contour Interval
1967	1951	1:125,000	500 ft.
1967	1951	1:50,000	50 m.
1967	Aug. 1966 (provisional map)	1:25,000	20 m.
1968	Sept. 1966 (provisional map)	1:25,000	20 m.
1968	August 1967	1:25,000	20 m.

H. WORK IN PROGRESS: The post-surge aerial photography will be flown in August 1969 if weather and snow conditions permit. Ground control targets are being placed on and around the glacier by the Icefield Ranges Research Project.

Revised versions of the 1:25,000 maps of the glacier in August 1966, and September 1966, and new 1:25,000 maps of the glacier in 1951, are being produced.

I. FUTURE WORK: A map of the glacier (scale 1:25,000 and contour interval 20 meters) will be produced in its post-surge conditions (based on 1969 photography, if successful).

The 1:25,000 scale maps referred to above are working "glaciologists" maps; they are not designed for the general public or for illustrative purposes. In view of the wide interest in Steele Glacier and the unique documentary material available, consideration is being given to producing a composite glacier map which would show the extent and nature of the surge in a form suitable for the general public.

A. PROJECT 30 - Glacier Inventory (G-67-15).

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division).

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: C.S.L. Ommanney.

E. OBJECTIVES:

1. To prepare an inventory of perennial ice and snow masses on and beneath the land surfaces as part of the Canadian IHD program.
2. To develop computer programs for the storage, analysis and reduction of inventory data.
3. To investigate on the basis of the collected data the factors that influence the geographical distribution and types of ice masses and the role of perennial ice in the Canadian water balance.

F. LOCATION: Ottawa, Ontario.

G. PREVIOUS WORK ON THIS PROJECT:

1. Office: Two pilot studies were made for a manual on the inventory produced by a working group under the Chairmanship of Dr. Fritx Müller of McGill University. The Glacier inventory of Axel Heiberg Island has been completed.

   A computer program for obtaining totals, averages, weighted averages and histograms from the basic inventory data has been developed.

2. References:

Müller, F., Ommanney, C.S.L., and Stanley, A.D., 1967. Three Pilot Studies for the IHD World Inventory of Glaciers. Paper presented at the International Association of Scientific Hydrology General Assembly, Bern, 1967.

Ommanney, C.S.L., 1968. An Assessment of the Ice Masses of Axel Heiberg Island, N.W.T.: a study in glacier inventory. M.Sc. thesis, McGill University, 183 pp.

Ommanney, C.S.L., Goodman, R.H. and Müller, F., 1969. Computer Analysis of a Glacier Inventory of Axel Heiberg Island: Canadian Arctic Archipelago. Bulletin of the International Association of Scientific Hydrology, XIV, 1, pp. 19-28.

Ommanney, C.S.L., 1969. Glaciers of the High Arctic. Pilot Study for Guide to World Inventory of Perennial Ice and Snow Masses On and Beneath the Land Surfaces. Report of the I.C.S.I. Working Group, IHD Resolution I-12 partial, I.A.S.H., I.U.G.G., Appendix I, to be published by U.N.E.S.C.O., (in press).

Stanley, A.D., (in press). Glaciers of the Rocky Mountains. Pilot Study for Guide to World Inventory of Perennial Ice and Snow Masses On and Beneath the Land Surfaces. Report of the I.C.S.I. Working Group, IHD Resolution I-12 partial, I.A.S.H., I.U.G.G., Appendix II, to be published by U.N.E.S.C.O., 1969.

H. WORK IN PROGRESS:

1. Data sheets for every glacier on Baffin and Bylot Islands are being compiled with information on location, orientation and photo coverage as a basis for subsequent more detailed studies.
2. New routines are being developed in the computer programs for card input, analysis output, editing and the addition of new data.
3. A report on the glacier inventory of Axel Heiberg Island and a manual for glacier inventory studies in Canada are in preparation.

I. FUTURE WORK:

1. Short-term: To complete the glacier inventory of all glacierized areas in Canada mapped at a scale of 1:50,000 or better.

   To compile data sheets for all glaciers in Canada showing orientation, location and existing photo coverage, in conjunction with Projects G-69-1 and G-69-2.

   Further testing and modifications to existing computer programs.

2. Long-term: Completion of all glacier inventory measurements for the remaining glacierized areas.

   Publication of detailed glacier inventory reports in line with approved international standards.

   Refinement of computer programs for detailed analysis of data, the drawing of trend surfaces and for map printouts of glaciological data.

   To extend the inventory to include ground ice.

A. PROJECT 31 - Glacier Atlas of Canada (G-69-1)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH (Hydrologic Sciences Division)

C. COOPERATING AGENCY: None

D. PRINCIPAL INVESTIGATOR: C.S.L. Ommanney

E. OBJECTIVES: To compile and publish index maps showing the location and identification of every glacier in Canada, as part of the national IHD program for an inventory of perennial ice and snow masses.

F. LOCATION: Ottawa, Ontario.

G. PREVIOUS WORK ON THIS PROJECT: Glacier index maps of Axel Heiberg and Bylot islands are completed.

H. WORK IN PROGRESS: Glacier index maps of Baffin Island are expected to be published in 1969.

I. FUTURE WORK: In conjunction with Project G-67-15, index maps of all glaciers in Canada will be compiled and printed at a scale of 1:500,000 on 11" x 15" sheets. Maps issued individually when completed, will be bound into the inventory reports (Project G-67-15) and, at the termination of the project, will be presented as a Glacier Atlas of Canada.

A. PROJECT 32 - Glaciological Archive (G-69-2)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH (Hydrologic Sciences Division)

C. COOPERATING AGENCY: Americal Geographical Society (World Data Centre A; Glaciology)

D. PRINCIPAL INVESTIGATOR: C.S.L. Ommanney

E. OBJECTIVES: To develop a glaciological archive, referenced to the glacier index numbers (Project G-69-1), for filing all available information on individual ice masses in Canada in the form of data sheets, maps, photographs, published and unpublished literature.

F. LOCATION: Ottawa, Ontario.

G. PREVIOUS WORK ON THIS PROJECT:

1. Collection of glacier photographs as an extension of the glacier inventory conducted for the I.G.Y.

2. Indexing and transferring to stable-base film of photographic records of the International Boundary Commission surveys along the B.C.-Alaska border.

H. WORK IN PROGRESS:

1. Identification and indexing of all early photographs of Baffin, Bylot and Axel Heiberg islands in conjunction with Project G-69-1.

2. Identification, copying and filing of International Boundary Commission photographs of Canadian glaciers in cooperation with Dr. W.O. Field, A.G.S.

3. Development of a cross-referenced file system for identification of all International Boundary Commission photo survey points, in cooperation with Dr. W.E. Field, A.G.S.

I. FUTURE WORK:

1. Identification and indexing of all glacier information obtained from Federal, Provincial, Municipal and private sources as well as any obtained from extra Canadian sources.

2. Observation of glaciers with long-term historical records and of those glaciers 'typical' of certain areas as determined from data collected for Project G-67-15.

A. PROJECT 33 - Glacier Maps of Canada (1:1,000,000) (Completed 1969)
(G-67-10)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH (Hydrologic Sciences Division)

C. COOPERATING AGENCY: None

D. PRINCIPAL INVESTIGATOR: W.E.S. Henoch

E. OBJECTIVES: To compile and print a series of seven maps at the scale of 1:1,000,000 to show the distribution of glaciers in Canada. Location of snow courses, stream gauging stations and selected meteorological stations to be shown and the data sources listed on the reverse of each sheet.

F. LOCATION: Ottawa, Ontario.

G. PREVIOUS WORK ON THIS PROJECT:

1. References:

Geographical Branch, 1965. Glacier Map of Southern British Columbia and Alberta.

Inland Waters Branch, 1967. Glacier Map of Northern British Columbia and Southern Alaska.

Inland Waters Branch, 1967. Glacier Map of Yukon Territory and District of Mackenzie.

Inland Waters Branch, 1968. Glacier Map of Northern Queen Elizabeth Islands.

Inland Waters Branch, 1968. Glacier Map of Southern Queen Elizabeth Islands.

Inland Waters Branch, 1968. Glacier Map of Northern Baffin Island.

Inland Waters Branch, 1969. Glacier Map of Southern Baffin Island and Northern Labrador Peninsula.

Falconer, G., Henoch, W., and Ostrem, G., 1966. A Glacier Map of Southern British Columbia and Alberta. Geog. Bull., v. 8, no. 1, pp. 108-112.

Henoch, W.E.S., 1969. Topographic maps of Canada in glaciological research. The Canadian Cartographer (in press).

Henoch, W.E.S., and Stanley, A., 1969. Maps produced for glaciological research, Inland Waters Branch (in preparation).

A. PROJECT 34 - Fluctuations of Glaciers in the Rocky Mountains (G-68-2).

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division).

C. COOPERATING AGENCY: Geological Survey of Canada.

D. PRINCIPAL INVESTIGATOR: W.E.S. Henoch.

E. OBJECTIVES: To collect available records of glacier fluctuations in the Rocky Mountains north of latitude 49° N., to ensure retention of all available data of glacier variations and to assess their effect on discharge records from streams.

F. LOCATION: The Rocky Mountains.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Over the last 20 years, several studies have been completed in the Rocky Mountains including studies of mass balance measurements on glaciers, direct observations of water discharge, a series of geomorphological studies of glacier fluctuations and dendrochronological investigations of glacier retreat. These studies have been undertaken in a number of disciplines and all have some bearing on the hydrology of the area.

H. WORK IN PROGRESS:

1. Location of readily available information such as maps, aerial and terrestrial photographs, including the photography of the International Boundary Commission taken in 1912.
2. Contacting government agencies, both Federal and Provincial, together with private individuals who possess data of historic value.

I. FUTURE WORK:

1. Study of glacier fluctuations in the watershed of the North Saskatchewan River, particularly in the area of Peyto Glacier to determine the contribution to discharge during the period of record and to investigate the relationship of water balance to the growth of vegetation in the alpine areas.
2. Preliminary study of trees at Peyto Glacier show white pine unsuitable but spruce giving good chronology for the periods 1680 to the present. New techniques of tree ring X-ray photography and automatic densometer measurement promise to give good quantitative data suitable for statistical analysis and comparison with discharge records.

A. PROJECT 35 - Glacier Mapping.

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Water Survey of Canada).

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: I.A. Reid.

E. OBJECTIVES: To determine volumetric and linear changes of seven glaciers on the basis of biennially detailed topographic mapping. The following glaciers are investigated: Sentinel, Sphinx, Bugaboo, Kokanee and Nadahini in British Columbia, and the Athabasca and Saskatchewan glaciers in Alberta.

F. LOCATION: Ottawa, Ontario.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: A terrestrial photogrammetric survey of the glaciers in British Columbia was made in 1964, 1966 and 1968; of the Athabasca Glacier in 1959, 1962, 1965, 1967 and 1968; and of the Saskatchewan Glacier in 1965 and 1967.

2. References:
Campbell, P.I., Reid, I.A. and Shastal, J., 1969. "Glacier Surveys in Alberta", Inland Waters Branch, Report Series No. 4, 15 pp.

Campbell, P.I., Reid, I.A. and Shastal, J., 1969 (in press), "Glacier Surveys in British Columbia", Inland Waters Branch, Report Series No. 5.

Map	Scale	Contour Interval
Bugaboo (1966)	1:2,500	50 feet
Sentinel Glacier (1966)	1:2,500	20 feet
Sphinx Glacier (1966)	1:5,000	25 feet
Nadahini Glacier (1966)	1:5,000	20 feet
Kokanee Glacier (1966)	1:2,500	20 feet
Saskatchewan Glacier (1967)	1:10,000	20 feet
Athabasca Glacier (1967)	1:10,000	25 feet

H. WORK IN PROGRESS:

1. Terrestrial photogrammetric surveys of the Athabasca and Saskatchewan glaciers.
2. Ice discharge measurement of the Saskatchewan and Athabasca glaciers.
3. Mapping the Columbia Icefield and outlet glaciers by aerial photogrammetry (in collaboration with the Glaciology Subdivision).

I. FUTURE WORK: The mapping projects of the seven glaciers will likely continue to the mid-1970's.

A. PROJECT 36 - Peyto Glacier Area Map (G-67-8).

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division).

C. COOPERATING AGENCIES: Surveys and Mapping Branch; National and Historic Parks Branch, (Department of Indian Affairs and Northern Development).

D. PRINCIPAL INVESTIGATOR: W.E.S. Henoch.

E. OBJECTIVES: To prepare a detailed multicoloured map of the Peyto Glacier area (scale 1:10,000) with marginal notes about the local environment to:

1. Determine the feasibility of using sophisticated cartographic techniques to portray a glacier in an Alpine environment.
2. Promote more extensive use of maps among the general public and to provide information for park visitors.

F. LOCATION: Peyto Glacier (51° 40' N., 116° 34' W.) in the Rocky Mountains 45 km. northwest of Lake Louise, Alberta.

G. PREVIOUS WORK ON THIS PROJECT: Peyto Glacier has been shown on all topographic maps compiled at scales of 50,000 and smaller by the Surveys and Mapping Branch. The 'Water Resources' group compiled maps of the terminal area for a number of years between 1945 and 1960, and in 1966 aerial photographs were obtained so that the Surveys and Mapping Branch could compile a detailed map of the area (scale 1:10,000).

H. WORK IN PROGRESS: Drafting of the map showing glaciological and geomorphological features of importance. The techniques used will give a final map comparable to the best available.

Marginal notes on glaciology, mountaineering, history, etc., are being prepared in cooperation with the National and Historic Parks Branch for printing on the reverse of the map sheets. Projected publication date late-1969.

I. FUTURE WORK:

1. Coordination of all phases of compilation until publication.

2. Assessment of use and demand to identify any need for similar maps of other glaciers.

A. PROJECT 37 - Radio Echo Sounding Project (RESP) (WS-68-1).

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division).

C. COOPERATING AGENCIES: Contractors for equipment: Leigh Instruments, Carleton Place, Ontario; Applicon Computer Systems, Ottawa, Ontario; Motorola Government Electronics Division, Scottsdale, Arizona.

D. PRINCIPAL INVESTIGATORS: R.H. Goodman and A.C.D. Terroux.

E. OBJECTIVES: To develop instrumentation for the measurements of glacier depths using pulsed radar techniques; to test this equipment in the field and to prepare computer programs for automatic processing of the data.

F. LOCATION: Field tests to be conducted on Wapta Icefield, near Lake Louise, Alberta.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Initial trials were conducted on Athabaska and Peyto glaciers during the 1968 field season which indicated the feasibility of this project. New equipment has been developed as a result of these trials.

2. Reference:
Goodman, R.H., Stanley, A.D., and Terroux, A.C.D. 1968 Paper: Alaska Science Conference (1968), Whitehorse, Y.T.

H. WORK IN PROGRESS:

1. Equipment has been field tested and initial depth profiles have been obtained.

2. The position measuring system (PMS) was calibrated using a Tellurometer. The PMS gave reproducible average values to an accuracy of ± 1 meter.

3. Tapes containing radio echograms have been produced, and analyses programs have been written.

I. FUTURE WORK:

1. To prepare a contour map of Wapta Icefield.

2. To study water effects in a glacier using the radio echo sounder.

3. To analyse intra glacier reflections.

4. To use the instrumentation for ice depth measurements as a contribution to the Glacier Inventory and for specific practical investigations, e.g. in preparation for tunneling projects under glaciers.

A. PROJECT 38 - Geomorphic Processes, Mackenzie Valley - Arctic coast.

B. PRINCIPAL AGENCY: GEOLOGICAL SURVEY OF CANADA, (Division of Quaternary Research and Geomorphology).

C. COOPERATING AGENCY: University of British Columbia.

D. PRINCIPAL INVESTIGATOR: J. Ross Mackay.

E. OBJECTIVES: To describe, measure, and explain geomorphic features and processes related to permafrost, and to fluvial, lacustrine, coastal, eolian, and mass-wasting activity in a permafrost environment.

F. LOCATION: Mackenzie Valley, Mackenzie Delta and adjacent Arctic coast.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Investigations of nature, form, distribution, thermal regime and origin of ground ice have been underway for more than a decade, under sponsorship of the Geographical Branch, and lately from Geological Survey.

2. References:
Mackay, J.R., 1963. The Mackenzie Delta, Geog. Branch, Mem. 8, 202 pp.

Mackay, J.R., 1966. Segregated epigenetic ice and slumps in permafrost, Mackenzie Delta area, N.W.T., Geog. Bull., vol. 8, no. 1, pp. 59-80.

Mackay, J.R., 1966. Pingos in Canada, Proc. Permafrost Intl. Conf. 1963, N.A.S.-N.R.C., Wash., Publ. No. 1287, pp. 71-76.

H. WORK IN PROGRESS:

1. Installation of markers and devices to record growth of pingos, ice wedges, permafrost along channels and delta-islands.
2. Determination of thermal regime and permafrost distribution adjacent to water bodies.
3. Measurement of temperature and permafrost depth in boreholes.
4. Measurement of thaw of frozen ground in fire area.
5. Determination of ice content of various kinds of material and the form, nature, and origin of ground-ice bodies.

I. FUTURE WORK:

1. Continuation of measurements as above.
2. Delineation of ice bodies in pingos.
3. Derivation of system for mapping distribution of ground ice.

CURRENT PROJECTS CATALOGUE

2. Floating Ice

A. PROJECT 39 - Aerial Surveys of Sea Ice, Arctic Archipelago and Adjacent Seas.

B. PRINCIPAL AGENCY: Polar Continental Shelf Project.

C. COOPERATING AGENCY: Meteorological Branch, Department of Transport.

D. PRINCIPAL INVESTIGATORS: E.F. Roots, K. Peister, P.F. Cooper.

E. OBJECTIVES: To study the type, distribution, movement and condition of sea ice in the channels of the Arctic Archipelago, in the Beaufort Sea, and on the adjacent parts of the Arctic Ocean.

F. LOCATION: Arctic Archipelago, Beaufort Sea, Arctic Ocean between Longitude 45° W. and 141° W.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Aerial reconnaissance surveys started in 1961 and have continued each year. In 1968, approximately 320 hours were flown on sorties between April 7 and November 3; additional observations were made in the Beaufort Sea in December.

2. References:

Black, W.A., 1965. Sea Ice Surveys, Queen Elizabeth Islands Region, summer 1962, Geographical Branch, Department of Mines and Technical Surveys, Ottawa, Geographical Paper No. 44, 34 pp.

Lindsay, D.G., 1968. Sea Ice in the Canadian Arctic Archipelago. Unpublished M.Sc. Thesis, McGill University, 178 pp.

Lindsay, D.G., 1969. Ice Distribution in the Queen Elizabeth Islands, Bulletin Can. Inst. Min. and Metall., Special vol. no. 10, pp. 45-60.

Lindsay, D.G. and Hermann, P. Sea Ice Atlas of the Canadian Arctic (in preparation).

H. WORK IN PROGRESS: Aerial surveys continue. Aerial observations were started in the Beaufort Sea area on January 14, 1969, and have continued at roughly fortnightly intervals. The first of the systematic surveys of the channels of the archipelago and of the Arctic Ocean started on May 9. Since 1968, the observations from these surveys are integrated with those of the Department of Transport and incorporated in the weekly ice reports and periodic forecasts issued by the Department of Transport, as well as used for the more permanent atlas and analytical reports prepared by the Polar Continental Shelf Project.

I. FUTURE WORK: The aerial surveys are planned on a continuing basis, in co-operation with the Department of Transport. Arrangements are being worked out which, it is hoped, will result in the regional data-gathering activities eventually being carried out by the Department of Transport, and special observations, surface studies and interpretations carried out by the Department of Energy, Mines and Resources.

A. PROJECT 40 - Ice Drift Studies in the Arctic Ocean.

B. PRINCIPAL AGENCY: Polar Continental Shelf Project; Gravity Division, Observatories Branch; Geodetic Survey, Surveys and Mapping Branch (A. Geiger).

C. COOPERATING AGENCIES: Control Data Corporation, Minneapolis, Minnesota (R.L. Lillestrand); Inter Ocean Systems, Inc., San Diego, California (M.D. Pearlman); Marine Sciences Center, McGill University (O.M. Johannessen).

D. PRINCIPAL INVESTIGATOR: J.R. Weber.

E. OBJECTIVES: To study the interaction between ice drift, winds, ocean currents, atmospheric pressure gradients, and ocean tilt.

F. LOCATION: Polar region of the Arctic Ocean.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: During a 7-day period in May 1967 the drift path of a station in the vicinity of the North Pole was determined from astro observations using a radio link to a computer in Minneapolis for data reduction. The ocean tilt was measured and found excessively great (8 arc seconds). The drift path was compared with the effect of winds and ocean currents.

2. Reference:
Lillestrand, R.L., Grosch, C.B., Vannelli, B.D., 1967. Astronavigation during Dominion Observatory Polar Research Project. Interim Technical Report, Aerospace Research Department, Control Data Corporation, Minneapolis, Minn. 143 pp.

H. WORK IN PROGRESS:

1. During a 24-day period in April and May 1969 (in conjunction with "Project North Pole - 1969") the drift path of a floating station in the vicinity of the North Pole was determined from star observations, and by tracking from satellites with a satellite receiver and by sonar ranging from transponders on the ocean floor. Speed and direction of winds and ocean currents were continuously recorded. The ocean tilt was measured using a specially designed hydrostatic level.

2. The data is presently being compiled and computer programs developed for processing the information.

I. FUTURE WORK:

1. Depending on the results of the work in progress, further ice drift studies may be carried out in conjunction with "Project North Pole - 1971".

2. The hydrostatic level for measuring ocean tilt is being further developed and will be tested in the Beaufort Sea in March 1970.

A. PROJECT 41 - Fine Structures of the Ice Movement in the Arctic Ocean.

B. PRINCIPAL AGENCY: Polar Continental Shelf Project; Gravity Division, Observatories Branch.

C. COOPERATING AGENCIES: Inter Ocean Systems, Inc., San Diego, California (M.D. Pearlman); Control Data Corporation, Minneapolis, Minnesota (R.L. Lillestrand).

D. PRINCIPAL INVESTIGATOR: J.R. Weber.

E. OBJECTIVES: To study the micro movement of the pack ice in the Arctic Ocean using continuous sonar tracking from acoustic transponders on the ocean floor.

F. LOCATION: Polar region of the Arctic Ocean.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: In May 1967 the first sonar tracking was carried out in the vicinity of the North Pole using one transponder on the ocean floor and one transducer on the ocean surface.

2. References:
Lillestrand, R.L., Grosch, C.B., Vannelli, B.D., 1967. Astronavigation during Dominion Observatory Polar Research Project. Interim Technical Report, Aerospace Research Department, Control Data Corporation, Minneapolis, Minn. 143 pp.

H. WORK IN PROGRESS:

1. In April and May 1969 (in conjunction with "Project North Pole - 1969") the micro movement of a floe station was recorded with an estimated accuracy of ± 3 m. using continuous sonar ranging between a transducer and hydrophones at the station and acoustic transponders on the ocean floor.

2. Computer programs have been developed to determine the drift path from the sonar data, and the data is presently being compiled and analysed.

I. FUTURE WORK: Sonar ranging using improved instrumentation is planned in conjunction with "Project North Pole - 1971".

A. PROJECT 42 - The Oscillatory Vertical Movement of the Ice Pack of the Arctic Ocean.

B. PRINCIPAL AGENCIES: Observatories Branch and Polar Continental Shelf Project.

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: J.R. Weber.

E. OBJECTIVES: To study the wave induced vertical motion of the ice cover of the Arctic Ocean.

F. LOCATION: Polar region of the Arctic Ocean.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: In May 1967, vertical displacement and acceleration of the ice cover have been measured using a gravimeter as detector. Similar work has been carried out by Hunkins and Leschack who sometimes used two detectors.

2. References:
Hunkins, K., 1962. Waves on the Arctic Ocean. J. Geoph. Res., 67, pp. 2477-89.

Leschack, L.A. On the generation and directional recording of waves in the Arctic Ocean. U.S. Naval Oceanographic Office, Technical Report TR-179.

H. WORK IN PROGRESS: None in 1969.

I. FUTURE WORK: To study the ice motion with emphasis on direction and phase velocity of the waves, using three detectors with digital output in a tripartite array.

A. PROJECT 43 - Study of the movements of "Ice Islands" (Tabular Icebergs).

B. PRINCIPAL AGENCY: Polar Continental Shelf Project.

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: D.G. Lindsay.

E. OBJECTIVES: To mark and identify, and track the movement of selected tabular icebergs or "ice islands" in order to obtain information on the movement and distribution of ice and its relationship to winds and currents.

F. LOCATION: Canadian sector of the Arctic Ocean, and the channels of the Canadian Arctic Archipelago.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: In 1959 the Polar Continental Shelf Project discovered and identified a debris-covered iceberg in the Arctic Ocean offshore from the Sverdrup Islands; the rock on this iceberg enabled its source on Ellesmere Island to be identified; two years later this iceberg was occupied by a party from the U.S. Arctic Research Laboratory and as floating station "Arlis II" travelled around the Arctic Ocean, passed close to the North Pole, until abandoned east of Greenland in 1966. These events demonstrated the value of tracking the drift of ice islands.

   Other ice islands, notably "T-1" and a group that calved from the Ward Hunt Ice Shelf in 1963, have been followed in their drift through the archipelago or along the coast, in the course of the regional sea ice surveys of the Polar Continental Shelf Project.

   In 1967 a program was started to place identifying markers on selected ice islands, to enable them to be followed from season to season, and, it was hoped, to enable them to be identified by other observers and on radar screens. A number of ice islands have been marked with piles of empty fuel drums in distinctive patterns; each drum has a stainless steel numbered tag for positive identification should it ever be recovered. The technique has proved to be successful, and marked icebergs have been identified and reported by other agencies.

2. References:

   Canadian Geophysical Bulletin:

1961:	vol. 14, p. 98	1964:	vol. 17, p. 134
1962:	vol. 15, p. 101	1965:	vol. 18, pp. 142-143
1963:	vol. 16, pp. 124-125	1967:	vol. 20, pp. 188-189

Lindsay, D.G. 1968. Sea Ice in the Canadian Arctic Archipelago. M.Sc. Thesis, McGill University, 178 pp.

Lindsay, D.G. 1969. Ice distribution in the Queen Elizabeth Islands. Bulletin Canadian Inst. Mining and Metallurgy, Special volume no. 10, pp. 45-60.

H. WORK IN PROGRESS: The drift of ice islands is followed and recorded by aerial surveys and reports from other agencies. Additional ice islands are marked as opportunities arise. Few large islands have calved since the "burst" of 1961-62.

I. FUTURE WORK: The surveys will be continued over as long a period as possible to obtain statistical information on the rate and path of drifting ice and the distribution and longevity of icebergs from the ice shelves and glaciers of Ellesmere Island. Particular attention will be given to debris-laden bergs (such as Arlis II) which are important agents in the distribution of ice-rafted boulders now found scattered over the floor of the Arctic Ocean.

A. PROJECT 44 - Dynamics of Free-floating and Shore-fast Bay Ice.

B. PRINCIPAL AGENCY: Polar Continental Shelf Project.

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: P.F. Cooper, Jr.

E. OBJECTIVES: To study the movement and deformation of the ice in Kugmallit Bay and to relate this to the stresses applied by wind, current, and resistance of land-fast ice.

F. LOCATION: Kugmallit Bay, near Tuktoyaktuk, N.W.T. Lat. 69° 20' - 69° 40' N., Long. 133° - 134° 00' W.

G. PREVIOUS WORK ON THIS PROJECT: Studies of the surface features and deformation of the ice in Kugmallit Bay were started in February 1966 under the auspices of the Department of Northern Affairs and National Resources, and have been continued each winter and spring since. Particular attention has been paid to the crack and pressure ridge system, to ascertain their cause and learn why ice failure occurs from year to year in roughly the same place but sometimes with opposite sign (i.e. a tension crack may develop instead of a pressure ridge).

H. WORK IN PROGRESS: During the 1968-69 winter, observations and movement surveys were made every month from freeze-up in November to complete break-up in late June. Equipment is being devised for more precise measuring and recording of small-scale dislocations along fractures, and for measuring absolute movement of unfractured ice in places too far from shore for convenient precision surveys in winter.

I. FUTURE WORK: The work is continuing. When a better understanding of the mechanisms operating in land-bound bay ice has been reached, it is planned to carry out comparative investigations on unconfined ice that normally does not break up in the summer.

A. PROJECT 45 - Sea Ice Atlas of the Canadian Arctic.

B. PRINCIPAL AGENCY: Polar Continental Shelf Project.

C. COOPERATING AGENCY: Department of Transport.

D. PRINCIPAL INVESTIGATORS: D.G. Lindsay, P. Hermann.

E. OBJECTIVES: To assemble all available data on the distribution and nature of sea ice in the Canadian Arctic, and to reproduce this in a permanent atlas illustrating as completely as possible the extent, type, age and condition of sea ice in the Canadian Arctic Archipelago and adjacent ocean.

F. LOCATION: Ottawa.

G. PREVIOUS WORK ON THIS PROJECT:

1. Office and field: The first comprehensive atlas of sea ice for northern Canada was assembled in 1960 by the Defence Research Board, and included all available useful information from 1900 to 1958. Since the advent of systematic aerial ice patrols by the Department of Transport, the Polar Continental Shelf Project, and the U.S. Navy, the amount of information on sea ice is very much greater; to this is now added the small-scale information produced on a year-round basis (weather and light permitting) from satellite photography. These data warrant the production of a permanent, detailed and uniform atlas, based on the periodic surveys of the Polar Continental Shelf Project (project 39), supplemented with information from other agencies.

2. References:
Swithinbank, C.W.M. 1960 Ice Atlas of Arctic Canada, Defence Research Board, Canada, Pub. DR3-1060, 62 pp.

Department of Transport, Meteorological Branch, Ice Central. Weekly sea ice maps (facsimile); forecasts; seasonal outlook, annual summaries of ice observations.

H. WORK IN PROGRESS: Compilation of information for seasons 1961 to 1968 inclusive is now complete and the first volume of the atlas is in the final stages of drafting. It is hoped that this volume will be in press by the end of 1969; it will comprise approximately 117 coloured maps each with a text analysing the progressive seasonal changes in sea ice cover commencing with 1961.

I. FUTURE WORK: The atlas will be a continuing project, with annual supplements incorporating each successive years' observations.

A. PROJECT 46 - Thermal Imagery of Sea Ice.

B. PRINCIPAL AGENCY: Polar Continental Shelf Project.

C. COOPERATING AGENCY: Cold Regions Research and Engineering Laboratory, U.S. Army Terrestrial Sciences Center.

D. PRINCIPAL INVESTIGATOR: A.O. Poulin.

E. OBJECTIVES: To study the thermal contrast across an arctic coastline and across sea and lake ice of various thicknesses and structures.

F. LOCATION: Beaufort Sea and Arctic Ocean, and land areas in vicinity of Tuktoyaktuk Peninsula, Lat. 69° 30' N., Long. 133° W.

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Studies of the thermal emission or thermal reflectivity of ice-covered and snow-covered terrain have been carried out for several years as a part of military research, and have indicated a promising method of identifying the physical conditions of the surface from infra-red imagery.

2. References:

Poulin, A.O. 1965. Infrared aerial reconnaissance in the Arctic, spring conditions. Cold Regions Research and Engineering Laboratory (U.S. Army Corps of Engineers), Research Report 194, 80 pp. (restricted).

Poulin, A.O., and Harwood, T.A., 1966. Infrared mapping of thermal anomalies of glaciers. Canadian Journal of Earth Sciences, vol. 3, no. 6, pp. 881-885.

Poulin, A.O., and Harwood, T.A., 1966. Infrared imagery in the Arctic under daylight conditions. Proceedings of the 4th Symposium on Remote Sensing of the Environment, University of Michigan, pp. 231-241.

H. WORK IN PROGRESS: The radiation signatures of sea ice of various types, lake ice, and land were measured and compared, and related to temperature profiles on the ground and observations of surface and meteorological conditions, from the Arctic midwinter (February) through to the onset of thaw in May.

I. FUTURE WORK: The work done to-date demonstrates a very useful method of obtaining information about the physical conditions along Arctic coastlines and the structure and history of sea ice on both large and small scales. Future work will be directed toward applying the techniques on a regional and problem basis.

A. PROJECT 47 - Microclimate of the Sea Ice - Water Interface.

B. PRINCIPAL AGENCY: Marine Sciences Branch, (Frozen Sea Research Group).

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATORS: R.A. Lake and E.L. Lewis.

E. OBJECTIVES: To study in great detail the freezing process by which sea ice is formed.

F. LOCATION: Greely Fiord (80° 36' N, 79° 35' W) Ellesmere Island, N.W.T.

G. PREVIOUS WORK ON THIS PROJECT:

1. Laboratory: In 1966, ice was grown in FSRG cold rooms and Schlieren techniques used to observe streamers of salt released during freezing.
2. Field: At Cambridge Bay in 1965, thermistors were fixed just below the ice which then grew downward over them. Detailed temperature records in water and ice were thus obtained. At Cambridge Bay in 1966 a shadowgraph was constructed and the water immediately below the ice was surveyed. No streamers such as found in the laboratory were found. At Cambridge Bay in 1968 both thermistor and shadowgraph experiments were repeated in greater detail. Investigation of the ice cover itself was undertaken.
3. Reference:
Lewis, E.L., 1966. "Heat Flow through Winter Ice". Proceedings of the International Conference on Low Temperature Science, Sapporo, Japan, v. 1, pp. 611-631.

H. WORK IN PROGRESS: The Cambridge Bay data are being prepared for publication. The interesting results from Cambridge Bay are being confirmed (it is hoped) by similar experiments at Greely Fiord, March-April, 1969.

I. FUTURE WORK:

1. The results from Cambridge Bay which indicated that the freezing process may be in part at least discontinuous or intermittent in nature are being further investigated in laboratory freezing experiments in 1969.
2. Details of further work in the field, where the freezing process may be somewhat different than in the laboratory, will be decided after results of laboratory work and the 1969 field season are known.

A. PROJECT 48 - Water Structure Below Sea Ice.

B. PRINCIPAL AGENCY: Marine Sciences Branch, (Frozen Sea Research Group).

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATORS: E.L. Lewis and E.R. Walker.

E. OBJECTIVES: To investigate and physically account for the water structure below Arctic sea ice.

F. LOCATION: Greely Fiord (80° 36' N, 79° 35' W) Ellesmere Island, N.W.T.

G. PREVIOUS WORK ON THIS PROJECT:

1. Laboratory: None directly. However, very extensive instrumentation development and testing has proceeded continuously.

2. Field: At Cambridge Bay, N.W.T., numerous temperature and salinity soundings have been made since 1965 at different seasons. In February-March 1968, time series of temperatures were obtained at various depths below ice cover.

H. WORK IN PROGRESS: Time series of temperature and extensive temperature salinity depth soundings were taken at Greely Fiord during March-April 1969. Use of dye and radioactive tracers is being attempted.

I. FUTURE WORK: A large amount of oceanographic data, temperatures, salinities, currents, etc. will be gathered in the Greely Fiord-Nansen Sound area in the near future.

A. PROJECT 49 - Convective Processes in Polar Seas.

B. PRINCIPAL AGENCY: Marine Sciences Branch, (Frozen Sea Research Group).

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: E.R. Walker.

E. OBJECTIVES: To describe in physical and mathematical terms the types of convective processes occurring in Polar seas.

F. LOCATION: Greely Fiord (80° 36' N, 79° 35' W) Ellesmere Island, N.W.T.

G. PREVIOUS WORK ON THIS PROJECT:

1. Laboratory: The boundary conditions at the ice water interface were investigated by J.A. Elliott.

2. Field: Water temperature and salinity structure have been gathered at Cambridge Bay since 1965. On two occasions observations may have included a convective element.

H. WORK IN PROGRESS: Extension of similarity models of penetrative convection are presently being tested on the observations available.

I. FUTURE WORK: The mathematical models of penetrative convection will be extended to include in realistic detail the effects of convection upon the general water structure.

A. PROJECT 50 - Computer Applications - Sea Ice Research.

B. PRINCIPAL AGENCY: Marine Sciences Branch, (Frozen Sea Research Group).

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: E.R. Walker.

E. OBJECTIVES: To develop procedures and computer techniques for efficient scientific computing and data processing.

F. LOCATION: Esquimalt, British Columbia.

G. PREVIOUS WORK ON THIS PROJECT:

Office and Laboratory: About 10 oceanographic programs have been written in Fortran IV. A preliminary data processing program was written for the University of Victoria IBM360-44 and used to process thermistor data from Cambridge Bay in 1968. Convective mathematical models of not too much complexity have been written and run.

H. WORK IN PROGRESS:

1. A procedure to process the output of the in situ salinometer recently acquired is under development.
2. Data processing programs are being refined.
3. Convective models of increasing complexity are being programmed.

I. FUTURE WORK:

Apart from continuation and extension of the scientific and data processing work noted above, the major work in future is expected to include tying a small computer into the data logging system for on-site analysis and control.

A. PROJECT 51 - Mobile Arctic Oceanographic Laboratory.

B. PRINCIPAL AGENCY: Marine Sciences Branch, (Frozen Sea Research Group).

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATORS: E.L. Lewis and R.B. Sudar.

E. OBJECTIVES: To develop and test a mobile Arctic Oceanographic laboratory.

F. LOCATION: Construction at Esquimalt, British Columbia. Field testing and use in Greely Fiord-Nansen Sound area, Ellesmere Island, N.W.T.

G. PREVIOUS WORK ON THIS PROJECT:

Office, Laboratory and Workshop: Two tracked vehicles, each towing two sleds completely equipped for laboratory work and data gathering, and including living quarters, were made ready over a period of several years at Esquimalt. Very complete navigation and communication equipment was included. The whole meets strict environmental specifications and forms an operating system capable of gathering oceanographic and ice-cover data during prolonged trips over sea ice.

In addition, a great deal of effort has been put into oceanographic instrumentation. Two periscopes have been constructed for use through thick ice cover. Underwater camera and lighting equipment have been prepared for use through ice. Extensive thermistor arrays have been constructed. A high-grade, in situ temperature depth salinometer instrument has been acquired and tested.

The data-logging system has undergone extensive testing and modification. It is now an extremely rugged and sensitive system.

H. WORK IN PROGRESS: The mobile laboratory is undergoing field tests in Greely Fiord, March-April, 1969.

I. FUTURE WORK: The mobile laboratory will be subject to continuous modification and improvements.

A. PROJECT 52 - Growth Mechanisms of River and Lake Ice (G-69-5).

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division).

C. COOPERATING AGENCY: Department of Civil Engineering, Laval University.

D. PRINCIPAL INVESTIGATOR: R.O. Ramseier.

E. OBJECTIVES: To study the formation of the primary and secondary ice and surface ice and to relate the ensuing structure and texture to gross meteorological and hydrodynamic conditions.

F. LOCATION: Laboratory, Quebec City, Quebec.

G. PREVIOUS WORK ON THIS PROJECT:

1. Laboratory: Laboratory studies were made to determine the mechanism causing the occurrence of a preferred orientation of the c-axis in columnar ice.

2. References:
Michel, B., and Ramseier, R.O., 1969. Classification of River and Lake Ice Based on its Genesis, Structure and Texture. Université Laval, Faculté des Sciences, Departement de Génie Civil, Section Mécanique des Glaces, Report S-15, 57 pp.

Ramseier, R.O., 1968. The origin of preferred orientation in columnar ice. Journal of Crystal Growth 3, 4 (1968), pp. 621-624, North-Holland Publishing Co., Amsterdam.

H. WORK IN PROGRESS: Additional data are being collected from field studies to confirm the theory on preferred orientation in columnar ice. A study is in progress to classify the major ice types occurring in rivers and lakes and to simulate them in the laboratory.

I. FUTURE WORK: To study particular rivers, e.g., the St. Lawrence River, to determine the ice thickness using a modified radar system and the locations where the various ice types form. This work will be coordinated with the Coast Guard and the Department of Transport to relate the fundamental and applied studies to the economy of the region.

CURRENT PROJECTS CATALOGUE

3. Ice As a Material

A. PROJECT 53 - Defects in Ice Crystals (G-67-17).

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division).

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: S.J. Jones.

E. OBJECTIVES:

I. Short-term: To determine the density of dislocations and their velocity under stress in pure and impure ice.

II. Long-term: By studying the distribution of defects, in particular dislocations in ice crystals, it is hoped to understand:

1. The nature of the flow of ice under stress (glacier movement).
2. The underlying reason for the effect that impurities have on the flow of ice (see G-68-1).
3. The role of dislocations in the formation of ice.

F. LOCATION: Ice Science Laboratory, Ottawa, Ontario.

G. PREVIOUS WORK ON THIS PROJECT: Nil.

H. WORK IN PROGRESS: An X-ray topographical "Lang" camera has been set up and preliminary results have been obtained.

I. FUTURE WORK:

1. The collection of results will continue to improve the quality of the topographs. Topographs will then be taken before and after stressing the crystal.
2. The effect of impurities on the dislocation velocity will be examined in conjunction with G-68-1.

A. PROJECT 54 - Creep Mechanisms of River and Lake Ice (G-69-6).

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division).

C. COOPERATING AGENCY: Department of Civil Engineering, Laval University.

D. PRINCIPAL INVESTIGATOR: R.O. Ramseier.

E. OBJECTIVES: To study the creep properties of ice types identified in the Project (G-69-5) on ice formation in order to assess the mechanical properties due to structure and texture.

F. LOCATION: Laboratory, Quebec City, Quebec.

G. PREVIOUS WORK ON THIS PROJECT:

Reference:
Michel, B., and Ramseier, R.O., 1969. Classification of River and Lake Ice Based on its Genesis, Structure and Texture. Université Laval, Faculté des Sciences, Département de Génie Civil, Section Mécanique des Glaces, Report S-15, 57 pp.

H. WORK IN PROGRESS: The test procedure has been established and the equipment is being assembled to commence the testing in the FY 70. A general theory for creep is being adopted to account for the variations in creep rate due to the various ice types.

I. FUTURE WORK: Laboratory tests to determine the effect of subboundaries and grain boundaries on the creep mechanisms are contemplated to gain insight into the microscopic aspect of creep deformations. Field investigations to determine the statistical behaviour of major flaws on the mechanical properties are planned to obtain a working relationship between laboratory and field investigations to better serve the engineering community.

A. PROJECT 55 - Mechanical Properties of Ice Containing Impurities (G-68-1).

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division).

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: T. Nakamura.

E. OBJECTIVES: To study the effects that impurities have on the mechanical properties of single crystal ice and the practical importance of this to natural conditions.

F. LOCATION: Ice Science Laboratory, Ottawa, Ontario.

G. PREVIOUS WORK ON THIS PROJECT:

1. Laboratory: A study of the effect of HF, NH_3 and NH_4F on the mechanical properties of ice has been made by Glen and Jones (see publications below).

2. References:

Glen, J.W., and Jones, S.J., 1967. The deformation of ice single crystals at low temperatures. Conference on Physics of Snow and Ice, August 1966, Hokkaido University, Japan, v. 1, Part 1, pp. 267-275.

Jones, S.J., 1967. Softening of Ice Crystals by dissolved fluoride ions. Physics Letters, v. 25 A, pp. 366-367.

Jones, S.J., and Glen, J.W., 1968. The mechanical properties of single crystals of ice at low temperatures. I.U.G.G. General Assembly, Bern, 1967. Publication no. 79, pp. 326-340.

Jones, S.J., and Glen, J.W., 1969. The effect of dissolved impurities on the mechanical properties of ice crystals. Phil. Mag., v. 19, no. 157, pp. 13-24.

H. WORK IN PROGRESS:

1. The present project is to determine the effect that different impurities have on the mechanical properties of ice and the application of this to conditions found in nature.
2. An Instron mechanical tester has been set up in a cold room and preliminary results have been obtained using pure ice single crystals.

I. FUTURE WORK: Results with various impurities will be obtained for single and polycrystal ice. Results from the X-ray work, Project G-67-17, will be used to help explain the effects observed.

A. PROJECT 56 - Mechanical Properties of Polycrystalline Ice (G-69-7)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH (Hydrologic Sciences Division)

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATORS: S.J. Jones and G. Barnett.

E. OBJECTIVES: To investigate the effect of impurities on the mechanical properties of polycrystalline ice and to assess the importance of impurities in natural ice masses, glaciers, river and lake ice,etc.

F. LOCATION: Ice Science Laboratory, Ottawa, Ont.

G. PREVIOUS WORK ON THIS PROJECT:

1. Laboratory: Work on the effect of impurities on single crystal ice has been started - project G-68-1. This is a complementary project for polycrystals.

2. Reference:
Jones, S.J., 1967. Softening of Ice Crystals by Dissolved Fluoride Ions. Physics Letters, no. 5, v. 25A, 366-367.

H. WORK IN PROGRESS:

1. Polycrystalline ice has been prepared in moulds to give samples suitable for mechanical tests.
2. Constant strain-rate compression tests are being conducted using the presently existing Instron mechanical tester. Reproducible results have been obtained for pure ice at -10°C.

I. FUTURE WORK:

1. Prepare polycrystalline ice doped with various impurities.
2. Extend tests to lower temperatures.

A. PROJECT 57 - Scanning Electron Microscopy of Ice Surfaces (G-69-9)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH (Hydrologic Sciences Division)

C. COOPERATING AGENCY: Canada Department of Agriculture.

D. PRINCIPAL INVESTIGATOR: J.D. Cross.

E. OBJECTIVES:

1. Short-term: To study the surface structure of ice crystals containing known amounts of impurities.

2. Long-term: By studying the influence of impurities and methods of crystallization on the structure of ice surfaces it is hoped to understand the reasons for the widely different electrical properties of the surface and bulk of ice.

F. LOCATION: Ice Science Laboratory, Ottawa, Ont.

G. PREVIOUS WORK ON THIS PROJECT:

1. Reference:
Cross, J.D., 1969. Scanning Electron Microscopy of Evaporating Ice. Science, vol. 164, pp. 174-175.

H. WORK IN PROGRESS: Water samples with known impurities are being prepared.

I. FUTURE WORK: Micrographs will be taken using a "Stereoscan" scanning electron microscope at the Department of Agriculture. Samples with different impurity content will be studied and the effect of different methods of crystal production will be investigated.

A. PROJECT 58 - Thermo-electric Power of Ice (G-69-10)

B. PRINCIPAL AGENCY: INLAND WATERS BRANCH (Hydrologic Sciences Division)

C. COOPERATING AGENCY: None.

D. PRINCIPAL INVESTIGATOR: J.D. Cross.

E. OBJECTIVES:

1. Short-term: To develop an accurate means of measuring the thermo-electric power of ice without using contact electrodes.

2. Long-term: To determine whether the present discrepancy between theoretical predictions and experimental results for the thermo-electric effect of ice are due to a fault in the theory or to an experimental error by measuring the thermo-electric power accurately without the disturbing influence of contact electrodes.

   By varying the volume to surface ratio of the samples to determine the thermo-electric power of the ice surface.

F. LOCATION: Ice Science Laboratory, Ottawa, Ont.

G. PREVIOUS WORK ON THIS PROJECT: Nil.

H. WORK IN PROGRESS: A vibrating electrode system for measuring surface charge is being designed.

I. FUTURE WORK: The measuring system will be developed and measurements of the thermo-electric power of ice will be made over a wide temperature range.

A. PROJECT 59 - Study of the Physical and Mechanical Properties of Sea Ice along the Northwest Passage.

B. PRINCIPAL AGENCY: Polar Continental Shelf Project.

C. COOPERATING AGENCY: Bedford Institute of Oceanography.

D. PRINCIPAL INVESTIGATOR: L.R. Colby.

E. OBJECTIVES: To determine the thickness, temperature profile, textural and chemical composition of representative types of sea ice along the route of the U.S.S. Manhattan through the Northwest Passage, and to relate the ice conditions and strengths in late winter and spring with those that will be experienced by the ship during her passage in late summer.

F. LOCATION: Parry Channel, Lat. 74° N - 75° N, Long. 100° W - 125° W; M'Clure Strait, Lat. 72° 30' N - 73° 30' N, Long. 115° W - 118° W.

G. PREVIOUS WORK ON THIS PROJECT: Related work has been carried out at Mould Bay (spring 1966 and spring 1967) and in Parry Channel in connection with the trials of the Alexbow icebreaker design (summer 1968). These studies served mainly to identify promising lines of approach to the problem, and to allow development of field measurement techniques and equipment.

H. WORK IN PROGRESS: Investigations were made in May and June 1969 at thirteen stations selected with the co-operation of the Department of Transport, Humble Oil Ltd. (operators of the U.S.S. Manhattan), and the Cold Regions Research and Engineering Laboratory (U.S. Army Terrestrial Sciences Centre). Complete temperature, texture and salinity profiles were made at each station. The salinity analyses are being carried out by the Bedford Institute.

A. PROJECT 60 - Isotope Ratios in Ice from an Arctic Ice Caps.

B. PRINCIPAL AGENCY: Polar Continental Shelf Project.

C. COOPERATING AGENCY: University of Alberta, Department of Physics.

D. PRINCIPAL INVESTIGATOR: Dr. H.R. Krouse, University of Alberta.

E. OBJECTIVES: To examine the variations of the O^{18}/O^{16} ratio with depth in Meighen Ice Cap by analyses of samples of the core, and to relate this to stratigraphic and petrofabric information.

F. LOCATION: Meighen Island, N.W.T. (80° N., 99° W.).

G. PREVIOUS WORK ON THIS PROJECT:

1. Field and Office: The petrofabric and stratigraphic analysis of the 1965 core from Meighen Island shows, among other variations, a discontinuity at depth that may represent two generations of ice cap development. Estimates have been made of the possible age and significance of this discontinuity. It is desired to check these estimates by oxygen isotope analyses.

2. References:
Koerner, R.M. 1968. Fabric analysis of a core from the Meighen Ice Cap, N.W.T., Canada. Journal of Glaciology, vol. 7, no. 51, pp. 421-430.

Paterson, W.S.B. 1968. A temperature profile through the Meighen Ice Cap, Arctic Canada. International Association of Scientific Hydrology, Publication No. 79, pp. 440-449.

H. WORK IN PROGRESS: Laboratory analysis of the core is continuing.

I. FUTURE WORK: Further analysis of the cores, and of cores from other glaciers, is expected.

A. PROJECT 61 - Textural and Mechanical Properties of Ice from an Arctic Ice Cap.

B. PRINCIPAL AGENCY: Polar Continental Shelf Project.

C. COOPERATING AGENCY: INLAND WATERS BRANCH, (Hydrologic Sciences Division).

D. PRINCIPAL INVESTIGATOR: R.M. Koerner.

E. OBJECTIVES: To study the petrofabrics, stratigraphy, and thermal and electrical properties of ice from the borehole on Meighen Island, and on the basis of these data, to refine the interpretation of the history of the ice cap.

F. LOCATION: Meighen Island, N.W.T. (90° N., 99° W.).

G. PREVIOUS WORK ON THIS PROJECT:

1. Field: Mass balance and weather information and movement and mapping surveys since 1959 give an indication of the present setting and trend of behaviour of Meighen Ice Cap. A botanical reconnaissance in 1960 gave evidence of its history in the recent geological past.

   A borehole through the glacier near the summit has provided a core from top to bottom, essentially unaffected by flowage. A petrofabric analysis of this core has yielded a tentative interpretation of the history.

2. References:

Savile, D.B.O. 1961. The botany of the northwestern Queen Elizabeth Islands. Canadian Journal of Botany, vol. 39, no. 4, pp. 909-942.

Arnold, K.C. 1965. Aspects of the glaciology of Meighen Island, Northwest Territories, Canada. Journal of Glaciology, vol. 5, no. 40, pp. 399-410.

Koerner, R.M. 1968. Fabric analysis of a core from the Meighen Ice Cap, Northwest Territories, Canada, Journal of Glaciology, vol. 7, no. 51, pp. 421-430.

H. WORK IN PROGRESS: Further study of the ice cores will commence in September 1969.

I. FUTURE WORK: The information from the study of the Meighen Ice Cap core will be compared with that from similar or comparable studies on cores from other arctic glaciers, including glaciers that are known to be flowing or to have recently flowed.

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INLAND WATERS BRANCH (Hydrologic Sciences Division)

POLAR CONTINENTAL SHELF PROJECT

INLAND WATERS BRANCH (Water Survey of Canada)

OBSERVATORIES BRANCH

GEOLOGICAL SURVEY OF CANADA
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