CANADA. INLAND WATERS DIRECTORATE. REPORT Series #15



INLAND WATERS BRANCH

DEPARTMENT OF ENERGY, MINES AND RESOURCES



Research Projects in Glaciology

REPORT SERIES NO.15

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Research Projects in Glaciology

INLAND WATERS BRANCH DEPARTMENT OF ENERGY, MINES AND RESOURCES OTTAWA, CANADA, 1971

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RESEARCH PROJECTS IN GLACIOLOGY

INTRODUCTION

This report presents the glaciological projects currently undertaken by the Inland Waters Branch of the Department of the Environment.

It is the third in a series that started with "Research Projects in Glaciology 1968" which presented the glaciological projects then sponsored by the Inland Waters Branch. The following year "Ice Studies in the Department of Energy, Mines and Resources - 1969" was published as Inland Waters Branch Report Series No. 7. This report contained all ice studies in the whole Department; a total of 68 of which 34 were undertaken by Inland Waters Branch. The present report is less comprehensive than the last one because this, as the first one, contains the projects of one Branch only.

The modified scope of the report is determined by the desire to have a clear presentation of the Branch activities and by the major realignment of glaciological studies in the Federal Government which followed the introduction of the Government's reorganization bill (C-207) proposing the creation of a Department of the Environment. The implementation of this bill will bring together in one department the activities of the Meteorological Branch, the Marine Sciences Branch and the Inland Waters Branch, while several other activities, notably those of the Polar Continental Shelf Project will remain in another Department. At present the organization of glaciological studies in the new department is not yet clearly defined.

After a brief outline of the objectives, the organization structure and a definition of functions follows a short review of the major program changes during the last year and a half and a list of recent publications. The major part of the report contains the project catalogue where the projects are listed in the sequence they were started with the exception of two projects of the Water Science Subdivision and one of the Water Survey of Canada. These projects are listed at the end. Throughout this report the term glaciology covers the study of snow and ice in all its forms, and it is clearly distinct from the more restricted term 'glacierology' i.e. the study of glaciers.

THE RESEARCH FRAMEWORK

In accordance with the Canada Water Act, the Federal Government has responsibilities for "the management of the water resources of Canada including research and the planning and

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implementation of programs relating to the conservation, development and utilization of water resources". At the federal level the Inland Waters Branch, provides services in natural sciences and engineering which are required for optimum management of Canada's water resources.

Within this overall framework the glaciological studies are almost exclusively undertaken by the Hydrologic Sciences Division, the objectives of which are:

- 1. To establish a federal research centre to provide leadership in the study of glaciology, groundwater, surface water, snow hydrology and the properties of water in relation to its occurrence in the hydrologic cycle.
- 2. To develop new concepts pertaining to the hydrologic processes and to incorporate these concepts into hydrologic models for prediction purposes.
- 3. To study the structure and properties of water and ice in order to provide new knowledge concerning their relationship with the environment.
- 4. To develop computerized data storage systems, pertaining to glaciers, groundwater and lakes, for use by federal and provincial water resource agencies, universities and industrial concerns.
- 5. To achieve coordination of a national water inventory.
- 6. To develop new methods of evaluating and exploiting Canada's inland water resources.

ORGANIZATION

The organization chart shows the present structure and scientific staff of the Subdivision. A scientist and an engineer with respectively the Water Science Subdivison and the Water Survey of Canada both of whom are involved in glaciological studies are also listed.

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Glaciology Subdivision

Løken, O.H. Head

Logan, Mrs. L. Secretary

Arctic Section

Holdsworth, G., Head

Arnold, K.C. Christian, D.M. Embacher, U.H.O. Fogarasi, S.F. Terroux, A.D. MacKay, D.K. Thakur, T. (Postdoctorate Fellow)

Cordillera Section

Stanley, A.D., Head

Beck, T.H.M. Bellaar-Spruyt, T. Derikx, L. Henoch, W.E.S. Loijens, H. Mokievsky-Zubok, O. Föhn, P. (Postdoctorate Fellow)

Glacier Inventory Section

Ommanney, C.S.L., Head

Strome, M.M. Clarkson, J. (term appointment) Ice Science Section

Jones, S.J., Head

Barnett, G.A. Chen, E.F. Dickins, D.F. Ramseier, R.O. Gilra, N. (Postdoctorate Fellow)

Goodman, R. Water Science Subdivision Reid, I. Water Survey of Canada

Functions Of Sections

Arctic and Cordillera Sections. These sections carry out field research in the two main regions of the country where glaciers occur. The glaciers are considered as the cold-climate equivalent of lakes in warmer regions and their fluctuations due to climatic factors, their role as water reservoirs, their temperature characteristics and dynamic responses are investigated. Increased emphasis is being put - particularly in the Arctic - on studying potential problems associated with mineral exploration and exploitation in glacierized areas and on the role of calving outlet glaciers as sources of icebergs.

Glaciology also comprises the study of snow and detailed investigations of snowmelt processes are conducted in conjunction with glacier-hydrology studies. These snowmelt processes are of fundamental importance to all parts of the Nation as a large proportion of the total runoff is derived from snow.

Ice Science Section. The function of this section includes studies of the fundamental physical properties of ice samples collected from glaciers, from ice sheets on lakes and rivers and of special ice samples grown in the laboratory. Studies of lake and river ice and of the characteristics and behaviour of hydrocarbon oils in contact with ice and snow are also carried out.

<u>Glacier</u> <u>Inventory Section</u>. Work in this area is directed toward compiling the national inventory of Canada's permanent snow and ice masses. This includes an inventory of ground ice and the project forms a major part of our contribution to the Canadian program under the International Hydrological Decade.

FUTURE OF PROJECTS

Several criteria have been developed to assess new project proposals; the two major being <u>national need</u> and <u>scientific</u> <u>significance</u>. The former reflects the necessity of directing our effort towards satisfying identifiable needs; this is imperative if the Federal Government is to fulfill its functions. However, we must also be engaged in what may appear to be somewhat esoteric research, because, in addition to meeting immediate needs we must prepare to solve future problems. Many of these problems are not yet defined and their solutions are not known, but they are likely to be unconventional, i.e. they are now at the research stage. It is difficult to foresee accurately which projects will be most useful, but high scientific significance must remain an important criterion.

It is necessary to take into account that the selection criteria to a certain extent are time variable as the emphasis is subject to change in accordance with Government priorities. This may result in the cancellation of some projects and in the starting of others. Also, there may be cases in which the distribution of manpower and financial resources between the various projects will shift as changing needs become apparent.

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While scientific research is important it must not become a goal in itself and the importance of translating scientific research results into techniques applicable to operational situations must contantly be stressed.

COOPERATION AND LIAISON

It was pointed out in the last project presentation that scientific research is indeed a continuum and that any form of subdividing the field will to some extent be arbitrary. Cooperation with other agencies is therefore imperative, particularly in the strongly scientifically oriented project where new fundamental knowledge common to all is sought. Projects which are more operationally oriented may to a larger degree be handled 'in house' but even these often require coordination of logistic operation; this is particularly true in remote areas such as in the Canadian Arctic.

Cooperation with other agencies also extends beyond Canada as many problems can only be solved through international cooperation. Our extensive participation in the program of the International Hydrological Decade clearly shows this international orientation.

RECENT CHANGES IN RESEARCH ACTIVITIES

This section deals with the project changes which have taken place since the last report was published about 18 months ago.

The previous report contained 34 projects sponsored by the Inland Waters Branch; this report contains 49 projects. One of these projects has been completed: G-67-19, Summit Lake Drainage; two projects have been terminated because the principal investigator has left: G-69-9, Scanning Electron Microscopy of Ice Surfaces, and G-69-10, Thermo-electric Power of Ice; one project: G-67-10, Baffin Island Climatology has been modified and reappears as G-70-7 under the same title; and finally one project G-69-4, Glacier climate relationship on the Devon Ice Cap, is dormant due to the delay in start of the closely associated North Water Project of the Arctic Institute of North America. There are thus 44 active projects including 13 new projects which have been added during 1970 and 1971. The distribution of the new projects reflects the changes in priorities which have taken place.

1. Four of the 13 projects relate to the study of hydrocarbon oils in a cold environment, particularly in contact with ice and snow. These projects were started in response to the perceived need for better practical and fundamental knowledge of how oils behave in contact with snow and ice. The increasing awareness of our environment and the accelerated pace of oil exploration in the Arctic show that such a need exists. These four projects are part of a much larger Oil Pollution Research Program which is jointly undertaken by the Glaciology and the Water Science Subdivisions.

- 2. Another 4 projects deal with hydrologic conditions in the Mackenzie Valley. This area is a focal point for all developments in the Western Arctic; the Mackenzie River is our second largest river and a major transportation route; oil has been discovered in the Delta region; a gas pipeline Alaska-Alberta appears to be a strong possibility and the prospects of an oil pipeline to follow is looming on the horizon. With the high possibility of major new developments taking place it is obvious that we cannot waste time in obtaining fundamental facts about the environment of this region.
- 3. With the discovery of rich mineral deposits and recent advances in icebreaker technology, shipping activities in the Arctic are expected to increase over the next few years, and information about icebergs will be required. Project G-70-2, Iceberg Production Survey in Arctic Canada, will provide information about their source areas. This is an important first step although the immediate dangers caused by icebergs are best appreciated from a ship or an oil drill-rig on the Grand Banks off Newfoundland.
- 4. Basic information about the Arctic environment is eagerly sought at the present time, and this is unquestionably important. But we must also study the rate and direction of environmental change. The study of glacier variations may provide such information - hence project G-71-5 which will monitor the fluctuations of selected small Arctic ice caps by photogrammetric methods.
- 5. The planned launching of the Earth Resources Technology Satellite (ERTS) opens new possibilities for the application of remote sensing techniques to environmental studies. One new project (G-71-7) aims specifically at investigating how ERTS data may be used for glaciological purposes.
- 6. Project G-71-6 reflects the need for developing reliable meteorological instrumentation for automatic recording of meteorological and other data at remote stations (particularly in the Arctic) on an all-year basis.
- 7. Project G-71-1 investigates the diffusion of various substances in ice, as such diffusion may substantially change the physical characteristics (e.g. the mechancial strength) of the ice.

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OTHER DEVELOPMENTS

In 1968 the Inland Waters Branch commissioned H.G. Acres Ltd. to "Review the current state of ice technology, to identify deficiencies in present knowledge to assess the overall economic impact of ice on a national scale and to identify and order ice research needs in terms of potential economic payoffs". The report "Review of Current Ice Technology and Evaluation of Research Priorities" was submitted in 1970 and will be used as a basis for developing our research program. The report will be published by the Inland Waters Branch.

PROGRESS

It is inherently difficult to measure the progress and achievements of a research oriented organization as the practical usefulness of many research results may not be appreciated until several years have passed. However, published scientific papers, reports and maps constitute concrete achievements and the following items have been published in 1970 and early 1971 as results of Inland Waters Branch glaciology studies. Some of the studies have been undertaken in close cooperation with universities, such as Laval, McGill and Toronto, and the contributions of the faculty members are gratefully acknowledged.

SCIENTIFIC PAPERS AND REPORTS

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Fisher, D.A. and Jones, S.J.

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Goodison, B.

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- 1970 : <u>Peyto Glacier Map</u>, 1:10,000; Sedgwick, J.K. and Henoch, W.E.S. Interpretive notes and map. English and French Edition, 1970.
- 1971 ; Estimate of glaciers secular (1948-1966) volumetric change and its contribution to the discharge in the Upper North Saskatchewan River Basin. Journal of Hydrology, Vol. 12, pp. 145-160.

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Holdsworth, G.

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Løken, O.H. and Hodgson, D.A.

1971 : On the submarine geomorphology along the east coast of Baffin Island. <u>Canadian</u> <u>Journal</u> of <u>Earth</u> <u>Sciences</u>, Vol. 8, No. 2, pp. 185-195.

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MacKay, D.K.

- 1970 : Electrical resistivity measurements in frozen ground, Mackenzie Delta area, Northwest Territories. Symposium on the Hydrology of Deltas, Bucharest, Romania, 1969. International Association of Scientific Hydrology Publication, Reprint Series No. 82, pp. 364-375.
 - The ice regime of the Mackenzie Delta, Northwest Territories. <u>Symposium on the Hydrology of Deltas</u>, Bucharest, Romania, 1969. <u>International Association</u> of <u>Scientific</u> <u>Hydrology</u> <u>Publication</u>, Reprint No. 83, pp. 357-362.
 - : The Ramparts of the Mackenzie River. Waterways. Inland Waters Branch, Department of Energy, Mines and Resources, No. 16, pp. 7-11.

Michel, B. and Ramseier, R.O.

- 1970 : <u>Structural and textural characteristics of river ice</u> <u>based on meteorological parameters, St. Lawrence Ship</u> <u>Channel.</u> Université Laval, Faculté des Sciences, Departement de Genie Civil, Section Mécanique des Glaces, Report T-13, 60 pp.
- 1971 : Classification of river and lake ice. <u>Canadian</u> Geotechnical Journal, Vol. 8, No. 36, pp. 36-45.

Müller, F. and Ommanney, C.S.L.

1971 : The contribution of glacier ice to the world water balance (a status report on the World Glacier Inventory). <u>Symposium on the World Water Balance</u>, Reading, 1970, Vol. 3, <u>International Association of</u> <u>Scientific Hydrology Publication</u>, No. 94, pp. 6-20. (I.W.B. Reprint Series No. 102).

Nakamura T. and Jones, S.J.

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Ommanney, C.S.L.

1970 : A pilot study for an inventory of the glaciers of the high Arctic. Glacier inventory of Steacie Ice Cap Area (79° N, 90°W), Axel Heiberg Island, N.W.T. In: <u>Perennial Ice and Snow Masses.</u> <u>UNESCO/IASH Technical</u> <u>Papers in Hydrology 1, A. 2486, pp. 25-35.</u> (I.W.B. Reprint Series No. 65). Glaciers in Canada: photographs and manuscripts held by the Scott Polar Research Institute, Cambridge, England. <u>Glacier Inventory Note 1</u>, Inland Waters Branch, Department of Energy, Mines and Resources, Ottawa, 8 pp. (Mim)

: Photographs of glaciers in Western Canada held by the Royal Geographical Society, Kensington Core, London, England. <u>Glacier Inventory Note 2</u>, Inland Waters Branch, Department of Energy, Mines and Resources, Ottawa, 11 pp. (Mim)

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- 1971 : Photographs of glaciers in British Columbia held by the Film and Photographic Branch, Department of Travel Industry, British Columbia. <u>Glacier Inventory Note</u> 3, Inland Waters Branch, Department of Energy, Mines and Resources, Ottawa 7 pp. (Mim)

The Canadian Glacier Inventory. In: Glaciers, <u>Proceedings of Workshop Seminar</u>, Vancouver, B.C., 1970, Canadian National Committee for the International Hydrological Decade, pp. 23-30.

Ommanney, C.S.L., Clarkson, J., and Strome, M.M.

1971 : Information booklet for the Inventory of Canadian Glaciers. <u>Glacier Inventory Note 4</u>, Inland Waters Branch, Department of Energy, Mines and Resources, Ottawa, 68 pp. (Mim)

Østrem, G. and Arnold, K.

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1970 : Ice-cored moraines in Southern British Columbia and Alberta, Canada. <u>Geografiska Annaler</u>, Vol. 52, Ser. A, pp. 120-128.

Ramseier, R.O.

1970 : Mechanical behaviour of ice at high temperatures. Bulletin American Physical Society, Vol. 15, pp. 812.

Reid, I.A. and Shastal, J.

1970 : Glacier surveys in British Columbia, 1968. Inland Waters Branch, Report Series No. 10, 26p.

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Stanley, A.D.

- 1970 : Inventory of glaciers in the Waputik Mountains. In: <u>Perennial Ice and Snow Masses</u>. A Guide for Compilation and Assemblage of Data for a World Inventory, <u>UNESCO/IASH</u> <u>Technical Papers in Hydrology</u>, Vol. 1, pp. 36-46.
- 1971 : Combined balance studies of selected glacier basins in Canada. In: Glaciers, Proceedings of Workshop Seminar, Vancouver, B.C., 1970, Canadian National Committee for the International Hydrological Decade, pp. 5-10.

Thakur, T.R.

1971 : Persistence patterns of river meanders, <u>Transactions</u> of <u>American</u> <u>Geophysical</u> <u>Union</u>, Vol. 52, No. 4, p. 203, (abstract).

Thakur, T.R. and A.E. Scheidegger

- 1970 : Chain model of river meanders, <u>Transactions of American</u> <u>Geophysical Union</u>, Vol. 51, No. 4, p. 278, (abstract).
 - : Chain model of river meanders, Journal of Hydrology, Vol. 12, No. 1, pp. 23-46.

Young, Gordon

1971 : Mass balance measurements related to surface geometry on Peyto Glacier, Alberta. <u>In: Glaciers, Proceedings</u> of Workshop Seminar, 1970, Canadian National Committee for the International Hydrological Decade, pp. 11-20.

MAPS

The following index maps for the Glacier Inventory have been published. (All at the scale 1:500,000).

4.0	Axel Heiberg Island	IWB	1129
4.1	Southern Axel Heiberg Island	IWB	1106
4.2	Central Axel Heiberg Island	IWB	1112
4.3	Western Axel Heiberg Island	IWB	1115
4.4	Northern and Eastern Axel Heiberg Island	IWB	1105
5.0	Baffin Island	IWB	1125
5.1	Bylot Island	IWB	1102
5.2	Brodeur Peninsula	IWB	1104

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5.3 5.4 5.5 5.6 5.7 5.8 5.9 5.10 5.11 5.12	Borden Peninsula - Wes Borden Peninsula - Eas Milne Inlet Tay Sound Pond Inlet Cambridge Fiord Barnes Ice Cap Gibbs Fiord Sam Ford Fiord Clyde Inlet	st	IWB IWB IWB IWB IWB IWB IWB IWB	1101 1103 1109 1111 1107 1114 1116 1117 1110 1113
5.12 5.13 5.14 5.15 5.16 5.17 5.18 5.19 5.20 5.21 5.22 5.22 5.23 5.24	McBeth Fiord Home Bay Okoa Bay Coronation Fiord Padle Fiord Hoare Bay Kingnait Fiord Penny Ice Cap Popham Bay Beekman Peninsula Blunt Peninsula Meta Incognita Peninsu	lla	IWB IWB IWB IWB IWB IWB IWB IWB IWB IWB	1108 1118 1119 1121 1126 1123 1122 1120 1127 1128 1130 1124
7.0 7.1 7.2 7.3 7.4	Nelson River Drainage Oldman River Bow River Red Deer River North Saskatchewan Riv	Basın ver	IWB IWB IWB IWB	1132 1134 1133 1131

Ottawa, May 1971.

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Catalogue of Projects

MASS AND WATER BALANCE MEASUREMENTS AT PLACE GLACIER

PRINCIPAL INVESTIGATOR: 0. Mokievsky-Zubok

COOPERATING AGENCY: Water Survey of Canada

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

The glacier is one of a worldwide network of glacier basins selected for detailed mass, water and energy balance measurements under the International Hydrological Decade (IHD) program.

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

PREVIOUS WORK ON THIS PROJECT:

- 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. <u>References</u>: Østrem, G., 1966. Mass balance studies on glaciers in Western Canada. <u>Geographical Bulletin</u>, Vol. 8, No. 1, pp. 81-107.

Inland Waters Branch, 1967. <u>Relief map of Place Glacier</u>, 1:10,000.

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

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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 installed at 1,850 m a.s.l.: Automatic precipitation gauge and long-term recorders for temperature, relative humidity, wind run and direction.

The gauging station has been constructed by the Water Survey of Canada to record stream discharge throughout the year.

FUTURE WORK: Continuation of glaciological, hydrological and meteorological observations throughout the decade.

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DISCHARGE COMPONENTS OF A MELTWATER STREAM FROM DRAINAGE BASIN OF SENTINEL GLACIER

PRINCIPAL INVESTIGATOR: O. Mokievsky-Zubok

COOPERATING AGENCY: Water Survey of Canada

- 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:
 - Evaluating existing techniques of measuring changes in glacier volume and by establishing criteria for direct comparison of these methods - surface measurement of stakes, terrestrial photogrammetry and hydrologic methods.
 - Developing a method of identifying the glacier meltwater component in a stream which includes runoff from unglacierized areas.
 - 3. Relating glacier variations to recent climatic trends. The glacier belongs to the worldwide network of glacier basins selected for detailed mass, water and energy balance measurements under the IHD program.
- LOCATION: Coast Mountains (49° 50' N, 122° 55' W) 70 km north of Vancouver, B.C.

PREVIOUS WORK ON THIS PROJECT:

 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.

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WORK IN PROGRESS:

- 1. Surface measurements along longitudinal and transverse profiles to establish the winter balance in late May, and measurements at 33 locations on the glacier's surface to obtain summer balance and ablation.
- Meltwater discharge measured within the main meltwater channel using a Stevens A-35 stage recorder located at 1,500 m a.s.l. The rating curve is re-established each year.
- 3. Meteorological observations are taken for the periods May-October. Instrumentation installed at 1,540 m a.s.l. includes:
 - *Thermohygrograph *Totalizing Anemometer Sunshine Recorder

Solarimeter Simple Precipitation Gauge

Seven precipitation gauges have been located throughout the basin and a thermohygrograph set at 1,900 m a.s.l.

- *The first two instruments have been replaced by longterm recorders.
- 4. Terrestrial photogrammetry of the ablation area was repeated during August 1970 by the Water Survey of Canada.

FUTURE WORK:

- 1. Continuation of all glaciological, hydrological and meteorological observations.
- Study of hydrology and sediment transport of the meltwater stream.

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MASS AND WATER BALANCE MEASUREMENTS AT WOOLSEY GLACIER

PRINCIPAL INVESTIGATOR: A.D. Stanley

COOPERATING AGENCY: Water Survey of Canada

- 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.
 - 3. Relating glacier variations to recent climatic trends.

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

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

PREVIOUS WORK ON THIS PROJECT:

- 1. <u>Field</u>: 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.
- <u>References</u>: Østrem, G., 1966. Mass balance studies on glaciers in Western Canada, 1965. <u>Geographical Bulletin</u>, Vol. 8, No. 1, pp. 81-107.

Inland Waters Branch, 1968. <u>Coloured Relief Map of Woolsey</u> Glacier, 1:10,000.

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WORK IN PROGRESS:

- 1. Measurement of winter balance in mid-May and continuous study of ablation throughout the summer at more than 37 locations on the glacier surface.
- 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 installed at 1,990 m a.s.l. includes an automatic precipitation gauge and long-term recorders for temperature and relative humidity.

FUTURE WORK: Continuation of mass balance and water balance measurements until the end of the decade.

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MASS AND WATER BALANCE MEASUREMENTS AT PEYTO GLACIER

PRINCIPAL INVESTIGATOR: A.D. Stanley

COOPERATING AGENCY: Water Survey of Canada

- 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.

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

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

PREVIOUS WORK ON THIS PROJECT:

- 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. <u>References</u>: Goodison, B., 1969a. <u>Distribution of global</u> <u>radiation over Peyto Glacier</u>, Alberta. Report prepared for the Inland Waters Branch, 49 pp.

Goodison, B., 1969b. An analysis of climate and runoff events for Peyto Glacier. Report prepared for the Inland Waters Branch, 61 pp.

Goodison, B., 1971. The relation between ablation and global radiation over Peyto Glacier, Alberta. In: Glaciers,

Proceedings of Workshop Seminar, Vancouver, B.C., 1970. Canadian National Committee for the International Hydrological Decade, pp. 39-42.

Østrem, G., 1966. Mass balance studies on glaciers in Western Canada, 1965. <u>Geographical Bulletin</u>., Vol. 8, No. 1, pp. 81-107.

Sedgwick, K., 1966. <u>Geomorphology and mass budget of Peyto</u> <u>Glacier</u>, Alberta. M.A. Thesis, McMaster University.

Young, G., 1971. Mass balance measurements related to surface geometry on Peyto Glacier, Alberta. In: <u>Glaciers</u>, <u>Proceedings of Workshop Seminar</u>, Vancouver, B.C., 1970. Canadian National Committee for the International Hydrological Decade, pp. 11-20.

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 measurements 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 installed each summer at 1,900 m a.s.l. includes: sunshine recorder, solarimeter, rain gauge and long-term recorders for temperature, relative humidity, wind run and direction. Other instruments include seven precipitation gauges throughout the basin and a Stevens A-35 recorder in the meltwater channel. Thermographs were installed in the basin.
- 4. During the early summer, 1970, a detailed study of the pattern of snow distribution was completed by G. Young of McGill University. This will be used to evaluate snow distribution models based upon physical parameters of the basin.

FUTURE WORK: Continuation of all glaciological, hydrological and meteorological observations and calculation of mass and water balance for the duration of the decade.

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MASS AND WATER BALANCE MEASUREMENTS AT RAM RIVER GLACIER

PRINCIPAL INVESTIGATORS: A.D. Stanley

COOPERATING AGENCY: Water Survey of Canada

- 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.

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

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

PREVIOUS WORK ON THIS PROJECT:

- 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. <u>References</u>: Inland Waters Branch, 1967. <u>Coloured Relief</u> <u>Map of Ram Glacier</u>, 1:10,000.

Østrem, G., 1966. Mass balance studies on glaciers in Western Canada, 1965. <u>Geographical Bulletin</u>, Vol. 8, No. 1, pp. 81-107.

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WORK IN PROGRESS:

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- 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 installed at 2,550 m a.s.l. includes an automatic precipitation gauge and long-term recorders for temperature, relative humidity, wind run and direction.

FUTURE WORK: Continuation of all glaciological, hydrological and meteorological observations during the decade.

GLACIOLOGICAL INVESTIGATIONS IN THE AREA OF BERENDON GLACIER

PRINCIPAL INVESTIGATOR: A.D. Stanley

COOPERATING AGENCY: Granduc Operating Company Ltd.

- 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.

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

PREVIOUS WORK ON THIS PROJECT:

1. Field: In 1956-1957, an expedition to the Salmon Glacier area to make seismic, gravimetric, glaciological and photogrammetric studies 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 begin in late 1967 and include surface measurements of the mass balance, daily

discharge measurements of the stream below the lake and meteorological observations from late May to early October.

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 others have been added in later years.
- 4. A stream gauge was installed in August 1967 and rating curves and stage records obtained.
- 5. Meteorological parameters were obtained during the summer at one main site near the glacier terminus. Instruments installed at 630 m a.s.l. now include: sunshine recorder, actinograph, automatic precipitation gauge, and long-term recorders of temperature, relative humidity, wind run and direction.
- 6. D. Fisher and S. Jones completed an analysis of the glacier flow based on surveys in 1968 and 1969 and a paper has been sent to the Journal of Glaciology.

FUTURE WORK:

- Continuation of glaciological, hydrological and meteorological program during the decade.
- Measurement of glacier depths for selected longitudinal and transverse profiles using a radio-echo sounder.

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GLACIER SURGES

PRINCIPAL INVESTIGATOR: A.D. Stanley

- COOPERATING AGENCIES: Surveys and Mapping Branch; Polar Continental Shelf Project; Icefield Ranges Research Project, (Arctic Institute of North America and American Geographical Society).
- OBJECTIVES: To obtain information on glacier surges from maps, air photos, description of surges, etc. to evaluate existing theories as to their causes.
- LOCATION: Ottawa, and Steele and Fox glaciers, Icefield Ranges, Yukon.

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

Stanley, A.D., 1969. Observations of the surge of Steele Glacier, Yukon Territory, Canada. <u>Canadian Journal of Earth</u> Sciences, Vol. 6, pp. 819-830.

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

FUTURE WORK:

 In cooperation with other groups - to obtain further information on the final stages of the surge - including aerial photographs and surface measurements.

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- 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.

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PEYTO GLACIER AREA MAP

PRINCIPAL INVESTIGATORS: W.E.S. Henoch

- COOPERATING AGENCIES: Surveys and Mapping Branch; National and Historic Parks Branch, (Department of Indian Affairs and Northern Development).
- 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.
- LOCATION: Peyto Glacier (51° 40' N, 116° 34' W) in the Rocky Mountains 45 km northwest of Lake Louise, Alberta.
- 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).

Reference: Henoch, W.E.S., 1970. <u>Peyto Glacier Map</u> 1:10,000; Sedgwick, J.K. and Henoch, W.E.S. Interpretive notes and map. English and French Edition, 1970.

WORK IN PROGRESS: Application of shaded relief techniques to the Peyto Map. Several terrestrial photographs and low oblique aerial photographs were obtained showing details of rock exposures and steep walls in preparation for detailed cartography on the map.

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FUTURE WORK:

- 1. Publication of a map complete with shaded relief and bedrock portrayal.
- Assessment of use and demand to identify any need for similar maps of other glaciers.

BARNES ICE CAP STUDIES

PRINCIPAL INVESTIGATOR: G. Holdsworth

COOPERATING AGENCIES: Surveys and Mapping Branch, Geodetic Survey.

OBJECTIVES: Measurements will be continued on the Barnes Ice Cap as part of a long-term (10 year) 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. A second-order survey of pole arrays, extending from the summit of the south dome to the NE margin of the south lobe, will be remeasured yearly up until 1972 for purposes of establishing the flow regime and net balance of the region of greatest accumulation.

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

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. Up to 1969 the program was 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, <u>Geographical</u> Bulletin., Vol. 9, No. 3, pp. 232-261.

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

Løken, O.H., 1965, 1966 and 1967. Field Reports, North-Central Baffin Island. Geographical Branch, (Mim).

Løken, O.H., and Andrews, J.T., 1966. Glaciology and chronology of fluctuations of the ice margin at the south

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end of the Barnes Ice Cap, Baffin Island, N.W.T., Geographical Bulletin, Vol. 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. <u>International Association of Scientific Hydrology Publication</u> No. 79, pp. 282-291.

Løken, O.H., 1969. Evidence of surges on the Barnes Ice Cap, Baffin Island. <u>Canadian</u> Journal of Earth Sciences, Vol. 6, No. 4, pp. 899-901.

WORK IN PROGRESS:

- 1. An assessment of mass balance for the ice cap up to 1969 is being made.
- Ice depth measurements have been made (Jones, S.J., 1970) by radio-echo sounder for the survey network from the South Dome to the margin (results available December, 1970).
- 3. Surface movement and surface strain rate are being measured on the southern part of the ice cap. Near the margin surface deformation is related to the character of the ice margin. Factors controlling the type of margin and hence the marginal mode of flow are to be studied. Two localities to begin with will undergo intensive study, one is a margin which flows into a lake (Generator Lake); the other is a landbased margin without shear moraine development. The latter is being studied by Professor R. LeB. Hooke, University of Minnesota.
- 4. Temperatures at 10 m depth in the ice cap are measured by guartz thermometer (1969, 1971).
- 5. Glacier-climate relationships are investigated under the Baffin Island climatology project.

FUTURE WORK:

- 1. Drill hole through part of the ice cap is planned for summer 1971 or 1972 and associated core and borehole investigations would start when the hole is completed. Alternatively a deep remote probe for measuring basal temperatures could be ready by 1971 or 1972.
- 2. Studies of margins showing shear moraines by deformational and structural measurements (R. Hooke, University of Minnesota).

- 3. 10 m temperatures are to be studied in additional shallow drill holes.
- 4. Accumulation of data (temperature, deformation) to enable generalized flow laws to be determined for the ice cap, and a more precise net balance to be established for a part of the ice cap.
- 5. Investigation of surface instabilities including crevasses on the top of the south shoulder and undulations near the margins of the ice cap.

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BAFFIN ISLAND CLIMATOLOGY

PRINCIPAL INVESTIGATOR: S. Fogarasi

Project discontinued - see G-70-7
DECADE GLACIER STUDIES

PRINCIPAL INVESTIGATOR: U.H.O. Embacher

COOPERATING AGENCY: None

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;
- 3. Relating glacier variations to recent climatic trends;
- 4. Comparing glacier runoff to the regime of an adjacent unglaciated basin.

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

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

PREVIOUS WORK ON THIS PROJECT:

 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

- concurrent discharge records of the two rivers were taken;
- stakes have been surveyed for movement studies and three profiles were leveled across the glacier to determine changes in surface elevation:

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- extent, amount and profiles of aufeis formations of two basins.
- References: Løken, O.H., 1965, 1966, 1967. Field Reports, 2. North-Central Baffin Island. Geographical Branch, (Mim.).

Østrem, G., Bridge, C.S. and Rannie, W.F., 1967. Glaciohydrology, discharge and sediment transport in the Decade Glacier area, Baffin Island, N.W.T., Geografiska Annaler, Vol. 49, pp. 268-282.

Surveys and Mapping Branch, E.M.R., 1965. Decade Glacier Base Map, 1:10,000.

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WORK IN PROGRESS:

- 1. Continuation of all glaciological, hydrological and meteorological observations, with more emphasis on both river regimes, extending observations well into the freezeup period.
- Investigation of the use of special forms and surfaces as 2. markers in the stratigraphic column of a glacier, to trace the areal extent and annual variation of mass balance.
- Study of the lake, permafrost, groundwater and aufeis system 3. of two river basins.

FUTURE WORK:

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

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PER ARDUA GLACIER STUDIES

PRINCIPAL INVESTIGATOR: U.H.O. Embacher

COOPERATING AGENCY: Defence Research Board.

- 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. Measurement of mass balance.
 - 2. Relating glacier variations to recent climatic trends.

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

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

PREVIOUS WORK ON THIS PROJECT:

- Field: Glacier was originally selected by Geophysics Section, Defence Research Board and field work was started in 1964, then taken over by the Glaciology Subdivision in 1968 as an International Hydrological Decade project.
- 2. <u>Reference:</u> Hattersley-Smith, G., 1967. <u>Operation Tanquary</u> <u>preliminary report</u>, D.R.B., D.I.R. PHYS. R. (G) Hazen, pp. 22-25.

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

FUTURE WORK:

- 1. Installation of instrumentation for summer discharge measurements.
- Installation of long period recording equipment.

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3. Investigation of detailed studies of snow and firn metamorphosis in a high-Arctic environment.

4. Measurement of glacier thickness.

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GLACIER INVENTORY

PRINCIPAL INVESTIGATOR: C.S.L. Ommanney

COOPERATING AGENCY: None

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.

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LOCATION: Ottawa, Ontario.

PREVIOUS WORK ON THIS PROJECT:

1. Office: Two pilot studies were completed for the UNESCO Guide to the Inventory of Perennial Ice and Snow Masses. Glacier inventories of Axel Heiberg Island and Vancouver Island have been completed. All glaciers on Baffin, Bylot and Devon islands have been indexed. Inventory work maps for all glaciers between Waterton Lakes and the Columbia Icefield have been prepared as well as for part of the Columbia River headwaters.

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

2. <u>References</u>: 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 <u>International</u> <u>Association of Scientific Hydrology General Assembly</u>, 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. <u>International</u> <u>Association of Scientific Hydrology</u> <u>Bulletin</u>, Vol. 14, No. 1, pp. 19-28.

Ommanney, C.S.L., 1969. The ice masses of Axel Heiberg Island, Canadian Arctic Archipelago: a study in glacier inventory. <u>Axel Heiberg Island Research Reports</u>, Glaciology, No. 3, McGill University, Montreal, approx. 90 pp.

Ommanney, C.S.L., 1969. Glacier Inventory of Canada: Axel Heiberg Island, N.W.T. <u>Inland Waters Branch</u> <u>Technical</u> <u>Bulletin No. 37</u>, Department of Energy, Mines and Resources, Ottawa, 97 pp.

Ommanney, C.S.L., 1970. A pilot study for an inventory of the glaciers of the high Arctic. Glacier inventory of Steacie Ice Cap area (70° N, 90° W), Axel Heiberg Island, N.W.T. In: Perennial Ice and Snow Masses, UNESCO/IASH Technical Papers in Hydrology No. 1, A.2486, pp. 25-35. (I.W.B. Reprint Series No. 102).

Ommanney, C.S.L., 1970. A national inventory of glaciers. Park News, October, pp. 15-20 (I.W.B. Reprint Series No. 93).

Stanley, A.D., 1970. Inventory of glaciers in the Waputik Mountains; a pilot study for an inventory of the glaciers in the Rocky Mountains. In: <u>Perennial Ice and Snow Masses</u>, <u>UNESCO/IASH Technical Papers in Hydrology No. 1</u>, A.2486, pp. 36-46.

Ommanney, C.S.L., 1971. The Canadian Glacier Inventory. In: <u>Glaciers Proceedings of Workshop Seminar</u>, 1970, Vancouver, B.C., Canadian National Committee for the International Hydrological Decade, (in press).

Müller F. and Ommanney, C.S.L., 1971. The contribution of glacier ice to the world water balance; (a Status Report on the World Glacier Inventory). <u>Symposium on the World</u> <u>Water Balance</u>. Reading, 1970, <u>Vol. 3. International</u> <u>Association of Scientific Hydrology</u>, <u>Publication No. 94</u>, pp. 6-20 (I.W.B. Reprint Series No. 102).

Ommanney, C.S.L., Clarkson, J. and Strome, M.M., 1971. Information booklet for the inventory of Canadian glaciers. Glacier Inventory Note 4, Inland Waters Branch, Department of Energy, Mines and Resources, Ottawa, 68 pp.

WORK IN PROGRESS:

- 1. Inventory work maps for glaciers in the headwaters of the Columbia and Kootenay rivers systems are being prepared.
- Using a D-Mac pencil follower interfaced with a PDP 8/I computer, location, length, area and elevation data on all glaciers in the Nelson River system is being digitized from the work maps.
- 3. A report on the glacier inventory of Vancouver Island is being prepared.
- 4. Modifications are still being made to the computer program for the analysis of inventory data.

FUTURE WORK:

- 1. <u>Short-term</u>: 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 the remaining 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.

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DETERMINATION OF ICE ABLATION BY TERRESTRIAL PHOTOGRAMMETRY

PRINCIPAL INVESTIGATOR: K.C. Arnold

COOPERATING AGENCY: McGill University, Polar Continental Shelf Project

- 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.
 - Examine some criteria by which benchmark glaciers may be selected, with special reference to those in Arctic Canada.
- LOCATION: White Glacier, Axel Heiberg Island (79° 28' N, 90° 45' W), N.W.T.

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.

 <u>References</u>: Arnold, K.C., 1966. The glaciological maps of Meighen Island, N.W.T. <u>Canadian Journal of Earth Sciences</u>, Vol. 3, No. 6, pp. 903-908.

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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 pp.

Weber, J.R., Sandstrom N., and Arnold, K.C., 1960. Geophysical surveys on Gilman Glacier, Northern Ellesmere Island, N.W.T. International Association of Scientific Hydrology, Publication No. 54, pp. 500-511.

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.
- A detailed field program to test the technique has been 3. 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.

FUTURE WORK:

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

DEFECTS IN ICE CRYSTALS

PRINCIPAL INVESTIGATOR: S.J. Jones

COOPERATING AGENCIES: Polar Continental Shelf Project; Axel Heiberg Expedition, McGill University.

OBJECTIVES:

- 1. Short-term: To determine the density of dislocations and their velocity under stress in pure and impure ice.
- 2. Long-term: By studying the distribution of defects, in particular dislocations in ice crystals, it is hoped to understand:
 - a) The nature of the flow of ice under stress (glacier movement).
 - b) The underlying reason for the effect that impurities have on the flow of ice (see G-68-1).
 - c) The role of dislocations in the formation of ice.

LOCATION: Ice Science Laboratory, Ottawa, Ontario.

PREVIOUS WORK ON THIS PROJECT: The first results of this work have been published:

Jones, S.J., 1970. X-ray topographic evidence for prismatic dislocation in ice. <u>Journal of Applied Physics</u>, Vol. 41, No. 6, pp. 2738-2739.

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WORK IN PROGRESS: Equipment is being designed that will enable the samples to be stressed while on the X-ray apparatus. Natural ice from Meighen Ice Cap and White Glacier (Axel Heiberg Island) is being examined.

FUTURE WORK:

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- 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.
- 3. Natural ice will continue to be examined to see what information can be obtained about its history from a study of the topographs.

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COMPUTER APPLICATIONS TO GLACIER FLOW: BERENDON GLACIER, B.C.

PRINCIPAL INVESTIGATORS: S.J. Jones and D.A. Fisher.

COOPERATING AGENCY: None.

OBJECTIVES: To repeat some earlier calculations using much better data collected by the Subdivision in order to see what effect this would have on the predicted behaviour of Berendon Glacier.

LOCATION: Berendon Glacier, B.C. (lat. 56° 15' N, long. 130° 05' W).

PREVIOUS WORK ON THIS PROJECT:

1. <u>References</u>: Fisher, D.A. and Jones, S.J. 1971. The possible future behaviour of Berendon Glacier, British Columbia a further study. <u>Journal of Glaciology</u>, Vol. 10, No. 58, pp. 85-92.

Untersteiner, N. and Nye, J.F., (1968). Computations of the possible future behaviour of Berendon Glacier, Canada. Journal of Glaciology, Vol. 7, No. 50, pp. 205-213.

FUTURE WORK: It is anticipated that the calculations will be repeated in about 1972 when another two years data will be available.

DRAINAGE BENEATH THE SALMON GLACIER-HYDROLOGIC STUDIES SUMMIT LAKE

PRINCIPAL INVESTIGATOR: D. Fisher.

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

Project Completed

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MECHANICAL PROPERTIES OF ICE CONTAINING IMPURITIES

PRINCIPAL INVESTIGATOR: T. Nakamura (Postdoctoral Fellow)

COOPERATING AGENCY: None.

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.

LOCATION: Ice Science Laboratory, Ottawa, Ontario.

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. <u>References</u>: Glen, J.W., and Jones, S.J., 1967. The deformation of ice single crystals at low temperatures. <u>In: Physics of Snow and Ice, International Conference on</u> <u>Low Temperature Science, Hokkaido University, Japan, 1966,</u> <u>Vol. 1, Part 1, pp. 267-275.</u>

Jones, S.J., 1967. Softening of ice crystals by dissolved fluoride ions. <u>Physics Letters</u>, Vol. 25 A, No. 5, pp. 366-367.

Jones, S.J., and Glen, J.W., 1968. The mechanical properties of single crystals of ice at low temperatures. <u>I.U.G.G.</u> <u>General Assembly</u>, Bern, 1967. <u>International Association</u> of Scientific Hydrology, 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. Philosophical Magazine, Vol. 19, No. 157, pp. 13-24.

Nakamura, T. and Jones, S.J., 1970. Softening effect of dissolved hydrogen chloride in ice crystals. <u>Scripta</u> Metallurgica, Vol. 4, pp. 123-126.

WORK IN PROGRESS: A second report summarizing Dr. Nakamura's two years work is being prepared.

FUTURE WORK: The principal investigator has returned to Japan so there will be no further work until another staff member is obtained.

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FLUCTUATIONS OF GLACIERS IN THE ROCKY MOUNTAINS

PRINCIPAL INVESTIGATOR: W.E.S. Henoch.

COOPERATING AGENCY: Geological Survey of Canada.

OBJECTIVES: To study secular glacier fluctuations in selected areas of the Rocky Mountains and examine glacier fluctuations, correlation with climatic parameters, river discharge and dendrochronological records.

LOCATION: The Rocky Mountains.

PREVIOUS WORK ON THIS PROJECT:

- 1. <u>Field</u>: 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.
- 2. <u>References</u>: Henoch, W.E.S., 1970. Estimate of glacier secular volumetric change and its contribution to the discharge in the Upper North Saskatchewan River Basin. Journal of Hydrology, Vol. 12, pp. 136-151.

(Henoch, W.E.S.) and (Parker, M.L.), 1971. The use of Engelmann Spruce latewood density for dendrochronological purposes. Canadian Journal of Forest Research, (in press).

WORK IN PROGRESS: Study of glacier secular fluctuations and the state of contemporary glacier activities will be examined in selected areas peripheral to the major ice masses in the Canadian Cordillera.

FUTURE WORK:

- 1. Tree ring and glaciological data analysis applied to water resources research.
- 2. In preparation: a paper on maximum latewood density correlation with both August temperature and August runoff in the Peyto Glacier area.
- 3. Wood samples collected above the recent elevation of treeline are indicative of the past warmer climate. Several wood samples were collected above treeline in the Peyto Glacier area. They are being analyzed for dendrochronological records. One of these samples dated by C_{14} method yielded the date 2790± 170 G.S.C. A number of wood samples collected in the Canadian Cordillera were C_{14} dated and described by several researchers in: Radiocarbon dates No. I to IX, G.S.C. The implication of these dates as to the climatic changes and glacier fluctuations are being examined.

RADIO-ECHO SOUNDING PROJECT (RESP)

PRINCIPAL INVESTIGATORS: R.H. Goodman and T. Beck

COOPERATING AGENCIES: Polar Continental Shelf Project, and contractors for equipment: Leigh Instruments, Carleton Place, Ontario; Motorola Government Electronics Division, Scottsdale, Arizona; E.D.A. Electronics Ltd. Ottawa; Datagen Canada Ltd., Ottawa.

- OBJECTIVES: To develop instrumentation for the measurement 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.
- LOCATION: Field tests to be conducted on accessible glaciers in the Cordillera including Athabasca Glacier, part of the Columbia Icefield.

PREVIOUS WORK ON THIS PROJECT:

- 1. Field: Initial trails were conducted on Athabasca and Peyto glaciers during the 1968 field season which indicated the feasibility of this project. Equipment was developed and used on sections of Wapta Icefield in 1969. Instrumentation now being redesigned.
- Reference: Goodman, R.H., Stanley, A.D., and Terroux, A.C.D. 1968. Paper: Alaska Science Conference (1968), Whitehorse, Y.T.

Goodman, R.H. and Terroux, A.C.D., 1971. The Use of radioecho sounder Techniques in the study of glacial hydrology. Presented at the <u>Symposium on the Hydrology of Glaciers</u>, Cambridge, England, September 1969.

Goodman, R.H. 1971, Radio echo soundings on temperate glaciers: a Canadian view. <u>Proceedings of the International</u> <u>Conference on Radio Glaciology</u>, Copenhagen, 1970. (in press).

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WORK IN PROGRESS:

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- 1. Assembling equipment and installation within an oversnow vehicle.
- 2. Testing of all systems including communication and recording unit together with compilation of analysis programs.
- 3. Preparation of logistic support including workshop, living trailers and vehicles.

FUTURE WORK:

- 1. Extensive tests at Athabasca Glacier to:
 - a) determine effects of water movement within a glacier
 - b) analyze intra-glacier reflections
 - c) determine under ice topography.
- 2. Use equipment at selected glaciers for scientific and practical information required for:
 - a) ice depth measurements for the glacier inventory,
 - b) under ice topography prior to development of economic deposits below glaciers.

HYDROLOGY OF GLACIERIZED BASINS

PRINCIPAL INVESTIGATOR: L. Derikx

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COOPERATING AGENCY: None.

OBJECTIVES:

- To study in detail the energy, mass and momentum transfer processes in the atmosphere - water - ice system in different scales, both in time and in space.
- 2. To synthesize the results of these and other studies into a flexible and adequate digital simulation model for the runoff from glacierized basins in the Canadian Cordillera.

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

PREVIOUS WORK ON THIS PROJECT:

1. Field: Data have been collected to test the conceptual model.

Standard meteorological and hydrological data since 1965 (Project G-67-4).

Detailed profile measurements of air temperature, "wet bulb" temperature and wind speed, measurements of incoming and reflected shortwave radiation, net-allwave radiation, precipitation and the runoff from an experimental plot (area 5,000 square meters) on the glacier tongue.

Preliminary measurements of areal variability of temperature, relative humidity, run of wind, global radiation and precipitation.

2. Office: The computer programs of the earlier model have been rewritten and extended to include most recent developments and results.

References: Derikx, A.L., 1969. Glacier discharge simulation by groundwater analogue. Presented at the Symposium on the Hydrology of Glaciers, Cambridge, England, 1969.

Goodison, B., 1969. The distribution of global radiation over Peyto Glacier, Alberta. Internal Report to the Inland Waters Branch, 48 pp. and appendices.

Goodison, B., 1969. An analysis of climate and runoff events for Peyto Glacier, Alberta. Internal Report to the Inland Waters Branch, 61 pp.

WORK IN PROGRESS: Application of the present model to a number of glaciers to assess the glacier meltwater contribution to the flow of the Mistaya River, Alberta (part of Project G-69-3). A study of the mass and energy transport properties of the porous ice at the glacier surface. Refinement of computations of mass and energy balance resulting from simultaneous mass, energy and momentum transfer. A study of a routing method applicable to highly turbulent mass transport in the water-ice system. A study of the energy transfer and resulting thermal erosion in a surface meltwater stream to understand the physics and thermodynamics of this water-ice system. A study of the relationships between mass balance observations on the glacier, the physical characteristics of the surface and selected meteorological variables. Development of a procedure to optimize the operation of a multi-parameter simulation model.

FUTURE WORK:

3.

- 1. <u>Field</u>: Continuation and extension of existing field programs to provide adequate test data. Improvement of accuracy of present measurements is required.
- Office: A study of the mass and energy transport properties of a glacier snowpack (extension of Project G-69-8). Digital modeling of temperature, wind and humidity fields in a glacierized basin. Further refinement of mass and energy balance computations.

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GLACIER ATLAS OF CANADA

PRINCIPAL INVESTIGATOR: C.S.L. Ommanney

- COOPERATING AGENCY: Surveys and Mapping Branch, Department of Energy, Mines and Resources.
- 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.

LOCATION: Ottawa, Ontario.

- PREVIOUS WORK ON THIS PROJECT: Glacier index maps of Axel Heiberg, Baffin and Bylot Islands and for the Nelson River drainage area have been completed.
- WORK IN PROGRESS: All completed maps are being printed. Maps of Devon Island, Vancouver Island and part of the Columbia River Basin are being compiled.
- 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.

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GLACIOLOGICAL ARCHIVE

PRINCIPAL INVESTIGATOR: C.S.L. Ommanney

COOPERATING AGENCY: American Geographical Society, World Data Centre A: Glaciology, Seattle.

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.

LOCATION: Ottawa, Ontario.

PREVIOUS WORK ON THIS PROJECT:

- 1. Office:
 - a) Collection of glacier photgraphs as an extension of the glacier inventory conducted for the I.G.Y.
 - b) Indexing and transferring to stable-base film of photographic records of the International Boundary Commission surveys along the B.C. - Alaska border.
 - c) Identification and indexing of early photographs of Baffin, Bylot and Axel Heiberg islands; obtained during the I.G.Y. in conjunction with Project G-69-1.
 - d) Listing of Canadian glacier information in the Royal Geographical Society and the Scott Polar Research Institute.
- <u>References</u>: Photographs and manuscripts held by the Scott Polar Research Institute, Cambridge, England, <u>Glacier</u> <u>Inventory Note 1</u>, Inland Waters Branch, Department of Energy, <u>Mines and Resources</u>, Ottawa, 8 pp.

Ommanney, C.S.L., 1970. Photographs of glaciers in Western Canada held by the Royal Geographical Society, Kensington Gore, London, <u>Glacier Inventory</u> <u>Note 2</u>, Inland Waters Branch, Department of Energy, Mines and Resources, Ottawa, 11 pp. Ommanney, C.S.L., 1971. Photographs of glaciers in British Columbia held by the Film and Photographic Branch, Department of Travel Industry, British Columbia. <u>Glacier Inventory</u> <u>Note 3</u>, Inland Waters Branch, Department of Energy, Mines and Resources, Ottawa, 7 pp.

WORK IN PROGRESS:

- Continuation of identification and indexing of all early photographs of Baffin, Bylot and Axel Heiberg Islands in conjunction with Project G-69-1.
- 2. Continuation of 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. O. Field, A.G.S.
- 4. Compilation of a list of glacier photographs held by the Film and Photographic Branch, Department of Travel Industry, Victoria, B.C.
- 5. Identification and indexing of early photographs of Devon Island.

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.

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GLACIER MELTWATER CONTRIBUTION TO THE FLOW OF THE NORTH SASKATCHEWAN RIVER

PRINCIPAL INVESTIGATORS: H.S. Loijens

COOPERATING AGENCY: None.

- 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.
- LOCATION: North Saskatchewan River headwaters (52° 45' N, 117° 40' W) Banff National Park, Alberta.
- PREVIOUS WORK ON THIS PROJECT: Streamflow data from Mistaya River (No. 05DA-7) and North Saskatchewan River (No. 05DA-6) since 1950 (mainly from May - November). Streamflow, mass balance and meteorological observations from Peyto Glacier since 1965 (Project G-67-4).

Snow courses were established in the Mistaya River Basin in 1969 on the east side of the river, maintained in 1970 and three new courses laid out on the west side. Since 1969 three temperature/relative humidity recording stations have been maintained. Additional observations during the summer of 1970 of wind run, precipitation, sunshine and global shortwave radiation. Streamflow, precipitation and glacier ice sampling for tritium analysis. Stream gauging station established in May 1970 in three creeks (Rampart, North Saskatchewan just below glacier and Nigel Creek). Ablation stakes on Saskatchewan Glacier.

WORK IN PROGRESS:

- 1. Analyzing field data.
- Inventory of perennial snow and ice in basin (Project G-67-15).
- 3. Distribution of snow accumulation in Mistaya Basin.

4. Development of snow melt runoff model.

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Application of glacier runoff model (Project G-68-4) to 5. glaciers in Mistaya Basin. aciers in Mistaya Basin.

FUTURE WORK:

- Development of mathematical computer model for the continuous 1. simulation of streamflow in glacierized alpine basins. Application to other basins.
- 2. Snow distribution and melt in alpine areas. Use of remote sensing techniques.
- 3. Continuation of hydrometeorological observations.

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GLACIER CLIMATE RELATIONSHIP ON THE DEVON ISLAND ICE CAP

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

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

OBJECTIVES: To study the relationship between glacier variations 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.

Project temporarily suspended

GROWTH MECHANISMS OF RIVER AND LAKE ICE

PRINCIPAL INVESTIGATOR: R.O. Ramseier

COOPERATING AGENCY: Department of Transport, CCIW, and Marine Sciences Institute, Finland.

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

LOCATION: Ottawa, Lake Ontario, Mackenzie Delta and Finland.

PREVIOUS WORK ON THIS PROJECT:

References: Ramseier, R.O., 1968. The origin of preferred orientation in columnar ice. Journal of <u>Crystal</u> <u>Growth</u>, Vol. 4, pp. 621-624.

Michel, B. and Ramseier, R.O., 1969. Classification of river and lake ice based on its genesis, structure and texture. Université Laval, <u>Section</u> <u>Mécanique</u> <u>des</u> <u>Glaces</u>, <u>Report</u> <u>S-15</u>, 54 pp.

Michel, B. and Ramseier, R.O., 1969. Crystallographic analysis and theoretical flexural strength of river ice. Université Laval, <u>Section Mécanique des Glaces</u>, Report T-6, 17 pp.

Michel, B. and Ramseier, R.O., 1969. Structural and textural analysis of river ice, St. Lawrence Seaway, Montreal. Université Laval, Section Mécanique des Glaces, Report T-9, 18 pp.

Michel, B. and Ramseier, R.O., 1970. Structural and textural characteristics of river ice based on meteorological parameters. Université Laval, <u>Section Mécanique des Glaces</u>, <u>Report</u>, <u>T-13</u>, 60 pp.

Michel, B. and Ramseier, R.O., 1970. Classification of river and lake ice. <u>Canadian Geotechnical</u> Journal Vol. 8, No. 36, pp. 36-45. Ramseier, R.O., 1971. Formation of primary ice layers. <u>Ice</u> <u>Symposium</u>, Reykjavik, Iceland 1970. International Association for Hydraulics Research, (in press).

- WORK IN PROGRESS: Two field programs have been set up to obtain more quantitative data relating texture of primary ice to air temperature, wind velocity, water quality and state of water surface.
- FUTURE WORK: Regional assessment of ice formation based on developed theories. Investigation of the texture of a perennially frozen lake (secondary ice) to check the theory of preferred orientation in columnar ice.

MECHANICAL PROPERTIES OF RIVER AND LAKE ICE

PRINCIPAL INVESTIGATOR: R. O. Ramseier

COOPERATING AGENCY: Water Survey of Canada, Queens University.

- OBJECTIVES: To study the influence of macroscopic defects and impurities on the ductile behaviour of laboratory and naturally grown river and lake ice and to determine the relationship between small- and large-scale tests of ice in the ductile-brittle range.
- LOCATION: Laboratory, Ottawa, Lake Ontario, St. Lawrence River, Niagara Falls.

PREVIOUS WORK ON THIS PROJECT:

Reference: Ramseier, R.O., 1970. Mechanical behaviour of ice at high temperatures. <u>Bulletin of American Physical Society</u> Vol. 15, p. 812

- WORK IN PROGRESS: The first phase of laboratory testing has been completed and the results are being written up. A review of published results from other investigations and field tests have been started in preparation for large-scale outdoor tests.
- FUTURE WORK: Laboratory tests are contemplated to determine the effect of subboundaries and grain boundaries on creep mechanisms and to gain insight into the microscopic aspect of creep deformations. Field investigations are planned to determine the statistical behaviour of major flaws on the mechanical properties. The effect of impurities will also be investigated.

MECHANICAL PROPERTIES OF POLYCRYSTALLINE ICE

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

COOPERATING AGENCY: None.

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.

LOCATION: Ice Science Laboratory, Ottawa, Ontario.

PREVIOUS WORK ON THIS PROJECT:

- 1. <u>Laboratory</u>: Work on the effect of impurities on single crystal ice has been started - project G-68-1. This is a complementary project for polycrystals.
- <u>References</u>: Jones, S.J., 1967. Softening of ice crystals by dissolved fluoride ions. <u>Physics Letters</u>, Vol. 25A, No. 5, pp. 366-367.
- WORK IN PROGRESS: Work on this project has been combined with G-69-6, Creep Mechanisms of River and Lake Ice, and any work done will be done under that number.

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MASS AND ENERGY TRANSFER IN A SHALLOW SNOWPACK

PRINCIPAL INVESTIGATORS: P. Föhn, L. Derikx

COOPERATING AGENCY: Central Experimental Forest, Department of the Environment.

OBJECTIVES:

- 1. To determine the mechanisms of mass and energy transfer in a shallow snowpack during the period of snow accumulation.
- 2. To determine the mechanisms of moisture flux in terms of mass transfer properties of the snowpack during the period of snow ablation.
- 3. To synthesize the results of these studies into mathematical physically-based models and investigate the applicability in hydrologic systems analysis.

LOCATION: Mer Bleue, near Ottawa, Ontario.

PREVIOUS WORK ON THIS PROJECT:

- An experimental site at Mer Bleue (Central Experimental Forest) near Ottawa was selected in the spring of 1969 for cooperative investigations of snow melt and associated groundwater recharge by the Glaciology and Groundwater subdivisions (R. Harlan, Project GW-69-2).
- Instrumentation installed by Glaciology Subdivision in 1969 and 1970:

Mass in and output - standard Canadian snow gauge with Nipher shield

- Fisher and Porter recording precipitation gauge with Alter windshield
- MSC tipping bucket rain gauge*
- 12-foot snow pillow (Bollay Associates)*
- 6-foot snow pillow (Bollay Associates)*
- snow boards and snow density measuring equipment

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- net loss plastic pans - recording snow melt lysimeter Energy in and - Thornthwaite wind profile register output system* - Cambridge thermoelectric dew point profile system* - ventilated air temperature profile system* - 3 Kipp and Zonen pyranometers* - 2 C.S.I.R.O. net-allwave radiometers* Energy and mass - Troxler two probe gamma density gauge balance - snow capacitor (model Howorka and Amback) - 3 snow temperature thermistor profiles*
- * These instruments are connected to a central data acquisition system, located in a heated trailer on the measuring site.

WORK IN PROGRESS:

- 1. Instrumentation has been installed, is being tested and being calibrated.
- 2. Evaluation of measuring techniques and procedures.
- 3. Development of physically-based digital simulation models.

FUTURE WORK:

- 1. Collection of data to establish time variable boundary conditions and test several models.
- 2. Continuation, refinement and extension of scientific data collection.
- 3. Refinement and extension of models.

SCANNING ELECTRON MICROSCOPY OF ICE SURFACES

Project terminated

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THERMO-ELECTRIC POWER OF ICE

Project terminated

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INVESTIGATION OF SURFACE INSTABILITIES ON GLACIERS

PRINCIPAL INVESTIGATOR: G. Holdsworth

COOPERATING AGENCY: Surveys and Mapping Branch.

- OBJECTIVES: To study the distribution and geometry of surface instabilities on selected glaciers, as expressed by compression waves, and relate these to the flow of the ice mass in response to particular stress conditions. Certain properties of ice must also be examined.
- LOCATION: Conn Glacier, Baffin Island, N.W.T., and glaciers in the Canadian Cordillera (Yoho Glacier, B.C.).
- PREVIOUS WORK ON THIS PROJECT: Reconnaissance of Conn Glacier and Yoho Glacier for purposes of setting up ground survey.
- WORK IN PROGRESS: Planning for photogrammetric survey and preparation of maps.
- FUTURE WORK: Detailed measurements at selected points (including shallow drilling) on these glaciers will be made. On the basis of photo-scanning, additional glaciers will be selected for later study in order to establish the generality of this type of glacier structure.
MACKENZIE DELTA REGION STUDIES

PRINCIPAL INVESTIGATORS: D.K. MacKay (IWB) and J.R. Mackay (U.B.C.).

COOPERATING AGENCY: University of British Columbia, Geological Survey of Canada.

OBJECTIVES:

To conduct hydrologic - geomorphic studies in the Mackenzie Basin by investigating:

- a) Water budget of a tundra-taiga transitional basin, Boot Creek, N.W.T.
- b) Water budget of a tundra basin, Peter Lake, N.W.T.
- c) Katabatic winds at Paulatuk, N.W.T.
- d) The significance of cryostatic pressure caused during freeze-back of the active layer (in conjunction with Dr. J.R. Mackay).
- e) Effects of snow cover on ground temperatures (in conjunction with Dr. J.R. Mackay).
- f) Ice shove and jamming on the Mackenzie River.

LOCATION: Mackenzie Delta region, N.W.T.

PREVIOUS WORK ON THIS PROJECT:

 Field: Cryostatic pressure - transducers and thermistor cables installed in 1967 and read on weekly basis since then.

Katabatic winds - anemometer installed at two locations near Paulatuk in 1968. Initially only totalizing anemometers were used but since August 1969, instruments recording both run and direction of wind have been used.

Water budget, Boot Creek - discharge measurements began in 1967 but discontinued in 1968. More comprehensive program began in July 1970.

Water budget, Peter Lake - bathymetry of lake and basin reconnaissance completed in summer 1970.

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Snow cover and ground temperatures - thermistor cables and snow depth markers installed on Garry and Ellice islands, Paulatuk, and near Peter Lake. Measurements on Garry and Ellice when possible, Paulatuk on weekly basis since October 1969, and weekly at Peter Lake from December 1970.

Ice shove on Mackenzie - field work in various past years on trips down river.

2. <u>References</u>: MacKay, D.K., 1965. Break-up on the Mackenzie River and its Delta, 1964. <u>Geographical Bulletin</u>, Vol. 7, No. 2, pp. 117-128.

MacKay, D.K., 1966. Characteristics of river runoff and discharge in Canada. <u>Geographical Bulletin</u> Vol. 8, No. 3, pp. 219-227.

MacKay, D.K., 1966. Mackenzie River and Delta ice survey, 1965. Geographical Bulletin, Vol. 8, No. 3, pp. 270-278.

MacKay, D.K., 1967. Discharge of the Liard and Mackenzie Rivers. Geographical Bulletin, Vol. 9, No. 1, pp. 11-19.

MacKay, D.K., 1971. The ice regime of the Mackenzie Delta, Northwest Territories. Symposium on the Hydrology of Deltas, Bucharest, Romania, 1969. International Association of Scientific Hydrology Publication, pp. 357-362, (in press).

MacKay, D.K., 1971. Electrical resistivity measurements in frozen ground, Mackenzie Delta area, Northwest Territories. <u>Symposium on the Hydrology of Deltas</u>, Bucharest, Romania, 1969. <u>International Association of</u> Scientific Hydrology, Publication, pp. 363-375, (in press).

MacKay, D.K., 1970. The Ramparts of the Mackenzie River. Waterways, Inland Waters Branch, Department of Energy, Mines and Resources, No. 16, pp. 7-11.

WORK IN PROGRESS: Continuation of measurements and evaluation of results.

FUTURE WORK: Phasing out of some projects and introduction of new ones as progress warrants.

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ICEBERG PRODUCTION SURVEY IN ARCTIC CANADA

PRINCIPAL INVESTIGATORS: G. Holdsworth and C.S.L. Ommanney.

COOPERATING AGENCIES: Polar Continental Shelf Project, Marine Sciences Branch and the Department of Transport.

- OBJECTIVES: To study the distribution of tidal glaciers in Arctic Canada, the physics of ice calving and the present rate and volume of iceberg production by:
 - 1. Inventory of all tidal glaciers.
 - 2. Estimating glacier velocities, rates of ice discharge and significant changes in iceberg production by establishing a continuous survey of calving glaciers.
 - 3. Selecting one or more suitable outlet glaciers for accurate determination of calving rates and to study the process or processes of calving and its controls by:
 - a) field investigations
 - b) laboratory studies.

LOCATION: Ottawa, Ontario, and the Canadian High Arctic.

PREVIOUS WORK ON THIS PROJECT: Department of Transport, 1967. <u>Publications on Ice Conditions in Canada</u>. Met. Branch, D.O.T., <u>DS #6-67</u>, Toronto, Ontario, 5 pp.

WORK IN PROGRESS:

- A list of all tidewater glaciers and glaciers that approach to within .25 km of tidewater has been compiled for Baffin, Bylot and Devon islands.
- 2. An aerial reconnaissance of calving glaciers on Devon Island and in southeast Ellesmere Island was completed in the summer of 1970.

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FUTURE WORK:

Phase I - Inventory and Reconnaissance

a) Inventory of calving glaciers on Ellesmere Island.

- b) Photography and re-photography of calving termini to establish present snout positions.
- c) Photographic and photogrammetric estimation of glacier velocities.

Phase II - Field Investigations and Physical Processes

- a) Laboratory study of ice bending.
- b) Establishment of tide-level gauges.
- c) Ground reconnaissance of glaciers selected from Phase I.
- d) Geophysical, glaciological, topographic and hydrographic surveys.

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OIL POLLUTION IN ICE INFESTED WATERS

PRINCIPAL INVESTIGATOR: R.O. Ramseier.

COOPERATING AGENCY: Polar Continental Shelf Project and the United States Coast Guard.

OBJECTIVES: To study the interaction between oils and ice to develop effective containment and clean-up techniques which will be applicable to an ice-infest environment.

LOCATION: Laboratory, Ottawa, and various field locations.

PREVIOUS WORK ON THIS PROJECT:

References: Ramseier, R.O., Gantcheff, G.S. and Colby, L., 1970. Oil spill at Deception Bay, Hudson Strait, Department of Energy, Mines and Resources, Inland Waters Branch (in preparation).

Ramseier, R.O., 1971. Preliminary report of oil spill at Deception Bay, Hudson Strait, <u>Arctic Circular</u>, Vol. 11, No. 1 (in press).

Ramseier, R.O. 1971. Oil pollution in ice infested waters, International Symposium on Identification and Measurement of Environmental Pollutants, Ottawa, June 1971, (in press).

WORK IN PROGRESS: Laboratory tests are being carried out on the evaporation and combustion of various oils as a function of temperature (+20C to -50C), wind velocity and state of ice surface.

FUTURE WORK: Testing of oil behaviour in a series of pools located in the vicinity of Ottawa in conjunction with the remote sensing program.

EXTREME SUMMER STORM CONDITION IN THE TRIBUTARY HEADWATERS OF THE LOWER MACKENZIE, N.W.T.

PRINCIPAL INVESTIGATORS: D.K. MacKay, S. Fogarasi.

COOPERATING AGENCY: None.

OBJECTIVES: To document and analyze an extreme meteorological event which occurred in the headwaters region of the Arctic Red, Ramparts and Mountain tributaries of the Mackenzie in July 1970 and to describe and discuss the hydrologic and geomorphic manifestations of this event.

LOCATION: Lower Mackenzie Region, N.W.T.

PREVIOUS WORK ON THIS PROJECT: Nil.

WORK IN PROGRESS: Collection and analysis of pertinent meteorological and hydrological data.

FUTURE WORK: Field work involving sectioning of trees levelled by floodwaters, mapping of changes in fluvial geomorphology and possible determination of flood heights.

REGIONAL HYDROLOGIC CHARACTERISTICS OF MACKENZIE RIVER BASIN

PRINCIPAL INVESTIGATOR: T. Thakur

COOPERATING AGENCY: None

OBJECTIVES:

- 1. To study the hydrologic characteristics of the Mackenzie River Basin.
- 2. To Mathematically Formulate the Seasonal runoff variations of the rivers in the region.
- 3. To construct a mathematical model of periodic water levels for the Mackenzie River.

LOCATION: Mackenzie River Basin.

PREVIOUS WORK ON THIS PROJECT:

References:

- 1. Mackay, D.K., 1967. Discharge of the Liard and Mackenzie Rivers, <u>Geographical</u> <u>Bulletin</u>, Vol. 9, No. 1, pp. 11-19.
- 2. Water Survey of Canada, Calgary, 1970. Study of probability and frequency of Mackenzie River water levels. Water Survey of Canada, Inland Waters Branch, Dept. of Energy, Mines and Resources, 100 pp. + 31 pp. Appendix.
- WORK IN PROGRESS: Evaluation and analysis of Published Hydrologic Data. Testing of the Preliminary Seasonal discharge model on available data.
- FUTURE WORK: Further refinement of the discharge model. Development of the water level model. Writing of report.

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MATHEMATICAL STUDIES OF MACKENZIE DELTA PROCESSES

PRINCIPAL INVESTIGATOR: T. Thakur.

COOPERATING AGENCY: None.

OBJECTIVE: To describe and explain the intricate network of channels and inter-connecting lakes in the Mackenzie Delta by Mathematical Analysis.

LOCATION: Mackenzie Delta, N.W.T.

PREVIOUS WORK ON THIS PROJECT:

References: Mackay, J.R., 1963. The Mackenzie Delta, Geographical Branch Memoir No. 8, 202 pp.

The District of Mackenzie Maps of the Department of Mines and Technical Surveys.

WORK IN PROGRESS: The theoretical and mathematical analysis is being carried out.

FUTURE WORK: The study is continuing.

BAFFIN ISLAND CLIMATOLOGY

PRINCIPAL INVESTIGATOR: S. Fogarasi.

- OBJECTIVES: To develop a physical model that will relate the mass balance parameters of local glaciers to the short-term atmospheric water balance components; to calculate atmospheric water balance of selected weather conditions in the 1968 summer when heavy precipitation is observed over the Baffin Island region by:
 - 1. calculating the precipitation pattern, and
 - 2. applying streamline analysis for the calculation of moisture flux divergence.

LOCATION: Ottawa, Ontario.

PREVIOUS WORK ON THIS PROJECT:

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

Computer processing of moisture flux divergence over selected areas for the period 1961-1965.

Computerized Arctic weather type classification for the 1968 summer season.

Horizontal velocity divergence, total vertical velocity, and precipitation patterns have been calculated for selected weather conditions over the Canadian Archipelago in the 1968 summer.

2. <u>References</u>: Barry, R.G., 1966. Meteorological aspects of the glacial history of Labrador-Ungava with special reference to atmospheric vapour transport. <u>Geographical</u> <u>Bulletin</u>, Vol. 8, No. 4, pp. 319-340.

Barry, R.G., 1969. In: Field Report, North-Central Baffin Island 1967, Inland Waters Branch, Report Series No. 2, pp. 103-135. Barry, R.G., 1967. Seasonal location of the Arctic front over North America. <u>Geographical Bulletin</u>, Vol. 9, No. 2, pp. 79-95.

Barry, R.G. and Fogarasi, S., 1968. Climatological studies of Baffin Island, N.W.T., Inland Waters Branch, Technical Bulletin No. 13, 106 pp.

Barry, R.G., 1969. Final Report - further climatological studies of Baffin Island, Manuscript.

WORK IN PROGRESS:

- 1. Atmospheric water balance components, precipitation and evaporation is being estimated over unaccessible areas along a grid point network and the preparation of the report.
- Synoptic climatology of the head of Inugsuin Fiord is being 2. investigated.

The physical model of water balance and precipitation FUTURE WORK: calculation will be applied to:

- the periods of selected weather types,
 a period when mass balance observations are made in order to study the glacier climate relationship.

DIFFUSION IN ICE

PRINCIPAL INVESTIGATORS:

G. Barnett S.J. Jones (Supervisor)

COOPERATING AGENCY: None.

OBJECTIVES: To study the rate of diffusion and solubility of various substances in ice.

LOCATION: Ice Science Laboratory, Ottawa, Ontario.

- PREVIOUS WORK ON THIS PROJECT: No previous work has been done by our Section on diffusion. In the literature, the diffusion of tritium (H^3) and oxygen (0^{18}) has been studied, both in pure and impure ice. Diffusion of HF has been studied with conflicting results. No other impurities have been studied.
- WORK IN PROGRESS: A rather crude apparatus was assembled and preliminary measurements of the diffusion of He have been obtained. These show a very high rate of diffusion (10^6 cm² sec⁻¹) compared to the self-diffusion (10^{-11} cm² sec⁻¹). At present a more reliable apparatus is being built.
- FUTURE WORK: The diffusion coefficient of He in ice will be obtained as a function of temperature. Other substances, H_2 , Ne, Ar, will then be used instead of He.

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SPREADING COEFFICIENTS OF OILS ON ICE AND SNOW SURFACES

PRINCIPAL INVESTIGATOR: E. C. Chen

COOPERATING AGENCY: None

OBJECTIVES: To obtain information on spreading coefficients as parts of the studies on the mechanism of oils spreading on ice and snow surfaces.

LOCATION: Laboratory, Ottawa, Ontario.

PREVIOUS WORK ON THIS PROJECT: Nil.

WORK IN PROGRESS: Determination of the spreading coefficients of arctic diesel on ice and snow surfaces as a function of temperature.

FUTURE WORK: The study is continuing.

FREEZING OF OIL/WATER EMULSIONS

PRINCIPAL INVESTIGATOR: E.C. Chen

COOPERATING AGENCY: None

OBJECTIVES: To study the nature and stability of oil/water emulsions at low temperatures in order to understand their significance for combating oil pollution in the arctic regions.

LOCATION: Laboratory, Ottawa, Ontario.

PREVIOUS WORK ON THIS PROJECT: Nil

WORK IN PROGRESS: None in 1970. Planning for experimental work to investigate the effects of temperature on emulsion properties began in Spring 1971.

FUTURE WORK: Future studies will be in the following areas:

- Mechanism of formation of oil/water emulsions at low temperatures.
- 2. Kinetics of development in oil/water emulsions at low temperatures.
- 3. Influence of surface-active agents on the properties of oil/water emulsions at low temperatures.
- 4. Breaking and separation of oil/water emulsions at low temperatures.

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VAPOUR-LIQUID EQUILIBRIA OF HYDROCARBON OILS-ICE/SNOW SYSTEM

PRINCIPAL INVESTIGATORS: E.C. Chen & S.D. Cheng

- COOPERATING AGENCY: Department of Chemical Engineering, University of Ottawa.
- OBJECTIVES: To develop correlations for predicting the vapour compositions and vapour pressures of oils spilling on ice and snow surfaces.
- LOCATION: Laboratory, Department of Chemical Engineering, University of Ottawa.

PREVIOUS WORK ON THIS PROJECT: Nil

WORK IN PROGRESS: Investigation of the effects of temperature and composition on the K-values of a three-component system (from each of the aliphatic, alicyclic and aromatic group respectively) in the presence of ice/snow and air.

FUTURE WORK: The study will be extended to a multi-component system.

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REGIONAL MASS BALANCE MEASUREMENTS IN THE QUEEN ELIZABETH ISLANDS BY USING AERIAL PHOTOGRAMMETRY

PRINCIPAL INVESTIGATOR: K. C. Arnold

COOPERATING AGENCY: Polar Continental Shelf Project, Department of Energy, Mines and Resources.

OBJECTIVES: To extend the limited number of mass balance measurements that have been made in the conventional manner by ground parties to a larger number of locations. Regional and altitudinal variations in mass balance will be determined, and the concept of representative glaciers will be tested. At first dynamically uncomplicated ice masses will be chosen for study, so that height changes can be easily related to mass balance changes. Air photography will be taken from low altitude at the end of each budget year at all sites, and at the onset on the melt season at a limited number of sites.

LOCATION: Queen Elizabeth Islands.

PREVIOUS WORK ON THIS PROJECT: Nil.

WORK IN PROGRESS: Selection of sites for initial studies in 1971.

FUTURE WORK: The number of sites will be extended by five to ten each year over a period of five years. APPRAISAL OF LONG TERM METEOROLOGICAL RECORDERS

PRINCIPAL INVESTIGATORS: A.D. Terroux, J. Kruus, A.D. Stanley

COOPERATING AGENCY: Nil

- OBJECTIVES: Obtain, modify or develop a long term meteorological recorder capable of operating unattended under winter conditions in the Arctic and Cordillera. The recorders are to operate at selected glacier basins included in the I.H.D. program.
- LOCATION: Main tests in Ottawa for proposed installations at I.H.D. glacier basins.
- PREVIOUS WORK ON THIS PROJECT: In 1969 all known manufactures of meteorological recorders were contacted and instrument specifications appraised. Of the 30 manufacturers approached - Ott, Plessey, Epsylon Leach and Braincon have developed models that include some of the features required.

Two Ott instruments have been purchased and power systems have been designed to operate at low temperatures. A wind generator has been supplied by Lubing and a thermo-generator using a radioactive source has been designed under contract by Atomic Energy of Canada Ltd.

- WORK IN PROGRESS: One Ott station together with power unit and wind generator were installed at Churchill weather station to compare performance with standard meteorological instruments.
- FUTURE WORK: Tests will be continued on the Ott recorders until they are completely functional under the specified conditions. During the period 1971-72 one station, using the nuclear power supply, will be installed at the weather station in Resolute Bay in order to test all components of the system.

APPLICATIONS OF REMOTE SENSING TECHNIQUES TO GLACIOLOGY

PRINCIPAL INVESTIGATORS: A.D. Terroux & A.D. Stanley

COOPERATING AGENCY: U.S. Geological Survey (Dr. M.F. Meier)

OBJECTIVES: To determine area of application of ERTS imagery to the study of snow and ice. The initial program will establish the resolution and accuracy for

- (1) Distribution of snow over large areas.
- (2) Assessment of snow depletion during the spring runoff.
- (3) Variation of glacier mass balance based on snow line levels at the end of the summer.

LOCATION: Western Cordillera between 46°N and 64°N.

PREVIOUS WORK ON THIS PROJECT: Examination of existing Federal and Provincial photography from the Canadian Cordillera.

WORK IN PROGRESS: In 1971 - June 1 and June 10 high level flight by CF100 aircraft to obtain imagery along an E-W transect across southern British Columbia and Alberta. Snow line information will be compared with ground truth data from selected glacier basins.

- late August, low level aerial photography of glaciers to determine snow line at the end of the summer.

FUTURE WORK: Interpretation of CF100 imagery, and of ERTS imagery when it becomes available in 1972.

In 1972 - south-north flight by U-2 aircraft along the Coast mountains in early June and mid-August to obtain high level imagery.

Comparison of ground data from selected glacier basins with snow line data from high level imagery to determine resolution and accuracy.

Project WS-68-6

RESISTIVITY MEASUREMENTS TO DETECT MELT WATER

PRINCIPAL INVESTIGATOR: R.H. Goodman

COOPERATING AGENCY: None

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

LOCATION: Peyto Glacier, Alberta

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

WORK IN PROGRESS: Resistance measurements indicate a resistance of greater than 10⁷ ohm-cm. The present equipment cannot measure greater resistance.

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.

Project WS-69-1

COMPUTER MODELING OF GLACIER FLOW

PRINCIPAL INVESTIGATOR: R.H. Goodman

COOPERATING AGENCY: None

OBJECTIVES: To predict glacier flow on the basis of laboratorymeasured values of the mechanical properties of ice.

LOCATION: Ottawa, Ontario.

PREVIOUS WORK ON THIS PROJECT:

Reference: Campbell, W.J. and Rasmussen, L.A. 1970: A heuristic numerical model for three-dimensional time dependant glacier flow. International Association of Scientific Hydrology Publication, No. 86, pp 177-190.

WORK IN PROGRESS:

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

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

GLACIER MAPPING

PRINCIPAL INVESTIGATORS: I.A. Reid

COOPERATING AGENCY: None

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.

LOCATION: Ottawa, Ontario.

PREVIOUS WORK ON THIS PROJECT:

- 1. Field: A terrestrial photogrammetric survey of the glaciers in British Columbia was made in 1964, 1966, 1968 & 1970 of the Athabasca Glacier in 1959, 1962, 1965, 1967, 1968 & 1969, and of the Saskatchewan Glacier in 1965, 1967 & 1969.
- 2. <u>References</u>: Campbell, P.I., Reid, I.A. and Shastal, J., <u>1969.</u> Glacier surveys in Alberta. <u>Inland Waters Branch</u>, Report Series No. 4, 15 pp.

Reid, I.A. and Shastal, J., 1970 Glacier Surveys in British Columbia, <u>Inland Waters Branch</u>, <u>Report Series</u> No. 10-26pp.

Map	Scale	Contour	Interval
Bugaboo (1968)	1:2,500	50	feet
Sentinel Glacier (1968)	1:2,500	20	feet
Sphinx Glacier (1968)	1:5,000	25	feet
Nadahini Glacier (1968)	1:5,000	20	feet
Kokanee Glacier (1968)	1:2,500	20	feet
Saskatchewan Glacier (1967)	1:10,000	20	feet
Athabasca Glacier (1967)	1:10,000	× 25	feet

WORK IN PROGRESS:

- 1. Terrestrial photogrammetric surveys of the Athabasca and Saskatchewan glaciers.
- 2. Ice discharge movement of the Saskatchewan glacier.

3. Mapping the Columbia Icefield and outlet glaciers by aerial photogrammetry (in collaboration with the Glaciology Subdivision).

The ice discharge measurement of the Athabasca was completed in 1968.

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

5. 2. C.

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