Energy Mines and Resources Canada
Earth Physics Branch

Énergie, Mines et Ressources Canada
Direction de la physique du globe

CANADIAN GEOPHYSICAL BULLETIN

BULLETIN CANADIEN DE GÉOPHYSIQUE

Volume 38

Editor/Rédacteur en chef R.A. Gibb

Published by the Canadian National Committee for the International Union of Geodesy and Geophysics of the National Research Council of Canada

Publié par le Comité national canadien pour l'Union géodésique et géophysique internationale du Conseil national de recherches du Canada

December/décembre 1985
Ottawa, Canada

Energy Mines and Resources Canada
Énergie, Mines et Ressources Canada

Earth Physics Branch
Direction de la physique du globe

CANADIAN GEOPHYSICAL BULLETIN

BULLETIN CANADIEN DE GÉOPHYSIQUE

Volume 38

Editor/Rédacteur en chef R.A. Gibb

Published by the Canadian National Committee for the International Union of Geodesy and Geophysics of the National Research Council of Canada

Publié par le Comité national canadien pour l'Union géodésique et géophysique internationale du Conseil national de recherches du Canada

December/décembre 1985
Ottawa, Canada

MEMBERS OF THE CANADIAN NATIONAL COMMITTEE

FOR THE

INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

Dr. G.A. McBean	Chairman, Institute of Ocean Sciences, Sidney, B.C.	IAMAP
Dr. D.R. McDiarmid	Secretary, Herzberg Institute of Astrophysics, NRC, Ottawa, Ont.	IAGA
Dr. M.J. Berry	Earth Physics Branch, EMR, Ottawa, Ont.	IASPEI
Prof. J. Derome	McGill University, Montreal, P.Q.	IAMAP
Prof. M.I. El-Sabh	Université du Québec à Rimouski, Rimouski, P.Q.	IAPSO
Prof. R.M. Farquhar	University of Toronto, Toronto, Ont.	IAVCEI
Prof. R.L. Gerard	University of Alberta, Edmonton, Alta.	IAHS
Dr. W. Gibbins	Indian and Northern Affairs Canada, Yellowknife, N.W.T.	IAVCEI
Dr. D.J. McEwen	University of Saskatchewan, Saskatoon, Sask.	IAGA
Prof. M.G. Rochester	Memorial University of Newfoundland, St. John's, Nfld.	IASPEI
Prof. D.E. Smylie	York University, Toronto, Ont.	IAGA
Prof. P. Vanicek	University of New Brunswick, Fredericton, N.B.	IAG
Prof. D.E. Wells	University of New Brunswick, Fredericton, N.B.	IAG
Dr. G.J. Young	Inland Waters Directorate, Environment Canada, Ottawa, Ont.	IAHS

Ex-officio

Mr. C. Gauvreau	Bureau of International Relations, NRC, Ottawa, Ont.	
Dr. R.A. Gibb	Earth Physics Branch, EMR, Ottawa, Ont.	Editor, CGB
Prof. D.I Gough	University of Alberta, Edmonton, Alta.	President, IAGA
Dr. M.J. Berry	Earth Physics Branch, EMR, Ottawa, Ont.	Chairman, CNC/ICL
Prof. R.D. Russell	University of British Columbia, Vancouver, B.C.	General Assembly IUGG 1987

Honorary Members

Prof. A.E. Beck	London, Ont.
Dr. B.T. Dennis	Ste-Foy, P.Q.
Dr. H.B. Hachey	St. Andrews, N.B.
Dr. J.H. Hodgson	Ottawa, Ont.
Prof. J.A. Jacobs	Cambridge, Eng.
Dr. G.T. Needler	Sidney, B.C.
Dr. D.C. Rose	Brockville, Ont.
Prof. R.J. Uffen	Kingston, Ont.
Dr. K. Whitham	Ottawa, Ont.
Dr. J.T. Wilson	Toronto, Ont.

MEMBRES DU COMITÉ NATIONAL CANADIEN

POUR

L'UNION GÉODÉSIQUE ET GÉOPHYSIQUE INTERNATIONALE

Dr. G.A. McBean	Président, Institut des sciences océaniques, Sidney, C.-B.	AIMPA
Dr. D.R. McDiarmid	Secrétaire, Institut Herzberg d'astrophysique, CNRC, Ottawa, Ont.	AIGA
Dr. M.J. Berry	Direction de la physique du globe, EMR, Ottawa, Ont.	AISPIT
Prof. J. Derome	Université McGill, Montréal, QC	AIMPA
Prof. M.I. El-Sabh	Université du Québec à Rimouski, Rimouski, QC	AISPO
Prof. R.M. Farquhar	Université de Toronto, Toronto, Ont.	AIVCIT
Prof. R.L. Gerard	Université de l'Alberta, Edmonton, Alb.	AISH
Dr. W. Gibbins	Affaires indiennes et du Nord Canada, Yellowknife, T.N.-O.	AIVCIT
Dr. D.J. McEwen	Université de la Saskatchewan, Saskatoon, Sask.	AIGA
Prof. M.G. Rochester	Université Mémorial de Terre-Neuve, St-Jean, T.-N.	AISPIT
Prof. D.E. Smylie	Université York, Toronto, Ont.	AIGA
Prof. P. Vanicek	Université du Nouveau-Brunswick, Fredericton, N.-B.	AIG
Prof. D.E. Wells	Université du Nouveau-Brunswick, Fredericton, N.-B.	AIG
Dr. G.J. Young	Direction générale des eaux intérieures, Environnement Canada, Ottawa, Ont.	AISH

Ex-officio

M. C. Gauvreau	Relations internationales, CNRC, Ottawa, Ont.	
Dr. R.A. Gibb	Direction de la physique du globe, EMR, Ottawa, Ont.	Rédacteur, BCG
Prof. D.I. Gough	Université de l'Alberta, Edmonton, Alb.	Président, AIGA
Dr. M.J. Berry	Direction de la physique du globe, EMR, Ottawa, Ont.	Président, CNC/CIL
Prof. R.D. Russell	Université de la Colombie-Britannique, Vancouver, C.-B.	Assemblée générale UGGI 1987

Membres honoraires

Prof. A.E. Beck	London, Ont.
Dr. B.T. Dennis	Sainte-Foy, QC
Dr. H.B. Hachey	St. Andrews, N.-B.
Dr. J.H. Hodgson	Ottawa, Ont.
Prof. J.A. Jacobs	Cambridge, Angl.
Dr. G.T. Needler	Sidney, C.-B.
Dr. D.C. Rose	Brockville, Ont.
Prof. R.J. Uffen	Kingston, Ont.
Dr. K. Whitham	Ottawa, Ont.
Dr. J.T. Wilson	Toronto, Ont.

INTRODUCTION

The Canadian Geophysical Bulletin is an annual report of geophysical research, development and services in industry, government and universities in Canada. Its main purpose is to provide a record, continuous from year to year, of active researchers and their projects and of the current year's publications. Brief mention is made of research results, but the latter are not recorded to any extent since they may be found from the extensive bibliographies. Since 1974 the Bulletin has been published under the authority of the Canadian National Committee for the International Union of Geodesy and Geophysics (CNC/IUGG).

The editor wishes to thank all of his colleagues who have cooperated as chapter compilers or as researchers responding to the requests for information issued by the compilers. During 1981 a sub-committee of the CNC/IUGG prepared a set of guidelines to aid compilers and individual contributors in preparing their reports. The compilers are to be thanked for their efforts in applying the guidelines and in the difficult task of reducing copy so that the Bulletin could be confined to 200 pages, a limit set by financial restraint. It is also a pleasure to acknowledge the assistance of Mr. E.B. Manchee, Ms. Karen Clarke, Ms. Irene Wilkes, Mrs. Lana Birmann, Miss Maxine Brunke and Ms. Jo-Anne Wagner of the Earth Physics Branch, Energy, Mines and Resources, Canada.

The Bulletin is produced and distributed to readers inside and outside Canada by the Earth Physics Branch, Energy, Mines and Resources Canada, at the request of the CNC/IUGG, and the Canadian Geoscience Council. Anyone wishing individual copies of the current issue or recent back issues should request these from:

Publication Distribution Office
Geological Survey of Canada
Energy, Mines and Resources Canada
601 Booth Street
Ottawa, Ontario
Canada
K1A 0E8

There is no charge for the Bulletin, but the Canadian National Committee appreciates receiving similar national or international reports in exchange.

R.A. Gibb
Editor

INTRODUCTION

Le Bulletin canadien de géophysique est un rapport annuel des recherches, des développements et des services géophysiques dans l'industrie, les gouvernements et les universités au Canada. Le but principal est d'établir un dossier permanent des chercheurs actifs, de leurs travaux et des publications de l'année. On y présente un bref aperçu des résultats de recherche. Cependant, ces résultats ne sont pas donnés en détail puisqu'on peut se renseigner à leur sujet en consultant la liste des ouvrages de référence. Ce bulletin, depuis 1974, est publié sous la direction du Comité national canadien de l'Union géodésique et géophysique internationale (CNC/UGGI).

Le rédacteur en chef désire exprimer sa reconnaissance à tous ses collègues qui ont contribué à la publication du bulletin à titre de compilateurs, et à tous les chercheurs qui ont fourni des renseignements aux compilateurs. Au cours de 1981, un sous-comité du CNC/UGGI a préparé une série de lignes directrices destinées à aider les compilateurs et les autres participants à rédiger leurs rapports. Nous remercions les compilateurs d'avoir appliqué ces lignes directrices et d'avoir réussi la tâche ardue de raccourcir les textes de manière à ce que ce bulletin ne dépasse pas 200 pages, limite fixée par des contraintes financières. C'est avec non moins de reconnaissance que nous tenons à souligner l'aide apportée par: M. E.B. Manchee, Mlle Karen Clarke, Mme Irene Wilkes, Mme Lana Birmann, Mlle Maxine Brunke et Mlle Jo-Anne Wagner de la Direction de la physique du globe, d'Énergie, Mines et Ressources Canada.

Ce bulletin est produit et distribué aux lecteurs du Canada et de l'étranger par la Direction de la physique du globe, d'Énergie, Mines et Ressources Canada, à la demande du CNC/UGGI et du Conseil canadien des sciences de la Terre. Les demandes pour obtenir un exemplaire du numéro courant ou des numéros récents doivent être adressées à:

Bureau de distributions
Commission Géologique du Canada
Énergie, Mines et Ressources Canada
601 rue Booth
OTTAWA, Ontario
Canada
K1A 0E8

Ce bulletin est offert à titre gratuit, mais le Comité national canadien serait heureux de recevoir, en échange, tout rapport de même nature de source nationale ou internationale.

R.A. Gibb
Rédacteur en chef

CONTENTS

TABLE DES MATIÈRES

Cat. No.: M74-37/38

ISBN: 0-662-54808-6

ISSN: 0068-8819

N° de cat.: M74-37/38

ISBN: 0-662-54808-6

ISSN: 0068-8819

1 (A) GEODESY

Compiled by: R.B. Langley

1. Summary

Geodesy in Canada continues to be an area of increased interest and accelerated development. The Global Positioning System (GPS), in particular, is receiving much attention. Almost one-third of the entries in the bibliography of this chapter relate directly to GPS. This satellite-based positioning system is routinely providing relative position accuracies of 1 to 2 ppm. With satellite orbit adjustment, accuracies of 0.1 ppm have been obtained, and there is some justification for believing that accuracies approaching 0.01 ppm eventually can be realized. These developments have attracted the attention of a number of provincial survey organizations who are already implementing GPS control surveys or developing strategies for the introduction of such surveys. Significant developments have also occurred in the areas of inertial surveying for vertical control and gravity surveys, photogrammetric mapping, and trigonometric height traversing; in the application of satellite altimetry to geoid description and in the use and development of instrumentation for very long baseline interferometry. The re-adjustment of the North American Horizontal Datum is finally nearing completion with publication of coordinates to begin in 1987.

2. Geodetic Survey of Canada

The Canadian contribution to NAD83, the redefinition of the North American Horizontal Datum, was delivered to the U.S. National Geodetic Survey (NGS) on 18 December 1985. Preparations for the integration of federal and provincial secondary surveys continued in the offices of the ten participating agencies (eight provincial/regional agencies, the Canadian Hydrographic Service, the International Boundary Commission). A version of the Helmert block adjustment program GHOST for the VAX computer was prepared for use by the provinces. In September the Canadian Council on Surveying and Mapping approved publication of NAD83 coordinates province-by-province, commencing in 1987.

Good progress was made on the North American Vertical Datum (NAVD) project. Verification and automatic handling of levelling data are on schedule, and software to compute and preprocess the effects of systematic errors on levelling data is being developed. Further

tests and investigation of gravity interpolation, particularly in mountainous areas of western Canada, are required.

A data analysis procedure based on block validation has been started. This is compatible with the U.S. NGS approach and will allow final adjustment of the North American Vertical Network using the Helmert blocking technique. Research has also begun on the weighting of all observations to be included in the NAVD readjustment. Observations from levelling, Doppler, GPS, and gravimetric determination of the geoid will be included.

In 1985, GPS was used to strengthen the existing horizontal control network in Ontario; 35 GPS points were positioned. GPS was also used to position a five-station network to monitor horizontal movements in the vicinity of the main radio telescope at the Algonquin Radio Observatory (ARO), and also for a high-precision trilateration net for crustal deformation study at Gold River, Vancouver Island.

Satellite Doppler was used to position 58 new points in British Columbia and the Northwest Territories, required for primary network densification.

Eighteen astro-deflections were observed at sites in northwestern Canada for geoid-ellipsoid computations.

Substantial levelling (5200 km) mainly related to the relevelling needs of the NAVD project was carried out by contract in 1985. An additional 500 km of special-order and 200 km of first-order work was completed mainly for crustal deformation study, bench mark stability testing, research on systematic errors, and levelling technique refinement and evaluation.

An inertial survey project consisting of 950 km of traversing in the Mackenzie River delta provided 174 elevations for a gravity survey undertaken by the Earth Physics Branch of EMR.

Considerable research was centred on the development of software for GPS data analysis and processing. Studies have also begun on the "proof of concept" implementation of an Active Control System for geodetic surveying and positioning in Canada, based on GPS and LBI. The transfer of NASA's GEODYN geodynamic and orbital analysis software to the Geodetic Survey's computer facilities was negotiated and is being implemented.

Analysis of adjustment procedures for combining networks of ISS traverses was completed.

A study of the estimation of precise geoid heights using a Fast Fourier Transform technique, and their use with the results of GPS interferometry, was completed.

Work on the representation of the Canadian geoid by an analytical surface is near completion. Study of the application of SEASAT altimetry data, for estimating the marine geoid, continued.

3. Earth Physics Branch, Gravity, Geothermics and Geodynamics Division

Precise Photographic Zenith Tube (PZT) observations of rotational time and latitude continued from observatories near Ottawa and Calgary, contributing high quality data to the Bureau International de l'Heure (BIH), Paris, and the International Polar Motion Service (IPMS), Mizusawa, Japan. The PZT obervations have been reduced using MERIT standards and transmitted weekly to BIH and IPMS via the General Electric Mark III computer communications network.

Satellite Doppler tracking stations collated with the Canadian PZT instruments since 1975 were upgraded in February 1985 to TRANET II compatible operations and equipped with HP 5061 cesium clocks. Minicomputer software has been developed to facilitate real-time evaluation of orbital parameters, Doppler data validation and timing analysis. Computer-aided satellite tracking and daily data transmissions to the DMAHTC Satellite Polar Monitoring Centre, Washington, via GE Mark III high-speed service are also fully automated. The GERDOP sequential multiparameter Doppler data reduction software, based on the DMA precise satellite ephemeris, yields corrections to the earth rotation parameters, satellite orbital elements,

and station coordinates which are used in studies of long-term systematic trends and for comparison with other techniques.

Development of the Canadian Geophysical LBI (CGLBI) System continued in cooperation with York University and the University of Toronto with the general objective of achieving geodetic capabilities comparable to the U.S. Mark III system. Significant reduction of capital and operating costs is expected due to implementation of such features as wave front clock delay and fringe phase tracking; time domain data multiplexing; 24Mb/sec data recording on 4-hour standard video cassettes.

The three-station CGLBI correlator and data processor which is based on a customized 68 000 microcomputer board and multi-tasking real-time operating system is in final stages of integration. The system will be tested on the ARO-Dominion Radio Astrophysical Observatory (Penticton) baseline in 1986.

A submission to the Federal Government has been prepared for commissioning a three-element CGLBI system consisting of a 25-32 m diameter main radio telescope at Yellowknife, a 10 m fixed antenna also on the Canadian Shield to provide a stable calibration baseline, a mobile LBI station and a correlator and dataprocessing facility. Earth rotation monitoring, crustal plate dynamics and establishment of fiducial points for GPS and other high precision geodetic surveys are the primary objectives of the proposed CGLBI system.

4. National Research Council, Division of Physics

The study of refractional influences in satellite geodesy has been continued on the basis of mathematical theory completed in 1982 for the calculation of pure astronomical refraction.

Since 1 January 1972, national time services have been operated on atomic time with no frequency offset. The time disseminated, UTC, differs from atomic time, TAI, by an integral number of seconds, and is stepped by leap seconds to remain within 0.9 second of the astronomical time UT1. The value of DUT1, which is the difference between UT1 and UTC to the nearest 0.1 second, is included in code in the broadcast of the NRC Canadian Time Service on shortwave station CHU. A series of bulletins (TF-B) announces relevant changes, such as DUT1 and leap seconds, several weeks in advance. Four primary cesium standards are used to implement the NRC time scale. The time scale is compared continuously to other countries' time scales by means of GPS. Two satellite ground stations with 3 m antennas have been set up at the NRC laboratory for time transfers with low power CW tones, using commercial satellites. Sub-nanosecond precision has been achieved. The objective is to design an economical system for time transfer using commercial satellites.

5. Canadian Hydrographic Service

The Canadian Geodesy Section, located at CHS Headquarters, Ottawa, carried out several large adjustments of horizontal control surveys established by the regional offices of CHS. The major areas adjusted were the Gaspé coast, the portion of the St. Lawrence River from Rockport to Cornwall, Sault Ste Marie and Little Current-North Channel.

Loran-C calibration data were collected in Lake Erie, Lake Ontario, and along the coast of Newfoundland. The data will be converted into Additional Secondary Factor (ASF) chartlets published in Radio Aids to Marine Navigation and into lattices for the marine navigation charts. Thirty-five charts were published with Loran-C lattices during the period December 1984 to December 1985.

A network of approximately 125 permanent water level gauging stations is operated along the coastal and inland navigable waters by the Tidal Division of the various regions of CHS. The accumulation of long and continuous time series of water levels at these sites provides information on sea level variations and vertical crustal movements, as well as contributing to the establishment and maintenance of vertical datums for levelling networks.

Data from three of the above stations located on the Pacific coast were used in 1985 in the Integrated Global Ocean Station System-supported Sea Level Pilot Project in the Pacific Ocean. This project is based at the University of Hawaii and produces monthly sea level anomaly diagrams for the Pacific Ocean. Canadian oceanographers have shown interest in

developing a similar project for the North Atlantic Ocean, for which the CHS permanent gauges would provide a valuable contribution.

Submersible pressure gauges have been operating year-round for the past three years at four sites in the Arctic Islands in order to determine sea level variations and to correlate these with water mass transport through the Archipelago. In addition, a permanent water level gauging system engineered for the Arctic was installed in the summer of 1985 at the Polaris mine site on Little Cornwallis Island. Data are transmitted south from the station via the ARGOS satellite system in order to monitor the gauging system's performance.

6. Bedford Institute of Oceanography, Canadian Hydrographic Service, Atlantic Region

Investigations in the use of GPS, again done under contract by Nortech Surveys (Canada) Inc., Calgary, with contributions from the University of New Brunswick, Fredericton, have concentrated on mathematical modelling and error estimation for the general GPS position calculation; on producing accuracy diagrams for the full constellation; and on preparing for differential GPS, with emphasis on communications techniques.

Loran lattices have been produced for 30 large-scale charts (typically 1:75 000) of the Atlantic Region, using theoretical ASF corrections (land-path phase lags) adjusted by hand to all existing calibration observations in the vicinity of the chart. This laborious technique, necessary because there are not enough data to make a mathematical surface fit, produces about 3 mm accuracy on the chart (200 m on the ground), which is consistent with the realities of radio navigation.

In a first sea-test of the Electronic Chart Test Bed, Universal Systems Ltd., Fredericton, in collaboration with McGill University Radar Observatory, successfully merged ship's position, a digital representation of the chart, and a digital radar overlay, on one display. The Test Bed will be used to investigate changes in CHS procedures required to prepare for the electronic chart.

7. Newfoundland and Labrador Department of Forest Resources and Lands, Lands Branch

Establishment and maintenance of the Provincial Geographical Referencing System continued with the emplacement of 233 markers. The preparation of archival observation data sets for the NAD83 redefinition also continued.

8. Maritime Provinces Land Registration and Information Service, Surveys and Mapping Division

LRIS is mandated to provide the secondary control requirements for the Maritime provinces. The responsibility for the control activity is shared between the Control Survey Section in Summerside and eight regional offices. The present (September 1985) distribution of the control markers is as follows: N.B. 22 570; N.S. 22 358; and P.E.I. 4312. Data on these markers are available from LRIS Summerside.

The 1985-86 Control Survey program included the inspection of 7774 control monuments and the placement of 681 new monuments.

Under contract with UNB, a project was begun to review future control survey requirements with the introduction of GPS technology.

9. Ministère de l'Énergie et des Ressources du Québec, Domaine territorial

Service de la géodésie du Québec established about 1000 new secondand third-order horizontal points and 300 km of second-order levelling in 1985. In a first production experience with GPS, 20 points were determined. Also, 1000 existing points were inspected, of which 21 were replaced. Computations were completed for the above production and for 1500 points from other organizations. Various software packages were developed for improving efficiency of electronic notekeeping and for interfacing with in-house least-squares programs TOGAS and ASTRAL; an interface was also developed for translating GANET input format to TOGAS. Geodetic data base "GEODEQ" activities were continued: about 1000 copies of network compilation maps were issued; descriptions and coordinates for 4500 points were stored. This

brings the total content of GEODEQ to 54 000 points. In the sector of standardization/ classification/micro-geodesy assistance was provided to municipalities for the establishment and computation of 35 horizontal and three vertical networks; 3000 horizontal and 300 vertical points were integrated and classified; new EDM calibration bases were installed at Québec and Mont-Joli; stability investigations were begun for Île d'Orléans and Trois-Rivières bridges; and lastly, preparations for NAD83 were pursued by further exchange of data with the Geodetic Survey of Canada, by updating the data for 1500 points and by preparing some data pertaining to the Québec/Ontario boundary.

Research activities included a continuation OF GPS investigations and new projects in inertial positioning and satellite laser ranging. The results of the 1984 GPS (Macrometer™) research were published (Moreau et al., 1985). A further test was conducted in March 1985 using T1 4100 receivers through a contract to Perron, Pagé et associés and a subcontract to Nortech Surveys (Canada) Inc. Further mathematical work pertaining to GPS continues under contract at Université Laval (UL). Also, in a joint effort with GSC, tests were conducted on the specially adapted Québec network near Victoriaville in May 1985, with the Litton LASS II inertial system. Results of the GSC part of the test were published (Penton et al., 1985). Analysis of the Québec part of the test results shows that this system permits relative positioning accuracies at standard deviation levels of 25 to 35 cm in the horizontal and 10 to 15 cm in the vertical, within a grid configuration with point spacing of about 7 km and coordinate updates about every 40 km. Finally, a research project involving some mathematical aspects of satellite laser ranging has been planned: this will be a cooperative effort between MER, UL and NASA; official acceptance by NASA of the Québec proposal was received in December 1985.

10. Ontario Ministry of Natural Resources, Surveys and Mapping Branch

Approximately 400 vertical control stations (bench marks) have been established in northwestern Ontario using ISS technology. These stations were established primarily to support mapping and control densification.

Eleven new three-dimensional control stations were established by GPS in the Huntsville/ Parry Sound area of Ontario to support small scale mapping and control densification. Four Macrometrics Macrometer™ V-1000 satellite receivers were employed. Twenty-three individual baseline vectors were observed over a period of six days. The vector lengths ranged from 7 to 193 km. Although only second-order relative positional accuracies were required, first-order results were achieved with the average baseline vector accuracy being 2 ppm.

In preparation for the forthcoming NAD83 readjustment, the Ministry has to analyse numerous control surveys and has found weaknesses in many of these networks. These weaknesses combined with known weak links between primary triangulation chains in Ontario prompted the Ministry to embark upon a project using GPS technology to strengthen portions of the existing provincial control network and to include the resulting GPS data in the NAD83 readjustment. The project was a joint effort between the Ministry and the Geodetic Survey of Canada. The Ministry designed the network and performed the preliminary reconnaissance. The GSC observed the network using T1 4100 Navstar Navigator receivers. Data processing was done by Nortech Surveys (Canada) Inc. of Calgary, Alberta. Thirty-five stations were occupied with the GPS receivers and about 91 interstation vectors ranging from a few kilometres to over 400 km were observed. The average baseline vector accuracy was 2 ppm, well within the 5 ppm originally desired. First-order spirit levelling to the 35 GPS stations is currently in progress and will provide accurate determination of the geoid-ellipsoid separation at these sites.

Second- and third-order horizontal and third-order vertical municipal densification networks, established in 1984/85, were analyzed for about 15 municipalities throughout the province. About ten new contracts have been let for second- and third-order horizontal and vertical municipal control densification networks in 1985. These networks will support large-scale mapping and integrated surveys in these municipalities.

Positional and associated observational data for nearly 3500 horizontal control stations have been stored in the Ontario horizontal control survey data bank COSINE in 1985. This gives a total of 41 000 stations complete with positional and observational data, currently residing in COSINE. COSINE is a control survey data base capable of storing positional, observational, and textual data associated with horizontal control stations; i.e.,

ellipsoidal and geoidal parameters, station names, positional values, angles, azimuths, distances, accuracy estimates, error ellipses, and relevant data such as station descriptions.

Area readjustments were completed for two large blocks of the province, the Metropolitan Toronto area and the south-central portion of Ontario. The Metro Toronto block consisted of 2151 stations involving 7174 observations and the south-central block had 4310 stations involving 22 181 observations. This brings the total number of stations readjusted in Ontario to 15 991 involving a total of 76 824 observations. Hence 42% of all the horizontal control in the province has been successfully adjusted onto near NAD83 datum values.

The Ministry has responded to their recently acquired mandate to manage vertical control data in Ontario. New staff have been hired and a vertical control adjustment program has been purchased. Nineteen existing vertical control networks, involving about 600 of the 2000 bench marks installed by the Ministry, have been processed, adjusted and loaded into a temporary vertical control data bank.

A precise calibration baseline for calibrating EDM equipment was constructed in Thunder Bay.

11. Manitoba Department of Natural Resources, Surveys and Mapping Branch

Under a cooperative inertial survey program with the Geodetic Survey of Canada, coordinate values were published for 220 stations in western Manitoba. As well, 174 inertial stations were selected, prepared, and measured in southeastern Manitoba.

The Dominion Land Survey system and geodetic framework were integrated at 65 locations.

Investigation into GPS technology is being carried out with the aim of purchasing receivers for field activities in the future.

Ground control and targetting were carried out in the Souris area to support an experimental photogrammetric test project. This required the placement of 350 targets, 100 miles of third-order spirit levelling, and 12 miles of second-order traversing. The main purpose of this project is to determine if photogrammetry combined with ground surveys can meet provincial survey, mapping and land information needs. Testing and analysis of this project are currently being carried out.

A photogrammetric test project was carried out within the City of Winnipeg. This project tested to see if photogrammetry could be used to generate positional information for targetted cadastral and utility points to an accuracy acceptable for plotting on 1:1000 City of Winnipeg maps. This project is in the final stages with the results looking very positive.

Data preparation and validation associated with secondary integration is in the final stages.

A computer program was developed which allows computation of positional data for cadastral parcels from legal survey plan information. This program has the acronym CADCOR (cadastral-coordinator) and calculates the positional data to an accuracy acceptable for the production of cadastral maps. It is written to run on a DEC VAX 11 computer under the VMS operating system using VAX FORTRAN 77.

A study on a land classification system to integrate remotely sensed data with a reference framework was funded by the Manitoba Department of Natural Resources and carried out by R.D. Knock (1985). The study was done as partial fulfilment of the requirements for a Master's degree in Natural Resources Management.

12. Alberta Bureau of Surveying and Mapping

An information document explaining NAD83 in Alberta in layman's terms (Barnes, 1985a) was put together to communicate the approach and timing as well as impact of the readjustment in Alberta to the public. This document was included in a questionnaire that was sent to a user sample to determine their needs with respect to survey control. A summary of the

responses to the questionnaire was compiled (Barnes, 1985b) to provide input to the Bureau's longer range strategic planning.

A GPS workshop was held to consider the impact of new technology on survey controls. The results of this exercise were summarized by Tessari (1984).

A test project was conducted through the municipal control section, utilizing a data collector backed by conventional field note recording to collect survey control horizontal and vertical observations. The results showed promise but indicated more refinement in hardware, software, and procedures was required.

Development continues on MASCOT (Multipurpose Alberta Survey Control Operations and Tasks) to replace the existing ASC (Alberta Survey control) computer system. MASCOT incorporates several existing geodetic packages and interfaces with a flat master file structure through a fourth generation relational data base language called POWERHOUSE.

The automation of all the survey control positional and observational conventional data in Alberta was completed and has been loaded into the existing ASC computer system. Further data testing is being carried out through block validation exercises in preparation for the readjustment.

A project to predict deflection and undulation components on a grid throughout Alberta was completed through a contract with the University of Calgary. In addition, a program to interpolate between the computed grid values and estimate accuracies of the components was completed (Sideris and Schwarz, 1985a)

The implementation of CANDSN on an IBM PC AT continues with completion expected early in 1986.

Another large GPS project was completed for the Bureau through contract in the fall of 1985. The project involved three separate areas occupying a total of approximately 230 stations and covering an area of greater than 45 000 km^2.

13. University of New Brunswick, Department of Surveying Engineering

In the realm of geoid determination, the gravity files needed for the gravimetric solution (1° x 1° means, 5' x 5' means, point gravity) have been acquired, updated, homogenized, reduced to GEM 9-implied references surface and entered into the IBM system. A flexible algorithm for two-dimensional integration that uses approximate modified spheroidal kernels has been developed.

The project to convert satellite altimetry determined sea surface into gravity anomalies has continued. A two-dimensional filter was developed which converts the altimetry into a partial Stokes's contribution corresponding to an integration cap of a specified radius. Both the NASA and the Ohio State University files of adjusted SEASAT altimetric profiles have been gridded (on a 10' x 10' grid). The DIPIX ARIES-II digital image analysis system has been used for display and analysis of rasterized adjusted sea surface heights derived from the SEASAT altimetry data. A relief shading program for enhancement of data has been added to the existing package of the system.

The UNB earth tides station is now working in an automatic mode with the tilt, gravity, and meteorological data being periodically transferred by telephone modem into the departmental HP 1000 computer system. New analysis of the last two years of data indicate that the problem with M2 N-S tilt component persists and that a model of the Bay of Fundy diurnal tide would be needed to get reasonable diurnal results (Pagiatakis and Vanicek, 1985). There seems to be a sizeable (but modelable) effect of underground water level fluctuations on both tilt and gravity.

Work continues on the modelling of the earth's response to ocean tide loading on a local scale. The model under development considers a layered, viscoelastic, compressible, rotating, and self-gravitating earth. Anisotropies and heterogeneities in the upper layers of the earth will also be considered in the near future.

A study of the plumbline corrections was successfully terminated (Hung, 1985). It has been shown that curvature effects on the meridian and prime vertical components of the deflection of the vertical can be estimated with an accuracy of about 0.01 inch if local gravity and topography data are available.

The study to implement trigonometric height traversing in geodetic levelling of high precision continued during the summer of 1985. A computerized system of motorized height traversing has been developed utilizing Wild T-2000 and Kern E-2 electronic theodolites with Wild DI-5 and Kern DM-502 short range EDM instruments linked with Epson HX-20 and TRS 80 Model 100 microcomputers. A test levelling network with a total of 70 km of traverses (eight loops) was measured using leap-frog and reciprocal methods. Estimated standard deviations between 0.5 and 1.8 mm/km have been obtained from the test surveys in hilly terrain (up to 7° inclinations) at speeds ranging from 12 to 15 km/day. The project has included extensive investigation of the influence of atmospheric refraction on trigonometric height traversing. Progress in the project has been documented by Chrzanowski (1984; 1985), Chrzanowski et al. (1985c) and Greening (1985).

Work continues on the implementation of UNB's generalized method for the analysis of deformation surveys. The method has been employed successfully in an integration of geodetic, photogrammetric, and geotechnical surveys in an analysis of ground subsidence (Chrzanowski et al., 1985a, 1985b; Chen et al., 1985), in laboratory tests (Shi, 1985), and in studies of ground movements in oil fields in Venezuela (Chrzanowksi and Secord, 1985). In addition, analysis of the U.S. Geological Survey Hollister trilateration network has been carried out by considering 12 years of observations with at least yearly campaigns simultaneously using the generalized method software (Secord, 1985).

A new methodology to separate systematic and random components of an error model in levelling networks has been developed using Minimum Norm Quadratic Estimation (Chen and Chrzanowski, 1985).

Research on integration of geodetic levelling surveys with GPS in the study of deformation in oil fields and in seismically active areas has been initiated (Chrzanowski and Secord, 1985).

UNBSAT, an economical Transit satellite Doppler receiving system consisting of a CMA-722B receiver and an Apple 11 microcomputer, has been further developed (Vu, 1984). Systems are in use at the Geodetic Survey of Canada and Wuhan Technical University of Surveying and Mapping in the People's Republic of China.

DIPOP, a new comprehensive software package for processing differenced GPS data has been developed under contract for the Geodetic Survey of Canada (Vanicek et al., 1985c; Santerre et al., 1985). DIPOP is being used at UNB and elsewhere to process data collected by Macrometer™ and T1 4100 receivers in a number of observing campaigns. Relative position accuracy of about 1 ppm has been obtained without orbit adjustment (Kleusberg et al., 1985b; Moreau et al., 1985; Vanicek et al., 1985b) and about 0.1 ppm when orbital parameters are estimated using a separate software package (Beutler et al, 1985). Other GPS-related activities include hydrographic applications of GPS (Mertikas, 1984, 1985b; Kleusberg et al., 1985a; Wells et al., 1985c; Mertikas et al., 1985); study of the problem of GPS network design (Wells et al., 1985b; Lindlohr and Wells, 1985); recommendation of terminology standards (Paradissis and Wells, 1984; Wells, 1985); and promulgation of the advantages of GPS in positioning (Vanicek et al., 1984a, 1984b; Chrzanowski et al., 1984a, 1984b; Santerre, 1985)

Mk111 LBI observations were carried out in August at Whitehorse, Yellowknife, Penticton, and Algonquin Park in support of the Alaska Regional Deformation and North American Plate Stability (NAPS) campaigns of the NASA Crustal Dynamics Project. Data from the summer 1984 NAPS campaign were reduced at UNB using the HP 100-based CALC/SOLVE and GEOAIM data analysis packages. A study has been initiated to assess the scientific and cost effectiveness of a future Canadian mobile LBI facility.

Work continued on the assessment of navigation accuracies (Mertikas et al., 1985; Mertikas, 1985; Mertikas and Paradissis, 1985); Omega receiver performance (Quek and Wells, 1985), and tropospheric effects on UHF radio positioning (Janes et al., 1985, Janes, 1985).

Design and implementation of SEAHATS, an inshore hydrographic surveying system, continued (Hourdakis, 1985).

14. Université Laval, Département des sciences géodésiques et de télédétection

Dans le domaine de la métrologie appliquée à la géodésie, les projets entrepris en 1984, sous la direction de J. Jobin, se sont poursuivis à savoir le développement d'un système interférométrique de calibrage des mires invar et des rubans, la comparaison entre calibrage de mire en positions verticale et horizontale et l'évaluation d'instruments de type station totale. Un projet est en cours pour la conception, la construction et l'analyse d'un système de positionnement d'écrans optiques pour études ballistiques pour le compte du Centre de recherche de la défence de Valcartier. Une base interférométrique de 35 mètres a été mise au point pour le calibrage de divers types d'instruments de mesure de distances. Finalement, un cahier de notes électronique a été adapté à l'ordinateur Tower 1632 du NCR.

Dans le domaine du nivellement, le programme de mesure de nevellement de précision à l'observatoire géophysique de St-Hilarion s'est poursuivi. L'analyse des données de 1978 à 1984 a été reprise en incluant un modèle de dilatation thermique de l'assise rocheuse supportant les repères (Sanchez et al., 1985).

Dans le domaine de la géodésie spatiale, l'analyse des données GPS observées sur le réseau de Ste-Foy par Nortech et Géo-Hydro s'est poursuivie sous la direction de J.G. Leclerc. Un nouveau logiciel général est développé pour le traitement d'observations provenant de différents récepteurs. La première étape devrait être terminée à l'été 1986.

Un projet de recherche sur l'analyse des résiduels des mesures laser sur satellites (LAGEOS principalement) a été amorcé en collaboration avec la NASA par L. Jeudy. Ce projet implique l'implantation sur un des ordinateurs de l'Universiteé Laval du programme de calcul d'orbites de satellites GEODYN et l'utilisation d'un programme d'analyse des séries chronologiques par moindres carrés DATAN.

Le projet sur l'utilisation des données Doppler du projet ADOS pour l'analyse du réseau géodésique marocain se poursuit sous la direction de P. Gagnon.

Une recherche sur le positionnement dynamique a été commencée à l'automne 1985 sous la direction de J.G. Leclerc. Un logiciel permettant d'analyser les effets des différentes sources d'erreur sera développé pendant l'année 1986. Un système hybride INS-GPS est choisi pour le positionnement dynamique. La précision recherchée par ce nouveau système est de 0,1m en x,y,z. Les différentes observations permises par le système GPS seront analysées pour obtenir la précision désirée avec un équipement le moins cher possible.

Un autre projet a été commencé sous la direction de J.G. Leclerc sur le modelage du déphasage secondaire appliqué à l'étallonnage du réseau Loran-C dans le golfe du St-Laurent. Les effets de la topographie et des constantes électriques de la terre seront analysés de façon à corriger le déphasage secondaire des ondes Loran-C. Le modèle de propagation de JOHLER servira de modèle de base pour le traitement des différences de temps observées par un récepteur Loran-C. On espère ainsi déterminer une position avec une précision d'environ 100 m lorsque au moins deux différences de temps observées sont corrigées pour les effets de déphasage secondaire. Une attention particulière sera portée aux zones côtières où les erreurs sont les plus importantes.

Dans le domaine de la géodynamique, un projet de recherche sur le gyrocompas suspendu a été amorcé par L. Jeudy. Ce projet a pour but la détermination de l'azimut gyroscopique avec une précision de l'ordre de la fraction de seconde d'arc. On espère mettre en évidence les mouvements du pôle ainsi que des rotations de la croûte terrestre. Des résultats préliminaires ont fait l'objet d'un rapport (Jeudy, 1985).

15. York University, Department of Earth and Atmospheric Sciences

Work continued on the development of the Canadian Geophysical Long Baseline Interfermetry system, a collaborative project involving York University, the University of Toronto, Boojum Research Ltd., Toronto, and the Earth Physics Branch of Energy, Mines and Resources Canada, with participation of the Herzberg Institute of Astrophysics. When completed, the CGLBI

system will have baseline determination precision capabilities comparable to the NASA Mk 111 system (length precision of a few centimetres over 10 000 km and angular precision of 1 milliarc second in orientation).

Work on the correlator for the CGLBI system has recently been completed at York. Three data recovery and playback terminals have been delivered from Boojum Research and two of these are now fully integrated into the correlator facility which presently operates in a single baseline, dual sideband mode with an overall data rate of 24 megabits per second. Future work on the CGLBI correlator facility will see the expansion to three baseline, dual sideband capability as well as the establishment of a data analysis and data archiving centre at York.

Three data acquisition and recording terminals are being completed at Boojum Research and the University of Toronto. Shakedown tests of the CGLBI system in its present state are expected to be conducted in the spring of 1986.

When this phase of the development is satisfactorily completed, the CGLBI system will have a bankwidth synthesis feature added to its operational capabilities. This will either be accomplished by (i) a frequency agile local oscillator and time domain multiplexing of the band, or (ii) the use of a very rapid sampler and the implementation of a "burst mode" of operation of the data acquisition and recording system.

Researchers from the LBI group at York assisted in the second year of observations at Algonquin Radio Observatory (ARO) in August 1985 as part of the NASA Crustal Dynamics Project.

16. University of Toronto/Erindale College, Department of Survey Science

The development of methods to detect, model and correct for systematic errors in first-order levelling continued (Craymer, 1985; Craymer and Vanicek, 1985; Vanicek et al., 1985a).

An algorithm for reducing levelled height differences and heights of tidal bench marks to a selected epoch was prepared and applied to the first-order Canadian height network (Carrera and Vanicek, 1985).

An investigation into the possibility of increasing the accuracy of the North American vertical network by using tide gauge data and height differences obtained by GPS was started.

Comprehensive studies in the methodology of analysis and evaluation of levelling errors were pursued along the lines indicated in the terms of reference of Special Study Group 1.74 of the International Association of Geodesy (Wassef, 1984).

The report of the Second International Symposium on Recent Crustal Movements in Africa was published (Wassef, 1985a). The proceedings of this symposium were edited by A.M. Wassef, A Boud and P. Vyskocil for the Journal of Geodynamics.

Algorithms for the generation of precise solar and stellar ephemerides were further developed (Gunn and Craymer, 1985) and a microcomputer program for practical azimuth determination was published (Craymer, 1985). An earlier study of the effect of misalignment of the reference ellipsoid with respect to the geocentric coordinate system on azimuth and deflection components was published (Vanicek and Carrera, 1985).

The need to review the place of mathematics in surveying education was expounded (Carrera and Gracie, 1985).

The limitations on the use of modern technologies by developing countries were brought into focus at the FIG meeting on inertial, Doppler, and GPS measurements (Wassef, 1985b). The surveyor's liabilities arising from the promulgated policy of denial of accuracy of GPS have been considered.

17. University of Saskatchewan, Department of Geological Sciences

The first part of an investigation into transverse stresses at the earth's surface has been completed with the publication of a paper on toroidal Love numbers (Merriam, 1985). The

degree one toroidal Love number is particularly interesting because it represents a deformation of the mantle which, at the surface, is indistinguishable from a rigid rotation. Indications are that this mode may sometimes lead to an apparent failure of the coupled atmosphere and solid earth to conserve angular momentum.

The next phase of this project, to develop Green's functions for displacement, tilt, and strain induced by transvese stress (winds, currents and topographic loading) is progressing and a manuscript is near completion.

It is expected that a new project, which will more clearly define the areas where the atmosphere and solid earth are exchanging angular momentum, can begin soon.

18. University of Calgary, Division of Surveying Engineering

Research continued on the use of inertial technology for geodesy and on the real-time integration of inertial and satellite data. On the theoretical side, the stability of the system of differential equations describing the error behaviour of an inertial system has been studied by Vassiliou and Schwarz (1985). A comprehensive discussion of different approaches to real-time and post-mission processing of inertial data has been given by Schwarz (1985) and a proposal for a consistent mathematical framework has been made. An assessment of estimation methods and field procedures for inertial networks has been carried out using control data of high accuracy in the Gimli network in northern Manitoba. The rigorous adjustment of filtered data gives a significantly improved accuracy compared to the adjustment of smoothed data. In real-time INS/GPS integration, a discussion of results achieved so far in updating the inertial state vector by pseudo-ranges from GPS satellites has been given by Wong et al. (1985). Different approaches of combining inertial and satellite data for precise aircraft positioning have been analysed by Goldfarb and Schwarz (1985). Results are encouraging, with two methods showing a potential for submetre accuracy and actual data are currently being analyzed to confirm the simulation results. Applications in photogrammetry and in airborne gravimetry and gradiometry are envisaged.

In gravity field approximation, a comprehensive comparison of different methods to estimate deflections of the vertical has been concluded and results have been published by Kearsley et al. (1985). A similar comparison for precise geoid computation has been carried out by Schwarz and Sideris (1985) and results indicate that the current accuracy of relative geoid computation is compatible with the positioning accuracy of GPS. Thus, a combination of the two techniques can be used to determine orthometric height differences. The use of FFT techniques for terrain correction determination (Sideris, 1985a), and the relationship between spectra of mean and point anomalies (Sideris, 1985b) have been discussed. The application of the same technique to the numerical computation of higher order terms in the Molodenski solution was given by Sideris and Schwarz (1985b).

Research on precise GPS positioning and dynamical short-arc orbit improvement continued. A permanent Canadian GPS tracking network of four stations collocated at the projected Canadian Long Baseline Array sites is sufficient to attain ± 2.5 m orbital accuracies which, in turn, enable terrestrial positioning accuracies of 10^{-7} over distances ~ 10^{3}km (Nakiboglu et al., 1985). A prototype software package was developed for the determination of short-arc orbits and/or for local and regional multi-station terestrial positioning utilizing any combination of Doppler, pseudo-range and single difference phase observations (Krakiwsky et al., 1985).

A theory of thermo-mechanical response of the earth's lithosphere to temperature anomalies was developed (Nakiboglu and Lambeck, 1985b). Pratt isostasy is shown to be the asymptotic response of a viscoelastic lithosphere in which both horizontal and vertical thermal stresses are allowed to relax. The theory applied to the Hawaiian swell puts forward a consistent explanation of the observed surface heat flow, long wavelength bathymetry, and geoid in the region (Nakiboglu and Lambeck, 1985a) Another important conclusion is that the upstream part of the swell may be supported dynamically.

The analysis of the photogrammetric and auxiliary data from the 1983 aerial coverage of the Kananaskis Test Network area has largely been completed and documented (Blais et al., 1985b; Blais and Chapman, 1985). The current research relates to the Laser Profiler and Multi-Spectral Scanner data collected simultaneously with the aerial photography in 1983.

Various aspects of digital terrain modelling (Blais et al., 1985a), optimal estimation (Blais, 1985a) and land-related information systems (Blais, 1985b; Feuchtwanger and Blais, 1985) have also been investigated.

19. Nortech Surveys (Canada) Inc.

Developments related to the use of GPS for airborne, marine and land dynamic and static positioning were pursued using both TI 4100 and Trimble 4000A receivers. Fixed wing aircraft and helicopter-borne tests carried out with TI 4100 receivers in pseudo-range single point and differential modes, respectively, for the Canadian Hydrographic Service and the Canadian Coast Guard were successful and led to single point and differential three-dimensional accuracies of 20 m and 5 m, respectively.

Marine differential GPS operations were conducted in single point and differential pseudo-range mode in several parts of the world with both TI 4100 and Trimble 4000S receivers. Both receivers yielded very satisfactory results.

Precise land static differential tests were conducted in the spring of 1985 over baselines of 10 to 30 km and 300 to 500 km. The short baseline tests resulted in consistencies of the order of 1 to 3 ppm, while the long baseline tests yielded consistencies of the order of 0.5 to 2 ppm. In the long baseline tests, the effect of the ionosphere was assessed to about 1 ppm by comparing single and dual frequency results. A test carried out over a very long baseline (1700 km) resulted in similar consistencies (Cannon et al., 1985).

Other development activities took place in connection with Nortech's accurate helicopter-borne terrain profiling system and inertial positioning systems. Extensive terrain profiling and inertial positioning projects were carried out in several parts of the world.

20. Bibliography

Barnes, D.C. 1985a. North American Datum, 1983 (NAD83)-Alberta. Alberta Bureau of Surveying and Mapping report, Edmonton.

Barnes, D.C. 1985b. Alberta Bureau of Surveying and Mapping 1985 survey control user survey. Internal report, Alberta Bureau of Surveying and Mapping, Edmonton.

Beck, N. 1985. Pre-processing Texas Instrument 4100 GPS data. Internal Report, Geodetic Survey of Canada, Ottawa.

Beutler, G., Gurtner, W., Bauersima, I. and Langley, R. 1985. Modelling and estimating the orbits of GPS satellites. Proceedings of the First International Symposium on Precise Positioning with the Global Positioning System, Rockville, MD, April, 99-111.

Blais, J.A.R. 1985a. Least-square filtering and smoothing using Givens transformations. Manuscripta Geodaetica, 10(3), 208-212.

Blais, J.A.R., 1985b. Topological considerations for an Alberta land related information system. Final Report submitted to the Alberta Bureau of Surveying and Mapping, Edmonton.

Blais, J.A.R. and Chapman, M.A. 1985. Optimal use of auxiliary airborne inertial data in topographical mapping applications. Proceedings of the Third International Symposium for Surveying and Geodesy, Banff, September.

Blais, J.A.R., Chapman, M.A. and Kok, A.L. 1985a. Digital terrain modelling and applications. Proceedings of the American Congress of Surveying and Mapping, American Society of Photogrammetry Fall Convention, Indianapolis, IN, September, 646-651.

Blais, J.A.R., Chapman, M.A., Kok, A.L., Thyer, N. and Stoliker, P. 1985b. Photogrammetric measurements and data processing for integration of auxiliary sensor data into photogrammetric block adjustment process for the Kananaskis Test and Calibration Network. Final report submitted to the Canada Centre for Remote Sensing, Energy, Mines and Resources Canada, Ottawa.

Boal, J.D., Gareau, R. and Young, F. 1985. Status of vertical control networks in Canada. Proceedings of the Third International Symposium on the North American Vertical Datum, Rockville, MD, April, 1-10.

Cannon, M.E., Lachapelle, G. and Goad, C.C. 1985. Recovery of a 1700 km baseline using dual frequency GPS carrier phase measurements. Proceedings of the First International Symposium on Precise Positioning with GPS, Rockville, MD, April, 593-602.

Carrera, G. and Gracie, G. 1985. Mathematics in surveying education: a tool in need of review. Collected papers, Colloquium on Surveying and Mapping Education, Fredericton, June 2-16.

Carrera, G. and Vanicek P. 1985. A temporal homogenization of the Canadian height network. Proceedings of the Third International Symposium on the North American Vertical Datum, Rockville, MD, April, 217-226.

Chen, Y.Q. and Chrzanowski, A. 1985. Assessment of levelling measurements using the theory on MINQE. Proceedings of the Third International Symposium on the North American Vertical Datum, Rockville, MD, April, 389-400.

Chen, Y.Q., Chrzanowski, A. and Secord, J. 1985. Generalized modelling of ground movements by integrating geodetic surveys with geotechnical measurements. Proceeding of the 6th International Congress of ISM, Harrogate, England, September, 912-920.

Chrzanowski, A. 1984. Feasibility study on the implementation of the motorized trigonometric height traversing for precise levelling. Final contract report to the Geodetic Survey of Canada, Ottawa.

Chrzanowski, A. 1985. Implementation of trigonometric height traversing in geodetic levelling of high precision. Final contract report to the Geodetic Survey of Canada, Ottawa.

Chrzanowski, A. and Secord, J.M. 1985. Monitoring of the Tia Juana dyke. Contract report to Maraven, S.A., Venezuela.

Chrzanowski, A., Chen, Y.Q., Romero, P. and Secord, J.M. 1985a. Integration of geodetic and geotechnical deformation surveys in the geosciences. Proceedings of the International Symposium on Recent Crustal Movements, Maracaibo, Venezuela.

Chrzanowski, A., Langley, R.B., Wells, D.E. and McLaughlin, J.D. 1984a. Prognozy dotyczace wplywu globalnych systemow wyznaczania wspolrzednych (GPS) na geodezje (Polish translation of "A forecast of the impact of GPS on surveying".), Przeglad Geodezyjny, 56(12), 10-12.

Chrzanowski, A., Langley, R.B., Wells, D.E. and McLaughlin, J.D. 1984b. Le système GPS: Les retombées possibles de la technologie GPS sur les activités d'arpentage (translation of "A forecast of the impact of GPS on surveying".), Arpenteur Géomètre, 11(1), 9-14.

Chrzanowski, A., Chen, Y.Q., Fisekci, M.Y., Secord, J. and Szostak-Chrzanowski, A. 1985b. An integrated approach to the monitoring and modelling of ground movements. Proceedings of the 4th Conference on Ground Control in Mining, Morgantown, WV, July, 273-285.

Chrzanowski, A., Greening, T., Kornacki, W., Secord, J., Vamosi, S. and Chen, Y.Q. 1985c. Applications and limitations of precise trigonometric height traversing. Proceedings of the Third International Symposium on the North American Vertical Datum, Rockville, MD, April, 81-93.

Craymer, M.R. 1985. SPADE--Solar and Polaris azimuth determination: FORTRAN program and users' guide (version 3.1). Survey Science, University of Toronto, Mississauga.

Craymer, M.R. and Vanicek, P. 1985. An investigation of systematic errors in Canadian levelling lines. Proceedings of the Third International Symposium on the North American Vertical Datum, Rockville, MD, April, 441-450.

Delikaraoglou, D. and Steeves, R.R. 1985. Impact of VLBI and GPS on geodesy in Canada. Proceedings of the First International Symposium on Precise Positioning with GPS, Rockville, MD, April, 743-752.

Delikaraoglou, D., Beck, N., McArthur, D. and Lochhead, K. 1985a. A tutorial comparison of geodetic positioning techniques using the code and carrier phase difference observations of GPS satellites. Geodetic Survey of Canada, Ottawa.

Delikaraoglou, D., Beck, N., McArthur, D. and Lochhead, K. 1985b. On the establishment of 3-D geodetic control by interferometry with the TI-4100 GPS receiver. Proceedings of the First International Symposium on Precise Positioning with GPS, Rockville, MD, April, 645-655.

Douglas, R.J. and Boulanger, J.-S. 1985. Cesium beam primary frequency standards at NRC. Proceedings of the Seventeenth Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, Washington, DC, December.

Feuchtwanger, M. and Blais, J.A.R. 1985. Research for the Alberta Cadastral Intelligent Data System. Final Report submitted to the Alberta Bureau of Surveying and Mapping, Edmonton.

Gingras, D. and Vanier, J. 1985. Comment on magnetic shielding in hydrogen masers. J. Phys. E. Sci. Instrum., 18, 967.

Goldfarb, J.M. and Schwarz, K.P. 1985. Kinematic positioning with an integrated INS-differential GPS. Proceedings of the First International Symposium on Precise Positioning with GPS, Rockville, MD, April, 757-772.

Grafarend, E., Lindlohr, W. and Wells, D.E. 1985. GPS redundancy design using the undifferenced phase observation approach. Proceedings of the Second Meeting of the European Working Group on Satellite Radio Positioning, Paris, November.

Gray, D.H. 1985a. Verifying the Gulf of Maine computations. Lighthouse, 32, 13-16.

Gray, D.H. 1985b. Why the St. Lawrence Seaway is unlatticed. The Hydrographic Journal, 38, 31-32.

Greening, W.J.T. 1985. Evaluation of precision trigonometric levelling methods. M.Sc.E. thesis, Department of Surveying Engineering, University of New Brunswick, Fredericton.

Gunn, R.C. and Craymer, M.R. 1985. An algorithm for azimuth of Polaris. In: Association of Ontario Land Surveyors Private Practice Manual.

Héroux, P., Gale, W. and Faucher, F. 1985. Field test report on the effect of systematic refraction in precise levelling. Proceeding of the Third International Symposium on the North American Vertical Datum, Rockville, MD, April, 311-320.

Hourdakis, P. 1985. Design and implementation of an inshore hydrographic surveying system. M.Sc.E. thesis and Department of Surveying Engineering Technical Report No. 120, University of New Brunswick, Fredericton.

Hung, P.-S. 1985. Evaluation of the plumb line curvature effect on the deflection of the vertical. M.Sc.E. thesis and Department of Surveying Engineering Technical Report No. 121, University of New Brunswick, Fredericton.

Janes, H.W. 1985. On the modelling of tropospheric effects in ultra-high frequency radio positioning. M.Sc.E. thesis and Department of Surveying Engineering Technical Report No. 119, University of New Brunswick, Fredericton.

Janes, H.W., Wells, D.E. and Tranquilla, J. 1985. Accuracy considerations in UHF radio positioning. Proceedings of the First Biennial Conference of the Canadian Hydrographic Service, Halifax, April.

Jeudy, L.M.A. 1985. Méthode des transits multiples et des moindres carrés pour les azimuts gyroscopiques. Rapport de recherche, Département des sciences géodésiques et de télédétection, Université Laval, Québec.

Kearsley, A.H.W., Sideris, M.G., Krynski, J., Forsberg, R. and Schwarz, K.P. 1985. White Sands revisited - a comparison of techniques to predict deflections of the vertical. Division of Surveying Engineering Publication No. 30007, University of Calgary.

Kleusberg, A., Quek, S.H., Wells, D.E. and Hagglund, J. 1985a. Comparison of GPS and INS ship velocity determination. Proceedings of the Third International Symposium on Inertial Technology, Banff, September.

Kleusberg, A., Langley, R.B., Santerre, R., Vanicek, P., Wells, D.E. and Beutler, G. 1985b. Comparison of survey results from different types of GPS receivers. Proceedings of the First International Symposium on Positioning with GPS, Rockville, MD, April, 579-592.

Knock, R.D. 1985. A land classification to integrate remotely sensed data with a provincial geographic information system. Master of Natural Resources Management practicum, Natural Resources Institute, University of Manitoba, Winnipeg.

Krakiwsky, E.J., Wanless, B., Buffett, B., Schwarz, K.P. and Nakiboglu, S.M. 1985. GPS orbit improvement and precise positioning. Proceedings of the First International Symposium on Precise Positioning with GPS, Rockville, MD, April, 73-86.

Lindlohr, W. and Wells, D.E. 1985. GPS design using undifferenced carrier beat phase observations. Manuscripta Geodaetica, 10(3), 255-295.

Lugoe, F.N. 1985. Rigorous densification of horizontal geodetic networks. Ph.D. dissertation and Department of Surveying Engineering Technical Report No. 118, University of New Brunswick, Fredericton.

McArthur, D.J., Beck, N., Lochhead, K. and Delikaraoglou, D. 1985. Precise relative positioning with the Marcometer™ V-1000 Interferometric Surveyor: experience at the Geodetic Survey of Canada. Proceedings of the First International Symposium on Precise Positioning with GPS, Rockville, MD, April, 521-532.

Merriam, J.B. 1985. Toroidal Love numbers and transverse stress at the earth's surface. J. Geophys. Res., 90, 7795-7802.

Mertikas, S.P. 1984. Evaluation of some parameters affecting the performance of differential navigation. Quaterniones Geodaesiae, 5(2), 105-124.

Mertikas, S.P. 1985a. Error distribution and accuracy measures in navigation. Department of Surveying Engineering Technical Report No. 113, University of New Brunswick, Fredericton.

Mertikas, S.P. 1985b. A revolution in navigation: Global Positioning System (GPS) (in Greek). Technika Chronika, 5(2), 81-104.

Mertikas, S.P. and Paradissis, D. 1985. Error distributions and accuracy measures in navigation and aviation: An overview (in Greek). Quaterniones Geodaesiae, 6(2), 103-168.

Mertikas, S.P., Wells, D.E. and Leenhouts, P. 1985, Treatment of navigational accuracies: proposals for the future. Proceedings of the First Biennial Conference of the Canadian Hydrographic Service, Halifax, April. Navigation, Journal of the Institute of Navigation, 32(1), 138-143.

Moon, W. and Tang, R.W. 1985a. On the hydrodynamic correction of SEASAT-ALT data. Marine Geodesy, 9, 291-333.

Moon, W. and Tang, R.W. 1985b. Ocean bottom friction study from numerical modelling of sea surface height and SEASAT-ALT data. J. Marine Geophys. Res., 7, 73-76.

Moreau, R., Beutler, G., Leclerc, J.G., Labrecque, B., Langley, R.B. and Santerre, R. 1985. The Quebec 1984 Macrometer test: comparison of phase-difference processing and network solution methods. Proceedings of the First International Symposium on Precise Positioning with GPS, Rockville, MD, April, 557-566.

Nakiboglu, S.M. and Lambeck, K. 1985a. Comments on thermal isostasy. J. Geodyn., 2, 51-65.

Nakiboglu, S.M. and Lambeck, K. 1985b. Thermal response of a moving lithosphere over a mantle heat source. J. Geophys. Res., 90, 2985-2994.

Nakiboglu, S.M., Krakiwsky, E.J., Schwarz, K.P., Buffet, B. and Wanless, B. 1985. A multi-station, multi-pass approach to Global Positioning System orbital improvement and precise positioning. Final Report to Energy, Mines and Resources Canada, Ottawa.

Pagiatakis, S.D. and Vanicek, P. 1985. Atmospheric perturbations of tidal tilt and gravity measurements at the UNB Earth tides Station. Proceedings of the 10th International Symposium on Earth Tides, Madrid, September.

Paradissis, D. and Wells, D.E. 1984. GPS standardization - status and problems. Proceedings of the International Symposium on Space Techniques for Geodynamics, Sopron, Hungary, July, 2, 219-242.

Penton, C. and Penney, R. 1985. An evaluation of the positioning capability of the Litton Auto Survey System, LASS-II. Proceedings of the Third International Symposium on Inertial Technology for Surveying and Geodesy, Banff, September.

Quek, S.H. and Wells, D.E. 1985. Evaluation of CMA-771 Omega receiver performance on Project CESAR. Department of Surveying Engineering Technical Report No. 112, University of New Brunswick, Fredericton.

Romero, P.J. 1985. Use of tiltmeters in an integrated subsidence study. M.Eng. Report, Department of Surveying Engineering, University of New Brunswick, Fredericton.

Sanchez, R.N., Jobin, J. Gagnon, P. et Arancibia, G. 1985. Études des résultats des measures mensuelles de nivellement à l'observatoire géophysique de Charlevoix. Rapport de recherche, Département des sciences géodésiques et de télédétection, Université Laval, Québec.

Santerre, R. 1985. Le système de positionnement global GPS. Arpenteur-géomètre, 12(2), 10-12 (part 1), 12(3), 8-9(part 2).

Santerre, R., Kleusberg, A. and Beutler, G. 1985. DIPOP: Software documentation. Department of Surveying Engineering Technical Memorandum TM-6, University of New Brunswick, Fredericton.

Schwarz, K.P. (Editor), 1984. Proceedings of local gravity field approximation. An international summer school held in Beijing, China, 21 August - 4 September. Division of Surveying Engineering Publication No. 60003, University of Calgary, Calgary.

Schwarz, K.P. 1985. A unified approach to post-mission processing of inertial data. Bull. Géodésique, 59, 33-54.

Schwarz, K.P. and Sideris, M.G. 1985. Precise geoid heights and their use in GPS interferometry. Contract Report 85-004, Geodetic Survey of Canada, Ottawa.

Secord, J.M. 1985. Implementation of a generalized method for the analysis of deformation surveys. M.Sc.E. thesis and Department of Surveying Engineering Technical Report No. 117, University of New Brunswick, Fredericton.

Sideris, M.G. 1985a. A Fast Fourier Transform method for computing terrain corrections. Manuscripta Geodaetica, 10(1), 66-73.

Sideris, M.G. 1985b. On the relationship between spectra of mean and point data with application on computing, inverting, and updating gravity field quantities. Proceedings of Potential Fields in Rugged Topography, Lausanne, Switzerland, July.

Sideris, M.G. and Schwarz, K.P. 1985a. Computation of geoidal undulations and deflections of the vertical for Alberta. Final contract report, Alberta Bureau of Surveying and Mapping.

Sideris, M.G. and Schwarz, K.P. 1985b. Solving Molodensky's series by fast Fourier transform techniques. Proceedings of First Hotine-Marussi Symposium on Mathematical Geodesy, Rome, June.

Tait, B.J. and Bolduc, P.A. 1985. An update on rates of apparent vertical movement in the Great Lakes basin. Proceedings of the Third International Symposium on the North American Vertical Datum, Rockville, MD, April 193-206.

Tessari, E.J. 1984. Proceedings of think tank on GPS potential. Internal report, Alberta Bureau of Surveying and Mapping, Edmonton.

Vanicek, P. (member of editorial committee) 1985. Geodesy: A Look to the Future. Committee on Geodesy, Commission on Physical Sciences, Mathematics and Resources, National Academy Press, Washington.

Vanicek, P. and Carrera, G. 1985. Reference ellipsoid misalignment, deflection components and geodetic azimuth. Canadian Surveyor, 39(2), 123-130.

Vanicek, P., Carrera, G.H. and Craymer, M.R. 1985a. Corrections for systematic effects in the Canadian levelling network. Technical Report No. 10, Survey Science, University of Toronto, Mississauga.

Vanicek P., Kleusberg, A., Langley, R.B. Santerre, R. and Wells, D.E. 1985b. On the elimination of biases in processing GPS observations. Proceedings of the First International Symposium on Positioning with GPS, Rockville, MD, April, 315-324.

Vanicek, P., Beutler, G., Kleusberg, A., Langley, R.B., Santerre, R. and Wells D.E. 1985c. DIPOP: Differential Positioning Program Package for the Global Positioning System. Department of Surveying Engineering Technical Report No. 115, University of New Brunswick, Fredericton, and Contract Report 85-005, Geodetic Survey of Canada, Ottawa.

Vanicek, P., Beutler, G., Faig, W., Chrzanowski, A., Langley, R. McLaughlin, J. and Wells, D.E. 1984a. Wplyw Rozwoju Metod Kosmicznychna Pomiary Terenowe (Polish translation of "Implications of new space techniques in land surveying"), Przeglad Geodezyjny, 56(11), 10-11.

Vancek, P., Wells, D.E., Chrzanowski, A., Hamilton, A.C., Langley, R.B., McLaughlin, J.D. and Nickerson, B.G. 1984b. Przyszlosc sieci geodezyjnych (Polish translation of "The future of geodetic networks"). Przeglad Geodezyjny, 56(8-9), 5-7.

Vanier, J. 1985. Le pompage optique et les étalons atomiques de fréquence. Ann. Phys. Fr., 10, 529.

Vanier, J., Jacques, C. and Audoin, C. 1985. Effect of spin-exchange on the ground-state density matrix of alkali-metal and hydrogen atoms. Phys. Rev. A, 31, 3967-3969.

Vassiliou, A.A. and Schwarz, K.P. 1985. Eigenvalues of the dynamics matrix used in inertial geodesy. Manuscripta Geodaetica, 10(3), 213-221.

Vu, A.T. 1984. Modification of the Apple II-CMA-722B satellite Doppler system to acquire nine-digit Dopplers. Department of Surveying Engineering Technical Memorandum TM-4, University of New Brunswick, Fredericton.

Wassef, A.M. 1984. Special Study Group 1.74: Comparison of Methods of Analysis and Evaluation of Levelling Errors. Bull. Géodésique, 58(3), 333.

Wassef, A.M. 1985a. Report of Second International Symposium on Recent Crustal Movements in Africa (Cairo, 26 November-3 December 1984). Bull. Géodésique, 59(2). 200-204.

Wassef, A.M. 1985b. Modern techniques for developing countries. Proceedings of Inertial, Doppler and GPS Measurements for National and Engineering Surveys, a Joint Meeting of FIG Study Groups 5B and 5C, Munich, July, 569-575.

Wells, D.E. 1985. Recommended GPS terminology. Proceedings of the First International Symposium on Precise Positioning with GPS, Rockville, MD, April, 903-932. Reprinted in Proceedings of Inertial, Doppler and GPS Measurements for National and Engineering Surveys, Munich, July, 179-208, (reprinted in Points and Positions, 3(3), 7-8).

Wells, D.E., Vanicek, P. and Pagiatakis, S. 1985a. Least squares spectral analysis revisited. Department of Surveying Engineering Technical Report No. 84, University of New Brunswick, Fredericton.

Wells, D.E., Lindlohr, W., Schaffrin, B. and Grafarend, E. 1985b. GPS design: undifferenced carrier beat phase observations and the fundamental differencing theorem. Department of Surveying Engineering Technical Report No. 116, University of New Brunswick, Fredericton.

Wells, D.E., Kleusberg, A., Quek, S.H., McCullough, J. and Hagglund, J. 1985c. Precise ship velocity from GPS: some test results. Proceedings of the First International Symposium on Positioning with GPS, Rockville, MD, April, 799-808.

Wong, R.V.C., Schwarz, K.P., Lachapelle, G. and Hagglund, J. 1985. Accurate positioning by a combination of inertial and GPS satellite techniques. Marine Geodesy, 9, 213-226.

I (B) GRAVITY

Compiled by: M.D. Thomas

1. Summary

Progress continued to be made in the national program to map the gravity field of the Canadian landmass and territorial waters: 8250 line kilometres of marine gravity data were obtained in areas off Vancouver Island, 790 underwater stations were occupied at various localities along the east coast continental shelf and 795 observations were made on sea-ice in the Gulf of Boothia; 216 stations in the Mackenzie Basin, N.W.T. serve the dual purpose of contributing to the national program and to a LITHOPROBE program that will include seismic reflection surveys in 1986. Improvements to existing regional coverage were made in southwestern Ontario (835 stations) and southern Newfoundland (89 stations). At least another 1700 observations (number of stations not reported for some surveys) were directed towards specific geological targets, the most common of which were granitic intrusions located in the Canadian Shield and Appalachians. In some cases the observations were made as a contribution to multidisciplinary studies with economic (e.g. Ackley granite, Newfoundland) or environmental (e.g. Nuclear Fuel Waste Management Program) objectives. Regional crustal structure, a sedimentary basin and a basic intrusion at Sept Îles were other targets of interest.

A major revision to the National Gravity Data Base involved editing of 2.2 million marine gravity observations acquired by the Atlantic Geoscience Centre (AGC) off the east coast of Canada in a region extending from the Bay of Fundy through the Labrador Sea into Baffin Bay. An edited data set of approximately 1.5 million measurements was incorporated into the data base. A revision was also made to a gravity data base for the Province of Nova Scotia. The data base, maintained by the Nova Scotia Research Foundation, contains about 26 000 gravity stations.

Four open file maps at a scale of 1:1 000 000 were released by the National Gravity Data Centre in 1985. In addition, a series of four-colour Applicon gravity maps of Canada at a scale of 1:10 000 000 (Bouguer, Free Air, Isostatic and Horizontal Gravity Gradient) was prepared and will be released in 1986.

Geological interpretation of gravity data focused largely on igneous intrusions, mainly granites, in the Canadian Shield and Appalachians, but included analysis of regional-scale structures such as the Alpha Ridge, the Innuitian orogen, an oceanic-continental transect in the Arctic and the Proterozoic Cape Smith Belt, as well as more localized features such as potash deposits and impact crater structures. In the field of microgravimetry, measurements taken over the last eight years are being analyzed in conjunction with relevelling data to study recent vertical movement of the crust on Vancouver Island. There has been a number of developments in the application of numerical methods to processing and interpretation of gravity data. Various fast Fourier transform (FFT) techniques, for example, have been derived for computation of terrain corrections, and continuation, differentiation and filtering of the gravity field. FFT techniques have also been applied to geodetic computations. Other numerical research has led to a simplified formula for obtaining the integral mean value of gravity, a 2D Hilbert transform algorithm, cross-spectral techniques for isostatic studies and an algorithm to compute gravity anomalies due to crustal loading.

Instrumentation studies have advanced on several fronts. A method utilizing a pulse-modulated signal to provide inherently linear electrostatic force feedback has been developed for use in astatic gravity meters. Work has been carried out on improving AGC's Bodenseewerk Seagravimeter (System KSS30); the platform has been upgraded and a new system (KSS31) produced an improvement in accuracy by a factor of two. Development and testing of marine navigation systems were also undertaken by AGC. Experimentation with a Ferranti inertial system in rough terrain indicates that inertial data can provide gravity anomalies with an accuracy of about 3 mGal. An airborne gravity gradiometry system has been evaluated and is expected to produce data with accuracies better than 1 mGal. Perhaps one of the highlights of the year with respect to instrumentation was the acquisition by the Earth Physics Branch of an absolute gravimeter.

2. Earth Physics Branch (EPB)

(a) Gravity Standards (R.K. McConnell)

A joint meeting of the International Gravity Commission and the Commission for Geodesy in Africa, chaired by J.G. Tanner of EPB, was held in Paris, France on May 22 to 24. In addition to a review of the status of gravity mapping activities in Africa the meeting focused on discussion of mechanisms for implementation of the plan for an African Gravity Standardization Network. Although African agencies must still find funding for the project, commitments for technical support were received from Canada, India, Italy and West Germany.

(b) Gravity Data Base (D.B. Hearty)

The Gravity Data Centre processed 326 external requests for information involving digital data (gravity and terrain), maps (manuscript, customized, open file and Applicon), gravity network control station descriptions, software routines and earth tide values.

Marine gravity data collected on 65 cruises between 1964 and 1984 by AGC, operating in collaboration with the Canadian Hydrographic Service and/or EPB, have been edited and added to the National Gravity Data Base. These data initially comprised 2.2 million raw gravity observations of which 1.2 million were provided to EPB in 1984 and another 1 million in 1985. The latter two data sets were merged and processed through four levels of editing and quality control, which resulted in a reduced data set of approximately 1.5 million raw observations at one minute (time) intervals. This data set was then processed using a least squares adjustment of gravity at ship track intersections to ensure homogeneity of datum and itself compressed to about 340,000 observations at five minute (time) intervals; these were added to the National Gravity Data Base. These data are available as EPB Open File 85-32, or by selective retrieval from the National Gravity Data Base.

Some 2895 observations obtained in seven projects conducted in the following areas: Southern Ontario, Prince Regent Inlet, Gulf of Boothia, Yukon, Newfoundland, Canadian Ice Island, various localities off the east coast (underwater surveys), were processed and added to the National Gravity Data Base.

The digital topographic data base for the Cordillera was augmented by some 467 000 data points compiled from 711 NTS maps at a scale of 1:50 000 covering an area between latitudes 62.5°N and 70.0°N and longitudes 125.5°W and 142.0°W. This compilation is continuing in 1986 to complete the data acquisition north of latitude 55°N and between longitudes 120°W and 143°W in the mountainous areas of the Northwest Territories and Yukon Territory. Enquiries regarding gravity or topographic data should be directed to D.B. Hearty, Gravity Data Centre, Geophysics Division, Geological Survey of Canada, 1 Observatory Crescent, Ottawa K1A 0Y3 (telephone: 613-995-5326).

(c) Gravity Map Production (J.F. Halpenny, L.A. Warren)

Four open file maps at a scale of 1:1 000 000 were produced: 84-30 (Scotian Shelf - Sable Island); 84-31 (Banquereau - Whale Deep); 85-19 (Northern Juan de Fuca Ridge); and 85-26 (Gulf of Boothia - Prince Regent Inlet).

Colour Applicon maps of Bouguer, free air and isostatic gravity anomalies of Canada at a scale of 1:10 000 000 were produced and presented at the National Convention of the Canadian

Society of Exploration Geophysicists and Canadian Geophysical Union. These maps, along with a map of horizontal gravity gradients, will be released in 1986. Prototype colour Applicon gravity maps have been produced for studies relating to the Decade of North American Geology (DNAG) in the following areas: polar region north of latitude 64°N (1:6 000 000), east coast (1:5 000 000), North America (1:10 000 000).

(d) Gravity Surveys (D.W. Halliday, R.V. Cooper, D.Seeman and P.J. Winter)

(i) Offshore British Columbia. Shipborne surveys conducted from CSS Parizeau collected 7500 line kilometres of dynamic gravity data (LaCoste and Romberg SL1 linear meter) along lines spaced 10 km apart in the economic resource zone off Vancouver Island. The surveys extended to the outer edge of the zone and completed mapping of the zone. The area is bounded by latitudes 49°N and 52°N and longitudes 129°W and 136°W. An additional 750 line kilometres of gravity data were obtained in the Strait of Georgia.

(ii) Mackenzie Basin, N.W.T.. A detailed gravity survey comprizing 216 stations was conducted in the Mackenzie Basin between Inuvik and the Beaufort Sea as a contribution to a Lithoprobe program that will involve collection of seismic reflection data in 1986.

(iii) Arctic. Regional gravity mapping at 6 km station spacing was carried out in the Gulf of Boothia; 795 observations were made. Gravity measurements (77) were made along seismic refraction lines surveyed from the Canadian Ice Island located north of Axel Heiberg Island.

(iv) Northern Quebec. A detailed gravity profile 210 km long was established across the Cape Smith Fold Belt. Station interval was about 2 km and 104 measurements were made. Detailed gravity surveys totalling 131 observations were also conducted over two granitic intrusions within the fold belt, one located at Pecten Harbour on the shore of Hudson Bay and the other east of Lac Serpentine.

(v) Southern Quebec. Gravity measurements (130) were made in the region of Sept Isles to improve coverage over an anorthosite/gabbro intrusion that crops out along the coastal area and on the offshore islands.

(vi) Northern Ontario. In gravity surveys made over the Eye-Dashwa Lake granitic pluton and marginal country rocks in the Superior Province a total of 180 observations was observed, spaced generally about 0.2 or 0.4 km apart. The surveys were made along a road profile and along lake shores. This work was done as part of the Nuclear Fuel Waste Management Program.

(vii) Southwestern Ontario. Regional coverage in southwestern Ontario was upgraded to 6 km station spacing. A total of 835 stations was observed.

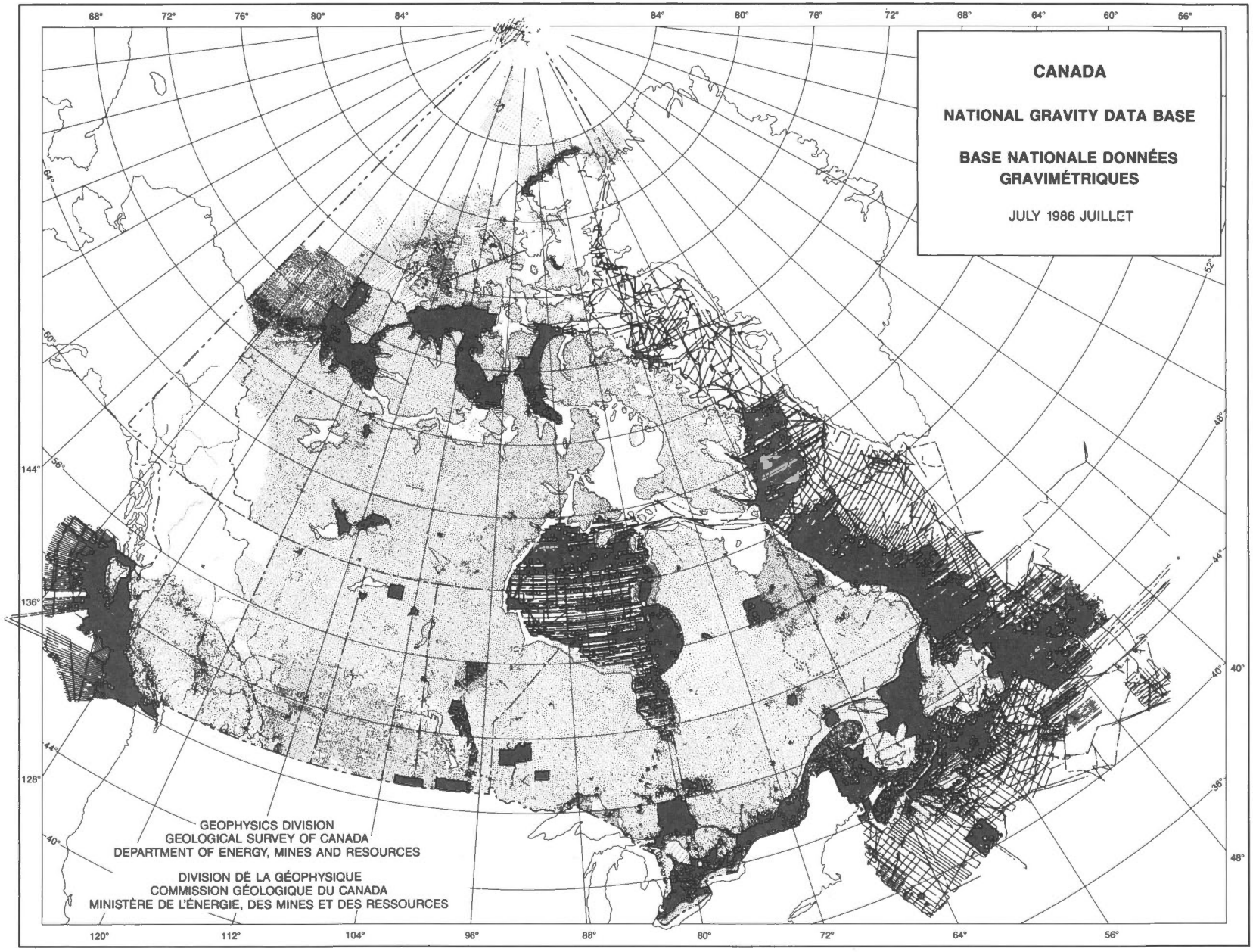
(viii) Manitoba. Twenty-two gravity stations at vertical intervals of about 10 m were occupied to a depth of 230 m in the Underground Research Laboratory shaft, located on property leased by the Whiteshell Nuclear Research Establishment, to estimate in situ rock densities. The shaft is sunk in granitic rocks of the Lac du Bonnet pluton of the Superior Province. The survey was made as a contribution to the Nuclear Fuel Waste Management Program.

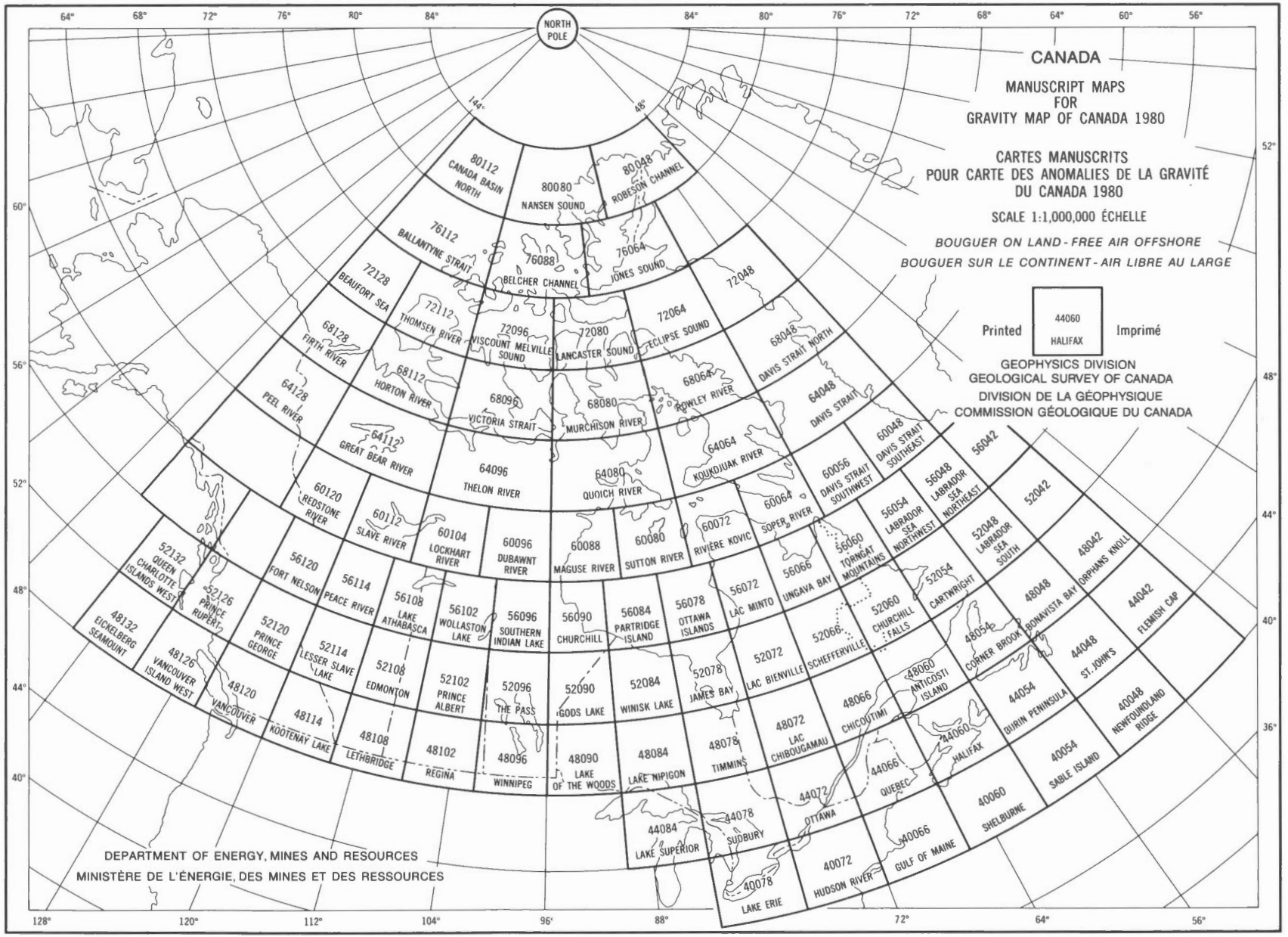
(ix) Nova Scotia Appalachians. A detailed gravity survey was carried out along several profiles crossing the Wedgeport granite as part of a multidisciplinary study of the intrusion. Station spacing was generally about 1 km; 120 stations were occupied.

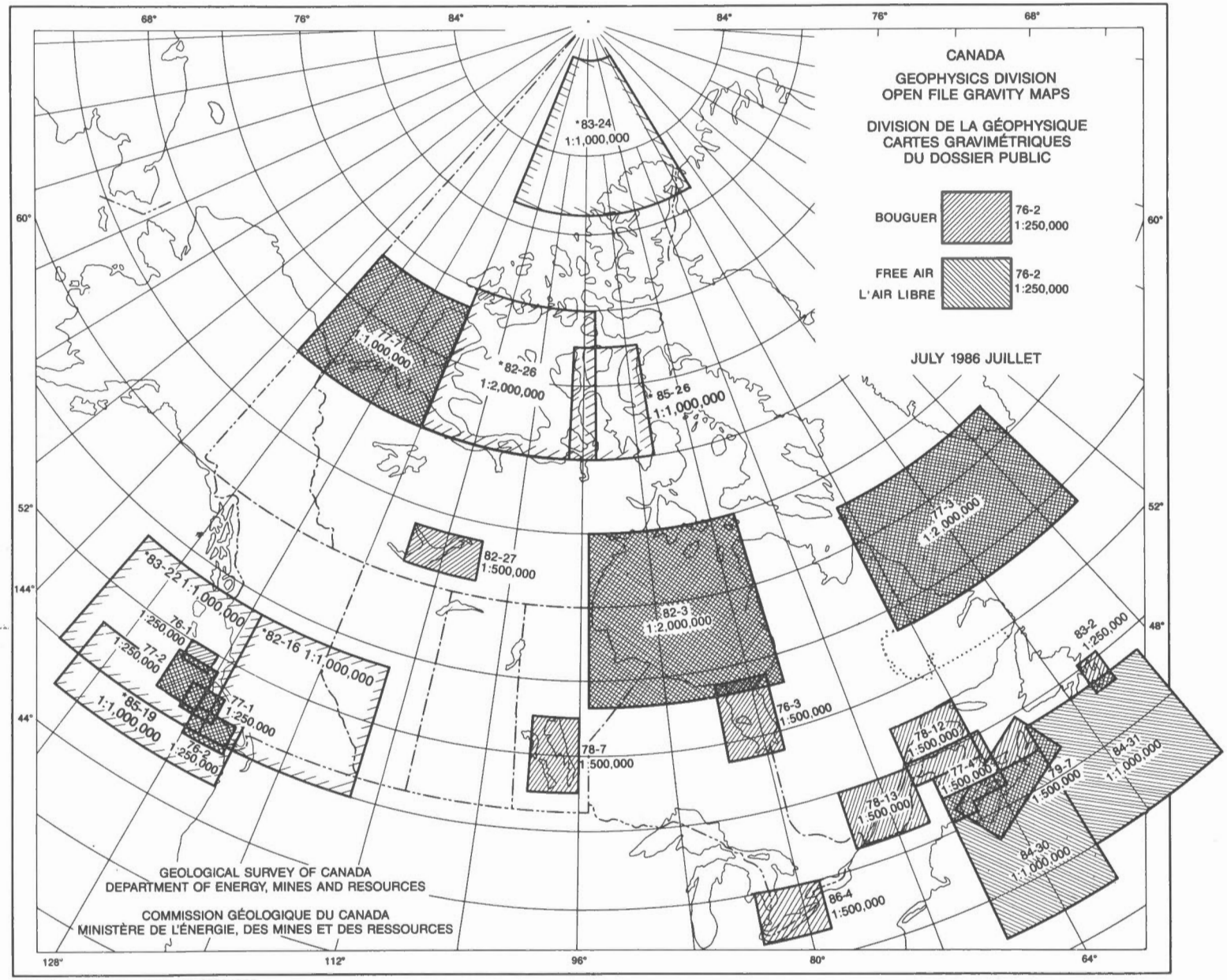
(x) East Coast Continental Shelf. Underwater gravity observations (790) were made on a random grid on the east coast continental shelf between the Bay of Fundy and the entrance to Hudson Strait. The measurements were made under contract by Geonautics of St. John's, Newfoundland from MV Polaris V.

(xi) Newfoundland. In collaboration with the Department of National Defence 89 stations were surveyed in southern Newfoundland to improve existing coverage.

(xii) National Gravity Net. Control stations of the National Gravity Net were established or inspected at ten ports on the coasts of Newfoundland (the island) and Labrador.


CANADA
NATIONAL GRAVITY DATA BASE
BASE NATIONALE DONNÉES GRAVIMÉTRIQUES
JULY 1986 JUILLET
GEOPHYSICS DIVISION
GEOLOGICAL SURVEY OF CANADA
DEPARTMENT OF ENERGY, MINES AND RESOURCES
DIVISION DE LA GÉOPHYSIQUE
COMMISSION GÉOLOGIQUE DU CANADA
MINISTÈRE DE L'ÉNERGIE, DES MINES ET DES RESSOURCES


CANADA
MANUSCRIPT MAPS
FOR
GRAVITY MAP OF CANADA 1980
CARTES MANUSCRITS
POUR CARTE DES ANOMALIES DE LA GRAVITÉ
DU CANADA 1980
SCALE 1:1,000,000 ÉCHELLE
BOUGUER ON LAND - FREE AIR OFFSHORE
BOUGUER SUR LE CONTINENT - AIR LIBRE AU LARGE
Printed
44060
HALIFAX
Imprimé
GEOPHYSICS DIVISION
GEOLOGICAL SURVEY OF CANADA
DIVISION DE LA GÉOPHYSIQUE
COMMISSION GÉOLOGIQUE DU CANADA
DEPARTMENT OF ENERGY, MINES AND RESOURCES
MINISTÈRE DE L'ÉNERGIE, DES MINES ET DES RESSOURCES
NORTH POLE
80112 CANADA BASIN NORTH
80080 NANSEN SOUND
80048 ROBESON CHANNEL
76112 BALLANTYNE STRAIT
76088 BELCHER CHANNEL
76064 JONES SOUND
72128 BEAUFORT SEA
72112 THOMSEN RIVER
72096 VISCOUNT MELVILLE SOUND
72080 LANCASTER SOUND
72064 ECLIPSE SOUND
72048
68128 FIRTH RIVER
68112 HORTON RIVER
68096 VICTORIA STRAIT
68080 MURCHISON RIVER
68064 ROWLEY RIVER
68048 DAVIS STRAIT NORTH
64128 PEEL RIVER
64112 GREAT BEAR RIVER
64096 THELON RIVER
64080 QUOICH RIVER
64064 KOUKDJUAK RIVER
64048 DAVIS STRAIT
60120 REDSTONE RIVER
60112 SLAVE RIVER
60104 LOCKHART RIVER
60096 DUBAWNT RIVER
60088 MAGUSE RIVER
60080 SUTTON RIVER
60072 RIVIÈRE KOVIC
60064 SOPER RIVER
60056 DAVIS STRAIT SOUTHWEST
60048 DAVIS STRAIT SOUTHEAST
56042
52132 QUEEN CHARLOTTE ISLANDS WEST
52126 PRINCE RUPERT
56120 FORT NELSON
56114 PEACE RIVER
56108 LAKE ATHABASCA
56102 WOLLASTON LAKE
56096 SOUTHERN INDIAN LAKE
56090 CHURCHILL
56084 PARTRIDGE ISLAND
56078 OTTAWA ISLANDS
56072 LAC MINTO
56066 UNGAVA BAY
56060 TORNGAT MOUNTAINS
56054 LABRADOR SEA NORTHWEST
56048 LABRADOR SEA NORTHEAST
52042
48132 EICKELBERG SEAMOUNT
48126 VANCOUVER ISLAND WEST
48120 VANCOUVER
52120 PRINCE GEORGE
52114 LESSER SLAVE LAKE
52108 EDMONTON
52102 PRINCE ALBERT
52096 THE PASS
52090 GODS LAKE
52084 WINISK LAKE
52078 JAMES BAY
52072 LAC BIENVILLE
52066 SCHEFFERVILLE
52060 CHURCHILL FALLS
52054 CARTWRIGHT
52048 LABRADOR SEA SOUTH
48114 KOOTENAY LAKE
48108 LETHBRIDGE
48102 REGINA
48096 WINNIPEG
48090 LAKE OF THE WOODS
48084 LAKE NIPIGON
48078 TIMMINS
48072 LAC CHIBOUGAMAU
48066 CHICOUTIMI
48060 ANTICOSTI ISLAND
48054 CORNER BROOK
48048 BONAVISTA BAY
48042 ORPHANS KNOLL
44084 LAKE SUPERIOR
44078 SUDBURY
44072 OTTAWA
44066 QUEBEC
44060 HALIFAX
44054 BURIN PENINSULA
44048 ST. JOHN'S
44042 FLEMISH CAP
40078 LAKE ERIE
40072 HUDSON RIVER
40066 GULF OF MAINE
40060 SHELBURNE
40054 SABLE ISLAND
40048 NEWFOUNDLAND RIDGE
144°
48°
64° 68° 72° 76° 80° 84°
84° 80° 76° 72° 68° 64° 60° 56°
52°
60°
56°
48°
44°
40°
36°
128° 120° 112° 104° 96° 88°
72° 64° 56°



* BOUGUER ON LAND — FREE AIR OFFSHORE
* BOUGUER SUR LE CONTINENT — AIR LIBRE AU LARGE

(xiii) Gravity Meter Calibration. Four gravimeters were calibrated on the Calgary-Inuvik line.

(e) Microgravimetry (H. Dragert)

A sixteen-station microgravity network in central Vancouver Island was resurveyed by contract in 1985. Simultaneous measurements were carried out using four LaCoste and Romberg model D gravimeters as opposed to the two instruments used in past surveys. Measurements over the last eight years are being compared with relevelling data to study crustal movement along a profile that passes near the epicentre of the 1946 Vancouver Island earthquake.

(f) Absolute Gravity (J.O. Liard)

In October EPB acquired and subsequently assembled a highly precise instrument for the absolute measurement of gravity. The instrument has been developed over four years in collaboration with the University of Colorado and is one of only 6 in the world of this design. It will complement standard gravimeters used in exploration surveys by providing an absolute reference framework for all gravity measurements in Canada. It will also be used to contribute to world gravity networks, and to measure small changes in gravity related to earthquakes and vertical movements of the earth's surface.

(g) Numerical Methods (D. Nagy)

The current representative parameters for the Geodetic Reference System have been used to calculate the coefficients required to evaluate theoretical gravity. Comparison of the coefficients of the series expansion of the gravity formulae for the Geodetic Reference System 1980 (adopted) with the coefficients based upon the most recent estimates of the parameters indicate that there is no need to suggest changes in the reference system presently adopted. Relations between the binomial and the conventional form of the closed gravity formula have been derived. The analytically derived integral mean value of gravity can be obtained simply from the weighted sum of normal gravity at latitudes 0°, 45° and 90° with an accuracy of approximately 1 μGal.

A package to carry out fast Fourier transform (FFT) has been implemented on the CYBER computer. Application programs for some basic work in interpretation (continuation, derivatives) have been written and tested using a 3-D modelling technique. Geoid computation using FFT has been carried out on models, with particular emphasis on selection of grid interval, noisy data and the elimination of leakage.

(h) Instrumentation (H.D. Valliant)

A method has been developed for using a pulse-width modulated signal to provide inherently linear electrostatic force feedback for application in astatic gravity meters. Previous methods were linearized through the use of dual force rebalance plates and careful adjustment. The suggested system works equally well with single and dual plate systems and requires no adjustment. Linearity to approximately 1 part in 8000 is demonstrated with a Lacoste and Romberg model G gravity meter.

(i) Gravity Interpretation (T. Feininger, R.A. Gibb, L. Losier, L.W. Sobczak, J.F. Sweeney, M.D. Thomas, J.R. Weber)

(i) Arctic. A number of reports documenting various aspects of interpretation of the gravity field in the Arctic has been completed and submitted to various journals and appropriate volumes of DNAG. The topics include (1) an Arctic gravity map with an accompanying report on observed and combined satellite, altimetry and terrestrial data, (2) a crustal section across the continental to oceanic transition zone from Somerset Island to the Canada Basin, (3) interpretation of the gravity field over the Innuitian Orogen and Arctic Platform, and (4) a study of the Alpha Ridge that indicates that it is comprised of material with remarkable lateral density homogeneity and a density that is considerably greater than the sedimentary and granitic Lomonosov Ridge; this and other information have led to the conclusion that the ridge is built of mafic material generated by plume and spreading activity.

(ii) Appalachians. Preliminary structural models were obtained from the negative gravity anomaly associated with the Devonian Araignées Lake granite, emplaced across the boundary of the Chain Lakes massif and Cambro-Ordovician rocks to the north. The granite is modelled as approximately 15 km thick with its base more or less coincident with a seismic reflector (detected by VIBROSEIS along the Quebec-Maine line) interpreted as Grenville basement. This raises the possibility that the basement surface was a locus for post-Devonian movement. Preliminary models of the Devonian St. George batholith in southern New Brunswick indicate that the granite intrusion is about 7.5 km thick with a tabular geometry. Several satellite intrusions located several kilometres from the batholith are interpreted as plug-like intrusions rooted in the buried roof of the batholith at depths of 1 to 3 km.

(iii) Canadian Shield. A crustal model has been interpreted from a detailed gravity profile across the Cape Smith Fold Belt. Interpretation of the Eye-Dashwa Lake granitic pluton in northern Ontario suggests that the intrusion slopes inwards and attains a maximum depth of 4 km. A roof pendant in the same area attains a depth of 2 km. Preliminary results of an in situ density study in the Underground Research Laboratory shaft in the granitic Lac du Bonnet pluton, Manitoba indicate that the granite is quite homogeneous over the depth section penetrated (230 m). The mean in situ density for the section is 2.61 g/cm^3, comparing with a value of 2.61 g/cm^3 based on measurements conducted on surface samples and 2.64 g/cm^3 for core samples obtained within 20 m of the shaft.

3. Atlantic Geoscience Centre (AGC) (J. Woodside)

(a) Gravity and Magnetic Surveys

This year was the second of a two-year moratorium on potential field surveys at sea. Work was concentrated instead on data processing, including final adjustment of all AGC gravity data and entry of data into the National Gravity Data Base, data interpretation, and instrumentation. One cruise was mounted in the North Atlantic to evaluate the new KSS31 gravity system, but no surveys were carried out.

(b) Data Processing

All AGC marine gravity data were adjusted by the EPB least-squares program for network adjustments. The resulting homogeneous gravity data set has an overall accuracy of 2.5 mGal with an internal consistency varying between ± 1 and ± 5 mGal. Although one-minute values were archived on tape, a compressed data set of over 339 000 five-minute values (representing a maximum data separation along track of less than 2 km) was merged into the National Gravity Data Base in Ottawa for on-line access. These data were scheduled for GSC Open File in January 1986. A report documenting the data acquisition, processing, editing, quality control, and adjustment procedures was prepared for Open File in January 1986 also.

Modification of the National Gravity Data Base to accommodate magnetic data has been postponed. The current System 2000 Data Base will be replaced within the next few years. It was decided to set up an improved potential fields data base incorporating AGC gravity and magnetic data using the new system when that becomes available.

(c) Data Interpretation

Emphasis over the past year has been on software development. Early in the year, the potential fields group started using two new microVAX computers and adapting software to the VMS operating system.

Some of the software implemented, but not yet used extensively on real data, included 2.5-D forward modelling programs for gravity and magnetics, routines utilizing fast Fourier transforms for the filtering, continuation and differentiation of gridded data sets, and cross-spectral techniques for the investigation of isostatic models set up to explain the admittance computed from observed gravity and bathymetry.

(d) Instrumentation

The Bodenseewerk Seagravimeter (System KSS30) has a demonstrated accuracy of 1-2 mGal under favourable conditions. Efforts continued to improve the accuracy so that the full

potential of the sensor could be realized. The accuracy is limited by the platform (and gyro) performance and the quality of navigational control. The platform has been upgraded recently by the manufacturers and the new system (KSS31) was compared with the older one during a ten-day test cruise in November 1985. The data analysis indicates an improvement in accuracy by a factor of two. On a small grid survey the RMS discrepancy on 20 track crossover points was less than 0.4 mGal.

The continuing efforts to improve the navigation included an evaluation of a new generation BIONAV system, testing of the GPS system and a development of MINAV System for on line processing of Range-Range Radio navigation systems such as MiniRanger and Argo.

4. Ontario Geological Survey (D.R. Wadge)

A small gravity survey of 37 stations at Night Hawk Lake in the Abitibi greenstone belt was conducted in May to complete the survey area of 1984. Interpretation of data is in progress.

5. Memorial University of Newfoundland (H.G. Miller)

A major gravity project was conducted in association with the Newfoundland Department of Mines and Energy. Gravity data were collected at 619 locations in five areas: the northern Gander Zone, the Ackley Granite, Third Berry Hill Pond area, along the Burgeo Road, and across the Mount Cormack Terrane. The data from the Gander Zone have delineated a small thrust belt initially deduced from combined aeromagnetic and geochemical data. The Ackley Granite data are being inverted to provide information on the topology and the lower surface of the granite. This project is being used as a case history in the joint interpretation of gravity, aeromagnetic, airborne spectrometry, and geochemical data. The final two projects are being interpreted for insights into the tectonics of southern Newfoundland. In western Newfoundland an M.Sc. thesis based on the 1983 gravity data from the St. George's sub-basin has been completed and another is in progress with a tentative completion date of July 1986.

6. Nova Scotia Research Foundation Corporation (K. Howells)

Terrain-corrected gravity measurements were used to interpret a potash deposit in southern New Brunswick using available geological control. A 2.5-D gravity modelling program is now functional on an IBM compatible microcomputer in Turbo-Pascal. A considerable effort was made to redigitize and replot several thousand gravity stations from a number of older surveys using more accurate base maps in northern Nova Scotia. These redigitized stations now reside in the Nova Scotia Research Foundation Corporation computer gravity file which contains approximately 26 000 gravity stations for the Province of Nova Scotia. Improvements were also made to the gravity plotting software.

7. Université Laval (M.K.-Séguin)

M.K.-Séguin et des étudiants gradués ont terminé les levés gravimétriques dans la région de Baie-St-Paul, Sainte-Anne de Beaupré, Québec. Toute la zone séismiquement active de la région de Charlevoix allant de Saint-Siméon à Cap-Tourmente a fait l'objet d'un levé gravimétrique détaillé. L'interprétation des données, la modélisation et l'écriture d'un rapport final sont en cours.

Le levé gravimétrique et pétrophysique effectué sur l'intrusif granitique dévonien de Sainte-Cécile et Saint-Sébastien effectué par D. Lapointe, étudiant diplômé sous la direction de M.K.-Séguin, a été interprété quantitativement donnant lieu à une modélisation 2.5-D. La thèse de maîtrise est déposée.

L. Plante, étudiant diplômé sous la direction de M.K.-Séguin a complété un levé gravimétrique sur les cratères du lac à l'Eau-Claire, Québec nordique. On a effectué une interprétation quantitative avec modélisation 2.5-D et 3-D. Cette modélisation permet de mieux comprendre le mode de formation et l'environnement des impacts météoritiques au Paléozoïque supérieur.

Au cours de l'été 1985, S. Roy, étudiante diplômée sous la direction de M.K.-Séguin, a effectué un levé gravimétrique et pétrophysique du mont Mégantic. Quelques 300 stations de

mesure ont été occupées. Les formations intrusives et encaissantes sont caractérisées par un champ spécifique sur un diagramme binaire: densité - susceptibilité. Une interprétation quantitative de la carte d'anomalie de Bouguer simple et de Bouguer corrigée topographiquement est en cours.

8. University of Calgary (J.A.R. Blais)

Gravity research at the University of Calgary can be subdivided into three major areas: the evaluation of new instrumentation for gravity surveys, the study of efficient processing techniques, and the geodetic use of gravity data.

In the first area a comprehensive study on the use of inertial data for gravity anomaly determination was started and first results on the Ferranti system have been published (Forsberg et al., 1985). Results indicate that in very rough terrain (Kananaskis Valley) gravity anomalies can be obtained with a standard error of about 3 mGal. Methods to improve the gravity signal extraction from the system output are discussed in Schwarz (1985). A very promising development in the area of new instrumentation is airborne gravity gradiometry. Studies which are partially published in Vassiliou (1985a) indicate that accuracies of better than 1 mGal can be expected from the system which will be tested in 1987.

The study of efficient processing techniques concentrated on the use of fast Fourier transform (FFT) techniques for gravity data processing and the computation of gravity corrections. Sideris (1985a) shows that terrain corrections can be computed very efficiently by this method and that the accuracy achieved is comparable to that of conventional methods. Vassiliou (1985b) discusses the application of these techniques to the spatial modelling of gravity data in a local area. The relationship between the spectra of point gravity anomalies and mean gravity anomalies is presented in Sideris (1985b) and some interesting applications are pointed out.

In the area of geodetic applications a detailed comparison of four different methods for deflection computation is presented in Kearsley et al. (1985). The analysis emphasizes the effect of different data types on long and short wavelength resolution and points to the excellent performance of FFT techniques in the numerical evaluation of the Vening-Meinesz integral. A similar comparison of methods for the determination of relative geoid heights has been published in Schwarz and Sideris (1985).

9. University of Manitoba (W. Moon)

W.C. Brisbin, W. Mandziuk and P. Johannson have completed a gravity survey over Falcon Lake Igneous Complex, southeastern Manitoba. Interpretation of the data is being undertaken in conjunction with local geology. A detailed gravity survey is also in progress over Chisel Lake intrusion, Snow Lake, Manitoba. J. Young, W.C. Brisbin, G. Partyka and L.D. Ayres are the working group on this project.

A. Ushah and W. Moon have completed the development of a 2-D Hilbert transform algorithm and tested it with simple theoretical digital data. Currently it is being tested and evaluated with real field data from northern Ontario. The results indicate that it can be an extremely useful tool in exploration and crustal geophysics. A. Adrian, W. Moon and L.D. Ayres have developed an algorithm to compute the gravity anomaly caused by crustal loading.

10. Bibliography

Beutler, G., Davidson, D.A., Langley, R.B., Valliant, H.D., Vanicek, P. and Wells, D.E. 1984. The Ottawa macrometer experiment: an independent analysis. Publication of the University of New Brunswick, Surveying Engineering.

Forsberg, R., Vassiliou, A., Schwarz, K.P. and Wong, R.V.C. 1985. Inertial gravimetry - A comparison of Kalman filtering and post-mission adjustment techniques. In: Proceedings of the Third International Symposium on Inertial Technology for Surveying and Geodesy, Banff, Canada, September 16-20, 1985. UCSE Report #60004, Division of Surveying Engineering, University of Calgary, Calgary, Alberta.

Gupta, V.K. and Grant F.S. 1985. Mineral-exploration aspects of gravity and aeromagnetic surveys in the Sudbury-Cobalt area, Ontario. In: The Utility of Regional Gravity and Magnetic Anomaly Maps, W.J. Hinze (Editor), Society of Exploration Geophysicists, Tulsa, Oklahoma, 392-412.

Kearsley, A.H.W., Sideris, M.G., Krynski, J., Forsberg, R. and Schwarz, K.P. 1985. White Sands revisited - a comparison of techniques to predict deflections of the vertical. USCE Report #30007, Division of Surveying Engineering, University of Calgary, Calgary, Alberta.

Lefebvre, D.L. 1985. Levés gravimétriques dans la région de Rouyn-Val-d'Or, 1 carte Applicon, 1:250 000. Ministère de l'Énergie et des Ressources, Québec, ET 85-02.

Macnab, R., Loncarevic, B.D., Cooper, R.V., Girouard, P.R., Hughes, M.D. and Shouzhi, F. 1985. A regional marine multiparameter survey south of Newfoundland. In: Current Research, Part B, Geol. Surv. Can. Paper 85-1B, 325-332.

McConnell, R.K. 1985. A plan for African gravity activities. International Gravity Commission of the International Association of Geodesy.

Miller, H.G., Goodacre, A.K., Cooper, R.V. and Halliday, D. 1985. Offshore extensions of the Avalon Zone of Newfoundland. Can. J. Earth Sci., 22, 1163-1170.

Moon, W. and Ushah, A. 1985. Application of 2-D Hilbert transform in potential field data interpretation. Congressus Numerantium, 37, 305-319.

Peavy, S.T. 1985. A gravity and magnetic interpretation of the Bay St. George Carboniferous sub-basin in western Newfoundland. Unpublished M.Sc. thesis, Memorial University of Newfoundland, 207 pp.

Schwarz, K.P. 1985. Inertial modelling - a survey of some open problems. In: Proceedings of the Third International Symposium on Inertial Technology for Surveying and Geodesy, Banff, Canada, September 16-20, 1985. UCSE Report #60004, Division of Surveying Engineering, University of Calgary, Calgary, Alberta.

Schwarz, K.P. and Sideris, M.G. 1985. Precise geoid heights and their use in GPS-interferometry. Geodetic Survey of Canada, Energy, Mines and Resources Canada, Ottawa, Contract Report #85-004.

Sideris, M.G. 1985a. A fast Fourier transform method for computing terrain corrections. Manuscripta Geodaetica, 10(1), 66-73.

Sideris, M.G. 1985b. On the relationship between spectra of mean and point data with applications in computing, inverting and updating gravity field quantities. In: Proceedings of the International Meeting on Potential Fields in Rugged Topography, Lausanne, Switzerland, July 30 - August 1, 1985. IGL Bulletin No. 7, Institut de Géophysique, Université de Lausanne, Lausanne, 82-87.

Sweeney, J.F. 1984. Arctic tectonics: what we know today. GEOS, 13(4), Department of Energy, Mines and Resources, Ottawa, 8-10.

Sweeney, J.F. 1985a. Comments about the age of the Canada Basin. In: Geophysics of the Polar Regions, E.S. Husebye, G.L. Johnson and Y. Kristoffersen (Editors), Elsevier, Amsterdam, 1-10.

Sweeney, J.F. 1985b. Comments about the age of the Canada Basin. Tectonophysics, 114, 1-10.

Thomas, M.D. 1985. Gravity studies of the Grenville Province: significance for Precambrian plate collision and the origin of anorthosite. In: The Utility of Regional Gravity and Magnetic Anomaly Maps, W.J. Hinze (Editor), Society of Exploration Geophysicists, Tulsa, Oklahoma, 109-123.

Thomas, M.D. and Gibb, R.A. 1985. Proterozoic plate subduction and collision: processes for reactivation of Archean crust in the Churchill Province. In: Evolution of Archean Supracrustal Sequences, L.D. Ayres, P.C. Thurston, K.D. Card and W. Weber (Editors), Geol. Assoc. Can. Special Paper 28, 263-279.

Thomas, M.D. and Tomsons, D.K. 1985. A Bouguer gravity anomaly map of Chalk River, Ontario (Atomic Energy of Canada Limited Research Area 2). Atomic Energy of Canada Limited Technical Record 325.

Valliant, H.D. 1984a. Canadian evaluation of the Macrometer Interferometric Surveyor. Earth Physics Branch Open File 84-4.

Valliant, H.D. 1984b. Build a frequency counter with a micro-computer. EDN, August 23, 233.

Valliant, H.D. and Gagnon, C. 1985. A 12-bit pulse width modulator. EDN June 27, 244.

Valliant, H.D., Halpenny, J. and Cooper, R.V. 1985. A microprocessor-based controller and data acquisition system for LaCoste and Romberg air-sea gravity meters. Geophysics, 50, 840-845.

Vassiliou, A. 1985a. Comparison of methods for the processing of gravity gradiometer data. In: Proceedings of the Third International Symposium on Inertial Technology for Surveying and Geodesy, Banff, Canada, September 16-20, 1985. UCSE Report #60004, Division of Surveying Engineering, University of Calgary, Calgary, Alberta.

Vassiliou, A. 1985b. The use of spectral methods for the spatial modelling of gravity data. Manuscripta Geodaetica, 10(4), 235-244.

Weber, J.R. and Jackson, H.R. 1985. Cesar bathymetry. In: Initial Geological Data Report of CESAR: Canadian Expedition to Study the Alpha Ridge. Geol. Surv. Can. Paper 84-22, 15-17.

Weber, J.R. and Sweeney, J.F. 1985. Reinterpretation of morphology and crustal structure in the Central Arctic Ocean Basin. J. Geophys. Res., 90, 663-677.

Yorath, C.J., Woodsworth, G.J., Riddihough, R.P., Currie, R.G., Hyndman, R.D., Rogers, C.G., Seemann, D.A. and Collins, A.D. 1985. Centennial continent/ocean transect B-1: Intermontane Belt (Skeena Mountains) to Insular Belt (Queen Charlotte Islands). Geol. Soc. Amer., Boulder, Colorado.

II SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR

Compiled by: E.R. Kanasewich

1. Introduction

Seismologists are undertaking the interpretation of massive amounts of seismic reflection data obtained under project LITHOPROBE. Data, both onshore and offshore, are available from the Maritimes, British Columbia and Kapuskasing, Ontario. New refraction data are available in Ontario under the same project and old data are being reinterpreted in the light of current geophysical and geological information. Other topics receiving increased emphasis are Canadian seismicity and high pressure studies.

2. Canadian Seismicity, Earth Physics Branch (Ottawa and Pacific Geoscience Centre, Sidney, British Columbia)

Provisional data for approximately 850 earthquakes with epicentres in or bordering Canada during 1985 have been collected. Out of this total there were 13 events with magnitude greater than 4.0. Details of the six largest earthquakes are as follows:

January 9	m_b 5.7	St. Elias region - felt in southwestern Yukon
March 30	m_b 4.7	Baffin Bay
September 15	m_b 5.3	Southeastern Alaska - felt in southern Yukon
October 5	M_S 6.6	Mackenzie Mountains, NWT - felt over a wide area
October 6	m_N 4.8	Queen Elizabeth Islands, NWT
December 23	M_S 6.9	Mackenzie Mountains, NWT - felt over a wide area

The overall seismicity pattern is, in general, similar to that of previous years. However, there are a few notable events that may be considered as slight deviations from the "normal" pattern. During the first three months there were three tremors near magnitude 3 with epicentres near Buchans, Newfoundland. Since the local mine was closed in 1984 and subsequently flooded, it is not possible to confirm whether or not these events were rockbursts. Near Rocky Mountain House in southwestern Alberta, two moderate sized earthquakes were felt. The first, a magnitude 3.9 on March 11, was followed by many aftershocks. The second, a magnitude 3.8 event, occurred on August 24. On August 6 a magnitude 4.0 event occurred near Trail, British Columbia and was widely felt. However the earthquakes that created the greatest media interest and public response were the M_S 6.6 October 5 and the M_S 6.9 December 23 earthquakes in the Nahanni region, which is in the southern part of the Mackenzie Mountains. Both earthquakes were felt throughout the Yukon, Northwest Territories, northern British Columbia, northern Alberta and northwestern Saskatchewan. Immediately following the occurrence of each of these two noteworthy events, intensity questionnaires were mailed to numerous communities in the reported felt areas and an aftershock field survey was carried out in the epicentral region. These two field surveys, as carried out by R.J. Wetmiller and M. Lamontagne (EPB), R.B. Horner (PGC) and J.D. Aitkin and S.G. Evans (GSC) delineated the aftershock zone of the first main shock and also the aftershock area of the second main shock, which migrated to the southeast.

Landslides triggered by both main shocks were identified and strong ground motion records from the second large shock were obtained. Preliminary analysis of the first event indicates rupture of a north trending thrust fault, which extends from the cratonic basement through the Cordilleran sediments to the near surface. However, no surface rupture of the fault plane has been found. Analysis of the data for the second event is just now beginning.

An aftershock survey in the epicentral region of the Miramichi, New Brunswick earthquake sequence by R.J. Wetmiller (EPB) and K.B.S. Burke (UNB) recorded more than 300 events, 16 of which were in the magnitude (M) range $0 < M < 2$. Analysis of the spatio-temporal pattern of this sequence is being carried out at UNB.

Additional details of all events for which a reliable magnitude and epicentre could be determined are obtainable from either the National Summary produced quarterly by EPB or the annual Canadian Earthquake Catalogue.

3. Atlantic Geoscience Centre

The crustal refraction group at AGC [I. Reid, B. Nichols, S. Perry, W. Kay and B. Todd (Dalhousie)] has brought its new processing system into full production and is currently working on data collected from the southwestern margin of the Grand Banks in 1984. Results so far confirm the extreme sharpness of the ocean-continent-boundary. Strong mantle refractions were obtained on crust of continental thickness using airguns and ocean bottom seismometers. A reflection and refraction study of the ocean-continent boundary south of Flemish Cap was carried out in 1985.

H.R. Jackson participated in a joint AGC, EPB, ISPG refraction program on the polar continental margin north of Axel Heiberg, using the Canadian Ice Island as a base for operations. In summary, on the outer margin a 2 km thick unconsolidated sedimentary layer with a velocity of 2.1 km/s was deposited on 10 km of sedimentary strata with a velocity of 4.4 km/s which overlies a 6.2 km/s basement velocity. All layers have associated velocity gradients. Mantle was measured at 26 km.

C. Keen, G. Stockmal, G. Quinlan (MUN) along with others from Memorial University of Newfoundland and the Newfoundland Department of Mines interpreted two LITHOPROBE EAST seismic lines across the northern Appalachians and northeast of Newfoundland which were shot in 1984. C. Keen, G. Stockmal, B. Mudford, C. Dicke, and H. Welsink (Petro-Canada) interpreted a third 1984 LITHOPROBE EAST line which was 600 km long and passed from continental to oceanic crust just south of Orphan Knoll. In 1985 three lines totalling about 1500 km were shot in the southern Grand Banks area as part of the LITHOPROBE EAST program. All 1984 and 1985 lines were shot and processed by GSI, Calgary.

4. Earth Physics Branch

R. Haddon is developing fast and accurate methods for the computation of complete synthetic seismograms in layered media and in axially symmetric boreholes using leaking modes. Several papers are being submitted.

R. Haddon and G. Buchbinder have investigated possible alternatives to the lower mantle transition layer model proposed by Lay and Helmberger in 1983. A promising plausible alternative has been found.

G. Buchbinder deployed 3-component (digital recording) seismographs in the seismically active Charlevoix, Quebec, seismic zone to study dilatancy induced shear-wave splitting.

D.A. Forsyth, I. Asudeh, L.W. Sobczak, M. Schmidt, R. Schieman and scientists from Atlantic Geoscience Centre, Pacific Geoscience Centre and Institute of Sedimentary and Petroleum Geology participated in planning and execution of a seismic refraction survey from the Ice Island on the polar continental margin off Ellesmere Island during March-April 1985. A ladder-style survey grid, consisting of parallel lines 60 and 90 km offshore with connecting spreads, was initiated along the shelf. New shooting techniques permitted a total of 31 shots into five 60 km spreads, yielding 300 km of reversed refraction data with an effective spacing of 2.5 km. Offset shots into the offshore line permitted upper mantle observations.

I. Asudeh, D.A. Forsyth, H.R. Jackson, R. Stephenson and D. White completed the phase I data reduction analysis of the Ice Island 1985 refraction survey which has been released as Earth Physics Branch Open File Report 85-23. Preliminary results, presented at the fall 1985 AGU meeting, show agreement between the nearshore line and adjacent geology, while the offshore line suggests about 5 km of sedimentary section.

D.A. Forsyth, I. Asudeh, A.G. Green and H.R. Jackson have prepared a manuscript on the interpretation of the CESAR 1983 refraction survey for submission to Nature.

D.A. Forsyth and R.F. Mereu have completed a paper on the COCRUST 1982 refraction results from the Ottawa-Bonnechere Graben-Central Metasedimentary Belt area. The paper is a contribution to the GAC Special Paper, New Perspectives on the Grenville Problem.

D.A. Forsyth, H.R. Jackson and G.L. Johnson have submitted a manuscript to Marine Geology on the first attempt at correlating available geological and geophysical results from the 1983 CESAR survey over the Alpha Ridge complex.

D.A. Forsyth, L.W. Sobczak and A. Overton have submitted a manuscript on the Crustal Structures of the Innuitian Region from Seismic and Gravity Studies for inclusion in Vol E, Decade of North American Geology.

D.A. Forsyth, H.R. Jackson, A. Overton and J. Hall have submitted a manuscript on the Crustal Structures of the Innuitian Region from Seismic and Gravity Studies for inclusion in Vol. E., Decade of North American Geology.

K. Fujita, D. Cook, H.S. Hasegawa, D.A. Forsyth and R.J. Wetmiller have submitted a manuscript on Seismicity and Focal Mechanisms for the Arctic Ocean Region for inclusion in Vol. L., Decade of North American Geology.

M.L. Zoback, S.P. Nishenko, R.M. Richardson, H.S. Hasegawa and M.D. Zoback completed a chapter on Mid-Plate stress, Deformation, and Seismicity in The North Atlantic Volume, Decade of North American Geology (accepted for publication).

D.A. Forsyth, J.R. Weber, A.S. Judge and H.R. Jackson have prepared a document entitled "A Geoscience Program for the Canadian Arctic Ice Island Research Project" (Earth Physics Branch Internal Report No. 85-26) as a proposal outlining the types and costs of programs that could be mounted from the Canadian Ice Island that calved in 1982.

A.G. Green, C. Spencer, M.J. Berry and colleagues from the Pacific Geoscience Centre and the Universities of British Columbia and Alberta have been working on the processing and interpretation of the LITHOPROBE PHASE I seismic reflection lines across Vancouver Island. Results of this work are contained in a series of papers that are either published (three), in press (two) or submitted.

A.G. Green, C. Spencer and colleagues from the Geological Survey of Canada, Laval University and the United States Geological Survey have completed a preliminary interpretation of the Quebec-Maine seismic reflection survey. This interpretation has been published in a Geodynamics Volume of the American Geophysical Union.

A.G. Green, B. Milkereit and colleagues from the Geological Survey of Canada and the University of Calgary have completed, via a contract to industry, the collection and preliminary processing of 270 km of seismic reflection data across the Southern Cordillera between Kimberley and Lower Arrow Lake, British Columbia. Tests are being conducted on these data in preparation for the final stack sections.

B. Milkereit and L. Mayrand have completed the reprocessing of two of the LITHOPROBE Vancouver Island seismic reflection lines, with work underway on the other lines. The reprocessing gave an improved image of the deep reflectors and new information on the shallow geology of the region. Manuscripts dealing with these results are at the preparation stage.

B. Milkereit has developed an image processing package for the analysis and inversion of seismic data; it is based on complex trace analysis and plane wave decomposition. The package is applicable to reflection and refraction seismic data. A manuscript has been

submitted for publication. Work in the general area of image processing and migration is continuing.

P. Morel et C.B. Wright ont participé à l'expérience PRASE (Peace River Arch Seismic Experiment) qui s'est déroulée du 17 juin au 5 juillet 1985. Cette opération a été conduite en collaboration avec l'Institut de géologie sédimentaire de la Commission géologique du Canada, l'Université de Colombie-Britannique, l'Université de l'Ouest de l'Ontario, l'Université de Toronto, l'Université de la Saskatchewan et l'Université de l'Alberta.

P. Morel et A.G. Green on complété leur interpretation des données des expériences COCRUST de 1977, 1979 et 1981. Un premier article sur l'aspect sismique est en cours de révision interne, et un deuxième article sur les implications du modelage sismique est en préparation.

Des résultats préliminaires sur la partie du graben d'Ottawa du projet COCRUST de 1982 (OGGFAB) sont actuellement en cours d'impression dans le Geophysical Journal of the Royal Astronomical Society. Un deuxième article sur la partie abitibienne du projet dont des membres de la Direction sont également co-auteurs a été soumis au Journal canadien des sciences de la Terre.

Les nouveaux systèmes d'enregistrement développés par la Section d'instrumentation de la Division de la séismologie et du géomagnétisme pour la sismique réfraction ont été testés avec succès lors de l'expérience de La Malbaie qui s'est déroulée du 4 au 8 novembre 1985.

H. Huang and C. Spencer have continued applying inverse methods to refraction data sets. The method has been successfully applied to the 1982 Ottawa Valley COCRUST data and a paper has been accepted for publication in the Bulletin of the Seismological Society of America.

C. Spencer has completed an interpretation of refraction and reflection data from southeastern Quebec obtained jointly with the U.S.G.S. as part of the 1983-1984 Trans-Appalachian profile. Results of this work will be presented at a workshop in Reston, Virginia in early 1986.

P.W. Basham and R.G. North represented Canada at the two 1985 meetings of the Ad Hoc Group of Scientific Experts of the Committee on Disarmament, preparing a draft chapter of the Group's fourth report. Efforts are being made to test the exchange of waveform data by direct computer-to-computer connection with West Germany and Japan.

R.G. North and C.R.W. Duff continued their studies related to seismic verification of a test ban treaty. A large number of digital ECTN recordings of earthquakes, rockbursts, mining blasts, and refraction experiment shots are being analyzed for possible discriminants at regional distances. A project to regionalize P, S and Lg velocities across the stable portion of Canada is almost complete, and studies of the attenuation of these phases are underway. A computer code to determine the detection and location capabilities of hypothetical seismic station networks has been written, and steps are now being taken to obtain the necessary input parameters such as station noise levels and phase attenuation characteristics. An attempt has been made to rationalize the m_N magnitude scale so that it provides a consistent measure of source size.

R.J. Wetmiller (EPB) and D. Hedley (CANMET) have published an open file report on rockbusts in Ontario mines 1984. The report gives seismological properties for rockbursts and geological properties of their source areas in four different Ontario mines. The information covers rockbursts as large as magnitude 4.

R.J. Wetmiller has completed a study of the seismotectonic implications of recent earthquake activity in northern Ontario. He finds consistent evidence of thrust faulting for the earthquakes controlled by the regional stress field.

H.S. Hasegawa and H. Kanamori have completed an analysis of possible source mechanisms for the magnitude 7.2 Grand Banks earthquake of 1929. The results indicate the possibility of either a double couple or a submarine landslide source mechanism.

V.S. Allen and staff of the geothermal laboratory of the Earth Physics Branch have been conducting a thorough modernization of the geothermal laboratory. All routine operations are now designed to be monitored by automatic data-acquisition systems, including the divided bar for measurement of thermal conductivity, the thermal column for the measurement of thermal diffusivity, and the calibration system for calibration of borehole thermometers.

In cooperation with the Geophysics Department of the University of Western Ontario, old holes of the geothermal drilling programme of 1962-1969 have been relogged by means of a continuous-logging system. The resulting data will be analyzed by members of both groups to reveal evidence of water-flow in fractures and record of climatic history. Some of these holes have been open for 17 years and full core has been preserved, so they constitute a very valuable resource in geophysical research.

M.J. Drury has published new heat-flow and heat-generation data from Proterozoic mobile belts of the Churchill Province of the Canadian Shield, and has interpreted them in terms of a model of redistribution of radiogenic elements during the tectonic development of the belts.

A number of research projects which commenced several years ago are reaching fruition. By means of a combination of the results of the deep temperature well logs with conventional well logs, permafrost debts have been interpreted for over 1000 locations in northern Canada (Judge and Taylor, 1985). In a parallel study an extensive collection of ground temperature information has been compiled using the microcomputer software package Lotus 1-2-3. Regional ground temperature relationships have been outlined in a short paper correlating air and ground temperatures with latitudes (Young and Judge, 1985).

Until recently, little high quality temperature information has been available beneath the continental shelves. An acoustic telemetering system has been developed to gather data from an 800 m thermistor cable installed in an abandoned offshore Arctic exploration well (Taylor and Judge, 1985). The system is operating successfully at the Sverdrup site and discussions are proceeding for a Beaufort Sea installation.

The network of thermal observation sites along and adjacent to the 800 km Norman Wells to Zama Lake pipeline is now complete and is being routinely read through a combination of monthly visits and unattended data loggers. Although few sites as yet have a complete year of data, indications exist of natural warming of the permafrost at the higher elevation sites including the Alberta Plateau.

Extensive contracted research has continued in the areas of permafrost and gas hydrates in cooperative projects with universities and industry. Highlights include the completion of the analysis of existing results for the Calgary Frost Heave test-loop; the imminent implementation of a tear-down research phase to examine the frost-bulb and the distribution of ground-ice; and the mapping of the somewhat unexpected broad distribution of gas hydrates on the Atlantic shelf.

J.A. Lyons has continued to maintain and develop the ECTN and WCTN operating and application software systems. A hardware prototype for the next generation of CTN data acquisition system, dubbed CTN Mark IV, has been installed in the Ottawa Datalab. Software development for the new systems has been completed under contract. Procurement is underway for five additional systems in Ottawa and PGC, and two as base stations for the new digital telemetered portable seismic arrays.

C. Wong has continued to add new features to the Seismic Analysis Monitor software system (SAM) to support the Current Seismicity project on the in-house VAX. A major new development has been the incorporation of a multi-layer crustal model capability within the epicentre location program.

M. Andrew has continued to provide technical assistance to Science North for the operation of the Sudbury Local Telemetered Network (SLTN) system. As part of a joint federal and provincial initiative to improve rockburst monitoring in the Sudbury basin, he is coordinating the addition of two more seismograph outstations to the network and enhanced data communications to Ottawa. He has also undertaken system specification for the new portable seismic arrays. M. Andrew continues to study data communications related to the transmission of digital seismic waveforms, both within Canada and internationally.

W.E. Shannon has continued to be involved with digital data processing in the Ottawa Datalab and the Eastern Canada Telemetered Network (ECTN) operations.

R. Hayman has prepared plans for a Telemetry System for the Collection of Precursory Earthquake Data. These were developed for the use of the State Seismological Bureau (SSB) of the People's Republic of China. They were the result of visits to China in December 1984 and December 1985, sponsored by the United Nations Development Program. Two members of the SSB visited Earth Physics Branch, where EPB staff assisted them in preparing contracts related to this project.

F. Andersen and G. Buchbinder travelled to Colombia in response to a request from the Colombian government for Canadian aid in the wake of the El Ruiz volcano disaster. They were the first to deploy seismic event recorders there, and subsequently 14 pre-production prototypes were assembled. The software development proceeded in parallel with this work and the units were tested in a successful array experiment conducted at Charlevoix in November. Some refinements were suggested and will be incorporated in the 135 units which have been ordered by EMR.

5. Pacific Geoscience Centre

G.C. Rogers has been investigating the depth distribution and focal mechanisms of microearthquakes in the Vancouver Island region since the tele- metered array was expanded in 1984. Preliminary analysis suggests almost all earthquakes are within the subducted plate beneath Vancouver Island and none have mechanisms consistent with slipping on the subduction thrust interface.

G.C. Rogers and R.M. Ellis of UBC have compiled and edited a comprehensive data base of earthquakes and arrival times for the region west of Vancouver Island.

D.H. Weichert and R.B. Horner completed a study of magnitude bias in the Western offshore area. They show that the earthquakes without observable L_g phase have M_L magnitudes about 0.9 units lower than m_b, and about 1.1 units lower than equivalent events whose L_g phase is observed. Appropriate corrections for future seismic catalogues have been suggested.

Pacific Geoscience Centre operated a regional seismic package on the Ice Island in order to aid in the location and depth determination of Beaufort Sea earthquakes. The Ice Island is expected to drift to that area in a few years.

Special regional seismic networks in western Canada continued operation with only minimal changes. The Beaufort net remained unchanged at four stations. The BC Hydro/EMR network in northern B.C. was terminated, with only Dease Lake remaining. This action reflects loss of interest in a hydro dam in northern B.C. The Queen Charlotte network was increased by four stations. WCTN remained unchanged with 18 stations telemetering into PGC. This includes three UBC stations under contract.

There have been changes in Regional Stations in the West/North.

Stations Closed:	Bob Quinn Lake, B.C.	April 1, 1985
	Muncho Lake, B.C.	February 9, 1985
	Tasu, B.C.	February 28, 1985
Stations Opened:	Barry Inlet, B.C.	September 6, 1985
	Cumshewa, B.C.	September 2, 1985
	Prince Rupert, B.C.	August 29, 1985
	Van Inlet, B.C.	September 6, 1986

Also the Nicholson Point station, whose signal was being telemetered to Inuvik for recording on helicorder, was discontinued March 31 1985.

E.E. Davis, R.G. Currie and B.S. Sawyer are continuing co-operative, detailed SEABEAM mapping efforts with S. Hammond, NOAA, with the production of several new 1:50 000 10m contour interval map sheets over the central and northern Juan de Fuca ridge and northern Explorer ridge.

E.E. Davis, R.G. Currie and B.C. Sawyer have continued acoustic imaging studies of the seafloor off western Canada with extensive surveys carried out, in cooperation with Hawaii Institute of Geophysics, over the central Juan de Fuca and northern Explorer ridges, and the Vancouver and Queen Charlotte Islands continental margins. Some of the more striking results include the observation of frequent massive slope failures at the base of off-axis volcanism about the crest of the Juan de Fuca Ridge. Data processing is currently underway, and publication of the resulting acoustic mosaics will begin in Spring, 1986.

E.E. Davis, B. Bornhold and H. Villinger have completed a detailed heat-flow, coring, and seismic reflection study of mounds, observed with SEABEAM and SeaMARC II imaging in a sedimented rift valley of the northern Juan de Fuca ridge, which were believed to be of hydrothermal origin. Extremely high heat flow in the vicinity of the mounds (up to 50 mW m^{-2}), and hydrothermal sulphide sediments collected from one of the mounds verified their hydrothermal origin. These and future observations of these features will provide invaluable insight into hydrothermal processes in the oceanic crust, and about the formation of ancient massive sulphide ore deposits now found on land.

T.J. Lewis and M. Bone built, tested and used an 11 m Lister heat flow probe. The probe is designed for deeper penetration of soft sediments in order to overcome temperature perturbations at the sediment-water interface. The probe was used successfully in some of the northern B.C. fiords.

W.H. Bentkowski and T.J. Lewis contracted the drilling of two boreholes in the Fraser Valley to look for a larger transition in heat flow such as is seen to the north along Jervis Inlet.

T.J. Lewis, H. Villinger and E.E. Davis used a pulsed needle probe in the laboratory to measure the thermal conductivity of rock chips and fragments. The results were good, and sample preparation appears easier than for the cell method.

D. Weichert (PGC) and J. Adams (EPB), under the sponsorship of the Canadian Committee on Earthquake Engineering (CANCEE), visited Mexico City in October to investigate the damage caused by the destructive M 8.1 Mexican earthquake of September 19, 1985. They took numerous pictures of structural damage, talked to many professional groups (Earthquake Engineers, Seismologists and others) and reported back to CANCEE. An EPB Open File report and a paper for the Canadian Journal of Civil Engineering are in preparation.

6. University of Alberta

A team that included E.R. Kanasewich, R. Clowes, A. Green, C. Spencer and C. Yorath supervised the Vancouver Island experiment. We believe that this process was responsible for setting high standards of data acquisition and will serve as a model for future Vibroseis recording contracts and supervisory teams. The LITHOPROBE seismic profiles on Vancouver Island have given us a very detailed and extraordinary image of the formation of continental crust near an active plate margin. A strong group of reflecting events at 10 to 15 km is seen on all four profiles on the southern half of Vancouver Island. They appear to represent another thrust fault that outcrops as the Hurricane Ridge fault on the Olympic Mountains in Washington State, 45 km to the south. Seismic reflection data between 4 and 8 seconds indicate that this is a decollement zone of underplating that was formed by subduction and accretion beneath an overriding continental plate. An extensive group of deeper reflected events at 25 to 35 km (8 to 10 seconds) is interpreted as the image of the top of the current or modern subduction zone under Vancouver Island. It represents the Juan de Fuca plate subducting under the North American plate. The most significant aspect of the Vancouver Island seismic reflection profiles is that it presents a model by which one can build up a thick section of continental crust. The process involves several stages of underthrusting of subduction in addition to overthrusting and listric faulting. Sedimentation and volcanism adjacent to the present continental margin is involved in addition to the accretion of exotic terranes. Data analyses are being continued by E.R. Kanasewich, S. Chiu and S. Phadke.

The research program for the recording and inversion of wide angle seismic reflection and refraction data to obtain a three-dimensional structure using kinematic data (ray analysis) has been completed (Kanasewich and Chiu, 1985). Seismic tomography involves

three-dimensional imaging so that it is possible to present the structure as two-dimensional slices in any desired azimuth or attitude. An area over the Williston Basin in southern Saskatchewan was interpreted in our paper and we successfully imaged several block faulted zones in the Precambrian crust under the sedimentary basin. As a bonus, we used the inversion techniques and unprocessed vertical and near vertical incidence seismic reflection data from the LITHOPROBE experiment on Vancouver Island. Normally seismic lines are arranged to obtain two- dimensional sections only and crooked seismic lines in mountainous areas contribute to poorer record quality and complications in the data processing. However, we were able to exploit the crooked line data by inverting the data directly to obtain three-dimensional structure and so obtain a tomographic section of two of the thrust faults.

New observational refraction data were recorded by E.R. Kanasewich, A. Vafidis and S. Phadke with instruments in the vacinity of Turtle Mountain in the Crowsnest Pass in the summer of 1985. The project was carried out in cooperation with Alberta Environment, a provincial government agency. We also contributed instrumentation and student help for the LITHOPROBE refraction profile at Kapuskasing, Ontario and on the COCRUST-EMR refraction experiment in the Peace River area.

Three VSP (Vertical Seismic Profiling) data sets were obtained from Panarctic Oils Ltd. from the vicinity of Melville Island at latitude 76°N to 77.5°N. This data set is of very high quality and we are in the process of interpreting these data to obtain Q for this area. The project is managed by E.R. Kanasewich and N. Keehn.

The seismicity of small earthquakes is being studied by E.R. Kanasewich, E. Nyland and S. Kapotas in three Alberta areas: Cold Lake, Rocky Mountain House and Turtle Mountain. Seismic activity has been monitored continuously at Cold Lake since 1981. Approximately 237 microtremors occurred between 1981 and 1984 with magnitudes between -1.6 and +1.5. They are located mainly at the confluence of two buried erosional valleys at depths less than 0.5 km. It is possible that they are triggered by changes in the annual water content or rate of flow. Approximately 230 small earthquakes (magnitudes 1.6 to 4.1) have been recorded in the Rocky Mountain House area between 1975 and 1984. Some of these may be associated with the Strachan gas field. Focal depths and source parameters were computed by Rebollar, Kanasewich and Nyland in 1982 and 1984.

Seismic imaging in steam injection of heavy oil projects is being studied by E.R. Kanasewich and C. Macrides. This work is funded by Esso Resources. Crosshole seismic measurements before and after steam injection were obtained to delineate the steam invaded zone. Analysis of the seismic data from an initial experiment showed significant changes in the amplitude spectra.

P.F. Daley and F. Hron completed development of an entire computer software package for the numerical simulation of total seismic response along vertical lines of receivers located in three-dimensional geological structures of varying degrees of complexity. Their programs are based on the original work of B.G. Mikhailenko and his colleagues in the Computing Centre of the Siberian Branch of the Soviet Academy of Sciences in Novosibirsk, U.S.S.R. with whom F. Hron and his co-workers have been closely collaborating on joint research projects for the last six years. This new set of programs has been used extensively for numerical modelling of the seismic response which one obtains in the so-called Vertical Seismic Profiling technology that has become very popular in seismic exploration for hydrocarbons. Special attention was paid to the simulation of diffracted seismic waves whose dynamic properties were being compared with high-frequency approximations based on ray approaches, such as those recently developed by Klem-Musatov and his colleagues in Novosibirsk. The pertinent computer programs for seismic diffracted waves, which are based on the Klem-Musatov work, have been completed by R. Chan and F. Hron, and their accuracy, speed and range of applicability tested against the results produced by the previously mentioned programs.

Z. Berkes and F. Hron concluded their work on the computer inversion of seismic data pertinent to vertically inhomogeneous structures. They used the Gel'fand-Levitan method to produce velocity and density profiles from the angular dependence of the reflection coefficient of the seismic waves. The numerical values of the reflection coefficient were obtained with the help of a plane-wave decomposition of the common source-point data.

Bao-Shan Zheng and F. Hron concluded development of the computer software for a numerical simulation of higher order terms in the asymptotic ray series into which a ray contribution to the total wavefield is decomposed according to Asymptotic Ray Theory. Knowledge of the importance of the higher order terms is necessary for estimating the zero-order approximation in Asymptotic Ray Theory which is used almost exclusively in practice.

M. Shahriar, G.L. Cumming and F. Hron successfully studied iterative matrix inversion of seismic kinematic and dynamic data. They used Asymptotic Ray Theory for efficient parameterization and iterative inversion of seismic data. Their analysis reveals earth structure in terms of density, compressional and shear wave velocities for isotropic, homogeneous and horizontally layered models. The program has been used for both head wave and reflection amplitudes including multiple reflection arrivals. Excellent numerical results indicate the potential of this method for further application in complex geological structures.

F.W. Jones and J.S. Rogers of the Low Temperature-Solid State Group in the Department of Physics have employed short base-length mercury-level tiltmeters to monitor Earth tides and local tilts at four locations in western Canada: Leduc, Alberta; Regina, Saskatchewan; Penticton, B.C; and Victoria, B.C. From these measurements, the tidal tilt components are being studied as well as the coupling between the seismic piers and the surrounding rock.

A new biaxial mercury-level borehole instrument has been designed and constructed and is currently being tested. This new instrument maintains the sensitivity of the longer baselength horizontal instruments, but senses tilt in two mutually perpendicular directions and can be installed in a borehole. The package includes the transducer, designed to operate in a 10 inch well, and an electronic package controlled by a mini-computer which includes automatic rebalance as well as digital data logging.

A numerical method to study heat flow through regions with lateral thermal conductivity contrasts has been developed by F.W. Jones and M. Rahman. The heat flow associated with both two-dimensional and three-dimensional thermal conductivity contrasts is being studied. A model which includes thermal anisotropy has been developed and used to investigate whether such an effect may have contributed to metamorphism in a zone in the southwest Scottish Highlands.

F.W. Jones, J.A. Majorowicz, R. Beach, M. Rahman, I. Vinokurov, C. Nguyen and A.M. Jessop studied heat flow in the western Canadian sedimentary basin. Variations in thermal gradients and heat flow in the western Canadian sedimentary basin are being studied on the basis of approximately 63 000 bottom-hole temperature values from Alberta, Saskatchewan and Manitoba. Both regional heat flow variations and variations with depth exist.

F.W. Jones, J.S. Rogers, P. Rouleau, J. Thibault and F. Pascal are making tiltmeter measurements and doing petroleum recovery enhancement studies. Detection, monitoring and interpretation of near-surface tilt related to fracturing and inflation effects associated with steam drive and other enhanced petroleum recovery schemes can provide important additional information for both improved recovery and better economy in such schemes as well as a better understanding of the effects of such procedures.

C.M. Scarfe, J.E. Dickinson, J.T. Dunn, M. Brearley, P. Metcalfe, D. Canil and D. Sykes are carrying out high pressure petrological studies. These include experimental studies of the properties and structure of silicate melts as a function of P-T-X. Studies of mantle xenoliths and their basalts in British Columbia are being done, as well as dissolution studies of mantle minerals in basalt melts and xenolith survival in transit to the surface. The generation of komatiite magmas at high pressures and the melting phase relationships of mantle peridotite is in progress.

Using the results of seismic refraction and reflection surveys and gravity measurements in the Vancouver Island region a finite element model has been built by E. Nyland and Li Qing for that region. Stress estimates are obtained from this model and have been combined with rock failure criteria to yield measures of seismic risk in terms of probability. These measures allow the study of geodynamic processes in such a way that the observed seismicity

can be linked to a tectonic driving mechanism. The results obtained from the instability analysis for the Vancouver Island region are in agreement with the observed seismicity and lead to the suggestion that the driving mechanism of the oceanic plate and continental plate is one of the main reasons for the seismicity in the region beneath Vancouver Island.

X. Wu, L. Le and E. Nyland are designing an artificial intelligence algorithm for the interpretation of well log data. Following the logic of human interpreters, the procedure begins with a contact recognition operation. An iterative linear regression with variable break point algorithms was designed to describe a curve and intervals with certain features were picked as candidate intervals containing contacts. Because there is always a normal order of geological beds in the section where the test broehole is located, there is a normal order of subcurves of log responses. The test set of intervals is compared, using LISP code, to a pattern set of intervals and the goal is to find the best matching of these two sets. We modified and extended the 1982 string-to-string matching technique of S.Y. Lu and K.S. Fu to emulate such an inference.

Our major modification is that no fixed classes of symbols are defined and the similarity of two strings is evaluated by the sum of the costs of matching, deleting or inserting an interval in the test borehole. One of the measures of similarity of these two strings is the smallest number of operations required for the transformation of one into another. The best matching is the one which costs the least in total. It will illustrate how the geological column of the pattern should be mapped onto the test borehole.

E. Nyland is developing a prototype of a "smart" seismic recording system. The system will be used in a project involving failure near a fireflood. Initial attempts to design a digital algorithm for recognizing seismic events involve the use of pattern recognition and expert system techniques which are now being developed in a project for automated interpretation of well logs. The analysis and transformation of strings or lists of symbols is very close to the process of interpreting waveforms on seismic records and response patterns on well logs.

7. University of British Columbia

E. Gens-Lenartowicz, M. Demartin (a visiting scientist from Italy) and R.M. Clowes have completed an interpretation for the southern 500 km of the FENNOLORA (Scandinavian) seismic profile which extends for 2500 km from the East German sedimentary basin across the Precambrian shield to northern Sweden and Norway. The major feature of the interpretation is a rapid lateral transition in structure of the Precambrian crust, from a thickness of 35 km in southernmost Sweden to 48 km south of Stockholm, which may be associated with the juxtaposition of two different age provinces.

Interpretation of data acquired during an offshore-onshore refraction program carried out in 1983 in collaboration with the Pacific Geoscience Centre, Victoria, and the Seismology and Geomagnetism Division, Earth Physics Branch, Ottawa is continuing. The objective of the study is to determine crust/lithosphere structure (i) of the Queen Charlotte transform fault zone; (ii) below the Queen Charlotte Islands; and (iii) below Hecate Strait. D.J. Mackie, R.M. Clowes and R.M. Ellis have completed one aspect of the Queen Charlotte program - a model of the deep crustal structure beneath the fault zone, the Queen Charlotte Islands, and Hecate Strait. The model, while not definitive, supports the interpretation of oblique shallow underthrusting of the Pacific plate beneath Queen Charlotte Islands. S. Dehler and R.M. Clowes are using airgun and explosion data to interpret a detailed model of the Queen Charlotte transform fault zone and adjacent regions. C. Pike and R.M. Clowes are interpreting the high quality airgun data recorded on four ocean bottom seismographs (OBS) in Hecate Strait to determine a seismic sedimentary basin model in the region where interest in hydrocarbon exploration has recently revived.

R.M. Clowes has been working with a number of co-investigators from the government and academic communities on the interpretation of Phase 1 LITHOPROBE reflection data recorded along four profiles totalling 206 km in length on southern Vancouver Island. Existing and new geological data have been integrated with the seismic section to enable complete interpretations. Many significant results have been obtained so far, for example: (i) mapping the top of the subducting Juan de Fuca plate; (ii) identifying and mapping thrust faults (previously interpreted as transcurrent faults); (iii) first direct evidence for the

process of subduction underplating or subcretion; and (iv) development of tectonic models to explain the observed results and subcretion process.

J. Drew and R.M. Clowes are proceeding with a reinterpretation of the 1980 Vancouver Island Seismic Project (VISP) refraction data recorded along the island and on an offshore-onshore profile across the island. The original interpretations are published, but there are discrepancies with the new LITHOPROBE data. By using the constraints of the two-way travel times to major reflecting zones, the objective is to derive seismic structures which are consistent with both data sets.

R.M. Clowes is collaborating with C.J. Yorath of the Pacific Geoscience Centre on the analysis and interpretation of a set of marine multichannel crustal reflection data. The data were obtained by contract as part of EMR's Frontier Geoscience program. More than 500 km of 30-fold data were acquired along a number of lines extending from the deep ocean to the west coast of Vancouver Island. Some of the data represent an extension of the LITHOPROBE Vibroseis data on Vancouver Island to the offshore region in an attempt to further clarify the geometry and characteristics of the subduction of the Juan de Fuca plate.

R.M. Clowes as Principal Investigator and A. von Breymann as Project Manager are continuing their work on a geophysical reconnaissance study of the Caribbean continental margin of Costa Rica for the purpose of petroleum exploration under the terms of a contract with Recope, the national oil company of Costa Rica. Free air and Bouguer gravity anomaly maps, a magnetic anomaly map and a bathymetric map have been compiled. Analysis of 14 airgun sonobuoy reflection/refraction profiles is nearing completion. Interpretation of the entire data set, including constraints from single channel seismic reflection profiles recorded during the field program and multichannel CDP reflection sections made available by Recope, is well advanced. The final report to Recope will be presented in early 1986.

D.J. White (also Pacific Geoscience Centre) and R.M. Clowes, with critical technical assistance from R. Meldrum, B. Ciammiachella and J. Bennest have planned and carried out (in October-November 1985) a marine seismic refraction experiment centred on a segment of the Juan de Fuca ridge where hydrothermal activity and other features indicate that a magma chamber could exist. There are three principal components to the study: (i) regional crustal structure across and along the ridge with particular emphasis on the role of the Moho; (ii) development of a tomographic algorithm for imaging a three-dimensional velocity-attenuation anomaly; and (iii) investigation of the presence of a crustal magma chamber. Fourteen successful deployments of 10 OBSs recorded 153 90 kg charges along 310 line kilometres and shots from a 32 litre airgun fired at 0.25 km interval along a pattern of lines totalling 400 km. Thirteen OBSs successfully recorded data.

I.F. Jones with T.J. Ulrych, D.W. Oldenburg and S. Levy has developed new seismic reflection data processing procedures based on the Karhunen-Loève transform which optimally extracts coherent information from multichannel data. Most algorithms are tested on synthetic and real data examples and 'production-line' industrially viable versions of some of the programs have been developed. These include a new signal-to-noise ratio enhancement technique and a new multiple suppression methodology based on the ability of the transform to segregate coherent information.

R.M. Ellis led the four university (British Columbia, Toronto, Western Ontario, Alberta)/EPB recording teams in the Peace River Arch Seismic Experiment. Shooting was by the University of Saskatchewan. The objective of this Institute of Sedimentary and Petroleum Geology sponsored refraction program is to provide a velocity model of the sedimentary basin to upper mantle depths and thus additional parameters to investigate its subsidence history. C.A. Zelt has undertaken this study as a Ph.D. project.

A.V. Boland and R.M. Ellis are analyzing the refraction data from the Kapuskasing Structural Zone, a LITHOPROBE Phase I experiment. The objectives of this experiment are to test the geologic/gravity model of Percival and Card (1983), a velocity profile to aid reflection interpretation, and a regional crustal model. Preliminary travel time studies using crustal and Pn arrivals show general agreement with the Percival and Card model.

J. Bérubé, R.M. Ellis and G.C. Rogers (Pacific Geoscience Centre) have completed analysis of Queen Charlotte seismicity data acquired in 1983. Analyses of the 261

earthquakes recorded show significant earthquakes (i.e. M > 4) do occur east of the Queen Charlotte Fault within the continental crust with thrust mechanisms consistent with oblique convergence of the Pacific and North American Plate; one earthquake (M = 2.4) was located in central Hecate Strait; only two events were observed in the seismic gap between the 1949 and 1970 rupture zones; and the b-value is very low (0.55).

R.M. Ellis, L. Fisk and G.C. Rogers have completed a preliminary study to assess the accuracy and improve the location of earthquake epicentres off the B.C.-Washington coast. Revised epicentres have been determined, using a standard earth model with station corrections for 89 earthquakes M > 5 which occurred in the period 1917-80. Selected teleseismic epicentres in three areas have been used to determine station delays through a standard crustal model to local stations. Use of these station corrections leads to significant movement of epicentres. These data are now being used to investigate the seismotectonics of the ridge-fracture zone system west of Vancouver Island.

R.M. Ellis and R.D. Meldrum continue to operate the UBC digital array which now has six stations. The research array complements the Earth Physics Branch stations and is designed to provide accurate hypocentres and high quality digital data to aid our understanding of the current geodynamic processes in the Georgia Strait region. Initial research studies will use both teleseismic and local earthquake arrivals to improve our crust-upper mantle models.

J.F. Cassidy and R.M. Ellis are studying the 1918 (M = 7) and 1957 (M = 6) earthquakes of central Vancouver Island to gain an improved understanding of the stress regime and seismic potential. The epicentre of the 1918 earthquake has been relocated at 46.62N 126.13W. Tests using different earth models, rejecting late arrivals, and varying the azimuth distribution of stations indicate an accuracy near 15 km. Based on 20 stations the surface wave magnitude Ms = 6.85 $\pm$ .15 and from the felt area M = 6.90 $\pm$ .16. Initial surface wave studies indicate that analysis will be severely limited by the lack of long period instruments; however, analysis with body wave synthetics is likely to be more productive. Records have now been received from more than 50 stations for the 1957 earthquake of which 30 will be useful for surface wave analysis.

M. Yedlin, B. Seymour and B. Zelt are developing uniformly valid solutions, at all frequencies, for one dimensional elastic wave propagation. So far the results have demonstrated that the new method works as well as the WKBJ technique in one dimension. Extensions are planned for two dimensional wave propagation.

M. Yedlin and D. Mitsakis are investigating new applications of Chebychev polynomials for finite difference computations on an irregularly sampled grid. The Chebychev calculations require an order of magnitude fewer nodes than conventional finite difference methods, applied to one dimensional wave propagation problems. The Galerkin, tau and pseudospectral techniques have been coded and tested for the Helmholtz equation, and are being extended to include time-dependent equations.

B. Narod and M. Yedlin have developed an apparatus for modelling acoustic edge diffractions. It has been demonstrated that the diffraction hyperbola for a zero-offset experiment is asymmetrical about the diffracting edge. This experimental result has been confirmed by synthetic seismogram calculations.

8. University of Calgary

E.S. Krebes and students, D.J. Hearn and K.C. Coflin, carried out theoretical studies on the propagation of visco-elastic waves. D.J. Hearn and E.S. Krebes found a general Fermat principle for 2D/3D visco-elasticity ray tracing which eliminates the arbitrariness currently present in choosing the attenuation direction of the ray at the source. K.C. Coflin and E.S. Krebes studied the effects of causal absorption and dispersion on vibrator-generated seismic signals, and suggested a method for extracting Q and for improving vibrator data processing.

F.A. Cook was involved in seismic reflection profiling in the Cordillera. Acquisition of seismic reflection data near the Columbia River fault took place during May 1985. Nearly 15 km of data were recorded and reflections were received with travel times of 11-12 s. The Columbia River fault is seen as an eastward dipping listric normal fault which flattens near

10-12 km depth. Beneath the fault is a westward dipping (to 15 km) zone of reflections which likely represent the base of an east-tapering wedge and delimits the eastern extent of the duplexed Monashee complex.

9. Dalhousie University

K.E. Louden was involved in marine heat flow studies. He has built a multi-penetration marine heat flow probe which measures temperature gradients and in situ conductivities over a 4-7 m interval. He has used this instrument to measure heat flow offshore eastern Canada in the Sohm basin and Labrador Sea. Values in the Sohm basin are high (54 mW/m^2) for its expected age (160 Ma) and sediment corrected basement depth (6400 m) while values in the Labrador Sea are average (74 mW/m^2) for its age (60 Ma) and water depths (4200 m) are less than expected.

K.E. Louden is also in the process of producing a new digital ocean bottom seismometer. He is building digital recording packages to interface with Bedford Institute of Oceanography's existing analogue ocean bottom seismometers. These instruments will be tested during 1986 on refraction profiles in the Indian Ocean to study the nature of compressional features within the central basin.

10. University of Manitoba

A. Carswell and W. Moon completed testing of a multioffset VSP seismic technique for mapping fracture zones. The test results from the Pinawa URL site (Manitoba) indicate that broad and/or intensely fractured zones can be effectively mapped using this technique.

C. Dilliston and W. Moon have developed a surface wave synthetic seismogram algorithm for Earth models with oceanic and continental paths. Currently a systematic inversion scheme is being tested to process the real data.

During the summer of 1985, the University of Manitoba seismic group (E. Kublick and W. Moon) and INCO geophysics field exploration personnel (B. Krause) collected high resolution reflection data across the North Range of the Sudbury basin. The main objective of this experiment is to map the prominent geological structures associated with ore bodies. The data are being processed.

Currently, the tidal energy dissipation processes are being reviewed by W. Moon and Seongho Na and the most acceptable rheological model of the mantle is being tested mathematically. Na and Moon are also developing a model to test an Earth-Moon system throughout the Earth's past history.

J. Morrish and W. Moon are developing an integrated geophysical imaging formalism based on a multi-dimensional information shell approach and a generalized inverse type optimization process.

11. McGill University

D. Crossley and R. del Valle used the Monte Carlo method for interpretation of seismic refraction data, mainly profile records, as an objective technique to determine one- and two-dimensional velocity structure. Once a suite of acceptable models has been determined, using primarily first arrival travel times but also qualitative culling of amplitude information, an average model is computed. This model then forms the basis of a general linearized inversion that determines which features of the averaged model are necessary in the data fitting. They have demonstrated that this method works successfully on one dimensional synthetic and observational data (from the 1982 Abitibi Greenstone Belt experiment) and are considering extending the method to two-dimensions.

D. Crossley, O. Jensen and J.A. Jacobs have successfully added a variety of stochastic processes (white noise, fractal flicker noise and brown noise) to simple models of the Earth's magnetic field (such as modification of Bullard's single disk dynamo). The objective was to determine if identifiable elements of the paleomagnetic reversal sequence could be attributed preferentially to either a noise-stimulated dynamo, or whether the idea of a chaotically reversing model was adequate. We found that the noise processes induced much

more realistic (paleomagnetically) time sequences (of main field amplitude) and that the slow buildup of an oscillation infield intensity (not always observed) need not be present with stochastic forcing.

12. University of Saskatchewan

Computation by Z. Hajnal and B. Pandit of synthetic seismograms with the reflectivity method is based on complex mathematical relationships. The discrete, computer based approximations of these functions can create unwanted numerical artifacts. A procedure is developed which eliminates these features on the synthetic records by establishment of limiting parameters. The computed synthetic multitrace records permit analysis of amplitude variations with distance, source efficiency by variation of shot depth, and influence of multiples on primary events.

An 11 km long reflection profile and a 6 km reversed refraction profile were shot under the direction of Z. Hajnal along the western flank of the Haughton impact crater. This unique feature is located in the north central region of Devon Island in the High Arctic. The field records were contaminated by strong ground roll and source generated air waves. A recently developed optimum array filtering algorithm efficiently attenuates these persistent coherent noise events. Sonic log based modelling is in progress to recognize several of the consistent reflection events.

In cooperation with several members of the COCRUST group, four reversed and two broadside refraction profiles were shot over the Peace River Arch. A crew from Saskatchewan directed by Z. Hajnal manned the shooting procedures. Two-dimensional modelling analysis of the collected data is in progress.

One thousand reflection records were collected on a moving ice platform along the eastern coast region of the Arctic Ocean. Standard digital processing of this data set is in progress under Z. Hajnal. It is hoped that continuous velocity spectral analysis of a large set of these records will provide new information about the acoustic properties of the upper crust under the Arctic coastline.

D. Gendzwill is developing equipment to monitor seismic activity near mines. This features radio data communication and computer monitoring with automatic event recognition, automatic time picking, automatic source location, comprehensive file manipulation, plotting and printing.

D. Gendzwill is also monitoring and analysing mining induced seismicity especially with respect to potash mines. Development is proceeding on source location algorithms and analysis of source mechanisms.

J.B. Merriam is studying the anelasticity of the mantle which may be quantified by a general parameter according to the absorption band hypothesis. The measurement of this parameter by its effect on the amplitude of long period Earth tide terms in the Earth's rotation rate is a useful extension of mantle rheology into the tidal band. The M_f, M_m and Ssa terms have been shown to place strong constraints on this parameter.

13. University of Western Ontario

A combined analysis by T. Cox, J. Baery, K. Michel, K. Morrissey, T. Hewak and R.F. Mereu of long range refraction and deep seismic reflection data was performed on data which were obtained by the USGS across the San Andreas Fault in Southern California. The results and techniques of analysis were presented and compared at a Controlled Source Seismology Workshop held at Shizuoka, Japan in August 1985.

The analysis of the Ottawa Valley COCRUST experiment was also completed and a study was begun on the spectrum and attenuation characteristics of coda waves recorded in 1984 in the Kapuskasing refraction experiment.

During the summer of 1985 the University of Western Ontario sent a crew of four people and nine recording instruments to participate with the ISPG and other universities in the Peace River seismic experiment in northern Alberta.

During the summer of 1985, R.F. Mereu, T. Cox, S. Altman and M. Gipp participated with the Geological Survey of Canada in the Arctic Ice Island seismic reflection experiment. The aim of the experiment was to study the subsurface structure of the continental shelf near Ellesmere Island. Shots were fired every few hours as the island drifted and were recorded by a large two-dimensional array of 132 sensors.

Seismic data recorded by R.F. Mereu, G. Miller, S. Pamidi and D. Kennedy along a number of lines in southwestern Ontario were obtained from the Cangeo Company in Oil Springs, Ontario. In this project, a number of data processing methods were tested in an effort to identify and correct some of the interpretational problems which plague seismic data shot in Ontario.

The Charlevoix region along the St. Lawrence River northeast of Quebec City has been the site of continuous micro-seismic activity. Last year, a detailed study of earthquake hypocentres was completed by R.F. Mereu, M. Lamontagne and K. Morrissey, and events were classified according to their fault-plane patterns.

The analysis of induced seismic events in data collected from the Gobles oilfield in southern Ontario was also continued in an effort to determine and classify patterns of events.

The variation of the amplitude of the reflected P wave with distance has been determined by L. Mansinha in a shallow seismic reflection survey. The amplitude curve shows two humps which are ascribed to the increase in the P reflection coefficient at the P-P and P-S critical refraction angles. A curve matching procedure with theoretical amplitude-distance curves was used to determine the P and S velocities below the reflecting interface.

P.Y. Shen and A.E. Beck carried out stabilization studies of bottom-hole temperatures. The so-called "Horner" method consists of plotting temperatures observed over a few to several hours at the bottom of a borehole against a logarithmic function of the shut-in time and circulation time, and then drawing a least squares straight line through the points to obtain the equilibrium temperature; this method always underestimates the equilibrium temperature, the magnitude of the underestimate increasing with decreasing shut-in time and increasing initial temperature difference between the well fluid and the equilibrium temperature, leading to an underestimate of the temperature gradient. Equilibrium temperature underestimates can be as large as 14°C if the temperatures are measured one to four hours after drilling has ceased to as little as 4°C if the measurements are made 5 to 20 hours after drilling has ceased. By using more realistic boundary conditions, and taking into account the finite time of mud circulation, and loss or gain of fluid in the hole, we have reduced the equilibrium temperature underestimates to a fraction of a degree C, even for measurements made only a few hours after drilling has ceased.

Because of the experimental simplicity, increasing use is being made by A.E. Beck and P.Y. Shen of the oceanic technique to obtain heat flow values from the sediments of lakes. However, thermal properties and bottom temperatures vary much more in continental lakes than in oceanic basins. An investigation is underway to determine the significance of these and other variations. To date, we can say categorically that at least extreme care has to be exercised, particularly in the case of bottom temperature variations which should be monitored at frequent intervals (at least every few weeks) over a period of five years prior to sediment temperatures versus depth being measured; some effort should also be made to determine the variation of thermal conductivity with depth, although the errors from this source are unlikely to exceed 20%.

N. Balling and A.E. Beck are studying the effect of casing on stratigraphic resolution. Since borehole casing has a high conductivity relative to the formations it penetrates, the stratigraphic signal from temperature gradients is damped, thus leading to a loss of resolution. The resolution could be improved either by decreasing the downhole logging velocity, with a consequent increased cost due to the longer logging time required, or by deconvolving the temperature data. We have started to investigate inversion procedures to take the effect of the casing into account.

Determinations of underground fluid movement are being made by A.E. Beck and P.Y. Shen. Three types of underground water movements can be estimated through temperature measurements in a single borehole. Firstly, the vertical movement in the hole itself where the rate can

be estimated directly from the temperature offset but is limited to a high flow rate of the order of ml/s. Secondly, the perturbation of temperature gradients at the depth of outflow (and inflow), is a much better characteristic to be used but exists only in a very small depth range and is therefore virtually undetectable using the traditional point by point logging technique. In the third method, with the continuous logging equipment developed at this university, it is now possible to resolve such sharp changes. It is also possible to detect and measure the vertical component of water movement in the formation which gives rise to a continuous change in the gradient profile. A program is underway to develop well founded inversion procedures to give quantitative information on flow rates and onset times.

The physical properties of matter under conditions of planetary interiors is being studied by H.H. Schloessin. The major part of experimental work in 1984-85 was on p- and T-induced phase transitions and the attendant physical property changes. The phase diagrams of Bi, Fe, Hg, Pb, Sn, Tl, $CaCO_3$ and KBar were redetermined by in situ, on-line p,t calibration inside the 1000 ton cubic press. Abundant, self-consistent calibration was achieved by means of the fluid encapsulation method which provides true hydrostatic and isothermal conditions in large, ~1500 mm^3 volumes. Theoretical studies were made on the subject of magnetic field and fluid velocity field variations in the earth's outer core imposed by boundary conditions especially the dielectric properties of the lower mantle, as well as on the subject of seismogenic perturbations of the fair-weather electric field as possible source of EQLs and sferics.

14. Bibliography

Anglin, F.M. and Buchbinder, G.G.R. 1985. Induced seismicity at the LG3 Reservoir, James Bay, Quebec, Canada. Bull. Seism. Soc. Am., 75, 1067-1076.

Basham, P.W., Weichert, D.H., Anglin, F.M. and Berry, M.J. 1985. New probabilistic strong seismic ground motion maps of Canada. Bull. Seism. Soc. Am., 75, 563-595.

Bentkowski, W.H. and Lewis, T.J. 1985. Preliminary results from shallow drilling in the Anahim Volcanic Belt, B.C. Earth Physics Branch Open File Report 85-9.

Bortfeld, R.K., Gowin, J., Stiller, M., Baier, B., Behr, H.J., Heinrichs, T., Durbaum, H.J., Hahn, A., Reichert, C., Milkereit, B., and Gebrade, H. 1985. First results and preliminary interpretation of deep-reflection seismic recordings along profile DEKORP 2-South. J. Geophys., 57, 137-163.

Buchbinder, G.G.R. 1985. Shear wave splitting and anisotropy in the Charlevoix seismic zone, Quebec. Geophys. Res. Lett., 12, 425-428.

Childerhouse, C., Davis, E.E., and Rogers, G.C. 1985. The Juan de Fuca Ridge. EMR Public Information Pamphlet.

Clowes, R.M. and Gens-Lenartowicz, E. 1985. Upper crustal structure of southern Queen Charlotte Basin from sonobuoy refraction studies. Can. J. Earth Sci., 22, 1696-1710.

Clowes, R.M., Spence, G.D., Ellis, R.M. and Waldron, D.A. 1985. Structure of the lithosphere in a young subduction zone: results from reflection and refraction studies. In: Reflection Seismology: The Continental Crust, M. Barazangi and L. Brown (Editors), AGU Geodynamics Series, 14, 313-321.

Clowes, R.M., Green, A.G., Yorath, C.J., Kanasewich, E.R., West, G.G., and Garland, G.D., 1984. LITHOPROBE - A national program for studying the third dimension of geology. J. Can. Soc. Explor. Geophys., 20, 23-29.

Currie, R.G. Davis, E.E. and Sawyer, B.S. 1985. Juan de Fuca Ridge Atlas: Preliminary SEABEAM Bathymetry. Earth Physics Branch Open File Report 85-18.

Daley, P.F. and Hron, F. 1985. Wave methods for shear waves in elastic media. In: Shear Waves, Geophysical Press, Haarlem.

Davis, E.E. and Clowes, R.M. 1985. High velocities and seismic anisotropy in Pleistocene turbidites off Western Canada. Geophys. J.R. Astr. Soc., 83.

Davis, E.E., Currie, R.G. and Sawyer, B.S. 1985. Juan de Fuca Ridge Atlas: regional SeaMARC II acoustic image mosaics and SEABEAM bathymetry. Earth Physics Branch Open File Report 85-2.

Davis, E.E., Currie, R.G., Riddihough, R.P. and Sawyer, B.S. 1985. A new look at the Juan de Fuca Ridge: high resolution bathymetry and side-scan acoustic imagery. GEOS, 14, 10-15.

Drury, M.J. 1985a. Heat flow and heat generation in the Churchill Province of the Canadian Shield and their palaeotectonic significance. Tectonophysics, 115, 25-44.

Drury, M.J. 1985b. The Iceland Research Drilling Project Crustal Section: physical properties of some basalts from the Reydarfjordur borehole. Can. J. Earth Sci., 22, 1588-1593.

Drury, M.J. 1985c. A simple needle-probe method for measuring thermal diffusivity of unconsolidated materials. Division of Gravity, Geothermics and Geodynamics, Earth Physics Branch, Internal Report 85-6.

Drury, M.J. 1985d. Continental scientific drilling: review of EPB activities 1984-85. Division of Gravity, Geothermics and Geodynamics, Earth Physics Branch, Internal Report 85-22.

Drury, M.J. and Jessop, A.M. 1985. Scientific drilling at the Earth Physics Branch - past achievements and present possibilities. Division of Gravity, Geothermics and Geodynamics, Earth Physics Branch, Internal Report 85-3.

Ellis, R.M. and Denham, D. 1985. Structure of the crust and upper mantle beneath Australia from Rayleigh and Love wave observations. Phys. Earth Planet. Int., 38, 224-234.

Evans, R., Asudeh, I., Campin, S. and Ucer, S. 1985. Tectonics of the Marmara Sea region of Turkey: new evidence from micro-earthquake fault plane solutions. Geophys. J.R. Astr. Soc., 83, 47-60.

Feng, Rui and Kanasewich, E.R. 1985. Propagating enclosure method in finite element analysis. Acta Sinica, 28, 53-63.

Green, A.G., Weber, W. and Hajnal, Z. 1985a. Evolution of Proterozoic terrains beneath the Williston basin. Geology, 13, 624-628.

Green, A.G., Weber, W. and Hajnal, Z. 1985b. An evolutionary model of the western Churchill province and the western margin of the Superior province in Canada and the north-central United States. Tectonophysics, 116, 281-332.

Hasegawa, H.S. 1985. Attenuation of L_g waves in the Canadian Shield. Bull. Seism. Soc. Am., 75, 1569-1582.

Hasegawa, H.S., Adams, J. and Yamazaki, K. 1985. Upper crustal stress and vertical stress migration in eastern Canada. J. Geophys. Res., 90, 3637-3648.

Jessop, A.M. 1985a. Catalogue of Boreholes: 1 - Scientific Geothermal Holes. Division of Gravity, Geothermics and Geodynamics, Earth Physics Branch, Internal Report 85-9.

Jessop, A.M. 1985b. Geothermal Energy in Canada. Trans. Geothermal Resources Council, 9.

Jessop, A.M. 1985c. Geothermal Energy. In: The Canadian Encyclopedia, 736-737.

Judge, A.S. and Pilon, J. 1984. Climate change and geothermal regime. In: Final Proceedings, Fourth International Permafrost Conference, National Academy Press, Washington, D.C., U.S.A., 137-159.

Judge, A.S. and Taylor, A.E. 1985. Permafrost distribution in northern Canada: interpretation of well-logs. In: Workshop on Permafrost Geophysics. Cold Regions Research and Engineering Special Report 85-5, Hanover, U.S.A., 19-25.

Kanasewich, E.R. and Chiu, S.K.L. 1985. Least squares inversion of spatial refraction data. Bull. Seism. Soc. Am., 75, 865-880.

Krebes, E.S. and Hearn, D.J. 1985. On the geometrical spreading of viscoelastic waves. Bull. Seism. Soc. Am., 75, 391-396.

Lewis, T.J., Jessop, A.M. and Judge, A.S. 1985. Heat flux measurements in southwestern British Columbia: the thermal consequences of plate tectonics. Can. J. Earth Sci., 22, 1262-1273.

Majorowicz, J.A., Jones, F.W., Lam, H.-L. and Jessop, A.M. 1985a. Regional variations of heat flow differences with depth in Alberta, Canada. Geophys. J.R. Astr. Soc., 81, 479-487.

Majorowicz, J.A., Jones, F.W., Lam, H.-L. and Jessop, A.M. 1985b. Heat flow and geothermal gradient studies on the Alberta Basin, an essential part of geothermal potential evaluation. Proc. Energex 85, Regina, 279-284.

Majorowicz, J.A., Rahman, M., Jones, F.W., and McMillan, N.J. 1985. The paleogeothermal and present thermal regimes of the Alberta basin and their significance for petroleum occurrences. Bull. Can. Petrol. Geol., 33, 12-21.

Majorowicz, J.A., Jones, F.W., Lam, H.-L., Linville, A. and Nguyen, C.D. 1985. Topography and the subsurface temperature regime in the western Canadian sedimentary basin: implications for low enthalpy geothermal energy recovery. Geothermics, 14, 175-187.

Merriam, J.B. 1984. Tidal terms in Universal Time: effect of zonal winds and mantle Q. J. Geophys. Res., 89, 10,109-10,114.

Merriam, J.B. 1985. Lageos and UT measurements of long-period Earth tides and mantle Q. J. Geophys. Res., 90, 9423-9430.

Milkereit, B. and Fluh, E.R. 1985. Saudi Arabian refraction profile: crustal structure of the Red Sea-Arabian Shield transition. Tectonophysics, 111, 283-298.

Milkereit, B., Mooney, W.D. and Kohler, W.M. 1985. Inversion of seismic refraction data in planar dipping structure. Geophys. J.R. Astr. Soc., 82, 81-103.

Monger, J.W.H., Clowes, R.M., Price, R.A., Riddihough, R.P., Simony, P. and Woodsworth, G.J. 1985. Continent-ocean transect B2: Juan de Fuca plates to Alberta plains. Geol. Soc. Am., Decade of North American Geology, Continent:Ocean Transect 7, 2 sheets, 21 pp.

Nyland, E. 1985. Theory for estimating seismic wave velocity in oil sands. AOSTRA J. Research, 1-13.

Pilon, J.A., Annan, A.P. and Davis, J.L. 1985. Monitoring permafrost soil conditions near a buried oil pipeline using ground-probing radar and time-domain reflectometry techniques. 55th Annual International Society of Exploration Geophysicists Meeting, October 1985, Washington, D.C. Extended Abstract Volume, 3-5.

Reiter, M.A. and Jessop, A.M. 1985. Estimates of terrestrial heat flow in offshore eastern Canada. Can. J. Earth Sci., 22, 1503-1517.

Rogers, G.C. 1985a. Variation in Cascade volcanism with margin orientation. Geology, 13, 495-498.

Rogers, G.C. 1985b. Juan de Fuca Plate Map - JFF12: Seismograph Stations, January 1, 1985. Earth Physics Branch Open File 85-35.

Rozenberg, G., Henderson, J.D., Sartorelli, A.N. and Judge, A.S. 1985. Some aspects of transient electromagnetic soundings for permafrost detection. In: Workshop on Permafrost Geophysics, Cold Regions Research and Engineering Special Report 85-5, Hanover, U.S.A., 74-90.

Shimada, M., Scarfe, C.M. and Schloessin, H.H. 1985. Thermal conductivity of a sodium disilicate melt at high pressures. Phys. Earth Planet. Int., 37, 206-213.

Spence, G.D., Clowes, R.M. and Ellis, R.M. 1985. Seismic structure across the active subduction zone of western Canada. J. Geophys. Res., 90, 6754-6772.

Spencer, C.P. 1985. The use of partitioned matrices in geophysical inversion problems. Geophys. J.R. Astr. Soc., 80, 619-629.

Takahashi, E. and Scarfe, C.M. 1985. Melting of peridotite to 14 GPA and the genesis of komatiite. Nature, 315, 566-568.

Taylor, A.E. and Judge, A.S. 1985. Obtaining precise temperature measurements in abandoned offshore petroleum exploration wells. In: Workshop on Permafrost Geophysics, Cold Regions Research and Engineering Special Report, Hanover, U.S.A., 95-99.

Weichert, D.H. 1985. New Brunswick strong ground motion records. Phys. Earth Planet. Int., 38, 83-91.

Yorath, C.J., Green, A.G., Clowes, R.M., Sutherland Brown, A., Brandon, M.T., Kanasewich, E.R., Hyndman, R.D. and Spencer, C. 1985. LITHOPROBE - Southern Vancouver Island: vibroseis reflection sees through Wrangellia to the subducting Juan de Fuca plate. Geology, 13, 759-762.

Yorath, C.J., Clowes, R.M., Sutherland Brown, A., Brandon, M.T., Massey, N.W.D., Green, A.G., Spencer, C., Kanasewich, E.R. and Hyndman, R.D. 1985. LITHOPROBE - Phase 1: Southern Vancouver Island: Preliminary analyses of reflection seismic profiles and surface geological studies. In: Current Research, Geol. Surv. Can. Paper 85-1A, 543-554.

Young, S. and Judge, A.S. 1985. A ground temperature data collection for northern Canada. McGill Workshop on Climate and Thermal Regimes in Northern Canada, Montreal, Canada.

Zahradnik, J. and Hron, F. 1985. Seismic ground motion of sedimentary valley La Molina, Lima, Peru. In: Proceedings of the 3rd International Symposium on the Analysis of Seismicity and Seismic Risk, Liblice, Czechoslovakia.

III (A) GEOMAGNETISM

Compiled by: G. W. Pearce

1. Summary

In 1985 no marine survey operations were undertaken, but the Geological Survey of Canada, Ottawa (GSC) carried on extensive aeromagnetic surveys principally on the north and east coasts. Two of these surveys - in the Laurentian Channel and off NE Newfoundland - were cooperative efforts with the Atlantic Geoscience Centre and, in part, with five oil companies. Earth Physics Branch (EPB) and GSC established a joint data base of marine data, and EPB completed the Canadian magnetic chart for epoch 1985.0.

The Geomagnetic Observatory unit of EPB, in addition to its regular data collection, finished converting the Canadian network to digital output with Alert and Mould Bay, N.W.T. being upgraded during the year. The unit also worked on a number of refinements and developments in instrumentation and analysis during the year including evaluation of ring-core fluxgates, a new type of multizone forecast of magnetic activity and a numerical technique of K index determination.

EPB and four universities reported activity in electromagnetic induction studies during the year. Again included among these were EMSLAB, an international project to study the Juan de Fuca plate at depth, with EPB, University of Alberta and Queen's University personnel involved in field work during the year, and MOSES (magnetometric off-shore electrical sounding), a joint project of Pacific Geoscience Centre (PGC) and University of Toronto to measure seafloor resistivity. University of Alberta did much work on western surveys, particularly in the Cordillera and Rocky Mountains. Queen's University completed an investigation of the Kapuskasing Structural Zone and University of Toronto used the scalar audiomagnetotelluric method in a regional study near Timmins. EPB did surveys in many parts of the country. University of Victoria concentrated on theoretical and analogue model studies.

Paleomagnetic and rock magnetic studies were carried out by many groups with one new university, McMaster, beginning a program during the year. EPB, Laval University, McMaster, University of Toronto, University of Western Ontario and University of Windsor were engaged in Precambrian projects in all parts of the country and on the Baltic shield (Laval). PGC

and Windsor have been active in the Cordillera. EPB, Alberta, Laval, Memorial and Toronto are currently running projects in Paleozoic terranes, particularly in Eastern Canada. The evaluation study by the Alberta group on the use of mining company core in magnetostratigraphy is potentially of great interest. The universities of Alberta and Toronto have ongoing programs on Cenozoic samples, with both groups working in NW Yukon, particularly the Old Crow area. EPB and Alberta, McMaster, Memorial and Toronto Universities have projects on rock magnetism, with the Toronto group being extremely active. Finally, mention must be made of the Toronto study of meteorite magnetism, which is a natural outgrowth of the earlier lunar project. In brief, geomagnetism remains a vital, active line of research in Canada in all its branches.

2. Geomagnetic Surveys, Charts and Compilations

(a) Atlantic Geoscience Centre, Geological Survey of Canada (R. MacNab)

(i) Magnetic Surveys

No marine survey operations were undertaken in 1985, but two major airborne surveys were conducted over parts of the continental shelf off eastern Canada and adjacent oceanic areas. The first airborne survey was designed to map the magnetic field over the Laurentian Channel, and to link up data sets that had been collected previously on Cape Breton Island and southern Newfoundland. This will permit a tracing of trends across the Laurentian Channel, where the Appalachian System undergoes a major offset. A total of 85 000 line kilometres were flown at spacings of 1, 2, and 4 km. Data quality was rated as generally high, with good navigation control provided by Loran over water, camera over land. The survey was carried out by Kenting Earth Sciences Limited, under contract to the Geological Survey of Canada.

The second airborne survey covered two contiguous regions: the first on the Northeast Newfoundland Continental Shelf and the adjacent Orphan Basin, where 116 500 kilometres of high resolution data were collected on a 3 x 9 km grid; the second in the southeast Labrador Sea, where regional data were collected over 12 000 kilometres at a 30 km spacing. The first part of the survey was sponsored by a consortium consisting of the Geological Survey of Canada and five oil companies; the second part was sponsored by the GSC alone. Data quality in this survey was also rated as high, with navigation control provided by a combination of rho-rho Loran and GPS (Global Positioning System). The survey was carried out by Geoterrex Limited, with Kenting Earth Sciences Limited as sub-contractor.

(ii) Data Management

The marine magnetic data that had been accumulated over two decades of field work was consolidated and organized during 1985. As a result of intense cooperative effort between components of the Earth Physics Branch and the Geological Survey of Canada, a joint data base management system was implemented in order to rationalize the storage and handling of all marine potential field data collected by the Federal Government off the east and west coasts. Prior to its entry in this data system, the entire AGC marine data set has been undergoing a major process of editing and adjustment.

A review of public reports held by the Canada Oil and Gas Lands Administration resulted in the creation and release (through GSC Open File) of a catalogue that describes commercial activity in the measurement of magnetic and gravity data in the East Coast Offshore prior to 1980. The catalogue has served to identify a number of projects in which commercial data might serve as a useful complement to similar data collected in the region during the course of Government surveys. The preparation of this catalogue was done by Earth and Ocean Research Limited, working under contract to the Geological Survey of Canada.

(iii) Data Interpretation

High resolution aeromagnetic data from the continental shelf and slope southwest of Nova Scotia were interpreted through the application of automatic processes such as Werner deconvolution, second vertical derivative analyses, and filtering. Supplementary control was derived from seismic reflection data. Results suggest the presence of two distinct magnetic horizons: a deep one associated with 'true' magnetic basement, and a shallow one which may correlate with volcanic activity.

(b) Earth Physics Branch, Ottawa (G.V. Haines, L.R. Newitt, R.L. Coles)

As part of a continuing study of geomagnetic secular variation, 14 repeat stations were occupied in Ontario, the Atlantic Provinces and the Northwest Territories. Six of these were done by contract. The routine occupation and observations are similar to those outlined in CGB, 1979. A compendium of repeat station observations, collected since 1962, has been published; it includes a description of the changes in repeat station instrumentation and methodology which have taken place over the years. Investigation is being undertaken on ways to further improve methods of data reduction.

The magnetic information retrieval program, which allows the determination of magnetic field values using the CGRF or IGRF is fully operational and available to anyone with access to the EMR computer. A report describing the service has been prepared.

The Canadian Geomagnetic Reference Field 1985 has been produced by the method of spherical cap harmonic analysis, from both EPB aeromagnetic and Magsat satellite data, updated on the basis of the Canadian spherical cap harmonic model of secular variation 1960-1983. The Magnetic Charts of Canada epoch 1985.0 were produced from this model.

(c) Geological Survey of Canada, Regional Geophysics Sub-division, Ottawa. (P.J. Hood)

Thirty-three aeromagnetic maps were published by the Geological Survey of Canada during 1985. Of these, seven were 1:50 000 coloured total field pixel maps, seven were 1:50 000 coloured vertical gradient pixel maps, 13 were 1:250 000 line contour maps and six were 1:1 000 000 coloured magnetic anomaly pixel maps in the National Earth Science Series.

Excellent progress was made in aeromagnetic surveys. Approximately 4560 line km were flown in northern Baffin Island to complete the 64 085 line km survey commenced by Geoterrex in 1984. The flying component of the 82 000 line km survey of the Beaufort Sea and northern Yukon awarded to Questor Surveys on February 12, 1985 has been completed. The PCSP Decca navigation system was used over the water as the prime navigation aid; visual flight path recovery was utilized over land. A survey of Newfoundland covering the Laurentian Channel was awarded to Kenting on July 12, 1985. The crash of Piper Navajo C-GNID survey aircraft on July 21 resulted in the loss of three lives. A replacement aircraft was on-site by August 26. The flying of this 85 853 line km survey was completed on September 27 using Loran C as the prime navigation aid. A survey between Queen Charlotte Islands and mainland B.C. was awarded to Sander Geophysics on June 11, 1985. The 35 730 line km survey was completed on September 28 using Loran C as the prime navigation aid. A 128 119 line km survey NE of Newfoundland covering the Orphan Knoll was awarded to the Geoterrex-Kenting consortium on July 4, 1985, and was completed in a 63 day period. This is a joint survey with five oil companies led by Chevron. This survey is noteworthy as being the first aeromagnetic survey in the world in which the satellite-based Global Positioning System has been utilized as a prime navigation aid.

Ten aeromagnetic gradiometer/VLF EM surveys amounting to almost 150 000 line km are being carried out under various Mineral Development Agreements in Newfoundland, Nova Scotia, New Brunswick, Quebec, Manitoba and Saskatchewan and in the Gaspé Peninsula, Quebec under the Gaspé-Lower St. Lawrence Federal Initiatives Program.

The aeromagnetic survey of Lake Erie, started in 1984, has been completed by the GSC Queenair survey aircraft, with an additional 10 842 line km. A 2273 line km survey of Lake Simcoe has also been completed and the survey of Georgian Bay commenced. In addition tie lines amounting to 6195 line km were flown in northern Ontario and Quebec to level the regional magnetic anomaly data at the 1:1M scale across Canada.

The tracing of the axial dyke system in the Nares Strait between Ellesmere Island and Greenland was continued in April 1985, using the NAE Convair aircraft and extended further south. Two tie lines were also flown between Newfoundland and the southern tip of Greenland to support the compilation of the Magnetic Anomaly Map of North America. Additional coverage was obtained across the southern part of the Greenland Ice Cap, funded by the Geological Survey of Greenland.

3. Magnetic Observatories and Instruments

Earth Physics Branch, Ottawa (R.L. Coles, J.K. Walker, G. Jansen van Beek, J. Hruska, G. Brown, H.-L. Lam, F. Plet, D.F. Trigg, F. Kollar, M. Gervais, G.R. Libbey)

(i) Magnetic Observatories

The Geomagnetic Observatory unit of the Division of Seismology and Geomagnetism continued its management of the Canadian Magnetic Observatory Network (CMON) consisting of the following ten digital magnetic observatories: Resolute Bay, Cambridge Bay, Baker Lake and Yellowknife in the Northwest Territories; Fort Churchill, Manitoba; Poste-de-la-Baleine, Quebec; Meanook, Alberta; St. John's, Newfoundland; Ottawa, Ontario; and Victoria, British Columbia. The observatories at Alert and Mould Bay, N.W.T. have had a version of the AMOS MKIII installed in February 1985 and July 1985 respectively. With the removal of the photographic analogue recorders at Alert and Mould Bay, the CMON is now completely digital. Glenlea, Manitoba was operated in cooperation with the University of Manitoba in Winnipeg. A full description of the present network is given in the "Annual Report for Magnetic Observatories - 1984" (in press).

Specific data sets for the EMSLAB project (June 1985 to October 1985) are in preparation. These data sets from Victoria, Meanook and Ottawa magnetic observatories will contain one-minute averages as well as selected ten-second data. To assist the Viking project incremental tape decks gathering five-second data have been installed in the Fort Churchill and Baker Lake magnetic observatories.

In order to evaluate the absolute stability of ring-core fluxgates, a vector proton precession magnetometer manufactured by Elsec (U.K.) has been acquired. Preliminary evaluation of the declination and inclination data from the vector ppm against conventional absolute magnetometers is in progress.

The final 1984 digital magnetic observatory data which includes one-minute values, hourly means and hourly ranges were deposited in the World Data Centre in Boulder, Colorado in June 1985. Copies of magnetograms and digital data are available at cost plus handling charge from: Geophysics Division, Geological Survey of Canada, Department of Energy, Mines and Resources, 1 Observatory Crescent, Ottawa, Ontario, K1A 0Y3. Telephone: (613) 995-5474. Details of other services are listed in the Catalogue of Services for the Geomagnetic Service of Canada. To provide timely data on the state of the AMOS network, a computer file containing summary information on the magnetic variations and the operation of the AMOS MKIII is updated each day.

(ii) Forecasts of Magnetic Activity

Two types of forecast of geomagnetic activity are issued regularly by the Earth Physics Branch. These forecasts include long-term - 27 day - mailed on request, and short-term - 72 hours on the telephone answering service - (613) 992-1299. They are based on data from the Canadian Magnetic Observatory Network, EMR and on the solar radio data from HIA, NRC and on other solar and interplanetary data from SESC, NOAA, USA.

A new experimental multi-zone, 27 day forecast of geomagnetic activity gives a daily estimate of a range parameter for each major zone (i.e. polar cap, auroral and subauroral) over Canada. The parameter forecast is the daily mean of the twenty-four hourly ranges in the X-component of the magnetic field. An evaluation of this 27 day three zone forecast during the experimental stage revealed the validity of this concept as well as directions for improvement. The overall accuracy for approximately a one year period exceeded 70% in all three zones. This new, multi-zone forecast will be available on request in 1986.

Present geomagnetic prediction schemes are largely qualitative and empirical. It is therefore essential to develop computer algorithms based on numerical techniques so that the subjectivity of particular forecasters can be reduced. To this end, a prediction filter based on Wiener linear prediction theory has been developed for medium term (27 days) forecasts of geomagnetic activity in Canada. The filter has been tested using magnetic data from Canadian observatories from the three zones of distinct magnetic characteristics and the

results are encouraging. It will be implemented for routine three zone geomagnetic forecasts by computer in the near future.

(iii) Magnetic K Indices

A numerical data-adaptive separation method was developed for the discrimination of quasi-regular magnetic variations from the irregular variations for the determination of the K indices. This method is based on a pattern comparison and discrimination technique using harmonic analyses. The wave characteristics of a quiet regular or reference day are compared with those of the disturbed day. The harmonic components that are consistent with those of the regular variation are determined by a cosine function. The Fourier coefficients are calculated from these modified "wavelets" and then they are transformed back to the time domain. This "regular variation" is then subtracted from the data before the ranges are determined for the semilogarithmic K values. This numerical method was tested on the Canadian magnetic observatories Victoria, Meanook and Ottawa over a 4-month period. These K's were compared with handscaled values, which were carefully determined and independently checked from reconstructed magnetograms from the same data. The two methods were found to agree 97% of the time with most errors occurring during very irregular periods. This is comparable with values carefully determined by highly skilled observers.

4. Electromagnetic Induction in the Earth

(a) Earth Physics Branch, Ottawa (R.D. Kurtz, A.G. Jones, E.R. Niblett, J.C. Gupta, C. Michaud, J.A. Ostrowski, L.K. Law, J.M. DeLaurier, D.R. Auld, D.C. Nobes)

Magnetotelluric data are routinely recorded at two stations (reduced to one in November 1985) in the seismically active area near La Malbaie, Quebec. A correlation still exists between the time variation of electrical impedance and the seismic P-wave travel-time residuals at the southwest station (near Baie-St-Paul). No outstanding changes have occurred since 1979. A tensor magnetotelluric and scalar audiomagnetotelluric survey was conducted by the Mineral Exploration Research Institute, Montreal (M. Chouteau) under contract to the Department of Energy, Mines and Resources. Preliminary results indicate that conductive zones may be associated with faults, confirm the presence of a conductive channel beneath the Malbaie Valley and suggest a very conductive layer exists in the mid crust. Detailed interpretation is in progress at École Polytechnique.

A two-dimensional electrical conductivity model has been constructed to simulate the subduction of the Juan de Fuca plate beneath Vancouver Island, the Strait of Georgia and Coast Ranges of British Columbia. The model accurately predicted most of the magnetotelluric responses that were obtained over Vancouver Island in 1984. A good conductor was located beneath western Vancouver Island, at depths that increased from southwest to northeast, and is associated with either the top of the downgoing plate or represents the thin lubricating zone at the convergent boundary between the American and the Juan de Fuca plates. The conductivity of this zone suggests that the materials are porous (between 1% - 4%) and saturated with saline or super-saline fluids. The expected temperatures at the depths (23 km - 28 km) for this conductor suggest that metamorphic reactions equivalent to the glaucophane schist stability field are occurring and that dehydration contributes fluid and enhances the porosity of this conducting region. Such saturated materials in a thin zone may reduce friction so that aseismic creep could occur. It could also explain the variation in acoustic impedance that is observed across this same region. The magnetotelluric experiment across Vancouver Island has provided important physical properties of the materials near the convergent boundary between the American and Juan de Fuca plates.

Interpretation has been completed of magnetotelluric data acquired on the sea ice over the Alpha Ridge during Operation CESAR in 1983. Inversions of E-polarization data indicate a resistive lithosphere about 85 km thick with a conductive (10 ohm.m) region beneath. Two-dimensional forward modelling shows that the anisotropic character of the impedance measurements can be attributed entirely to the bathymetry of the Alpha Ridge.

As part of the largest-ever collaborative induction experiment, ten long-period magnetotelluric systems were operated in Oregon, USA during EMSLAB (see University of Alberta contribution by Gough and co-workers). An international group, comprised of the Scripps Institute of Oceanography, the U.S. Geological Survey, the University of Tokyo, Flinders

University of Australia and the Pacific Geoscience Centre, amassed for EMSLAB the largest-ever array of seafloor instruments. Located between 44° and 47° N the twenty sites span from the Pacific Plate side of the Juan de Fuca Ridge, across the Cascadia Basin to the continental shelf area of Oregon. Nine sites are along a central profile which meets the coast near 45° N. Three component magnetometers were deployed at every site. In addition eleven of the sites had horizontal electric field sensors, three had vertical electric field sensors and six had pressure sensors. After 70 or more days on the seafloor thirty-nine of the forty instruments were recovered. A remarkable achievement! The data are of excellent quality and are currently being analyzed.

Results from controlled-source electrical soundings and heat flow measurements obtained near the Juan de Fuca Ridge in 1984 show that this combined analysis tightly constrains most of the physical properties of the sediments.

The monitoring of changes in apparent resistivity, related to the increase in tectonic strain in central Vancouver Island, continued at two established sites in the area. Site testing was completed for a third station in the region to be located directly on the Beaufort Range fault. Results from a site located on a fault zone in Japan showed a marked decrease in electrical potential preceding a magnitude 4.9 earthquake.

A preliminary map was compiled in digital format showing the major terrane boundaries for the Juan de Fuca map area. An overlay of the terrane maps allows correlations to be made with other compilations of geophysical data in the Juan de Fuca map series, namely: magnetic anomalies, seismicity, heat flux, and gravity anomalies.

Measurements of magnetic field variations and natural earth currents, made by the German IPY I party at Kingua Fiord on Baffin Island, have been analyzed (with G.D. Garland, Geophysical Laboratory, Dept. of Physics, University of Toronto) to obtain information on the electrical conductivity structure in the region. It is shown first, that these observations from 1882 form a remarkably consistent set, and secondly, that the station displays the characteristics of a "normal continental station" located on crystalline rock. A similar treatment of magnetic measurements made at Fort Rae by the British IPY I party yielded inconclusive results, probably because of the station's proximity to the auroral zone.

(b) University of Alberta

(i) Electromagnetic Studies (D.I. Gough, D. McA. McKirdy, Chen Guangming, Wang Xishuo, K. Wilson, M. Connors, P.W. Brundin, S. Kapotas; V.R.S. Hutton, G.J.K. Dawes, J. Travassos, University of Edinburgh, Scotland; M.R. Ingham, Victoria University of Wellington, New Zealand; D.K. Bingham, Department of the Environment, Government of Alberta; W.D. Parkinson, Department of Geology, University of Tasmania, Hobart, Australia.)

The general objective is a major study of conductive structures in western Canada, and of their tectonic and geothermal implications. A large array of magnetometers was operated in 1980. Structures detected and approximately located in that study were mapped with high precision by the concentration of our magnetometers in smaller arrays of greater resolution, in 1981 and 1983. In 1982 a program of magnetotelluric soundings was begun with the help of V.R.S. Hutton and G.J.K. Dawes with their (then) new SPAM Mark I system. We have now acquired a SPAM Mark II system from the University of Edinburgh, and long period equipment is being assembled. Magnetotelluric (MT) soundings will dominate our program in the next few years. The strategy is to use broadband tensor MT to measure the depths of the numerous conductive structures already mapped by the magnetovariation arrays. In 1984-85 D.I. Gough took advantage of study leave to spend time with V. Hutton, G. Dawes and M. Ingham to complete the interpretation of data from 1981 and later years. Results are noted below and will be published within the next year.

The 1981A Magnetovariation Array. A paper (Bingham et al., 1985) has been published which showed the presence of even higher conductance in the crust beneath the Main Ranges of the Rocky Mountains, than under the region to the southwest. Gough (1986) has proposed the name Canadian Cordilleran Regional (CCR) conductor for the latter, which has been known for many years from the work of Caner and Dragert.

Models of Conductive Structure under the Canadian Cordillera. Two-dimensional models have been calculated by the finite difference method, of the Canadian Cordilleran Regional (CCR) conductor and its extensions beneath the Rocky Mountains and Rocky Mountain Trench. The observational data are the real parts of single-station transfer functions, from the horizontal component across the regional strike to the vertical component, of magnetovariation fields at periods of 600s and 1500s at stations of the 1980A and 1981A arrays chosen to give a profile which avoids large three-dimensional anomalies. We have shown that the imaginary parts of the transfer functions refer to currents induced in other conductors, in particular the deep sedimentary basin east of the Rockies in Alberta. They are thus irrelevant to the CCR conductor.

Very large real transfer functions at stations in the Main Ranges of the Rockies, together with very small values in the Trench, require a highly conductive ridge under the Main Ranges and Trench rising to depths of a few kilometres, in all models which fit the data. Model calculations assuming induction alone, in two-dimensional structures, require a thick, highly conductive layer rising to depths of a few kilometres, under the Intermontane and western Omineca Belts as well as beneath the Rockies. The addition to the induced current of a small amount of channelled current produces a good fit at all stations and at both periods, and allows the CCR conductive layer to be placed in the lower crustal/upper mantle depth range indicated by prior measurements by others. Beneath the Rocky Mountains the conductor has to rise into the upper crust, whether channelled current is assumed or not. The nature and tectonic significance of the Northern Rockies conductor are discussed after presentation of the magnetotelluric results which follow. A paper describing this work by Ingham, Gough and Parkinson has been submitted for publication.

Magnetotelluric Soundings in the Canadian Rocky Mountains. Magnetotelluric soundings were made in 1982 at 25 stations in the Rocky Mountain Trench (RMT) and Main Ranges near 53° N, close to the centre of a major conductivity anomaly which had been mapped with the 1981A magnetovariation array. Most stations covered the frequency range 0.01 to 500 Hz and three stations 0.0002 to 500 HZ. The resistivity tensor shows low to moderate anisotropy in the RMT, but is strongly two- or three-dimensional in the Rocky Mountains. In preparation for two-dimensional modelling, one-dimensional inversions have been used to construct resistivity-depth sections satisfying both magnitudes and phases of the MT responses. Very low resistivities, in the range 1 to 10 ohm.m, are found in the upper crust under the RMT and even lower values under the Main Ranges. The latter values completely confirm the Northern Rockies conductor reported from the 1981A array study and are in agreement with the models of the conductors fitted to long-period magnetovariation fields (see above). The MT results here reported add essential depth and resistivity information. The conductors beneath the Rocky Mountains Main Ranges and Trench constitute a thickening at the edge of the Canadian Cordilleran Regional (CCR) conductor. The tectonic significance of the CCR has been discussed by Gough (1986). At the upper crustal depths penetrated in this magnetotelluric study, it is considered much more probable that the high conductivity is caused by hot, saline water of mantle origin than by silicate melt. The CCR in general may have two layers of fluid producing its high conductivity, silicate melt below and saline hot water above. A paper with the above title, by Hutton, Gough, Dawes and Travassos, has been submitted for publication.

Although it was not possible to undertake any magnetotelluric fieldwork this year, some important improvements have been made to the equipment. The purchase of three new magnetic sensors means that it is now possible to measure the three components of the magnetic field, therefore the traditional MT analysis can be complemented by the estimation of transfer functions. M. Connors has succeeded in interfacing the digital computer of the MT system to an IBM-PC microcomputer so that the field data can be transferred from cartridges to diskettes, which will facilitate further analysis of the data.

Magnetometer Arrays in Southern Alberta and British Columbia. Two magnetovariation arrays, 1981B and 1983, have been operated in this region to study an elongated anomaly mapped by means of the 1980A array, which strikes NE-SW across the width of Alberta and across the trend of the Rocky Mountains to the United States border near 49° N, 117° W. The 1983 array was designed in addition to detect any continuation of the conductor beneath the Northern Rockies, along the Main Ranges southeast of 51° N latitude.

Results from these two arrays are still unpublished, mainly because other studies (notably EMSLAB) have pre-empted completion of the interpretation. M.R. Ingham and D.I. Gough took up the data from the 1981B array in Wellington during May, and have a paper in preparation. It appears likely that there are two conductive structures at different depths, which coincide on the map from the U.S. border to the latitude of Calgary but then diverge, with that at smaller depth following the lower crustal rift reported by Kanasewich, Clowes and others. Further analysis is needed.

The 1983 array shows no evidence of a conductor under the Rocky Mountains south of 51° N, but improves the definition of the edge of the Canadian Cordilleran Regional conductor along the Kootenay Arc, and of the SABC conductor. Chen Guanming is studying the region by means of well-determined transfer functions and hypothetical event analysis.

The EMSLAB Experiment. EMSLAB is the largest electromagnetic induction study of the planet ever undertaken. The general objective is to study the lithosphere, the asthenosphere and related structures in terms of electrical conductivity, over the complete Juan de Fuca plate from the Ridge through the subduction along the Oregon-Washington-British Columbia coast, and across the Cascade back-arc volcanoes. The magnetovariation fields were recorded through August and September into October 1985. An array of 63 Gough-Reitzel magnetometers on land recorded simultaneously with 37 seafloor stations, some magnetometers and some electric field recorders. Long-period magnetotelluric soundings were made along a profile running WNW-ESE near the central latitude of the magnetovariation array.

Suitable storms and substorms occurred (which might not have happened), and present indications are that most of the stations recorded for most of the time. Much of the next year will be required for the massive task of data processing prior to full interpretation. Thus far the experiment appears to have been successful. Responsibility for the land array was shared between D.V. Woods' group (Queen's University) and ourselves, with D. McKirdy and Wang Xishno carrying the main burden of the field work. They successfully survived a fire which destroyed their University vehicle towards the end of the operation. The EMSLAB data likewise survived, D. McKirdy saving the logbook and as a result losing all of his luggage. K. Wilson and P.W. Brundin have already digitized the first event selected for analysis.

Electromagnetic Induction Modelling and Inversion Studies. D. McKirdy has made the diakoptic version of Brewitt-Taylor's finite difference program more suitable for the study of models of geophysical interest, which should assist in the interpretation of both magnetotelluric and magnetometer array data. Progress has also been made in the field of two-dimensional integral equation modelling which will also be applicable to three-dimensional techniques. It is now possible to study the anomalies induced by finite sources situated at the surface of a thin sheet conductor, which should be of interest to the prospecting community, while the extension of thin sheet modelling has led to an approximate method for examining the effects of surface and near-surface anomalies whose thicknesses may be as large as one half skin depth.

Wang Xishuo has developed a unified potential in the wave number domain, for use in separating the fields of internal and external currents and adjusting the fields to be curl-free. Trial applications of the method to both synthetic and field data are promising.

(ii) Numerical Modelling Studies (F.W. Jones)

The perturbation of uniform and non-uniform electromagnetic fields by two-dimensional and three-dimensional electrical conductivity anomalies is being investigated by a numerical method. A series of three-dimensional models of isolated inhomogeneities and of intrusions is being studied. Perturbation and induction arrows associated with these models are being calculated and compared for a series of different periods. The larger three-dimensional (37x37x37=10 653 points) program adapted for the FPS164 array processor is being used for this work.

(c) Queen's University (D.V. Woods, M.Allard, H. Geiger)

(i) Kapuskasing Magnetometer Array Study (D.V. Woods, M. Allard)

A reconnaissance scale electromagnetic induction investigation of the Kapuskasing Structural Zone (KSZ) was carried out during the summer of 1984 using an array of 30 Gough-Reitzel magnetic variometers. The experiment was part of the Phase I LITHOPROBE study of the KSZ and was intended to investigate for any possible electrical conductivity expression of this zone of high-grade metamorphic rocks of lower crustal origin. Analysis of the data indicates that, although there is no overall response from the KSZ, anomalies are observed in the vicinity of major faults and at stations within a few kilometres of the buried Trans-Canada gas pipeline. The absence of a measurable response from the KSZ implies that the high conductivity of the lower crust in this region of the Canadian Shield, known from previous MT, GDS and CSEM soundings, is related to intrinsic conditions at lower crustal depths and not to the mineralogical composition of lower crustal rocks.

(ii) The EMSLAB Experiment (D.V. Woods, H. Geiger)

The Queen's University contribution to this large international collaborative project (discussed in detail elsewhere) was to deploy our set of 30 Gough-Reitzel magnetic variometers over the southern portion of the land array, covering Oregon and parts of northern California, northern Nevada and western Idaho. Field work was carried out in coordination with the University of Alberta (D.I. Gough, D. McKirdy) from June to October 1985. Data recovery was very high with only one instrument malfunction during the first half of the recording period and two instruments out during the latter half. An additional contribution to the EMSLAB project is the development of an automated, microcomputer-based system to digitize the Gough-Reitzel film records. The digitizing system is being established at the University of Washington, the principal institution of the EMSLAB experiment.

(d) University of Toronto (D.W. Strangway, J.D. Redman, S.K. Zhao)

The scalar AMT method has been applied to mapping the location and structure of the Destor-Porcupine fault zone near Timmins, Ontario. Thick conductive clays cover the regions surveyed. Several profiles over the fault zone have been fitted with two-dimensional resistivity structures using a forward modelling process. A conductive and highly anisotropic region in the basement, 300 m in width, is interpreted to be the fault zone. Tensor AMT stations indicate that, within the metasediments, the strike of the most conductive axis is east-west. This is interpreted as the principal direction of faulting or as an intrinsic anisotropy that has been observed previously for metasediments in this region.

Development of a tensor AMT system has been completed and several stations near Timmins have been measured. The six channel truck-mounted system covers the frequency range 5 Hz to 10 kHz. The system is battery operated and uses a low power IBM-PC compatible computer. Further development of hardware and software for this system is anticipated during the coming year.

(e) University of Victoria (J.T. Weaver, H. Poll, H.W. Dosso, W. Nienaber, W.B. Hu, Z.W. Meng)

(i) Theoretical Studies (J.T. Weaver, H. Poll)

In collaboration with colleagues B.V. LeQuang and G. Fischer (Neuchâtal, Switzerland) a 2-dimensional 'control' model comprising three segments of different conductivity over a perfect conductor has been proposed as a check on the various numerical modelling programs that have been developed for calculating the electromagnetic response of a conducting earth to a uniform source field. The control model has been solved analytically for both E- and B-polarizations of the field and tables of numerical results have been published for a particular set of model parameters. Comparisons have been made with the results given by the finite difference program developed in Victoria and by another finite element program. Work is now in progress on developing a new 3-dimensional finite difference program for modelling problems in electromagnetic induction.

(ii) Analogue Modelling (H.W. Dosso, W. Nienaber, W.B. Hu, Z.W. Meng)

An analogue model study of the coast effect for an elliptical island near semicircular bays and cape continental coastlines was studied in order to examine the importance of current channelling. Irregularities in a coastline in the form of bays and capes lead to significant spatial field variations in coastal regions due to variations in density of induced current flowing in the ocean caused by current deflection or channelling by the coastal irregularities. The addition of a nearby island, which for the appropriate field polarization can result in current channelling through the strait, greatly influences these field spatial variations.

Measurements for an analogue model of the Tasmania region were used to aid in the interpretation of magnetic field measurements in Tasmania. This work continues in collaboration with W.D. Parkinson, University of Tasmania.

An analogue model of the west coast region, including a simulation of the subducting Juan de Fuca Plate, was constructed and is now being used to study induced magnetic field for the regions of interest to the LITHOPROBE and EMSLAB projects. Measurements for the model ocean, with and without the subducting plate structure, are being studied to attempt to delineate the effects of the dipping tectonic structure. Model measurements will be compared with field measurements for the region.

5. Paleomagnetism and Rock Magnetism

(a) Earth Physics Branch, Ottawa (J. Roy, J. Park, P. Lapointe, E. Tanczyk, L. Latham, K. Harding)

(i) Precambrian Program

Present work is focused on the Cordillera of the Yukon and Northwest Territories, and relates to several problems concerning the apparent polar wander path derived from detailed studies of the Mackenzie Mountains supergroup (MMs). One problem, involving the nature of the hiatus between the MMs and the overlying rift-related Coates Lake Group, may be solved by current studies on the Rusty Shale Formation near the top of the MMS, on the Redstone River Formation of the Coates Lake Group, and on the Harper Volcanics of the Yukon. The Harper Volcanics collected in the summer of 1985 are probably related to the Little Dal lavas at the top of the MMs. They are also being analyzed to shed light on the seemingly aberrant pole from the lavas. A third problem is the possibility of rotations between thrust sheets. To test for this possibility in relevant regions, a suite of samples from diabase dykes and sills located above the arc of the mountain belt from the Yukon to British Columbia is currently being thermally demagnetized. The samples were originally collected by D. Norris and A. Larochelle of the GSC in 1968(?), but were unsuccessfully analyzed at that time using alternating field treatment.

(ii) Appalachian Program

Studies in Nova Scotia are aimed at unravelling the tectonic history of the Meguma Block in the context of the Appalachian Orogen. Paleomagnetic results from the Mavilette Intrusion, a Middle Paleozoic continental tholeiite, are largely consistent with the pervasive Permo-Carboniferous overprint of the area, but other remanences can also be distinguished. A preliminary $^{40}Ar/^{39}Ar$ age determination (C. Hall, University of Toronto) indicates more than one setting event, which may explain the origin of multiple remanences.

A feasibility study of the greisenized granite at the East Kemptville mine site showed that sufficiently stable remanences are present both in the host rock and the greisen veins. An extensive field survey was carried out this summer for investigating the use of paleomagnetic techniques to study the greisenization process.

On the Îles de la Madeleine, a study of the Cap aux Meules Permian redbeds has isolated a Lower Permian pole in agreement with the latest North American results of this age. The hematization process of these redbeds is currently under investigation.

A sampling program in the Hermitage Bay area of Newfoundland is aimed at studying the magnitude and timing of movement along the Hermitage Bay fault. Devonian and Carboniferous granites in the area were sampled.

A catalogue of paleomagnetic results from the Appalachian Orogen, with accompanying notes and locality map is to be published in the form of an internal report.

(iii) St. Lawrence Platform Program

Since it has now been accepted that our results from the Carboniferous Basin are representative of the reference path for cratonic North America, efforts are being intensified to obtain results from pre-Carboniferous units from the St. Lawrence Platform. The goal of the program is to define the Lower Paleozoic reference path from the stable part of the craton. This is necessary if we are to interpret properly the results from the Appalachian foldbelt.

A study of the Cambrian layered mafic intrusion at Sept-Îles has yielded a well-dated Middle Cambrian pole. The development of this intrusion encompassed a lengthy time period, and distinct later remanences may also be present. A complexity of the apparent polar wander path for North America is suggested for the Lower Paleozoic.

(iv) Secular Variation Studies Program

A program to study remanence in stalagmites has been introduced with the aim of producing secular variation records for western Canada and the U.S. This extends work begun at McMaster University and the University of Toronto. It is hoped to produce dated secular variation type curves which will increase understanding of how the Earth's magnetic field is generated. A peculiarity of the western Canadian paleofield between 31 and 15 Ka was a signal characterized by shallow inclinations and easterly declinations repeated in four 1000 year long pulses between 31 and 15 Ka. They are believed to be due to a pulsating core-source to the west of N. America.

(v) Nuclear Fuel Waste Management Program

The Paleomagnetic section of the Earth Physics Branch is responsible for the Rock Magnetic Property Task within the Nuclear Fuel Waste Management Program. The ground magnetic properties of the East Bull Lake gabbro on surface and at depth illustrate the value of rock magnetic properties in mapping lithological changes and the extent of fracture/alteration zones on the surface and at depth. Recent statistical tests have established a strong correlation between fracture density and the alteration so produced, as determined from the susceptibility logs.

(vi) Technical and Analytical Program

Comparison and results obtained from a variety of natural rock samples using both continuous and alternating field (c.f. and a.f.) techniques demonstrates the complementary nature and potential of the two methods. It also indicates that a clear distinction must be made between remanence coercivity (rc) as defined by the c.f. results and the remanence a.f. stability (rafs) as defined by the a.f. results. A new parameter (R_e) is used to establish a relationship between the rc and rafs spectra. R_e provides one with means of using either c.f. or a.f. experiments or alternating between them. The combination can be used: (i) to extend the range of the coercivity spectrum that can be investigated, and (ii) to analyze in great detail any part of the rc spectrum.

A susceptibility meter has now been coupled to a continuous rock core feeder programmable by a microcomputer. Bulk magnetic susceptibility on bore cores can be measured quickly and routinely, and this instrument is being put to use in the Canadian Nuclear Fuel Waste Management Program, on New Brunswick and Nova Scotia granite cores, ODP, and elsewhere. A similar instrument for cores is being developed to continuously measure remanence, using a ring core fluxgate sensor. It is expected that the combined results of these two instruments will lead to almost unique interpretation of rock alteration and lithology via their magnetic properties.

(b) Pacific Geoscience Centre, Sidney, British Columbia (E. Irving, P.J. Wynne, B. Globerman)

Laboratory analysis of Cretaceous basalts from Axel Heiberg and Ellesmere islands has been completed. These rocks show the same magnitude of rotations first observed in Permian volcanics from the same area. One of the first of the M series of reversals at the base of the Cretaceous long normal has been identified as well. This work was carried out with the assistance of geologists from the ISPG in Calgary. Work has been carried out on Quaternary soft sediments, Tertiary volcanics and gneisses, Cretaceous intrusions and volcanics. This work has been done in collaboration with geologists from the GSC at PGC, in Vancouver and in Ottawa, Carleton University, the University of Minnesota and Queen's University. Results from some of the Tertiary collections show rotations; none show any displacement relative to the craton. Results from the Cretaceous studies show displacements from the south of up to 2000 km.

(c) University of Alberta (M.E. Evans)

(i) Archeomagnetism (M.E. Evans, M. Mareschal, W.I. Gough, V. Froch)

Steady progress has been made on the large archeological collection from Italy, Greece and north Africa. Most sites are yielding well-grouped magnetic vectors and a coherent picture is gradually emerging. For example, data from six kilns in a restricted area of southern Italy fall on a smooth curve similar to the historic secular variation observed in western Europe. Furthermore an undated kiln from the same area falls on this curve and can therefore be dated magnetically.

In an attempt to extend the type of heated feature exploitable for archeomagnetic investigation, oriented samples were also collected from two funeral cremation pyres. In both cases the remanent magnetizations of the bedrock samples are very weak and it is not clear whether the heat was superficial or whether the rock magnetic properties are unfavorable. Directions are scattered and partial demagnetization is ineffective.

At the suggestion of Monsieur Jean-Yves Empereur (École Française, Athens) a collection of small cores from Greek amphorae was made to assess the possibility of helping define the provenance, and hence add to the general understanding of patterns of trade in antiquity. This material consists of small fragments which include all, or part of, one of the handles and can therefore be roughly oriented relative to the vertical. It was therefore thought possible that latitude information might be recoverable, but the results are scattered and at face value imply that the potters of the day did not stack the fruits of their labour in a precise manner during firing. Nevertheless it is interesting to note that the majority (39 out of 45) of these amphorae were fired upside down - indeed there is a definite peak in "apparent inclination" between -40° and -50° which is consistent with the ambient field directions although defined with insufficient precision to provide useful latitude control.

Shaw-Kono paleointensity work on several ancient kilns (and a modern one) in southern Italy has been completed and a paper submitted for publication. The modern kiln yields a field strength (F) of 45.7±0.7 μT compared to the known value of 44.7 μT, whilst a third century B.C. kiln yields 79.7±1.3 μT. These results employ Kono's scheme of allowing for mineralogical change during laboratory heating (by comparing AF spectra of ARM's). The evidence germane to this proposal has been re-assessed and it now appears that the so-called Kono factor is valid, but new data on the actual magnitude of changes it can effectively monitor is urgently needed.

(ii) Permian Paleomagnetism (M.E. Evans, V. French; J.-M. Maillol, Université des Sciences et Techniques du Languedoc, Montpellier, France)

There is a growing need for long sequences of stratigraphically ordered paleomagnetic data in order to describe the temporal behaviour of the geomagnetic field. An attempt has therefore been made to exploit vertical, but azimuthally unoriented, drill-cores from a mining environment. The world's core stores represent an enormous potential source of relevant data and it was therefore felt worthwhile to undertake a pilot study to assess the feasibility. Samples spanning 66 m of Permian redbeds were drilled from a core recovered as part of a uranium exploration program in southern France. Inclinations are well-grouped

($\bar{I}$ = -6.5°, k = 121.5) and consistent with the known paleolatitude of stable Europe. Declinations were estimated by equating the local bedding to the orientation of best-fit sinusoids to bedding traces on the surface of the core. The results are very encouraging. If the declinations are analysed in terms of a circular normal (von Mises) distribution, a mean of D = 197.2° (standard deviation 28.4°) is obtained; the mean is in good agreement with other studies (including 15 fully-oriented surface samples collected near the drill hole; $\bar{D}$ = 202.7°), and the scatter is reasonable for the sedimentological environment involved. The corresponding pole lies at 151° E, 53° N, and is in good agreement with other Permian Eurasian poles. Temporal variations are apparent, and can be interpreted as the elusive dipole-wobble (on a time scale of 10^5 years or more), on which is superimposed a more rapid non-dipole secular variation.

An article summarizing this work has been completed and submitted for publication, but the general topic is being pursued further in view of the promise of this material to provide constraints on the secular variation in the geological past and to yield data relevant to the detailed evolution of Pangaea. To this end several continuous segments of core (comprised of articulating pieces) have been selected for detailed temporal studies, and a new collection of surface samples has been made.

(iii) Quaternary Magnetostratigraphy (M.E. Evans, M. Hedlin, C. Hedlin, W.I. Gough, V. Frnoch)

With the active collaboration of J. Matthews (Geological Survey of Canada), J. Westgate (University of Toronto), O. Hughes (Geological Survey of Canada, Calgary), and C. Schweger (Department of Anthropology, University of Alberta) a series of lacustrine sediment sequences were sampled for paleomagnetic work. A total of 760 2-cm cubes were recovered from four sections in the banks of the Old Crow River between latitudes 67° and 68° in the Yukon Territory. Between them these sections span the six metres immediately beneath the Old Crow Tephra which provides an easily-recognizable reference horizon. This tephra is thought to be about 95 000 years old and one objective is to seek further evidence for the so-called Blake Event which is emerging as a possible candidate for a genuine reversal within the Bruhnes Epoch. A second goal is to provide much-needed high-latitude data for secular variation studies. Laboratory measurements on this large collection are about two-thirds complete and it appears that the material does indeed constitute a reliable magnetic recorder. Smooth declination and inclination magnetograms are obtained and a certain amount of optimism that meaningful secular variation data will be forthcoming is justified.

There is some indication that the Blake Event has been recorded in the sections. At -188 cm in section A there is a dramatic declination swing which may be due to these sediments having been deposited at a time of reversed polarity. A similar declination swing is recorded in one of the three other sections that penetrate this depth.

The fact that these anomalous declinations only occur in thin bands and in only two of four sections has caused us to be cautious in saying that this represents the Blake Event. Further work, involving the partial demagnetization of these samples, has been started but has not yet enabled us to conclusively say whether or not this is the Blake.

(iv) Crowsnest Volcanics (W.I. Gough, M.E. Evans, E. Irving, P.J. Wynne)

A paper entitled "Anomalous Paleomagnetism of the Crowsnest Formation of the Rocky Mountains" has been submitted for publication to the Canadian Journal of Earth Sciences. The authors are E. Irving and P.J. Wynne (Pacific Geoscience Centre, Sidney, British Columbia), M.E. Evans and W.I. Gough.

A small collection of samples made in 1968 gave a magnetization with inclination lower than expected for the mid-Cretaceous. In order to check this anomalous result, further collections were made in 1981 and 1982 with extended stratigraphic coverage.

It was not possible to discriminate between four interpretations: (a) the Crowsnest Formation, and the thrust-sheet in which it occurs, have been transported from the south relative to cratonic North America by 17±6° (about 1800 km) and rotated 24±10° clockwise; (b) the flattening of inclination is caused by magnetic anisotropy, but tests show this to be unlikely; (c) the magnetization is secondary and of latest Cretaceous age (there

are good reasons for believing this is not so); (d) the preferred interpretation of the flattened inclination is that it is possible that the unit could have been formed close to its present position relative to the craton, but was deposited so quickly that the paleosecular variation was not adequately sampled, and the result is only a "spot" reading of the paleofield. The clockwise deflection of the declination could reflect rotation.

(d) Université Laval (M.K. Séguin)

(i) Ecuador and Coastal Peru

Paleomagnetism investigation aimed at a better understanding of the formation of the Andean mountain chain. In sedimentary, volcanic and granitic rocks of Cretaceous and Tertiary age in Peru and in different metamorphic and unmetamorphosed terranes ranging from Precambrian to Eocene from the Sierra, Oriente and Costa regions of Ecuador. Collaborators are T. Feininger and E.I. Tanczyk, EPB, Ottawa.

(ii) Baltic Shield (Norway, Sweden and Baltic Islands)

Paleomagnetic study of tillites of Vendian age and most of the Cambrian, Ordovician and Silurian sequences of the Baltic platform sedimentary units. Collaborators are P. Nystueen (Norway) and G. Bylund (Sweden).

(iii) Newfoundland - Avalon Zone

Paleomagnetic studies include: (a) Late Precambrian Finn Hill Sequence (Ignimbrites); (b) Late Precambrian porphyritic intrusions and rhyolite sills (collaborator, J. Lortie); (c) Harbour Main and Colliers Bay mafic volcanics (Late Precambrian) (collaborator, M. Giasson); (d) Cape St. Francis and Bauline rhyolite flows and tuffs (Late Precambrian) (collaborator, J. Jessop); (e) Cambrian Brigus Shale Formation (collaborator, K.V. Rao).

(iv) Quebec

Investigations include: (a) paleomagnetism of Archean rock units (lavas, gabbros, ultramafics, granodiorites, tonalites, granites and tuffs) from the Troilus-Frotet greenstone belt (collaborators, A. Simard, E. Gah and D.T.A. Symons); (b) detailed magnetostratigraphic investigation of Ordovician and Silurian formations on Anticosti and Mingan Islands (collaborator, A.A. Petryk); (c) detailed paleomagnetic study of Ordovician rock units from the St. Lawrence Lowlands - Chazy, Black River, Beekmantown and Utica formations; (d) structural paleomagnetic study of the Ordovician Mictaw Group, southern Gaspé Peninsula (collaborators, G.D. Brouker, E. Gah); (e) paleomagnetic investigation of Devonian sedimentary units of eastern Gaspé Peninsula; (f) detailed paleomagnetic study of Carboniferous-Devonian diabase dykes from the Gaspé Peninsula; (g) paleomagnetic sampling of Silurian dioritic and syenitic intrusives and country rocks from the St. Lawrence Lowlands (collaborators, S. Kumarapeli and R. Boiselle).

(v) New Brunswick

Paleomagnetic study of Lower Carboniferous lavas and redbeds from northern and central New Brunswick (collaborator, L. Fyffe).

(vi) Nova Scotia

Many paleomagnetic studies were undertaken in collaboration with Memorial University of Newfoundland, St. John's. The following is an incomplete summary: (a) Cambrian Morrison River Formation (redbeds) (collaborators, E.R. Deutsch and K.V. Rao); (b) Silurian Dunn Formation; (c) Devonian Fisset Brook Formation (collaborators, M.A. Audet and E.R. Deutsch); (d) Late Precambrian Fourchu Formation (collaborators, E.R. Deutsch and D. Vermette); (e) Cambrian Antigonish alaskite and Eden pluton (collaborators, K.V. Rao and E.R. Deutsch; (f) Cambrian Bourinot Formation (collaborator, S. Barr); (g) Ordovician Torbrook Formation (collaborators, E.R. Deutsch and K.V. Rao).

(vii) Vendée of France (Armorican Plate)

Work is continuing.

(e) McMaster University (C.J. Hale)

This year has seen the establishment of a new rock and paleomagnetism laboratory at McMaster University. The instrumentation includes a computerized Schonstedt SSM-2 spinner magnetometer and GSD-1 demagnetizer as well as air and vacuum furnaces for thermal demagnetization.

The modification of primary NRM during burial metamorphism is the subject of an honours B.Sc. thesis by M. Miller. Burial conditions have been modelled by heating synthetic magnetite (dispersed in kaolin) samples at 400°C for times ranging from a few hours to 32 days. The experiment involves about 200 specimens, permitting a wide range of initial conditions. While some samples are initially demagnetized, others contain TRM, either parallel or perpendicular to the ambient field during the storage. Most samples have been heated in air but a few have been sealed in vacuum capsules so that we can separate the roles of CRM and VRM in the process of secondary remanence acquisition.

Preliminary results indicate that VRM acquired by initially demagnetized samples is stable at temperatures approaching the magnetite Curie temperature. Samples containing primary TRM's were found to demagnetize during in-air storage but no directional change occurred, even though the primary TRM in some samples was initially perpendicular to the 0.6 Oe ambient field.

The laboratory study is supported by a field study of contact reheating. Samples have been collected from the Gunflint Formation which is cut by a Keweenawan diabase sill, near Thunder Bay, Ontario. We are attempting to determine paleotemperatures from the contact to test the hypothesis that mineralization of some Gunflint cherts is related to the Keweenawan heating episode.

Current paleomagnetic projects at McMaster include documentation of an apparent increase in the geomagnetic paleointensity which occurred at about 2.65 Ga (Hale, 1985). Samples have also been collected from 2.2 Ga diabase dykes near Whitefish Falls, Ontario and 700 Ma dykes from Sept Iles, Quebec for paleointensity studies.

(f) Memorial University of Newfoundland (E.R. Deutsch, J.P. Hodych, G.S. Murthy, R.R. Patzold, J.N. Präsad, M. Tubrett)

Paleomagnetic studies of dyke swarms from coastal Labrador were continued (G. Murthy, R. Pätzold, M. Tubrett). The dykes are grouped according to their paleomagnetic behaviour into three swarms: (i) an east-west trending swarm, probably of mid-Carboniferous age; (ii) a north-south trending swarm, probably Eocambrian; and (iii) numerous Michael Gabbro equivalents. Each of them have a characteristic magnetization retained over a wide temperature and alternating-field range. Further laboratory work is in progress.

J. Hodych, R. Pätzold and K. Buchan (G.S.C. Ottawa) (1985 and Can. J. Earth Sci., 21, 127, 1984) found a stable, single-component remanence in the oolitic hematite ores of Birmingham, Alabama. Despite being stable enough to have survived major folding, the remanence was very likely acquired in the Pennsylvanian - about 130 million years after Silurian deposition of the ores. This long delay in remanence acquisition is thought to be due to the ores originating as goethite and not magnetizing stably until deep burial in the Pennsylvanian raised the temperature enough to transform goethite to hematite. Similar long delay in remanence acquisition could be expected in those continental redbeds whose deep burial is long delayed.

J. Hodych and K. Buchan are currently engaged in a paleomagnetic study of Silurian red beds and volcanics in central Newfoundland.

A major study of Early Paleozoic carbonates from cratonic western Newfoundland was completed by Ph.D. student J. Prasad, with E. Deutsch, using a CTF cryogenic magnetometer. A stable remanence in magnetite with SE declination and low + inclination was isolated in the

Cambrian to Ordovician sequence on Port au Port peninsula. Laboratory results and comparisons with published cratonic N. American data suggests that this component is original or early diagenetic. Some samples carry a Late Paleozoic (Kiaman-age) chemical remanence in hematite. Early Ordovician carbonates exposed 300 km further north fail to show Kiaman overprints but are misaligned 30° in declination with rocks of the same age on Port au Port, which may be due to apparent polar wandering or to tectonic rotation between the two localities.

Work is continuing (G. Murthy, M. Tubrett) on the constituents of the Bay St. George sub-basin to locate the beginning of the Kiaman reversed superchron for this basin (Murthy, 1985).

Scottish Ordovician paleomagnetism was re-evaluated by K. Storetvedt (Bergen, on leave at Memorial University) and E. Deutsch. (Storetvedt and Deutsch, 1985, in press). Taking account of multi-component magnetizations, a refined Ordovician to Silurian apw path has been proposed, and an earlier conclusion (Deutsch, J. Geomag. Geoelec., 32, SIII 77, 1980), that the British Isles must have rotated 30° anticlockwise relative to the geomagnetic field during the Ordovician, is strongly supported.

J. Hodych extended earlier measurements (Hodych, Nature, 298, 542, 1982) on hysteresis as a function of low temperature in rocks, finding further evidence of magnetostrictive control of coercive force in multidomain magnetite. For some of these samples, magnetic susceptibility was also measured as a function of low temperature, providing evidence that susceptibility is also magnetostrictively controlled. These studies also yield a new method for estimating the self-demagnetizing factor (Hodych, 1986).

E. Deutsch, G. Murthy and R. Pätzold measured susceptibility vs. temperature and low- and high-field hysteresis on synthetic titanomagnetites up to TM75. They had been studied by the Bitter technique (Soffel et al., Phys. Earth Planet. Interiors, 30, 281, 1982), demonstrating that classical domain structures exist over the full TM range to TM75. However, our rock magnetic results for $\geq$ TM30 and also for natural oceanic basalts are consistent with such materials being in a stable-SD or mixed SD-SP rather than MD state. These new results were reported at the 1985 IAGA Assembly, Prague.

(g) University of Toronto, Department of Geology (N. Sugiura, D.J. Dunlop and G.W. Pearce)

(i) Extra-terrestrial Magnetism (N. Sugiura, D.W. Strangway)

The NRM carried by a centimetre-sized dark inclusion, the surrounding matrix, and individual chondrules in the Allende meteorite was measured to determine the magnetic history of the meteorite. It was found that (1) Chondrules and the inclusion were magnetized before accretion of Allende, hence carry the record of early solar system magnetic field. (2) The whole rock was partially remagnetized after accretion by a thermochemical event, thus carrying a record of a magnetic field that was present during or after accretion. (3) The bulk matrix, the inclusion, and some of the chondrules have rotated (or were deformed) after they were remagnetized.

(ii) Chemical Remanent Magnetization (CRM) Studies (O. Ozdemir, D.J. Dunlop)

The CRM of synthetic single-domain maghemite has been measured during inversion to hematite at temperatures of 295, 410, 505, 555 and 605°C in a field of 0.5 Oe. A fresh sample was used in each run and inversion was monitored by DTA analysis and by saturation magnetization. CRM intensity increases with increasing T, peaking at 555°C, which is the peak inversion temperature indicated by DTA. At peak CRM intensity, the maghemite is about three-quarters converted to hematite. At 605°C, conversion is complete and CRM intensity is weak. CRM hardness increases steadily with degree of conversion to hematite. CRM is parallel to the field applied during inversion. In the next generation of experiments, the direction of CRM will be studied when the maghemites are given initial remanences perpendicular to the field applied during inversion.

(iii) High-temperature Viscous Remanent Magnetization (VRM) Studies (D.J. Dunlop, O. Ozdemir)

These experiments are being undertaken because a fraction of the CRM acquired in high-temperature runs seems to be viscous in origin. Since this VRM component is absent from CRM produced at low temperature in nature, we wish to be able to distinguish it from "true" grain-growth CRM. An obvious method is alternating-field demagnetization. Vacuum-sealed submicron magnetites of various sizes will be given VRMs at 500°C in runs lasting up to 4 days, and these VRMs will be AF demagnetized at room temperature to reveal the characteristic coercivity spectrum.

(iv) Magnetic Properties of Hydrothermally Recrystallized Magnetite (F.Heider, T.Bryndzia, D.J.Dunlop, N.Sugiura)

Narrowly sized 1 μm and 12 μm euhedral magnetite crystals have been grown in a hydrothermal pressure cell. TEM studies show relatively low dislocation densities similar to those measured for natural titanomagnetites and coercive forces are 5-10 times lower than published values for crushed magnetites of similar sizes. The hysteresis properties continue the same smooth trend with particle size previously observed for < 0.3 μm precipitated crystals and expected from theoretical considerations for crystals up to 12 μm. The striking discontinuity between published hysteresis data for < 1 μm and > 1 μm magnetites has thus been shown to be an artifact of grinding and stressing the larger grains. It is not an inherent property of magnetite.

(v) Micromagnetic Studies in Rock Magnetism (R.J. Enkin)

The previously described micromagnetic model of small ferromagnetic particles, which assumes Bloch-type domain walls, has been perfected and used in extensive calculations. Stable magnetic structures (equilibrium and non-equilibrium), their free energies and their net moments have been found as a function of grain size and shape, temperature, and external magnetic field strength and direction. Reversible susceptibility and thermoremanence mechanisms have been studied in perfect pseudo-single-domain size magnetite grains. The effect of crystal defects and surface roughness will be included in future calculations. Also under development is a less constrained formulation that will allow a component of magnetization normal to domain walls.

(vi) Paleothermal and Uplift Histories from Dykes and Intruded Rocks (H. Hyodo, D.J. Dunlop)

The background to this project was described last year. Dykes and their contact zones have been sampled in the Southern Province near Gowganda, Ontario and in the Grenville Province near the Ottawa River and in several parts of the Adirondacks. Ideal contact zones, in which magnetic overprinting of the country rocks is purely thermal and the unbaked country rock retains a stable pre-intrusion remanence, are rare. Instead, country rocks tend to have altered magnetic properties in contact zones and the overprinting is in part chemical. It is hoped that dykes of different ages sampled in the Adirondacks will yield a capsule uplift history during Paleozoic and Mesozoic time. A traverse has also been made across the main anorthosite massif to try to detect Grenvillian-age uplift and cooling.

(vii) Kapuskasing Zone Paleomagnetism (LITHOPROBE Project) (V. Costanzo, D.J. Dunlop)

Three magnetization components have been isolated by AF and thermal cleaning in anorthosites and tonalitic gneisses sampled in two across-strike traverses in the Kapuskasing structural zone (KSZ) of the central Superior Province. The A is a NNE, intermediate downward remanence, probably about 2500 Ma in age. A significantly greater structural rotation is required to bring A vectors from the east side of the KSZ onto the late Archean apparent polar wander path (APWP) than is needed for A vectors from the west side. This result supports the easterly steepening listric thrust fault model of the KSZ proposed by Percival and Card (1983). The B is an easterly, steeply upward remanence, whose paleopole, without structural correction, falls among Keweenawan reversed poles (1150-1100 Ma). It is probably a Proterozoic overprint, related either to Keweenawan rifting or to intrusion of carbonatites along the KSZ (e.g. the nearby Nemegosenda carbonatite, whose paleopole (Symons and Garber, 1974) is similar, except for polarity). The C is a novel remanence with an

easterly, shallow direction. It could be a composite of A and B or a middle Proterozoic overprint (1300-1250 Ma according to its position on the APWP) related to the early stages of Keweenawan rifting.

(viii) Yukon Sediments (G.W. Pearce and J. Westgate)

The Old Crow and neighbouring basins of northern Yukon and Alaska have remained unglaciated during the Pleistocene Ice Ages and may, in many partial and broken sections, contain a complete sedimentary record throughout the last several million years. Some lithostratigraphic correlations can be made but need to be buttressed by alternative techniques, such as fission track dating of tephra layers.

A 1982 study determined that a well studied section along the Porcupine River contained a major unconformity with the upper sediments of late Quaternary age and the lower, middle Quaternary or earlier (> 750 000 yr). The lower section contained a very well determined reversed zone with both reversals preserved. This reversed zone is now being hunted throughout the area as an excellent stratigraphic tool. In particular, a number of sections taken to the north along the Old Crow River are being examined. A number of Quaternary workers correlate the lower parts of these sequences with the lower section on the Porcupine. The preliminary measurements suggest that the Old Crow sediment is younger than the base of the Porcupine River section.

An event with shallow inclination has been identified just below a tephra layer that has been identified widely throughout northern Alaska and Yukon and called the Old Crow tephra. The paleomagnetic record of this event has been recorded at two other locations in the area - at Halfway House in Alaska and at a site near the original Porcupine River Site. An earlier study by Marino (M.Sc. thesis, Ohio State University, 1977) describes a possibly correlatable excursion in lake sediment from a core taken from Imuruk Lake on the Seward Peninsula. These features may be related to the Blake Event since the ash has been dated by fission tracks to be 60-120 Ka. Work is in progress on further tephra bearing sites of similar or identical age to see if this feature of the field can be further elucidated.

(ix) European Sedimentary Rocks (C. Jowett, G.W.Pearce)

Graduate student C. Jowett and G.W. Pearce have been working on paleomagnetic analysis of Permian sedimentary rocks of Europe. The prime reason for this study was to attempt to date the mineralization associated with them - the Kupferschiefer Cu-Ag-(Pb-Zn) sulphides. The rocks include the Zechstein Limestone (Upper Permian), the Rotliegendes continental redbeds and volcanics, and similar aged sedimentary sequences in Germany and England. The mineralization is complex. The ore zone is directly underlain by the Rote Feaule, a barren oxidized part of the lower Zechstein. The Rote Feaule is considered however to be part of the metal zoning. It is overlain by the copper ore and surrounded by equivalent reduced pyritic Zechstein. In a paper submitted to JGR the paleomagnetism of the ore, Rote Feaule and pyritic zones are principally examined. Thermal demagnetization showed that all three contained multicomponent remanent moments. A high temperature component was revealed above about 500°C and was generally reversed in direction. It has paleopole coordinates of 49.0° N and 157.2° E with a_{63}= 2.2° (the statistical averaging was performed on the paleopoles). It is considered to be carried by hematite (it is stable to over 620°C) and to represent the secondary CRM acquired during mineralization. The pole position for this component was compared with apparent polar wandering paths for Europe and Russia, obtained by using available pole positions in 20 and 30 Ma running averages. The stable component pole coincides very well with the 210 Ma position on both paths with outside limits at > 90% confidence of ±10 Ma. This Middle Triassic age is consistent with a late diagenetic age for the mineralization. This is in disagreement with many earlier models which suggest syngenetic timing.

A paper on the general paleomagnetic results of the study is in preparation. It will include use of a new spherical contouring technique which enables a visual vector subtraction of components. The latter technique allows an examination of the shape of a cluster of points identified with a particular component and hence can isolate two closely spaced components which may be lumped together by other techniques. This technique was developed by C. Jowett and P. Robin.

(h) University of Western Ontario (H.C. Palmer)

(i) A Paleomagnetic Study of the Powder Mill Group (H.C. Palmer; H.C. Halls, University of Toronto)

A paper describing the paleomagnetic results from this Keweenawan unit has been revised and re-submitted for publication.

(ii) Paleomagnetism and U/Pb Age of the Volcanics of Michipicoten Island, Lake Superior (H.C. Palmer; D.W. Davis, Royal Ontario Museum)

A new study of the volcanics of Michipicoten Island has revealed that the directions of remanence from the upper part of the Mamainse Point Formation exposed on the island are slightly different from the directions recorded by the unconformably overlying Michipicoten Island Formation. A quartz porphyry intrusive into the Mamainse Point Formation and overlain by the Michipicoten Island Formation has yielded zircons giving an age of 1086 Ma. This result, together with results of Davis and Sutcliffe (1985), indicates that one of the R to N polarity changes in the Keweenawan took place in the 1095-1090 Ma interval.

(iii) Eocene-Oligocene Volcanics of East-central Nevada (H.C. Palmer; W.D. MacDonald, SUNY, Binghamton)

Early to mid Tertiary volcanic rocks were sampled during the summer of 1985 in the Elko-Eureka region of Nevada. The purpose of this project is to test for evidence of rotation of rock units as a consequence of strike-slip displacement along the Oregon-Nevada lineament. Preliminary results indicate that rocks east of the lineament yield directions which agree with the expected field direction whereas rocks within the lineament are rotated in a counter clockwise sense. Efforts will be made this summer to obtain coeval material from west of the lineament.

(iv) Paleomagnetism and Susceptibility Anisotropy of the Mulcahy and Lac des Isles Gabbros, District of Kenora (H.C. Palmer; R.H. Sutcliffe, Ontario Geological Survey)

A preliminary sampling of both the Mulcahy and Lac des Isles gabbros was completed last summer. The principal objective of this study is to determine the amount of rotation each of these bodies has undergone subsequent to cooling through the blocking temperatures of the magnetic minerals contained within them. A second objective is to use the orientation of susceptibility ellipsoids to define the orientation of planar and linear fabrics within parts of these bodies where megascopic layering is not well developed and, as a consequence, not clearly visible in outcrop. Since the known platinum group element (PGE) deposits in the Lac des Isles gabbro are broadly stratabound, the susceptibility data can be used in defining the optimum orientation of exploratory drill holes in the body where layering is not visible. Results from the preliminary collection suggest that the above objectives can be met and a comprehensive sampling program is planned for this summer.

(i) University of Windsor (D.T. Symons)

Three paleomagnetic projects are now being written up as Master's theses. D. Dunsmore has studied three gabbroic plutons near Lynn Lake, Manitoba. He finds that the mineralized and non-mineralized plutons record the same thermal and tectonic history. Deklerk has studied Eocene, Cretaceous and Jurassic plutons in the Nelson area of southeastern British Columbia. His data suggest that clockwise rotation of the Eastern-Quesnellia subterrane predates northward translation with no relative motion since Eocene time. Vandall has studied several rock units with well established radiometric age dates in the Wawa-Gamitagama area of north central Ontario. These results suggest that this area is an essentially undisplaced portion of the Abitibi Belt. Three Bachelor's thesis projects are currently in the analysis stage. These studies are on the Triassic redbeds in New Brunswick, Archean basalts and granites in northwestern Quebec, and the Cutler granite in northern Ontario.

6. Bibliography

Ajakaiye, D.E., Hall, D.H. and Millar, T.W. 1985. Interpretation of aeromagnetic data across the central crystalline shield area of Nigeria. Geophys. J. Roy. Astr. Soc., 83, 503-517.

Arkani-Hamed, J., Strangway, D.W., Teskey, D.J. and Hood, P.J. 1985. Comparison of MAGSAT and low-level aeromagnetic data over the Canadian Shield: implications for GRM. Can. J. Earth Sci., 22, 1241-1247.

Armstrong, R.L., Monger, J.W.H. and Irving, E. 1985. Age of magnetization of the Axelgold Gabbro, north-central British Columbia. Can. J. Earth Sci., 22, 1217-1222.

Bingham, D.K., Gough, D.I. and Ingham, M.R. 1985. Conductive structures under the Canadian Rocky Mountains. Can. J. Earth Sci., 22, 384-398.

Broome, J., Simard, R., and Teskey, D.J. 1985. Presentation of magnetic anomaly map data by stereo projection of magnetic shadowgrams. Can. J. Earth Sci., 22, 311-314.

Coles, R.L. 1985. Magsat scalar magnetic anomalies at northern high latitudes. J. Geophys. Res., 90, 2576-2582.

Daudier, B.S. and Schwarz, E.J. 1985. An interpretation method for gravity and magnetic data for areas peripheral to the Canadian Shield. In: Current Research, Part A, Geol. Surv. Can. Paper 85-1A, 421-430.

Dods, S.D., Teskey D.J. and Hood P.J. 1985. The new series of 1:1,000,000 scale magnetic anomaly maps of the Geological Survey of Canada: compilation techniques and interpretation. In: The Utility of Regional Gravity and Magnetic Anomaly Maps, W.J. Hinze (Editor), Soc. Explor. Geophys., 69-87.

Dosso, H.W., Nienaber, W. and Parkinson, D. 1985. An analogue model study of EM induction in the Tasmania region. Phys. Earth Planet. Inter., 39, 118-133.

Edwards, R.N. 1985. Ice-MOSES: the theory of a new offshore electrical method and a proposal for an Arctic trial. Earth Physics Branch Open File Report 85-14.

Edwards, R.N., Law, L.K., Wolfgram, P.H., Nobes, D.C., Bone, M.N., Trigg, D.F. and DeLaurier, J.M. 1985. First results of the MOSES experiment: sea sediment conductivity and thickness determination, Bute Inlet, British Columbia, by magnetometric off-shore electrical sounding. Geophysics, 50, 153-160.

Flores, C., Kurtz, R.D. and DeLaurier, J.M. 1985. Magnetotelluric exploration in the Meager Mountain geothermal area, Canada. Acta. Geodset. Geophys. et Montanist. Hung., 20, 165-171.

Gravenor, C.P. and Symons, D.T.A. 1985. A fast and accurate paleomagnetic sampler for field use: a discussion. Boreas, 14, 154.

Gupta, J.C., Kurtz, R.D. and Camfield, P.A. 1983. An induction anomaly near the west coast of Hudson Bay, Canada. Earth Physics Branch Open File Report 83-29.

Gupta, J.C., Kurtz, R.D., Camfield, P.A. and Niblett, E.R. 1985. A geomagnetic induction anomaly from IMS data near Hudson Bay, and its relation to crustal electrical conductivity in Central North America. Geophys. J. Roy. Astr. Soc., 81, 33-46.

Haines, G.V. 1985a. Spherical cap harmonic analysis. J. Geophys. Res., 90, 2583-2591.

Haines, G.V. 1985b. Magsat vertical field anomalies above 40° N from spherical cap harmonic analysis. J. Geophys. Res., 90, 2593-2598.

Haines, G.V. 1985c. Spherical cap harmonic analysis of geomagnetic secular variation over Canada 1960-1983. J. Geophys. Res., 90, 12563-12574.

Haines, G.V. and Newitt, L.R. 1985. Magnetic charts of Canada. Lambert conformal conical projection, standard parallels 49° N and 77° N, scale 1:10,000,000. (i) Magnetic declination chart 1985.0: Map MCR701; (ii) Total intensity chart 1985.0: Map MCR702; (iii) Horizontal intensity chart 1985.0: Map MCR703; (iv) Magnetic inclination chart 1985.0: Map MCR704; (v) Vertical intensity chart 1985.0: Map MCR705. Energy, Mines and Resources, Earth Physics Branch, Ottawa.

Hale, C.J. 1985. Evidence of the Archean Geomagnetic Field. Ph.D. thesis, University of Toronto, Toronto.

Hall, D.H., Noble, I.A. and Millar, T.W. 1985. Crustal structure of the Churchill-Superior boundary zone between 80° and 98° W longitude from MAGSAT anomaly maps and stacked passes. J. Geophys. Res., 90 (B3), 2621-2630.

Heard, G.J., Dosso, H.W., Nienaber, W., Lokken, K.E. 1985. Laboratory analogue modelling of the Schumann resonance source field. Phys. Earth Planet. Interiors, 39, 178-181.

Hodych, J.P., Pätzold, R.R. and Buchan, K.L. 1985. Chemical remanent magnetization due to deep-burial diagenesis in oolitic hematite-bearing ironstones of Alabama. Phys. Earth Planet. Interiors, 37, 261-284.

Hood, P.J. 1985. Mineral exploration: trends and developments in 1984. Can. Min. J., 106, 14-41.

Hood, P.J., McGrath, P.H. and Teskey, D.J. 1985. Evolution of Geological Survey of Canada magnetic anomaly maps; a Canadian perspective. In: The Utility of Regional Gravity and Magnetic Anomaly Maps, W.J. Hinze (Editor), Soc. Explor. Geophys., 62-68.

Hood, P.J., Bower, M.E., Hardwick, C.D. and Teskey, D.J. 1985. Direct geophysical evidence for displacement along Nares Strait (Canada-Greenland) from low-level aeromagnetic data: a progress report. In: Current Research, Part A, Geol. Surv. Can. Paper 85-1A, 517-522.

Irving, E. 1985. Whence British Columbia? Nature, 314, 673-674.

Irving, E. and Strong, D.F. 1985. Paleomagnetism of rocks from Burin Peninsula, Newfoundland: hypothesis of Late Paleozoic displacement of Acadia criticized. J. Geophys. Res., 90, 1949-1962.

Irving, E., Davidson, A. and McGlynn, J.C. 1984. Paleomagnetism of gabbros of the early Proterozoic Blanchford Lake intrusive suite and Eastern Island Dyke, Great Slave Lake, N.W.T.: possible evidence for the earliest continental drift. Geophysical Surveys, 7, 1-25.

Irving, E., Woodsworth, G.J., Wynne, P.J. and Morrison, A. 1985. Paleomagnetic evidence for displacement from the south of the Coast Plutonic Complex, British Columbia. Can. J. Earth Sci., 22, 584-598.

Jansen van Beek, G., Newitt, L.R. and Coles, R.L. 1984. Annual report for magnetic observatories - 1983. Geomagnetic Series, Earth Physics Branch, Ottawa, 28.

Jones, A.G. and Garland, G.D. 1984. Electromagnetic sounding from observations taken during the First International Polar Year. Musk-Ox, 34.

McGrath, P.H. and Henderson, J.B. 1985. Reconnaissance ground magnetic and VLF profile data in the vicinity of the Thelon Front, Artillery Lake map area. In: Current Research, Part A, Geol. Surv. Can. Paper 85-1A, 455-462.

McKirdy, D.McA., Weaver, J.T. and Dawson, T.W. 1985. Induction in a thin sheet of variable conductance at the surface of a stratified earth - II. Three-dimensional theory. Geophys. J. Roy. Astr. Soc. 80, 177-194.

Murthy, G.S. 1985. Paleomagnetism of certain constituents of the Bay St. George sub-basin, western Newfoundland. Phys. Earth Planet. Interiors, 39, 89-107.

Newitt, L.R. and Dawson, E. 1984. Magnetic observations at international polar year stations in Canada. Arctic, 37, 255-262.

Newitt, L.R. and Haines, G.V. 1985. An interactive magnetic information retrieval program. Division of Seismology and Geomagnetism, Earth Physics Branch Internal Report 1985-4(G).

Newitt, L.R., Coles. R.L. and Clark, J.F. 1985. Canadian magnetic repeat stations 1962-1983: instruments, procedures and observation. Geomagnetic Series, Earth Physics Branch, Ottawa, 29.

Niblett, E.R., Gibb, R.A., Kurtz, R.D., Lapointe, P., Morris, W.A., Ostrowski, J.A. and Sinha, A.K. 1985. Ground geophysics results from the East Bull Lake Pluton. In: Proceedings of the 17th Information Meeting of the Nuclear Fuel Waste Management Program, Atomic Energy of Canada Limited. Technical Record TR-299, 165-199.

Peteherych, S., Shepherd, G.G. and Walker, J.K. 1985. Observation of vertical E-region neutral winds in two intense auroral arcs. Planet. Space Sci., 33, 869.

Prugger, A.F. and Woods, D.V. 1984. The pattern of anomalous geomagnetic field fluctuations over the mid-continent gravity high. J. Geophys. Res., 89, 7773-7782.

Rees, C.J., Irving, E. and Brown, R.L. 1985. Secondary magnetization of Triassic-Jurassic volcaniclastic rocks of the Quesnel Terrane, Quesnel Lake, B.C. Geophys. Res. Lett., 12, 498-501.

Séguin, M.K. 1985. Paleomagnetism of some lithological units from the Lower Palaeozoic of the Vendée, France - Reply. Tectonophysics, 118, 88-90.

Séguin, M.K. and Clark, T. 1985. Reconnaissance paleomagnetic study of igneous rocks from the eastern sector of the Labrador Trough. Can. J. Earth Sci., 22, 1561-1571.

Séguin, M.K. and Gah, E. 1985. Paleomagnetism of Lower Devonian volcanics and Devonian dykes from north central New Brunswick, Canada. Phys. Earth Planet. Interiors, 38, 262-276.

Séguin, M.K. and Michaud, C. 1985. The Bécancour-Yamaska area, Québec: a paleomagnetic study. J. Geomag. Geoelectr., 37, 895-912.

Séguin, M.K. and St-Hilaire, B. 1985. Magnétochronologie des formations rocheuses du Mont Mégantic et des environs, Québec méridional. Can. J. Earth Sci., 22, 487-497.

Séguin, M.K., Singh, A. and Fyffe, L. 1985. New paleomagnetic data from carboniferous volcanics and red beds from central New Brunswick. Geophys. Res. Lett., 12, 81-84.

Spector, A., Hood, P.J., Farah, A. and Ahmed, W. 1985. Applications of aeromagnetic data to mineral resources exploration - Baluchistan, Pakistan. In: The Utility of Regional Gravity and Magnetic Anomaly Maps, W.J. Hinze (Editor), Soc. Explor. Geophys., 132-143.

Sugiura, N. and Strangway, D.W. 1985. NRM directions around a centimeter-sized dark inclusion in Allende. Proc. 15th Lunar Planet. Sci. Conf., C729-C738.

Symons, D.T.A. 1984a. Paleomagnetism of the Triassic Nicola volcanics and geotectonics of the Quesnellia Subterrane of Terrane I, British Columbia. Geodynamics, 2, 229-244.

Symons, D.T.A. 1984b. Paleomagnetism of the Westcoast Complex and geotectonics of the Vancouver Island segment of the Wrangellian subterrane. Geodynamics, 2, 211-228.

Thorning, L., Bower, M. Hardwick, C.D. and Hood, P.J. 1985. Greenland ice cap aeromagnetic survey 1984: reconnaissance lines in southern Greenland. In: Report of Activities 1984, Gronlands Geologiske Undersogelse, 125, 83-84.

Weaver, J.T. 1985. Comment on "Généralisation et optimalisation de la méthode des différences finies pour la modelisation en magnétotellurique (MT)" by D. Doucet and Pham van Ngoc. Geophys. Prospect. 33, 303-307.

Weaver, J.T., LeQuang, B.V. and Fischer, G. 1984. Remarks on the comparison of analytical and numerical model calculations. Protokoll ber das Kolloquium "Electromagnetische Tiefenforschung", Grafrath/Oberbayern, J. Homilius and V. Haak (Editors).

Weaver, J.T., LeQuang, B.V. and Fischer, G. 1985. A comparison of analytic and numerical results for a two-dimensional control model in electromagnetic induction - I. B-polarization calculations. Geophys. J. Roy. Astr. Soc., 82, 263-277.

Westgate, J.A., Walter, R.C., Pearce, G.W. and Gorton, M.P. 1985. Distribution, stratigraphy, petrochemistry and palaeomagnetism of the late Pleistocene Old Crow tephra in Alaska and the Yukon. Can. J. Earth Sci., 22, 893-906.

Woods, D.V. 1985. Large-scale electromagnetic induction investigation of the Kapuskasing Structural Zone. Geol. Surv. Can. Paper 85-1A, 533-542.

III (B) AERONOMY AND SPACE PHYSICS

Compiled by: D. Venkatesan

1. Introduction

The following report summarizes the research carried out during 1985 in the areas of aeronomy and space physics. The executive of the Division of Aeronomy and Space Physics/ Canadian Association of Physicists (DASP/CAP) are L.L. Cogger (University of Calgary) Chairman; R. Lowe (University of Western Ontario) - Vice-Chairman; R. Koehler (York University) - Secretary-Treasurer; D. Walis (HIA, Ottawa) - Past Chairman; the Editor for the DASP/CAP Newsletter was R.L. Gattinger (HIA, Ottawa).

2. University of Alberta, Institute of Earth and Planetary Physics and Department of Physics

Magnetospheric Physics (G. Rostoker and J.C. Samson)

Studies have identified the Kelvin-Helmholtz (K-H) instability taking place in velocity shear zones, as causing large scale auroral forms, viz. westward travelling surges, omega bands, and Pc5 ULF pulsation activity; the involved shear zones are located in the boundary plasma sheet (BPS), in the onosphere, in the plasma sheet boundary layer (PSBL), in the high latitude magnetotail (HLM) and the inner edge of the low latitude boundary layer adjacent to the central plasma sheet (CPS) near the tail's midplane. The particle and field observations are placed in this framework in the iono- and magneto-spheres. G. Rostoker and collaborator T.E. Eastman (University of Iowa) have continued the development of a boundary layer dynamics model of magnetospheric substorm activity based on the assumption that the parallel electric fields responsible for substorm particle acceleration are confined to regions cited above. In the model, the substorm expansive phase arises from a K-H instability in the velocity shear zone near the interface between LLBL and CPS. The field-aligned drops in potential (generated by field-aligned currents trying to stabilize the instability) lead to acceleration of auroral particles; the anisotropic motions of these explain bulk earthward and tailward flows detected in the tail during substorms, while the field-aligned currents produce the negative B_z magnetic perturbations attributed, by some, to near-earth neutral line formation.

In a study of precursor activity to substorm expansive phase onsets using magnetometer array data from the Churchill, Alberta and east-west IMS lines, C. de Groot-Hedlin and G. Rostoker have identified magnetic signatures. These suggest that the substorm current wedge is already growing prior to its explosive development at the onset of the expansive phase. The precursor signature also indicates a small N-ward expansion of the growing wedge system (interpreted as due to the growth of a K-H instability). They suggest that the expansive phase onset (signalled by the brightening of the breakup arc) indicates the instant upward field-aligned current densities exceed 10^{-6} A m^{-2} at which time acceleration associated with parallel electric fields is initiated.

The Ps 6 magnetic perturbations study by G. Rajaram (collaborators- G. Rostoker and J.C. Samson) now includes westward travelling surge phenomena. From correlations of riometer and magnetic variations, she has identified vortex type current flows in the ionosphere; these may account for the observed pertubations. A physical mechanism (Rostoker) explains how these current systems arise from the K-H instability at the interface between the LLBL

and CPS in the dawn and dusk sectors of the deep magnetotail. This model treats this velocity shear zone as a surface of discontinuity composed of vortex lines (equivalent in the MHD context to a space charge sheet), perturbations of which lead to field-aligned current flow and account for the sunward motion of surges and omega bands associated with Ps 6 perturbations.

The study of G. Rostoker, N. Rowlands and M. Yeremy attributes the morning sector Pc 5 ULF activity to the same K-H instability at the LLBL/CPS interface where surges and omega bands originate (but in that shear zone much closer to earth where the LLBL effect is more pronounced). Using energetic particle (ISEE 1) and magnetometer data (ISEE 1 and 2) they show that tail particle and field oscillations in the Pc 5 frequency range occur in the localized region of the LLBL/CPS interface; they correlate this pulsation activity with ground Pc 5 pulsations observed along the ground sector by the Alberta IMS magnetometer array.

W. Kamocki will study particle and magnetic field variations in the magnetotail to identify field-aligned current effects, with respect to phases of substorm activity.

J.C. Samson and B.G. Harrold have mapped transient ULF (5-15 mHz) magnetic fields associated with shear Alfven wave propagation carrying the enhanced field-aligned current associated with the substorm expansive phase. Ground-based magnetometer data are used to measure phase and group velocities, and polarizations of these magnetic oscillations. All the data are compatible with Alfven waves localized on field lines threading the auroral ionosphere. These waves show E-ward and W-ward propagating modes, originating at the location of the expansive phase onset. The effective phase velocities are very high, 30-50 km/s, and are probably connected with the initial brightening quiet arc before the expansive phase onset.

J.C. Samson and M.G. Connors are developing two computer codes to simulate the propagation of localized disturbances of plasma waves and to model the transient plasma waves associated with the substorm expansive phase: a two-dimensional code based on the cold plasma kinetic equations and a hydromagnetic code; the former allows the possibility of finite, field-aligned potential drops and particle accelerations. They hope to deal with scale sizes comparable to the local ion gyroradius and the evolution of kinetic Alfven waves in disturbances with these scale sizes. In Samson's study of magnetospheric ion cyclotron waves (in collaboration with B.J. Fraser, University of Newcastle, Australia and R.L. McPherson, UCLA) magnetic fields of ion cyclotron waves with frequencies near the local oxygen gyro-frequency are sometimes seen when spacecraft ISEE 1 and 2 pass through the plasmapause region. The onset of the waves is followed by significant increases in the thermal (0-100 eV) O^+ and the warm (0.1-16 kev) O^+ and He^+ ion populations. Data clearly show spectral slot and polarization crossover predicted by multicomponent plasma propagation theory, suggesting that the growth rate of the ion cyclotron waves is strongly influenced by both hot and cold heavy ions. The space physic group at the University of Alberta developed multivariate time series software used in analysis. Samson and K.L. Yeung have developed a subroutine library for detecting polarized waves in an array of vector instruments; this will be used by the CANOPUS acquisition network of the Canadian Space Science Program. The new estimators for the common structure in multivariate time-series data derived by Samson and Yeung (based on the superposed epoch analysis technique) are used in a study of the N-S component of the IMF, with times keyed to the onset of the expansive phase of polar magnetic substorms. The results confirm that the the N-ward IMF turnings trigger expansive phases.

3. University of Calgary, Space Science Group (SSG/UC) and Department of Physics

(a) Auroral Physics and Aeronomy

Setting up the Viking UV Imager ground station in Kiruna, Sweden and software development for instrument control and imager data processing were carried out by J.S. Murphree, C. Marcellus, D. Hardy and L. Koop. The hardware, including a VAX11/750, was shipped from Calgary; R. King and G. Enno of Calgary were involved in calibration and image analysis. C.D. Anger on sabbatical in U.K. was involved with Viking and Galileo mission preparations. S. Achal is working on a Get-Away Special project to observe the spectrum of meteorites with help from H. Richardson, DAO, Victoria and the SSG/UC. Launch date is

uncertain. S. Babey and E.P. King have nearly completed construction of the prototype all-sky auroral imager for the CANOPUS program; when operational, it will be located at Gillam, Manitoba. Two small projects using ISIS 2 satellite data, viz. high resolution images of the auroral oval and a novel analysis of large quantities of two-dimensional data (e.g., airglow data from satellites) have been carried out. The airglow observatory at RAO, Priddis operated intermittenly during 1985; analysis of OH rotational temperature data has yielded information on gravity waves: periods, horizontal wavelengths, and horizontal phase velocities. L. Cogger spent two months at the Arecibo Observatory conducting an experiment on nighttime F-region behaviour.

(b) Multi-Spacecraft Studies of the Heliosphere

In collaboration with a number of other institutions, including the Applied Physics Laboratory at John Hopkins University (APL/JHU), University of Iowa (UI), and University of Kansas (UK), many projects related to heliospheric physics are in progress using data from Spacecraft Voyagers 1 and 2, Pioneers 10 and 11, and earth orbiting satellites IMP 7 and 8. Cosmic ray modulation, radial and latitudinal cosmic ray gradients, heliospheric boundary, long- and short-term cosmic ray intensity variations, shock acceleration of cosmic rays in the heliosphere and physics of the geomagnetic tail are being addressed. Collaborators are D. Venkatesan, J. Murtha, C. Marshall (UC), S.M. Krimigis, R.B. Decker, R.E. Gold, and A.T.Y. Lui (APL/JHU), T.P. Armstrong (Kansas) and J.A. Van Allan (Iowa).

(c) Magnetospheric Physics

(i) Conjugate Study. In a new collaboration between Calgary (D. Venkatesan and J.F. Bamber) and AT&T Bell Laboratories, Murray Hill, NJ (A. Wolfe and L.J. Lanzerotti) help has been provided to set up a new observatory (since mid-1985) at Frobisher Bay, N.W.T., Canada; this is the conjugate of Siple Station in Antarctica, where a similar observatory has been operated by Bell Laboratories for over two years. A comparison of magnetometer and riometer records from the two stations has been initiated to throw light on conjugacy in magnetospheric problems. A number of papers relating to coupling of solar wind with the magnetosphere have been published.

(ii) Jovian Plasma Study. Using Voyager 2 data, a study of the Jovian plasma sheet has been started. Preliminary results have been reported at the Chapman Conference on Magneto-tail Physics, APL/JHU, Laurel (Md) by L.J. Lanzerotti, C. MacLennan and J. Medford (Bell Laboratories) and D. Venkatesan and J. Broughton (UC).

(d) Study of Particle Precipitation in the Polar Regions

A collaboration between Calgary (D. Venkatesan and D. Hudon), University of Kansas, Lawrence (T.P. Armstrong, Ed Briggs) and the University of Maryland, College Park (T.J. Rosenberg and S. Krishnaswamy) relates to the correlative study of particle fluxes from satellite IMP 8 and cosmic noise absorption data from a riometer at Siple Station in Antarctica. This has provided some new results connecting fluxes of protons, alphas and medium nuclei to an event registered by the 35 MHz riometer. A paper was presented at the American Geophysical Union meeting, San Francisco, December 1985.

(e) The Sulphur Mountain Book

The Sulphur Mountain Cosmic Ray Laboratory operated from mid-1957 to mid-1978. D.C. Rose and B.G. Wilson (NRC, Ottawa) set up the station (IGY Program). B.G. Wilson from 1957 and D. Venkatesan and T. Mathews from 1966 were involved in its operation. The University Press, UC, Calgary, published a book in August 1985 containing the cosmic ray intensity data, an introductory historical article by B.G. Wilson about the station and a number of manuscripts published since 1966. The Historical Board of Canada has recognized the laboratory as an historical site with an appropriate plaque.

(f) Weather Research - Frost-Free Period

L. Nkemdirim, Department of Geography and D. Venkatesan, Department of Physics, University of Calgary deal with the length of the frost-free season, using temperature data from 13 Canadian stations over the past 70 years. The consequence of urbanization, viz., the

increase in the average length of the frost-free period by seven days since the 1940's, is considered to be of significance and of importance to agriculture. The quest for the solar connection to the problem of weather is being pursued further.

(i) Balloon Astronomy. Analysis of far IR solar spectra (balloon observations, 1982) yielded, for the first time by any group, an in-flight radiometrically calibrated solar temperature measurement from the important layers around the temperature minimum. These contribute significantly to the improvement in solar atmospheric modelling. Several intense emission lines from high n level transitions of H and Mg were discovered on top of the above continuum solar spectrum, presumably originating in a recombination process in the high solar atmosphere. R. Boreiko obtained her Ph.D. on this work; she is currently working with A. Betz, Space Sciences Laboratory, University of California, Berkeley.

A balloon observation (last campaign, Gimli, Manitoba, July 1985), with completely rebuilt payload following the 1984 retrieval from Lake Manitoba, extended the wavelength range of solar spectra. Several more intense emission-line complexes from high n transitions of Rydberg atoms (from n=13-12 and n=12-11 transitions in particular) have been identified, in which signal/noise levels and spectral resolution are sufficient to separate H, Mg and Si contributions. The payload was completely destroyed on impact with ground.

(ii) Airborne Solar Eclipse Studies. Analysis of data from the 1980, 1983 and 1984 far and intermediate IR solar eclipse observations from jet aircraft continues. The planned extension of the study of solar emission lines, particularly the examination of line shapes and intensity changes over active regions (in which the strong Zeeman splitting at far IR wavelengths should provide an interesting solar atmospheric magnetic field probe) from a jet aircraft is ruled out by loss of three heliostats in the NASA Convair 990 aircraft fire.

(iii) Atmospheric Studies. An atlas of atmospheric transmission for the far IR between 80 and 200 cm^{-1} from balloon altitudes, combining observational data from ESA flights with synthetic spectra, is planned in collaboration with D.A. Naylor, University of Lethbridge.

4. Communications Research Centre, Ottawa

(a) Radio Propagation Laboratory

RF pulses generated by the topside sounder on ISIS-II charge the spacecraft body to a few hundred volts negative. The ensemble is regarded as a triple probe whose geometric asymmetries are responsible for a net charge being left on system capacitances at the end of the RF pulse. The discharge has been studied principally with data from the Soft-Particle Spectrometer and support from other instruments onboard. The access of energetic ions to the detector of the spectrometer as a function of the angle between the velocity direction and the spectrometer axis is consistent with a quasi-central electric field on the spacecraft upstream side. On the wakeside, turbulent particles are attracted back to the spacecraft body within a conic surface centred on the velocity axis. Some recently published plasma-line observations are explained (J. Geophys. Res., 90, 662, 1985) assuming that the electrostatic waves generated in ionospheric heating are trapped in ionization ducts. A paper on the numerical simulation of the electric field, electron density and electron temperature near the ionospheric reflection height of a powerful HF wave has been completed (J. Geophys. Res., in press).

(b) Waves in Space Plasmas (WISP) (H.G. James, D.B. Muldrew)

The WISP/HFSS project passed Critical Design Review in September and is contracted to Canadian Astronautics Ltd.; the flight hardware delivery of the HFSS flight model is scheduled for spring 1987. NASA announced two flight dates for the Space Plasma Laboratory (SPL) in December 1990 and December 1992.

The WISP/HG Group is contemplating possible pre-SPL ground experiments with HFSS, including Doppler-ionosonde measurements, ideally coordinated with other instruments. Laboratory measurements of (non) linear antenna impedances are also envisaged. Such activities constitute valid current research and provide hands-on practice in HFSS operation. We welcome anyone interested in pre-SPL or SPL experiments.

5. Earth Physics Branch, Division of Seismology and Geomagnetism

(a) Magnetic Observatories and Instruments (G. Jansen van Beek, R.L. Coles)

The Geomagnetic Observatory unit, Division of Seismoloy and Geomagnetism continued its management of the Canadian Magnetic Observatory Network (CMON); these are the 10 digital magnetic observatories at Resolute Bay, Cambridge Bay, Baker Lake and Yellowknife in the Northwest Territories; Fort Churchill, Manitoba; Poste-de-la-Baleine, Quebec; Meanook, Alberta; St. John's, Newfoundland; Ottawa, Ontario; and Victoria, British Columbia. The observatories at Alert and Mould Bay, N.W.T. have installed a version of the AMOS MKIII in February and July 1985 respectively. With the removal of the photographic analogue recorders at Alert and Mould Bay, the CMON is now completely digital. Glenlea, Manitoba was operated in cooperation with the University of Manitoba, Winnipeg. A full description of the present network is given in the Annual Report for Magnetic Observatories - 1984 (in press).

Specific data sets for the EMSLAB project (June 1985 to October 1985) are in preparation. Those from Victoria, Meanook and Ottawa magnetic observatories will contain one-minute averages and selected ten-second data. To assist the Viking project, incremental tape decks gathering five-second data have been installed in the Fort Churchill and Baker Lake magnetic observatories. In order to evaluate the absolute stability of ring-core fluxgates, a vector proton precession magnetometer manufactured by Elsec (U.K.) has been acquired. Preliminary evaluation of the declination and inclination data from the vector ppm against conventional absolute magnetometers is in progress. The final 1984 digital magnetic observatory data which include one-minute values, hourly means and hourly ranges were deposited in the World Data Centre in Boulder, Colorado in June 1985. Copies of magnetograms and digital data are available at cost plus 100% handling charge from: Geophysics Division, Geological Survey of Canada, Department of Energy, Mines and Resources, 1 Observatory Crescent, Ottawa, Ontario, K1A 0Y3; Telephone: (613) 995-5474. Details of other services are listed in the Catalogue of Services of the Geomagnetic Service of Canada. To provide timely data on the state of the AMOS network, a computer file containing summary information of the magnetic variations and the operation of the AMOS MKIII is updated each day.

(b) Forecasts of Magnetic Activity (J. Hruska, H.-L. Lam, R.L. Coles)

The Earth Physics Branch issue regular 27 day (mailed on request) and 72 hour forecasts of geomagnetic activity in Canada (telephone answering service (613) 992-1299). These are based on data from the Canadian Magnetic Observatory Network, EMR and on the solar radio data from HIA, NRC and on other solar and interplanetary data from SESC, NOAA, USA. A new experimental three zone (polar cap, auroral and sub-auroral) 27 day forecast for geomagnetic activity gives a daily estimate of a range parameter for each zone over Canada; the parameter is the daily mean of the 24 hourly ranges in the X-component of the magnetic field. The validity of this concept has been tested; the overall accuracy of this new forecast for about a one year period exceeded 70% in all three zones. This forecast will be available on request in 1986. In view of the qualitative and empirical nature of predictions, development of computer algorithms based on numerical techniques is needed to reduce the subjectivity of particular forecasters. Hence, a prediction filter based on Wiener linear prediction theory has been developed for medium term (27 days) forecasts of geomagnetic activity in Canada. This test using data from Canadian magnetic observatories in the three zones is encouraging. Hence, routine implementation for the three-zone geomagnetic forecasts by computer is being planned.

(c) Magnetic K Indices

A numerical data-adaptive separation method, developed for the discrimination of quasi-regular magnetic variations from the irregular variations, for the determination of the K indices is based on a pattern comparison and discrimination technique using harmonic analyses. The wave characteristics of a quiet regular or reference day are compared with those of the disturbed day; the harmonic components that are consistent with those of the regular variation are determined by a cosine function. The Fourier coefficients are calculated from these modified "wavelets" and then they are transformed back to the time domain. This "regular variation" is then subtracted from the data before the ranges are determined for the semilogarithmic K values. This numerical method was tested at the Canadian magnetic observatories in Victoria, Meanook and Ottawa over a four-month period.

These K's were compared with hand-scaled values, which were carefully determined and independently checked from reconstructed magnetograms from the same data. The two methods were found to agree ~ 97% of the time with most errors occurring during very irregular periods. This is comparable with values carefully determined by highly skilled observers.

(d) Auroral Radio Absorption and Atmospheric Heating (J.K. Walker)

The auroral radio absorption measured with a riometer has been calibrated in terms of the D region ionization by Collis et al. (J.A.T.P., 46, 21, 1984). These different height profiles of the electron density were transformed to those of energetic particle heating rates with the aid of the effective recombination coefficient, α, and by assumeing 35 eV is lost per collision. The total D region particle heating was determined for each of the different levels of absorption. A quadratic regression analysis of these values was then used to relate the absorption to the D region energetic particle heating. A Chapman layer was also fitted to these electron density height profiles so that the lower ionosphere can now be modelled from the auroral absorption observations.

6. The University of Lethbridge, Department of Physics, Infrared Astronomy/Aeronomy

(a) Astronomical Infrared Fourier Transform Spectrometer

A versatile, compact and inexpensive high resolution Fourier spectrometer optimized for mid-infrared astronomical observations has been designed, built and is currently undergoing extensive laboratory testing. This is for use at the Cassegrain foci of a variety of telescopes (CFHT, IRTF, etc.). The first field test is planned for early 1986.

(b) ESA Collaboration (D.A. Naylor)

Analysis of data obtained with the European Space Agency's F.T.S. on balloon-borne and ground-based telescopes continues to yield results. Analysis of far infrared emission spectra of the stratosphere resulted in the first measurements of the downward flux from the 63 μm fine structure line ($^3P_1$-$^3P_2$) of atomic oxygen from balloon altitudes. The next goal is to analyze mid-infrared spectra of SIV and NeII line emission from a variety of astronomical objects obtained with the E.S.A. F.T.S. on ground-based telescopes in Hawaii and Chile. Mapping in these lines will provide valuable information on the physical properties of the sources.

7. Herzberg Institute of Astrophysics, Planetary Sciences Section

(a) Photometry of the Aurora and Airglow (A.V. Jones, F. Creutzberg, R.L. Gattinger, F.R. Harris)

Developed techniques permit comparisons between ground-based optical data and rocket-borne particle measurements from the ARIES campaign; auroral heights deduced by triangulation agree well with model heights derived from the measured electron spectra. Height measurements of the early evening arc and height profiles of oxygen emissions in isolated arcs are planned. Use of echelle spectrograph resolved the two lines of the (NI) 5200 Å doublet in aurora while enabling obervation of the intensity and component ratio. With the aid of the auroral model, the observed zenith brightness of (NI) 5200 Å over a complete night will be compared with the theoretical value based on auroral input energy inferred from meridian scanner data. The 1978 IMS meridian scanner data were sorted to produce a set of latitude - time - magnetic activity plots for both (OI) 5577 Å and Hβ 4861 Å. This continuing study is to characterize the auroral oval.

A paper on the coordinated radar and photometer measurements at Sondrestrom concludes that there appeared to be a constant accelerating field superimposed upon a rather normal low energy electron spectrum. In this study, the use of I(6300)/I(4278) and I(8446)/I(4278) ratios as well as N_2^+ rotational temperature as indices of primary electron energy was further explored in comparison with energies derived from the radar data.

(b) CANOPUS (A.V. Jones)

CANOPUS has progressed over the year, although somewhat slowly; the BARS radar system has been installed and it is hoped that temporary delays due to building environment problems at the sites have been solved. The installed data collection system appears to work; when the front-end interface to DAN is installed early in 1986, data should start to come in from the radars. One magnetometer is installed at the Gillam site and soon Eskimo Point and Rankin Inlet will have magnetometers. The tellurics and riometers are also installed. The meridian scanning photometer has been undergoing rigorous tests and changes at NRC since last fall; photometer no. 1 will hopefully be in the field for automatic operation before too long. The All-Sky Imager is being fabricated at the University of Calgary.

(c) CANOPUS-VIKING Campaign (A.V. Jones)

The VIKING launch delay from October 1985 to February 1986 has been unavoidable. An extensive ground campaign had been planned from the CANOPUS sites in place of the CANOPUS magnetometer and optical instrumentation which would not have been ready even for January. This involves the deployment of one-degree campaign meridian scanning photometers at Rankin Inlet, Gillam and Pinawa and magnetometers using Apple IIe computers. All-Sky TVs and zenith photometers will provide additional information. The campaign has been rescheduled for 1986.

(d) Photometric Thermospheric Oxygen Nightglow Study (PHOTONS)(F.F. Harris, F. Creutzberg, R.L. Gattinger, E.J. Llewellyn)

This experiment, at the time of writing, is flying on the Space Shuttle (STS 61-C) as a Get Away Special. It is an optical, remote sensing payload with three basic objectives; to the role played by the $O_2(A^3$ state $\Sigma_u^+)$ state in the excitation of $O(^1S)$ and $O_2(b^1\ \Sigma_g^+)$ in nightglow; to measure the shuttle glow spectrum, with fractional Rayleigh sensitivity, over the wavelength range of 286 - 866 nm and explain the causes of the glow; and to evaluate the Get Away Special as a carrier for remote sensing optical experiments such as PHOTONS.

Bristol Aerospace provided the engineering and developed a sealed, ultraviolet-transmitting window for this payload. The flight-approved design for the window has been given to NASA and is available to other experimenters. INPE, Brazil is providing low latitude ground-based nightglow data for the flight period and will be collaborating in the interpretation of the results arising from the nightglow observations.

(e) BARS and Radio Aurora (A.G. McNamara, D.R. McDiarmid, B.A. McIntosh)

Considerable effort has been made at the BARS sites for the inspection, testing and acceptance of various installations and modifications to the radars and sites. The inadequacies of the original site environmental control systems have now been remedied. Satisfactory command and control via the dial-up lines has been achieved. Technical problems in using dedicated telephone lines has led to a major change in favor of geostationary satellite data transmissions, which are much more reliable and lead to error free data capture. The contractors, CAL and CNC, are developing and testing new software required for the satellite transmissions. During last year, software for sorting, collating and reconstituting the radar data received by the DCS has been compiled and tested in simulations. Real data have not been available but are expected shortly. The programs developed at Saskatoon to merge observations from the two radars have been integrated into a facility for displaying and visually scanning various aspects of the data. Analysis of previous auroral radar campaign data is continuing slowly.

(f) Plasma Probes (A.G. McNamara, J.M.-Chaker)

Data analyses of several earlier rocket flights have continued, giving particular attention to the analyses of ARIES-A and B for the auroral modelling campaign. Two papers have been written for the special ARIES publication, another extends the analysis of the plasma data from the injected electron beam experiment on AAF-NVB-06. The final probe experiment from the Canadian rocket program is still to be flown on COBRA from White Sands, probably during 1986. An invitation from Cornell University has been accepted to fly the plasma probe experiment on two American rockets in Greenland early in 1987.

(g) Meteor Radar Observations of Shower (B.A. McIntosh)

Analysis of the Perseid meteor shower (collaborator, M. Simek, Ondrejov Observatory, Czechoslovakia) is completed. The time of occurrence of the peak of the shower is determined with a greater precision than ever before at solar longitude 139.19±0.036 degrees (epoch 1950.0). The possibility of an unusually narrow central core in the shower is supported by our data.

(h) Comet Halley Meteor Stream

The two meteor showers associated with Halley's Comet - the Eta Aquarids, in May, and the Orionids, in October - will be subjected to intensive study in the next few years, coordinated by the Meteor Studies Discipline of the International Halley Watch. A world-wide study is expected to enhance both meteor science and comet science by determining the stream structure with high resolution, and thereby allow one to infer the method of dynamical evolution of dust, and by determining the physical properties and composition of the particles. Nearly twenty observatories plan to participate. The main observing techniques will utilize meteor radars, photoelectric devices, photographic methods (direct and spectroscopic), and visual recording (naked-eye and telescopic). The current passage of the Comet is not expected to cause an observable increase in meteor activity. The goals of the study are independent of this. The co-discipline specialists are: P.B. Babadzhanov, Dushanbe, USSR; A. Hajduk, Bratislava, Czechoslovakia; B.A. Lindblad, Lund, Sweden; B.A. McIntosh, NRCC, Canada.

(i) Comet Research (I. Halliday, B.A. McIntosh)

Observations of the inner regions of the coma of Comets Halley, Giacobini-Zinner and Wild 2 were obtained with the Canada-France-Hawaii telescope (CFHT) in September 1985. Giacobini-Zinner was observed during the night of the encounter with the ICE spacecraft; Comet Halley was further observed (using the IHW comet filters) in October and November with the CFHT although all three observing runs were affected by adverse weather. Data reduction of these and the previous observations from December 1984 are in progress.

(j) Meteorite Research (I. Halliday, A.T. Blackwell)

The 12 observing stations of the meteorite camera network in western Canada were closed down at the end of March 1985. Reductions are continuing on a group of fireballs chosen to represent an unbiased sample of large meteoritic bodies. Over 300 orbits have been reduced to date.

(k) Topographic Momenclature for Planets and Satellites (P.M. Millman)

A 457-page Annual Gazetteer of Planetary Nomenclature, dated 1986, has just been compiled for the Working Group for Planetary System Nomenclature (WGPSN) of the International Astronomical Union (IAU) under direction of the current chairman of the Working Group, Harold Masursky, U.S. Geological Survey, Flagstaff, Arizona. It contains a total of 4125 names of topographic features on 20 extra-terrestrial bodies in the solar system; most names have already been officially approved by the IAU for international use. This will help the production of the Gazetteer of Planets and Satellites, which will be on sale to the general public. The passage of Voyager 2 through the Uranian system of satellites and rings will require the addition of new names of satellites and topographic features in this group of bodies; the WGPSN has already approved naming newly discovered satellites of Uranus after mythical or fictitious minor characters from Shakespeare's plays.

8. University of Saskatchewan, Institute of Space and Atmospheric Studies

(a) Radio Auroral Studies Using Bistatic VHF CW Doppler Radar Links (G.J. Sofko, J.A. Koehler)

Major progress on the analysis and publication of the data from the summer campaigns from 1981, 1982, and 1983 occurred during 1985. The 1981 and 1983 campaigns involved radar scatter measurements from several radio links intersecting over Southend, Saskatchewan (magnetic latitude -64°) in the auroral zone, as a background for the BARS dual auroral radar system of CANOPUS: the 1982 campaign studied very high latitude scatter from over Sachs Harbour (magnetic latitude -77°), which is expected to be in the polar cap during magnetically disturbed periods,

and is near the cleft or throat region around magnetic local noon. A major new feature of our results is the frequent occurrence of ion-cyclotron spectral peaks, both at -28-30 Hz (probably O_2^+ or NO^+ or possibly N_2^+) and at -57 Hz (probably O^+). These peaks are seen only rarely by radars operating at near perfect aspect sensitivity (ΘB - 90°). This indicates that the ion-cyclotron waves have propagation vector components parallel and perpendicular to B such that $K_{||}/K$ can be as large as .20. These ion-cyclotron waves may occur simultaneously with ion-acoustic waves. Also, the ion-cyclotron peak on a path perpendicular to the electrojet current may be at -28 Hz while that from parallel to the electrojet may be at -57 Hz. One paper was published, and a paper in preparation shows some striking correlations between north-south optical auroral drifts, as seen with a meridian-scanning photometer at 5577 Å (operated by D.J. McEwen) and the corresponding Doppler shifts of ion- cyclotron echoes. This may indicate that the ion-cyclotron echoes could be produced by horizontal electrojet currents or particle drifts as well as by nearly vertical field-aligned currents (FAC).

Our by-product work on meteors has resulted in a paper which exploits a unique feature of our experiment - the ability to simultaneously measure E-region auroral drifts and D-region meteor drifts. The results were somewhat surprising, namely that although the meteor drifts from Southend (L-6) are in agreement with neutral winds measured by the partial reflection system (A.H. Manson) at Saskatoon during magnetically quiet periods, the meteor drifts become increasingly correlated with E-region auroral drifts as the magnetic activity increases, particulary in the period near magnetic local midnight. These results suggest that meteor drifts under high latitude disturbed conditions are not good indicators of neutral winds. The dependence of meteor drift on geomagnetic activity was observed by a meteor drift system operated for two years in Alaska by J.L. Hook (Planet. Space Sci., 18, 1623-1638, 1970), but Hook did not have simultaneous E-region auroral drifts. Strong auroral electric fields appear to cause the meteor plasma electron column to acquire a Hall drift component in addition to the usual neutral drift velocity. This result could have implications for MST radars, since they often use meteors to determine mesospheric drifts when, as is frequently the case, there is insufficient turbulence in the upper D-region to produce echoes.

Work on the 1982 campaign is nearing completion. M. McKibben is writing his thesis on the Doppler velocities obtained during the magnetic dawn to noon period (i.e. the cleft-associated period). A short paper recently written discusses E-region scatter from above Sachs Harbour (magnetic latitude -77°) during a moderately disturbed period when Sachs Harbour would be in the polar cap. This paper shows that the echo types observed - primary irregularities (of the ion-acoustic and, less frequently, the ion-cyclotron type) and secondary irregularities - are not very different from auroral zone echoes although the magnetic aspect angles are much less favourable over Sachs Harbour (-9.5 and 14 degrees for the two radio links looking roughly magnetic north and west, respectively). This behaviour is unexpected from existing plasma theory, and shows the need for new ideas regarding the nature of the scattering process. A more general paper on the echo structure for the whole campaign is almost complete. The campaign was dominated by echoes in the pre-magnetic midnight period (these may be strongly associated with the Harang discontinuity) which show a very strong bias towards southward motions out of the polar cap, near the polar cap-auroral zone interface. This campaign marked the first time anyone had made Doppler radar measurements at such latitudes with a system capable of both high time and spatial resolution, looking simultaneously in the E-W and N-S directions.

Our results show a unique signature for the onset of a substorm. It is well known that Pi2 pulsations are one of the best indicators of the substorm expansive phase onset, but our results show for the first time that there is an equally dramatic radar Pi2 signature of these onsets. T. Watanabe ran a four-magnetometer network in conjunction with radars in 1983, and his magnetometer records show excellent correlation with the radar data for the Pi2 events. A joint paper with Watanabe is in progress.

A comprehensive analysis of the ion-acoustic spectra pooled from all three campaigns has been completed. The aspect angle over the three campaigns varied from 1.5-14°. No other radar system has even taken comprehensive Doppler spectral measurements over such a range. The data analysis showed that the ion-acoustic spectral peak was commonly observed at all aspect angles in the range, with the Doppler velocity falling by only about 7 m/s for each additional degree of perpendicularity, a much slower rate of decrease than expected from current plasma theory, possibly requiring a novel explanation. One possibility is that the

effective electron collision frequency may be much higher than the usually assumed momentum-transfer value, due to orbit diffusion or anomalous resistivity or some related process.

(b) Aeronomy

The group's objective has been to improve our knowledge of the excitation mechanisms for various airglow and auroral emissions. We also had association with ground truth flights for the SME spacecraft and analysed the OGLOW experiment data. W. Brooks through an Industry/University iniative program, B. Solheim, NSERC post-doctorate and graduate student M. Gale have joined the group.

The solar mesospheric Explorer spacecraft observations of the 1.27 μ emission of molecular oxygen and the rocket results (SMERF) agree excellently. This latter flight (Churchill launch) within 20 minutes of the satellite overpass, included two TOI photometers to measure the dayglow infrared atmospheric oxygen emission at 1.27 μ and a third photometer to measure the atmospheric band at 762 nm. The height profiles derived from the TOI photometers were well within the error bars and indicated a maximum difference of 5%. The ability of instrument baffle systems to exclude scattered sunlight, suggests the suitability of the TOI photometer for the task of truthing the UARS spacecraft which will include the WINDII instrument to measure winds and temperatures in the mesophere and lower thermosphere. The second ozone layer's presence near 85 km was clearly identified in the SMERF flights and had the shape expected from the known seasonal variation. However, some scientists suggest that the second ozone layer may not exist but rather result from the measurement and analysis methods. In line with these ideas, we investigated the effect of vibrational excitation of ozone on the photolysis rate and have shown that it would be dissociated by wavelengths beyond the normal cut-off limit in a region of increasing solar output. Thus the J-value for vibrationally excited ozone is substantially increased above that for the ground state. However, the total excited state population in the atmosphere is such that the error in the second ozone layer concentration is typically < 10%.

For solar photolysis during auroral precipitation the electron impact could sometimes substantially increase the vibrationally excited populations. Thus the $O_2(a^1D)$ emission
in sunlit aurora could be much larger than that due to direct electron impact on O_2.

The pulsating aurora campaign observations have been analysed. The oxygen green line measurements indicated strongly an operative transfer mechanism; however, the excitation mechanism is not uniquely identified. For the O_2 atmospheric band the observations can be interpreted clearly. The pulsating aurora measurements clearly show the airglow emission can be identified below the weak auroral component. The absence of a predicted (from some ground-based observations) intense auroral emission, was used to identify the possible excitation mechanisms for the auroral red line. The $O(^1D)$ state is known to be quenched to the $O_2(b^1\ \Sigma_g^+)$ state, the source of the atmospheric bands. Note that the reaction between $N(^2D)$ and O_2 is not an effective source of $O(^1D)$ atoms; the suggestion is that direct electron impact on O atoms is the prime source.

For such effective excitation mechanisms the atomic oxygen concentration in the upper mesosphere and the lower thermosphere must approximate the CIRA 1972 model. Some investigators question such large concentrations, but we have shown that these values are consistent with the quenching of the N_2 Vegard-Kaplan bands in the aurora and the excitation of the atmospheric bands in the airglow. Recently, we have studied the possible airglow emission resulting from the recombination of oxygen atoms and have shown that the concentration must be close to $1X\ 10^{12}$. The ARIES (auroral) rocket campaign measurements will further clarify the excitation of the oxygen auroral emissions.

The rocket measurements from the ETON campaign designed to study the mesophere oxygen problems show that both the green line and the atmospheric band emissions must occur through a Barth type transfer process. In this analysis the precursor state could not be identified, although in a separate study, we have shown that if the $c^1\ S_u^-$ state were involved then the precursor state must be vibrationally excited. Also, the most probable vibrational levels for a transfer excitation were those in closest resonance to the green line energy. Such a vibrational dependence would make the laboratory confirmation of the excitation process quite difficult. As noted previously, the role of the $c^1\ S_u^-$ state in the auroral excitation of the green line is still uncertain.

The first Canadian astronaut flight (October 1984) provided a unique opportunity to obtain completely new airglow images and to derive emission profiles. The OGLOW experiment (P.I., D.J.W. Kendall, CCSS) was to measure the Shuttle glow in a high inclination orbit and to quantify the contamination effect for WAMDII. The observations made by M. Garneau indicated much weaker glow than previous Shuttle measurements. The inclusion of the airglow layer in these glow images provided an independent check on the recorded glow intensities. The observations revealed the glow spectrum as a continuum, at a resolution of 0.4 nm, although the emitting species could not be identified. The CCTV camera in the Shuttle cargo bay also made glow observations and revealed that the thruster-induced glow varied form firing to firing. The glow studies are to be repeated on the second Canadian astronaut flight, possibly in 1987. The airglow images of this experiment provide information on airglow intensity distribution and the temperature of the emitting layer. The spatial scanning technique, used to obtain wavelength information from these images, is quite similar to that planned for the atmospheric band observations with WAMDII and WINDII. Thus the OGLOW camera offers a valuable truthing experiment for the WAMDII/WINDII instruments.

We participated in field tests for the WAMDII instrument, operating a ground station at the Prince Albert National Park. For this work, we used an all-sky auroral TV and single channel photometers to provide detailed information of the auroral forms observed by WAMDII from Park Site (auroral TV camera, courtesy CCSS).

For the Shuttle atmospheric band observations, we had to consider the role of radiative transfer of the airglow emission when the layer is observed tangentially. Due to the long radiative lifetime of the excited state the analysis is much simpler than for the atomic oxygen resonance triplet at 130.4 nm. This latter system is important for both determination of the oxygen concentration, using resonance lamps, and the VIKING imager observation; we thus undertook an extensive analysis of line shapes in resonant scattering and showed that the line narrowing process can occur in the atmosphere further complicating the analysis of the measurements. A possible cooperative aeronomy program with Brazil may lead to a long duration balloon flight during September 1986 to measure the atmospheric ozone concentration profile above 35 km.

9. University of Victoria, Department of Physics (R.E. Horita)

Plasma Waves.

Counterstreaming ion (CSI) events observed on the ISEE-1 satellite were studied. In these events hydrogen and/or oxygen ions travel simultaneously both parallel and anti-parallel to the magnetic field direction. E.G. Shelley and W.K. Peterson (Lockheed) provided additional information; a paper is being prepared on proton cyclotron echoes and spurs; Canadian data from Alouette and ISIS satellites is under analysis. The Albert Head field site near Victoria was reopened during December 1985 to February 1986 to study the aurora and related geomagnetic and natural electromagnetic wave phenomena in collaboration with the University of Tokyo and the University of British Columbia.

10. York University, Centre for Research in Experimental Space Science

C.G. Shepherd spent a sabbatical at the Central Laboratory for Space Research, Bulgaria before Christmas 1985. In his absence, L. Cogger acted as WAMDII P.I., and W. Gault and R. Wiens looked after WINDII. Both experiments are scheduled for 1989 launch.

F. Hamade and R. Wiens have observed the 8446 Å emission in twilight, using a low resolution Fabry-Perot spectrometer. W. Ward has elegantly dealt with the non-linearity of piezoelectrics in his WAMI (Wide Angle Michelson Interferometer) data obtained during the Aries campaigns; J. Bird is converting this instrument into a polarizing WAMI with assistance from F. Liang, a visiting professor from China, and from B. Solheim. A portable WAMI will result and will prove handy for campaign-type field measurements.

Jun Lu has made progress with a new computer-controlled scanning wide-angle interferometer system; F. Liang has assisted in the computer interfaces and system electronics. Final assembly of main optical elements and precision translation devices and initial laboratory tests are to be done shortly.

A CANOPUS node at York (CANTOR) has been installed; the difficulties with Datapac/DECnet communications appear to be resolved. R. Koehler attended the fall CANOPUS network meeting. F. Liang and R. Koehler are developing and testing node-specific software and graphics software utilities for data handling/presentation.

Reduction of WAMDII field measurements made in winter 1984 at Saskatoon is progressing (collaborators K. Paulson, P. Kosteniuk and R. Wiens). WAMDII appeared on the cover of the June 1 issue of Applied Optics.

IV VOLCANOLOGY

Compiled by: Raymond Goldie

1. Introduction

Forty reports have been submitted from sixteen institutions: two federal government agencies, one provincial government agency, eleven universities and two consultants. The reports mostly concern field studies which are supplemented by laboratory work. Fifteen of the studies are principally concerned with Cenozoic rocks, four with Mesozoic rocks and twenty one with Precambrian rocks.

2. Geological Survey of Canada

(a) Iskut River - Telegraph Creek Map Areas (R.G. Anderson)

This is a continuing study which involves mapping at a scale of 1:250 000, geochronology and geochemical analyses. My objectives are to study the stratigraphy, age, structure and composition of Devonian to Recent volcanic sequences. Based on one field season's work, I am developing a coherent stratigraphy for the Jurassic volcanic package (which hosts lode gold deposits in this area). I also have some preliminary ideas of the Paleozoic and Triassic volcanic packages. I plan to continue mapping in 1986 with ancillary petrographic, geochronometric, biostratigraphic and geochemical analytical work.

(b) Volcanic Rocks of the Insular Belt: Queen Charlotte Islands, 53°N 132°W, Yakoun Group, Richardson Bay Formation (T.S. Hamilton)

This is a continuing study. Although this is basically a paleomagnetic study, with the objective of locating a Jurassic paleopole for the Queen Charlotte Islands fragment of the Wrangellia Terrane, I am also making petrologic studies of this calc-alkaline arc suite.

(c) Neogene Volcanic Rocks of the Pacific Ocean Basin: Kodiak-Bowie (also called Pratt/Welker) Seamount Chain, West of Queen Charlotte Islands (T.S. Hamilton)

This is a new study. I am employing petrological and geophysical studies to provide tectonic constraints on the Neogene evolution of the continent-ocean margin. So far, I have reviewed previous petrologic and geophysical studies of the chain. My plans are to undertake a series of cruises, beginning in 1986, to dredge samples and make profiles of the seamounts and adjacent seafloor. I also plan petrochemical and radiometric age studies of the samples thus acquired.

(d) Tertiary Volcanic Rocks of the Masset Formation, Insular Belt: Queen Charlotte Islands, 53°N 132°W (T.S. Hamilton)

This is a continuing study. I am using petrochemistry, petrography, paleomagnetism and mapping to place volcano-tectonic constraints on the Neogene evolution of the continental margin. In my 1985 field work, I concentrated on 1:10 000 and 1:20 000 scale mapping of a transect of Graham Island near latitude 53° 35' N and of a dissected rhyolite ignimbrite vent complex on West Moresby Island. I also studied some of the dykes in exposures of subjacent Mesozoic basement rocks on West Moresby. My plans are to perform detailed petrologic and petrogenetic studies on various lava suites within the Masset Formation, and paleomagnetic studies of core from the Naden well (of Bow Valley Industries et al.) on Northern Graham Island.

(e) Latest Cretaceous Sheeted Dykes of the Troodos Ophiolite, Cyprus (W.R.A. Baragar, Geological Survey of Canada; M.B. Lambert, Geological Survey of Canada; Baglow, Geological Survey of Zimbabwe; Gibson, University of Waterloo)

This is a continuing study with the objectives of determining the relations of the sheeted dykes, the lavas and the plutonic parts of the ophiolite. So far, we have found that the sheeted dykes cover the same range of compositions and show similar element variations as the Troodos pillow lava sequence. The dykes, however, are not as clearly defined into "less-depleted" and "more-depleted" suites as are the lower and upper pillow lavas respectively. Nevertheless, rocks with the same compositions as upper pillow lavas can be identified among the dykes by suitable chemical parameters. About 20-25% of the dykes sampled are of this compositional type. Such dykes show no preferred age relationships, unlike their counterparts in the lavas. This leads to the view that the ophiolite was formed from several magma chambers. Our plans are to perform probe analyses of relicts of primary minerals in the dykes to further compare the composition of the dyke magmas with those of the lavas and plutonic rocks.

(f) Stratigraphy and Petrology of the Late Aphebian Volcanic Rocks of the Circum-Superior Belt in the Eastern Hudson Bay Region (W.R.A. Baragar and others)

This is a continuing study of the petrography, mineralogy and geochemistry of the komatiitic and tholeiitic suites. Our objectives are to determine the primary composition of each of these suites and the effects of upper level fractionation. We have found that a large part of the variability in the komatiitic suite can be attributed to fractionation in the surface delivery system. The layered flow lenses, which we interpret as trunk distributors, are an important part of this system. The komatiitic rocks appear to have no genetic link with the tholeiitic lavas. Perhaps the two suites originated under different tectonic conditions (cf. Francis, Ludden and Hynes, 1983). We plan to continue our investigations of the chemical variability of flows and sills belonging to both suites. This may enable us to trace the high-level fractionation back to the primary or at least to the parental magmas. We will also examine the similarities of the inferred parental magmas at various places around the Circum-Superior Belt.

(g) Mineral Resources on the Seafloor (G.A. Gross)

This is a continuing study of rocks associated with recent and ancient metalliferous sediments. I have completed a manuscript, "Mineral Deposits on the Seafloor", which outlines types of metallic mineral deposits and factors controlling facies distribution in metalliferous sediments deposited by effusive hydrothermal systems.

(h) Resource Assessment of Western Labrador (T. Birkett)

This is a new study of the Proterozoic rocks of the Newfoundland and Labrador portion of the Labrador Trough. Although the primary objective of the study is metallogenic, I am examining the chemistry and physical volcanology of several volcanic sequences and associated gabbroic suites. I spent the summer of 1985 mapping and sampling selected areas around mineralized showings.

3. Geology Division, Northern Affairs Program, Indian and Northern Affairs Canada

(a) Relations of the Fluvial Sandstones and Conglomerates of the Jackson Formation to the Kam and Banting Group Volcanic Rocks, Yellowknife Archaean Volcanic Belt, Slave Structural Province (G. Bailey of the Geology Division, N.A.P., I.N.A.C., and H. Helmstaedt, Queen's University, Kingston, Ontario)

This is a continuing study, which will constitute G. Bailey's M.Sc. Thesis. We completed field work in 1985.

(b) Geological Mapping of the Western Edge of the Yellowknife Volcanic Belt, Fred Henne Park area (J.A. Brophy)

This study is terminating. Its objectives were to detail the geology of the Crestaurum Formation in an area that had previously been mapped only at a regional scale.

(c) Geological Mapping, Hepburn Island Area, 76 M (V.A. Jackson)

This is a continuing study. The objectives are to complete 1:50 000 scale maps of the Hepburn Island area and to compile a 1:250 000 quadrangle map and report. In 1985 I completed most of the field work.

(d) Geological mapping of the Quyta Lake Area, NTS 85 J/16, Archean Slave Structural Province Volcanic Rocks and Turbidites (V.A. Jackson, Geology Division, N.A.P., I.N.A.C. and H. Helmstaedt, Queen's University)

This is a continuing project with the objective of preparing a 1:50 000 scale map of the Yellowknife Volcanic Belt. We have completed field work and have begun petrographic and compilation work.

(e) Geochronology of Archean Slave Province Volcanic Belts (W.A. Padgham and V.A. Jackson, Geology Division, N.A.P., I.N.A.C.; S.A. Bowering, Washington University, St. Louis, Missouri)

This is a continuing study, with the objective of dating the major volcanic belts in the Slave Structural Province. In 1985, we sampled the Yellowknife Volcanic Belt and the High Lake Volcanic Belt.

(f) Yellowknife Volcanic Belt Project, Archean Slave Structural Province, N.W.T. (W.A. Padgham, Geology Division, N.A.P., I.N.A.C.; H. Helmstaedt, Queen's University and others)

This is a continuing project whose objectives are to compile new 1:10 000 geological maps of the Yellowknife Volcanic Belt and to relate the gold-bearing shear zones to the Belt's development. Since 1975, we have mapped at a scale of 1:10 000 those parts of the Yellowknife Volcanic Belt which had not been previously mapped at that scale. We will continue this project until new 1:10 000 scale geological maps have been prepared covering the whole Belt from the Mirage Islands, in the 85 J/1 area, north to the Clan Lake Volcanic Complex.

(g) Geological Mapping and Structural Studies of the Mirage Islands and Adjoining Parts, Archean Yellowknife Volcanic Belt, Slave Structural Province. (C. Relf and W.A. Padgham, Geology Division, N.A.P., I.N.A.C.; T. Rivers, Department of Earth Sciences, Memorial University of Newfoundland)

This is a continuing study. We have now mapped most of the Mirage Islands at a scale of 1:10 000.

4. E.W. Grove Consultants Ltd.

(a) Neogene Volcanism and Glaciation in Northwestern British Columbia (E.W. Grove)

This study is terminating. I have been examining the chemistry of Neogene flows and determining isotopic ages in order to date glacial stades and interstades.

(b) Geology of the Lower Jurassic Unuk River Formation and the Lower Middle Jurassic Betty Creek Formation, Iskut River Area, British Columbia (E.W. Grove)

This is a continuing geological and geochemical study of volcanic rocks and their relationships to gold mineralization.

(c) Geology of the Leech River Block, Vancouver Island, British Columbia (E.W. Grove)

This is a continuing geological and geochemical study of volcanic rocks and their relationship to gold mineralization.

5. K. Ashton, Geological Consultant

The Proterozoic Kisseynew Gneisses of Saskatchewan (K. Ashton, under a four-year ERDA contract with the Federal and Saskatchewan governments).

This is a new study. After one summer's mapping, I have found that there are at least three ages of volcanic rocks in this area. I am attempting to find out if they are geochemically distinct.

6. Ontario Geological Survey

(a) Archean and Possibly Proterozoic Rocks in Forbes and Conmu Township (M.W. Carter)

This is a new project. I have finished the field work. Volcanic rocks comprise komatiitic, tholeiitic, calcalkaline and shoshonitic rocks, and the calcalkaline and shoshonitic rocks belong to the Timiskaming. These rocks are intruded by thick gabbroic sills.

(b) Hawaiian Studies (R.M. Easton)

This is a continuing project. My objectives are to prepare a guide for geological field trips in Hawaii. I intend to publish the guide in time for the anniversary of the Hawaiian Volcanoes Observatory in 1987. I am also preparing a revised description of Kilauea's stratigraphy. This description will be in accord with the Code of Stratigraphic Nomenclature. I intend to complete the guide book by the summer of 1986. The stratigraphic revisions will be included in the United States Geological Survey's Professional Paper #1350.

(c) Archean Cyclic Volcanism in the Central Uchi Subprovince, Northwestern Ontario (G.M. Stott)

This is a new study, whose objectives are to define the nature and extent of volcanic cycles and their stratigraphic relationships.

7. McMaster University

B, Li and REE in Recent Rhyolites, Inyo Domes, Long Valley, California (M.D. Higgins)

This is a continuing study of the behaviour of B, Li and the REE during degassing and crystallization of rhyolites. Analysis of 60 surface and drill-core samples indicates that although none of these elements are lost during degassing, there is appreciable loss of B and Li following crystallization (devitrification). I hope to also examine Be and CO_2 abundances.

8. University of Toronto

(a) Major and REE Chemistry of Pleistocene-Recent Felsic Tephras in Copper River Basin, Alaska (P.C. Froggatt, Scarborough College)

This is a new study. My objectives are to establish the chemistry of felsic tephras as an aid to correlating these units and distinguishing their sources. I have determined major element compositions (by microprobe) and REE (by INAA) in glass and mineral separates from

tephras in sediments from the Copper River basin. I plan to carry out similar analyses on more samples to compare these analyses with those of tephras from other sources.

(b) Physical, Chemical, and Experimental Aspects of Subaqueous Explosive Volcanism in Archaean Rocks from Confederation Lake, Ontario; and Cretaceous Rocks from Guayama, Puerto Rico (J. Stix and M.P. Gorton)

This is a new study. Our plans are to develop an integrated model for subaqueous explosive volcanism.

(c) Geochemistry and Geochronology of Pyroclastic Deposits of Late Cenozoic Age in the Ethiopian Rift and the Middle Awash Basin of Ethiopia (R.C. Walter and J.A. Westgate, Scarborough College)

This is a continuing study. Our objective is to correlate proximal pyroclastic flows with distal air-fall deposits in the Middle Awash. Tephra beds in the Middle Awash Basin are associated with hominid-bearing sediments. These beds are typically thin and contaminated (due to reworking). Correlation of these beds with proximal flows in the Ethiopian Rift allows for development of a more reliable stratigraphic framework. Our studies involve geochemistry, fission-track dating, K-Ar dating, and palaeomagnetic analyses.

(d) Quaternary Tephrochronology of Alaska and the Yukon Territory (J.A. Westgate, Scarborough College)

This is a continuing study. My objective is to clarify the Quaternary stratigraphy of this area by dating and correlating widespread ash layers. In the past two years, I have mapped tephra sequences in the central Alaska region and the northern Yukon. I am characterizing these sequences by means of physical, chemical dating and palaeomagnetic studies. One of the most useful marker beds is the Old Crow Tephra, a unit which occurs across central Alaska and the western Yukon. I plan to continue laboratory studies, and to carry out field work in the eastern Alaskan Peninsula in 1987.

(e) Rare Earth Geochemistry of Archean Volcanic rocks of the Slave Province (A.M. Goodwin, Department of Geology, University of Toronto; V. Jackson, W.A. Padgham and W.A. Gibbins, Geology Division, Northern Affairs Program, Indian and Northern Affairs Canada, Yellowknife, N.W.T.)

This is a continuing study. Our objectives are to establish the rare earth contents of various volcanic belts of the Slave Province and to test the results for possible prospecting tools. In the summer of 1985, we collected additional samples from the Yellowknife Volcanic Belt and sampled two transects across the High Lake Volcanic Belt, one near High Lake and another on the James River.

(f) Tephrostratigraphy of Pleistocene Tephra Layers in the East Eifel Volcanic Field, West Germany (P. von den Bogaard, Scarborough College)

This is a new study. I am using petrography, XRF, NAA and Ar 40/39 dating in order to study the evolution of volcanism in the East Eifel and use tephrostratigraphy to correlate Pleistocene loess and soil sections. I have established criteria by which to distinguish the four major explosive phonolitic eruptive centres. These criteria are based on major, trace and rare earth element analyses of glass/matrix-separates. Preliminary Ar 40/39 ages indicate a bimodal age distribution of mafic eruptions, with peaks at around 250 000 yr B.P. and around 430 000 yr B.P. My plans are to do more REE and Ar 40/39 analyses, and to apply statistical methods to tephrostratigraphic correlations.

9. Queen's University

Geology of the Archaean Woodburn Group, North of Baker Lake, N.W.T. (K. Aston)

This is a terminating study which will establish the relative ages of a quartzite sequence and a metavolcanic suite. U/Pb dates indicate that both the quartzite sequence and the metavolcanic rocks are Archean. The metavolcanic rocks are chemically bimodal, indicating that they were deposited in an extensional environment, probably prior to

deposition of the clastic sequence. I am presently interpreting chemical analyses and trying to develop a depositional model for the two suites.

10. Carleton University

The Mina El Limon Area and the Telica Complex: Two Examples of Cenozoic Volcanism in Northwestern Nicaragua, Central America (D. Lefebure (now of Corporation Falconbridge Copper, Delta, B.C.))

I am completing this Ph.D. thesis.

11. University of Ottawa

Geological Mapping and Examination of the Gordon Lake Area in the Cameron River Archaean Volcanic Belt, N.W.T. (R. Gullen and W.K.S. Fyson, University of Ottawa; J.S. Seaton, Geology Division, Northern Affairs Program, Indian and Northern Affairs Canada).

This is a new study. Our objective is to prepare geological maps and structural, stratigraphic and economic evaluations of gold deposits in the Gordon Lake Area. We have begun geological mapping of the Fenton Lake area with emphasis on stratigraphy and structure.

12. McGill University

Origin of the Middle Proterozoic Onaping Formation, Sudbury, Ontario (J.S. Stevenson)

This is a continuing study. My objective is to gather and interpret field petrographic and chemical data supporting a volcanic origin for the Onaping Formation. All my new data, particularly petrographic and chemical, support such an origin. I plan to continue further study of field notes and petrography.

13. Acadia University

Field Relations and Geochemistry of Late Precambrian Volcanic Rocks (Coldbrook Group) in Southeastern New Brunswick (S.M. Barr)

This is a new study. My objectives are to interpret the tectonic setting of these rocks and their relationships to associated granitoid rocks. I mapped the Fundy National Park area at a scale of 1:25 000 during the summer of 1985. I am now examining the volcanic and granitoid rocks which I collected and plan to map an area to the north of this area in the summer of 1986.

14. Dalhousie University

(a) Geochemistry of Extrusive Rocks of the Troodos Ophiolite, Cyprus (P.T. Robinson and J.M. Mehegan)

This is a continuing study. We aim to determine the tectonic environment in which the Troodos Ophiolite formed. We have identified three lava suites, each geochemically similar to island arc sequences, and plan field studies to determine the stratigraphic relationships of these suites.

(b) Volcanism and Associated Mineralization of the Miocene-Pliocene Front in the Andes at 27°S (M. Zentilli)

This is a continuing petrologic, geochronologic, volcanologic, geochemical and metallogenic study. My objective is to unravel the evolution of the volcanic rocks and the associated gold and sulfur mineralization. I spent two months in the field in 1984 and 1985. Subsequent laboratory work includes geochronology (40 Ar/39 Ar), geochemistry of major and trace elements, sedimentology of ignimbrites up to 30 km away from their probable source, and geochemical study of areas of alteration and precious metals mineralization. I plan further geochronological work, mapping, and detailed studies of tectonics and the distribution of precious metals.

15. St. Mary's University

(a) Geochemistry of Non-Orogenic Volcanic Rocks from the Canadian Shield, Appalachian Belt, Liberia, Algeria, Sardinia, and French Polynesia (J. Dostal)

This is a continuing study. I aim towards a better understanding of the origin and evolution of these rocks and the relationship between lava composition and tectonic setting. Two main types of projects are underway: (i) a study of the relative importance of processes such as fractional crystallization, crustal contamination and partial melting in the evolution of continental tholeiite; (ii) elucidation of the relationship between Cenozoic alkali basalts and their xenoliths, and the heterogeneity of the upper mantle.

(b) Petrogenesis of the Late Proterozoic Natkusiak Continental Plateau Basalts, Victoria Island, N.W.T. (J. Dostal, St. Mary's; W.R.A. Baragar, Geological Survey of Canada; C. Dupuy, Centre Géologique et Géophysique, Montpellier, France)

This is a continuing geochemical and petrographic study of these flows and accompanying sills. Our objectives are to determine the composition of the mantle source of typical continental basalts. So far, we have found that the Natkusiak basalts can be divided into two fractionated cycles. The effects of crustal contamination decline up the section. The upper lavas, which are contaminated but little or not at all, show evidence of derivation from a depleted mantle source very similar to that from which N-type MORB is derived. We plan to complete this study by preparing a synthesis of the petrographic, geochemical, and mineralogical data for the basalts and accompanying sills.

16. Colorado School of Mines

Geology and Genesis of the Selbaie Polymetallic Sulphide Deposits, Northwestern Quebec (R.Y. Watanabe)

I intend to complete this Ph.D. study this year. My objectives are to reconstruct the volcanic setting and to decipher the stratigraphy and ore controls.

17. Johns Hopkins University

Basement-Supracrustal Structural Relationships in the Archean Slave Structural Province (T. Kusky)

This is a new study. My objectives are to elucidate the relationship between greenstone belts and basement granitoids. I have spent a season in the Sleepy Dragon Lake area studying contact relationships between the basement complex and the Cameron River Volcanic Belt. Structural evidence suggests that the supracrustal rocks have been thrusted over the basement.

18. Bibliography

Allard, G.O. and Gobeil, A. 1984. General geology of the Chibougamau region. In: Chibougamau Stratigraphy and Mineralization. J. Guha and E.H. Chown (Editors), Can. Inst. Mining Metal., Special Volume 34.

Allard, G.O., Caty, J.L. and Gobeil, A. 1985. The Archean supracrustal rocks of the Chibougamau area. In: Evolution of Archean Supracrustal Sequences. L.D. Ayres, P.C. Thurston, K.D. Card and W. Weber (Editors), Geol. Assoc. Can. Special Paper 28, 55-63.

Aston, K.E. and Wheatley, K. 1985. The Kisseynew Gneisses of Saskatchewan: Preliminary Report. In: Summary of Investigations 1985, Saskatchewan Energy and Mines, Saskatchewan Geological Survey Miscellaneous Report 85-4.

Bailey, G. 1985. Stratigraphic relations in the upper part of the Yellowknife Belt. Exploration Overview, Indian and Northern Affairs Canada.

Baragar, W.R.A. 1985. Paleomagnetism of the komatiitic basalts of the Ottawa Islands, N.W.T. Can. J. Earth Sci., 22, 553-566.

Barr, S.M., Brisebois, D. and Macdonald, A.S. 1985. Carboniferous volcanic rocks of the Magdalen Islands, Gulf of St. Lawrence. Can. J. Earth Sci., 22, 1679-1688.

Bogaard, P. von den and Schmincke, H-U. 1984. The eruptive center of the Late Quaternary Laacher See tephra. Geologische Rundschau, 73, 933-980.

Daigneault, R. and Allard, G.O. 1984. Evolution tectonique d'une portion du sillon de roches vertes de Chibougamau. In: Chibougamau Stratigraphy and Mineralization. J. Guha and E.H. Chown (Editors), Can. Inst. Mining Metal., Special Volume 34.

Dostal, J., Dupuy, C. and Poidevin, J.L. 1985. Geochemistry of Precambrian basaltic rocks from the Central African Republic (Equatorial Africa). Can. J. Earth Sci., 22, 653-662.

Dupuy, C., Dostal, J. and Traineau, H. 1985. Geochemistry of volcanic rocks from Mt. Pelée, Martinique. J. Volcanol. Geotherm. Res., 26, 147-165.

Dupuy, C., Dostal, J., Capedri, S. and Venturelli, G. 1985. Geochemistry of ophiolites from Northern Pindos (Greece). Bull. Volcanol., 47, 39-46.

Helmstaedt, H., Bell, R., Ellis, C., Howson, S., Jackson V. and Relf C. 1985. Geology of Sito Lake area, 85 J/16, Indian and Northern Affairs Canada, EGS 1985-10.

Jackson V.A. 1985a. Geology of the Eastern Hepburn Island area (76 M), Exploration Overview, Indian and Northern Affairs Canada.

Jackson V.A. 1985b. Geology of Quyta Lake Area (86 J/16), Exploration Overview, Indian and Northern Affairs Canada.

Jackson, V.A., Crux, J., Ellis, C.E., Howson, S., Padgham, W.A. and Relf, C. 1985. Geology of the Mistake Lake area, Anialik River greenstone belt, N.W.T., 76 M/11, Indian and Northern Affairs Canada, EGS 1985-5.

Kusy, T.M. 1985. Thrusting between the Cameron River Greenstone Belt and the Sleepy Dragon Metamorphic Complex, Slave Province, District of Mackenzie. Exploration Overview, Indian and Northern Affairs Canada.

Moores, E.M., Robinson, P.T., Malpas, J. and Xenophontos, C. 1984. A model for the origin of the Troodos massif, Cyprus, and other Mideast ophiolites. Geology, 12, 500-503.

Murphy, J.B., Cameron, K., Dostal, J., Keepi, J.D. and Hynes, A.J. 1985. Cambrian volcanism in Nova Scotia. Can. J. Earth Sci., 22, 599-606.

Padgham, W.A., 1985. Observations and speculations on supracrustal successions in the Slave Structural Province. In: Evolution of Archean Supracrustal Sequences. L.D. Ayres, P.C. Thurston, K.D. Card and W. Weber (Editors), Geol. Assoc. Can. Special Paper 28, 133-151.

Robinson, P.T. and Stewart, J.H. 1984. Upper Oligocene ash-flow tuffs of western Nevada. U.S. Geological Survey Professional Paper 1557, 53 pp.

Robinson, P.T., Brem, G.F. and McKee, E.H. 1984. The John Day Formation of Oregon, a record of early Cascade volcanism. Geology, 12, 229-232.

Westgate, J.A. et al. 1985. Distribution, stratigraphy, petrochemistry, and palaeomagnetism of the late Pleistocene Old Crow tephra in Alaska and the Yukon. Can. J. Earth Sci., 22, 893-906.

V ISOTOPE STUDIES AND GEOCHRONOLOGY

Compiled by: A. Hayatsu

1. University of Alberta, Department of Physics (G.L. Cumming and J. Gray)

(a) Instrumentation

Our MM354 instrument has recently had the automatic collector installed and the machine is functioning reasonably well. Minor problems have been resolved and we have verified the excellent performance claimed for the instrument on Sr, Nd and U. Tests are still ongoing for Pb. The machine will be in routine operation during 1986.

(b) Radiogenic Isotope Studies

(i) Molson Dykes. A complex pattern of resetting of the U-Pb system which is not evident in the visible appearance of samples from a single outcrop area indicates an original age of about 2440 Ma and a resetting at 1960 Ma. Smaller dykes show younger resetting ages or erratic data unsuitable for dating.

(ii) Portman Lake. An area of late Archean rocks in northern Saskatchewan and the adjacent Northwest Territories has been studied by U-Pb on zircons, Pb-Pb whole rock and mineral dating. Ages range up to 2600 Ma and no evidence of Hudsonian resetting of any of the U-Pb systems is evident. These results confirm earlier work using K-Ar and Rb-Sr systematics carried out some years ago by members of the Geology Department.

(c) Stable Isotope Studies

(i) A tree ring cellulose study in collaboration with B.H. Luckman at the University of Western Ontario has been completed. The study involved $^{18}O/^{16}O$ measurements on cellulose extracted from Picea engelmannii and Abies lasiocarpa from the Canadian Rockies close to the Columbia Icefield. Significant correlations with mean annual temperature were found. However, unexplained anomalies in some data indicate that the ring width effects may reduce this correlation.

(ii) Measurements of $^{18}O/^{16}O$ and $^{17}O/^{16}O$ have been made on heavy water samples from the Bruce Heavy Water Plant and on moderator water samples from Douglas Point and Pickering nuclear generating stations. Enrichments of >50% in ^{17}O and >100% in ^{18}O were found. This enrichment was shown to occur exclusively in the finishing (distillation stages) and not in either the Girdler-sulfide chemical exchange or the electrolytic upgrading stages.

(iii) Stable isotope studies of fluid inclusions have been carried out on a number of systems in collaboration with R. Morton of the Geology Department, University of Alberta.

2. University of British Columbia, Department of Geological Sciences (R.L. Armstrong).

(a) Insular Belt

Our LITHOPROBE studies are now complete and a series of papers are in preparation - on the Sicker Group, the geology and geochronometry of the West Coast Complex, geochronometry and Sr isotopes of Mesozoic and Cenozoic igneous rocks, and petrochemistry of the Mesozoic and Cenozoic igneous rocks.

(b) Coast Plutonic Complex

J. Gabites has completed her M.S. thesis on the Settler Creek area east of Harrison Lake in the Coast-Cascade overlap region. Her Sr isotopic data for Settler Schist is identical to results for the Chiwakum Schist of the Cascade Mountains in Washington, analyzed by J. MacLoughlan of the University of Washington in our laboratory. This is further confirmation of a more than 100 km offset along the Fraser fault system. The presence of Precambrian, Yellow Aster Complex, tectonic slivers in the area and Precambrian detrital zircons in the Settler Schist was also demonstrated. All of the Jurassic(?) and older eugeosynclinal rocks are intruded by Cretaceous and Cenozoic plutons.

P. van der Heyden is continuing his Ph.D. thesis study of the Prince Rupert-Whitesail Lake region using U-Pb dating. His rocks range in age from Early Paleozoic in the Alexander Terrane to Eocene in the eastern part of the batholith. Other U-Pb dates are in progress for samples from Bella Coola, Bridge River, and Vancouver areas.

In the northern Coast Plutonic Complex near Stewart a detailed geochronometry for Triassic-Jurassic magmatism and mineralization now exists due to the U-Pb aspects of Ph.D. thesis work of D. Alldrick and M.S. thesis work of D. Brown. The area between Stewart and Prince Rupert has been covered in a regional Sr isotopic study by K. Scott. There, the largest body of rock is of Eocene age and constitutes much of the Ponder pluton, but near Prince Rupert part of the Ponder pluton is late Cretaceous by U-Pb and Rb-Sr dating done for M.L. Louise Hill of Princeton University.

(c) Intermontane Belt

R. Freidman has finished mapping gneisses in the Tatla Lake area on the western edge of the Intermontane Belt. He has discovered an overall domal exposure of mylonite and mylonitic gneiss overlying higher grade gneiss. Low grade, Jurassic(?), mostly metavolcanic rocks of the Intermontane Belt lie structurally above all of these rocks. Minor structures indicate west vergence and the implications are that the area is a window exposing infrastructure on a Tauern Fenster scale. U-Pb geochronometry of early, syn- and post-kinematic plutons is now in progress. In this area, all K-Ar dates are Eocene. The geology here has much in common with the metamorphic core complexes of the Omineca Belt but the tectonic setting is quite separate.

N. Mortimer (Killam postdoctoral fellow) has been studying the Nicola Group from a stratigraphic and petrochemical standpoint. He has collected a Triassic(?) biotite ankaramite for K-Ar dating and a Guichon batholith sample for U-Pb dating. Other Intermontane Belt plutons are being dated in an honours thesis project by A. Jung. His study includes the Jurassic Thuya and Takomkane batholiths and the Cretaceous Raft and Baldy batholiths. The Raft straddles the Intermontane-Omineca Belt boundary. His data should locate the initial Sr 0.704 line at 51°N. S. Gareau is dating a Cretaceous Selwyn Plutonic Suite stock in the Yukon for her honours project.

(d) Omineca Belt

D. Parkinson has completed his M.S. thesis on the Okanagan Valley fault zone, an Eocene, low angle, core complex boundary fault. His study included related U-Pb geochronometry. Rb-Sr data and a Sm-Nd isotopic analysis of Shuswap paragneiss, the latter run by V. Bennett at U.C.L.A., indicate that these gneisses along the Okanagan Valley are Precambrian, and similar in age to the Frenchman Cap Dome core gneiss. A Precambrian age has also been obtained for Grand Forks gneisses near the Kettle River. The tectonic implications of these results are major - all of Quesnellia east of the Okanagan Valley is a thin allochthon. The

Precambian rocks are probably the basement upon which the miogeocline and continental margin plastic wedge were deposited.

J. Mortensen continued his U-Pb dating of Quesnell Lake Gneiss in the Cariboo region. A Paleozoic age is now established for several bodies of S-type and alkalic plutons which have counterparts from the Sierra Nevada to Alaska. The Trail Gneiss, another Paleozoic body, has also been dated. J. Mortensen dated the Hellroaring Creek stock as 1340 Ma by U-Pb, very close to the Rb-Sr data published by Ryan and Blenkinsop in 1971 for the S-type pluton in the Purcell Geanticline. The late Paleozoic age for a post deformational tonalite pluton in the Sylvester allochthon adds a complication to the history of the Slide Mountain Terrane.

(e) Mantle

Sun Min completed his M.S. thesis - analysing the minerals of ultramafic rocks for Rb/Sr ratio and Sr isotopic composition. Precambrian and Paleozoic mineral isochrons establish that nodules in alkalic basalts of the Omineca Belt come from an underlying enriched mantle lithosphere and have nothing to do with Cenozoic magma genesis. Sun Min also obtained reproducible Paleozoic Rb-Sr mineral isochrons for the Josephine Peridotite of southwestern Oregon.

(f) Cenozoic Volcanic Rocks

L. Erdman's M.S. thesis on the chemistry of six Late Cenozoic volcanic suites from B.C. and the adjacent ocean floor has evaluated the usefulness of tectonic discrimination diagrams based on both major and minor elements. Her data show that many diagrams successfully distinguish arc and within-plate magmas, even in a continental margin environment, but that different types of within-plate magmas cannot be distinguished from one another. Nearly all of the rocks she analysed also have Sr isotopic data and these will be the first candidates for Pb and Nd analyses in the future.

(g) Foreign

A paper by Ronggui Sun of Peking University and others reporting Rb-Sr and K-Ar dates for Archean gneisses from the Sinokorean Platform is in preparation. E. Agyei, a CIDA fellow, is now revising his paper on Rb-Sr and K-Ar dating of basement rocks in Ghana. He has completed calibration of Sm-Nd spikes and standards.

We have dated Early Jurassic blueschists (Raspberry Schist) in Alaska for S. Roeske of U.C. Santa Cruz and Early Paleozoic blueschists (Skookum Gulch occurrence) of the Klamath Mountains in California for S. Cotkin of the University of Wisconsin.

3. University of Calgary, Departments of Physics (H.R. Krouse, C.J. Bland, C. Yonge, A. Ueda), Geology and Geophysics (F.A. Campbell, I. Hutcheon, A. Oldershaw, R.J. Spencer, J. Nicholls, A. Levinson), Geography (S. Harris), Archaeology (J. Kelly), Biology (E. Laishley, R. Davies), Chemical Engineering (D. Bennion, G. Moore), Medicine (H. Parsons), Kananaskis Centre for Environmental Research (A. Legge).

Projects

(i) Trace sulphide and sulphate in carbonates, silicates, and phosphates. Meterorites; volcanic rocks of western Canada; Devonian reefs, Alberta; Precambrian carbonates (B.D. Ricketts, ISPG; E.M. Cameron, GSC; P.I. Abell, University of Rhode Island); teeth; kidney stones; bones of animals on cassava diets (B. Kennedy).

(ii) S and O isotopes in sulphate. Soil; springs (R. van Everdingen, Environment Canada); body fluids (J. Thirsk).

(iii) C, S, O isotopes in sedimentary rocks. Permian carbonates, Sverdrup Basin (B. Beauchamp); Swan Hills reef buildups (C. Viau), Wabamun Formation (L. Eliuk, Shell Canada).

(iv) S isotopes in S pollution studies. Air; water; soil and vegetation (G. Latonas, Western Research Division of Bow Valley Resources); insects and higher animals in Alberta.

(v) S isotopes in food chain studies. Arctic food chain; Heron Island, Great Barrier Reef; kangaroos and koala bears.

(vi) C isotopes in food chain and paleodiets. In addition to topics under (v); aquatic insects in mountain streams (M. Kavanagh); buffalo bones at jump sites (N. McKinnon); kidney stones.

(vii) Hydrology, glaciology. Stratified lakes in the Arctic (M. Jeffries, University of Alaska), Ward Hunt Ice Shelf (M. Jeffries); rock glaciers (W. Blumstengle).

(viii) C, H and/or S isotopes in natural gases, petroleum, coal. Arctic (Panarctic); East Coast (Petro-Canada; sour gas in Wabamum Formation (L. Eluik, Shell); noble gases (E. Mazor, Israel; B. Kennedy, Berkeley); coal in western Canada; monitoring of in situ steam and combustion recoveries of heavy oil; sewage treatment plant.

(ix) Disequilibrium of uranium and thorium minerals.

(x) Isotope fractionation during bacterial conversions.

(xi) S and C isotope composition of gases evolved during pyrolysis of fossil fuels.

4. Dalhousie University, Departments of Geology and Physics (P.H. Reynolds)

Two mass spectrometer systems continue to be in routine operation: (i) a modified MS10 now interfaced to an Apple computer, and (ii) a Micromass 602D which is equipped with an on-line carbonate extraction system. Acquired this year was a Nd: YAG high power laser which will be used to melt individual mineral grains for argon dating. It is hoped that this can be done directly from a thin section without mineral separation.

(a) $^{40}Ar/^{39}Ar$ Geochronology

Graduate student P. Elias has completed the major portion of his work on the igneous and metamorphic rocks of southwestern Nova Scotia. Well-defined apparent age plateaus are found in the case of many of the samples. However, many other spectra are discordant and a number have been completely over-printed, apparently in Carboniferous times. The latter event has been dated in the mining district at East Kemptville, N.S. by Zentilli and Reynolds (1985); more recently, it has been detected in the potassium feldspar age spectra of samples collected from the large South Mountain batholith (A. Grist, honours student). It now appears that low-grade slates once thought to be relatively simple K-Ar systems tend to yield complex age spectra in which irradiation-induced effects may play a part.

Under the general supervision of R.A. Jamieson, graduate student, H. Plint is studying a suite of metamorphic rocks from the NW Cape Breton Highlands. She plans to use $^{40}Ar/^{39}Ar$ age data along with experimentally-determined metamorphic P-T paths to elucidate metamorphic/ tectonic history in this region.

Work continues on a number of smaller projects: (i) in collaboration with M.E. Brookfield (Guelph University) on the Indus Suture Zone, (ii) continuing studies of the Mealy dykes of Labrador in an attempt to put constraints on the ages of paleomagnetic poles, (iii) a study of a late Precambrian dyke swarm in southeastern New Brunswick thought to be related to continental rifting and the opening of the Iapetus Ocean (with W.H. Blackburn and others, University of Kentucky).

(b) Stable Isotope Studies

Graduate student, C. Ravenhurst (with P.H. Reynolds and M. Zentilli) has completed over 100 carbon/oxygen isotopic analyses on carbonates associated with the mineralization at Gays River, N.S. and with a number of other Carboniferous deposits in the Shubenacadie Basin. A collaborative research project (with J. Blenkinsop, Carleton University through a DSS contract) has produced over forty $^{87}Sr/^{86}Sr$ isotope ratios on carbonates and barites from these deposits. It seems that strontium and lead were derived from the surrounding metasediments (and granites) and were introduced into the host carbonates by means of a hot (200°C) basinal brine. Sulphur and carbon isotopic compositions in the deposit can be understood in terms of changing oxidation state in the ore fluid.

5. McMaster University

(a) Sulphur and Carbon Isotope Geochemistry (H.G. Thode, Department of Chemistry)

(i) Precambrian Evolution. Work in progress includes isotope geochemical studies of the major Precambrian banded iron formations of the world to resolve problems as to their origin and mode of formation, and possible role of living organisms in the early Precambrian.

(ii) Archean Gold Ores and Bedded Barites. $\delta^{34}S$ and $\delta^{13}C_{CO_2}$ distribution patterns in the unique late Archean gold ore deposits at Hemlo, Ontario, containing bedded barite coexisting with pyrite are being studied in depth. The source of sulphate and its introduction into a hydrothermal system and the genetic relationship between isotope exchange, barite and pyrite deposition and metal mineralization, are under investigation.

(iii) Environmental Studies. Investigation of sulphur content, isotope ratios and microbiota populations in soft water and lake sediments are being carried out in an attempt to identify natural and anthropological sources of sulphur, and from down core profiles, to follow environmental changes over the past century. $\delta^{34}S$ profiles both for the water columns and sediment cores for merimictic, seasonally stratified and aerated lakes at different sulphate loading are obtained.

(b) Sr Isotopic Studies (R.H. McNutt, Department of Geology)

New mass spectrometer and chemistry laboratories were built during this year. The former houses a VG354, now operational, a solid source machine and the SCIEX ICP/MS. The latter instrument continues to have problems eighteen months after installation. With a final retrofit (January 1986) most of the bugs should be gone and it will become a reliable analytical tool. The chemistry laboratory has taken eight months longer to complete than predicted. We hope it will give us the low blank levels we want for Rb-Sr, Sm-Nd and Pb analyses.

An Sr isotopic study of brines in crystalline rocks of the Shield has been expanded to look at dilute waters and at a wide range of host rocks. In addition, brines from operating gas wells in S.W. Ontario have been analyzed, with host rocks varying in age from Cambrian to Devonian. A comparison of the Sr isotopic composition of a Cambrian hosted brine and a calcite cement in the host rock show identical values.

6. Queen's University, Department of Geological Sciences (E. Farrar, J.A. Hanes, D.A. Archibald, S. Clark, R. Langridge, S. Heinrich, P. Chaursiri, M. Gerasimoff, L. Wong)

The argon extraction system has been rebuilt and is used on-line (to a modified MS-10 mass spectrometer) for conventional K-Ar dating and with a Lindberg furnace for high-resolution $^{40}Ar/^{39}Ar$ step-heating experiments. Recently a fission track dating facility has been reactivated. Several geochronological investigations are currently underway.

(a) South American Studies

(i) Investigations into the tectonic, magmatic and metallogenic evolution of the Cordillera Carabaya, S.E. Peru (D.J.K., Ph.D. 1985; E. Farrar) have revealed a close temporal and spatial relationship between Sn-W-base metal mineralization and specific magmatic and tectonic events. In addition, a 500 km long zone of thermal overprinting of enigmatic orgin (the Zongo-San Gaban zone) has been identified.

(ii) An isotopic (K-Ar) and petrologic study (L.F., M.Sc. 1985; E. Farrar) of Neogene volcanic rocks from southern Peru has been completed.

(iii) A paleomagnetic investigation (R.Langridge) in southern Peru is underway. The aim of this study is to compare the remnant magnetizations of rocks of known age (E.Farrar) in the Andes with magnetizations of rocks of comparable age from cratonic South America. The overall objective is to examine the tectonic integrity and history of this portion of the Andes. Well constrained poles have been obtained for the Precambrian Arequipa Massif and for Cretaceous plutons in S. Peru that support the previously determined counter clockwise rotation. The timing of the the rotation is being investigated.

(iv) A study is in progress (S.Heinrich; E. Farrar) to examine the tectonic and thermal history of the Zongo-San Gaban zone in the Cordillera Oriental of Bolivia and Peru. Geomorphologic studies combined with K-Ar, $^{40}Ar/^{39}Ar$ and fission track dating will be used.

(b) Canadian Cordillera

(i) Kootenay Arc and neighbouring regions. A study of the geology and geochronology of the southern Kootenay Arc and Purcell Anticlinorium, B.C. (D.A. Archibald; E.Farrar) continues. The study comprises conventional K-Ar dating as well as $^{40}Ar/^{39}Ar$, U-Pb (with T. Krogh, R.O.M.) zircon dating, Rb-Sr studies (with R.L. Armstrong), and fission track dating of apatites of selected plutons. The study has succeeded in elucidating the thermal and tectonic history of the southern Kootnay Arc and Purcell Anticlinorium from Precambrian to Eocene time. A $^{40}Ar/^{39}Ar$ study of dykes in the Irene Volcanics (Windermere Supergroup near 49°N) complements this work and supports the idea of an early Cambrian thermal event possibly related to the collapse of the miogeocline.

(ii) Other studies in the Canadian Cordillera. In a $^{40}Ar/^{39}Ar$ study (D.A. Archibald) of the west flank of Frenchman's Cap dome from the core zone to the Anstey pluton, biotite and muscovite yield concordant or nearly concordant K-Ar dates between 45 and 55 Ma. In contrast, hornblende yielded mid- to late-Cretaceous K-Ar dates (117 to 88 Ma). $^{40}Ar/^{39}Ar$ step-heating results for hornblende reveal a component of excess argon as well as complex age spectra with two plateau segments (~185 and ~110 Ma). These results highlight the problems associated with interpreting conventional K-Ar hornblende dates for high-grade metamorphic rocks. Other studies include a $^{40}Ar/^{39}Ar$ and U-Pb zircon study (M. Gerasimoff, E. Farrar with T. Krogh, R.O.M.) of plutonic and metamorphic rocks on the northeast margin of the Shuswap Metamorphic Complex, Wells Gray Provincial Park, B.C.; a K-Ar and $^{40}Ar/^{39}Ar$ study (D.A. Archibald) of metamorphic rocks near the Purcell thrust (Canoe River map-area); and an isotopic study (K-Ar, $^{40}Ar/^{39}/Ar$), step heating and fission track dating of selected intrusive bodies in the Selwyn Mountains north and east of Cantung, N.W.T. (D.A. Archibald).

(c) Studies of Ore Deposits

(i) An isotopic study of the Lake George antimony deposit (D.A. Archibald) in southern New Brunswick is underway. K-Ar mica dates for a variety of rocks suggest that mineralization is not younger than Late Silurian. A $^{40}Ar/^{39}Ar$ study of these samples is in progress.

(ii) A $^{40}Ar/^{39}Ar$ study of the Mt. Pleasant Sn deposit is in progress (D.A. Archibald). Results to date suggest that the age of mineralization is Late Devonian and that the area was affected by a low temperature thermal event in Triassic-Jurassic time.

(iii) In cooperation with A.H. Clark, a K-Ar study (D.A. Archibald, E. Farrar) of selected W mining districts in Korea is in progress. K-Ar dates (80 to 1700 Ma) and $^{40}Ar/^{39}Ar$ age spectra suggest a complex thermal history for these areas.

(iv) In cooperation with A.H. Clark, a $^{40}Ar/^{39}Ar$ study (P. Chausiri, E. Farrar) of W mining districts in Thailand has been initiated.

(d) Precambrian studies

(i) An ongoing $^{40}Ar/^{39}Ar$ thermochronometric study (J.A. Hanes, S. Clark) of the Grenville Elzevir trondhjemite in southeastern Ontario has demonstrated that Grenville muscovite is an ideal thermochronometer. Results from plagioclase and K-feldspar cast doubt on earlier models of protracted cooling for the Grenville, and also indicated a low-temperature Ordovician hydrothermal event. This work will be extended as a $^{40}Ar/^{39}Ar$ thermochronometric transect of the Grenville Front from Montreal to Val d'Or (with J. Martignole, Université de Montréal). Electron microprobe studies of the mineral phases dated will be related to the $^{40}Ar/^{39}Ar$ age and diffusion data.

(ii) In a study (J.A. Hanes, L. Wong) of the tectonothermal history of the Archean Abitibi greenstone belt, $^{40}Ar/^{39}Ar$ thermochronometry and U-Pb dating (with T. Krogh,

R.O.M.) are being used to elucidate the timing of late stage plutonic activity and major gold mineralizing events in Sigma Mine in Val d'Or, Quebec (with F. Robert, G.S.C.).

(iii) $^{40}Ar/^{39}Ar$ geochronology (J.A. Hanes, D.A. Archibald) of diabase dyke swarms in the Wawa-Kapuskasing-Abitibi transect of the Canadian Shield is providing information on the long-term tectonothermal history of these regions.

(iv) $A^{40}Ar/^{39}Ar$ study (D.A. Archibald, E. Farrar, J.A. Hanes with J. Percival, G.S.C.) of the sheared eastern margin of the KSZ is in progress. Initially, this study of sheared and unsheared granitic and amphibolitic rocks was undertaken in an attempt to resolve the time of brittle deformation in the Ivanhoe Lake fault zone. This study has been incorporated into a regional $^{40}Ar/^{39}Ar$ study of the KSZ and western Abitibi greenstone belt as part of a LITHOPROBE transect.

7. University of Toronto, Department of Physics (R.M. Farquhar)

(a) Hafnium-176 Measurements

P.E. Smith has completed a series of measurements of Hf and Lu concentration, and $^{176}Hf/^{177}Hf$ determinations, in whole rocks and zircons from the Gamitagama and Michipicoten greenstone belts of the Canadian Shield. ^{176}Hf is produced by the long-lived decay of ^{176}Lu, but is highly and selectively concentrated in zircons. Since zircons can be accurately dated by the U-Pb method, the variation of $^{176}Hf/^{177}Hf$ in crustal/subcrustal source reservoirs can be accurately charted. Data obtained indicate that a major fractionation of mantle into depleted mantle, upper, and lower crust appears to have taken place in the region of Shield rocks about 2.9 Ga ago.

(b) Lead-Uranium-Thorium Measurements

P.E. Smith has also studied the lead, uranium and thorium concentrations and lead isotope systematics in rocks and mineral of the Gamitagama and Michipicoten greenstone belts. Leaching experiments on sulphides from these rocks (which are well-dated) suggest that lead isotope variations can provide useful age information about the time of deposition. Investigation of the lead isotope ratios from rocks and minerals within a Precambrian iron formation from Wawa, Ontario, suggest that initial lead isotope ratios varied systematically with stratigraphic level, and reflect in some way the mixing processes which took place when the iron-rich sediments were laid down.

(c) Lead Isotope Studies

R.M. Farquhar has begun a joint investigation, with J. Fox, of isotopic variations in sulphides from Besshi-type deposits in Norwegian Caledonide rocks. Most deposits contain mantle-related (low $^{207}Pb/^{204}Pb$) lead, but some evidence for upper crustal mixing has appeared. The isotopic ratios in a series of galenas from Tunisia, from deposits related to sedimentation and diapiric uplift, show a small but significant age dependence. The data are also useful for determining the sources of lead used by Phoenician and Roman metalsmiths in the production of lead-rich artifacts found in and near ancient Carthage. The project is continuing, with the cooperation of H. Rouvier and V. Vitali. A series of galenas from mineral deposits in central and southeastern Missouri has been analyzed in an effort to pin down the source of galenas found in abundance in native graves in the southern U.S. Collaborators with R.M. Farquhar on this project are J. Walthall and S.H. Stow. A third project of this type involves the comparison of lead isotope ratios in southwest African ores with those in brass and leaded copper artifacts. Local ores were used to provide the lead in the latter, but not the former. The project is being undertaken jointly with Z. Volavka.

8. University of Western Ontario, Department of Geophysics (A. Hayatsu)

The projects in progress include: K-Ar isochron study of Triassic-Jurassic rocks in northeastern North America; solubility of rare gases in silicate melts; K-Ar dating of kimberlites in the Kirkland Lake area, Ontario (with M. Arima, Geology Department).

9. Bibliography

Armstrong, R.L. 1985. Rb-Sr dating of the Bokan Mountain Granite Complex and its country rocks. Can. J. Earth Sci., 22, 1233-1236.

Armstrong, R.L., Monger, J.W.H. and Irving, E. 1985. Age of magnetization of the Axelgold Gabbro, north-central British Columbia. Can. J. Earth Sci., 22, 1217-1222.

Armstrong, R.L., Muller, J.E., Harakal, J.E. and Muhlenbachs, K. 1985. The Neogene Alert Bay Volcanic Belt of northern Vancouver Island. J. Volcanol. Geothermal Res., 26, 75-97.

Duncan, I.J. 1984. Structural evolution of the Thor-Odin gneiss dome. Tectonophysics, 101, 87-130.

Erdman, L. 1985. Chemistry of Neogene basalts of British Columbia and the adjacent Pacific Ocean floor. M.S. thesis, University of British Columbia, Vancouver.

Farquhar, R.M. and Fletcher, I.R. 1984. The provenance of galena from Archaic/Woodland sites in northeastern North America: lead isotope evidence. American Antiquity, 49, 774-785.

Fyles, J.T. 1984. Geological setting of the Rossland Mining Camp. B.C. Min. Energy, Mines and Petrol. Resources Bull., 74, 61.

Gabites, J. 1985. Geology and geochronology of the Cogbum Creek-Settler Creek area, northeast of Harrison Lake, B.C. M.Sc. thesis, University of British Columbia, Vancouver.

Godwin, C.I. and Cann, R. 1985. The Mac porphyry molybdenite property, central British Columbia. B.C. Min. Energy, Mines and Petrol. Resources Paper, 1985-1, 443-449.

Goodwin, A.M., Thode, H.G., Chou, C.L. and Karkhanis, S.N. 1985. Chemo-stratigraphy and origin of the late Archean siderite-pyrite rich Helen Iron Formation, Michipicoten Belt, Canada. Can. J. Earth Sci., 22, 72-84.

Grond, H.C., Churchill, S.J., Armstrong, R.L., Harakal, J.E.and Nixon, G.T. 1984. Late Cretaceous age of the Hutshi, Mount Nansen and Caramacks groups, southwestern Yukon Territory and northwestern British Columbia. Can. J. Earth Sci., 21, 554-558.

Hattori, K., Campbell, F.A. and Krouse, H.R. 1985. Distribution of sulphur isotopes in sedimentary rocks in connection with the evolution of the Precambrian atmosphere. Geokhimiya, 6, 834-849.

Hayatsu, A. and Waboso, C.E. 1985. Solubility of rare gases in silicate melts: implications for K-Ar Dating. Chem. Geol. (Isotope GeoScience), 52, 97-102.

Hutcheon, I., Nahnybida, C. and Krouse, H.R. 1985. The geochemistry of carbonate cements in the Avalon sand, Grand Banks of Newfoundland. Min. Mag., 99, 457-467.

Jeffries, M. 1985. Growth and structure of arctic ice shelves. Ph.D. thesis, University of Calgary, Calgary.

Jeffries, M. and Krouse, H.R. 1985. Isotopic and chemical investigations of two stratified lakes in the Canadian Arctic. Zeitschrift f. Gletcherkund u. Glazialgeolog., 21, 71-78.

Jeffries, M., Krouse, H.R., Shakur, M.A. and Harris, S.A. 1985. Isotope geochemistry of stratified Lake "A", Ellesmere Island, N.W.T., Canada: Reply. Can. J. Earth Sci., 22, 648-649.

Lawrence, R.B., Armstrong, R.L. and Berman, R.G. 1984. Garibaldi Group volcanic rocks of the Salal Creek area, southwestern British Columbia: alkaline lavas on the fringe of the predominantly calc-alkaline Garibaldi (Cascade) volcanic arc. J. Volcanol. Geotherm. Res., 21, 255-276.

Mathews, W.H. and Rouse, G.E. 1984. The Gang Ranch-Big Bar area, south-central British Columbia: stratigraphy, geochronology, and palynology of the Tertiary beds and their relationship to the Fraser Fault. Can. J. Earth Sci., 21, 1132-1144.

Parkinson, D. 1985. U-Pb geochronometry and regional geology of the southern Okanagan Valley, British Columbia. M.S. thesis, University of British Columbia, Vancouver.

Pigage, L.C. and Anderson, R.G. 1985. The Anvil plutonic suite, Faro, Yukon Territory. Can. J. Earth Sci., 22, 1204-1216.

Rashid, K. and Krouse, H.R. 1985. Selenium isotopic fractionation during SeO_3^{2-} reduction to Se and H_2Se. Can. J. Chem., 63, 3195-3199.

Smit, H., Armstrong, R.L. and van der Heyden, P. 1985. Petrology, chemistry and radiogenic isotope (K-Ar, Rb-Sr and U-Pb) study of the Emerald Lake pluton, eastern Yukon Territory. Geol. Survey Can. Paper 85-1B, 349-359.

Souther, J.G. 1984. The Ilgachuz Range, a peralkaline shield volcano in central British Columbia. Geol. Survey Can. Paper 84-1A, 1-10.

Souther, J.G., Armstrong, R.L. and Harakal, J.E. 1984. Age of the peralkaline Late Cenozoic Mount Edziza Volcanic Complex, northern British Columbia. Geol. Soc. Amer. Bull., 95, 337-349.

Suh, M. 1985. Sr isotope study of ultramafic nodules from Neogene alkalic lavas of British Columbia, Canada and Josephine Peridotite, southwestern Oregon, U.S.A. M.S. thesis, University of British Columbia, Vancouver.

Thorkelson, D.J. 1985. Geology of the mid-Cretaceous volcanic units near Kingsvale, southwestern British Columbia. Geol. Surv. Can. Paper 85-1B, 333-339.

Van Everdingen, R.O. and Krouse, H.R. 1985. The isotopic composition of sulphate generated by bacterial and abiological oxidation. Nature, 315, 395-396.

Van Everdingen, R.O., Shakur, M.A. and Krouse, H.R. 1985. Role of corrosion by H_2SO_4 fallout in cave development in a travertine deposit - evidence from sulfur and oxygen isotopes. Chem. Geol., 49, 205-211.

Watters, B.R. and Armstrong, R.L. 1985. Rb-Sr study of 5 metavolcanic rocks from the La Ronge and Flin Flon domains, northern Saskatchewan. Can. J. Earth Sci., 22, 452-463.

Xu, F.C., Krouse, H.R. and Swaddle, T.W. 1985. Conjugate base pathway for water exchange on aqueous chromium III: variable pressure and temperature kinetic study. Inorg. Chem., 24, 267-270.

Zentilli, M. and Reynolds, P.H. 1985. $^{40}Ar/^{39}Ar$ dating of micas from the East Kemptville tin deposit, Yarmouth County, Nova Scotia. Can. J. Earth Sci., 22, 1546-1548.

VI METEOROLOGY AND ATMOSPHERIC SCIENCE

Compiled by: E.J. Truhlar

1. University of British Columbia, Department of Geography (J.E. Hay, D.G. Steyn, T.R. Oke)

The radiation, mesoscale, sea-breeze and energy/water balance studies continued (see CGB, 1984).

Monographs on solar radiation climatology and the Canadian solar radiation climate are being prepared.

Results from a 3-D model used to investigate sea breezes in the lower Fraser Valley (LFV) are being compared with observed fields. A one-level model with spatially varying surface properties is being developed for the same domain.

Observations of the spatial and temporal dependence of the mixed layer depth in coastal portions of the LFV, are being made to validate a general advective model of mixed layer growth.

Studies in cities focused on evaluation of a new fast-response hygrometer for eddy correlation work. Energy balance data have also been used to study heat storage by the city system. A simple energy balance model has been developed to study urban/rural temperatures.

2. University of Calgary, Department of Physics (L.L. Cogger, C.A. Coombes, A.W. Harrison, R.B. Hicks and T. Mathews)

A mesoscale network of monitoring stations with conventional meteorological instruments and several acoustic sounders has been set up in southern Alberta, east of the Livingstone range. Wind profile data measured by a Doppler acoustic sounder during several chinooks are being analyzed.

An all-sky radiometer operated continuously to provide sky maps for short- and long-wave radiation intervals and cloud cover, and cloud temperatures were deduced. A prototype cloud detector has been developed to utilize the radiometer technique of cloud cover and temperature estimation. A CCD-TV camera coupled with a fish-eye lens has been used to study atmospheric optical effects and visibility. All-sky images at various wavelengths have been analyzed for sky brightness variation; ice crystal and water droplet scattering, reflection and refraction of solar radiation; solar aureole measurements and urban pollution studies.

A 1-m spectrometer, a multichannel photometer and Fabry-Perot spectrometer controlled by an LSI/II computer which permitted automatic operation were used to measure Doppler and rotational temperatures and neutral wind velocities in the altitude region from 85 to 300 km. The optical emissions that were monitored included OI (5577, 6300); N_2 (3914); NI (5200);

OH (8-3); O_2 (0-0). Measurements were taken from the Rothney Astrophysical Observatory at Priddis near Calgary, which is one of a network of such stations studying thermospheric dynamics.

3. University of Alberta, Meteorology Division and Institute of Earth and Planetary Physics (N. Aktary, K. Al-Jumily, D. Ball, R. Blackmore, E. Chan, R.B. Charlton, K. Finstad, K.D. Hage, F. Hopper, W.-W. Jiang, E.P. Lozowski, A. Nowak, E.R. Reinelt, C. Sackiw, F. Safwat, G. Strong, K. Szilder, R. Wong, D. Yiu, Y. Zhuang.)

Recent-year claims are that cloud seeding by the emission of AgI from ground-based generators has resulted in rainfall increases of 30-40% in southwestern Alberta. All pertinent rainfall data were re-examined, using various estimates of target area rainfall. No evidence was found of a significant change in the observed rainfall. The correlation method (which utilized 57 years of rainfall data) should have been capable of detecting a 12% change in target rainfall with 95% confidence.

Atmospheric and marine icing is being simulated by experiment and by computer modelling. A new marine-icing wind tunnel is under construction, the only such facility in Canada. Aspects of ice accretion being examined include droplet generation, transport and measurement, thermodynamics, heat transfer, and physical properties of accreted ice.

Analysis of the severe weather of May 20-21 in Oklahoma and Texas produced detailed evidence for the interaction between the synoptic- and meso-scales of atmospheric motion. The sensitivity of the AES General Circulation Model to the sea-surface temperature forcing associated with the most recent El Nino event was tested.

A 2-D finite-difference numerical model of airflow and pollutant dispersion in a small valley has been devised and tested. It simulates the vertical development of a supercritical Richardson Number layer of air containing nocturnal downslope drainage, by decoupling such a layer from the prevailing winds above. The predicted wind and temperature distributions within a few metres of the surface agree well with observations taken in the North Saskatchewan River Valley in Edmonton.

An extensive study of cloud configurations associated with cold lows and upper-level cyclogenesis has been completed. The current synoptic cloud classification has been revised and extended by including the post-frontal band, a cloud formation not previously recognized as a distinct and separate entity.

A study has been completed on the cohesiveness of upper-air soundings in space and time. Differences in pressure, temperature and wind were examined from data sets obtained from serial releases of radiosonde balloons. The results will help in the design of an upper-air network capable of detecting and tracking atmospheric systems on a scale of a few kilometres.

The climatological catalogue (see CGB, 1984) of upper-air parameters relevant to the incidence and control of forest fires has been extended to specific sites within the boreal forests of northwestern Canada.

Studies of man-made snow, fog and cloud on very cold days in the petrochemical district of Edmonton continue. Of special interest is the increasing frequency of ice fog, enhanced by the addition of substantial amounts of water vapour and particulates by motor vehicles and the burning of large volumes of natural gas in winter.

Investigations continue on the chemical composition of Arctic aerosols, using AES data. Observations of sky turbidity during the past several years suggest that the atmosphere of the High Arctic is subject to high aerosol loads in winter, thought to be due to pollution originating in Eurasia.

Radar and airborne cloud physics data obtained from the Alberta Research Council Hail Project are being analyzed.

4. Alberta Environment, Environmental Protection Service

Acid deposition research concentrated on effects in forested ecosystems in northern Alberta. The data bases of precipitation chemistry studies were evaluated and the frequency

distribution model, FREDIS, used to predict ground-level concentrations of SO_2 was validated.

An air quality/climatology research program was developed. Completed projects include the selection of an urban air quality model for Alberta and a study of the feasibility of converting radar imagery data to storm intensity/duration values. Two other projects investigated plume behaviour under conditions of stack downwash and the effect of air quality on visibility.

Staff participated in a project to develop a compressor station stack design model. Sulphur deposition measurements in Calgary were assessed. Work was initiated to quantify sulphate and nitrate in high volume air samples in Edmonton and Calgary.

5. Western Research, Division of Bow Valley Resource Services Limited

Specialized data relating to a wide range of chemical species and meteorological parameters were collected at three sites as part of Alberta's Acid Deposition Research Program (ADRP), which is jointly funded by government and industry. Sites are strategically located upwind and downwind of a moderately-sized sulphur plant. A third site, used for background measurements, is located in mountainous terrain west of Calgary. An observational study to assess sulphur deposition at a site located near a forest clearing showed that there was a pattern of convergence towards the clearing caused by the diurnal heating cycle. Hourly averaged vertical velocities were often large. Assumptions commonly used to deduce sulphur deposition from measurements solely of eddy fluxes were found not to be applicable.

6. Saskatchewan Research Council

Continuing programs in climatology include the 20-year operation of a benchmark climate station, which has been significantly automated. The main research studies in climatology deal with the impact of climatic change on agriculture; dust storms and their wind erosion impact; the simulation of spring wheat yields; the trend of mean annual temperatures; and the atmospheric portion of environmental impact assessments.

Laboratory experiments have been designed to trace the origin of strong acidity in the snow pack of northern Saskatchewan. It appears that natural organic acids cannot be discounted as a source of acidity there.

SRC monitoring services to industry and modelling studies of metal particulate deposition continue (see CGB, 1984).

7. University of Windsor, Department of Physics

A wide variety of experiments are studying the interaction of electrons with atomic and molecular species, with particular emphasis on the impact excitation of $O(^1S_o)$, and the low energy heavy particle collisions involving atmospheric species.

8. McMaster University, Department of Geography (J.D. Davies, W.R. Rouse)

Analysis of spectral optical depth measurements at McMaster University in 1981, 1983 and 1985 is in progress to show effects of stratospheric aerosol enhancement by El Chichon and to determine the importance of NO_2 absorption on aerosol optical depths and inverted particle size distribution. Other projects include: (i) evaluation of solar radiation models under the aegis of the International Energy Association using data from North America, Western Europe and Australia; (ii) estimation of the seasonal surface albedos of land surfaces for possible use in the AES GCM; (iii) evaluation of GCM cloudless sky solar radiation codes using surface and satellite measurements of radiation.

Simultaneous energy-balance measurements during the growing season were taken for two sedge grass communities and one forest community which form a sequence moving inland from the southern James Bay coast. These measurements include the monitoring of stomatal resistances of the sedge grasses and trees for use in a combination model. Growth rates of the dominant sedge grass species in terms of biomass accumulation were compared with measured climatic elements for two-day periods. They respond in a very sensitive fashion to air temperature,

which in turn is closely related to onshore and offshore winds. Energy balance measurements in central Hudson Bay over a sedge swamp were taken at the same time as those in southern James Bay. Comparisons indicate that ground, sensible and latent heat fluxes respond most sensitively to air temperature and that predictive functions using air temperature can handle both data sets. The energy budget in the intertidal zone of Hudson Bay near Churchill is being studied during the frozen and thaw periods using aerodynamic, mass transfer and energy-balance approaches.

9. University of Toronto

(a) Department of Physics

(i) Cloud Physics. The numerical modelling of the evolution of rain in 1-D shafts has demonstrated that an equilibrium distribution will be achieved, given sufficient time, and that this distribution has three peaks at 286, 790 and 1760 μm - independent of rainfall rate. The original distribution of the drops is of no consequence. This work was based on 17 years of laboratory measurements.

The growth of gyrating hailstones in the pressure, temperature, speed and LWC controlled icing tunnel led to the recognition of new growth regimes. One where the surface is dry and drops are shed into the air stream is remarkable.

The most interesting result of the modelling of the growth of aerosols in the presence of trace gases is that the presence of soot in Arctic haze can advance the spring melting by up to two weeks.

(ii) Mesoscale Atmospheric Dynamics. Dynamics of rainbands, polar front cyclo-genesis. Kelvin-Helmholtz Instabilities, cloud-mean flow interactions, melting-induced mesoscale circulations.

(iii) Planetary Waves. The structures of free and forced planetary waves are examined using a high vertical resolution model, which consists of a minimum of 25 vertical levels. The linear stability of such waves is also examined, with particular emphasis on the interaction of unstable modes with the forcing. The latter mechanism can produce realistic planetary wave patterns, including blocking flows.

(iv) Climate Studies. The sensitivity of energy balance climate models depends crucially on the meridional energy transport. Various linear and nonlinear parameterizations of this transport are examined. Stochastic forcing has also been incorporated in these linear/nonlinear models. Techniques of modern physics are used, e.g., the Fokker-Planck equation and the fluctuation-dissipation theorem.

(b) Institute for Environmental Studies

The Institute's interdisciplinary programs focus on problem-oriented research on the quality of the environment, including such topics as environmental ecotoxicology, stress on ecosystems, pollution, persistent substances and acidic precipitation; and on environmental management, including such areas as water resource management and environmental impact assessment. Specific recent studies have dealt with the human and environmental effects of hazardous contaminants, nuclear winter, effects of acidic deposition on terrestrial ecosystems, and climate impact assessment in the Great Lakes Basin.

10. York University, Department of Physics (J. Miller, W.J. Megaw)

A double-scatter radiative transfer model for a single-layer atmosphere has been employed to study the utility of AVHRR/NOAA imagery for mapping the spatial variability of aerosol optical depth over the Great Lakes.

Field measurements of in situ up- and down-welling spectral irradiances (380-700 nm) have been conducted in the Niagara River plume and mid-lake regions of Lake Ontario. Analysis of these data is intended to investigate the applicability of Case I and Case II optical models for Lake Ontario.

A comprehensive study of the atmospheric aerosol is being undertaken with a view to investigating the condensation and ice forming properties of nuclei and their "poisoning" by atmospheric trace gases.

The effectiveness of trace quantities of a number of organic compounds in inhibiting condensation of water on sodium chloride and other particles at supersaturations of up to one per cent is being investigated.

Determination of droplet size distributions for insecticides used in forestry is conceptually simple but experimentally difficult. A series of experiments has been performed to determine spread factors for water and oil-based droplets collected on various substrates.

11. Ontario Ministry of the Environment, Air Resources Branch

An Eulerian model for long range transport and deposition of acidic pollutants has been developed and evaluated with observed data from the OSCAR period. A Lagrangian trajectory model of the long range transport of sulphur oxides has been used to compute trajectories, sulphur concentrations and deposition amounts for 1978 to 1980, inclusive. Statistics of these trajectories have been calculated and their incorporation in the Statistical Model is being assessed.

Across Ontario, routine monitoring continued for acid rain related compounds, as well as trace metals, in air and precipitation. Persistent, toxic organics in precipitation continue to be monitored at two sites. Development of an air sampler for such substances, for use at rural sites, commenced.

Daily sampling and analysis techniques were set up to sample precipitation and the air, for various trace metals that act as tracers of coal combustion and smelting operations. These will be used to define source-receptor relationships better.

12. National Aeronautical Establishment, Flight Research Laboratory (FRL)

Significant efforts were expended on developing and installing improved instrumentation and software on the FRL Twin Otter Research Aircraft. In Cloud Physics studies, the aircraft essentially carries two communication systems, one belonging to NAE for measuring aircraft motion and the thermal and dynamic structure of the atmosphere, the other belonging to AES for cloud physics and atmospheric chemistry measurements. AES acquired a new data acquisition system which is lighter and uses less power than its predecessor, but can record cloud physics data at a very high rate on a 200-megabyte streamer. Improvements to the NAE system also feature modifications to a streamer recorder and the necessary software.

After two series of wind-tunnel calibrations, a Rosemount 858 5-hole probe was installed on the aircraft noseboom to measure airspeed, altitude and the angles of attack and sideslip, replacing the vanes that were prone to icing problems. A Loran-C Navigation System was acquired as an alternate to the GNS-500 to give more accurate positional data in project areas with good Loran coverage. A video recording system was installed with three selectable cameras - straight ahead for clouds, under the nose for terrain, and weather radar to document precipitation. In preparation for the Canadian Atlantic Storms Program (CASP) in January, 1986, additional airframe deicing protection was fitted on the aircraft with specially built deicing boots on the vertical tail and the wing and wheel struts.

Major field experiments were flown for Cloud Physics or Air Quality Research. About 25 hours were spent flight testing new instrumentation for CASP, including a wing-mounted King Liquid Water Probe and an AES-developed probe to record the equivalent water content during flight in snow.

In the Cloud Physics Research community, much recent discussion has centred on the effects of aircraft mounting location on the results from airborne spectrometers used to measure cloud and precipitation particles. FRL developed a special canister to measure airflow velocities and angles that can be flown on the PMS probe mounting locations on any Cloud Physics Research Aircraft. After careful wind-tunnel calibration, the device was flown on the underwing pylons of the Twin Otter and results were compared with theoretical predictions. Then, in a cooperative study with the National Center for Atmospheric Research

(NCAR) in Boulder, it was flown on their Sabreliner, Electra and King Air research aircraft, thus providing valuable data concerning flow effects ahead of PMS probes mounted at wingtips, beneath swept wings and on fuselage pylons. The project should lead to improved computer models for predicting errors in measured particle concentrations and to possible explanations for the distorted images seen at some mounting locations.

In cooperation with Agriculture Canada, FRL continues to conduct vertical flux measurements for CO_2 and water vapour above vegetation. The aircraft logged 55 flying hours over crops and vegetation in Ontario, Québec and Manitoba. Airborne flux calculations compared favourably with ground-based measurements over a wheat field near Winnipeg. Results from flights over a hail swath and a fire-damaged forest corroborate last year's results.

13. McGill University

Department of Meteorology

The main research areas are as outlined in CGB, 1984. Work continued on the dynamics of atmospheric blocking using simple models. The stability of finite-amplitude wavy flows has been investigated to understand why some blocking patterns are so long lasting. Earlier work on the construction of exact finite-amplitude solutions to the quasi-geostrophic equations is being extended to include the effects of friction.

A three-dimensional cloud chemistry model has compared simulated and observed concentrations of various species for a particular case. The response of the model to variations in input conditions is being examined.

Attempts are being made to develop new methods of deriving wind information from Doppler radar measurements.

Recent developments in non-linear wave theory are being used to study the creation of large-scale, localized, persistent atmospheric disturbances resulting from topographic forcing. Emphasis is placed on developing simple models that incorporate interactions between two separated space scales.

Aspects of the numerical simulation of cloud physics and dynamics are being investigated. Studies have been completed on the effects of topography and lateral boundary conditions on numerical models of mesoscale phenomena.

14. Agriculture Canada, Agrometeorology Section, Ottawa

(a) Crop Environment Assessment

Yield and production estimates for the three cereals seeded on fallow and on stubble land were prepared for the Production and Marketing Branch's analyses of production trends on the Prairies during the growing season. These provided some earlier quantitative assessments of the sharp drop in production in the southern CRDs of Saskatchewan and Alberta in contrast to the extremely high yields in the remainder of the Prairies.

The manuscripts for the Uniform Productivity Area (UPA) and Land Use (LU) maps for each prairie province were completed and photographs (positive/ negatives) were produced. Corresponding reference base and Crop Reporting District maps were produced as transparencies at the same scale (1:1 000 000).

(b) Agroclimatic Resources Assessment

Good progress was made on crop data collection and modelling of plant growth and development in relation to physiological and environmental factors. The data include measurements of photosynthesis, dry matter accumulation, yield, leaf area, water status and phenological development. Main crops studied were corn, barley and soybeans.

Climatic zonation work for forage crops and winter cereals led to improved management recommendations for the Atlantic region that were published in the new 1985-1990 Field Crop Guide.

A much better model for estimating soil temperatures from climatic data was developed and will be very helpful for characterizing overwintering conditions for crops in the Atlantic region.

(c) Operations Management

Current computer weather data files for Ontario and the Prairie Provinces were updated weekly for researchers across Canada for near real-time estimates of insect populations, diseases or crop maturity. Current weather and soil conditions in the Prairie Provinces were reported weekly. A special assignment was made for CIDA relative to a drought warning system for Ethiopia. The prototype sonic snow depth sensor and the Sereda wetting duration sensor were successfully field tested. A project in Québec to monitor soil moisture and develop a soil moisture model incorporating a water table function has been completed. Parameters have been developed for 3 different soils for maize. Snow on the ground was investigated as a critical parameter for estimating soil temperature.

15. Canadian Forestry Service

(a) Newfoundland Forestry Centre, St. John's

The following studies are continuing (see CGB, 1984): the impact of wind on forest stand dynamics and forest management strategies; the ENFOR-funded work on short-rotation willow plantations with successful field testing of the energy balance measurement system.

New studies deal with: the potential of peatland (in a project area near Badger) for forestry purposes and the effects of hydrologic characteristics of drained peatland on tree growth; the characteristics of Newfoundland soils to provide data for assessing the impact of acid rain on forest soils, and of logging and fire on the hydrologic properties of soils.

The dendrochronology study of red pine in relation to fire history has been completed (see CGB, 1982)

(b) Maritime Forestry Centre, Fredericton

Several studies are being made within the LRTAP project to measure the effects of atmospheric deposition of SO_X compounds on tree growth and soil fertility processes such as decomposition activity and nitrogen transformation. A study of the effects of point source pollution on white spruce dendrochronology was completed. A second phase of this study was initiated to examine effects of the long-range transport of pollutants on dendrochronology of red spruce and sugar maple in southeastern Québec and the Maritimes. Several new ARNEWS (Acid Rain National Early Warning System) monitoring plots were established.

(c) Laurentian Forestry Centre, Ste. Foy

Meteorological data from the Montmorency and Lac Laflamme stations are being used in the LRTAP project to plan research and to calculate the deposition amounts of major ions to a boreal balsam fir catchment. Monitoring of the biogeochemistry of the Laflamme catchment continues (see CGB, 1983). The CFS ARNEWS program in cooperation with the LRTAP program provides meteorological data to evaluate forest health (dieback) and to analyze tree rings. Meteorological and climatological data are used in several projects (in addition to those listed in CGB 1983) such as: application of Bacillus thuringiensis (B.t.) to forest stands; provenance trials; establishment of plantations of plus trees; analysis of plantation success; site characterization prior to planting of container grown plants; phytotron studies of container grown plants. Electronic weather stations monitor the atmosphere hourly (May-August) in two remote Québec sites for studies of spruce budworm population dynamics and parasite behaviour, and especially to determine the effect of weather on the insect's life system from diurnal to seasonal time periods.

(d) Petawawa National Forestry Institute, Chalk River

The forest wind study described in CGB 1984 is continuing and has yielded sufficient data to carry out a statistical analysis of zero plane displacement and roughness length at two locations. Winds in an open site are being compared with winds over a mature forest and

across a valley. The WINDS program of the U.S. Forest Service is running, but is inappropriate for the small-scale topography of the Canadian Shield. The program for computing solar radiation in a clearcut strip is being tested for accuracy using data obtained from several strips, and the errors caused by reflected radiation will be assessed. The rainfall study for remote forested regions (see CGB 1984) is continuing and uses data from an X-band radar at Maniwaki, a C-band radar at Carp and an S-band radar at Ste-Anne-de-Bellevue, a 3-element LLP system, GOES satellite images and a network of 9 automatic raingauges to estimate rainfall in Québec's Outaouais region. Because of numerous problems the raingauge network yielded data of little value. As a result of the continuing work on monitoring and identification of forest fires using NOAA satellite AVHRR scanner data a case study for the Slave Lake Forest region was completed. Research on modifying the Fire Weather Index System includes studies of forest fuel drying rates and the effect of rain on forest fuel moisture content. Fuel moisture models are being developed for such fuels as slash and reindeer lichen for incorporation into a fire behaviour prediction system for specific forest and slash fuels.

(e) Great Lakes Forestry Centre, Sault Ste. Marie

Weather and climate data are used for: calculating the fire weather index in wildfire and control burn case studies; relating weather occurrence at critical times of the season to germination, survival and growth in regeneration silviculture; assessing conditions for insect control operations, such as aerial spraying and distribution and persistence of sprays; enquiries into important forest damage losses, such as windthrow and drought stress; modelling to improve comprehension of insect outbreak initiation; measuring success or failure in regeneration trials; studying the impact of the long range transport of air pollutants on the biogeochemistry of forest ecosystems.

(f) Northern Forestry Centre, Edmonton

Results of forest clear-cutting experiments on Marmot (Cabin Creek) and Streeter watershed basins indicate that forest clear-cutting does alter water yield predictably, and that, if carefully done, it need not increase sedimentation. These results, coupled with those from prior studies of snow accumulation/ablation in Alberta and other watershed experiments in the United States, indicate that clear-cuts approximately 5 tree heights across in all dimensions, could be used to maximize water yield from the subalpine and foothills forests of Alberta.

Three forest-land drainage experimental areas (131-312 ha) have been established in western and northern Alberta as part of the Canada/Alberta Forest Resources Development Agreement, in order to develop optimal silvicultural regimes for increasing the growth of commercial tree species on drained wetlands, and to assess the effects of drainage on soils/peat, local hydrology, ground vegetation and tree growth.

Several reports have been prepared dealing with the diagnosis and recognition of winter damage in trees, frost damage and ice nucleating agents, frost hardiness of overwintered containerized seedlings, and climatic variation in the boreal forest region of western Canada. The latter examines long-term (1872-1981) temperature and precipitation data from 77 locations in the three subregions of the boreal forest.

Six successful experimental fires were conducted in a joint CFS/Alberta Forest Service experimental burning project in the black spruce-Labrador teacladonia fuel type of northern Alberta. The CFS Fire Danger Group continued to refine the Canadian Forest Fire Danger Rating System. An interim edition of the Forest Fire Behaviour Prediction System was released for field testing. Ten ARNEWS plots were set up to monitor tree health in relation to atmospheric pollutants.

(g) Pacific Forestry Centre, Victoria

Studies reported in CGB, 1984 are continuing. Six ARNEWS plots were added to the 3-plot network in order to monitor the impact of acid rain on forests using foliar, soil and stand measurements.

Following treatments in 1972, continuing measurements of stand response at Shawnigan Lake have produced a unique data base on the effects of thinning and fertilization. An

evapotranspiration model incorporating interception losses has been applied to some of the data in order to predict soil and plant water status and explain some of the observed growth differences.

Microclimate data collected for the inland spruce cone rust and the mountain pine bark beetle dispersal studies are being analyzed. Overwinter under-bark temperatures for lodgepole pine are being measured to study mountain pine beetle survival relative to cold temperatures and snowpack conditions. Fosberg's 3-D wind model is being used to examine wind patterns for selected B.C. areas.

16. Atmospheric Environment Service

(a) Meteorological Services Research Branch (MSRB)

The wave forecast system for the North Pacific Ocean was implemented. The choice of a spectral ocean wave model for application in Canadian waters and improvements to the Great Lakes wind-wave prediction model are being studied. Experiments show that buoy observations provided superior input to the latter model, and further refinements could be obtained by including the air-water temperature difference. Contract work was commenced on the application of the Donelan model to the Beaufort Sea area.

The AES oil spill model was used successfully to predict the movement of an oil spill during a Beaufort Sea storm in September 1985.

The Nova Scotia storm surge model has been modified to account for the effects of the Bay of Fundy-Gulf of Maine water body.

A comprehensive report on the technique for forecasting ice accretion on marine structures was prepared for the World Meteorological Organization.

The first AES knowledge-based system using the maturing technology of Artificial Intelligence was developed to simulate the intellectual processes undertaken by a forecaster when evaluating wind forecast data. In participation with MacDonald, Dettwiler and Associates Limited, AES continued development of a general precipitation forecasting knowledge-based system.

A surface wind forecast system for Canadian airports was made fully operational in January. It produces surface wind speed and direction forecasts twice daily for 159 airports using statistical regression equations based on the output of the operational numerical weather prediction model. Sets of equations have been derived to predict precipitation type, temperature, winds for marine areas, cloud and visibility, and will be tested operationally in real-time in the Atlantic region.

The design and testing of a statistical forecasting procedure for detailed weather forecasts for up to 12 hours has been completed. The procedure can predict sudden weather changes such as wind shifts and is designed to build in to each station's forecast a knowledge of weather trends based on 28 years of data.

A sea-ice dynamics model using a micromechanics approach was developed. This approach appears to be a significant improvement in the understanding of sea-ice behaviour. The response of pack ice to wind stresses is also being tested. Tests of an iceberg ensemble drift model have shown that iceberg deterioriation is an important factor. A model for iceberg rolling is being developed.

Research on parameterization of subgrid-scale effects in numerical weather prediction models led to further improvements. In a relatively sophisticated (second-order closure) boundary-layer model of the atmosphere, now imbedded in both regional and global spectral models of the atmosphere, there was added: a new formulation for the mixing length forecast equation; a counter-gradient term in the vertical transport term of the turbulent kinetic energy equation; and a modified height calculation of the boundary layer for stable and unstable conditions. Preliminary tests of a scheme for modelling stratiform condensation processes have been encouraging; this is designed to improve cloud cover and precipitation forecasts in a regional weather forecasting model, as well as the wet chemistry of a long

range transport air pollution model. A gravity wave drag parameterization scheme was tested in a global spectral model of the atmosphere, yielding significant improvements in four- to seven-day forecasts. The use of radar and satellite (infrared and visual) information for improving the initial time analysis of precipitation in a regional forecasting model was studied and work on an operational version of the scheme has started. A scheme developed to calculate surface temperature in atmospheric circulation models with coarse resolution of the boundary layer produced quite satisfactory results. It is now used in the CMC's hemispheric spectral forecast model. In order to quantify the importance of convective phenomena in the deepening of low pressure systems the dynamics of mid-latitude synoptic systems was investigated via scale analysis of the governing equations, and via a case study of an explosive deepening cyclogenesis event.

In the work on improved numerical techniques, very efficient numerical time integration schemes are being developed for use in numerical atmospheric models: the semi-Lagrangian technique has been tested in grid-point, spectral and finite-element models, with and without interpolation, and with two or three time levels. Gains of up to 10 are now possible over the present most efficient semi-implicit time integration schemes, and one unexpected benefit seems to be increased accuracy. An implicit method was also examined, but was discarded. New nesting techniques (for use in limited area forecasting models) are being investigated, and one technique seems to reduce to an acceptable level the part of the total forecasting error that is caused by the boundary conditions around the limited area. An implicit non-linear normal mode initialization scheme was also developed that does not require an explicit knowledge of the normal modes of the particular model to which it is applied, and is thus ideal for regional or limited area models. Preliminary results were good so that the scheme is being implemented in the CMC regional finite-element model. Use of finite-element techniques for the vertical discretization of a global spectral model has yielded smaller phase and amplitude errors in the medium range (four to seven day) forecast of planetary waves; the technique will be imbedded in the next CMC global spectral model. A similar application with a variable resolution grid in a frontogenesis model showed the scheme was more powerful than other more conventional finite-difference schemes, at least for this particular problem. Work was carried out on a prime factor FFT algorithm for a CRAY-1S, on the vertical equation in sigma coordinates, and on the horizontal structure of the hemispheric forecast error correlation for geopotential and temperature.

CMC has received and accepted the regional finite-element model (190-km resolution), and the core software of a new objective analysis package that is 2.5 times more efficient than the preceding package.

Work on the RAINSAT System (see CGB, 1983) which produces precipitation analyses and short-range forecasts from weather radar and GOES-VISSR data continued, and provided products to the Quebec Meteorological Centre and collected data for algorithm development. A new display subsystem was developed for forecast office use, with the capability of providing soft and hard copies of the products.

The statistical and non-linear iterative techniques for TOVS temperature and humidity soundings was compared using a data set of about 850 retrievals.

The microwave scatterometer application studies were continued in collaboration with UCLA, JPL and NASA.

The report on the main field experiment of the Askervein Hill project was completed.

(b) Atmospheric Processes Research Branch (APRB)

(i) Cloud Physics Research Division. The Division was involved in four major activities: 1) coordinating the Canadian Atlantic Storms Program (CASP), 2) directing the Chemistry of High Elevation Fog Project (CHEF), 3) analysing Cloud Chemistry data collected during past field projects, and 4) examining the usefulness of Doppler Weather Radar.

CASP is designed to study east coast winter storms with a field program from 15 January to 15 March 1986. Several planning documents were prepared, including the Experimental Design Plan, the Operations Plan, a Data Management Plan, an overall Management Plan, and a Data Analysis Plan.

The CHEF study began its first field measurements at two sites in Quebec, viz., Mont Tremblant (northwest of Montreal) and Roundtop Mountain (near Sutton), of chemical deposition from cloud water to the forest, along with precipitation chemistry, gaseous pollutants and meteorological parameters.

The installation of a new C-Band Doppler weather radar research/operation facility at King City, Ontario (Toronto) was completed. Techniques of processing the Doppler radar data and producing real-time displays were developed. Analysis of data acquired during the severe storm (thunderstorm/ tornado) season showed areas where improvements in technique were required, and some useful storm identification signatures were discovered. A system to integrate lightning locations from a new DF network with the radar echo mapping was begun.

(ii) Experimental Studies Division. The STRATOPROBE program contributed to the international effort of monitoring atmospheric constituents from space. Stratospheric balloon probes and remote sensing from the ground provided validation data for the SAGE II and SME satellite-borne instruments.

The Canadian ozone network is changing as preparations are made to replace the five manually-operated Dobson spectrophotometers, which have been in operation since the IGY (1957), by automatic Brewer spectrophotometers with at least a two-year overlap. The Brewer network expanded to ten stations during 1985, on the installation of Brewer instruments at Goose Bay, and in Taiwan and Italy. Fully automated, scheduled operation is being implemented at several stations.

A fully automated ground-based Brewer has been modified to measure atmospheric nitrogen dioxide and has been making measurements routinely in Toronto since August.

Weekly ozonesonde measurements have continued at Edmonton (Stony Plain), Churchill, Resolute Bay and Goose Bay. The schedule has been made more flexible to allow a sonde to be airborne while an ozone measuring satellite passes reasonably close to the station. In cooperation with the NOAA Environmental Laboratories the satellite ground-truthing is being extended by flying high altitude plastic balloons and special ozonesondes from Edmonton during satellite overpasses.

Preparations are being made to fly a Brewer spectrophotometer in a NASA Get-Away Special (GAS) package on board a Shuttle in 1988.

Studies of ozone trends as derived from ozonesonde and Umkehr observations have continued. Particular emphasis was placed on the following: the impact of different Umkehr inversion algorithms on the trend analysis results; the sensitivity and resolution of the algorithms for real changes in the ozone profile; the impact of stratospheric haze of volcanic origin on the measurements and, thereby, on the trend results; and the application of new temperature-dependent ozone absorption cross-sections on surface-based ozone measurements.

In order to test theory concerning nuclear winter, pilot measurements were made with a sunphotometer and chopping pyroelectric radiometer to determine the optical depths of clouds produced by intense fires such as the "prescribed burn" of forest at Chapleau.

The National Atmospheric Radiation Centre (NARC) continued as the lead agency in an international program to improve solar irradiation measurement. As part of this program all the short-wave calibration techniques routinely used at AES have been validated. A total of 260 radiometers were calibrated at NARC, including 15 non-Canadian instruments from eight countries. Monitoring of the solar UV-B irradiance in 8 spectral intervals has continued. A pilot data set of sky and solar spectral radiance has been derived from measurements with a spectral radiometer over the wavelength region 300-3000 nm.

(c) Air Quality and Inter-Environmental Research Branch (AQRB)

(i) LRTAP. The development of a comprehensive Eulerian model of acidic deposition continued. The hybrid meteorological driver model, consisting of the operational V9 spectral model augmented by a high-resolution boundary-layer model, was completed and has been systematically tested and improved. The AES Lagrangian Long Range Transport model was one of 11 models used in the International Sulphur Deposition Model Evaluation project. All model results have been statistically analyzed by the University of Ottawa and the US EPA.

The CAPMoN precipitation monitoring network has been reconfigured to 18 stations in eastern Canada. The first data from this network (1983/84) have been published.

Periodic intensive studies at Camp Borden since August 1985 to measure directly the fluxes of ozone and sulphur dioxide have yielded enough data to determine the effect of the seasonal change from a leafed to a leafless canopy during autumn on the deposition velocities of ozone. Such velocities are near 1 cm s^{-1} mid-afternoon dropping to near 0.1 cm s^{-1} at night. Similar results have been obtained for sulphur dioxide.

Field studies on atmospheric nitrogen near North Bay have shown that in winter the contribution of nitrates to atmospheric acidity can be as important as that of sulphates. During September 1985, the Branch participated with groups from Canada, U.S. and Italy in a comparison study on the methods for measuring atmospheric nitrogen species.

(ii) Toxic Chemicals. Lichens and mosses were used successfully as biomonitoring agents for measuring airborne pollutants in both rural and urban areas of Canada. Regional surveys of lichen element concentrations showed that only sulphur and lead were present in consistently higher concentrations in eastern Canada than in the Northwest Territories. Regional gradients within eastern Canada were evident for lichen sulphur concentrations and the patterns correlated well with other methods of measuring the wet deposition of sulphur.

Field data from sites in the Toronto area showed that less than 5% of the total airborne mercury concentration was in the particulate phase at all sites. Furthermore, elemental mercury vapour (over 85%) was the predominant form of the vapour phase mercury species present in ambient air.

(iii) Climate Change. Analysis of data from the weekly "grab flask samples" showed that low concentrations of CO_2 at Sable Island are associated with northerly or southeasterly air flows and at Alert are associated with southerly or southwesterly air flows. High concentrations occur with westerly or southwesterly air flows at Sable Island and with northerly air flows at Alert. Cooperative flask sampling programs are being undertaken at Alert with the Scripps Institute of Oceanography and NOAA. The continuous monitoring system to be installed at Alert has been tested and calibrated in the Downsview calibration laboratory.

(iv) Core Research. Work continued on the differential absorption lidar (DIAL) to measure vertical profiles of sulphur dioxide and ozone concentrations remotely. Data from the Arctic Haze lidar study has shown that at least three mechanisms move Arctic haze vertically in the stably stratified atmosphere: isentropic movement, foehn (warm wind) subsidence and ice crystal precipitation scavenging.

In support of the Northern Oil and Gas Action Program (NOGAP) intensive studies have been conducted to assess the environmental impact of air pollutant emissions in the Beaufort Sea area. Meteorological and air quality data are being processed.

Analysis of wind measurements made in and above a forest canopy show that the aerodynamic characteristics of the canopy are independent of the roughness length upstream of the canopy. This has reduced the calculations of zero-plane displacement to only one equation. Comparisons with previous methods are good.

A "Mixed Spectral Finite Model" for flow over complex terrain has been developed that simulates turbulence better than the original variable-roughness model. Using data from the 1983 Askervein study, good agreement was shown between the model and the observed results.

In support of the 1988 Winter Olympics in Calgary, data have been collected at the ski jump site for the use of decision makers in assessing the safety to skiers under certain wind conditions.

(v) Air Quality Services. A source-strength quantifying model has been added to the Air Quality Modelling Package (AQPAC) that provides a first estimate of the quantity of chemical released. Graphical displays of model results have been developed for the plume and puff models. To evaluate the AQPAC models, concentrations from field experimental data and from the model were compared. Pattern analysis indicated that the area of maximum

concentration computed by the model agreed with the observed area better under some stability classes than others.

(d) Canadian Climate Centre

The Canadian Climate Centre issued 141 publications including "Snow Cover Data" for the 1983-84 season, "Climatic Perspectives", and the remaining 24 issues of "Principal Station Data" summaries. "District and Station Climate Extremes" were published on fiche for 267 sites. About 100 000 weather documents were microfilmed and 600 000 archived. The newspaper clipping files on Climate Impact news for 1983 and 1984 were also microfilmed and made available on request. Climate data and information were supplied in response to 13 000 requests. About 450 requests were received for magnetic tape copy or special computer statistical analyses of digital data retained in the National Climatological Archive.

(i) Hydrometeorology. In support of changing national network requirements, the impact of micro-electronic technological advances on existing precipitation gauges and data collection procedures is being evaluated. For example, the feasibility of unattended operation of the AES standard rain gauge (Type B) and the use of solid state memory in recording precipitation gauges are being investigated. The ability to download climate archive data from the main frame computer to 5" floppy diskettes was developed and, in cooperation with an engineering consulting firm, an urban design rainstorm was distributed.

Work continued on radar rainfall analysis and surface water temperature and snow cover determination from satellite data. Radar and gauge rainfall estimates are being compared with estimates based on three techniques employing satellite data.

Weekly monitoring of hydrometeorological impacts continued with the regular production of national maps and tabulations of water budget parameters. Associated projects completed include the development of procedures to generate future water budget scenarios for prediction and impact assessment, and to compute historical and current Palmer Drought Indices for Canadian synoptic stations.

Snowmelt and snowpack chemistry measurements continued for the third season at Dorset, Ontario. An acidic snowmelt shock model was modified to permit interactive use on a microcomputer, and was tested using data from several Canadian basins.

Routines to transfer hydrometeorological parameter data bases onto IBM PC storage format for quick access and retrieval were completed.

The initial algorithms for determining snow water equivalent from airborne passive microwave data (18 and 37 GHz) have been developed for regions of southern Saskatchewan, for dry snow conditions, and are being tested on NIMBUS-7 SMMR data for the southern Prairies on different dates and years. Maps of snow water equivalent correspond well to coincident ground patterns. Areas of wet snow are clearly detected. Development of a snow depth algorithm continues.

Continuing development of an inexpensive ultrasonic snow depth sensor for use at automatic stations has led to improved sensor performance; accuracy is $\pm$ 12 cm compared to conventional ruler estimates. Testing of an automatic evaporation pan, also for use at automatic stations, was commenced. The aim is for reliable short-period operation without daily manual observation.

Planning for Canadian participation in the five-year WMO Solid Precipitation Measurement Intercomparison was initiated.

Development of Marine Climate Information Systems continued (see CGB, 1984).

(ii) Climate Applications. New work included: development of a computerized analysis system for historical sea-ice data (CRISP); an organized program of arctic climate change studies; development of microcomputer-based analytical procedures to estimate site-specific design wind pressures; investigation of methods of fitting the Weibull distribution to observed wind-speed distributions for wind energy applications; and development of methods to improve the derivation of climate values needed for design purposes.

Several reports or papers were completed as follows: studies reconstructing past climate in the Hudson Bay area; the effects of climate change on winter recreation, forest fires and solar and wind energy in southern Ontario; climatic aspects of forestry seed-orchard planning and operations; the potential use of phenology in forest climatology; classify synoptic weather patterns for use in forest-fire suppression and other applications.

(iii) Monitoring and Prediction. Experimental forecasts of monthly and seasonal temperature and precipitation were begun in early 1985 to evaluate skill and utility. The forecasts are produced in real time and disseminated to users across Canada who have agreed to supply feedback on utility and format. The experiment is scheduled to continue at least until the summer of 1986 when the project status will be reviewed.

The forecasts are based on subjective assessment of outputs from a variety of tools, including regression models, analogue models, and extended range numerical weather forecast products to day 10. The methodology is undergoing continual evolution with the goal of achieving automated and totally objective forecasts. In the fall, a pilot project was set up to evaluate the applicability of information entropy concepts for classifying predictive information. The method, called the Entropy Minimax method, avoids the necessity of assuming linear statistical models.

(iv) General Circulation Modelling. Development of the General Circulation Model (GCM) has continued and is directed towards CO_2 simulations. High-resolution simulations were done at thirty waves (T30) and at forty waves (T40) compared to the usual twenty waves (T20). Unlike the results reported by some other modellers, the simulations do not become much too zonal in response to an increase in resolution. While there are a number of differences in the high-resolution simulations, they are neither dramatic improvements nor degradations. It appears that the sensitivity to resolution results mainly from the sensitivity of the parameterizations to resolution.

A dynamical extended range forecast (DERF) experiment was carried out in conjunction with a student from the University of Alberta. An ensemble of forecasts was performed for January 1983 with and without the El Nino tropical sea surface temperature as the lower boundary condition. The results indicate an ability to predict the January anomalies in the tropical regions with some skill. For the extra-tropics, some, albeit marginal, skill appears to exist.

The atmospheric response to the 1982/83 El Nino modelled with the GCM was compared with the observations from NMC in terms of vertically integrated budgets. Despite the difficulties in modelling and especially in observing the dynamical quantities affected, the correspondence between observations and the model was good.

A new gravity wave drag parameterization was extensively tested and has been implemented in the GCM as well as in the CMC operational numerical weather prediction model.

The surface energy balance equation in the GCM was modified to make use of the more accurate force-restore method for calculating ground surface temperatures over land. In addition, the surface hydrology has been extensively modified to allow for spatially variable moisture holding capabilities and to permit the surface albedo to be a function of soil moisture.

A new interactive cloud scheme to account for fractional coverage and optical feedback processes has been developed as well as a trade wind cumulus parametrization.

(v) Radiative-Photochemical Climate Modelling. The solar and long-wave radiation transfer codes used in the 1-D and the 2-D climate models have been validated and improved through active participation in the program of intercomparison of radiative codes used in climate models (ICRCCM study).

Using these improved radiation transfer codes and revised chemical kinetics and photochemical data, sensitivity experiments were carried out with a 1-D coupled radiative-convective and photochemical climate model to assess the possible effects of past and future anthropogenic emissions of important trace gases (CO_2, CFCs, N_2O, CH_4) on atmospheric ozone and temperature structure and surface climate. Experiments with a 1-D climate model were also

carried out to estimate the climatic and other atmospheric effects of smoke, dust and NO_x generated from a nuclear war.

(vi) General Circulation Diagnostics. Atmospheric energy transports in two FGGE III-b data sets (ECMWF and GFDL) were compared with those in the GCM. There is considerable disagreement in the transports obtained from the two data sets. The GCM agrees best with the ECMWF-based results. The comparison of these estimates with previous values obtained from radiosonde data underlines the difficulty in obtaining these basic climatological values from current approaches. Statistical techniques for evaluating climate change experiments are being reviewed.

A study of the solar thermal tide as manifest in the GCM was completed. The model's semidiurnal tide was found to correspond very closely with observations. Experimentation with classical linear theory suggests that the good agreement may depend on the effect of the rigid lid condition of the model.

Five years (1980-1984) of the ECMWF/WMO data set were archived and spectrally analyzed. The resulting data were used to begin a wavenumber frequency study of the KE of the Northern and Southern Hemispheres and to study the growth and decay of APE and KE. The Division is coordinating a WGNE project to compare the surface interchange terms of the world's GCMs. A spectral energetics study of the GCM showed that the model has a very realistic APE-KE budget when viewed in terms of the 2-D wavenumber.

(e) Central Services Directorate

(i) Ice Branch. Ice reconnaissance, data handling and ice forecasting continued substantially as reported in the CGB, 1982, with the addition of limited iceberg reconnaissance in preparation for the introduction of an iceberg information service in 1986. The timeliness of the service has been improved through more efficient use of HF radio-facsimile systems. A workable system for providing useful data from iceberg reconnaissance has been developed and implemented. All ice charts more than three years old have been transferred to microfilm cartridges as part of the program to make the ice data archive generally available to users.

(ii) Data Acquisitions Services Branch. The Doppler radar for the measurement of the fall velocity of atmospheric aerosols, and thereby the inference of precipitant type, has been further improved. The separation of transmit and receive antennae has been successful in avoiding droplet shimmy interference, and a very promising and practical technique has been developed to rid the sensor of water and ice. In preparing for the CASP experiment it was discovered that the sensor was excessively sensitive to direct interference from airport radars.

The AES 6-channel microwave radiometer has been tested at Downsview and mounted in a mobile laboratory for use in CASP. It appears to be working very well, but needs experience in operational support. An improved model has been engineered under contract in Montreal and is being constructed there.

A line of remotable basic meteorological sensors has been engineered, and prototypes of sensor and display packages tested and found satisfactory. A number of systems will be procured in 1986 for operational network installation and performance evaluation.

The prototype of operational weather radar processing systems for the CWSR-81 radars is nearing completion at McGill and will be installed at the Quebec Weather Centre in Montreal in 1986.

(f) Weather Services Directorate

(i) Canadian Meteorological Centre. Following on work initiated in 1984, the code of the spectral model was substantially optimized (vectorization for the CRAY computer) to allow an increase of resolution to 59 waves (triangular truncation) in the horizontal and 15 levels in the vertical. Major efforts were also devoted to solve a serious problem of overdevelopment, sometimes fictitious development, mostly of sub-tropical lows over the Pacific and the Gulf of Mexico. The problem was found to be related to moisture surface

fluxes over warm oceans and was attributed to the lack of adequate convective mixing processes above the boundary layer. No satisfactory solutions were found immediately, other than limiting these fluxes with a known drawback, an insufficient latent heat release over warm oceans and concomitant systematic cooling of the tropical regions.

Efforts were concentrated on improving the precipitation forecasts, and on solving the overdevelopment problem, with the replacement of the convective adjustment scheme by Kuo's convection parameterization, the elimination of the onset scheme for stable precipitation (release of latent heat at 100% saturation only) and the introduction of a more suitable precipitation evaporation scheme. Results were positive: less overdevelopment, increased precipitation amounts overall and decreased precipitation areas.

Conservative constant finite elements were introduced in the vertical. Stability-dependent vertical diffusion coefficients were introduced in the free atmosphere. Sensitivity tests were performed to adjust the horizontal diffusion coefficients. Horizontal diffusion of temperature was replaced by that of static energy, a more suitable variable especially in sigma coordinates. True anemometer-level winds were provided as a model output option. A semi-implicit advection scheme for vorticity and moisture was implemented, allowing for larger integration time steps (30 minutes). A gravity wave drag scheme was tested and implemented. All resulted in some forecast improvements. Finally, an experimental global version of the spectral model was tested and global versus hemispheric integrations were compared.

Research continued on direct model output weather element forecasts (WEDGE) and on the use of digital GOES satellite data in NWP models.

A MOS (Model Output Statistics) system was developed, tested and implemented to forecast total cloud amounts every three hours out to 72 hours, and the probability of precipitation for 6- and 12-hour periods out to 72 hours for 133 stations. These forecasts are being transmitted nationally.

Forecasts of spot temperatures at three-hourly intervals are produced by the MOS system for 171 Canadian stations and the output is being prepared for implementation to the operational run.

(ii) Regional Centres. Regional studies included applications of atmospheric science and meteorology to agriculture, forestry, hydrology and environmental problems, for example, a field investigation of the dispersion climatology of a shoreline site at Port Hope, Ont.; a case study of the extreme deposition episode at Chalk River, Ont.; studies of the meteorological conditions associated with high deposition episodes as well as source-receptor relationships; acid rain and snow in Nova Scotia; analysis of the daily pH of rain in southern Quebec; evaporation from Prairie lakes; comparisons of snow gauges; Prairie wind storms and blizzards.

17. Bibliography

Journal Articles

Adams, W.P. and Lasenby, D.C. 1985. The roles of snow, lake ice and lake water in the distribution of major ions in the ice cover of a lake. Ann. Glaciol., 7, 202-207.

Admirat, P., Goyer, G.G., Wojtiw, L., Carte, E.A., Ross, D. and Lozowski, E.P. 1985. A comparative study of hailstorms in Switzerland, Canada and South Africa. J. Climatol., 5, 35-52.

Anlauf, K.G., Fellin, P., Wiebe, H.A., Schiff, H.I., Mackay, G.I., Braman, R.S. and Gilbert, R. 1985. A comparison of three methods for measurement of atmospheric nitric acid and aerosol nitrate and ammonium. Atmos. Environ., 19, 325-333.

Anlauf, K.G., Bottenheim, J.W., Brice, K.A., Fellin, P., Wiebe, H.A., Schiff, H.I., Mackay, G.I., Braman, R.S. and Gilbert, R. 1985. Measurement of atmospheric aerosols and photochemical products at a rural site in SW Ontario. Atmos. Environ., 19, 1859-1870.

Arnott, J.T. and Macey, D.E. 1985. Effect of supplemental light intensity on white spruce, engelmann spruce, and mountain hemlock seedlings grown under an extended photoperiod. Can. J. For. Res., 15, 295-300.

Barrie, L.A. 1985a. Atmospheric particles: their physical and chemical characteristics, and deposition processes relevant to the chemical composition of glaciers. Ann. Glaciol., 7, 100-108.

Barrie, L.A. 1985b. Features of the atmospheric cycle of aerosol trace elements and sulphur dioxide revealed by baseline observations in Canada. J. Atmos. Chem., 3, 139-152.

Barrie, L.A. and Hoff, R.M. 1985. Five years of air chemistry observations in the Canadian Arctic. Atmos. Environ., 19, 1995-2010.

Barrie, L.A., Fisher, D. and Koerner, R.M. 1985. Twentieth century trends in Arctic air pollution revealed by conductivity and acidity observations in snow and ice in the Canadian high Arctic. Atmos. Environ., 19, 2055-2063.

Barthakur, N.N. 1984. Foliar absorption of tritiated water by tobacco plants. J. Nucl. Agric. Biol., 13, 97-99.

Barthakur, N.N. 1985a. A comparative study of radiometric and electronic leaf wetness sensors. Agric. For. Meteorol., 36, 83-90.

Barthakur, N.N. 1985b. The beta-ray gauge as an evaporimeter. Int. J. Appl. Radiat. Isot., 36, 162-163.

Baumgardner, D., Strapp, J.W. and Dye, J.E. 1985. Evaluation of the forward scattering spectrometer probe. Part II: Corrections for coincidence and dead-time losses. J. Atmos. Ocean. Technol., 2, 626-632.

Béland, M. and Beaudoin, C. 1985. A global spectral model with a finite element formulation for the vertical discretization: adiabatic formulation. Mon. Weather Rev., 113, 1910-1919.

Blanchet, J.-P. 1985. On radiative heating due to polar stratospheric clouds. Tellus, 37B, 348-362.

Boer, G.J. and Sargent, N.E. 1985. Vertically integrated budgets of mass and energy for the globe. J. Atmos. Sci., 42, 1592-1613.

Bohlendar, D.A., Irwin, P.J. and Mathews, T. 1985. Observations of sound propagation during a southern Alberta chinook. J. Acoust. Soc. Am., 77, 2043-2049.

Bootsma, A. and Suzuki, M. 1985. Critical autumn harvest period for alfalfa in the Atlantic region based on growing degree-days. Can. J. Plant Sci., 65, 573-580.

Bourgeois, J.G., Koerner, R.M. and Alt, B.T. 1985. Airborne pollen: a unique air mass tracer, its influx to the Canadian high Arctic. Ann. Glaciol., 7, 109-116.

Brach, E.J., Mack, A.R., Hayhoe, H. and Scobie, B. 1985. Electrical determination for frost depth in soil. Agric. For. Meteorol., 34, 173-181.

Brix, H. and Mitchell, A.K. 1985. Effects of disrupting stem sapwood water conduction on the water status in douglas fir crowns. Can. J. For. Res., 15, 982-985.

Brzezinska-Paudyn, A., Van Loon, J.C. and Balicki, M.R. 1985. Study of the elemental composition of marine particulate matter collected on different filter material. Water, Air Soil Pollut., 24, 239-248.

Burrows, W.R. 1985. On the use of time-offset model output statistics for production of surface wind forecasts. Mon. Weather Rev., 113, 2049-2054.

Castonguay, Y. and Dubé, P.A. 1985. Climatic analysis of a phenological zonation: a multivariate approach. Agric. For. Meteorol., 35, 31-45.

Chan, W.H. and Lusis, M. 1985. Post-superstack Sudbury smelter emissions and their fate in the atmosphere. Water, Air Soil Pollut., 26, 43-58.

Cheng, L., English, M. and Wong, R. 1985. Hailstone size distributions and their relationship to storm thermodynamics. J. Clim. Appl. Meteorol., 24, 1059-1067.

Cho, H.-R. 1985a. Rates of entrainment and detrainment of momentum of cumulus clouds. Mon. Weather Rev., 113, 1920-1932.

Cho, H.-R. 1985b. Stochastic dynamics of precipitation: an example. Water Resour. Res., 21, 1225-1232.

Chung, Y.-S. and Dann, T. 1985. Observations of stratospheric ozone at the ground level in Regina, Canada. Atmos. Environ., 19, 157-162.

Cogger, L.L., Murphree, J.S., Tepley, C.A. and Meriwether, J.W., Jr. 1985. Measurments of the E-region neutral wind field. Planet. Space Sci., 33, 373-379.

Coombes, C.A. and Harrison, A.W. 1985. Radiometric estimation of cloud cover. J. Atmos. Ocean. Technol., 2, 482-490.

Daley, R. 1985. The analysis of synoptic scale divergence by a statistical interpolation procedure. Mon. Weather Rev., 113, 1066-1079.

Daley, R. and Chervin, R. 1985. Statistical significance testing in numerical weather prediction. Mon. Weather Rev., 113, 814-826.

Daley, R. and Williamson, D. 1985. The existence of free Rossby waves during January, 1979. J. Atmos. Sci., 42, 2121-2141.

Daley, R., Hollingsworth, A., Plosahay, J., Miyakoda, K., Baker, W., Kalnay, E., Dey, C., Krishnamurti, T. and Barker, E. 1985. Objective analysis and assimilation techniques used for the production of FGGE III-b analysis. Bull. Am. Meteorol. Soc., 66, 532-538.

Danard, M. 1985. On the use of satellite estimates of precipitation in initial analyses for numerical weather prediction. Atmos.-Ocean, 23, 23-42.

Davidson, C.I., Santhanam, S., Fortmann, R.C. and Olson, M.P. 1985. Atmospheric transport and deposition of trace elements onto the Greenland Ice Sheet. Atmos. Environ., 19, 2065-2081.

Davies, J.A. 1985. Carbon dioxide and climate. Can. Geogr., 19, 74-85.

Davies, J.A., Abdel-Wahab, M. and Howard, J.E. 1985. Cloud transmissivities for Canada. Mon. Weather Rev., 113, 338-348.

De Jong, R. 1985. Soil water modelling using daily and mean-daily data derived from historical monthly values. Atmos.-Ocean, 23, 254-266.

Delage, Y. 1985. Surface turbulent flux formulation in stable conditions for atmospheric circulation models. Mon. Weather Rev., 113, 89-98.

DeLuisi, J.J., Mateer, C.L. and Bhartia, P.K. 1985. On the correspondence between standard Umkehr, short Umkehr, and solar backscattered ultraviolet vertical ozone profiles. J. Geophys. Res., 90, 3845-3849.

Desjardins, R.L. 1985. Carbon dioxide budget of maize. Agric. For. Meteorol., 36, 29-42.

Drummond, A.M. and MacPherson, J.I. 1985. Aircraft flow effects on cloud drop images and concentrations measured by the NAE Twin Otter. J. Atmos. Ocean. Technol., 2, 633-643.

Drummond, J.R. and Steckner, M. 1985. Voigt function evaluation using a two-dimensional interpolation scheme. J. Quant. Spectrosc. Radiat. Transfer., 34, 517-521.

Drummond, J.R., Turner, D. and Ashton, A. 1985. Altitude determination in a limb scanning balloon radiometer. Adv. Space Res., 5, 73-76.

Dwyer, L.M. and Hayhoe, H.N. 1985. Comparison of observations and macro-climatic model estimates of monthly winter soil temperatures at Ottawa. Can. J. Soil Sci., 65, 109-122.

Dwyer, L.M. and Stewart, D.W. 1985a. Water extraction patterns and development of plant water deficits in corn. Can. J. Plant Sci., 65, 921-933.

Dwyer, L.M. and Stewart, D.W. 1985b. Water stress conditioning of corn (Zea mays L.) in field and greenhouse. Can. J. Bot., 63, 704-710.

Elkiey, T.M., Bhartendu, S. and Barthakur, N. 1985. Air ion effect on respiration and photosynthesis of barley and Antirrhinum majus. Int. J. Biometeorol., 19, 285-292.

Ellenton, G., Ley, B.E. and Misra, P.K. 1985. A trajectory puff model of sulfur transport for eastern North America. Atmos. Environ., 19, 727-737.

Emery, W.J. and Hamilton, K. 1985. Atmospheric forcing of interannual variability in the northeast Pacific Ocean, connections with El Nino. J. Geophys. Res., 90, 857-868.

Evans, W.F.J. and McElroy, C.T. 1985. The conversion of N_2O_5 to HNO_3 at high latitudes in winter. Geophys. Res. Lett., 12, 825-828.

Evans, W.F.J., Cann, M., Kerr, J.B., McConnell, J.C., McElroy, C.T., Davies, J., Shah, G., Garneau, M., Wardle, D.I., MacLean, S. and Nicholls, R.W. 1985. The SPEAM Sunphotometer Experiment on Mission 41-G. Can. Aeronaut. Space J., 31, 240-248.

Fast, H., Evans, W.F.J., Vail, G.L. and Buijs, H.L. 1985. A measurement of the stratospheric HCl profile at 32°N on 8 November 1978. Atmos.-Ocean., 23, 177-187.

Fisher, D.A. and Alt, B.T. 1985. A global oxygen isotope model - semi-empirical zonally averaged. Ann. Glaciol., 7, 117-124.

Forand, J.L., Becker, K. and McConkey, J.W. 1985. Absolute electron-impact emission cross sections of the He^+ 304A line produced by simultaneous ionization-excitation. J. Phys., B18, 1409-

Goodison, B.E. 1985. "Snow" in focus: hydrology of snow and ice, M.-K. Woo (Editor). Can. Geogr., 29, 173-176.

Grace, B., Gillespie, T.J. and Puckett, K.J. 1985a. Uptake of gaseous sulphur dioxide by the lichen Cladina rangiferina. Can J. Bot., 63, 797-805.

Grace, B., Gillespie, T.J. and Puckett, K.J. 1985b. Sulphur dioxide threshold concentration values for Cladina rangiferina in the Mackenzie Valley, NWT. Can J. Bot. 63, 806-812.

Granberg, H.B. 1985. Distribution of grain sizes and internal surface area and their role in snow chemistry in a sub-Arctic snow cover. Ann. Glaciol., 7, 149-152.

Grover, R., Shewchuk, S.R., Cessna, A.J., Smith, A.E. and Hunter, J.H. 1985. Fate of 2,4-D iso-octyl ester after application to a wheat field. J. Environ. Qual., 14, 203-210.

Guiot, J. 1985. Reconstruction of seasonal temperatures and sea-level pressures in the Hudson Bay area back to 1700. Climatol. Bull., 19, 11-59.

Hage, K.D. 1985. Weather extremes in Alberta: 1880 to 1960. Climatol. Bull. 19, 3-15.

Halevy, I. and Peltier, W.R. 1985. Barotropic instability and Rossby wave radiation. J. Atmos. Sci., 42, 1825-1837.

Hamilton, K. 1985a. A possible relationship between tropical ocean temperatures and the observed amplitude of the atmospheric (1,1) Rossby normal mode. J. Geophys. Res., 90, 8071-8074.

Hamilton, K. 1985b. The westerly acceleration phase of the stratospheric quasi-biennial oscillation as revealed in FGGE analyses. Atmos.-Ocean, 23, 188-192.

Harrison, A.W. and Coombes, C.A. 1985a. Anomalous telephotometer results for the ambient atmospheric aerosol. Atmos. Environ., 19, 1725-1730.

Harrison, A.W. and Coombes, C.A. 1985b. Telephotometer extinction coefficient and error. J. Air Pollut. Control Assoc., 35, 956-958.

Haves, M. and Likens, G.E. 1985. Toxicity of aluminum and hydrogen ions to Daphnia catawba, Holopedium gibberum, Chaoborus punctipennis, and Chironomus antrocinus from Mirror Lake, New Hampshire. Can. J. Zool., 63, 1114-1119.

Hay, J.E. 1985. Radiation climatology: some illustrative examples. Phys. Geogr., 6, 5-24.

Hay, J.E. and Hanson, K.J. 1985. Evaluating the solar resource: problems resulting from temporal, spatial and angular variations. Solar Energy, 34, 151-161.

Hay, J.E. and McKay, D.C. 1985. Estimating solar irradiance on inclined surfaces: A review and assessment of methodologies. Int. J. Solar Energy, 3, 203-240.

Hayhoe, H.N. and Bailey, W.G. 1985. Monitoring changes in total and unfrozen water content in seasonally frozen soil using time domain reflectometry and neutron moderation techniques. Water Resour. Res., 21, 1077-1084.

Henderson-Sellers, A., McGuffie, K. and Cogley, J.G. 1985. Seasonal climatology of spatial resolution on archives of land cover type. Clim. Change., 7, 391-402.

Hicks, J.F. and Megaw, J.J. 1985. The growth of ambient aerosols in the conditions of the respiratory system. J. Aerosol Sci., 16, 521-527.

Higuchi, K. and Daggupaty, S.M. 1985. On variability of atmospheric CO_2 at station Alert. Atmos. Environ., 19, 2039-2044.

Hoff, R.M. and Gallant, A.J. 1985. The use of an available SO_2 tracer during the 1983 CAPTEX experiment. Atmos. Environ., 19, 1573-1575.

Holdsworth, G. and Peake, E. 1985. Acid content of snow from a mid-troposphere sampling site on Mount Logan, Yukon Territory, Canada. Ann. Glaciol., 7, 153-160.

Hollands, K.G.T. 1985. A derivation of the diffuse fraction's dependence on the clearness index. Solar Energy, 35, 131-136.

Hyde, W.T. and Peltier, W.R. 1985. Sensitivity experiments with a model of the ice age cycle: the response to harmonic forcing. J. Atmos. Sci., 43, 1-19.

Kanipayoor, R., Naranjit, D. and Van Loon, J.C. 1985. Determination of trace elements directly by atomic absorption spectrometry. Anal. Chim. Acta, 163, 235-245.

Kendall, D.J.W., Swenson, G.R., Gattinger, R.L., Llewellyn, E.J., Wochowicz, R., Gaull, W.A., Garneau, M., Shepherd, G.G., Buttner, G.J., Solheim, B.H., Mende, S.B. and Cogger, L. 1985. OGLOW - An experiment to measure orbiter and earth optical emissions. Can. Aeronaut. Space J., 31, 227-238.

King, W.D., Dye, J.E., Strapp, J.W., Baumgardner, D. and Huffman, D. 1985. Icing wind tunnel tests on the CSIRO liquid water probe. J. Atmos. Ocean. Technol., 2, 340-352.

Klaassen, G.P. and Peltier, W.R. 1985a. The effect of Prandtl number on the evolution and stability of Kelvin-Helmholtz billows. Geophys. Astrophys. Fluid Dyn., 32, 23-60.

Klaassen, G.P. and Peltier, W.R. 1985b. The high Reynolds number evolution of finite amplitude Kelvin-Helmholtz waves. J. Atmos. Sci., 42, 1321-1339.

Klaassen, G.P. and Peltier, W.R. 1985c. The onset of turbulence in finite amplitude Kelvin-Helmholtz billows. J. Fluid Mech., 155, 1-35.

Knox, J.L. and Hay, J.E. 1985. Blocking signatures in the Northern Hemisphere: frequency distribution and interpretation. J. Clim., 5, 1-16.

Kochtubajda, B. and Lozowski, E.P. 1985. The sublimation of dry ice pellets used for cloud seeding. J. Clim. Appl. Meteorol., 24, 597-605.

Lafleur, G., Hill, S.B. and Barthakur, N.N. 1985. Observations on mortality, detection distance, and rate of loss of label in plum curculio (coleoptera curculionidae), using improved techniques for topical application of radioisotopes on insects. J. Econ. Entomol., 78, 1157-1165.

Lamb, R.J., Turnock, W.J. and Hayhoe, H.N. 1985. Winter survival and outbreak of Bertha Armyworm, Mamestra Configurata (Lepidoptera: Noctuidae), on Canola. Can. Entomol., 117, 727-736.

Leahey, D.M. and Hansen, M.C. 1985. Meteorological evidence for greater dispersion of elevated plumes. J. Air Pollut. Control Soc., 35, 828-830.

Leclerc, M.Y., Thurtell, G.W. and Gillespie, T.J. 1985. Laboratory simulation of evaporation of water droplets on artificial soybean leaves. Agric. For. Meteorol., 36, 105-112.

Leduc, R. et Lamothe, A.-M. 1985. Tendances à long terme de la visibilité dans l'axe Windsor/ Sept-Îles. Climatol. Bull., 19, 3-10.

Lin, C.A. 1985. Nonlinear meridional scale interaction in baroclinic instability. Dyn. Atmos. Oceans, 9, 1-16.

Lozowski, E.P., Finstad, K.J. and Gates, E.M. 1985. Comments on "Calculation of the impingement of cloud droplets on a cylinder by the finite-element method". J. Atmos. Sci., 42, 306-307.

Manson, A.H. and Meek. C.E. 1985. Middle atmosphere (60-110 km) tidal oscillations at Saskatoon, Canada (52°N, 107°W) during 1983-1984. J. Geophys. Res., 90, 1441.

Manson, A.H., Meek, C.E., Smith, M.J. and Fraser, G.J. 1985. Direct comparison of prevailing winds and tidal wind fields (24-, 12-h) in the upper middle atmosphere (60-105 km) during 1978-1980 at Saskatoon (52°N, 107°W) and Christchurch (44°S, 173°E). J. Atmos. Terr. Phys., 47, 463-476.

McCaughey, J.H. 1985. A radiation and energy balance study of mature forest and clear-cut sites. Boundary-Layer Meteorol., 32, 1-24.

McConkey, J.W., Trajmar, S., Nickel, J.C. and McAdams, R. 1985. Rotationally resolved electron-photon coincidence study of H_2 ($d^3\Pi_u$) excitation. J. Phys., B18, L207.

McGuffie, K., Cogley, J.G. and Henderson-Sellers, A. 1985. Climatological analysis of Arctic aerosol quantity and optical properties at Resolute, N.W.T. Atmos. Environ., 19, 707-714.

Meek, C.E. and Manson, A.H. 1985. Combination of Primrose Lake (54°N, 110°W) RACOB winds (20-60 km) and Saskatoon (52°N, 107°W) M.F. radar winds (60-110 km): 1978-1983. J. Atmos. Terr. Phys., 47, 477-488.

Meek, C.E., Reid, I.M. and Manson, A.H. 1985. Observations of mesospheric wind velocities, 1, Gravity wave horizontal scales and phase velocities determined from spaced wind observations; 2, Cross sections of power spectral density for 48-8 hours, 8-1 hours, and 1 hour to 10 min over 60-110 km for 1981. J. Geophys. Res., 90, 1363-1382.

Millan, M.M., Gallant, A.J., Chung, Y.-S. and Fanaki, F. 1985. COSPEC observation of Mt. St. Helens volcanic SO_2 eruption cloud of 18 May 1980 over southern Ontario. Atmos. Environ., 19, 255-264.

Misra, P.K., Chan, W.H., Chung, D. and Tang, A.J.S. 1985. Scavenging ratios of acidic pollutants and their use in long-range transport models. Atmos. Environ., 19, 1471-1475.

Mitchell, H. and Derome, J. 1985. Resonance of topographically forced waves in a quasi-geostrophic model. J. Atmos. Sci., 42, 1653-1666.

Moore, G.W.K. 1985a. A comparison of hydrostatic and non-hydrostatic wave-CISK. J. Atmos. Sci., 42, 1510-1520.

Moore, G.W.K. 1985b. The organization of convection in narrow cold-frontal rain-bands. J. Atmos. Sci., 42, 1777-1791.

Moore, G.W.K. and Stewart, R.E. 1985. The coupling between melting and convective air motions in stratiform clouds. J. Geophys. Res., 90, 10659-10666.

Morton, F.I. 1985. What are the limits on forest evaporation? - Reply. J. Hydrol., 82, 184-192.

Mukammal, E.I., Neumann, H.H. and Nichols, T.R. 1985. Some features of the ozone climatology of Ontario, Canada and possible contributions of stratospheric ozone to surface concentrations. Arch. Meteorol. Bioclimatol., 34, 179-212.

Mustafa, M.A., de Jong, R., Hayhoe, H.N. and Topp, G.C. 1985. Effects of intermittent ponding on salt redistribution through a saline-sodic clay soil. Can. Agric. Eng., 27, 105-110.

Naranjit, D.A., Radziuk, B.H., Rylaarsdam, J.C., Larkins, P.L. and Van Loon, J.C. 1985. A microprocessor controlled simultaneous multielement non-dispersive atomic fluorescence spectrometer. Appl. Spectrosc., 39, 128.

Neumann, H.H. and den Hartog, G. 1985. Eddy correlation measurements of atmospheric fluxes of ozone, sulphur, and particulates during the Champaign intercomparison study. J. Geophys. Res., 90, 2097-2110.

Nkemdirim, L.C. and Venkatesan, D. 1985. An urban impact model for changes in the length of the frost free season at selected Canadian stations. Clim. Change., 7, 343-362.

Ozvacic, V., Wong, G., Tosine, H., Clement, R.E. and Osborne, J. 1985. Emissions of chlorinated organics from two municipal incinerators in Ontario. J. Air Pollut. Control Assoc., 35, 849.

Peake, E., MacLean, M.A. and Sandhu, H.S. 1985. Total inorganic nitrate (particulate nitrate and nitric acid) observations in Calgary, Alberta. J. Air Pollut. Control Assoc., 35, 250-253.

Peltier, W.R. and Chagnon, R. 1985. Sensitivity experiments with a model of stratospheric sudden warming. PAGEOPH, 123, 99-140.

Peteherych, S., Shepherd, G.G. and Walker, J.K. 1985. Observation of vertical E-region neutral winds in two intense auroral arcs. Planet. Space Sci., 33, 869-873.

Puckett, K.J. 1985. Temporal variation in lichen element levels. In: Lichen Physiology and Cell Biology, D.H. Brown (Editor), Plenum Press, London, 211-225

Pudykiewicz, J., Benoit, R. and Staniforth, A. 1985. Preliminary results from a partial LRTAP model based on an existing meteorological forecast model. Atmos.-Ocean, 23, 267-303.

Regier, H.A. and Grima, A.P. 1985. Fishery resource allocation: an exploratory essay. Can. J. Fish. Aquat. Sci., 42, 845-859.

Ritchie, H. 1985a. Application of a semi-Lagrangian integration scheme to the moisture equation in a regional forecast model. Mon. Weather Rev., 113, 424-435.

Ritchie, H. 1985b. Rossby wave resonance in the presence of a nonlinear critical layer. Geophys. Astrophys. Fluid Dyn., 31, 49-92.

Robert, A., Yee, T.L. and Ritchie, H. 1985. A semi-Lagrangian and semi-implicit numerical integration scheme for multilevel atmospheric models. Mon. Weather Rev., 113, 388-394.

Robertson, E. and Barry, P.J. 1985. The water and energy balances of Perch Lake (1969-1980). Atmos.-Ocean, 23, 238-253.

Rouse, W.R. and Bello, R.L. 1985. Impact of Hudson Bay on the energy balance in the Hudson Bay Lowlands and the potential for climatic modification. Atmos.-Ocean., 23, 375-392.

Royer, A., Vincent, P. and Bonn, F. 1985. Evaluation and correction of viewing angle effects on satellite measurements of bidirectional reflectance. Photogram. Eng. Remote Sensing, 51, 1899-1914.

Safranyik, L. and Whitney, H.W. 1985. Development and survival of axenically reared mountain pine beetles, Dendroctonus ponderosae, (Coleoptera: Scolytidae), at constant temperatures. Can. Entomol., 117, 185-192.

Sahota, H., Kiely, P. and Lusis, M. 1985. Air quality impact of the Nanticoke industrial development. Water, Air Soil Pollut., 25, 249-264.

Schemenauer, R.S. and Tsonis, A.A. 1985. Comments on "Physical interpretation of results from the HIPLEX-1 Experiment". J. Clim. Appl. Meteorol., 24, 1269-1274.

Schemenauer, R.S., Summers, P.W., Wiebe, H.A. and Anlauf, K.G. 1985. Spatial and temporal variability of surface snowfall and snowpack chemistry in central Ontario. Ann. Glaciol., 7, 185-190.

Schroeder, W.H. and Jackson, R.A. 1985. An instrumental analytical technique for speciation of atmospheric mercury. Int. J. Environ. Anal. Chem., 22, 1-18.

Schroeder, W.H., Hamilton, M.C. and Stobart, S.R. 1985. The use of noble metals as collection media for mercury and its compounds in the atmosphere. Rev. Anal. Chem., 8, 179-209.

Shah, G.M. and Evans, W.F.J. 1985. Latitude survey of aerosol optical thickness of the El Chichon eruption cloud in May 1983. Geophys. Res. Lett., 12, 255-258.

Shewchuk, S.R. 1985. A study of atmospheric deposition onto the snowpack in northern Saskatchewan. Ann. Claciol., 7, 191-195.

Staniforth, A. and Pudykiewicz, J. 1985. Reply to comments on and addenda to "Some properties and comparative performance of the semi-Lagrangian method of Robert in the solution of the advection-diffusion equation". Atmos.-Ocean, 23, 195-200.

Stathers, R.J., Black, T.A. and Novak, M.D. 1985. Modelling soil temperature in forest clear-cuts using climate station data. Agric. For. Meteorol., 36, 153-164.

Stathopoulos, T. 1985. Wind environmental conditions around tall buildings with chamfered corners. J. Wind Eng. Ind. Aerodyn., 21, 71-88.

Stewart, D.W. and Dwyer, L.M. 1985. A resistance model for water balance calculations and spring wheat yield estimates. In: ASEA National Symposium on Advances in Evapotranspiration, 16-17 December, 1985, Chicago.

Stewart, D.W., Dwyer, L.M. and Desjardins, R.L. 1985. A mathematical model of transpiration using a nonlinear least squares analysis. Can. Agric. Eng., 27, 1-6.

Steyn, D.G. 1985. An objective method to achieve closure of overdetermined surface energy budgets. Boundary-Layer Meteorol., 33, 303-310.

Steyn, D.G. and Ayotte, K.W. 1985. Application of two-dimensional terrain height spectra to mesoscale modelling. J. Atmos. Sci., 42, 2884-2887.

Steyn, D.G. and Lyons, T.J. 1985. Comments on "The determination of view-factors in urban canyons". J. Clim. Appl. Meteorol., 24, 383-385.

Sturges, W.T. and Harrison, R.M. 1985a. An assessment of the contribution from paint flakes to the lead content of some street and household dusts. Sci. Total Environ, 44, 225-234.

Sturges, W.T. and Harrison, R.M. 1985b. Bromine: lead ratios in airborne particles from urban and rural sites. Atmos. Environ., 20, 577-588.

Sturges, W.T., Harrison, R.M. and Dams, R. 1985. Development of a technique for the determination of lead and bromine in atmospheric particles by X-ray fluorescence. Atmos. Environ., 19, 1495-1502.

Summers, P.W. 1985. Reply to "Comments on the long range transport potential of Inco's Sudbury emissions". J. Air Pollut. Control Assoc., 35, 132-133.

Swift, C.T., Fedor, L.S. and Ramseier, R.O. 1985. An algorithm to measure sea-ice concentration with microwave radiometers. J. Geophys. Res., 90(C1).

Syed, M.Q., Coombes, C.A. and Harrison, A.W. 1985. Transient analysis of a radiation test cell using continuous simulation language. Energy Eng., 82, 35-48.

Taylor, C.H. and Pierson, D.C. 1985. The effect of a small wetland on runoff response during spring snowmelt. Atmos.-Ocean, 23, 137-154.

Thiébaux, H.J. 1985. On approximations to geopotential and wind-field correlation structures. Tellus, 37A, 126-131.

Tsonis, A.A. and Isaac, G.A. 1985. On a new approach for instantaneous rain area delineation in the midlatitudes using GOES data. J. Clim. Appl. Meteorol., 24, 1208-1218.

Tuller, S.E. and Brett, A.C. 1985. The goodness of fit of the Weibull and Rayleigh distributions to the distributions of observed wind speeds in a topographically diverse area. J. Clim., 5, 79-94.

Vupputuri, R.K.R. 1985. The effect of ozone photochemistry on atmospheric and surface temperature changes due to increased CO_2, N_2O, CH_4 and volcanic aerosols in the atmosphere. Atmos.-Ocean, 23, 359-374.

Vupputuri, R.K.R. and Blanchet, J.-P. 1984. The possible effects of El Chichon eruption on atmospheric thermal and chemical structure and surface climate. Geof. Int., 23, 433-447.

Walmsley, J.L. and Howard, A.D. 1985. Application of a boundary-layer model to flow over an eolian dune. J. Geophys. Res., 90(D6), 10631-10640.

Warn, T. 1985. Statistical mechanical equilibria of the shallow water equations. Tellus, 38A, 1-11.

Wilson, J.D. 1985. Numerical studies of flow through a windbreak. J. Wind Eng. Ind. Aerodyn., 21, 119-154.

Zwiers, F. 1985. Estimating the probability of collision between an iceberg and a fixed marine structure. Can. J. Stat., 13, 92-105.

Reports and Memoranda

(a) Alberta Environment

Gourlay, P. 1985. An overview of solar radiation data collection and applications in Alberta. Research Management Division RMD Report L-88, 23 pp.

Rudolf, R.C. et al. 1985. Estimates of roughness length from minisonde profiles in the Athabasca Oil Sands Area. Prepared for Research Management Division, Alberta Environment by INTERA Technologies Ltd., RMD Report L-87, 42 pp.

Wilson, D.J. 1985. Plume dynamics and concentration fluctuations in gas emissions. Prepared for Pollution Control Division, Alberta Environment.

Wilson, Y.K. and Simms, B.W. 1985. Exposure time effects on concentration fluctuations in plumes. Prepared for Pollution Control Division, Alberta Environment.

(b) Western Research

Leahey, D.M. and Hansen, M.C. 1985. Doppler acoustic radar observations of wind in the Ellerslie Region of Alberta. Prepared for Research Management Division, Alberta Environment, RMD Report 85/31, 77 pp.

Leahey, D.M. and Schroeder, M.B. 1985. Sulphur. In: Atmospheric Emissions Monitoring and Vegetation Effects in the Athabasca Oil Sands Region, Don L. Dabbs (Editor), Syncrude Canada Ltd., Environmental Research Monograph 1985-5, 127 pp.

Leahey, D.M., Paskall, H.G., Schroeder, M.B. and Zelensky, M.J. 1985. A preliminary study of the chemical composition and combustion efficiency of a sour gas flare. Prepared for Research Management Division, Alberta Environment, RMD Report 85/80, 93 pp.

(c) Saskatchewan Research Council

Shewchuk, S.R. 1985. A precipitation chemistry and air mass trajectory analysis over a selected region in northern Saskatchewan. SRC Tech. Rep., 173, Publ. E-906-9-B-85.

Wheaton, E.E. 1985a. Some climatological aspects of duststorms and their impact on soil erosion in the agricultural lands of Saskatchewan. SRC Tech. Rep., 176, Publ. E-906-35-B-85.

Wheaton, E.E. 1985b. The value of climatic information - a Saskatchewan Research Council Climatologist's perspective. SRC Tech. Rep., E-906-31-D-85.

Wheaton, E.E. and Begrand, R.M. 1985a. Saskatoon SRC Climatological Reference Station, Annual Summary, 1985. SRC Tech. Rep., 181.

Wheaton, E.E. and Begrand, R.M. 1985b. Sunrise, solar noon and sunset times, daylight duration and solar energy for selected Saskatchewan and Manitoba locations. SRC Tech. Rep., E-906-30-E-85.

(d) University of Toronto, Institute for Environmental Studies

Bobra, A.M., Shiu, W.Y. and Mackay, D. 1985. Structure-activity relationships for toxicity of hydrocarbons, chlorinated hydrocarbons and oils to Daphnia magna. In: QSAR in Environmental Toxicology, K.L.E. Kaiser (Editor), Reidel, Dordrecht, The Netherlands, 3-16.

Francis, G.R., Grima, A.P., Regier, H.A. and Whillans, T.H. 1985. A prospectus for the management of the Long Point ecosystem. Great Lakes Fishery Comm., Tech. Rep. 43, Ann Arbor, Michigan, 1-109.

Grima, A.P. 1985. Participatory rites: integrating public involvement in environmental impact assessment. In: Environmental Impact Assessment: The Canadian Experience, J.B.R. Whitney and V.W. Maclaren (Editors). IES Publ. EM-5, 89-94.

Mackay, D. and Shiu, W.Y. 1985. Relationships between physical, chemical and environmental partitioning coefficients. In: QSAR in Environmental Toxicology, K.L.E. Kaiser (Editor), Reidel, Dordrecht, The Netherlands.

Munn, R.E. 1985. Atmospheric impacts. In: Environmental Impact Assessment: The Canadian Experience, J.B.R. Whitney and V.W. Maclaren (Editors). IES Publ. EM-5, 89-94.

Timmerman, P. and Grima, A.P. (Editors). 1985. Climate impact assessment in the Great Lakes Basin: overview and research recommendations. IES Publ. EM-7, 32 pp.

(e) Ontario Ministry of the Environment

Chan, W.H., Tang, A.J.S., Chung, D.H.S. and Lusis, M.A. 1985. Air concentration and dry deposition fields of pollutants in Ontario - 1982. ARB-001-85-AQM.

Lusis, M.A., Sahota, H. and Yap, D. 1985. The Sarnia oxidants study - analysis of the air quality and meteorological data. ARB-124-85-AQM.

Sahota, H., Kiely, P. and Lusis, M.A. 1985. The Sarnia oxidants study - report on the airborne measurements. ARB-124-85-AQM.

(f) National Aeronautical Establishment, Flight Research Laboratory

MacPherson, J.I. 1985. Wind tunnel calibration of a PMS canister instrumented for airflow measurement. Nat. Res. Counc. Canada Aeronaut. Note NAE-AN-32, Ottawa, Ont.

(g) McGill University

Derome, J. and Fyfe, J. 1985. On finite-amplitude forced disturbances. Proceedings Stanstead Seminar, McGill Univ. Publ. in Meteorol., 128, 125-137.

Hamilton, K. and Emery, W.J. 1985. Regional atmospheric forcing of surface temperature and sea-level variability in the northeast Pacific. El Nino North. Proceedings I.R.I.S. Symposium on El Nino Effects in the Subarctic Pacific, W. Wooster and D. Fluharty (Editors), 22-30.

Reuter, G. and Yau, M.K. 1985. Simulation of penetrative downdrafts in cumulus congestus clouds. Proceedings Fourth WMO Scientific Conference on Weather Modification, Hawaii, World Meteorological Organization, 109-114.

(h) Université de Sherbrooke

Royer, A. et Pilon, D. 1985. Programme de corrections atmosphériques CORATM, description et guide d'utilisation. Rapport de recherche, CARTEL, Université de Sherbrooke, 68 pp.

Royer, A., Bernier, R. et Pilon, D. 1985. Calcul de la diffusion de la lumière par les aérosols : description des programmes MIELOR et résultats obtenus. Bulletin de recherche 80, Département de Géographie, 63 pp.

(i) Agriculture Canada

Bootsma, A. 1985. The behaviour of frost in Ontario. Ont. Min. Agric. Food, Factsheet 85-055, Agdex 079, 3 pp.

Bootsma, A. and Suzuki, M. 1985. Optimum seeding period for winter wheat in the Atlantic region. Agric. Canada, Canadex 112.22, 2 pp.

Edey, S.N. 1985. The role of the micrologger in the taking of standard agroclimatic observations at agriculture Research Stations. Res. Br. Int. Rep., 31 pp.

Mack, A.R. and Bootsma, A. 1984. Agroclimatic resource maps for agriculture in Canada. Canada Agriculture, 30(3 and 4), 16-20.

(j) Canadian Forestry Service

Alexander, M.E. (Compiler and Editor) 1985a. Proceedings of the First Central Region Fire Weather Committee Technical and Scientific Seminar, April 17, 1984, Winnipeg, Manitoba. Agriculture Canada, Canadian Forestry Service, Nor. For. Res. Cent., Edmonton, Alberta. Study NOR-5-191 File Rep., 10, 26 pp.

Alexander, M.E. (Compiler and Editor). 1985b. Proceedings of the Second Western Region Fire Weather Committee Technical and Scientific Seminar, March 6, 1984, Edmonton, Alberta. Agriculture Canada, Canadian Forestry Service, Nor. For. Res. Cent., Edmonton, Alberta. Study NOR-5-191 File Rep., 9, 29 pp.

Dennis, J.J. 1985. Effect of pH and temperature on in-vitro growth of ectomicorrhiza fungi. Pac. For. Cent. Info. Rep. BC-X-273, 19 pp.

McCaughey, J.H. 1985. Development of field testing of an energy balance measurement system for climatic studies of energy plantations in Newfoundland. Department of Geography, Queen's University, (ENFOR Contract Rep.), 46 pp.

McCaughey, J.H. and Pond, B.A. 1985. User's manual for reversing temperature difference measurement system data analysis software for the digital Rainbow-100 microcomputer. Department of Geography, Queen's University, ENFOR Contract Rep., 56 pp.

Reinelt, E. 1985. Climatology of atmospheric conditions related to extreme forest fire behaviour in west-central and northern Canada. Department of Geography, University of Alberta, PRUF Contract Rep.

(k) Atmospheric Environment Service

1. Internal Research Reports

Bottenhiem, J., Brice, K., MacTavish, D. and Wiebe, H.A. 1985. Data summary of 1984 summer experiments at AES Headquarters, Downsview. Rep. AQRB-85-007-T.

Csanady, S. 1985. A three dimensional mesoscale K-theory boundary layer model. Rep. MSRB-85-2, 67 pp.

Hoff, R.M. 1985. Project overview of the 1982 Nanticoke II Shoreline Diffusion Experiment. Rep. AQRB-85-003-T, 35 pp.

Kerman, B.R. and Mitchell, R.E. 1985. An airborne scanning video camera to study the life cycle of breaking wind waves. Rep. AQRB-85-004-L, 73 pp.

Macdonald, K.A. 1985. An evaluation of wave forecasting in the Beaufort Sea, summer 1984. Rep. MSRB-85-4, 35 pp.

MacTavish, D.C., Anlauf, D.G. and Wiebe, H.A. 1985. Data summary of air chemistry measurements for the Nanticoke II Shoreline Diffusion Study, June 1-14, 1982. Rep. AQRB-85-002-A, 217 pp.

Mathias, C.S. and Lo, A.K. 1985. Application and evaluation of the Fay and Rosenzweig long range transport model. Rep. AQRB-85-001-M, 57 pp.

Olson, M.P., Panigas, A. and Oikawa, K.K. 1985. A user's guide to the interactive trajectory computation and plotting system (ITCAPS). Rep. AQRB-85-006-T.

Teunissen, H.W. and Shokr, M.E. 1985. The Askervein Hill project: wind-tunnel simulation (smooth model) at length scale 1:1200. Rep. MSRB-85-1, 143 pp., Vol. II, App., 308 pp.

Teunissen, H.W., Vanek, K.O. and Gould, W.E. 1985. Field intercomparisons of a propeller and sonic anemometer as sensors of atmospheric turbulence. Rep. MSRB-85-5, 47 pp.

Turner, H.E. 1985. Environmental risk management: an introduction. Rep. AQRB-85-M-007, 15 pp.

Wannamaker, B. 1985a. Operational compression of AVHRR data. Rep. MSRB-85-6, 20 pp.

Wannamaker, B. 1985b. Surface emissivities and satellite surface temperature measurements. Rep. MSRB-85-7, 29 pp.

Wardle, D.I., Evans, W.F.J., Kerr, J.B., McIlroy, C.T. and Shah, G.M. 1985. Sunphotometer measurements from a commercial air flight. Rep. 117X40.

Wiebe, H.A., Vet, R.J., Barrie, L. and Anlauf, K. 1985. Canadian Air and Precipitation Monitoring Network (APN) final data report, December 1982-1983. Rep. AQRB-85-008-T.

Yip, T. 1985. Interim report on 1984 TOVS summer experiment and verification of TOVS retrieved temperatures vs. radiosonde temperatures. Rep. MSRB-85-3, 20 pp.

2. Canadian Climate Centre Reports

Acres Consulting Services. 1985. Past climatic change in the Canadian Arctic. CCC Rep. No. 85-14, 127 pp.

Benchimol, N. 1985. The mesoscale variability of insolation over the lower Fraser Valley resolved by geostationery satellite data. CCC Rep. No. 85-8, 141 pp.

Blanchet, J.-P. and Morcrette, J.J. 1985. Radiative processes in the AES/CCC multi-level spectral general circulation model. CCC Rep. No. 85-6, CCRN16, 83 pp.

Brown, R.D. and Roebber, R. 1985. The ice accretion problem in Canadian waters related to offshore energy and transportation. CCC Rep. No. 13, 295 pp.

Carrieres, T. 1985. Interactive experiments with an atmospheric general circulation model and a simple ocean and sea ice model. CCC Rep. No. 85-5, CCRN15, 39 pp.

Crowe, R.B. 1985. Effect of carbon dioxide warming scenarios on total winter snowfall and length of winter snow season in southern Ontario. CCC Rep. No. 85-19, 55 pp.

Environmental Applications Group Ltd. 1985. Feasibility study on generating wind speed direction frequency roses from statistical distributions fitted to sparse observations of ships' wind data over marine areas. CCC Rep. No. 85-15, 62 pp.

Findlay, B.F. 1985. Climatological interpolation/extrapolation techniques. CCC Rep. No. 85-4, 9 pp.

Johnstone, K. 1985. Climate network design. A Gandin approach with computer procedures. CCC Rep. No. 85-1, 55 pp.

Kel Research Corporation. 1985. Evaluation of Naval Environmental Data Network (VEDN data set). CCC Rep. No. 85-10, 108 pp.

Lewis, C.J. and Moran, M.D. 1985. Severe storms off Canada's west coast: a catalogue summary for the period 1957 to 1983. CCC Rep. No. 85-7, 380 pp.

McFarlane, N. and Laprise, R. 1985. Parameterization of sub-grid scale processes in the AES/CCC Spectral GCM. CCC Rep. No. 85-12, CCRN17, 70 pp.

Moran, M.D. and Alp, S. 1985a. Optimization of offshore hindcast winds. Phase 1 Report. CCC Rep. No. 85-2, 75 pp.

Moran, M.D. and Alp, S. 1985b. Ibid. Phase 2 Report. CCC Rep. No. 85-18, 136 pp.

Mortsch, L.D., Agnew, T., Saulesleja, A. and Swail, V.R. 1985. Marine climatological atlas - Canadian East Coast. CCC. Rep. No. 85-11, 343 pp.

Shabbar, A. 1985. AES experimental and seasonal forecasts. CCC Rep. No. 85-16, 11 pp.

Shabbar, A. and Knox, J.L. 1985. Monthly prediction by the analogue method. CCC Rep. 85-17, 15 pp.

Swail, V.R. 1985. Geostrophic wind climatology of Canadian marine areas. CCC Rep. 85-9, 50 pp.

Wilson, C.V. 1985. The summer season along the east coast of Hudson Bay during the nineteenth century. Part III. Summer thermal and wetness indices. A. Methodology. CCC Rep. No. 85-3, 77 pp.

3. Canadian Meteorological Centre Reports

Brunet, N. 1985. Operational evaluation of statistical forecast. CMC Information, 3(4), 10-16.

Delage, Y. 1985. Forecasting surface temperature with the CMC spectral model: sensitivity study. CMC Information, 3(2), 28-35.

Dunlop, M. and Johnstone, K. 1985. Numerical weather element data to day 5 - an experimental output form. CMC Information, 3(1), 15-22.

Findleton, I.B. 1985a. A factor analysis study of the weather at Montreal. Part I. The factors affecting the weather at Montreal. CMC Tech. Doc., 22, 42 pp.

Findleton, I.B. 1985b. The value of observational data in the forecast production process. CMC Information, 3(1), 2-14.

Hallé, J. 1985a. Numerical processing of satellite data at the CMC: effects on objective and numerical forecasting. CMC Information, 3(1), 23-42.

Hallé, J. 1985b. The spectral model and sea surface temperature: sensitivity study. CMC Information, 3(4), 17-29.

Jones, R. 1985. Estimation of the real wind considering pressure tendencies and some ageostrophic components. CMC Tech. Doc., No. 24.

Verner, G. 1985. Normal mode initialization of CMC operational models. CMC Information, 3(3), 9-45.

Verret, R. 1985a. MOS forecasts of sky cover: cloud amount versus opacity. CMC Information 3(2), 8-27.

Verret, R. 1985b. Verification of CMC objective sky cover forecasts. CMC Information, 3(3), 2-8.

(1) Miscellaneous Reports

Blanchet, J.-P. and List, R. 1984. On the optical properties of Arctic haze. In: Aerosols and their Climatic Effects, H.E. Gerber and A. Deepak (Editors), 179-196.

Crutzen, P.J., Kley, D., Barrie, L.A. and Whelpdale, D.M. 1985. The cycling of sulphur and nitrogen in the remote atmosphere. In: The Biogeochemical Cycling of Sulphur and Nitrogen in the Remote Atmosphere, J.N. Galloway, R.J. Charlson, M.O. Andreae and H. Rodhe (Editors), NATO Advanced Study Institute Series, Reidel, Dordrecht, 203-212.

Desjardins, R.L., MacPherson, J.I., Alvo, P. and Schuepp, P.H. 1985. Measurements of turbulent heat and CO_2 exchange over forests from aircraft. In: The Forest-Atmosphere Interaction, B.A. Hutchison and B.B. Hicks (Editors), Reidel Publishing Company, 645-658.

Goodison, B.E., Langham, E.J. and Athanassiadas, D. 1985. RADARSAT and MSAT proposed Canadian satellite systems with hydrological applications. In: Hydrological Applications of Remote Sensing and Remote Data Transmission. IAHS Publ., 145, IAHS Press, Wallingford, U.K., 75-85.

Goodison, B.E., Wilson, B. and Metcalfe, J. 1985. An inexpensive remote snow-depth gauge. Third WMO Technical Conference on Instruments and Methods of Observation. Instruments and Observing Methods Report No. 22. WMO/TD No. 50, Geneva, Switzerland, 111-116.

Goodison, B.E., Whiting, J.M., Weibe, K. and Cihlar, J. 1985. Operational requirements for water resources remote sensing in Canada: now and in the future. In: Hydrological Applications of Remote Sensing and Remote Data Transmission. IAHS Publ., 145, IAHS Press, Wallingford, U.K., 647-657.

List, R. 1985. Properties and growth of hailstones. In: Thunderstorm Morphology and Dynamics, E. Kessler (Editor), University of Oklahoma Press, Norman and London, 259-276.

McKay, D.C. and Morriss, R.J. 1985. Solar radiation data analyses for Canada 1967-1976. 6 Vols., Atmos. Environ. Serv., Downsview, Ont.

Miller, J.M., Whelpdale, D.M., Rodhe, H., Barrie, L.A., Isaksen, I.S.A. and Smith, F.B. 1985. Working Group Report. Chapter 7 in The Biogeochemical Cycling of Sulphur and Nitrogen in the Remote Atmosphere, J.N. Galloway, R.J. Charlson, M.A. Andreae and H. Rodhe (Editors), NATO Advanced Study Institute Series, Reidel, Dordrecht, 127-139.

Phillips, D.W. 1985. Canada's Climate Impacts Program. Environment Canada, Ottawa, Land, 6, 8.

Schroeder, W.H. and Jackson, R.A. 1985. Field testing and evaluation of an atmospheric mercury monitor with speciation capabilities. International Conference on Heavy Metals in the Environment, T.D. Lekkas (Editor), CEP Consultants Ltd., Edinburgh, U.K., I, 88-93.

Zakshek, E.M., Percy, K.E. and Puckett, K.J. 1985. Deposition patterns of lead, sulphur and other elements in Eastern Canada as monitored by the lichen, Cladina rangiferina. International Conference on Heavy Metals in the Environment, T.D. Lekkas (Editor), CEP Consultants Ltd., Edinburgh, U.K., II, pp. 578-581.

Theses

(a) University of British Columbia, Department of Geography

Benchimol, N. 1985. The mesoscale variability of insolation over the lower Fraser Valley as resolved by geostationary satellite data. M.Sc. Thesis, 141 pp.

Loudon, S.M. 1985. Verification of urban energy balance models. M.Sc. Thesis, 145 pp.

(b) University of Alberta, Department of Geography

Aktary, N. 1985. Evaluation of ground generator cloud seeding in southern Alberta (1977-1983). M.Sc. Thesis, 166 pp.

Sackiw, C. 1985. Determination of upper-air data resolution using stability indices. M.Sc. Thesis, 98 pp.

Safwat, F. 1985. Synoptic cloud analysis and development. M.Sc. Thesis, 281 pp.

Strong, G. 1985. Synoptic to mesoscale dynamics of thunderstorm environments. Ph.D. Thesis, 346 pp.

Wong, R.K. 1985. Valley drainage winds and dispersion. Ph.D. Thesis, 298 pp.

(c) University of Windsor, Department of Physics

Zetner, P.W. 1985. The application of laser induced fluorescence to the study of electron impact excitation of atoms and molecules. Ph.D. Thesis.

(d) York University, Department of Physics

Freemantle, J. 1985. Aerosol mapping using AVHRR imagery. M.Sc. Thesis.

Liu, P.S.K. 1985. Spread factors for oil based and water droplets. M.Sc. Thesis.

(e) University of Toronto

Bixby, A. 1985. The Great Lakes Water Quality Agreement and areas of concern: a program audit assessing an institution. M.A. Thesis, Department of Geography/IES.

Donaldson, N.R. 1985. Raindrop evolution with collisional breakup, theory and models. Ph.D. Thesis, Department of Physics, 181 pp.

Ferguson, A. 1985. A cost effective comparison of the conventional ground-based snow survey and the airborne gamma ray snow survey. M.A. Thesis, Department of Geography/IES.

Hudak, D.R. 1985. Selected cases of precipitation development in natural and seeded cumulus clouds in southern Africa. Ph.D. Thesis, Department of Physics, 190 pp.

Whillans, T.M. 1985. Related long-term trends in fish and vegetation ecology of Long Point Bay and marshes, Lake Erie. Ph.D. Thesis, Department of Zoology.

(f) McGill University, Department of Meteorology

Bartello, P. 1985. A simple atmospheric model on infinite domains. M.Sc. Thesis, 88 pp.

Bilodeau, B. 1985. Accuracy of a truncated barotropic spectral model: numerical versus analytic solutions. M.Sc. Thesis, 90 pp.

Blaskovic, M. 1985. Mesoscale study of a squall line system. M.Sc. Thesis, 62 pp.

Lemoine, R. 1985. Diagnostic studies of the May 9-10 squall lines during SESAME. M.Sc. Thesis, 94 pp.

Ling, A. 1985. Blocking-like flows in a hemispheric barotropic model. M.Sc. Thesis, 66 pp.

Mailhot, J. 1985. On the effects of cumulus convection on mid-latitude explosive cyclones. Ph.D. Thesis, 204 pp.

Menard, R. 1985. Saturation d'ondes de gravité et balance nonlinéaire. Mémoire de M.Sc.

Reuter, G. 1985. Observations and numerical simulations of mixing mechanisms in south African cumulus congestus clouds. Ph.D. Thesis, 286 pp.

Rivest, C. 1985. Topographically forced waves in a time-dependent flow. M.Sc. Thesis, 84 pp.

Tremblay, A. 1985. A three-dimensional cloud chemistry model. Ph.D. Thesis, 129 pp.

VII OCEANOGRAPHY

Compiled by: F.M. Boyce

1. Memorial University, Newfoundland Institute for Cold Ocean Science

Interdisciplinary studies of seabird/fish interactions in Witless Bay, Bay d'Espoir, and Fortune Bay have progressed and involve fields as diverse as mathematics, physics, biology, psychology, and geology. NICOS obtained the use of the Canadian research submersible, PISCES, which led to the discovery of oases of life surrounding freshwater seepage vents in Baffin Bay and also revealed an unexpected diversity and density of deepwater fauna in the Bay d'Espoir. A physical study is underway on the transport of energy and materials across the continental shelf. R. Knoechel participated in a cruise to the subtropical Central Pacific as part of an international study of plankton growth rates and food webs. S. Macko and A. Aksu are involved with the Canadian Ice Island project in the high arctic and in the international deep ocean drilling project that involves the research drillship, the Joides Resolution.

2. Dalhousie University, Department of Oceanography

Research interests in physical oceanography at Dalhousie include nearshore/continental shelf processes, flow through straits, deep convection in the Labrador Sea, predictions of extremes and iceberg trajectories, decay of "Meddies" and dispersion in the open ocean.

(a) Nearshore Processes

C.S. Kim used data from the C2S2 experiment at Pte. Sapin, New Brunswick to look at incident and reflected long waves on a beach. These incident waves (forced waves associated with groups of incoming surface waves) were reflected from the beach and propagated seaward as free waves. Correlation analysis revealed the general nature of the phenomenon, but it proved difficult to obtain useful estimates of the amplitude of the incident and reflected waves due to the variation in amplitude across the nearshore region and the broad spectral distribution of this energy. However, an important conclusion was that the amplitude of the seaward propagating waves was of the same order as that of the incident.

J. Haines is studying the relation between low frequency energy and the strongly barred topography which is characteristic of the C2S2 site at Stanhope Lane, P.E.I. There is strong evidence of very energetic low frequency motion, apparently at preferred frequencies.

J. Doering has been looking at the spectral properties of the wave field observed at various sites. He has been particularly concerned with the higher order moments given by the bispectra, the wave skewness and wave asymmetry. It is clear that the data from the East Coast of Canada shows wave evolution patterns significantly different from those observed on the US west coast.

R. Tatavarti is studying how to identify the inshore and offshore propagating components of the wave field using the p,u,v arrays that are becoming our standard measurement systems.

Further data for all these projects may result from the Canadian Atlantic Storm Project, a major oceanographic and meteorological program during the winter of 1985/6.

(b) Continental Shelf Processes

F. Schwing and K. Thompson have embarked on an analysis of subtidal circulation variability on the Scotian Shelf and the role of local and distant wind forcing. Seven bottom pressure records from the shelf break (400 m) are an important part of this study.

S. Todoroff is analyzing BIO bottom pressure data from the Labrador Shelf off Nain and Hopedale in an attempt to understand the role of wind and air pressure forcing on coastal sea level and circulation.

Y. Andrade is working with B. Petrie and B. Topliss (BIO) on an analysis of satellite imagery for the Scotian Shelf.

L. Royer is continuing her modelling of the response of the Labrador Shelf to a variety of forcing mechanisms. She is paying particular attention to the choice of suitable boundary conditions for the cross-shelf open boundaries.

(c) Flow Through Straits

M. Bormans, C. Garrett and K. Thompson have studied the seasonal variability of surface inflow through the Strait of Gibraltar, attributing part to the indirect effect of wind and hypothesizing that the rest is a consequence of the summertime draining of the Levantine Intermediate Water.

B. Toulany, B. Petrie (BIO) and C. Garrett have completed their observational and theoretical study of the baroclinic flow fluctuations in the Strait of Belle Isle. One model allows for the finite thickness of the bottom Ekman layer.

(d) Labrador Sea Circulation

Low-frequency variations of the Labrador current and the role of large scale wind forcing and buoyancy input has continued to be an active research area in 1985 (this work is being undertaken in collaboration with D. Wright and J. Lazier of the Bedford Institute of Oceanography). The major findings to date are that (i) the submonthly barotropic current variations, measured by the moored current meters, are not due to bottom- modified Sverdrup transport fluctuations and appear to be trapped in deeper water and (ii) the seasonal variation in the surface current of the offshore core is driven by the input of fresh water from more northerly latitudes.

Y.H. Seung has investigated a generation mechanism for the winter time cyclonic gyre in the Labrador Sea. His model shows a highly localized cooling just offshore from the Labrador shelf ice cover. The modified density structure due to this cooling, with some lateral eddy-mixing, is then shown to create the cyclonic gyre by the Rossby adjustment process.

(e) Iceberg Trajectories

J. Middleton and C. Garrett have discussed the use of a rotary correlation function in the analysis of drifter data, and have shown how the senses of rotation of the velocity vector, for Eulerian and Lagrangian analyses, can be different (and actually are different for iceberg data from the Labrador shelf).

Garrett's iceberg trajectory prediction scheme has now been made operational by S. de Margerie of ASA Consulting, with the assistance of J. Middleton, F. Majaess and others.

(f) Variability of Events

J. Middleton and K. Thompson have now developed and successfully tested a new method for estimating return periods of extreme events from short spans of data. M. Bormans, C. Garrett and K. Thompson continue their study of the seasonal variability in the flow through the Strait of Gibraltar. R. Trites, R. Loucks (BIO) and K. Thompson have now completed an

analysis of interannual sea surface temperature variability along the eastern seaboard of the US and Canada.

Lung-fa Ku (Ottawa), D. Greenbery (BIO), C. Garrett and F. Dobson (BIO) have published their results on the nodal (18.6 year) modulation of tides in the Bay of Fundy and Gulf of Maine. Data, a numerical model and a simple theory all show that the +/- 3.7% astronomical modulation is reduced to +/- 2.4% in the observed M_2 tide.

(g) Ocean Mixing

Research aimed at quantifying mechanisms of ocean mixing is following two complementary directions; a major collaborative field study, and laboratory measurements of fluxes and microscale velocities in double-diffusive convection.

The fieldwork took advantage of an ongoing experiment in which a large, subsurface, rotating lens of Mediterranean water is being tracked by L. Armi (Scripps) and T. Rossby (URI). We found the lens, surveyed it with CTD, velocity probes and microstructure instrumentation, and are currently estimating the mechanisms and rates of decay of energy, angular momentum, heat and salt. N. Oakey (BIO) made measurements of turbulent dissipation that point to a rate of energy decay consistent with the long lifetime of a Meddy.

D. Hebert is working out the detailed profiles and distributions of the passive (T,S) and dynamic quantities of the "Meddy", and will infer from these the overall energetics and modes of decay. We have also found strong evidence for intrusive features at the periphery of the lens, and plan to look for their signature in the velocity and dissipation profiles. One extremely exciting result is that the region affected by intrusions had grown inward from 12 miles radius in September 1984, to 8 miles in June 1985, and by October 1985 the entire lens had been affected by intrusive mixing. B. Ruddick has also been investigating theoretically the ability of such lenses to withstand the straining and tugging due to a larger scale eddy field.

In the laboratory, B. Ruddick is currently working on an experiment designed to measure double-diffusive transports of heat and salt at the low values of stability found in several parts of the ocean. J. Hamilton, a part- time student from BIO, is undertaking a study of the microscale velocity and viscous dissipation in convecting systems in order to answer questions about where the turbulent kinetic energy that was produced by the buoyancy flux is dissipated.

D. Kelley has completed a thesis entitled Oceanic Thermohaline Staircases. Extending previous work (Kelley, 1984), the thesis deals with the parameterization of vertical double-diffusive fluxes of heat and salt through pycnocline thermohaline staircases.

D. Brickman is investigating several aspects of deep-water formation. Using a small numerical model, he has shown why a cooled, diffusively growing boundary layer becomes unstable to convection much later (at larger Rayleigh numbers) than "standard" theory predicts. He also plans to extend his ideas to unsteady baroclinic vortices.

C. Garrett has proposed a simple mixing length interpretation of the variance in the spectrum of a passive scalar in turbulent flow.

3. Bedford Institute of Oceanography, Atlantic Oceanography Laboratory

(a) Ocean Circulation Division

The field phase of a major two-year study of the eddy scale structure of the Gulf Stream near 60°W was successfully completed with the recovery of the second 12-month deployment of an array of five year-long moorings. Principal investigator, R. Hendry, is collaborating with the Woods Hole Oceanographic Institution in a study of the meandering and eddy structure of the upper and deep portions of the flow. A hydrographic grid surrounding the mooring area was occupied five times during the two-year period and remote sensing imagery collected for all cloud-free days.

N. Oakey, in a cooperative project with Dalhousie University, carried out a field investigation of an isolated lens of Mediterranean Water (Meddy) that had previously been

surveyed and tagged using SOFAR floats by L. Armi of Scripps and T. Rossby of University of Rhode Island. Using a microstructure instrument, EPSONDE, developed in-house over the last several years, plus a standard CTD, estimates of the dissipation and mixing were obtained with the Meddy. EPSONDE is also being used by scientists in MEL in experiments to relate rates of biological productivity to mixing. J. Loder participated in one such study this year within the tidally induced current at the edge of Georges Bank.

Deployments of ice beacons were made across the Labrador Ice Pack in January and February of 1985 by G. Symonds. These beacons were tracked using System Argos and most were carried by the ice the entire length of the Labrador Shelf. Only two, both of which had been set close to the ice edge in February, melted out of the ice and entered the Labrador Sea north of the Newfoundland Shelf. The data will be used with a Markov model to estimate offshore flux of ice. M. Ikeda has completed a number of models and calculations which explore the relationship between wind, air/sea fluxes and the dynamics and thermodynamics of the Labrador Shelf and its ice. He is also using satellite imagery to guide a modelling effort aimed at understanding the processes occurring at the ice edge. An analysis of the historical data for the north east Newfoundland Shelf has shown the importance of the oceanic heat flux in the melting of the ice in this region.

The last of a series of three cruises to collect wind, current and iceberg slope and size data was successfully completed by S. Smith, and a multilevel iceberg drift model has been developed. The preliminary analysis of atmospheric boundary data collected over both sea ice during MIZEX and open water during HEXOS pilot experiment has largely been completed by S. Smith and R. Anderson. Measurements of pressure fluctuations over ocean waves were carried out by F. Dobson during two separate field trips. The data will be analyzed to look at the forcing of waves by such pressure fluctuations.

J. Lazier is continuing his Labrador Current monitoring program at Hamilton Bank. The past several years' mooring data have been analyzed by J. Lazier and D. Wright to show its annual cycle and indicate how such an annual cycle in current might arise from the annual cycle in buoyancy forcing. The current meter array has been augmented by a bottom pressure gauge array in order to collect data to test ideas about atmospherically forced motions on the Labrador Shelf.

K.T. Tee has continued work on tidally induced residual currents and tidal modelling, as well as work on fresh water pulses in estuaries such as the St. Lawrence. H. Sandstrom continued his studies of non-linear internal waves by collecting observations of these features in the Hibernia area of the Grand Banks and tying their occurrence to tidal conditions at the shelf break.

Finally, current meter moorings that had failed to surface in 1984 in Baffin Bay were successfully recovered using the submersible PICES. C.K. Ross continued to collect data on the circulation of Baffin Bay using current meter moorings, hydrographic surveys and ARGO's drifters.

(b) Coastal Oceanography

During the past year the field program centred on the circulation around Brown's Bank has been largely completed by P.C. Smith. The results from this study have been compared with D. Greenberg's model results, where wind stresses from different directions are applied to a non-linear tidal model of the Scotian Shelf/Gulf of Maine. This tidal model has also now been applied to the Newfoundland Grand Banks with the complication that there the flow of the Labrador Current must be introduced as an upstream and downstream boundary current.

An experiment to compare the ability of a variety of current meters (S4, VMCM, VACM and modified Aanderaa's), surface drifters and CODAR to estimate near surface currents has been completed off S.E. Nova Scotia, and the data sets are being analyzed. Near surface data are needed for a variety of biological (surface larval drift) and physical (oil spill tracking) oceanographic studies; however, existing techniques are all contaminated, to some degree, by wind and/or wave effects (P.C. Smith).

B. Petrie has had all the satellite drifting buoy data over the Newfoundland Grand Banks brought together into a data base, and from these data produced maps of the average near

surface currents, as well as their variances. New drifter data, as they become available, are being added to the data base. A regional iceberg model for the Grand Banks has been developed. Given an estimate of the number of icebergs entering the region through the northern boundary, this model provides estimates of the number of icebergs remaining on the Grand Banks over the weeks ahead by predicting the numbers that move offshore. The model does this by calculating the on-offshore exchange through the Labrador Current based on a baroclinic eddy process model.

W. Perrie has compared the results of a Canadian wave forecast model developed in the 1970's with models developed by groups in Germany and the Netherlands. All the models were tested using the complete set of wave spectra data collected during major wave growth experiments such as JONSWAP. The differences and shortcomings of the various models were used to design the wave array for CASP, Canadian Atlantic Storms Program. This array was deployed in early December 1985.

An image analysis system has been installed and is producing maps of surface temperature and chlorophyl on geographic co-ordinates from satellite imagery. Two years of NOAA imagery on a daily basis has been archived on tape and a standard false colour temperature image has been produced in a quick-look colour slide file for each archived image. This allows a user to select potential images for further processing in studies of particular regions or processes. In addition, a file for transparencies of all the Coastal Zone Colour Scanner (CZCS) images for the eastern Canadian Arctic from 1978 to 1984 has been established. B. Topliss completed a ground truthing experiment for an aircraft borne Flourescence Line Imager (FLI). This instrument can be used to estimate chlorophyl levels in the sea surface.

C.L. Tang continued his work on the dynamics and mixing in fronts by publishing the results of his study on a warm core ring south of Nova Scotia. K. Kranck has been using a Plankton Camera to make in situ measurements of flow size. Preliminary analysis of the data confirm a model for the dynamic settling of flocculated suspensions that is applicable both to natural and to laboratory suspensions. G. Bugden has continued his work on the heat, salt and ice budgets of the Gulf of St. Lawrence, including the running of the annual ice forecast cruise in the Gulf. S.J. Prinsenberg published a number of reviews of the oceanography of Hudson Bay and adjacent waters based on work he had carried out while with the Bayfield Laboratory of Central region.

(c) Chemical Oceanography

Studies of the distribution of reactive mercury in the North Atlantic have been carried out (P.A. Yeats) and some investigations of trace metal exchanges between dissolved and particulate phases in the St. Lawrence estuary are nearing completion (P.A. Yeats and D.H. Loring). A review of cadmium and cadmium fluxes in the marine environment has been completed (P.A. Yeats and J.M. Bewers) and an analysis of the distributions of dissolved trace elements in the global ocean in relation to biological and physical oceanographic processes is being undertaken (P.A. Yeats). During 1985 an examination of the distributions of metals on the Scotian Shelf and Slope has been undertaken in order to examine where the predominance of nearshore mixing processes is outweighed by the effects of biological production and regeneration in the distribution of trace metals (P.A. Yeats). An intercomparison of methods for the analysis of trace elements in sub-milligram quantities of suspended particulate matter retained on filter membranes has been conducted on behalf of the International Council for the Exploration of the Sea (ICES) (P.A. Yeats).

Some further investigations of chemical conditions in the Arctic Ocean have been carried out by sampling from an ice-island in the Canadian Arctic. Data acquired from these activities will be interpreted in terms of previous studies at the FRAM-III and CESAR ice stations to determine the sources of nutrient maxima in the vertical profiles at these stations (E.P. Jones) and to examine further the distributions of metals and radionuclides in the Arctic Ocean (P.A. Yeats, J.N. Smith and K.M. Ellis). Analyses of the distributions of ^{14}C, freon-11, freon-12 and bromoform in Baffin Bay Bottom Water have been completed and new data on tritium should be available shortly to provide a more precise estimate of the rate at which this bottom water is replaced (E.P. Jones). Further studies of the stoichiometric composition of regenerating biogenic material in Baffin Bay are also being undertaken. Field and laboratory studies of the chemical composition of sea-ice, undertaken in order to determine the extent of any major ion enrichment in the freezing process that might have an

influence on meltwater, have been completed (E.P. Jones). The extent of sea-ice meltwater in Canadian Arctic and east coast waters is also being studied using stable isotopic techniques (F.C. Tan).

Studies of the dispersion and in-sediment mixing of weapons plutonium inadvertently released into the environment at Thule, Greenland, are nearing completion (J.N. Smith and K.M. Ellis). Concurrent investigations of the incidence of ^{99}technetium and ^{134}cesium in west Greenland waters have been carried out to determine the progression of the plume of radionuclides released from the Sellafield reprocessing plant in the United Kingdom (J.N. Smith and K.M. Ellis). Further studies of these nuclides in the Labrador Sea are planned in order to detect the entry of the Sellafield radionuclide tracers into these waters. Geochronological and geochemical investigations of the Saguenay Fjord sediments have continued and these have permitted a better understanding of the nature of radionuclide retention processes in the soil and aqueous reservoirs of the Saguenay drainage basin (J.N. Smith). Certain earthquake-induced events in the sediments are now undergoing further investigation. Studies of the differential behaviour of plutonium, ^{137}cesium and ^{210}Pb in pelagic sediments of the northeast Atlantic have been completed, and these reveal that remobilization of plutonium from marine sediments does not occur to any significant degree (J.N. Smith). The Point Lepreau Environmental Monitoring Program is being continued (J.N. Smith and K.M. Ellis). During 1985, interpretation of the uptake of fallout nuclides in lichens has indicated that different nuclides have differing retention times and that lichen may act as effective air- monitors for a variety of particle-associative chemicals (K.M. Ellis and J.N. Smith).

Carbon-isotope analyses of samples from the Amazon River/Estuary system have been completed and have been interpreted in the context of the transport of organic carbon within the Amazon basin as part of a collaborative project with the Department of Earth and Planetary Sciences, Massachusetts Institute of Technology (F.C. Tan). A three-year program, part of an international project under the auspices of the Scientific Committee on Problems of the Environment (SCOPE), of measurements of the flux and composition of organic matter from the St. Lawrence River has been completed (R. Pocklington and F.C. Tan). Methods for the determination of carbon isotopic composition of dissolved organic carbon are being developed to apply also to samples obtained through this and other projects (F.C. Tan).

Baseline studies of the incidence of petroleum residues in waters of the Canadian eastern seaboard have been completed, with most recent attention to the Hudson Strait/Labrador Shelf area (E.M. Levy). Additional studies of the oils seeping from sub-sediment deposits in Scott Inlet suggest that the source material is of terrigenous rather than of marine origin (E.M. Levy and K. Lee). Studies on the composition of Scotian Shelf condensate weathering in the inter-tidal zone of a sandy beach have been completed and have revealed surprising persistence of light oil components in this environment. These investigations are being extended with particular emphasis upon the potential acceleration of microbiological degradation through the provision of additional nutrients. This work is revealing that many of the results of laboratory simulations of degradation processes are not applicable to this environment since they consistently overestimate both the rate of degradation and its effects on the composition of the residual oil (E.M. Levy, P.M. Strain and K. Lee).

A major intercomparison of methods for the determination of major and trace metallic constituents of marine sediments is being carried out for ICES. The results of this exercise will be available early in 1986 (D.H. Loring). Investigations of the incidence of cadmium, lead and other metals in the fjordic receiving waters of an Arctic metalliferous mine on the west coast of Greenland, carried out in collaboration with the Greenland Geological Survey, have been completed (D.H. Loring). The incidence of metals in Greenland coastal waters remains a subject of some concern among the native population in Greenland, and further studies are planned as a prelude to examinations of the receiving environments of Canadian Arctic metalliferous mines (D.H. Loring).

(d) Ocean Technology

Survey and positioning methods, based on acoustic technology, are an important part of the program. The survey systems include multi-frequency probing of the water column for both biological and physical oceanographic purposes and the development of ship and bottom mounted current meters, which employ acoustic Doppler techniques to obtain vertical profiles of

current structure (N. Cochrane, J. Whitman and D. Belliveau). There is also a program underway to develop a system of acoustically tracked Lagrangian drifters designed to work in the near-surface layers at depths of 1 to 10 metres (D. McKeown, G. Fowler and D. Belliveau).

A multi-faceted project is being undertaken to improve current meters in many ways, including: shipboard deployment and recovery methods; relocation and recovery in the event of release failures; enhanced operational lifetimes through the use of new materials; improved operational design methods; and, improved performance of moorings operating in the wave zone (G. Fowler and J. Hamilton). Improved methods of deploying and recovering CTD's and similar instruments are being developed in order to reduce operational costs and ship time requirements (J-G. Dessureault). Development of an in situ particulate sampler for chemical oceanographers is nearing completion and further developments of a similar nature are anticipated (G. Fowler). The Canadian Hydrographic Service is acquiring a fleet of remote, unmanned vehicles for survey work. The Laboratory is assisting in this endeavour by developing underway refueling and vehicle recovery systems (J-G. Dessureault).

4. Bedford Institute of Oceanography, Marine Ecology Laboratory

Investigations into the intense vertical mixing in Hudson Strait have indicated that the tide is the primary forcing mechanism (K. Drinkwater). Comparison of observed stratification with predictions from a published numerical tidal model show good agreement. High nutrient concentrations and high phytoplankton biomass are found within and adjacent to tidally well-mixed regions.

Current meter data from Hudson Strait have been analyzed to investigate the vertical structure of the tidal and mean currents. Information on the tidal currents have been used to verify numerical tidal models of Hudson Strait. Data on the mean currents confirm historical surface circulation patterns and indicate similarly directed subsurface mean flows. Volume transports through the Strait have been calculated (K. Drinkwater).

Water mass properties in the southern Gulf of St. Lawrence during summer have been examined. The data reconfirm the importance of the St. Lawrence River discharge in controlling salinity distributions. Extensive interleaving was observed in a frontal region within the deep waters of the Cape Breton Trench (K. Drinkwater).

A completed study within St. Georges Bay, Nova Scotia, indicates important physical oceanographic influences on the biological dynamics. Physical processes control vertical nutrient and plankton distributions during winter. The high stratification during summer leads to a biological decoupling of the upper and lower layers with most of the production recycled within the upper layer. A long residence time for the water in the Bay helps promote successful pelagic spawning.

Studies continued into the role of the Hudson Bay outflow on the physical and biological processes over the Labrador Shelf. A field program was conducted to collect temperature, salinity, current and nutrient data as well as phytoplankton, zooplankton and fish abundance data (K. Drinkwater).

Larval transport and diffusion studies have been focused recently on the short-finned squid, Illex illecebrosus, an important species in the commercial fisheries of the Northwest Atlantic. Research cruises in the past three years indicate that a major spawning area is located off the coast of Florida, and that larvae and juveniles are entrained into the Gulf Stream and rapidly transported northeastward to areas seaward of the continental shelf along the northeastern U.S.A., the Scotian Shelf and the Grand Banks (R. Trites).

An investigation of variability of sea surface temperatures for selected areas of the Northwest Atlantic is underway using the very large data base derived from merchant ships reports and archived in the National Climatic Center, Asheville, North Carolina. Analyses include space-time plots of annual anomalies, correlations among monthly anomalies, and computation of empirical orthogonal functions by season. The role of fresh water discharge, wind effects, and offshore forcing in producing the observed variability is currently being examined (R. Trites).

An annual overview of environmental conditions in the Northwest Atlantic is prepared for use by the Scientific Council of NAFO and other fishery scientists as an aid in interpreting biological data (R. Trites).

Turbulent kinetic energy dissipation measurements have been collected in conjunction with biological rate measurements. The data show that turbulent dissipation and the photoadaptive properties of phytoplankton are closely related and more experiments to investigate this relationship are planned (E. Horne).

An experiment to directly measure tidal dissipation on Georges Bank was conducted and the data show a strong tidal signal which is not depth dependent (E. Horne).

Work has also been done in the Arctic on mixing driven by meltwater at a vertical ice - water interface and experiments with heated thermistors have been preformed to measure speed profiles in the top 30 cm beneath first year ice. These data, when combined with nutrient profile data, will allow us to calculate a nutrient flux to the ice algae growing on the underside of the ice. It is thought that their growth is nutrient limited and thus governed by tidal mixing (E. Horne).

5. Centre Champlain des sciences de la mer, Pêches et Océans, Québec

(a) Océanographie physique (D. Lefaivre, P. Larouche)

L'étude visant à déterminer le cycle saisonnier de l'eau douce et la circulation le long de la basse Côte-Nord s'est poursuivie. Elle devrait permettre d'estimer l'influence sur la circulation de la modification du cycle saisonnier par le harnachement des rivières.

Le traitement des résultats d'un modèle à trois dimensions du courant résiduel induit par la marée au large du sud-ouest de la Nouvelle-Écosse s'est poursuivie. Cette méthode permet d'identifier les régions de tourbillons permanents induits par la marée, ainsi que les régions de remontée et de plongée des eaux, lesquelles ont une incidence immédiate sur la productivité biologique, comme zones de rétention d'organismes et comme zones de support nutritif.

Une deuxième campagne de mesures avec mouillage de courantomètres a été effectuée afin d'étudier l'influence du vent et de la marée sur la circulation et le mélange à la tête de l'estuaire maritime du Saint-Laurent. Ce projet vise aussi à déterminer les facteurs physiques contrôlant la répartition du zooplancton.

Enfin, en relation avec la possibilité d'aménagement de rivières du Nord québécois à des fins hydroélectriques, plusieurs études se sont poursuivies sur (1) la distribution des glaces dans le sud-est de la baie d'Hudson, (2) le panache de la rivière La Grande lors d'un fort débit d'eau douce, (3) la variabilité interannuelle du panache de la Grande Rivière-de-la-Baleine et (4) l'évaluation de la circulation à grande échelle entre les îles Belcher et la côte du Québec.

(b) Océanographie chimique (C. Gobeil, J. Gearing et G. Tremblay)

La division d'océanographie chimique a poursuivi ses programmes de recherche dans le système de l'estuaire et du golfe du Saint-Laurent afin d'en évaluer "l'état de santé" et d'être en mesure de donner des avis sur l'exploitation et la gestion de ses ressources.

La plupart des activités ont concerné des substances reconnues pour leur haute toxicité. Plusieurs campagnes de prélèvement en mer ont été réalisées. Les travaux ont permis de démontrer que les concentrations en mercure, plomb et cadmium dans les eaux de l'estuaire sont inférieures à celles qui étaient rapportées jusqu'ici et qu'elles s'apparentent aux teneurs trouvées dans les océans, ce qui semble indiquer que le système estuaire-golfe du Saint-Laurent tend à échapper à la contamination par les métaux lourds. En outre, en collaboration avec des chercheurs universitaires, une étude sur le cycle biogéochimique du cadmium dans les sédiments du chenal Laurentien a été entreprise.

Les recherches sur les limites d'utilisation de la moule bleue en tant qu'organisme indicateur de la pollution marine ont progressé et donné lieu à d'autres publications. Enfin, les travaux sur la géochimie du sélénium et de l'iode dans l'estuaire ont été complétés.

(c) Océanographie biologique (J.C. Therriault, S. Demers, L. Fortier, M. Levasseur et J. Painchaud)

La division d'océanographie biologique a continué ses recherches visant à étudier les processus de production primaire et secondaire dans l'estuaire maritime du Saint-Laurent. Différentes études ont porté sur les facteurs contrôlant la répartition spatiale et temporelle de la production phytoplanctonique et ont permis de dégager que la lumière, la stratification et les débits d'eau douce sont les plus importants facteurs. Sur la base des patrons de distribution spatiaux de la biomasse planctonique, il a été possible de formuler un modèle divisant l'estuaire maritime en quatre régions distinctes contrôlées par des processus hydrodynamiques différents. D'autres études ont porté plus spécifiquement sur l'influence des variations du mélange vertical sur les processus photosynthétiques et sur les facteurs contrôlant la distribution spatiale et temporelle de l'activité bactérienne et la distribution de Protogonyaulax tamarensis (principale algue responsable de la toxicité chez les mollusques) dans l'estuaire du Saint-Laurent. En outre, des travaux ont porté sur l'écophysiologie du phytoplancton. Ces études ont nécessité l'utilisation d'enceintes fermées où les conditions environnementales sont contrôlées.

Le rôle biologique du phytoplancton et de ses produits d'excrétion dans la synchronisation du déclenchement de la ponte d'invertébres dans l'écosystème marin a fait l'objet d'un projet particulier. Enfin, un projet d'étude sur la productivité de la flore épontique ("des glaces") a débuté à la baie d'Hudson, de même qu'un projet visant à étudier l'influence du "front" séparant le courant de Gaspé du reste des eaux du golfe du Saint-Laurent sur la survie des stades larvaires de certaines espèces de poissons.

6. Groupe interuniversitaire de recherches océanographiques du Québec

(a) Hudson Bay

A large field program in SE Hudson Bay was completed in 1985. Analysis of the salinity distribution showed the Great Whale River freshwater plume area to be much larger under the ice than in open water for a given river discharge. Furthermore, the importance of cross-Hudson Bay atmospheric pressure forcing through the ice on the low frequency variations of coastal circulation was demonstrated. A trapped coastal wave propagating counter-clockwise along the SE Hudson Bay coast is thought to be the cause of the observed low frequency variability. The trial mooring of two near surface instruments during ice breakup in 1985 (June-July) showed the feasibility of such work. Replacement of the (nearly) continuous ice cover by ice floes and finally open water dramatically influenced the upper layer dynamics and water mass characteristics. Preliminary analysis shows the importance of melt water, penetrative convention and wind/tidal mixing on the observed properties. Tidal attenuation by friction on the underside of the ice cover was shown to be an important factor in limiting vertical mixing of the upper layer. (Ingram, Lepage, Shirasawa, Deguise and Peltola, McGill University).

In April-May 1985 twin sediment traps were deployed with current meters at three depths at a 100 m deep station on the shelf, during four intervals of one to three weeks each under ice. During breakup, sediment traps were moored at the winter station and near the river mouth, with retrieval in mid-July. In most cases, good agreement was found between traps in the same set, indicating that the calculated vertical fluxes are correct. Near bottom fluxes of up to 50 mg/cm^2/day were observed in the winter during the full productive cycle of the under ice biota. However, transfer of organic carbon to the surface sediments is negligible, as shown by their low organic carbon content (approximately 1%). This indicates that organic matter destruction occurs at the interface. Measurements of ^{210}Pb at the core surface also indicated extremely low rates of deposition. Work is proceeding in comparing pre- and post-break-up vertical fluxes and settling particles, as well as surface sediment composition (major, minor elements, C/N, biogenic vs detrital SiO_2).

(b) St. Lawrence

Field work in the St. Lawrence estuary consisted of a May cruise on the MV LAUZIER. This was the last of a series of routine spring and summer cruises carried out since 1980 to study seasonal fluctuations in the distribution and composition (particularly with respect to Fe and P) of the particulate matter. The influence of exchanges with intertidal marsh and flats in

regulating these fluctuations was also examined. (M. Lucotte, B. Anglejean, McGill University). Additional work on this latter topic has been undertaken throughout the fall on a weekly basis by small boat sampling, sediment traps and current meter moorings off the Cap Tourmente marshes during their destruction by the fall bird migration (supported by an Environment Canada grant).

In the estuary and gulf, Ouellet and Maltais (in press) have modeled water level variations and circulation for meteorological forcing so as to compare their magnitude to tidal variations. Bah has examined mixing characteristics and inertial wave generation on the Madgalen Islands plateau. (Université Laval).

7. National Water Research Institute, Canada Centre for Inland Waters

(a) Physical Limnology

The study of the interaction of the Niagara River plume with Lake Ontario continued in 1985 with additional satellite-tracked drifter experiments (C.R. Murthy).

Physical measurements taken in Lake Ontario during 1982/83 were used to improve several existing hydrodynamic models of large lakes and these results served to amplify and correct existing theories and concepts regarding coastal and open lake circulations. In particular, it was found possible to reconcile a number of different conceptual models advanced during the decade that followed the International Field Year on Lake Ontario (1972/73) (T.J. Simons).

A combination of spectral techniques, hydrodynamic models, and empirical procedures established conclusively that observed coastal current fluctuations cannot be explained by either a balance of local wind stress and bottom friction or by free topographic waves, but that both processes contribute equally. Semi-empirical transfer function models based on the concept of resonant topographic wave response to wind forcing in the presence of bottom friction were developed and found to explain 70 to 80 percent of the observed coastal current variations (T.J. Simons).

Regarding open lake circulations, it was shown that none of the models reported in recent literature were suitable for estimating seasonal mean circulations. In order to represent the circulations observed in the 1982/83 Lake Ontario field study, a high-resolution non-linear model was required. To test whether this result was applicable in general, circulations were computed for 12 years of collected historical wind data. For all years, the circulation obtained from the new model deviated from that obtained with the conventional model in the same manner (T.J. Simons).

An operational model for predicting the movement and dispersion of radioactive spills along the north shore of Lake Ontario was developed based on many years of data collecting and modelling. The model can be run on an IBM Personal Computer or similar device (C.R. Murthy).

In response to the many requests for our hydrodynamic models and for assistance in applying them, three of the most frequently requested models were documented in detail and sample runs were prepared. These models are (1) a single layer circulation/storm-surge model, (2) a multi-level model for computing circulation and temperature changes, and (3) a pollutant transport model (W. Schertzer).

The first part of a two-year circulation and sediment resuspension experiment was carried out in Lake St. Clair from May to November 1985 as part of a joint US-Canada study of the upper Great Lakes connecting channels (P. Hamblin, F. Boyce). During this study we deployed for the first time an array of newly acquired Neil Brown "smart" vector averaging acoustic current meters. Overall performance was good (J. Bull). Other measurements included estimates of the vertical and horizontal sediment fluxes near the bottom, measurement of the near-bottom velocity profile, satellite-tracked drifters, surface wave and water level measurements.

A combination of observations with one and two-dimensional numerical models have been employed on Lakes Laberge, Marsh, and Tagish of the headwater area of the Yukon River in order to determine the sensible heat transfer coefficient between the water and a surface ice cover, the dynamics of inflow and outflow-induced motions, and the simulation of the thermal regime of ice-covered lakes (including ice growth and ablation) (P. Hamblin and E. Carmack).

Laboratory and numerical experiments have been conducted to understand the principal balances and to formulate scaling relations for the areal extent of coastal zone thermal plumes in winter (P. Hamblin and Y. Marmoush).

A finite-element, time-stepping model has been developed and applied to Lakes Erie and St. Clair. Comparison of modelled free surface fluctuations with observations have been excellent at both shore and deep water sites. Current predictions at a point agree well with observations in connecting narrows where barotropic forcing predominates (P. Hamblin).

(b) Shore Processes

A joint project between the National Water Research Institute and the Woods Hole Oceanographic Institution to study breaking waves and wave- turbulence interactions has completed its first phase. During November and December 1985, measurements of wave directional properties (surface elevations) and subsurface velocities were made from the NWRI research tower in the west end of Lake Ontario. The analysis procedure, which includes separating wave and turbulent velocities, has begun. In a second experimental phase, direct estimates will be made of turbulent dissipation (M. Donelan).

As part of a continuing effort to improve shallow water wave modelling, a measurement program was undertaken in the autumn of 1985 in Lake St. Clair. This was a joint endeavour of NWRI and the NOAA Great Lakes Environmental Research Laboratory in Ann Arbor. Depths in Lake St. Clair range from 2 to 6 m and bottom topography is very smooth. An array of six towers distributed along a 20 km path (about one-half the lake's diameter) supported instrumentation to measure wave directional spectra (three towers), frequency spectra (three towers) and wind velocity (M. Donelan).

Laboratory experiments to explore the attenuation of waves in an adverse wind have shown that the direct attentuation is comparable to the magnitude of the amplification in an equivalent favourable wind (M. Donelan).

(c) Instrumentation

A data system was developed to support the breaking waves study described in (b) above. The system was built around two IBM microcomputers, a PC-AT as master on shore and a PC-XT with expansion chassis as remote on the tower. The two were connected through a 1.5 km cable with a transmission capacity of 19.2 kbaud. The tower computer gathered, digitized, and formatted data for transmission to the shore computer. The shore computer received, processed, and transcribed the data onto a 9 track tape for storage and transport to the user. It provided operator interface and sent control signals to the remote to begin and end processes and to actuate various accessories on the tower. The shore computer also provided D/A conversion and interface for display of up to six channels of data in real time. In all, the system handled 37 analog data input channels at a sampling rate of 20 Hz from a suite of 23 sensors, and 13 digital I/O channels for control and monitor of tower accessories.

Development continues on a frazil ice recorder for application to river ice studies. This system is based on through flow calorimeter measurements, and gives a continuous output record of percent frazil ice suspended in the water sampled. It comprises a sampling head which is placed in the stream channel and a shore console providing power and control and chart record display of output.

Other instruments and equipment developed in support of NWRI research activities are described in Prototype Designs for Surveys and Measurement in an Aquatic Environment published annually by Hydraulics Division, NWRI (F. Roy).

8. National Water Research Institute, Western and Northern Region

(a) Lake Manitoba

A study of the physical resuspension of bottom sediments in Lake Manitoba was completed using a sampling device designed to collect suspended sediment at closely spaced intervals in the vertical and velocity data from a hydrometeorological tower. The sampler collected gram quantities of suspended sediment over a variety of wind conditions during the one month

installation periods. Chemical analyses of the material collected suggest the resuspended sediment forms a large phosphorus pool which is potentially available to support algal blooms in shallow prairie lakes. Coherent discontinuities in the vertical distribution of the mean current, in the vertical distribution of the dried mass of resuspended sediments and in the vertical distribution of particle size have important implications for lakewide circulation, the turbulence regime and for the long-range transport and redistribution of sediments in large, shallow lakes. The device for sampling suspended sediments may also have applications for collecting suspended sediments for toxic contaminant studies in rivers (B. Kenney).

(b) Southern Indian Lake

A study was completed of the baroclinic circulation under winter ice in Wupaw Bay, Southern Indian Lake. Results indicate that temperature fluctuations and mixing frequently occur during winter in Wupaw Bay and the magnitude of the current is a significant factor in determining the under-ice residence time of water in the bay. Similar results are to be expected in other lakes and bays with similar morphometry. This work shows the importance of the winter period to redistribution of chemical and nutrient elements vital to the ecology of lakes. Consideration of the impact on the under-ice environment may be necessary for future development and diversion schemes in the north (B. Kenney).

(c) Phosphorus Dynamics

A numerical model based on the principles of first order linear dynamics was developed to predict total phosphorus in lakes. The model was tested using published data from Lake Washington and showed that lakes respond as a forced system to changes in inflow phosphorus concentrations. It was concluded that the dynamics of total phosphorus in Lake Washington can be adequately represented by the use of two independent phosphorus sinks; the flushing of phosphorus from the lake through the outlet and the sedimentation to the lake bottom. The theory of phosphorus dynamics was further extended to describe the dynamics of total phosphorus in the upper four Qu'Appelle river- lakes (the Fishing Lakes). Although numerical simulation of total phosphorus was hampered by inadequacies in the quantity and quality of available data, the major trends were successfully modelled. The results suggest that the Fishing Lakes are saturated with phosphorus and no net sedimentation of phosphorus has occurred in the ten year period for which data are available. This work clearly shows the importance of treating lakes as dynamic systems and has considerable potential for application to other locales (B. Kenney).

9. National Water Research Institute, Pacific and Yukon Region

The experiment to study the dynamic processes affecting intra-lake sediment transport in Lake Laberge and Kluane Lake has continued. Data from thermistor arrays have been analyzed to determine time and space scales of motion (E. Carmack).

10. University of British Columbia, Department of Oceanography

(a) Physical Oceanography and Meteorology

A numerical simulation of the circulations in Burrard Inlet and Indian Arm has been completed (R.W. Burling). During 1985, the UBC Satellite Oceanography Laboratory (SOL) was updated with the installation of a VAX 11-750 minicomputer with hardware for satellite data reception (W.J. Emery). A fully automated system for the reception of NOAA satellite data will soon be established. The SOL has been used for a variety of applications, both to the west coast of B.C. and to the Beaufort Sea. Studies have been completed on the long-period variations in the solar semidiurnal atmosphere tide and the lunar atmosphere tide (K.P. Hamilton). Also, investigations have been conducted on the interannual variability of the temperature and sea level pressure in the North Pacific and the relation of this variability to sockeye salmon migration routes has been determined (K.P. Hamilton). A number of Arctic Ocean problems have been investigated, including models of flows in Lancaster Sound and Hudson Strait, the propagation of wave groups (envelope solutions), and the growth of directional wind wave spectra in a field of ice flows (P.H. LeBlond). Studies on the 40-50 day oscillation in the Western Indian Ocean, the stability and propagation of modons and the wind stress curl generation of annual period Rossby waves in the North Pacific have been completed (L.A. Mysak). Currently underway are several numerical modelling studies of the North Pacific

Ocean, with the goal of determining the nature and causes of interannual variability in this region. These studies are part of project MOIST (Meteorological and Oceanographic Influences on Sockeye Tracks), which is a three-year multidisciplinary study (with C. Groot of the Pacific Biological Station) of the interannual variability of the Northeast Pacific Ocean and its influence on Fraser River sockeye salmon migration routes. A six month deployment of a nine-instrument mooring array (four cyclesondes and five current meters) in the central Strait of Georgia was completed in January (S. Pond). These data are being analyzed to determine the horizontal structure of the subtidal motions. Current meters and cyclesondes were deployed in Indian Arm from December 1984 to May 1985 during complete deep water exchange and results are currently being analyzed (S. Pond). A study of the internal tides in Knight Inlet has been completed.

(b) Chemical Oceanography (S.E. Calvert, T.F. Pedersen)

Research on the geochemistry of the sediments of oxic and anoxic B.C. coastal inlets is continuing. Methods are being applied for identifying trace-metal, sulphur and halogen associations with organic matter and for partitioning metals between sediment phases. Studies of the geochemistry of molybdenum mine tailings in Alice Arm, B.C. and of copper-molybdenum mine tailings in Rupert Inlet, B.C., designed to examine the post-depositional mobility of metals in the sediments, have been completed. A study of sulphur speciation, pyrite formation and salt diffusion in meromictic Powell and Sakinaw Lakes in southwestern B.C. is continuing (with B. Sanderson, Memorial University). Paleogeochemical studies of Quaternary eastern equatorial Pacific sediments are continuing. An investigation of the behaviour of metals and halogens in hemipelagic sediments at 21°N on the East Pacific Rise is nearing completion (with D.E. Nelson, J. Vogel, and J. Southon, SFU). Research on the genetic relationships between the chemistry and mineralogy of ferromanganese nodules and associated sediments from the DOMES Area (north equatorial Pacific) is continuing. A time-series investigation of the fluxes of organic matter and associated trace metals from the water columns to the floors of stratified and well-mixed B.C. fiords is continuing. The formation and chemical nature of sapropels in the Black Sea are being studied using detailed geochemical analysis and high-resolution accelerator ^{14}C measurements (with D.E. Nelson, J. Vogel and J. Southon, SFU). This work is leading to reinterpretation of the Holocene history of the Black Sea Basin. A mathematical model was developed which demonstrates that the regular alteration of manganese- and iron-oxide rich layers observed in manganese nodules is attributable to nonlinearities in reaction kinetics that produce regular, inversely related oscillations in the deposition rates of manganese and iron. A second model was developed to examine the effects of nonlinearities in oxidation kinetics on the manganese distribution in the surface layer of the oceans. Studies are underway on copper-manganese interactions and their possible control over species composition and the abundance of phytoplankton in different B.C. inlets. The influence of topographically induced inlet circulations on plankton distribution is also being investigated.

(c) Geological Oceanography

In 1985, a three week cruise aboard CFAV Endeavour resulted in further exploration of hydrothermal emission in the area of Magic Mountain, southern Explorer Ridge (49°45'N, 130°20'W). The number of known sulphide deposits in the area was increased, and basalt dredging indicated that the extent of the ridge segment was 65 km.
Camera-conductivity-temperature tows over Tuzo Wilson Seamounts indicated several anomalous areas in which hydrothermal venting may be occurring (R.L. Chase).

11. Institute of Ocean Sciences, Sidney, B.C.

(a) Fiords and Channels

In addition to continued work aimed at understanding and predicting the distribution of properties within fiords on the basis of external inputs, 1985 saw the first of a series of field programs to study the nature of mixing in tidal fronts. Simultaneous measurements of turbulent energy dissipation and vertical velocity were obtained in a tidal channel, which showed that maximum turbulent dissipation was located well behind the front, even though the front contained downward vertical velocities as high as 40 cm/sec, which carried air bubbles to depths of 50 m (A.E. Gargett, D.M. Farmer).

(b) Straits

The extension of the 2 km mesh vertically integrated barotropic tidal model to cover the whole of the Georgia Strait/Puget Sound/Juan de Fuca Strait system was completed. After calibration, the model was used to generate tidal constituents for each grid point. These were then incorporated in a personal computer tidal current prediction program, developed by a contractor with IOS assistance. This has been delivered to the Environmental Protection Service and Canadian Coast Guard for use in real time prediction of tidal currents in emergency situations (P.B. Crean).

The extension of the barotropic tidal model also permitted improvements to the "Fraser River plume" surface layer model. These improvements, and the addition of wind forcing, brought this model to the point where it is now capable of reproducing observed drifter tracks in all seasons (P.B. Crean).

The last of the current meter arrays deployed in the passages of the Arctic Archipelago were recovered in April. In the last three years a total of 66 current meter records and 15 bottom pressure records have been obtained. Of these, eight current records and four pressure records are of 12-month duration. The reduction and analysis of these data in terms of tides and mean flow was begun, together with that of the water property surveys conducted during current meter deployment and recovery. Work is proceeding on a triangular grid tidal model for the channels making up the Northwest Passage, with completion expected early in 1986 (H. Melling, T.S. Murty).

The first of two cruises to Straits of Gibraltar was conducted in November, in cooperation with U.S. scientists on a U.S. vessel. The internal structure was mapped using acoustic techniques in conjunction with more conventional means. The objective is to test the theoretical conclusion that the exchange between the Mediterranean and Atlantic, which determines the properties of the Mediterranean, is controlled by the same internal hydraulic mechanisms as control the exchange over the sills in many B.C. fiords (D.M. Farmer).

(c) Continental Shelf

The last phase of the field work in a 10-year program to obtain a basic description of oceanic conditions on the Pacific continental shelf was concluded with the recovery of the last moorings from the shelf west of the Queen Charlotte Islands in November. The general picture is one of complex flow patterns created by the interaction of large tides, rugged bottom topography, and seasonal variations in winds and coastal runoff. Off Vancouver Island the spatial pattern of tidal frequency currents is controlled by continental shelf wave dynamics. Vorticity associated with shear between offshore wind-driven flow and nearshore buoyancy (runoff)-driven flow generates a semi-permanent eddy locked to the bottom topography off the mouth of Juan de Fuca Strait. Further north, intensification of this shear by Brooks Peninsula results in eddy generation by baroclinic instability. In Queen Charlotte Sound, eddies are generated by the interaction of tidal currents with bottom topography. Whatever their origin, these eddies are the main contributor to the exchanges between the continental shelves and the open ocean offshore (R.E. Thomson, H.J. Freeland, W.R. Crawford).

A mooring array designed to measure the vorticity balance of the large eddy previously observed at the mouth of Juan de Fuca Strait was maintained for three months during the transition between winter and summer conditions. Although the vorticity was nearly constant during the latter part of the period, the closed streamlines of the eddy were observed for only a portion of the time (H.J. Freeland).

A project designed to improve predictions of surface drift on the west coast of Vancouver Island, for use in developing search and rescue plans, was conducted jointly with the Canadian Coast Guard over the last two years. Satellite surface drifters were used to build up a data base, which was in turn incorporated in a predictive model by the contractor conducting the project. It is planned to extend this work to other areas as funds permit (R.E. Thomson).

Numerical models combining continental shelf dynamics, topography and simple models of plankton growth and nutrient transfer have been developed and time-lapse movies of the output constructed. They qualitatively reproduce many of the features seen in satellite water colour images of the Pacific Coast. The importance of various parameters can be estimated by varying them in the model (G. Holloway).

A current meter array was installed on the outer continental shelf in the Beaufort Sea, to complement earlier measurements and to determine whether the expected eastward jet exists over the shelf break. This current is suggested by water property distributions and various theoretical ideas. Numerical and theoretical studies of the current patterns on the Beaufort shelf indicate that topographic effects are very important (H. Melling, W.P. Budgell).

Images of the ice cover from satellite radiometers and airborne SAR are being collected and compiled. Where sufficient continuity exists, time-lapse animation sequences were compared. Ice motion vectors have been extracted from the imagery for use in estimation of the spatial and temporal correlation scales of ice motion. These statistics determine the limits of predictability, as well as suggesting which processes are most important in controlling ice motion (J.F.R. Gower).

A variety of techniques were used to obtain information on the details of the flow field under a pressure ridge keel. The form drag on such keels is thought to be the major source of coupling between ice and water, but existing parameterizations do not correctly represent the physical processes involved, particularly when the water column is stratified. A two-dimensional numerical model was developed for use in planning the experiment and interpreting the results (D.R. Topham).

Ice growth on the continental shelf forms dense brine which then drains across the shelf. The rate of brine drainage can limit ice growth, while the associated flow field is an important element of the winter circulation. The parameters controlling this process are being studied by means of laboratory models. In addition it has been found that the pressure dependence of the freezing point of sea water implies that deep ice protrusions should melt, creating supercooled water which can then freeze on the bottom of thinner areas. The implications of this for the growth of ice sheets are being assessed through laboratory studies and theoretical calculations (D.R. Topham, E.L. Lewis).

(d) Deep Sea

In September, an array of moorings carrying sediment traps, current meters and transmissometers was deployed near a known hydrothermal vent plume field on the Endeavour Ridge segment of the Juan de Fuca Ridge, in cooperation with the Geological Survey of Canada and Oregon State University. A CTD survey was conducted and water samples were collected. A towed body carrying a CTD and transmissometer detected the plume about 10 km from the ridge. These moorings are to be recovered in July of 1986. (R.E. Thomson).

Three climate monitoring cruises to Ocean Station P (50°N, 145°W) were conducted in 1985. The data collected by the weatherships at this station between 1948 and 1981 were reviewed. Evidence of significant variations at depths as great as 3500 m was found, indicating responses of the overall circulation to variations in atmospheric fields (S. Tabata).

Experiments with various idealized basin-scale ocean models continued. The model developed by the Geophysical Fluid Dynamics Laboratory in the U.S. was obtained and installed on the AED Cray computer at Dorval (G. Holloway).

(e) Forecasting

After numerical storm surge models indicated that the hypothetical "100 year storm" based on extrapolations of meteorological data would generate a surge which would flood most of Tuktoyaktuk, a survey of driftwood around the town was conducted in an attempt to gather better information on the actual incidence of extreme water levels. This is being extended to other areas in the Beaufort Sea, in cooperation with Environment Canada (R.F. Henry).

As part of a project sponsored by the World Meteorological Organization, a workshop on storm surges was organized in Bangladesh in December. The primary focus of the workshop was the importance of collecting reliable and quantitative observations of storm surges when they occur, as such data are essential for the calibration of numerical models. Such models already exist, and could be used for predictions and warnings if accurately calibrated. The workshop was attended by meteorologists and coastal authorities from Bangladesh, Burma, Sri Lanka, Pakistan and Korea (R.F. Henry, T.S. Murty).

The effect of bottom roughness on deep ocean tsunami travel times was determined using a new theoretical model incorporating a statistical description of bottom topography. The potential response of Georgia Strait to local earthquakes was examined using the 2 km vertically integrated numerical model (G. Holloway, T.S. Murty). A successful conference, comprising the Tenth Meeting of the International Coordination Group for the Tsunami Warning System in the Pacific, a meeting of the Tsunami Society, a workshop, and an International Tsunami Symposium, was held at IOS.

In response to the recommendations of the inquiry into the loss of several fishing vessels in a storm on October 12-13, 1984, a number of activities designed to contribute to improved coastal weather and sea state forecasting were begun in cooperation with the Atmospheric Environment Service and the Canadian Coast Guard. These included a study of the impact of new observations on coastal sea-state forecasts, the continuation and upgrading of the coastal wave buoy network, and the groundwork for a new network of offshore meteorological buoys (J.F. Garrett).

(f) Processes

A two-dimensional numerical model of the evolution of double diffusive instabilities was developed on a local contractor's VAX-730 array processor computer system. This permits calculations with a resolution greater than that readily achievable on much larger machines. The model is being used to study the interaction of double diffusive instabilities with velocity shears such as might be created by internal waves. Such work is essential to the eventual development of an accurate parameterization of small scale processes for use in ocean circulation and climate models (G. Holloway).

(g) Observational Techniques

The FLI (Fluorescence Line Imager) is a programmable multispectral imager developed by contracts with funding from DFO and the Interdepartmental Committee on Space. The prototype has been flown over land, lakes and the ocean, and has demonstrated that the performance objectives are achievable. In addition to the flight program, work this year has focused on the analysis and interpretation of the data collected and planning for demonstrations in Europe and China (J.F.R. Gower).

A variety of acoustic remote sensing techniques for oceanic measurements are under investigation. Passive methods for determining wind speed and direction, precipitation, and ice strain by measuring sound levels in various frequency bands all show promise. Theoretical and experimental work is continuing in cooperation with the University of Victoria, various U.S. agencies and local contractors. These focus on the details of the sea surface processes which generate the noise. An observing system combining noise recordings with sea surface imagery obtained with both video and high frequency echo sounding was developed and tested for use in the FASINEX experiment in early 1986. Development of an operational wind speed sensor for buoy use was begun (D.M. Farmer).

Several projects using back-scattered acoustic signals were also conducted. These include studies of the measurement of the vertical profile of sound speed (and hence temperature or salinity), correlation sonar measurements of ice and water motion, and measurements of the directional spectrum of ocean waves from a bottom mounted array (D.M. Farmer).

The most exciting acoustic development of 1985 was the demonstration that the scattering of acoustic signals transmitted across a tidal channel could be used to measure the flow in the channel. This has great potential for measurements in areas where conventional techniques are difficult, such as channels with very strong currents or active shipping (D.M. Farmer).

The small solar powered robot vessel known as the "active drifter", was tested at sea several times during the year. Its ability to maintain speed and heading in moderate sea conditions appears to be about the same as in smooth water, and the performance of the solar array is not adversely affected by motion and spray. The stresses associated with buoy motion in the wave field are large, however, resulting in a burnt-out motor on one trial. Tests are continuing, along with the commercial development of the station keeping buoy and experiments with a simple retrofit package for ordinary meteorological drifters (J.F. Garrett).

(h) Tidal and Current Surveys

In addition to the 21 permanent, self-recording tide gauges maintained in the Arctic and along the Pacific coast, and two tsunami gauges, a new telemetering network is under development. When completed, two stations on the exposed Pacific coast will telemeter the tide height data to IOS through a Meteor Burst system, providing quick access to the sea level network. This new system will improve the reliability and speed of the Canadian Tsunami Warning Network (F.E. Stephenson). Data from all tide gauges is processed carefully to provide the observations necessary to predict tides for the Tide and Current Tables, to evaluate mean sea levels and to send to the IGOSS Sea Level Pilot Project (W.J. Rapatz).

Field work for our major current and tidal surveys of Hecate Strait and Dixon Entrance was completed and all moorings and sub-surface pressure gauges were recovered. Unexpectedly strong currents (greater than three knots) were observed near Cape Chacon and Langara Island in summer. Within the central portions of these straits, large scale gyres dominate the circulation. In Dixon Entrance, where they persist throughout the year, they are probably generated by the process of rectification of tidal currents. A study to examine the Dixon Entrance gyres is underway - a combined venture of scientists at IOS, the University of British Columbia and the State University of New York at Stony Brook. In Hecate Strait, a basin-wide gyre is set up, apparently in response to the strong SE storms in fall and winter. IOS scientists are presently assembling the wind and air pressure data for these storms to determine the relationship between atmospheric forcing and the oceanic response. One question they expect to answer is how much of the water in Hecate Strait leaves through its northern end into Dixon Entrance, and how much leaves through the south past Cape St. James. The answer to this question will assist in the prediction of salmon migration routes.

The Tidal and Current Surveys Division participated in the study of another gyre located off the western entrance to Juan de Fuca Strait. This cyclonic eddy is a permanent feature in summer, and appears to upwell most of the nutrient-rich water found off the west coast of Vancouver Island. A CTD survey, a study of turbulent mixing in the eddy, and ocean drifter studies were carried out. Scientists of Ocean Physics Division deployed current meters and carried out a late-winter CTD survey. Results show the presence of the eddy well, but reveal that the eddy does not trap surface water for long; all surface drifters exited from the eddy in a few days after completing one-half to three-quarters of a circuit. Current meter data show the eddy disappearing on occasion. These results could explain the observed spreading of nutrient-rich waters along the coastline in summer (W.R. Crawford).

Current surveys in narrow passes on the B.C. coast were completed and the refined current predictions for five passes are now available and will appear in the 1987 Tide and Current Tables. These successful surveys will be extended to other narrow passes in 1986 (W.S. Huggett).

Time series observations in the Fraser River were continued with a new CSTDV developed in IOS. The numerical model of the Fraser River was revised to include the capability to track drifting objects. Observations are still being made jointly with Water Survey of Canada to measure the distribution of flow at the trifurcation point near New Westminster. Tidal and Current Surveys Division was involved in the hydrodynamic section of the workshop conducted to make recommendations for future measurements of environmental parameters in the Fraser River (A.B. Ages).

12. Bibliography

Amos, C.L. and Topliss, B.J. 1985. Discrimination of suspended particulate matter in the Bay of Fundy using the number 7 coastal zone colour scanner. Can. J. Remote Sensing, 11, 1, 85-92.

Anderson, L.G. and Jones, E.P. 1985. Measurements of total alkalinity, calcium and sulfate in natural sea ice. J. Geophys. Res., 90(C5), 9194-9198.

Anderson, L., Coote, A.R. and Jones, E.P. 1985. Nutrients and alkalinity in the Labrador Sea and their use in the characterization of water masses and processes. J. Geophys. Res., 90(C4), 7355-7360.

Armi, L. and Farmer, D.M. 1985. The internal hydraulics of Gibraltar Strait and associated sills and narrows. Oceanologica Acta, 8, 37-46.

Bah, A. et Legendre, L. 1985. Biomasse phytoplanctonique et mélange de marée dans l'estuaire moyen du St. Laurent. Naturaliste can., 112, 39-49.

Banke, E.G. and Smith, S.D. 1984. A hindcast study of iceberg drift on the Labrador Coast. Can. Tech. Rep. Hydrogr. Ocean Sci., 49, 161 pp.

Bennett, A.F. 1985. Absolute velocity and the thermodynamics of sea water. Ocean Modelling, Oxford University/U.S. Office of Naval Research, 62, 1-3.

Bennett, A.F. and Denman, K.L. 1985. Phytoplankton patchiness: inferences from particle statistics. J. Mar. Res., 43, 307-335.

Benoit, J., El-Sabh, M.I. and Tang, C.L. 1985. Structure and seasonal characteristics of the Gaspe Current. J. Geophys. Res., 90(C2), 3225-3236.

Bezanson, D. and Vandall Jr., P.E. 1984. An investigation of surface drift on the Labrador Coast. Can. Tech. Rep. Hydrogr. Ocean Sci., 54, 24 pp.

Borstad, G.A., Gower, J.F.R., Edel, H.R. and Hollinger, A.B. 1985. Analysis of test and flight data from the Fluorescence Line Imager. Can. Spec. Publ. Fish. Aquat. Sci., 83, 38 pp.

Bowen, A.J. and Doering, J.C. 1985. Nearshore sediment transport: estimates from detailed measurements of the nearshore velocity field. Proc. 19th Conf. Coastal Engineering, Houston, ASCE., 1703-1714.

Campbell, J.A. and Yeats, P.A. 1984. Dissolved chromium in the St. Lawrence Estuary. Estuarine, Coastal and Shelf Sciences, 19, 513-522.

Chase, R.L. 1985. Canadian-American seamount expedition. Hydrothermal vents on an axis seamount of the Juan de Fuca Ridge. Nature, 313, 212-214.

Clarke, R.A. 1984. Transport through the Cape Farewell Flemish Cap Section. ICES Journal - Rapp. P.-v. Reun. Cons. Int. Explor. Mer, 185, 120-130.

Clarke, R.A. 1985. Temporal and spatial scales of Labrador Sea water formation. In: North Atlantic Deep Water Formation, T. Bennett, W. Broecker and J. Hansen (Editors), Proceedings of a Symposium 1984, Lamont-Doherty Geological Observatory, Palisades, NY.

Cochrane, N.A. 1985. An operational evaluation of an Ametak Straza DCP-4400 300 KHz Doppler Current Profiler aboard CSS Dawson. Can. Tech. Rep. Hydrogr. Ocean Sci., 68.

Colony, R., Moritz, R.E. and Symonds, G. 1985. Random ice trajectories in the Greenland Sea. POAC 85, 8th International Conference Port and Ocean Engineering under Arctic Conditions, Narssarssuaq, Greenland, Proceedings, 1, 220-229.

d'Anglejan, B. and Ingram, R.G. 1984. Near bottom variations of turbidity in the St. Lawrence estuary. Estuarine, Coastal and Shelf Science, 19, 655-672.

Dalziel, J.A. and Yeats, P.A. 1985. Reactive mercury in the central North Atlantic Ocean. Marine Chemistry, 15, 357-361.

Denman, K.L. and Freeland, H.J. 1985. Correlation scales, objective mapping and a statistical test of geostrophy on a continential shelf. J. Mar. Res., 43(3), 517-539.

Dobson, F.S. and Smith, S.D. 1985. Estimation of solar radiation at sea. In: The Ocean Surface, Y. Toba and H. Mitsuyasu (Editors), Reidel Publishing Company, 525-533.

Dobson, F.W. 1985a. Reflections on a probe support: a comment on "Measurement of High Frequency Waves using a Wave Follower" by S. Tang and O.H. Shemdin. J. Geophys. Res., 90, 9204-9205.

Dobson, F.W. 1985b. Comment on "Measurement of Wind Velocity and Pressure with a Wave Follower during Marsen" by S.V. Hsiao and O.H. Shemdin. J. Geophys. Res., 90, 9206-9207.

Doering, J.C. and Bowen, A.J. 1985. Skewness et al. The spatial distribution of some moments of the nearshore velocity field. Canadian Coastal Conference 1985, NRC., 5-16.

Donelan, M.A. and Pierson, W.J. 1984. Does the scatterometer see wind speed or friction velocity? Proceedings of the International Union of Radio Science Meeting, Frontiers of Remote Sensing of the Oceans and Troposphere from Air and Space Platforms, Israel, May 14-23.

Donelan, M.A., Hamilton, J. and Hui, W.H. 1985. Directional spectra of wind-generated waves. Phil. Trans. Roy. Soc. Lond., A315, 509-562.

Drinkwater, K., Taylor, G. and Petrie, L. 1985. Hydrographic conditions in the southern Gulf of St. Lawrence during July 26-August 3, 1982. Can. Tech. Rep. Aquat. Sci., 1338, 29 pp.

Dunbar, D.S. 1985. A numerical model of stratified circulation in a shallow-silled inlet. Ph.D. thesis, University of British Columbia, Vancouver.

El-Sabh, M.I., Tessier, B. and Murty, T.S. 1985. Fractal dimension and length of an irregular coastline. Science of Tsunami Hazards, 3(1), 41-44.

Emery, W.J. and Hamilton, K. 1985. Atmospheric forcing of interannual variability in the northeast Pacific Ocean, connections with El Nino. J. Geophys. Res., 91, 857-868.

Emery, W.J., Royer, T.C. and Reynolds, R.W. 1985. The anomalous tracks of North Pacific drifting buoys 1981-1983. Deep-Sea Res., 32, 315-347.

Farmer, D.M. and Denton, R.A. 1985. Hydraulic control of flow over the sill in Observatory Inlet. J. Geophys. Res., 90(C5), 9051-9068.

Fletcher, J., Mills, R.G. and Smith, S.D. 1985. Design, construction and performance of a moored stable platform. Can. Tech. Rep. Hydrogr. Ocean Sci., 62, iv + 41 pp.

Fofonoff, N.P. and Hendry, R.M. 1985. Current variability near the Southeast Newfoundland Ridge. J. Phys. Ocean., 15(7), 963-984.

Freeland, H.J., Church, J.A., Smith, R.L. and Boland, F.M. 1985. Current meter data from the Australian Coastal Experiment. CSIRO Marine Labs., Data Report 169.

Gargett, A.E. 1985. Evolution of scalar spectra with the decay of turbulence in a stratified fluid. J. Fluid Mech., 159, 379-407.

Garrett, C. 1985. Statistical prediction of iceberg trajectories. Cold Regions Science and Technology, 11, 255-266.

Garrett, C., Majaess, F. and Toulany, B. 1985. Sea level response at Nain, Labrador, to atmospheric pressure and wind. Atmosphere-Ocean, 23, 95-117.

Garrett, C., Middleton, J., Hazen, M. and Majaess, F. 1985. Tidal currents and eddy statistics from iceberg trajectories off Labrador. Science, 227, 1333-1335.

Garrett, C., Middleton, J., Majaess, F. and Hazen, M. 1985. Analysis and prediction of iceberg trajectories. Report to D.S. and S., Canada, 86 pp.

Giovando, L.F. 1985. Observations of seawater temperature and salinity at British Columbia shore stations, 1984. Can. Data Rep. Hydrogr. Ocean. Sci., 41, 102 pp.

Gonzales, F.I., Cokelet, E.D., Gower, J.F.R. and Mulhern, M.R. 1985. SLAR and in situ observations of wave current interaction on the Columbia River bar. In: The Ocean Surface: Wave Breaking, Turbulent Mixing and Radio Probing, Y. Toba and H. Mitsuyasu (Editors), D. Reidel, 303-310.

Gosselin, M., Legendre, L., Demers, S. and Ingram, R.G. 1985. Responses of sea ice microalgae to climatic and fortnightly tidal energy inputs (Manitounuk Sound, Hudson Bay). Can. J. Fish. Aquat. Sci., 42, 6, 999-1006.

Gower, J.F.R. 1985. Reduction of the effect of clouds on satellite thermal imagery. Int. J. Remote Sensing, 6, 1419-1434.

Greenberg, D.A. 1984a. A review of the physical oceanography of the Bay of Fundy. In: The Proceedings of the Fundy Environmental Studies Committee Meeting on Marine Environmental Consequences of Tidal Power Development in the Upper Reaches of the Bay of Fundy, Nov. 8-10, 1982, Moncton. Rep. Fish. Aquat. Sci., 1256.

Greenberg, D.A. 1984b. The effects of tidal power development on the physical oceanography of the Bay of Fundy and Gulf of Maine. In: The Proceedings of the Fundy Environmental Studies Committee Meeting on Marine Environmental Consequences of Tidal Power Development in the Upper Reaches of the Bay of Fundy, Nov. 8-10, 1982, Moncton. Rep. Fish. Aquat. Sci., 1256.

Gregg, M.C., Peters, H., Wesson, J.C., Oakey, N.S. and Shay, T. 1985. Intensive measurements of turbulence and shear in the equatorial undercurrent. Nature, 318, 140-144.

Haines, J.W. 1985. Steady flows in the nearshore zone. Proc. 19th Conf. Coastal Engineering, Houston, ASCE., 2280-2292.

Hamilton, K. 1985. A study of the variability of the return migration route of Fraser River sockeye salmon (Oncorhychus nerka). Can. J. Zool., 63, 1930-1943.

Hanes, D.M. and Bowen, A.J. 1985. A granular-fluid model for steady intense bedload transport. J. Geophys. Res., 90, 9149-9158.

Hargrave, B.T., Harding, G.C., Drinkwater, K.F., Lambert, T.C. and Harrison, W.G. 1985. Dynamics of the pelagic food web in St. Georges Bay, southern Gulf of St. Lawrence. Mar. Ecol. Prog. Ser., 20, 121-140.

Hasse, L. and Dobson, F. 1985. Introductory Physics of the Atmosphere and Ocean. Reidel, Dordrecht.

Hendry, R.M. 1985a. Deep circulation south of the Gulf Stream at 50 W. Progress in Oceanography, 14, 191-207.

Hendry, R.M. 1985b. Calibration of temperature measurements obtained from profiling CTD systems. International Council for the Exploration of the Sea. C.M. 1985/C:3 (Hydrography Committee), 19 pp.

Holyer, J.Y. and Mysak, L.A. 1985. Trench wave generation by incident baroclinic Rossby waves. J. Phys. Oceanogr., 15, 593-603.

Horne, E.P.W. 1985. Ice induced vertical circulation in an Arctic Fiord. J. Geophys. Res., 90(C1), 1078-1086.

Ikeda, M. 1985a. Wind effects on a front over the continental shelf slope. J. Geophys. Res., 90(C5), 9108-9118.

Ikeda, M. 1985b. A coupled ice ocean model of a wind driven coastal flow. J. Geophys. Res., 90(C5), 9119-9128.

Ikeda, M. and Emery, W.J. 1984a. A continential shelf upwelling event off Vancouver Island as revealed by satellite infrared imagery. J. Marine Res., 42(2), 303-317.

Ikeda, M. and Emery, W.J. 1984b. Satellite observations and modelling of meanders in the California Current System off Oregon and Northern California. J. Phys. Oceanogr., 14(9), 1434-1450.

Ingram, R.G. 1985. Frontal characteristics at the Head of the Laurentian Channel. Proceedings of Symposium on St. Lawrence estuary. Nat. Can., 112, 31-38.

Ingram, R.G., Legendre, L., Simard, Y. and Lepage, S. 1985. Phytoplankton response to freshwater runoff: the diversion of the Eastmain River, James Bay. Can. J. Fish. Aquat. Sci., 42, 6, 1216-1221.

Kelley, D.E. 1984. Effective diffusivities within oceanic thermohaline staircases. J. Geophys. Res., 89, 10484-10488.

Kenney, B.C. 1985a. Sediment resuspension and currents in Lake Manitoba. J. Great Lakes Res., 11(2), 85-96.

Kenney, B.C. 1985b. Under-ice circulation in Wupaw Bay, Southern Indian Lake. NWRI, W&NR, Unpublished Report, Winnipeg.

Kitaigorodskii, S.A. and Donelan, M.A. 1984. Wind-wave effects of gas transfer. In: Gas Transfer at Water Surfaces, D. Reidel Publishing Company, 147-170.

Koslow, J.A., Loucks, R.H., Thompson, K.R. and Trites, R.W. 1985. Relationships of St. Lawrence River outflow with sea surface temperature and salinity in the Northwest Atlantic. In: The Role of Freshwater Outflow in Coastal Marine Ecosystems. NATO Symposium Volume, Springer-Verlag.

Kowalik, Z. and Murty, T.S. 1985. Computation of tsunami amplitudes resulting from a predicted major earthquake in the Shumagin seismic gap. Geophys. Res. Lett., 11(12), 1243-1246.

Kranck, K. 1984a. Grain-size characteristics of turbidity. In: Fine Grained Sediments, D.A.V. Stow and D.J.W. Piper (Editors), Spec. Publ. J. Geol. Soc. Lond., 15, 83-92.

Kranck, K. 1984b. The role of flocculation in the filtering of particulate matter in estuaries. In: Estuary as a Filter, Victor S. Kennedy (Editor).

Kranck, K. and Mulligan, T.G. 1985. The origin of grain size spectra of suspension deposited sediment. Geomarine Letters, 5, 61-66.

Ku, L.F., Greenberg, D.A., Garrett, C.J.R. and Dobson, F.W. 1985. Nodal modulation of the semi-diurnal tide in the Bay of Fundy and Gulf of Maine. Science, 230 (4721), 69-71.

Kundu, P.K. and Thomson, R.E. 1985. Inertial oscillations due to a moving front. J. Phys. Oceanogr., 15(8), 1076-1084.

Lazier, J.R.N. 1985. Arctic run-off in the North Atlantic Ocean. BIO Review '84, 21-24.

Leblond, P.H., Hickey, B.M. and Thomson, R.E. 1985. Runoff driven coastal flow off British Columbia. Proceedings of NATO Workshop on the Influence of Fresh Water on the Sea, Bobo, Norway, May 20-26, 1985.

Lee, A.Y.P., Stucchi, D.J. and Freeland, H.J. 1985. Coastal ocean dynamics experiment CTD data report; 1979-81. Can. Data Rep. Hydrogr. Ocean Sci., 26, 330 pp.

Levy, E.M. 1985. Background levels of dissolved/dispersed petroleum residues in the Gulf of St. Lawrence 1970-1979. Can. J. Fish. Aquat. Sci., 42, 544-555.

Lewis, E.L. 1985a. Calibration of CTD sensors. In: Evaluation, Comparison and Calibration of Oceanographic Instruments. Soc. for Underwater Tech., Graham and Trotman Ltd., London.

Lewis, E.L. 1985b. The ice pump, a mechanism for ice-shelf melting. In: Glaciers, Ice Sheets and Sea Level: Effects of a CO_2-induced Climatic Change. National Academy Press, Washington, D.C., 275-278.

Lewis, E.L. and Perkin, R.G. 1985. The winter oceanography of McMurdo Sound Antarctica. In: Oceanology of Antarctic Continential Shelf, Jacobs (Editor), Antarctic Research Series, Am. Geophys. Union, Washington, D.C., 43, 145-165.

Lewis, M.R., Horne, E.P.W., Cullen, J.J., Oakey, N.S. and Platt, T. 1984. Turbulent motions may control phytoplankton photosynthesis in the upper ocean. Nature, 311, 49-50.

Lively, R.R. 1984. Current meter observations on the Scotian Rise for November 1980 to October 1981. Can. Tech. Rep. Hydrogr. Ocean Sci., 50, 156 pp.

Loder, J.W. and Wright, D.G. 1985. Tidal rectification and frontal circulation on the sides of Georges Bank. J. Mar. Res., 43(3), 581-604.

Loring, D.H. 1984. Trace metal geochemistry of sediments from Baffin Bay. Can. J. Earth Sci., 21, 1368-1378.

Losher, A.J. 1985. The geochemistry of sediments and mine tailings in the Alice Arm area. M.Sc. thesis, University of British Columbia, Vancouver, 189 pp.

Loucks, R.H. and Trites, R.W. 1985. Analyses of sea surface temperatures in the Northwest Atlantic. Can. Tech. Rep. Fish. Aquat. Sci., 1410, iv + 42 pp.

Lucotte, M. and d'Anglejan, B. 1985. A comparison of several methods for the determinations of iron and associated phosphorus in estuarine particulate matter. Chemical Geology, 48, 257-264.

Marles, E.W. 1985. Limnological survey techniques from small aircraft. Environment Canada, Technical Bull. 139, 33 pp.

McBean, G.A. and Murty, T.S. 1985. A marked mesoscale pressure-induced wind variation. Boundary Layer Meteorology, 31, 209-216.

McKeown, D. 1985. Sinking of the Kurdistan Bow Section: Observer's notes. In: The Kurdistan Oil Spill of March 16-17, 1979: Activities and Observations of the BIO Response Team, J.H. Vandermeulen and D.E. Buckley (Editors). Can. Tech. Rep. Hydrogr. Ocean Sci., 35, 101-113.

Mertz, G.J. 1985. Atmospheric and oceanic 40-50 day oscillations in the source region of the Somali Current. Ph.D. thesis, University of British Columbia, Vancouver.

Middleton, J.H. and Thomson, R.E. 1985. The arrested topographic wave on a beta-plane. J. Phys. Oceanogr., 15(12).

Moody, J.A., Butman, B., Beardsley, R.C., Brown, W.S., Daifuku, P., Irish, J.D., Mayer, D.A., Mofjeld, H.O., Petrie, B., Ramp, S., Smith, P. and Wright, W.R. 1984. Atlas of Tidal Evaluation and Current Observations on the Northeast American Continental Shelf and Slope. U.S. Geological Survey Bulletin, 1611, iv + 122 pp.

Murthy, C.R., Simons, T.J., Lam, D.C.L. and Walma, M. 1985. Simulation of pollutant transport along the north shore of Lake Ontario. NWRI #85-23, 33 pp.

Murty, T.S. 1985. Modification of hydrographic characteristics, tides and normal modes by ice cover. Marine Geodesy, 9(4), 451-468.

Murty, T.S. and El-Sabh, M.I. 1985a. The age of tides. Oceanogr. Mar. Biol. Ann. Rev., 23, 11-103.

Murty, T.S. and El-Sabh, M.I. 1985b. Gravitational oscillations in a rotating paraboloidal basin: a classical problem revisited. Bull. Nat. Inst. Oceanography, 180(2), 99-127.

Murty, T.S. and El-Sabh, M.I. 1985c. Simulation of gyres in the Gulf of St. Lawrence and St. Lawrence Estuary, modelling simulation and control. A.M.S.C., Series C, 2(3), 9-27.

Murty, T.S. and Holloway, G. 1985. Influence of marginal ice cover on storm surges. J. Waterway, Port, Coastal and Ocean Engineering, 111, 329-336.

Mysak, L.A. 1985a. On the interannual variability of eddies in the northeast Pacific Ocean. In: El Nino North: Nino Effects in the Eastern Subarctic Pacific Ocean, W.S. Wooster and D.L. Fluharty (Editors), 97-106.

Mysak, L.A. 1985b. Elliptical topographic waves. Geophys. Astrophys. Fluid Dynamics, 31, 93-135.

Mysak, L.A., Hamilton, K. and Groot, C. 1985. Year to year changes in the return migration routes of Fraser River sockeye salmon. Discovery, 14, 40-43.

Mysak, L.A., Salvade, G., Hutter, K. and Scheiwiller, T. 1985. Topographic waves in a stratified elliptical basin, with application to the Lake of Lugano. Phil. Trans. Roy. Soc. Lond., 316, 1-55.

Needler, G.T. 1985. The absolute velocity as a function of conserved measurable quantities. In: Essays on Oceanography: A Tribute to John Swallow, J. Crease, W.J. Gould, and P.M. Saunders (Editors), Progress in Oceanography, 14(1/4), 421-429.

Neu, H.A. 1985. Assessment of tanker and slick drift following breakup of the tanker Kurdistan. In: The Kurdistan Oil Spill of March 16-17, 1979: Activities and Observations of the BIO Response Team, J.H. Vendermeulen and D.E. Buckley (Editors), Can. Tech. Rep. Hydrogr. Ocean Sci., 35, 33-38

Pedersen, T.F. 1985. Early diagenesis of copper and molybdenum in mine tailings and natural sediments in Rupert and Holberg inlets, British Columbia. Can. J. Earth Sci., 22, 1474-1484.

Pedersen, T.F., Malcolm, S.J. and Scholkovitz, E.R. 1985. A lightweight gravity corer for undisturbed sampling of soft sediments. Can. J. Earth Sci., 22, 133-135.

Pocklington, R. 1985. Organic matter in the Gulf of St. Lawrence in winter. Can. J. Fish. Aquat. Sci., 42(9), 1556-1561.

Prinsenberg, S.J. and Danard, M. 1985. Variations in momentum, mass and heat fluxes due to changes in the sea surface temperature of Hudson Bay. Atmosphere-Ocean, 23(3), 228-237.

Quon, C. 1985. Transient multiple wave number convective instability in a 2-dimensional enclosed rotating fluid. Proceedings of 9th International Conference on Numerical Methods in Fluid Dynamics, M. Hott (Editor), Springer-Verlag, 447-452.

Rantala, R.T.T. and Loring, D.H. 1985. Partition and determination of cadmium, copper, lead and zinc in marine suspended particulate matter. Intern. J. Environ. Anal. Chem., 19, 165-173.

Reiniger, R., Dessureault, J.G. and Greifeneder, W.B. 1984. Improvement in the CTD system field operation. In: STD '84 Conference and Workshop (LaJolla, California), San Diego: Marine Technology Society, 72-77.

Ross, C.K. 1984. Temperature-salinity characteristics of the "Overflow" water in Denmark Strait during "Overflow '73". In: Hydrobiological Variability in the North Atlantic and Adjacent Seas, J. Meincke, L. Otto, A.J. Lee, and R.R. Dickson (Editors). Rapp, P.-V. Reun. Cons. Int. Explor. Mer., 185, 111-119.

Rowell, T.W., Trites, R.W. and Dawe, E.G. 1985. Distribution of short-finned squid (Illex illecebrosus) larvae and juveniles in relation to the Gulf Stream Frontal Zone between Florida and Cape Hatteras. NAFO Sci. Coun. Studies, 9, 77-92.

Royer, L. and Emery, W.J. 1985. Computer simulations of the Fraser River Plume. J. Mar. Res., 43, 289-306.

Royer, T.C. and Emery, W.J. 1985. Circulation in the Bering Sea 1982-83: satellite-tracked drifter observations. J. Phys. Oceanogr., 14, 1914-1920.

Ruddick, B.R. and Bennett, A.S. 1985. Fine structure and mixing at the edge of a warm core ring. J. Geophys. Res., 90(C5), 8943-8951.

Sackman, T. and Smiley, B.D. 1985. Arctic industrial activities compilation, Vol. 2, Sverdrup Basin: Hydrocarbon Exploration, 1974 to 1984. Can. Data Rep. Hydrogr. Ocean Sci., 32, 181 pp.

Sameoto, D., Cochrane, N.A. and Herman, A.W. 1985. Response of biological acoustic back-scattering to ships lights. Can. J. Fish. Aquat. Sci., 42(9), 1535-1543.

Schwab, D.J., Bennett, J.R., Lui, P.C. and Donelan, M.A. 1984. Application of a simple numerical wave prediction model to Lake Erie. Geophys. Res., 89(C3), 3586-3592.

Siedler, G., Zenk, W. and Emery, W.J. 1985. Strong current events related to a subtropical front in the Northeast Atlantic. J. Phys. Oceanogr., 8, 893-895.

Simons, T.J. 1985. Reliability of circulation models. J. Phys. Oceanogr., 15, 1191-1204.

Simons, T.J. and Schertzer, W.M. 1985. The circulation of Lake Ontario during the summer of 1982 and the winter of 1982/83. NWRI #85-26, 198 pp.

Simons, T.J., Murthy, C.R. and Campbell, J.E. 1985. Winter circulation in Lake Ontario. J. Great Lakes Res., 11, 423-433.

Smith, P.C., Lawrence, D.J. and Elliott, J.A. 1984. Current measurements near the ocean surface. AOL Research Note, 17 pp.

Smith, S.D. and Jones, E.P. 1985. Evidence for wind-pumping of air-sea gas exchange based on direct measurements of CO_2 fluxes. J. Geophys. Res., 90(C1), 869-875.

Staples, G. 1985. A geostrophic comparison off the coast of Vancouver Island. B.Sc. thesis, University of British Columbia, Vancouver.

Stephenson, F.E. and Gregson, D.J. 1985. Meteor burst tsunami warning systems. Proceedings of the International Tsunami Symposium, IUGG, August 6-9, 134-139.

Subba Rao, D.V. and Yeats, P.A. 1984. Effect of iron on phytoplankton production in the Sargasso Sea. J. Exp. Mar. Biol. Ecol., 81, 281-289.

Swaters, G.E. 1985a. On the stability and propagation of barotropic modons in slowly varying media. Ph.D. thesis, University of British Columbia, Vancouver.

Swaters, G.E. 1985b. Ekman layer dissipation in an eastward-travelling modon. J. Phys. Oceanogr., 15, 1212-1216.

Swaters, G.E. and Mysak, L.A. 1985. Topographically induced baroclinic eddies near a coast-line, with application to the northeast Pacific. J. Phys. Oceanogr., 15, 1470-1485.

Symonds, G. 1985. Sea ice as an indicator of climate change. B.I.O. Review '84.

Symonds, G. and Bowen, A.J. 1984. Interactions of nearshore bars with incoming wave groups. J. Geophys. Res., 89(C2), 1953-1959.

Symonds, G. and Peterson, I. 1984. MIZEX 83 - B.I.O. buoy data summary. In: MIZEX Bulletin IV: Initial Results and Analysis from MIZEX 83. Cold Regions Research and Engineering Laboratory, U.S. Army Corps. Engineers, Special Rep., 84-28, 13-17.

Symonds, G. and Peterson I.K. 1985. MIZEX: Ice floe trajectories through the Greenland Sea. Can. Data Rep. Hydrogr. Ocean Sci., 33, 68 pp.

Tabata, S. 1985a. Specific problems in maintaining time series observations. In: Time Series of Ocean Measurements. Intergovernmental Oceanogr. Comm. Technical Series, UNESCO, 2, 55-60.

Tabata, S. 1985b. El Nino effects along and off the Pacific coast of Canada during 1982-83. In: El Nino North, Nino Effects in the Eastern Subarctic Pacific Ocean, W.S. Wooster and D.L. Fluharty (Editors), Washington Sea Grant Program, University of Washington, Seattle, 85-96.

Tabata, S. and Peart, J.L. 1985. Statistics of oceanographic data based on hydrographic/STD casts made at Ocean Station P during August 1956 through June 1981. Can. Data Rep. Hydrogr. Ocean Sci., 31, 133 pp.

Tang, C.L., Bennett, A.S. and Lawrence, D.L. 1985. Thermohaline intrusions in the frontal zones of a warm-core ring observed by batfish. J. Geophys. Res., 90(C5), 8928-8942.

Tee, K.T. 1985. Depth-dependent studies of tidally-induced residual currents on the sides of Georges Bank. J. Phys. Oceanogr., 15, 1818-1846.

Thompson, K.R. 1985. North Atlantic sea level and circulation. National Academy of Sciences Report on Sea Level Changes, Chapter 9.

Thomson, R.E. and Gower, J.F.R. 1985. A wind-induced mesoscale eddy over the Vancouver Island continental slope. J. Geophys. Res., 90, 8981-8993.

Thomson, R.E., Tabata, S. and Ramsden, D. 1985. Comparison of sea level variability of the Caribbean and Pacific coasts of the Panama Canal. IOC. Time Series of Ocean Measurements. Vol. 2-1984 IOC Tech. Ser. 30, UNESCO, 1985.

Thomson, R.E., Crawford, W.R., Freeland, H.J. and Huggett, W.S. 1985. Low-pass filtered current meter records for the west coast of Vancouver Island: Coastal Ocean Dynamics Experiment, 1979-81. Can. Data Rep. Hydrogr. Ocean Sci., 40, 102 pp.

Topliss, B.J. 1985. Optical measurements in the Sargasso Sea: solar stimulated chlorophyll fluorescence. Oceanologica Acta., 8(3), 263-270.

Trites, R.W. and Drinkwater, K.F. 1985. Overview of environmental conditions in the northwest Atlantic during 1983. NAFO Sci. Coun. Studies, 8, 7-20.

Trites, R.W., McLain, D.R. and Ingham, M.C. 1985. Sea-surface temperatures along the continental shelf from Cape Hatteras to Hamilton Bank. NAFO Sci. Coun. Studies, 8, 21-23.

Webb, A.J. 1985. The propagation of the internal tide around a bend in Knight Inlet, B.C. Ph.D. thesis, University of British Columbia, Vancouver, 160 pp.

Wright, D.G. and Loder, J.W. 1985. A depth-dependent study of the topographic rectification of tidal currents. Geophys. Astrophys. Fluid Dyn., 31, 169-220.

Yao, T., Pond, S. and Mysak, L.A. 1985. Profiles of low-frequency subsurface current fluctuations in the Strait of Georgia during 1981 and 1982. J. Geophys. Res., 90, 7189-7198.

Yeats, P.A. and Bewers, J.M. 1985. Manganese in the western North Atlantic Ocean. Marine Chemistry, 17, 255-263.

13. Addresses of Reporting Institutes

Newfoundland Institute of Cold Ocean Science
Memorial University of Newfoundland
St. John's, Newfoundland. A1B 3X7

Department of Oceanography
Dalhousie University
Halifax, Nova Scotia. B3H 4J1

Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia. B2Y 4A2

Centre Champlain des sciences de la mer
Pêches et Océans Canada
C.P. 15,500
Québec, Québec. G1K 7X7

Groupe interuniversitaire de recherche océanographique du Québec
Département de biologie
Université Laval
Sainte-Foy, Québec. G1K 7P4

Marine Sciences Centre
Eaton Building
McGill University
3260 University Street
Montreal, Quebec. H3A 2B2

National Water Research Institute
Canada Centre for Inland Waters
P.O. Box 5050
Burlington, Ontario. L7R 4A6

National Water Research Institute
Western and Northern Region
501 University Crescent
Winnipeg, Manitoba. R3T 2N6

National Water Research Institute
Pacific and Yukon Region
2310 Marine Drive
West Vancouver, B.C. V5J 3E5

Department of Oceanography
University of British Columbia
Vancouver, B.C. V6T 1W5

Institute of Ocean Sciences
P.O. Box 6000
Sidney, B.C. V8L 4B2

VIII GLACIER RESEARCH

Compiled by: P.G. Johnson

1. Summary

Routine mass balance studies have now been reduced to a bare minimum with cutbacks at B.C. Hydro and Environment Canada eliminating much of the western program and the Axel Heiberg program being continued only by scientists working on other projects from the McGill research station. Government research programs from the National Hydrology Research Institute and the Polar Continental Shelf Project have continued in diverse field areas and remain the basis of government glacier research efforts in Canada. In the universities, the University of British Columbia continues its work on glacier surges, glacier hydrology and glacier ice dammed lakes and the Universities of Calgary, Ottawa, Sherbrooke, Trent and Waterloo have again been active in a variety of glacier related projects. Perhaps the most significant initiative is overseas; the Upper Indus Basin study in Pakistan is under the direction of Wilfrid Laurier University.

2. Environment Canada, National Hydrology Research Institute

(a) Ward Hunt Ice Shelf (G. Holdsworth)

A study of the dynamics of the Ward Hunt Ice Shelf, Ellesmere Island is in progress. This includes creep simulation, interaction with pack ice forces and vibration modelling. This work is directed towards studying the factors which are associated with or lead to calving of ice islands. A paper has been prepared on the preliminary creep simulation studies.

(b) Ice Core/Climate Change Project, Mount Logan, Yukon Territory (G. Holdsworth and M.N. Demuth)

The 103 m ice core retrieved from Mount Logan in 1980 is still being analyzed for d 180, trace chemistry and structural characteristics. The carbon dioxide concentrations in the air bubbles have been measured and the results presented. The relationship between volcanic events recorded in the core and climate perturbations is being examined. Work is continuing on the modification and redesign of the Canadian-Rufli-Rand ice-coring drill system. A new control and monitoring system based on cutter pressure and position feedback coupled with a hydraulically driven draw-works will enhance feedrate control and drill tripping speed. Improvements in core quality, operational ease and overall drilling efficiency in the retrieval of shallow cores is expected. The drill will continue to be used for core recovery in a program to study borehole deformation at sites currently being reconnoitred. Preparations are underway to return to the Mount Logan NW Col drilling site to recover previously collected ice cuttings for soot analysis and for short-term air sampling for ambient air/Co_2 analysis as part of an ongoing study of global atmospheric CO_2 variations (with D. Raynaud, CNRS).

(c) Ice Deformation (M.N. Demuth)

A study has been initiated to investigate borehole deformation in firn and glacial ice for the study and modelling of ice deformation in the vicinity of ice divides and to provide additional field data on the flow law of ice. A new borehole logging tool is being developed to assist in this study and a theoretical analysis of closure at the Mount Logan site has been undertaken to determine the feasibility of a resurvey.

(d) Iskut River Glaciers, Northern Coast Mountains (O. Mokievsky-Zubok)

After seven years of study, the regular mass balance measurements and monitoring of the periodicity of sudden discharges of several ice-dammed lakes in the Iskut/Stikine River basins was discontinued, in the summer of 1985. Winter balance was measured in spring on Andrei, Yuri and Alexander glaciers and found to be 2.17 m, 1.58 m and 2.07 m of H_2O respectively.

(e) Tiedemann and Bench Glaciers, Coast Mountains (O. Mokievsky-Zubok)

Similar to other Coast Mountain glaciers studied, mass balance measurements on the above two glaciers was strongly negative. Tiedemann Glacier had exceptionally high losses at the snout with an estimated 10.9 m of vertical ice melt. Net mass balance was -1.37 m on Teidemann and -0.88 m of H_2O on Bench glacier. 1985 was the final year of measurement.

(f) Bridge River Glaciers, Coast Mountains (O. Mokievsky-Zubok)

The highest negative mass balance since studies began in 1976 occurred on all three glaciers. Net balances for Bridge, Sykora and Zavisha glaciers were -1.87 m, -1.37 m and -1.22 m of H_2O respectively. Meteorological and river level data were obtained via satellite and will continue in the future. Mass balance measurements will be discontinued.

(g) Mass Balances, Southwest Coast Mountains (O. Mokievsky-Zubok)

Mass balance measurements continued on Sentinel, Helm and Place glaciers. All showed pronounced negative balances; even Sentinel Glacier which has only had five negative years during the 21 years studied. Net balances were -0.84 m, -1.73 m and -1.89 m of H_2O respectively. As a result of heavy rain in early October 1984, the river-level gauging station below Sentinel Glacier was washed away and meltwater flow records are not available.

(h) Glacier Inventory of Canada (A. Champoux, J.W. Clarkson and C.S.L. Ommanney)

A total of 513 glaciers were inventoried in the McGregor River basin (4*8KB), in the headwaters of the Columbia River. Work on the neighbouring Fraser River headwaters is in progress. Results of the analysis of data from the tripartite inventory of Glacier National Park were presented in Iceland. Two theses have also been accepted at Université de Sherbrooke. Landsat 5 TM imagery is being evaluated for future inventory use.

(i) Peyto Glacier, Rocky Mountains (J.M. Power and M.N. Demuth)

Collection of mass balance data at Peyto Glacier continued on a limited basis with spring and fall surveys. A drastic summer melt threatened the continuity of the record due to the loss of many stakes; an early winter upper basin profile showed that all the 1984-85 accumulation had melted. Work continued on incorporating glacier-melt runoff into conceptual hydrologic forecasting models such as the UBC model.

(j) Long Range Transport of Atmospheric Pollutants (G. Holdsworth)

The Mt. Logan ice core and other shorter cores retrieved from the vicinity of Mt. Logan are being analysed for their acid content (principally nitric and sulfuric acids). The source of these acids is being determined.

(k) Glacier Hazards (G. Holdsworth)

The monitoring of surging glaciers which flow into the Alsek River valley is being continued only as potentially hazardous conditions may arise.

3. Energy, Mines and Resources Canada, Polar Continental Shelf Project
(R.M. Koerner, D.A. Fisher, B.T. Alt, M. Parnandi and J.C. Bourgeois)

(a) Laboratory Investigations

Further work was done using the Reeh ice sheet model to compute a 3-dimensional Laurentide Ice Sheet using known marginal positions. The work has been accepted for publication. Analysis of all data on the unique properties of Pleistocene ice and its rheological implications was completed and submitted for publication. In cooperation with AES (L. Barrie) variations of acid levels in High Arctic snows were analyzed and the work published. Pollen analysis of one of the Agassiz Ice Cap cores has been completed and accepted for publication. Pollen analysis of 50 one-litre samples collected at over 110 m depth from an old bore hole are being analyzed. Mass balance results from four ice caps were studied. A new method for obtaining and using such measurements for climatic monitoring purposes was given at an international conference. In cooperation with S. Edlund (GSC) the relationship between summer climate and vegetation patterns in the High Arctic was studied. Work on the summer climate in the Queen Elizabeth Islands during the Franklin Period (as deduced from ice cores) and the part it played in the demise of the Franklin Expedition was submitted for publication.

(b) Field Investigations

The mass balances of Meighen, Melville, Devon (northwest side) and Agassiz (northern side) ice caps were measured. Boreholes drilled on Agassiz Ice Cap were monitored for closure rates and bulk samples from one hole were melted from seven separate depths of over 110 m. A suite of snow/firn samples was collected for chemistry studies from the same site. Levelling traverses were made over Meighen Ice Cap and across Sverdrup Glacier (Devon Island) to check for advance or retreat of these glaciers.

4. University of British Columbia, Department of Geophysics and Astronomy

(a) Glacier Studies, Yukon Territory (G.K.C. Clarke, F.H.M. Jones, J. Schmok and M.G. Maxwell)

Trapridge Glacier last surged around 1945 and its next surge is expected to occur within several years. The aims of our field study are to determine the cause and mechanics of surging. In 1985 we resurveyed the glacier, drilled four holes to the bed, installed a water pressure sensor in the one hole that connected to the subglacial drainage system, injected 25 kg Rhodamine WT into the connected hole, failed to detect any dye in Trapridge Creek, tested a new digitally-recording impulse radar, measured ice flow fluctuations using a computer-controlled laser ranger, and analyzed the "slurry till" layer exposed in the lower part of Trapridge basin.

(b) Ice-Dammed Lakes, Yukon Territory (J. Schmok and G.K.C. Clarke)

In 1984 and 1985, J. Schmok visited 23 small lakes and ponds situated within the basin of former glacier-dammed Lake Alsek. Cores from these lakes contain a record of past fillings and outburst floods from Lake Alsek. From the sedimentology of these cores, three distinct environments can be recognized: (i) Lake Alsek phase (varved silts and clays); (ii) Lake Alsek flood deposits (sands and gravels); (iii) Normal (organic horizons). This sequence is repeated many times within a single core.

(c) Radio Echo Sounding, Yukon Territory (F.H.M. Jones, B.B. Narod and G.K.C. Clarke)

F.H.M. Jones tested a prototype of a new impulse radar system on Trapridge Glacier in 1985. The system is fully back-portable and records sounding results on digital cassettes. A complete and reliable system will be ready for use in 1986.

(d) Isotope Glaciology (M.G. Maxwell, R.D. Russell and G.K.C. Clarke)

M.G. Maxwell is studying the processes of ice accretion and debris entrainment at the base of glaciers. The work involves analyses of water quality, crystal fabric, debris properties and isotopic fractionation of D/H and $^{18}O/^{16}O$ for 600 ice samples taken from the Backe and Trapridge Glaciers, Y.T. Maxwell's measurements enable various ice types to be distinguished and suggest that water flux through permeable substrate leads to ice and debris accretion at the bed.

5. K.E. Ricker Ltd. et al.

(a) Wedgemount Lake and Glacier Studies (K.E. Ricker of K.E. Ricker Ltd. and W.A. Tupper of B.C.I.T.)

The lower glacier was rephotographed (phototheodolite-stereos) at the end of the melt season in September 1985. This provided data on: surface velocities across two lines of monuments, the position and the height of the terminus and the amount of net ablation on the glacier. Lichenometric data on the moraines about the lake were compared to growth curves of a nearby Northern Cascades site (Mt. Shuksan), and the dates for the climax and inset subclimax moraines of Wedgemount Glacier compare quite favourably to dendrochronologic data reported previously in the Canadian Alpine Journal.

(b) Fyles Glacier and Age Lake Jökulhlaup (K.E. Ricker of K.E. Ricker Ltd.; J. Desloges, Department of Geography, U.B.C.; R. Gilbert, Department of Geography, Queens University; British Colombia Forest Service; and the Geological Survey of Canada)

The first technical report on this damaging jökulhlaup was released by the GSC as Open File 1139. Since this release, the following studies have been undertaken: historic glacier fluctuations in the area, radiocarbon dating of Neoglacial glacier advances, lake bottom seismic profiling and varve studies, lichenometry of annual (?) moraines located between the Fyles Glacier margin and its climax position, and monitoring the rate of refill of the lake after the October 20, 1984 drainage event. The lake was refilled, reaching full pool level on August 2, 1985 and has not redrained as of December 10, 1985. However, it is expected to release a jökulhlaup under the thin lobate Fyles Glacier snout next autumn or at least before 1989. A pressure sensor has been deployed to monitor the rate of drainage. Engineering studies are underway to find a best method of ameliorating the damaging consequences of future floods.

6. University of Ottawa, Department of Geography

(a) Holocene Palaeohydrology of St. Elias Mountains (P.G. Johnson)

The causes of variations in hydrological regimes of glacierized basins such as glaciological changes, glacier surges, ice dammed lake draining and the effects of climatological conditions projected back through the Holocene indicate very variable hydrological conditions spatially and over different time scales in the Holocene. Prediction of the future hydrological trends is therefore very uncertain even with greater accuracy in the prediction of climatic change.

(b) Rock Glacier Formation, Dalton Range, Kluane Ranges (P.G. Johnson)

Mass movement forms in the Dalton Range produced as a result of total debris cover development on glaciers emerging from the mountain front have been modified by a number of processes. The common cause of modification is the hydrological systems of the landforms. Surface debris flows and water outbursts from overtopping of the capacity of the subsurface drainage systems have caused reactivation of flow of the forms and collapse of sections of the termini. Stability of these Alpine environments is primarily a function of the hydrological conditions.

(c) Holocene Glacial History of Ruby Range and Dalton Range (D. Lacasse and P.G. Johnson)

Rock glaciers, cirque moraines, and valley moraines in the Ruby Range and Dalton Range demonstrate a number of periods of glacial activity in the Late Pleistocene and the

Holocene. Analyses of soil characteristics, lichen development, vegetation colonisation and weathering rind development are being used to establish relative ages for the sites. Absolute age determination may be possible from organic deposits at some of the sites.

7. University of Waterloo, Department of Geography

(a) Sediment Budget Studies at Boundary Glacier, Mt. Athabasca, Rocky Mountains (J. Gardner)

The glaciological aspects of this research include: bergschrund microclimate studies; glacier surface velocities; meteorology, ablation and meltwater discharge relationships; sediment yield from the glacier. A Neoglacial advance of Boundary Glacier prior to 4000 years BP is indicated. The glacier has followed the usual pattern of fluctuations since the Neoglacial maximum with the exception of a minor readvance 1965-1972 possibly reflecting positive mass conditions in the previous decade.

(b) Hydrological Conditions of Rock Glaciers, Mt. Athabasca (J. Gardner)

The primary objective of this study is to describe the meltwater discharge and quality conditions.

(c) Surveys of Glaciers, Nanga Parbat Region, Upper Indus Basin, Pakistan (J. Gardner)

Rakhiot Glacier terminus is 150-200 m up valley from its 1934 position indicating a 300-400 m advance since Pillewizer's survey in 1954. Current steady state mass balance conditions are indicated.

(d) Avalanche Hazard and Avalanche Snow Hydrology, Koghan Valley, Pakistan (F. de Scally)

This research has focussed so far on a survey to establish a base for study of altitudinal redistribution of water by avalanching.

8. Wilfred Laurier University, Department of Geography

Upper Indus Basin Study (K. Hewitt)

A glaciology and water resources study is being coordinated by Wilfred Laurier University.

9. University of Alaska, Geophysical Institute and University of Calgary, Department of Physics

Glaciological Studies on the North Coast of Ellesmere Island (M.O. Jeffries and H.R. Krouse)

In April and May 1985, fieldwork was undertaken on the north coast of Ellesmere Island involving sea ice coring and stratified lake sampling. Ice cores were drilled in adjacent ridges and troughs in multiyear landfast sea ice at the front of Ward Hunt Ice Shelf and Milne Ice Shelf and also in Ayles Fiord. Ice salinity has been measured and oxygen-18 and tritium analyses are also being undertaken to study the processes of the thermodynamic sea ice growth and ice shelf regeneration in this region. Stratified Lake "C" was found to have remained stratified since it was last investigated in 1969. In addition, a second stratified lake was discovered 3 km south of Lake "C". Isotopic investigations (^{18}O, D, ^{34}S, ^{13}C, ^{3}H, ^{14}C) of these lakes are in progress in an attempt to assess their paleoclimatological significance and study microbiological sulphate reduction and oxidation of organic matter at high latitudes.

10. Trent University, Department of Geography

Axel Heiberg Studies (W.P. Adams)

Mass balance measurements were completed for the White Glacier, Axel Heiberg Island, N.W.T. during the spring of 1985. The McGill Station, near the glacier, was refurbished (see Adams, W.P. 1985, The McGill Station on Axel Heiberg Island, N.W.T. Canada, Polar Record, 431-433).

11. University of Minnesota

Barnes Ice Cap Project (R. LeB. Hooke, Geology/Geophysics and G.W. Johnson, CE, University of Minnesota)

Measurements of mass balance, surface velocity and surface elevation were made along a 10.2 km flowline on Barnes Ice Cap, Baffin Island, Canada, on a number of occasions between 1970 and 1984. During this time period the average specific net balance was -0.19 m/a. As a result of this negative balance and despite a slightly compressive mean transverse strain, the glacier thinned at a rate of ~ 0.12 m/a. Transverse compression can account for only part of the discrepancy between these two figures. The rest is attributed to errors in mass balance. In particular "internal" accumulation (increases in density of old firn and freezing of water in crevasses) could not be evaluated adequately from our measurements. The thinning was not uniform. Near the margin the glacier thinned ~ 5 m and near the divide, ~ 2.5 m, but between 3.5 and 5.5 km from the divide there seems to have been no substantial change in thickness. The decrease in thickness was thus accompanied by an increase in slope along the down-glacier half of the flowline. Within 4 km of the margin the decrease in thickness resulted in a decrease in horizontal velocity of up to ~ 10%, despite the increase in slope. However, higher on the glacier the horizontal velocity increased as much as 4%. Vertical velocities appear to have been lower (less upward or more downward), during the last half of the study, than they were in 1970. However the uncertainties in the measurements are such that no other significant trends in these velocities are apparent. As a result of escalating costs and diminishing returns, this 14-year study of the dynamics of Barnes Ice Cap has now been terminated. We hope and expect, however, that the data obtained will be used in a number of publications during the next few years, and will willingly share the data available with other researchers.

12. University of Calgary, Department of Geography

Rock Glacier Study (W. Blumstengel and S.A. Harris)

An active rock glacier beneath a forest cover and situated 6 km above the lake along the right bank of the Slims River has been instrumented and surveyed in 1984 and 1985. Preliminary data on rates of movement suggest up to 10 cm per year along part of the front with considerable variation across the body of the mass. It has a core of rock fragments imbedded in interstitial ice. Studies of soil moisture distribution and movement commenced on a regular basis in August 1985. The ice (and water from the springs at the front of the landform) is being sampled for chemical analyses, including O^{16}/O^{18}. These results will be compared with the results from the snow, rain, and nearby groundwaters, in an attempt to determine the probable origin of the interstitial ice. The temperature regime of the surface 1.5 m is being monitored at 15 sites.

13. Université de Sherbrooke, Département de géographie

Glaciers Actuels (A. Champoux et C.S.L. Ommanney)

Une étude du comportement historique et actuelle des glaciers a été effectué à base de photo-interprétation de diverses couvertures de photographies aériennes.

14. Bibliography

Alt, B.T. 1985. 1550-1620: a period of summer accumulation in the Queen Elizabeth Islands. In: Climatic Change in Canada 5: Critical Periods in the Quaternary Climatic History of Northern North America, C.J. Harrington (Editor), Syllogeus, 55, 461-479.

Barrie, L.A., Fisher, D.A. and Koerner, R.M. 1985. Twentieth century trends in Arctic air pollution revealed by conductivity and acidity observations in the Canadian High Arctic. Atmospheric Environment, 19(12), 2055-2063.

Binda, G., Johnson, P.G. and Power, J.M. 1985. Glacier control of suspended-sediment and solute loads in a rocky mountain basin. Proc. Can. Hydrol. Symp., 1984, Quebec City.

Bourgeois, J.C., Koerner, R.M. and Alt, B.T. 1985. Airborne pollen: a unique air mass tracer, its influx to the Canadian High Arctic. Annals Glaciology, 7, 109-116.

Fisher, D.A. and Alt, B.T. 1985. A global oxygen isotope model - semi-empirical, zonally averaged. Annals Glaciology, 7, 117-124.

Fisher, D.A., Reeh, N. and Clausen, H.B. 1985. Stratigraphic noise in time series derived from ice cores. Annals Glaciology, 7, 77-83.

Jeffries, M.O. 1984a. Milne Glacier, Ellesmere Island, N.W.T.: a surging glacer? J. Glaciology, 30, 251-253.

Jeffries, M.O. 1984b. Specific electrolytic conductivity-salinity, oxgen-18 and tritium variations in the Ward Hunt and Milne Ice Shelves: a study of their origin, structure and behaviour. DREP Contractors Report Series 84-42, 91 pp.

Jeffries, M.O. 1985a. Physical, chemical and isotopic investigations of Ward Hunt Ice Shelf and Milne Ice Shelf, Ellesmere Island, N.W.T. Ph.D. thesis, University of Calgary, Calgary, 310 pp.

Jeffries, M.O. 1985b. Ice shelf studies off northern Ellesmere Island, Spring 1983. Arctic, 38, 174-177.

Jeffries, M.O., Krouse, H.R., Shakur, M.A. and Harris, S.A. 1984. Isotope geochemistry of stratified Lake "A", Ellesmere Island, N.W.T. Can. J. Earth Sci., 21, 1008-1017.

Jeffries, M.O., Krouse, H.R., Shakur, M.A. and Harris, S.A. 1985. Stratified lakes and paleo-environmental change, northern Ellesmere Island. A reply. Can. J. Earth Sci., 22, 648-649.

Johnson, P.G. 1985. Implications of Holocene palaeoclimatic changes for the glacier hydrology of the southwest Yukon. Zeitschrift für Gletschekunde und Glaciolgeologie, 21, 165-174.

Johnson, P.G. and Power, J. 1985. Flood and landslide events, Peyto Glacier terminus, Alberta, Canada, 11-14 July 1983. J. Glaciology, 31, 86-91.

Jones, D.P., Ricker, K.E., Desloges, J.R. and Maxwell, M. 1985. Glacier outburst flood on the Noeick River: the draining of Ape Lake, British Columbia, October 20, 1984. Geol. Surv. Can., Open File Report No. 1139, 81 pp.

Koerner, R.M. 1985. Canadian Arctic Islands: glacier mass balance and global sea level. In: Glaciers, Ice Sheets, and Sea Level: Effect of a CO_2 - Induced Climatic Change. Report of a Workshop, Seattle, Washington, September 13-15, 1984, 145-154.

Koerner, R.M. and Fisher, D.A. 1985. The Devon Island ice core and the glacial record. In: Quaternary Environments, J.T. Andrews (Editor), Allen and Unwin, Boston, 309-327.

Ricker, K.E. 1985. Ape Lake is indeed a beast - the 20 October 1984 jökulhlaup. Can. Alp. J., 68, 41-43.

Tupper, W.A., Ricker, K.E. and McKnight, B. 1985. Wedgemount Lake and Glacier, Northern Garibaldi Park: 1984 progress report. Can. Alp. J., 68, 41.

IX HYDROLOGY

Compiled by: E.M. Nicolson

1. Introduction

This report is a compilation of activities on hydrology for the period July 31, 1984 to July 31, 1985. It covers both the research and operational aspects but does not include glacier studies - this being the subject of a separate chapter in this bulletin. Hydrometeorology activities are also addressed separately.

The attention of the water resources community is still focused on acid rain and the seepage of toxic chemicals from dumps - the latter causing continuing grave concern, particularly in the Niagara River. While improvement in the phosphorus situation in the Great Lakes has been noted, the issue of toxic chemical pollution from industry and landfill sites and the unknown effects of intermixing is likely to share the top spot on the list of Canadian water resources concerns for some time to come.

Recent studies undertaken at our National Water Research Institute in another water quality related area - sources of Legionella - have shown for the first time that the organism is very much more widespread in Canada than had been previously reported. Widespread distribution has previously been reported in countries with more moderate climates than Canada's.

This year (1984/85) has seen very severe drought in the Canadian Prairies. The average river flows in southern Saskatchewan have been less than those experienced during the worst of the depression years of the early 1930's.

The National Research Council's Associate Committee on Hydrology (ACH) brings together hydrology researchers and managers from federal and provincial governments, universities and technical societies to advise on research priorities and on the application of hydrologic knowledge to Canadian water management. The Committee functions under three administrative subcommittees ("International Affairs", "Research Priorities" and "Dissemination of Knowledge") which focus on these main areas of ACH concern and two technical subcommittees on specialized areas of hydrology ("Glaciers" and "Hydraulics of Ice Covered Rivers").

The 1984/85 National Lecture Tour, cosponsored by the Canadian Society for Civil Engineering, was conducted by R.E. Jackson who spoke on the topic - Ground-Water Pollution and Remediation. A major project of ACH, the preparation of a Design Flood Guide is nearing completion and is scheduled for publication in 1986. The Committee made a submission to the Federal Water Inquiry and will now respond to the final report.

The ACH also acts as the Canadian National Committee for the Unesco International Hydrological Program (IHP) and for the International Association of Hydrological Sciences (IAHS). In November, Canada was one of 15 countries elected to serve on the IHP Intergovernmental Council for a four year term. The newly elected Chairman of ACH, D.L. MacLeod of the Saskatchewan Water Corporation, will represent Canada. The ACH will take the lead role in organizing five symposia and eight workshops for the IAHS/IUGG General Assembly to be held in Vancouver in August 1987.

2. Federal Government Departments

The final report of the 18 month, $1.5 million Inquiry on Federal Water Policy was released on September 30, 1985. It is the first comprehensive assessment of the federal government's role in managing Canada's water resources. The 222-page report - Currents of Change, documents the extent and distribution of freshwater resources in Canada, examines the growing demands on supplies and trends in pollution, and assesses the adequacy of federal water policies and programs. The three authors, appointed in January, 1984, make 56 major recommendations and numerous additional suggestions for improving the government's capability to protect and manage Canada's water resources in the face of emerging pressures. The findings of the report are based on extensive public hearings held in all provinces and territories, a series of expert research studies, and consultations with provincial and federal government agencies.

The theme of the report is the urgent need to clarify the federal role in water resource management in Canada, which has evolved in piecemeal fashion over the last century in response to particular problems and now consists of a variety of programs dispersed among more than a dozen departments and agencies. The recommendations aim at providing a more coherent policy and administrative framework, and at redirecting priorities toward present and future needs and opportunities.

The report finds that Canadians are extraordinarily well endowed with water resources by international comparisons, and the quality of most rivers and lakes remains high. Nevertheless, the demands of industry, agriculture and communities are approaching the limits of natural supplies in some regions notably the southern prairies. Serious pollution is evident in numerous waterways, typically near centres of industry and population where its effects are more severe. Encouraging progress has recently been made in reducing certain conventional types of industrial and municipal pollution, but effective means of controlling insidious new forms, such as toxic and persistent substances, and non-point pollution and acid rain, have yet to be implemented. The authors suggest that the abundance of water in Canada has led many Canadians to take it for granted, and that present management policies are inadequate to cope with new and rapidly developing problems, let alone anticipate them.

The report sets out several basic principles for reorienting and strengthening federal water policy. Among other things, individual watersheds provide the most appropriate units for resource management under integrated use plans; users should be made to recognize the value of the water they use by assuming the cost of providing it; water projects should be subjected to more systematic evaluation of their economic and environmental implications, including risks; and orderly provisions should be made for public participation in major management decisions. In defining the federal role in water management, the report recognizes the broad consitutional authority of the provinces, and suggests that federal programs, such as those relating to flood control and agriculture, should focus clearly on federal responsibilities and on cooperative agreements with provinces and territories. In view of the overlapping responsibilities of governments, and the need to coordinate and strengthen their management efforts, the authors recommend a National Water Conservation Program, which would enable the federal government to initiate a variety of needed programs in which the provinces and territories could participate flexibly but under consistent cost-sharing arrangements.

To adapt to new needs, the report proposes amendment of the Environmental Contaminants Act to shift the responsibility for registering toxic substances from the government to those who introduce them for sale or use in Canada; and changes to the Fisheries Act to enable integrated resource management according to the circumstances and opportunities of individual watersheds. Review of certain features of legislation dealing with navigation and agriculture is also recommended. To deal with a growing number of conflicting demands on waterways that cross or straddle the boundaries between provinces and territories, the report recommends novel changes to the Canada Water Act to provide means of resolving interjurisdictional disputes.

Because so many of Canada's waterways are shared with the United States, the authors examine in some detail the law, treaties and working arrangements governing international interests. They conclude that the existing federal structures are generally adequate, but that the International Joint Commission needs stronger support.

The authors consider it important to clarify federal policy on the controversial issue of water exports. They emphasize a need to distinguish between small-scale exports by tankers and local transborder piping systems (of which we have several longstanding examples) and massive overland diversions of Canadian water to the United States. The latter raises profound environmental, economic and strategic questions, and the authors recommend that such proposals be considered only if an explicit political decision is made to entertain them, and then only after special provisions are introduced for evaluating and adjudicating them.

With reference to the wide variety of federal water-related programs, the report recommends urgent attention to certain pressing needs. One is improved control of toxic substances through "cradle-to-the-grave" regulation and close coordination among regulatory agencies. Another is the massive requirement for improvement and rehabilitation of Canada's aging infrastructure of municipal water supply and waste treatment systems. A third priority is the development of more effective water management arrangements for the northern territories. A fourth is the strengthening and upgrading of water administration in Environment Canada and the coordination of its activities with other federal departments.

The report urges that steps be taken to stimulate public awareness of water resources and to develop channels for public participation in water policy decisions. Provisions for public hearings on all major projects are recommended, as is a vigorous program of public information on water management problems. To provide the government with continuing external advice on water and other environmental issues, a new environmental council is proposed which would have among its responsibilities the periodic preparation of a report on the state of the Canadian environment.

The authors report a widespread and growing public concern about the conservation of Canada's water resources, and particularly about the protection of water quality. They urge the government to invite the provinces and territories to join in the proposed cooperative arrangements to ensure safe, sufficient and sustainable water supplies for future Canadians. Copies of the report can be obtained from the Enquiry Centre, Environment Canada, Ottawa, Ontario, K1A 0H3 (819-997-2800).

Many federal departments have been involved in water management activities, during the past year. Some of the more important are Environment Canada, Fisheries and Oceans, Agriculture (PFRA), Regional and Industrial Expansion, Indian and Northern Affairs, Transport, National Health and Welfare, External Affairs, Public Works and Energy, Mines and Resources. Space limitations do not permit comprehensive reporting of all water-related work undertaken during the past year by these departments.

(a) Environment Canada

The principal department from the freshwater point of view is Environment Canada. The Conservation and Protection Service's Inland Waters Directorate (IWD) conducts its day to day programs under the Canada Water Act and the International River Improvements Act. It has a headquarters office at Ottawa and regional offices at Vancouver, Regina, Burlington, Quebec City and Dartmouth. IWD's role involves the development, planning for, and participation in national and international river basin programs, including a national flood damage reduction program. It conducts special water quality investigations; research on water quality, quantity and socio-economic aspects of freshwater resources and its useage; and maintains inventories relating to the quantity and quality of surface and ground waters. Much of IWD's hydrologic work is carried out at its two national research institutes - the National Hydrology Research Institute (NHRI) and the National Water Research Institute (NWRI), and in its three operational branches; the Water Resources Branch, the Water Quality Branch and the Water Planning and Management Branch.

The National Hydrology Research Institute (NHRI) is scheduled to be relocated to Saskatoon, Saskatchewan in April 1986 where it will be the principal tenant in the new National Hydrology Research Centre (NHRC).

NHRI is a national research facility specializing in research related to rivers and streams, snow and ice, and underground water. For the period of interest to this report it was made up of two research divisions; Surface Water and Ground Water. Since that time, reorganization of DOE's research institutes has resulted in the addition of a Limnological Research Division.

The Surface Water Division investigates watershed processes, in particular those that characterize elements of the hydrologic cycle other than the ground water regime, and develops and tests precipitation-runoff models. Hydrologic processes in alpine, prairie and permafrost environments are of particular interest. Studies of these processes include those on the interaction between Arctic streams and permafrost, on lake dynamics and flooding in the Mackenzie Delta and an interrelated group of studies on freeze up, breakup, ice jamming, and other fluvial processes in the Liard and Mackenzie Rivers and the Mackenzie River delta. Modelling activities include the design of statistical streamflow forecasting models with and without climatic forecasting ability, the analysis of the sampling, time-dependent and distribution properties of rainfall-runoff models; the development of a drainage model for the Mannes-Domain drains in Manitoba; the development of a physically based model of water flow in snow-covered terrain; the sensitivity analysis of a passive microwave snow cover model to a range of snow cover and soil moisture conditions and the operational testing of a modified UBC precipitation-runoff model that accounts for contributions of meltwater from glacierized areas. This division also conducts remote sensing studies including the application of gamma ray, radar and passive microwave to the measurement and observation of snowpack water equivalent, the use of aerial photography for surface water velocity measurements in rivers with moving ice and the application of conductivity and time domain reflectometry to ice thickness and soil moisture measurement. The division is also responsible for the Agricultural Land Drainage Research project which is being carried out cooperatively with the Ground Water Division. The major long-term objective is to gain an understanding of the hydrologic effects of both surface and subsurface modifications to drainage in agricultural areas. Other studies in agricultural areas include the effects of snow management practices on surface and ground water supplies and the contribution of sloughs and potholes to ground water recharge and salinization.

In snow and glacier environments the Surface Water Division studies movement of water through mountain snowpacks and evaluates mass, energy and water balances for selected glaciers in the Cordillera. In addition, it is responsible for the long-term undertaking to prepare a complete inventory of Canadian glaciers. A special study in support of the Canadian Climate Program involving glacier ice coring near Mount Logan, Canada's highest mountain, is yielding information on past climatic changes and on levels of atmospheric contamination. The Canadian Glacier Inventory project was recently reviewed to establish the nature and extent of the work to be done and the resources available to carry it out. On the basis of the review, a deadline date of 1992 was set for completion of the inventory. Subsequently, more manpower became availble to work on the inventory on a short-term basis and the deadline date has been advanced to September 1990. Reviews were also initiated of the division's snow and ice property and mass balance studies.

Resignation of the two key scientists in the snow and ice properties project led to a decision to terminate NHRI activities in this area and the review has been left in a preliminary draft form. The mass balance review is in an intermediate draft form but enough information has been obtained to suggest that mass balance studies at the major field site - Peyto Glacier - should be temporarily suspended to allow full time to be given to data analysis and determination of the value and significance of this particular mass-balance study. This suspension took effect in FY 1985-86 and will continue until analysis and appraisal have been completed. Related field studies in central and northern British Columbia that are furnishing knowledge that will be required for assessing the contribution of glacier melt to stream runoff in basins proposed for hydroelectric power are also under consideration.

The Ground Water Division is very heavily involved in studies of contaminant transport in subsurface waters and the geochemical controls that influence this transport. Major investigations are under way in the Niagara area, where subsurface migration of toxic contaminants from chemical dumps is a serious hazard to Canada's boundary waters, and at the Gloucester site (near Ottawa) where toxic materials seeping from a federal waste disposal facility are threatening the contamination of nearby aquifers. Contaminant transport studies have been conducted at a number of other sites and have included tracer investigations at Chalk River, Ontario; arsenic contamination at various locations in Nova Scotia, New Brunswick and Ontario; and pesticide contamination near Osoyoos, British Columbia. A major research project sponsored by Atomic Energy of Canada Limited is studying the ground water aspects of the underground disposal of nuclear wastes in crystalline rocks. The effect of the ground water/aquifer system in mitigating the adverse effects of acid rain is under investigation, principally at a field site near Sault Ste. Marie. In the North, research is directed towards

ground water discharge and recharge under permafrost conditions; and towards studies of the effect on the ground water regime of engineering structures and developments such as pipelines and roads. A number of studies have been phased out (e.g. mining hydrology) in order to free up resources for the urgent new contaminant related work.

The National Water Research Institute (NWRI) of the Inland Waters Directorate is an environmental research organization at the Canada Centre for Inland Waters (CCIW) in Burlington, Ontario, and is part of Environment Canada. NWRI is involved in research and development and is providing scientific services in the following areas: toxic chemicals; pesticides contamination; acid rain and atmospheric deposition; eutrophication; quality assurance; bacterial, mycological and viral contamination; analytical methodology development; flood control, erosion and wave prediction; reservoirs and diversions; northern research; climatic change; energy related research; national/international collaboration in water sciences; and techniques and instrument calibration for sediment and water flow.

The Environmental Contaminants Division investigates in the field and in the laboratory, the pathways, fate and effects of contaminants such as organic chemicals, toxic metals, organo-metallics and radionuclides.

The Hydraulics Division undertakes research into all aspects of the hydraulics of inland waters, maintains and calibrates current meters and sediment samplers, and develops methods and equipment to measure environmental variables in the field and laboratory.

The Aquatic Ecology Division is involved in problems associated with environmental degradation caused by eutrophication, acidification and infestation by aquatic weeds.

The Aquatic Physics and Systems Division conducts a program of research involving experimental measurements, environmental modelling via numerical simulation, and theoretical studies. This is directed towards the goals of understanding the interrelationship of fluxes of dissolved and suspended materials and water movements due to physical processes such as circulation, turbulent mixing and convection, transmission and scattering of light.

The Analytical Methods Division advances knowledge, establishes and maintains expertise, and provides information on analytical chemistry and microbiology.

Areas of responsibility of the Technical Operations Division include field measurement, sample collection and some basic analyses of physical, chemical and biological parameters and sediments from freshwater systems aboard major research ships, launches, shore-based field parties and diving operations. The Division is also responsible for the preparation, modification, field use and maintenance of a wide variety of mechanical, electronic and hydraulic sampling and data acquisition systems.

In October 1974, the Canada Centre for Inland Waters was designated by the World Health Organization as its Collaborating Centre on Surface and Ground Water Quality (WHO/CC). The main functions of the WHO/CC are the maintenance of an international inventory of key water quality assessment parameters, the coordination of international technical assistance and training programs to developing countries, and representation of Canada's freshwater interests in international forums.

Lack of space in this publication prevents full reporting on a project by project basis of the extensive research being undertaken at the NWRI. For further information contact the office of the Director at 1-416-336-4625 (Burlington, Ontario).

The Water Resources Branch of Environment Canada is composed of two Divisions, namely the Water Survey of Canada Division and the Hydrology Division.

The Water Survey of Canada Division is the agency responsible for the collection of water quantity data from over 3500 active sites in Canada, of which this Division operates in excess of 2650. To oversee such a large network, the Water Resources Branch has eight regional offices and employs more than 300 technicians and engineers to operate the gauging stations and interpret and compile the data. The regional offices at Dartmouth, Longueuil, Guelph, Winnipeg, Regina, Calgary, Yellowknife and Vancouver collect the field data in accordance with national standards, carry out the computations necessary to transform the raw field data into

a format suitable for dissemination and then pass the data to the headquarters unit located in Hull. This unit is responsible for maintaining the water data archives (streamflows, water levels and sediment data) from 3500 active and 3700 discontinued stations in a central national water data bank known as HYDAT. This bank contains over 83 700 station-years of streamflow data, 22 400 station-years of water level data, and 2100 station-years of sediment discharge data. The headquarters unit is also charged with the responsibility of developing manuals of procedures, guidelines, and standards for the field collection and office compilation of the water data. Data are published in an annual series of eight surface water data books, a biennial series of eight historial streamflow and water level summaries, and an annual series containing sediment data.

It has long been recognized that water data are essential to sound water management and that the efficiency of data collection programs is enhanced significantly by combining networks and standardizing methodology. Consequently, in April 1975, uniform cost-sharing Water Quantity Survey Agreements were implemented with all provinces and with the Department of Indian and Northern Affairs for the territories where the Water Survey of Canada conducts the Canada-wide program. These agreements recognize that water quantity data may be collected to meet federal needs, provincial needs, or a combination of needs. Thus funding for the operation of the networks is provided according to each party's needs. The provinces conduct some field surveys, usually on a short-term basis, for preliminary feasibility studies and for water quality purposes. However, in the province of Quebec, Environnement Québec is the principal operator of the gauging network under the federal-provincial cost-sharing agreement. Water quantity data collected by Canada in the province of Quebec are limited to the federal network operated by the Water Survey of Canada regional office in Longueuil. Companies, boards, and commissions, responsible for the operation of hydroelectric plants, the regulation of river flows and water levels, and management of wildlife areas, also collect water data related to the operation of their facilities. Data that are collected to national standards are published and included in the national (HYDAT) data bank. Other data are referenced to identify the source of supply.

In a continuing effort to provide data to meet federal, provincial, and user needs, the Water Survey of Canada is continually reviewing and updating its data collection computation and dissemination procedures to make use of the latest technology. Consequently, the Water Survey of Canada has embarked on an ambitious five-year program of installing 350 satellite data collection platforms (DCPs) at selected sites to improve monitoring and to provide timely data; to date, 140 DCPs have been installed. In support of this program and to improve the procedures used to compute and compile the data, minicomputer systems have been installed at each of the regional offices. These are only two of the many aspects which are being implemented by the Water Survey of Canada to improve services to the Canadian hydrologic community.

The Hydrology Division responsibilities are to analyze and interpret data collected in the nationwide stream-gauging program and to provide advice and consultation to the Water Survey of Canada concerning the evaluation and planning of the hydrometric network. The objectives of the Division are (1) to produce reports that interpret the basic data and provide information to the hydrologic community in a suitable form for planning and design purposes and (2) to improve the effectiveness and efficiency of hydrometric data collection activities through the use of analytical techniques. The analytical techniques include transferring information from gauged sites to ungauged sites, estimating daily streamflows by flow routing or statistical methods, and determining the accuracy of the daily streamflows relative to the measurement frequency and operating budget for the stream-gauging program. These techniques are used to determine the number, type, location, period of record, and operation schedule of stations for economically meeting designed areal coverage and accuracy requirements. During 1984/85, six analytical techniques were developed and implemented. The Hydrology Division at its Ottawa headquarters is primarily responsible for developing analytical techniques and guidelines for evaluating the hydrometric network and for analyzing and interpreting the basic data. This technology is transferred to the eight regional offices through dissemination of procedural manuals, visits to regional offices, and training courses. The headquarters Hydrology Division also provides consultation service as well as carrying out joint studies with the regional offices. In addition, it operates the Canadian HOMS National Reference centre which is part of the World Meteorological Organization program for the organized transfer of hydrological technology among more than 150 countries of the world.

The Water Quality Branch of Environment Canada is responsible for providing ambient water quality data and interpretive information on international, interprovincial and other waters of significant national interest. It operates a monitoring program through its regional offices by collecting samples from some 670 stations across Canada, analyzing these samples in the national laboratory and entering the data in the computerized National Water Quality Data Bank (NAQUADAT). These data are used to define the health of Canada's water resources, delineate areas of pollution, detect emerging pollution problems, identify transboundary movement of pollutants, provide baseline water quality data for environmental assessments of proposed developments, formulate regulations, develop water quality criteria and objectives, develop water pollution abatement programs and evaluate the effectiveness of such abatement programs, and meet the federal government's obligations under applicable legislation, federal-provincial and international agreements and treaties. The National Water Quality Data Bank (NAQUADAT) contains data from some 5000 locations in Canada. It stores the results of environmental analyses and other data about the samples and sampling locations, and produces a large variety of graphical and statistical reports.

The Branch operates a National Water Quality Laboratory at the Canada Centre for Inland Waters, Burlington, Ontario, and also has regional laboratories in Saskatoon, Vancouver, Longueuil and Moncton. These laboratories enable the Branch to meet the heavy demands for water quality analyses, resulting from federal-provincial water quality monitoring agreements, and to respond to the changes required in the analyses of parameters due to the change in emphasis from major ion and eutrophication constituents to toxic chemicals such as dioxins, polynuclear aromatic hydrocarbons, pesticides and heavy metals.

Surface water represents the major class of samples analyzed in these laboratories but other aquatic substrates such as precipitation, sediment, ground water and aquatic organisms are also analyzed. Approximately 50 000 samples are analyzed annually for over 500 000 physical, chemical and biological parameters. In addition to monitoring water quality and making this information available, the Water Quality Branch recommends water quality objectives for Canada. A water quality objective is expressed either as a concentration of a constituent or as a description of the body of water. The Water Quality Branch publication entitled Guidelines for Surface Water Quality contains summaries of important information on the harmful and beneficial effects of various substances on the major uses of water such as irrigation and livestock watering, raw public water supplies, aquatic life and wildlife, and the food industry. The interaction of other water parameters and toxic chemicals and their sediment chemistry is also discussed.

The Water Quality Branch has participated on regional, national and international committees and task forces in setting water quality objectives for the Great Lakes, the Saint John River, the St. Croix River in New Brunswick, the Red River in Manitoba, and the Poplar River in Saskatchewan. The Guidelines for Recreational Water Quality published by Health and Welfare Canada had direct input from the Branch. Interprovincial waters, rivers and lakes in national parks, Indian reserves, and the Territories also receive Water Quality Branch attention. In addition the Branch provides support and representation in international water quality programs of WHO, WMO, UNESCO and ISO.

The Water Planning and Management Branch (Atlantic Region), Water Planning and Management Branch and Water Resources Branch collaborated with the Water Resources Division of the Newfoundland Department of the Environment to produce a Regional Flood Frequency Analysis for the Island of Newfoundland. The report, completed in December 1984, provides a technique for estimating natural instantaneous peak flows at ungauged sites. The technique can also be applied to sites at or near a hydrometric station when the station has less than 10 to 20 years of record. A shorter Users Guide is being prepared.

A hydrology study project was initiated in 1983-84 by the Engineering and Development Division of the Water Planning and Management Branch to develop hydrologic design methodologies for small-scale hydro at ungauged sites. This multi-phased project was financed by the Federal Energy R&D program. The developed methodologies will determine available streamflow and flood magnitude at ungauged sites given basic data readily obtainable from published maps and information sources. Following the Phase I study completed in 1983-84, the Phase-II study was undertaken in 1984-85 to develop refined methodologies applicable for feasibility studies for the Atlantic provinces with the exception of PEI. This study was undertaken by a consultant under supervision of the Atlantic Region of the Water Planning and

Management Branch. A three-volume report - Summary Report, Documentation Report, and Application Manual including a computer model, is now available. While this study focused on small-scale hydro, the developed methodologies have broader applications where the streamflow pattern and flood magnitude are of interest.

Estimates of mean annual runoff (50 per cent of exceedence) and the 95 and 5 per cent values were computed for 25 regions of Canada. The estimates were published in the report of the Federal Inquiry on Water Policy (Pearse Commission).

The Ontario Region of the Water Planning and Management Branch initiated in 1983 a Regional Flood Frequency Analysis study for the province. Both the Index Flood and multi-regression methods are being employed to provide a technique for estimating natural instantaneous peak flows at ungauged locations. The study results will be presented in three volumes. The first volume dealing with the Index Flood method was completed in late 1985.

The Systems Division of the Water Planning and Management Branch completed hydrodynamic modelling studies of the Peace-Athabasca Delta (PAD) for the simulation period of 1960 to 1984. The PAD Implementation Committee used these results to assess the performance of the weirs installed in the Delta in 1976 for the purpose of mitigating the effects of Bennett Dam regulation on Peace River flows. These extensive simulations were performed on the CRAY super computer located at the AES Meteorological Forecasting Centre in Dorval.

A hydrodynamic model was designed and topographic data collected for the Red River (Manitoba) in cooperation with the Manitoba Water Resources Branch.

A joint applied research project with the Saskatchewan Water Corporation commenced in 1984 involving the design of special subroutines for a network flows optimization model for the Qu'Appelle basin. The special subroutines deal with flow routing and gate settings for structures subject to backwater effect.

Implementation of the national Flood Damage Reduction (FDR) Program in cooperation with the provinces and territories continued. The aim of the program is to discourage future flood vulnerable developments in designated areas by having the senior levels of government withhold support for such developments. By July 1985 maps prepared and designations made covered 300 communities in Newfoundland, Nova Scotia, New Brunswick, Quebec, Ontario, Manitoba, Saskatchewan and the Northwest Territories. All maps produced are referenced in Environment Canada's WATDOC system.

The Secretariat of the Canada Committee on Ecological Land Classification has coordinated production of two new maps on the distribution and ecological regions characterizing Canada's wetlands. These have been prepared by the CCELC National Wetland Working Group and are to be printed by June 86 by EMR for inclusion in the National Atlas of Canada. The Lands Directorate of Environment Canada is also completing a series of wetland land use monitoring case studies and a national fact sheet evaluating the rate and extent of wetland loss across Canada.

In the acid precipitation field, Lands Directorate is also finalizing, for publication by July 1986, a national map delineating areas of high, medium and low potential sensitivity of aquatic ecosystems across Canada as influenced by interpretations of the buffering of soil and bedrock in watersheds.

DOE's Conservation and Protection Service also develops regulations for specific industrial waste discharges, administers nutrient controls, regulates production of environmental contaminants and monitors environment aspects of federal facilities and activities.

Its Canadian Wildlife Service carried on activities to preserve endangered waterfowl habitat, research into effects of waterborne and other pollutants on wildlife, and research on aquatic ecology and limnology in national parks.

National Parks Branch, Parks Canada, (DOE) is the lead agency in the Canadian Heritage Rivers System (CHRS), established in January 1984. The Branch plays primarily a coordinating role in this cooperative federal-provincial/territorial program aimed at conserving heritage

rivers of Canadian significance. Rivers are nominated to the System on the basis of their natural, historical or recreational value. Nominations are made by the government agency responsible for management of the river to a Board composed of representatives from each participating government. Rivers designated to the System are managed by the agency originally having jurisdiction according to the conservation objectives of the CHRS. To date six provinces and both territories have agreed to participate in the System; British Columbia, Alberta, Quebec and Prince Edward Island have not yet joined. Parks Canada has direct responsibility for Canadian Heritage Rivers located within National Parks. Five such rivers have so far been nominated to the system.

Activities of the Atmospheric Environment Service (DOE) are reported in the meteorology and atmospheric science chapter.

(b) Agriculture Canada

The Research Branch of Agriculture Canada conducts hydrological research in various locations across Canada. The research stations address problems pertinent to the locations in which they are situated. The Land Resource Research Institute, which has responsibility for the soil and land inventory, works in collaboration with provincial ministries of agriculture and in some instances university departments of soil science in each province.

(i) The Research Stations

Land drainage research for improved agricultural production is undertaken in lower mainland B.C., southern Alberta, Ontario and Quebec. Investigation of plant nutrient movement to drainage water is ongoing in Summerland, B.C., Lethbridge, Alberta and Ottawa. Irrigation requirements for tree fruits is investigated in Summerland, B.C. and Harrow, Ontario while at Lethbridge irrigation for field crop production is the focus. At the various stations in the Canadian prairies research is aimed at improving the agricultural water use efficiency in a semi-arid environment. Studies include water movement in soil, water conservation under reduced tillage, water conservation by snow management, soil salinity evaluation and amelioration methods. Studies to assess and minimize water erosion of soil are a part of soil management projects in many locations.

(ii) Land Resource Research Institute

The soil survey operations include characterization of the soil water conditions under the various climatic and landscape settings in Canada. Survey projects are underway to assess the risk of water erodibility of various soils, and the incidence and occurrence of soil and salinization in the prairie provinces. Research and development is aimed at improving instrumentation and observational methods for characterization of the soil water conditions. An instrument for measurement of soil water content based on time-domain reflectometry has been developed along with improved methods for determination of hydraulic conductivity. Agrometeorology research is concerned with characterizing climate and weather effects on agricultural operations. Precipitation and evapotranspiration stresses are major focuses in models to predict crop responses to changing environmental conditions.

(iii) Northern Forest Research Centre, Edmonton

The microclimate of one, three and five tree-height diameter forest clearings was monitored during winter 84/85. Fourteen sites were instrumented with wind, net radiation (all wave), relative humidity, soil moisture, air and snow temperature sensors. In addition, snow evaporation was monitored for selected time periods by weighing small pans. Preliminary results indicate that evaporation from snow is small as long as wind speed near the ground is low. Most of the incoming energy causes melt -- even in January.

Weather and snow data for Marmot Experimental Watershed (Mount Allan) were in high demand this past year. The data from the four permanent stations that are operated by the Canadian Forestry Service are now available in IBM-PC format suitable for direct entry into Lotus 1,2,3. These data are expected to be available in ASCII-format files at the University of Alberta before the end of 1985.

A computerized version of a procedure to predict annual water yields from harvested or natural forested areas is on-line at the University of Alberta. This program uses a set of climatically similar zones, forest cover type and local precipitation to provide estimates of annual water yields that are generally within 10% of actual. Those who have access to the University of Alberta facilities can use this self-prompting program by typing $RUN VSAS:WRENSS (Basic familiarity with forest hydrology principles is assumed). A compiled version is also available for the IBM-PC.

(iv) Pacific Forest Research Centre, Victoria

Carnation Creek hydrology research involved continuation of subsurface water movement plot study and summer measurements of valley-bottom groundwater levels. Most of the past year has been spent working on a chapter on the importance of forests in the hydrological regime of Canada for the proceedings of the Rawson Symposium on Water. Other study areas included rain-on-snow in the Queen Charlotte Islands, and snow accumulation in forest and clear cuts in interior B.C.

(c) Energy, Mines and Resources Canada

The Geological Survey of Canada is working on a wide range of subjects more or less closely related to hydrology. These include: seismic reflection techniques for locating buried valleys and aquifers, vegetation - snow patch relationship in the high Arctic, permafrost and ground ice mapping, characterization of ground-ice occurrence in permafrost, tree-ring chemistry - flood frequency, permafrost in Arctic beaches, recent sediments in lake basins and tectonic disturbances, hydrologic parameters - stream bed grain size relationships, properties and distribution of permafrost, airborne gamma-ray snow surveys, lake sediment geochemistry, stream sediment geochemistry, groundwater geochemistry, relationship between metal content of surface waters and geological environment, geological characterization of Canadian lakes, Quaternary paleoecological studies of the Great Lakes, failure of natural dams, catastropic flood events in the Cordillera, composition, origin, and diagenesis of gases in lake sediments, isotopic composition of sediments, pore waters and marls as surrogate for palynology, pathways of migration and fixation of uranium in arctic lakes, relationship between dissolved helium in groundwater and major tectonic features, development of groundwater sampling and downhole analytical equipment, and geophysical studies of geothermal energy resources in southwestern British Columbia in cooperation with B.C. Hydro and Earth Physics Branch, EM&R.

Work related to hydrology is undertaken by the Earth Physics Branch in four main areas: geothermics, geothermal energy, permafrost studies, and crustal dynamics studies. The movement of groundwater has a profound effect on the thermal regime of the upper part of the earth's crust, particularly in sedimentary basins, areas of mountainous terrain and oceanic spreading centres and rift zones. Hydrothermal systems driven by volcanic heat are responsible for the deposition of sulphide minerals on the sea floor and the filling of fractures with mineral desposits in continental volcanic zones. Migration of water in sediments exerts a considerable control on the thermal maturation of hydrocarbon material to oil or gas and on the eventual accumulation of fossil fuel deposits.

The exploitation of geothermal energy depends on the production of hot groundwater or steam. The low-temperature geothermal resource (50-150° C) in Canada is very large but tends to be greatest in the areas where oil and gas are also plentiful. Large volumes of water at temperatures up to 20°C in abandoned mines may be exploitable for energy by means of heat pumps. The Branch has let contracts to examine this concept at Springhill, Nova Scotia.

Geothermal studies also seek to improve knowledge of permafrost distribution and the processes on- and offshore that contribute to its presence and its changes with time. The phenomenon of water migration associated with freezing, frozen or thawing soils is a research focus. Field research includes monitoring at a number of test sites along the Norman Wells to Zama Lake pipeline and at sites distributed through permafrost regions in general. Facility and laboratory experiments include contracted studies on soil freezing around a chilled pipeline at Calgary, Alberta, and Caen, France, and fundamental studies of the processes of ice lensing in soil. In a broader sense, the extensively mapped distribution of permafrost seems at least partially related to ground water movement.

In crustal dynamics studies, it is generally recognized that pore fluids play an important mechanical role in various processes, particularly those related to earthquakes. To understand this role better, the Branch has investigated the influence of fluids on the bulk elasticity of rock masses as in the response of fractures and porous media to tidal and coseismic stresses. Currently this investigation is concentrated on extensive borehole monitoring in the Nuclear Fuel Waste Management Program, under exceptionally well controlled conditions at the Underground Research Laboratory near Pinawa, Manitoba.

The Geographical Services Division, Surveys and Mapping Branch has prepared a new map of drainage basins in Canada, at the scale of 1:7 500 000 for inclusion in the 5th Edition of the National Atlas of Canada. The Topographical Survey Division provides technical advice concerning flood plain mapping to Environment Canada as part of the Flood Damage Reduction Program and/or manages flood plain mapping contracts.

3. Newfoundland

The Water Resource Division of the Newfoundland Department of Environment has exclusive responsibility for the management of water resources in the Province of Newfoundland. Some of the programs and activities are outlined as follows.

Hydrological Network. The department is involved in the expansion of hydrometric stations, water quality monitoring stations and climatological stations through cost shared agreements with the federal government in order to improve the existing inadequate data base.

Flood Damage Reduction Program. The hydrotechnical studies for the Placentia and Badger areas have been completed the flood risk maps completed. The studies involved the use of computer models to simulate the hydrologic and hydraulic systems associated with ice blockage flooding at Badger and tidal flooding in Placentia. A regional flood frequency analyses report has been completed for the province.

Regional Hydrological Study. A regional hydrogeological study of the Burin Peninsula has been completed. This includes the availability and use of groundwater resources, identification of groundwater problems and preparation of hydrogeology maps for the study area.

Waterford River Basin Urban Hydrology Study. The five year federal-provincial cost shared study was designed to quantitatively assess the impacts of urbanization on hydrologic characteristics of the Waterford River. Several computer models such as ILLUDAS, SWMM, HSPF, HYMO and HEC II are being used in the analysis of the data.

Hydrologic Impact Studies. Several studies have been initiated to evaluate the impacts of resource development and other activities on water resources and the environment. These include the impacts of sanitary landfills, peat mining, forest cutting and recreational activities.

Flood Forecasting. The Division is in the process of developing and implementing low cost flood forecasting programs for the Exploits River and a few other sites which are prone to ice related flooding during winter months and the spring.

The St. John's Newfoundland office of Acres International Limited undertook flood routing studies as a follow-up to development of a new probable maximum precipitation for south-central Newfoundland. A multi-reservoir balancing model was used for the flood routing to ensure that operating procedures (particularly gate openings) were realistically simulated.

4. New Brunswick

The Water Resources Branch of the New Brunswick Department of the Environment is active in assessing the Province's water resources, in flow and flood forecasting and in encouraging applied research on ice mechanics and ice jam problems. Considerable experience has been gained in the application of remote sensing techniques to snow distribution estimation for use in flood forecasting.

The New Brunswick Subcommittee on River Ice has been established with members from the N.B. Departments of the Environment and Transportation, Environment Canada and the N.B.

Electric Power Commission under the Flood Forecasting Technical Committee. The main goals of the subcommittee are related to the collection of data on river ice and the promotion of ice related research. Several reports depicting historical ice jam events in New Brunswick as well as actual ice thickness measurements on selected rivers have been produced under the direction of the Committee. The second Technical Workshop on Streamflow Forecasting was organized by the Water Resources Branch. The Workshop was held on June 3 and 4, 1985 in Montreal. Attendees from forecast centres and universities across the country gathered to exchange information on flood forecasting techniques, data collection and other aspects of flood forecasting.

The Water Resources Branch was again involved in organizing an airborne monitoring program of snow water equivalent within the Saint John River Basin. The gamma-ray technique was used by an aircraft from the National Weather Service U.S.A., to measure the snow water equivalent within the basin. Ground measurements of the water equivalent were also performed over several calibration lines. Satisfactory comparison between the airborne and the ground truthing data was obtained.

The long-term Nashwaak Experimental Watershed Project located in central New Brunswick is continuing. The project began in 1970 and was designed to determine the impact of certain forest management practices on environmental quality and on the hydrology of the watershed. The management of the project is provided by a Technical Committee which comprises university researchers and government representatives.

Two review reports on regional water resources within the Moncton and the Newcastle-Chatham regions have been published. These reports completed a set of seven regional review reports covering the entire Province. Valuable information relating to water availability and water use, hydrological and hydrogeological information can be found in these reports.

The Water Resources Branch is also actively involved with the Canadian Advisory Committee on Remote Sensing. A study on change-detection within water supply watersheds has been completed under the Technology Enhancement Program. Two demonstrations of remote sensing equipment are now being organized to take place on December 4, 1985 and early 1986.

Snow cover mapping using NOAA satellite imagery was produced by a local New Brunswick firm. The development of the local expertise was undertaken in cooperation with the Atmospheric Environment Service of Environment Canada, the National Weather Service, and the Canada Centre for Remote Sensing. This remote sensing technique is being used operationally for flood forecasting along the Saint John River, N.B.

In an effort to protect water supply watersheds, the Water Resources Branch is again involved with the production of digital maps covering the Five Fingers Brook, Turtle Creek, Loch Lomond, Chamcook, Blanchette Brook and Denis Stream Watersheds. These maps will be produced by the Maritime Resource Management Service (MRMS) by interpreting aerial photos at scale 1:10 000. Various land use characteristics such as property, infrastructure, forest, agriculture, etc. will be identified on these maps. A parallel field study is also underway to identify specific activities within these watersheds such as gas stations, industries, farms, etc. These activities will eventually be placed on the watershed maps.

A groundwater data review report aimed on facilitating the identification of future groundwater network requirements in New Brunswick was completed. A well-log review report as well as a historical media summary report of groundwater contamination were produced. A study aimed at the collection of available information pertaining to international aquifers was also carried out. Such information will be used in future studies of the implication of the various activities on both sides of the U.S./Canadian border on the water quantity and quality aspects of international aquifers. A provincial compilation of water supply chemical analysis is now being carried out. The Water Resources Branch in association with the Nova Scotia Department of the Environment sponsored the Atlantic Water Well convention which was held in Moncton, New Brunswick in early 1985.

The Environmental Services Branch continued its acid rain monitoring program. Three precipitation stations were located in rural areas where the monthly data are analyzed for pH. Also, four stations are located in an urban area forming an event type network. Snowmelt

chemistry analysis was also undertaken to determine the pH concentrations. General water quality monitoring on various rivers and lakes throughout the Province was carried out to determine the background conditions as well as the effects of domestic and industrial effluents. Water quality surveys of inaccessible lakes (helicopter survey) were carried out; 23 lakes in the summer of 1984 and 31 lakes in the summer of 1985. A study of bog vegetation was also carried out at 14 sites in order to determine trace metal concentrations. Water quality measurements were also carried out within the snow pack and river runoff on the Northwest Oromocto River basin in order to determine the interconnecting relationship.

The University of New Brunswick's Department of Civil Engineering has been involved in a study related to the estimation of suspended sediment load from sediment rating curves. Modelling of the effects of major changes in an estuary having a large tidal range has been carried out to evaluate the probable redistribution of sediments. Various studies related to river ice processes were undertaken; these include the determination of ice undersurface and channel bottom roughness from measured velocity profiles and the prediction of ice break-up and the associated flood stage.

At the Department of Forest Resources, several researchers are continuing collaborative research in the Nashwaak Experimental Watershed Project. The project, designed to determine the effects of clearcut harvesting on a small headwater stream, commenced in 1970, and was treated experimentally in 1978-1979. Impact and recovery continue to be monitored. Water and energy balance, streamflow regime, snow cover, water chemistry including acidity of precipitation, and throughfall and soil moisture, are being studied. A number of research papers and project reports are available. Several non-university organizations are also involved in the Project.

5. Nova Scotia

The Technical University of Nova Scotia's Centre for Water Resources Studies (CWRS) continued the Halifax Urban Watersheds Program with monetary support and assistance from NSERC, the Technical University, and cooperating government agencies. Four full years of water quality data have been collected. Specific projects regarding groundwater interactions, sodium chloride inputs to lakes, and the effectiveness of measures to control erosion and sedimentation were continued during the past year. A new data logging system designed and manufactured for CWRS was put in place. Lake models (OTTHYMO and CONHYMO) have been applied to the watersheds and microcomputer versions are being adapted for local use. Research on on-site sewage disposal, rainwater cistern systems, and urban runoff continued. Advisory panels on research and education related to these topics and to erosion and sediment control have been active during the past year.

6. Ontario

Carleton University's Geotechnical Science Laboratories which are associated with the Geography Department and the Ottawa-Carleton Geo-Science Centre, has a major co-operative experiment underway in France concerning movements of water and formation of ice around a buried pipeline. Related experiments into the thermodynamics and mechanics of freezing soils are being carried out in the laboratories in Ottawa. Field studies in the Yukon concern moisture migration within the permafrost and within the activity layer, and include consideration of effects of climatic change.

A study has been completed on hydrological conditions in a peat bog. An investigation of the use of the time domain reflectometer to measure water content in magnetic soils is underway.

Hydrological research in the Department of Civil Engineering at Queen's University involves the following projects: real-time flood forecasting for flood damage reduction and for reservoir regulation using stochastic and dynamic models; development of urban runoff models including a micro-computer version (PC-RUM); development of urban design storms; instrumentation, measurement and model development for agricultural drainage; and geophysical frequency analysis. The Department of Geography is developing measurement techniques and instrumentation for the determination of radiation and energy balances for forested sites. Various forms of the combination model for evapotranspiration are being examined.

The Department of Civil Engineering at the University of Toronto has ongoing research activities in the areas of statistical analysis of meteorologic data for use in engineering/decision-making models, the development of analytical probabilistic models for drainage system behaviour, the optimization of real-time reservoir operations, the optimization of irrigation water allocation in multi-reservoir systems, micro-computer applications of hydrologic simulation and optimization models, groundwater contamination and landfill design, and the design of groundwater quality monitoring programs.

Most hydrologic research at Trent University is undertaken in conjunction with the Watershed Ecosystems graduate program offered jointly by the Geography and Biology Departments. Current work has focused on the hydrology and chemistry of small wetland, agricultural and urbanizing catchments, and on hydrological and biological aspects of snow and ice in the Peterborough region, Muskoka-Haliburton, northern Manitoba, Labrador and on Axel Heiberg Island, N.W.T. Research is also being conducted on saturated and unsaturated flow on hillslopes, and on ice jams on the Liard-Mackenzie rivers. Work taking place outside of the graduate program includes the completion of a new worldwide terrestrial hydrographic database, the compilation of a global precipitation database, and a study of the land-surface hydrology and hydrometerology of the Canadian Climate Centre's general circulation climate model.

The Institute for Groundwater Research at the University of Waterloo has been involved in the following areas: flow and hydrogeochemistry of uncontaminated groundwater systems; isotopic studies of the origin and age of groundwater; movement of water, gas and solutes in the unsaturated zone; surface water and groundwater/surface water interactions; measurement and interpretation of contaminant transport parameters; mathematical modeling of groundwater flow or contaminant transport in non-fractured systems; hydrogeological characteristics and modelling of solute transport in fractured porous media; techniques and instrumentation for hydrogeological monitoring; aqueous geochemistry and analytical methods; hydrogeological and hydrochemical studies at landfills and at chemical spill sites; hydrogeological and hydrochemical aspects of radioactive waste disposal; hydrogeology and hydrogeochemistry related to mine wastes; groundwater contamination due to agricultural activities; geophysical studies of contaminated groundwater systems; and aquifer systems analysis, groundwater resources evaluation, permafrost.

The University of Windsor's Great Lakes Institute is currently involved in two major projects on the Great Lakes. The first concerns water quality and the impact of four toxic contaminants, lead, cadmium, PCBs and OCS (octachlorostyrene) on the St. Clair and Detroit rivers and Lake St. Clair. The second concerns water quantity and in particular the effects of possible climatic change on future lake levels and on navigation and hydro-electric power development.

At York University's Department of Geography, hydrological research is currently being undertaken by both graduate students and faculty. Current research interests focus on the biochemistry of stream ecosystems; Arctic land and lake evaporation; and the hydrology of Southern Canadian and Arctic wetlands. Specific research focuses on processes of nitrogen transport and transformation in rivers, and the influence of nutrient dynamics in hydrological source areas on stream water chemistry. A second research project is examining evaporation of water from both land and lake environments in the continuous permafrost region of the Hudson Bay Lowlands; the effects of advection on the latent heat flux and active layer development; and evaluations of instruments suitable for evaporation estimates in cold regions. The final research area involves studies of wetland hydrology, examining the inflow and outflow groundwater of isolated and headwater wetlands; the redistribution of groundwater and soil moisture within a wetlands peat structure; and the evaluation of water balances for several representative wetland types south of the Precambrian Shield.

The departments of geography and biology have carried out experimental work with needle ice forms in paleosols on Mount Kenya, East Africa and its influence on the development and maintenance of soil flora. The Department of Geography was also involved in field experiments into the formation of mud polygons by freeze, thaw, and wetting and drying on Mount Kenya.

The Niagara Falls office of Acres International Limited continued work on two earlier hydrology-related studies for the Government of Canada. A study entitled "Hydrologic Design Methodologies for Small Scale Hydro at Ungauged Sites - Phase II" was carried out for the Inland Waters Directorate of Environment Canada. This study developed hydrologic techniques

for use in feasibility-level assessments of ungauged small hydro sites in New Brunswick, Nova Scotia and Newfoundland. The techniques emphasized the generation of synthetic streamflow data, using parameters based on physiographic data. Further work was carried out on the study of "Water Supply Constraints to Energy Development", also for the Inland Waters Directorate of Environment Canada. Enhancements were made to a Water Use Forecasting Model, which examines the balance between water supply and industrial, agricultural, municipal and energy-related water demands. The model has been used to examine the water supply-demand balance in the Prairie Provinces to the year 2001.

MacLaren Plansearch, (Toronto) a member of the Lavalin Group, has carried out a number of hydrological studies in 1984-85. A flood forecasting study of the Trent-Severn system was completed for Parks Canada. The flood forecasting model, QFORECAST, developed by MacLaren Plansearch was selected after an initial evaluation of several methods of flow forecasting. The model was implemented using real-time data from a network of meteorological stations and snow courses to predict flows for the forthcoming week and expected total flows for the remainder of the spring season.

A snowmelt hydrology study was undertaken for the Ontario Ministry of Natural Resources to evaluate the runoff and infiltration component of snowmelt using the HSP-F and NWS models. Another study carried out for the Ministry involved the establishment of provincial technical guidelines for the selection of hydrologic, hydraulic and ice-jam modelling techniques.

A PMP analysis was conducted for Salmita Mines, N.W.T. to design tailing impoundments. Other tailings studies were carried out for the Winston Lake Mine in Northwestern Ontario and the Deloro Mine north of Belleville to derive flows for design of spillways and other diversion channelization works.

A study was conducted for CP Rail to assess the pre- and post- development flow conditions for the CP Yard in Windsor. A similar study was undertaken for Turtle Creek for the City of Mississauga to assess the effect on peak flows due to upstream embankment storage and the replacement of a collapsed culvert.

Marshall Macklin Monaghan Limited (Don Mills, Ontario), in association with Envirocon Limited, completed Phase 2 of the Elbow River Watershed Study for the City of Calgary. This study was carried out to determine the potential for contamination of the Glenmore Reservoir (one of the city's main sources of raw water) from development and recreational activities occurring both within the City and across the 467 square mile Elbow River Watershed. Extensive water quality sampling was carried out to test for a wide range of pollutants within the reservoir, at major storm sewer outfalls and on the Elbow River. Sampling was augmented by computer simulation to provide estimates of pollutant loading for present and future levels of development under a wide range of environmental conditions. Sediment samples were analyzed to assess the long term build-up of contamination, trend analyses of reservoir water quality were undertaken and a dispersion study was performed to assess the rates at which plumes of contamination are dispersed and diluted. Land use activities on the watershed were identified and assessed, recreational and related maintenance activities on lands adjacent to the reservoir were evaluated with regard to their potential to contaminate the water supply. Finally, a review of water supply management in other areas of North America was conducted to provide a perspective in which to assess the Elbow River situation.

7. Prairies

The federal Departmental of Agriculture's Prairie Farm Rehabilitation Administration's involvement in hydrology and hydrology-related activities covers a broad spectrum including the conception, planning, construction and operation of water resource projects and such hydrology activities as pertain to soil conservation and reclamation. Hydrology components of environmental impact assessments are included in studies associated with planning and development of water resource projects. Activities pertaining to surface and subsurface hydrology are primarily restricted to the three prairie provinces, although, due to PFRA's expertise, special studies have been done for agencies in other areas of Canada and for developing nations. PFRA also conducts a modest amount of hydrology-related research for the express purpose of furthering the cause of practical activities in the fields of water development and soil conservation and reclamation.

Surface water development projects range from small projects serving farming units to community projects (including town water supplies) to major water use projects involving dams on major streams and extensive water distribution systems. Hydrology studies for both water supply and flood potential involve state-of-the-art technology as well as innovative analytical techniques for data-sparse areas. Due to human intervention over time in the natural hydrological regime of streamflow (water use, diversion), recorded hydrometric data must first be adjusted to a common base (i.e. natural conditions) so that realistic water supply analyses can be made. "Naturalization" of streamflow records has been done as required to meet the needs of PFRA and other water resource agencies.

An important aspect of the design of earthfill dams is the adequacy of the spillway in handling major floods. PFRA has developed standards for categorizing spillway design floods depending on the height of embankment, the reservoir storage and the hazard (consequences) of dam failure. Standards have been developed for existing and proposed dams, with more stringent standards for new dams. Appropriate spillway design floods (e.g. Probable Maximum Flood for large dams) are determined on the basis of these standards.

Due to the high variability in runoff from year to year and the persistence of low runoff years, the construction of storage projects on small prairie streams often does not provide a reliable water supply for towns or for farms. In the past year, several surface water supply projects supplemented by groundwater have been designed or constructed. Also, water supply systems comprised of a pipeline from either a major reservoir, irrigation canal or reliable stream are being considered more frequently in an effort to provide reliable water supplies.

Since considerable erosion of agricultural lands is caused by rapid snowmelt and/or rainfall runoff, the effects of flood retention reservoirs and changes in agricultural practices have been investigated with regard to mitigation of damages. The effects of such activities on erosion are currently being evaluated from both a practical and a research perspective.

The drought of the last few years has heightened the awareness of the importance of the availability of surface and/or subsurface water supplies for domestic and stockwatering purposes. PFRA has undertaken a "Water Sourcing Study" to document existing used point sources of domestic and stockwatering supplies, and to identify areas deficient in water supply sources. This study has been conducted for Alberta and is currently being conducted for Saskatchewan and southwestern Manitoba, with a somewhat different emphasis.

The following activities that relate to research and/or development of analytical techniques have been undertaken or are continuing.

At the request of the Prairie Provinces Water Board, PFRA continues to delineate drainage areas for Water Survey of Canada hydrometric gauging stations. These drainage areas are published and circulated to concerned provincial and federal water resource agencies.

Due to a lack of runoff data on small streams, PFRA continues to gather runoff data on small streams through its Spring Runoff Monitoring Program. This information enables PFRA and other prairie agencies to provide better analyses for existing and proposed projects located in small drainage basins.

PFRA cooperates with the Atmospheric Environment Service, Water Survey of Canada and the Saskatchewan Water Corporation in gathering and assessing information related to the rainfall-runoff process of intense rainstorms in Saskatchewan.

Field investigation and analysis leading to an understanding of soil salinity (due to natural causes or resulting from irrigation practices) as an aid to developing mitigation proposals is being conducted in Alberta, Saskatchewan and Manitoba.

Research into the runoff processes causing soil erosion is being undertaken by the Soil and Water Conservation Service of PFRA.

Drought monitoring (i.e. monitoring of precipitation, flows in major streams and storage in minor and major reservoirs) was maintained to identify potential areas of shortage in both

soil moisture and surface water supplies. Four periodic reports were published in 1985 and distributed to concerned provincial and federal government agencies.

A data file of spring and summer flood peaks has been prepared as an initial step in conducting a regional flood frequency analysis for the prairie provinces. This study is intended to update a previous study conducted in 1961.

PFRA is developing prairie-wide drought sensitivity models to evaluate both the economic impacts of drought and drought-mitigating measures. These evaluations in turn will be used to formulate policies and programs for short and long-term drought strategies in the use and conservation of water.

8. Manitoba

At the Manitoba Department of Natural Resources a detailed report for Phase 1 of the Canada-Manitoba Agreement Respecting Flood Forecasting reached the final draft stage. Studies continued under Phase 2 of the Agreement. Calibration of the HSPF model on Willow Creek and on Gopher Creek, both tributaries of the Assiniboine River, was well advanced. Difficulties were encountered due to a lack of sufficient physiographic and climatological data and due to the model's inability to simulate the effects of frozen ground on the infiltration of meltwater.

User-friendly routines were developed for the Water Resources Branch's new VAX 11/750 minicomputer, to facilitate the handling of extensive data time series required for calibration of the HSPF model.

The application of the One-Dimensional Dynamic channel routing model to the Red River from Emerson to Winnipeg continued. This work is primarily being done by the Water Planning and Management Branch of Environment Canada in Ottawa, with data and technical assistance provided by the Manitoba Water Resources Branch. The present Agreement will terminate on March 31, 1986. Efforts are underway to have the Agreement extended.

Collection of hydrometeorological data continued in the Domain Drain and Mannes Drain watersheds. These data will be used to determine the effects of drainage improvement and land use changes on the water balance components of a watershed. Drainage works are being installed in the Domain Drain watershed while the adjacent Mannes Drive watershed will be left unchanged so as to provide a "control" watershed for this study. Environment Canada's National Hydrology Research Institute is the lead agency in the experimental design and analysis of this project.

Under the Canada-Manitoba Interim Subsidiary Agreement on Water Development for Regional Economic Expansion and Drought Proofing, exploratory drilling and testing was carried out in eastern Manitoba to define the nature and extent of sandstone aquifers associated with the Winnipeg Formation and to establish their relationship to other bedrock and drift aquifers in the area. Also under this Agreement additional exploratory drilling and pump testing was carried out to establish an adequate data base for modelling studies to establish the water supply capability of the Assinboine Delta Aquifer and the Oak Lake Aquifer.

9. Saskatchewan

At the University of Regina, hydrologic research activities are conducted in the Faculty of Engineering, the Department of Geography, the Energy Research Unit, and the Regina Water Research Institute.

The Faculty of Engineering's Regional Systems Engineering Unit is conducting research on drainage and stream flow simulation and water resource models. Estimation of peak runoff from ungauged catchments, land drainage aspects in Saskatchewan and snowmelt stages are some of the research projects presently under active investigation.

Studies on certain aspects of water resources especially related to climatology and thunderstorms are conducted in the Department of Geography.

The Energy Research Unit has continued work on computer-mathematical modelling of subsurface reservoirs for geothermal energy production. Modelling and study of the regional flow of water in deep sedimentary basins has been taken up.

A research project related to the determination of physico-chemical factors influencing the aerobic and anaerobic microbial degradation of specific organic chemicals in groundwater was carried out by the Regina Water Research Institute.

10. Alberta

The Alberta Department of the Environment's River Forecast Centre (RFC) is continuing its work with the Atmospheric Sciences Department of the Alberta Research Council on the development of weather radar data processing systems for application to streamflow forecasting. A prototype system is now fully operational. Future work will involve refinements to the existing system.

The Centre is working in cooperation with the University of Saskatchewan at Saskatoon on the implementation of the University of Saskatchewan snowmelt infiltration model in the SSARR (Streamflow Synthesis and Reservoir Regulation) hydrologic computer model. The infiltration model is to be tested using data from the Vermilion River, a large watershed in east-central Alberta. Results from the tests will be compared to results from the existing version of SSARR.

The RFC has also begun working in close cooperation with the Atmospheric Environment Service of Environment Canada and the Alberta Remote Sensing Centre of Alberta Environment on the use of NOAA imagery for near-real-time snowcover mapping in the Rocky Mountains. The purpose of this project is to improve water supply and streamflow forecasting capability in Alberta.

A network of real-time weather stations has been developed and is managed by the River Forecast Centre in conjunction with the Survey Branch of Alberta Environment. Most of the stations in the network are telemetered using the GOES satellite system. The rest are telemetered using the telephone system. A large number of streamflow stations are also telemetered by the RFC in cooperation with Water Survey of Canada, Environment Canada.

In 1984-85 six more precipitation and temperature stations equipped with Fischer Porter and data collection platforms were added to the real-time network covering the Eastern Slopes of the Rockies. The hydrometeorological network, which is now complete except for two stations, consists of forty-nine meteorological stations and twenty hydrometric stations. In April 1985 a paper outlining experience gained in operating snow pillows in real-time was presented to the National Research Council's sponsored workshop on Snow Property Measurement at Lake Louise.

As part of the Survey Branch's monitoring program, lake levels were monitored at 223 sites on a regular basis. There were also seventy recording streamflow and water level sites and seventy-seven miscellaneous streamflow sites. Most of the hydrometric work done is related to specific projects. The snow survey network now consists of 126 snow survey sites, fifteen of which are equipped with snow pillows. A historical summary of all snow survey data is available.

The hydrometeorological data network in the Peace-Athabasca Delta which was described in last year's report continued unchanged as did the basin in Spring Creek near Grande Prairie. All continuous streamflow and precipitation data are published through Environment Canada. Other data are available through the Technical Services Division of Alberta Environment.

The River Engineering Branch completed the flood risk mapping studies at Bow River at Cochrane Phase I, West Castle River, Blackmud Creek and revised the Okotoks Floodplain Study for the Sheep River. These studies delineate the flood risk area for the 1 to 100 year flood. Work also continued on aspects of floodplain management on the Elbow River through Calgary. A new method to select the best-fitting probability distribution for flood frequency analyses was developed by the Hydrology Branch. This method uses the multiple-binomial distribution equations. A hydrologic water balance was done for the Marmot Creek Research watershed in order to determine the effect of the land-use changes that have taken place in the basin.

The Hydrogeology Branch of the Earth Sciences Division has developed a groundwater management model to study the impact of long-term groundwater withdrawal by potential industrial water users on the aquifer system near Cold Lake, Alberta. The model incorporates the finite element method into a linear programming procedure. The combined simulation-optimization model permits simultaneous determination of the aquifer hydraulic response and the management decisions in accordance with the objective and constraints placed on groundwater development.

The observation well networks have been steadily expanded from 200 observation wells to approximately 230 wells. Water level and hydrochemical data collected from the network are used for assessment of groundwater resources, feasibility of subsurface fluid injection and effects of in situ process of heavy oil production.

The Branch has also initiated a program of hydrogeological cross-section preparation throughout the southern part of the province. These cross-sections contain information regarding lithology, major aquifers (their expected well yields and hydrochemistry) and the base of groundwater protection. In addition, base of groundwater protection maps have been compiled to supplement these cross-sections as a guideline for surface casing requirements involving oil and gas well drilling.

11. British Columbia

The British Columbia Ministry of Environment continued development of regional peak flow estimating procedures and provided peak flow estimates for ungauged streams for floodplain management and stream crossing design. Assessments of the hydrologic impact of past and proposed developments were made for several community water supply watersheds. Estimates of dependable water supply for various drought durations and return periods were made for irrigation projects. A program to monitor the low flow at a large number of natural streams was completed during the summer drought.

The network of automated snow survey stations using the GOES Data Collection System now totals 11 sites. The purpose of this network is to monitor snow accumulation and snow melt on a daily basis during the winter and spring freshet periods. The collected information which includes snow water equivalent, temperature and precipitation will reduce the requirement for manual readings and improve seasonal and daily runoff forecasting.

The Ministry maintains a network of 145 observation wells to monitor water level and water quality fluctuations in unconsolidated and bedrock aquifers and carries out groundwater investigations related to water supply, water quality, drainage and waste disposal problems.

Simon Fraser University's Department of Geography has been carrying out research during the spring and summer of 1984 and 1985 on the energy and water balance of Plateau Mountain in the Livingstone Mountain Range of southwestern Alberta. Emphasis has been directed toward the measurement of evaporation in high altitude environments. In addition, models of atmospheric and surface control on evaporation have been developed for mountain environments.

Research has been conducted in the arid interior of British Columbia on the conservation of soil water for agricultural purposes using shade and surface modification techniques. Research indicates that the combining of shade deployment with surface modification maintains soil water levels near field capacity without the application of irrigation. These principles have expanded use in other agricultural systems.

The University of Victoria's Department of Geography is conducting studies of the impact of water quality on health. This involves using data from Britain, Canada and the USA to look for links between such illnesses as multiple sclerosis and various substances in drinking water.

The Vancouver office of Acres International Limited carried out work in the following hydrology-related studies in British Columbia during 1984 and 1985.

Kenny Dam Cold Water Release Facility. A feasibility study for the Department of Fisheries and Oceans to examine various concepts for controlled releases of cold water through the Kenny Dam to improve the habitat for migrating salmon in the Nechako River downstream.

Osoyoos Lake Control Structure. Design and construction of a new dam and control structure at Oroville, State of Washington to control lake levels on Osoyoos Lake on southern British Columbia. The study included extensive analyses of flood flow peaks and backwater effects.

Kicking Horse Hydro. A review of a private proposal to develop a hydroelectric facility to supply the village to Field, B.C. and surrounding resort centres.

Small Hydro Design Manual. Acres contributed the financing and economics chapters for a Small Hydro Design Manual to be published by Energy, Mines and Resources Canada to assist potential developers of small hydro plants.

Ocean Falls Power Study. A study to determine the hydro power potential of the existing facilities at Ocean Falls, B.C. including condition assessment, and also to explore possible additional hydro power sources in the vicinity in order to attract potential industrial development.

Peter Ward and Associates Limited of Vancouver, in cooperation with UBC and BC MOE, is working on Ice Control in Lakes by Photovoltaics Powered Water Circulation. Many of the most productive lakes in Canada are hostile to fish species such as trout because of the winter kill problem. During the winter an ice cover seals off the water body from oxygen exchange with the atmosphere and the addition of new water to the lakes by river inflows is small because runoff is small. The lake becomes depleted in oxygen and eventually the fish die from suffocation.

One procedure that has been successfully used in treating these lakes is forced water circulation using airlift pumps. These pumps contribute oxygen directly to the water body, and more important, cause a substantial ice-free patch to be created in the lake through which air exchange with the atmosphere can occur. Because of the inverted temperature gradient in lakes during the winter (0°C water near the surface, 4°C water at significant depths below surface), a pumping system may be used to bring 4°C water to the surface to melt the ice cover. The routine operation of this technique has been well established in British Columbia by Fisheries Research Section, BC Ministry of Environment, using air lift pumps powered by compressors. However finding a suitable and cost effective energy source for the compressors (rated at 1 - 3kW) has been an intractable problem.

Solar energy from photovoltaic panels was considered as a possible energy source, and found to be feasible at latitude 50°N during the winter provided battery storage and a very low energy consumption pump was used.

12. Bibliography

A Canadian hydrology and water resource bibliography is normally published as a special edition of the "Hydrological Events" newsletter compiled by the ACH Secretariat using data supplied by Environment Canada's WATDOC data base. This will not be available for 1984/85 because of the reformatting of the WATDOC bibliographic database.

An update to the 1984 Bibliography will be prepared in 1987 for Volume 39 of the Canadian Geophysical Bulletin, 1986 at which time WATDOC will have the ability to extract the relevant hydrological literature from the AQUAREF database. Online access to AQUAREF is now available on the CAN/OLE system. For more information on WATDOC contact: WATDOC, Inland Waters Directorate, Environment Canada, Ottawa, Ontario K1A 0E7. Telephone (819)997-1238 or 997-2324

X MINING GEOPHYSICS

Compiled by: Stephen W. Reford and Norman R. Paterson

1. Introduction

Twenty-three organizations reported research in mining geophysics in 1985. A further four organizations reported no research in mining geophysics for 1985. A total of twenty-seven responses were received from eighty-eight organizations contacted. The apparent level of effort is distorted by a lack of information from several organizations in both the private and government/university sectors. Total research and development expenditure reported by nineteen organizations for 1985 was $6.33 million, comprising $4.11 million from industry, $1.60 million from government and $0.63 million from universities. Note that the reported levels of expenditure are exclusive of overhead, where applicable. These figures exclude approximately $7.9 million spent on airborne survey work by the Geological Survey of Canada and the Ministère de l'énergie et des ressources du Québec. A corresponding 1789 person-months of research employment was divided among industry with 979 months, government with 552 months and universities with 258 months. Within industry, $3.0 million was spent by two companies - Scintrex and A-Cubed. Since no information was reported by some of the larger companies or by a number of companies supported by the Ontario Government's Exploration Technology Development Fund (ETDF) Program, it is likely that total industrial effort is at least 50% higher than the amount reported. The ETDF support amounts to approximately $1.0 million annually. The

reported level of effort for industry shows an approximate 25% decrease from 1985. Level of effort in the government and university sectors is also understated, no figures being available from the Ontario Geological Survey, and no reports submitted by several of the major universities. However, the government sector shows a marked increase in effort. The Geological Survey of Canada's expenditure for 1985 was $1.5 million, double the 1984 figure. The amount of time devoted to R&D by the G.S.C. also doubled. We also note a $100 000 expenditure by the Ministère de l'énergie et des ressources du Québec, reporting for the first time in recent years. The level of effort in the universities sector has doubled from 1984 to 1985. This can be attributed to the significant contribution of the École Polytechnique to the totals for this sector. Research is underway in all areas of instrumentation, survey methods and interpretation. Those fields of study most often discussed are: airborne and ground electromagnetics, airborne magnetics, downhole geophysics, microcomputer processing and interpretation software and audiomagnetotellurics. A highly successful symposium, on airborne resistivity mapping, was sponsored by the Geological Survey of Canada and held in Ottawa in October 1985.

INDUSTRY

2. A-Cubed Incorporated, Mississauga, Ontario (A.P. Annan, G. Black, J.L. Davis)

The company continued with the design, development, construction and testing of the PROSPECT 1 airborne electromagnetic system (see CGB, 1984). The system is now airborne and in its initial test flying program. The design, development, construction and testing of the EKKO I, II and III radar systems also continued. This work includes the development of digital data processing software as well as field methodology evaluation. A total of one hundred seventy person-months and $1 million in R&D are being devoted annually to these projects.

3. Ager, Berretta and Ellis Incorporated, Vancouver, British Columbia (S. Cirka, G. Paquin)

The company is developing a geosciences data management system for microcomputers. The current software series, written in BASIC and FORTRAN, aid the geophysicist/geologist in entry, manipulation, calculation and plotter display of geophysical and geological data. The applications covered are magnetics, VLF-EM, induced polarization, gravity and geological drill hole plan and section drawing. A facility to plot curved holes and a better user interface are being developed. A total of seven person-months and $25 000 in R&D are being devoted annually to these projects.

4. Dighem Surveys and Processing Incorporated, Mississauga, Ontario (S.J. Kilty, D.C. Fraser, P.W. Strandberg)

Development of the microprocessor-based digital receiver console for the Dighem III/IV helicopter EM system continued. The system was test-flown over the Night Hawk Lake Geophysical Test Range in order to evaluate both system hardware and software. The testing resulted in software modifications to the sferic rejection filter and to the smoothing filters. Hardware modifications were carried out in the nulling section of the signal analyzers. The project will be concluded by April 1986, at which time the hardware will be available for commercial surveys. This project was partially funded by the Ontario Geological Survey's Exploration Technology Development Fund. R&D to extend the capabilities of airborne helicopter exploration and mapping systems is underway. The objectives of the work are the field testing of a four coil-pair sensor over areas of known conductors, the evaluation of the dielectric effect at 56 000 Hz, integration of the 56 000 Hz data into the inversion technique, and hardware and software redesign in response to problem identification. Progress to date consists of field testing of the three coil-pair prototype with 56 000 Hz, system design to include the four coil-pairs, field testing with four coil-pairs, and completion of the development of the inversion technique. Thirty person-months in R&D are being devoted annually to these projects.

5. GEM Systems Incorporated, Don Mills, Ontario (I. Hrvoic, J. Myzyk, S. Plotnik)

The development of a high sensitivity helicopter-borne tridirectional continuous proton (Overhauser) gradiometer, based on the GSM-11A Proton Oscillator, is underway. Ground tests of the system have been completed. A total of twenty-two person-months and $125 000 in R&D are being devoted annually to this project. The work is supported by a grant from the Ontario Geological Survey's Energy Technology Development Fund.

6. IFG Corporation, Brampton, Ontario (W.R. Thuma, D. Blohm)

The MAGLOG borehole logging system, which simultaneously measures the total and X, Y, and Z vector component magnetic fields, magnetic susceptibility, fluid temperature, differential SP and electrical conductivity, was completed and successfully field tested in 1985. The system shows considerable promise in locating lithologic boundaries, structural features and ore mineralization off-hole. All data are digitally recorded permitting automated processing and interpretation. Although it is now at a production status, work continues on integrating other geophysical sensors and an orientation capability. The project was supported in part by the Exploration Technology Development Fund administered by the Ontario Geological Survey. A total of seven person-months and $23 500 in R&D are being devoted annually to this project.

7. Instrumentation GDD Incorporated, Ste-Foy, Quebec (E. Gaucher, R. Desbiens, M. Dessureault)

Work to upgrade the Beep Mat is underway. This includes improvement and stabilization of circuits, creation of a roto-moulding plastic case and field trials. Work to improve the reliability and precision of the automatic chain and level is in progress. A total of twenty four person-months and $105 000 in R&D are being devoted annually to these projects.

8. Kenting Earth Sciences Limited, Ottawa, Ontario (R.W. Stemp, J. Wilson, J. Bremner, K. Hall, T. Payne, S. Baker)

Development of the SWEEPEM airborne electromagnetic (EM) system continued. Field testing of the system has been completed, as have modifications to the prototype system to prepare it for commercial field production. A high sensitivity magnetometer has been added to the system, with the sensor placed in the EM bird. A new helicopter-borne vertical gradiometer system is in the final testing phase of development. It incorporates the same hardware and software that is being successfully used in the company's fixed-wing systems. A total of thirty person-months and $200 000 in R&D are being devoted annually to these projects.

9. Paterson, Grant and Watson Limited, Toronto, Ontario (N.R. Paterson, D.J. Misener, I.N. MacLeod, S.W. Reford, E. Baranyi, R.B. Hearst, D.C. Gresham, M.E. Gregotski, J.E. Hanneson)

The company continued with a program to develop a comprehensive computer software library for both internal and public geophysical interpretation applications, with the assistance of an ETDF grant from the Ontario Ministry of Northern Development and Mines. This includes work on the SPECMAP method, for ternary colour mapping of three-element radiometric or geochemical data, the GEMINV method, for inversion of multi-channel frequency-domain ground electromagnetic (EM) data to an n-layered earth model, and the SUSMAP method, for space domain calculation of magnetic fields or susceptibility on arbitrary surfaces. SPECMAP has been significantly upgraded for ease of use and to allow for a much greater variety of available map presentations. The feasibility of joint EM and resistivity inversion applied to the GEMINV method is being studied. A simplified version of GEMINV is under development, tailored specifically to the MAXMIN system. Refinements to the SUSMAP method now allow for the continuation of magnetic fields between arbitrary surfaces of variable geometry. A particular application is the continuation of aeromagnetic data between drape-flown and barometric surfaces. The method was successfully applied to study the problem of minimizing terrain effects on aeromagnetic data in areas of rugged topography. Work continues for upgrading of the MAGMOD inversion method for the modelling of total field and vertical gradient magnetic data by individual source parameter optimization. Singular value decomposition (SVD) is being added for improved inversion characteristics and result analysis. A computer modelling study was prepared on the effects of current channelling on the measured EM fields for Turam and other frequency-domain moving receiver EM systems. These effects were found to be significant over moderate conductors lying in a resistive host rock. A total of thirty person-months and $90 000 in R&D are being devoted annually to these projects.

10. Phoenix Geophysics Limited, Markham, Ontario (P.G. Hallof, H. Reddering, G. Balint, J. Kok, J. Sevenhuysen, R. Anderson, D. Mills, L. Rijos, G. Graham)

A time-domain option has been added to the V-2 two-channel induced polarization (IP) receiver. The V-2 is a five frequency IP voltmeter that has been operating in the phase domain

or variable frequency domain previously. The software has been modified to permit time-domain measurements with an absolute time control, as crystal clocks are employed by both the transmitter and receiver. No reference signal or signal recognition are necessary. The V-4 universal geophysical receiver, with eight sensor channels and a frequency range of 2^{-10} to 2^{12} Hz, has been developed. It is a direct descendent of the older IPV3 spectral IP receiver. It can be used for a variety of geophysical applications as follows: (i) phase IP, variable frequency IP or time-domain IP; (ii) spectral IP with a frequency range of 2^{-10} Hz to 2^{12} Hz; (iii) controlled source audiomagnetotellurics (CSAMT) with a frequency range of 0.25 Hz to 4096 Hz; and (iv) centre-loop induction electromagnetics with a frequency range of 0.25 Hz to 4096 Hz.

The T-30 frequency/time domain transmitter has been developed. It operates at 30 Kva (30 amp max) with versions available for 20 Kva and 10 Kva. It is engineered to transmit any variable frequency or time domain waveform currently being used for IP or EM exploration methods. Development of the V-5 seven component tensor AMT sensor system is underway. This system will complement either the CSAMT (V-4) system or the widely used MT system. Field testing is planned for the summer of 1986. Development of MT-CSAMT-IP software, for instrument control, data gathering, data display and interpretation procedures, continues. All previous software for spectral IP, IP plotting and IP pseudo-section inversion has been updated to the Hewlett Packard 9000 series computer. New software for two-dimensional MT and CSAMT forward calculations has been completed. Development of programs for three-dimensional forward problems is well underway. Existing software is currently being developed for operation on the IBM.

A total of forty-one person-months and $209 400 in R&D are being devoted annually to these projects.

11. Sagax Géophysique Incorporated, Montreal, Quebec (R. Bazinet, P. Berubé, M. Lambert)

The company's induced polarization interpretation software is being rewritten for use on almost any microcomputer by an inexperienced geophysicist, and for use with more complex models. The software can simulate the response of up to five bodies for various arrays, including the company's PPL array, as well as dipole-dipole, pole-dipole and gradient arrays using a fully interactive graphic operator interface. The company is developing a phase and coherency detector for their scalar audiomagnetotelluric (SAMT) instrument. This accessory will increase the confidence level of SAMT measurements and will provide for faster surveys. An interactive 1-D interpretation program for magnetotellurics has been developed. This graphics-intensive program works on any IBM-PC compatible machine (e.g. IBM, Phillips, Compaq, Ogivar and Gridcase) with a graphics screen or, alternatively, can drive a Tektronix 4010 graphics terminal. A 1-D interpretation program for resistivity, similar to the above program for MT, has been developed. It can support Wenner, Schlumberger and dipole-dipole soundings. A total of seven person-months in R&D is being devoted annually to these projects.

12. Sander Geophysics Limited, Kanata, Ontario (G.W. Sander, N. McGowan, T. Chow, S. Ferguson)

The development of a helicopter-borne gradiometer system using two Overhauser magnetometers has been completed. The instrument was field tested for stability and noise level and was made conformable to the Geological Survey of Canada's gradiometer survey specifications. Software was developed to process and plot the resultant data. To complete the present phase of the research project, a large field survey in extremely rugged terrain was carried out. The system was found capable of measuring changes in the earth's field to 0.005 nanoteslas. A project is underway to mount Overhauser magnetometers, developed by the company in the two previous years, in stinger installations for fixed-wing aircraft. The new instrument is expected to combine the stability of proton precession magnetometers with the resolution of an Overhauser magnetometer. A total of $160 000 in R&D is being devoted annually to these projects.

13. Scintrex Limited, Concord, Ontario (H.O. Seigel, reporter)

The company's R&D laboratories were engaged in projects in the following technical areas: multi-frequency ground and borehole electromagnetics; induced polarization; mineral luminescence (Luminex); gravimetry; high sensitivity, optically pumped magnetometry and trace atmospheric vapour analysis. The development of new sensors and related electronics, to be

operated by and with the IGS-2 (Integrated Geophysical System) continues, and the EM-4 dual frequency, multi-purpose electromagnetic receiver was completed during the year. The airborne Luminex system was expanded to six channels (time and spectral) from four, and was successfully operated on field tests. A total of forty-eight person-years was devoted to these R&D projects during the calendar year, with a gross expenditure of approximately $2 million. Of this about 25% was funded from government sources of assistance.

14. Utah Mines Limited, Toronto, Ontario (K. Witherly, J. Wong)

Geophysical modelling software, designed for Hewlett-Packard microcomputers, is under development. The programs cover a broad range of potential and electric field problems in geophysical prospecting.

GOVERNMENT

15. Resource Geophysics and Geochemistry Division, Geological Survey of Canada, Department of Energy, Mines and Resources Canada, Ottawa, Ontario (K.A. Richardson, P.J. Hood, D.J. Teskey, E. Schwarz, P. Sawatzky, M.E. Bower, B.W. Charbonneau, A.V. Dyck, K.L. Ford, R.L. Grasty, P.B. Holman, P.J. Killeen, C.J. Mwenifumbo, G.J. Palacky)

As usual, most of the output of this Division took the form of aeromagnetic and gamma ray spectrometric survey data published, or being prepared for publication, as maps at various scales. This effort accounted for about $6.5 million of the $8 million expenditure recorded for 1985. Following our normal practice only the in-house research is described in this report. Ground investigation of airborne gamma ray spectrometric survey data was directed at radioactive granitic rocks in the Nueltin Lake area, NWT, and in Nova Scotia, and their associated concentration of gold, rare earth elements, tin, tungsten, molybdenum, beryllium, etc.

Borehole EM research, concerned with development of interpretation methods, studied the effects of conductive mine structures in order to improve application in deep mines, and the importance of EM diffusion effects in recognizing the presence of significant targets (supported by field results obtained in the Noranda mining camp before and after the mining of a massive sulfide lens). Multiparameter borehole logging (spectral gamma, self potential, IP, resistivity, temperature, magnetic susceptibility and density) was conducted at the Daniels Harbour Newfoundland zinc deposit. Sphalerite-rich zones were delineated by density measurements and some zones showed significant IP response. Temperature logging located groundwater flow zones which could be of interest in mine planning and water flow control.

Experiments on electrode material for borehole measurements of SP and IP were conducted; non-polarizable Cu-$CuSO_4$ was found to be best, lead electrodes second best, and aluminum the worst. Coal logging calibration facilities in Dartmouth, Nova Scotia and Calgary, Alberta, progressed with the installation of inground tanks to house the calibration zones of a model borehole.

Initial work started at the Val Gagné geophysical test site in northeastern Ontario (Abitibi clay belt). In the area, glacial and lacustrine sediments cover undulating Precambrian topography. The site will be used primarily to test newly developed airborne EM systems and their ability to map clays, tills and bedrock topography. Such knowledge is essential in planning base till geochemical sampling surveys, which are presently used in gold exploration programs. Ground electromagnetic resistivity surveys were carried out, and the site was flown with the new towed-bird Geotem system by Geoterrex Ltd. A workshop on Airborne Resistivity Mapping took place in Ottawa in October, 1985 with a total of 22 papers covering principles of airborne resistivity mapping, instrumentation, data processing, and applications. Panel discussions focussed on the future of airborne EM surveying. A volume of proceedings is now in the final stages of editing for publication in 1986. Exclusive of survey costs, roughly $1.5 million and a total of 528 person-months in R&D are being devoted annually to these projects.

16. Geophysics/Geochemistry Section, Ontario Geological Survey, Ministry of Northern Development and Mines, Toronto, Ontario (D.R. Wadge, R.B. Barlow, D.H. Pitcher, V.K. Gupta)

During the 1985 field season, the Night Hawk geophysical test range near Timmins, Ontario was utilized for testing, research and instruction purposes by personnel from industry, university and government. Section staff carried out field work using an ELFAST RTX/HL-30 electromagnetic system based on a standard large loop, fixed-source Turam principle. In addition, coverage was obtained using a recently modified MAXMIN III electromagnetic system. Complete grid coverage over the conductive feature was obtained to permit contouring of assorted parameters. Electromagnetic studies continued in the Black River-Matheson (BRIM) area. The 1984 drill sites and stratigraphic information resulting from the BRIM overburden drilling program were used to determine the effectiveness of specific airborne and ground electromagnetic methods for identifying areas of deep overburden and for exploring the potential of electromagnetic methods for mapping stratigraphic sections. Both airborne and ground electromagnetic techniques have considerable potential for mapping Quaternary deposits over resistive bedrock. Electromagnetic instrumentation is rapidly becoming available so that measurements, with high precision and accuracy, can be made on the spectrum of responses associated with rather complex overburden stratigraphy. An equal requirement exists at present for field studies directed at improving our ability to interpret these complex signatures. Utilizing the existing Federal-Provincial aeromagnetic information, a project was initiated to attempt to derive basement depths in the Cobalt Embayment area. A range of depths from 900 to 1800 m was found to be in agreement with sparse drilling information in the area.

17. Ministère de l'Énergie et des Ressources du Québec, Québec, Quebec (D.L. Lefebvre, R. Bazinet, D.J. Dion)

The final year of a three-year project to study and evaluate different types of significant INPUT electromagnetic conductors in the Chibougamau region has been completed. Geological, geochemical and geophysical ground-truth investigations help to characterize different long-strikelength conductors. The goal of the study is to establish a useful exploration guide for large electromagnetic conductors in the Abitibi. This project has been conducted in cooperation with École Polytechnique. Three helicopter-borne Rexhem 4 electromagnetic surveys, totalling about 9000 line km, are in various stages of completion. A total of $100 000 and twenty-four person-months are being devoted annually to R&D. In addition, some $1.4 million was spent on contracts for airborne surveys.

UNIVERSITIES

18. Department of Geophysics and Astronomy, University of British Columbia, Vancouver, British Columbia (W.F. Slawson, B.B. Narod, M. Maxwell)

The study of power line harmonics as an electromagnetic source is underway. Electromechanical prospecting methods are being studied in cooperation with Cominco Limited, Lamontagne Geophysics Limited and Hardy Associates (1978) Limited. The first field experiments, aimed at developing a prospecting tool for finding quartz, have been conducted. The method is based on piezoelectricity and other electromechanical phenomena. Seismic sources can activate such minerals as quartz, producing a detectable electromagnetic response. A total of 15.25 person-months and $36 000 (of which 90% is government funding) in R&D are being devoted annually to these projects.

19. Department of Geology and Geophysics, University of Calgary, Calgary, Alberta (K. Duckworth, C. Cummins, D. O'Neill, T. Calvert, R.J. Brown)

Development of interpretation methods, for use with the Turam prospecting device in difficult exploration environments, is underway. A physical scale modelling system is being employed to study the use of the Turam device in conductive environments using a tank of conductive fluid to simulate such environments. During 1985, the main emphasis has been on a study of a mode of operation in which traverses run parallel to the transmitter rather than perpendicular to it. A large suite of model responses has been obtained and field tasks of the concept were conducted by the Ontario Geological Survey at the Night Hawk Lake Test Range with very satisfactory results. A study of the effect of permafrost conditions on the induced polarization (IP) response of sulphide ores is being conducted. This project is an extension

of an earlier study which concentrated on lead zinc mineralization of the type found in Mississippi Valley-type deposits. This extension of the study will involve detailed petrographic studies of the specimens used in the electrical tests in an attempt to relate the Cole-Cole parameters as measured to petrographic features of the mineralized specimens. A model study of inductive coupling in multifrequency IP is underway. The objectives are to find simple mathematical models of the EM coupling in IP which are based on sound physical models and which represent faithfully both the full exact-solution results as well as experimental results.

20. Department of Geological Sciences, University of Saskatchewan, Saskatoon, Saskatchewan (D. Gendzwill, D. Reding, Z. Hajnal)

Software, operational on IBM-PC and Apple II microcomputers, has been written for the inversion of data measured by the Geonics EM-34-3 electromagnetometer. The routine is able to interpret conductivities and depths of three horizontal layers, and has been applied to engineering work in potash mines. Seismic reflection characteristics in the Athabasca Basin are being studied. Laboratory analysis of over 600 core samples, from two localities, established depth variant acoustic characteristics of the Athabasca sandstone and the underlying crystalline basement rocks. The derived reflectivity and synthetic seismic records indicate that some of the sandstone formation contacts and the sandstone basement interface are mappable by reflection techniques. A total of twenty-one person-months and $45 000 in R&D are being devoted annually to these projects.

21. Department of Earth Sciences, University of Manitoba, Winnipeg, Manitoba (D.H. Hall, T. Millar)

A study of magnetic susceptibilities of surface rock units and drill cores in the Project Cormorant area, Manitoba was completed. About 3000 sites (averaging twenty-five determinations per site) over about ten rock units were measured with an in situ susceptibility meter in a 7500 square kilometre area near Bakers Narrows, Cranberry Portage and Snow Lake, Manitoba. Susceptibilities at 2 m intervals on cores from about 300 drill holes were also measured. These data were summarized in a report to the Manitoba Department of Energy and Mines, and used in their interpretation of magnetic gradiometer surveys in the area.

22. Department of Geological Sciences, Queen's University, Kingston, Ontario (D.V. Woods, S.I. Taylor, D.H. Krentz, R.B. Barlow)

An inversion method has been developed to aid in the interpretation of borehole time-domain electromagnetic (TDEM) data. The technique is based on non-linear, least squares regression of the axial component of an anomalous borehole TDEM response to give an optimal, rectangular current loop position in 3-D space near the drillhole. The inversion routine was initially developed on a mainframe computer but is now being adapted to run on a microcomputer. A shallow overburden transient electromagnetic sounding experiment was carried out in 1984 by the Ontario Geological Survey to test the feasibility of mapping the clay/till/bedrock horizons in an area near Matheson, Ontario. Interpretation algorithms have been developed to analyze these data to give depth and/or conductance of the overburden layers. A total of fourteen person-months in R&D is being devoted annually to these projects.

23. Department of Mineral Engineering, École Polytechnique, Montreal, Quebec (G. Pouliot, R. Bazinet, M.A. Vallée, R. Darling, P. Trudel, M. Chouteau, L. Laverdure, K. Bouchard, C. Deschambault, J. Thevenin, R. Chakridi)

A new generation tensor magnetotelluric (MT) system is under development. Construction of the system is in progress. The instrumentation and techniques for high-frequency (up to 1 MHz) MT surveys are under development. The method will be useful in high resistivity shield environments and for civil engineering applications. Construction of the receiver and the appropriate electrical sensors is nearing completion. A project to evaluate prospecting tools for locating ore deposits in long INPUT conductors is underway in collaboration with the Ministère de l'énergie et des ressources du Québec. Various techniques are being studied for locating orebodies in "structural" conductors delineated by INPUT surveys. Drilling was included in this year's field work. An airborne geophysics test site was fully characterized and comparative work conducted on two other sites. Construction of an MT scale modelling facility for the study of 3-D structures is underway. This project is supported by grants

from FCAR (Quebec) and NSERC. Preliminary work is underway for the development of processing techniques and instrumentation of a very high resolution seismic method.

A project to evaluate the problems encountered using the audio-magnetotelluric (AMT) method for mineral exploration is underway. This includes studying the interpretation of scalar results versus tensor results, the topographic effect and the station separation. Numerical simulation is used in order to analyze the various responses. This work is supported by grants from EMR and NSERC. Ten tensor MT sounding stations in the 0.005-250 Hz frequency range and forty scalar AMT stations in the 14-5000 Hz range were recorded in the Charlevoix Crater region. Crude interpretation has revealed a complex crustal model. A more refined 2-D interpretation is in progress. This project is being conducted in collaboration with IREM-MERI. In collaboration with IREM-MERI, interpretation of an aeromagnetic and gradiometer survey in the Weedon region, Eastern Townships, Quebec is underway. Features such as dykes and faults have been revealed in this mining area of high economic potential. A tensor MT survey (frequency range: 0.005 Hz - 200 Hz) was carried out across the Abitibi Belt, Quebec, in 1983, to investigate the structure of the upper crust in this sub-province. Reprocessing and interpretation of the data are in progress. Static shift corrections are applied whenever suspected "screening effects" caused by large graphitic conductors are studied. A 2-D model will be proposed. Work is in progress to develop a technique of making scale models for electromagnetic simulation. The models are constructed of conductive plastic resins with good mechanical characteristics. Tests are being carried out to control electrical properties of the models. This work is supported by grants from NSERC and FCAR (Quebec). A total of 172 person-months and $461 000 in R&D are being devoted annually to these projects.

24. IREM/MERI (Mineral Exploration Research Institute), Montreal, Quebec (V.M. Virard, M. Chouteau, C. Deschambault, K. Bouchard)

In collaboration with École Polytechnique, ten tensor magnetotelluric (MT) sounding stations in the 0.005-250 Hz range and forty scalar audio MT stations in the 14-5000 Hz range were recorded in the Charlevoix Crater region. Crude interpretation has revealed a complex crustal model. A more refined 2-D interpretation is in progress.

In collaboration with École Polytechnique, interpretation of an aeromagnetic and gradiometer survey in the Weedon region, Eastern Townships, Québec is underway. Features such as dykes and faults have been revealed in this mining area of high economic potential.

A feasibility study to use MT soundings for determining the model of the Mont Vallières-de-St-Réal intrusive (Gaspésie, Québec), an area of very severe topography, has been completed. The objective of the work was mainly to find the depth to the bottom of this monzonite laccolith, which is thought to be overlying economic skarnified sediments (possibly disseminated copper mineralization). A reconnaissance survey and a thorough numerical simulation study have been carried out.

A total of thirty-six person months and $53 000 in R&D are being devoted annually to these projects.

25. Bibliography

Arkhani-Hamed, J., Strangway, D.W., Teskey, D.J. and Hood, P.J. 1985. Comparison of MAGSAT and low level aeromagnetic data over the Canadian Shield: implications for GRM. Can. J. Earth Sci., 22, 1241-1247.

Bazinet, R. and Legault, J. 1985. Scalar audiomagnetotellurics: a tool in the evaluation of nuclear waste disposal sites. In: Expanded Abstracts, 1985 Technical Program, Society of Exploration Geophysicts, 149-150.

Bhattacharyya, B.K. 1985. Two-dimensional harmonic analysis as a tool for magnetic interpretation (Classic paper of the past 25 years). Geophysics, 50, 1878-1906.

Bristow, Q. 1985. A digital processing unit for the Geoinstruments magnetic susceptibility sensors, with analogue and RS-232C outputs. In: Current Research, Part B, Geological Survey of Canada, Paper 85-18, 463-466.

Broome, J., Simard, R. and Teskey, D.J. 1985. Presentation of magnetic anomaly map data by stereo projection of magnetic shadowgrams. Can. J. Earth Sci., 22, 311-314.

Chouteau, M. 1985a. Magnetotelluric measurements in La Malbaie area (Québec): the anomalous vertical magnetic field. Can. J. Earth Sci., 22, 1530-1536.

Chouteau, M. 1985b. Comment on "Fractures as conducting dykes and corresponding two-dimensional models" by A. Adam. Geophysical Prospecting, 33, 888-890.

Chouteau, M. 1985c. An extremely low electrical resistivity anomaly near Ste. Mathilde (Québec). CIM Bulletin, 78, no.881, 69-74.

Daudier, B.S. and Schwarz, E.J. 1985. An interpretation method for gravity and magnetic data for areas peripheral to the Canadian Shield. In: Current Research, Part A, Geological Survey of Canada, Paper 85-1A, 421-430.

Dods, S.D., Teskey, D.J. and Hood, P.J. 1985. The new series of 1:1,000,000 scale magnetic anomaly maps of the Geological Survey of Canada: compilation techniques and interpretation. In: The Utility of Regional Gravity and Magnetic Anomaly Maps, W.J. Hinze (Editor), Society of Exploration Geophysicists, 69-87.

Dyck, A.V. and Young, R.P. 1985. Physical characterizations of rock masses using borehole methods. Geophysics, 50, 2530-2541.

Ford, K.L. and O'Reilly, G.A. 1985. Airborne gamma-ray spectrometric surveys as an indicator of granophile element specialization and associated mineral deposits in the granitic rocks of the Meguma Terrane of Nova Scotia, Canada. In: High Heat Production (HHP) granites, hydrothermal circulation and ore genesis, Institution of Mining and Metallurgy, London, England, 113-133.

Grant, F.S. 1985a. Aeromagnetics, geology and ore environments, I. Magnetite in igneous, sedimentary and metamorphic rocks: an overview. Geoexploration, 23, 303-333.

Grant, F.S. 1985b. Aeromagnetics, geology and ore environments, II. Magnetite and ore environments. Geoexploration, 23, 335-362.

Grasty, R.L. 1985. The analysis of multi-channel airborne gamma-ray spectra. Geophysics, 50, 2611-2620.

Gupta, V.K. 1985. Cobalt Embayment interpretation: depth to basement and distribution of Nipissing diabase from aeromagnetics. In: Summary of Field Work and Other Activities, 1985, J. Wood, O.L. White, R.B. Barlow and A.C. Colvine (Editors), Ontario Geological Survey, Miscellaneous Paper 126, 178-181.

Gupta, V.K. and Grant, F.S. 1985. Mineral-exploration aspects of gravity and aeromagnetic surveys in the Sudbury-Cobalt area, Ontario. In: The Utility of Regional Gravity and Magnetic Anomaly Maps, W.J. Hinze (Editor), Society of Exploration Geophysicists, 392-412.

Hood, P.J. 1985. Mineral explorations: trends and developments in 1984. Canadian Mining Journal, 106, No. 1, 14-41.

Hood, P.J., McGrath, P.H. and Teskey, D.J. 1985. Evolution of Geological Survey of Canada Magnetic Anomaly Maps: a Canadian perspective. In: The Utility of Regional Gravity and Magnetic Anomaly Maps, W.J. Hinze (Editor), Society of Exploration Geophysicists, 62-68.

Hood, P.J., Bower, M.E., Hardwick, C.D. and Teskey, D.J. 1985. Direct geophysical evidence for displacement along Nares Strait (Canada-Greenland) from low-level aeromagnetic data: a progress report. In: Current Research, Part A, Geological Survey of Canada, Paper 85-1A, 517-522.

Kilty, S.J. 1985. A microprocessor-based digital receiver console for the DIGHEM$^{III/IV}$ system. In: Exploration Technology Development Program of the Board of Industrial Leadership and Development, Summary of Research 1984-1985, V.G. Milne and R.B. Barlow (Editors), Ontario Geological Survey, Miscellaneous Paper 125, 29-32.

Lajoie, J.J. and West, G.F. 1985a. The electromagnetic response of a conductive inhomogeneity in a layered earth (Classic paper of the past 25 years). Geophysics, 50, 2189-2212.

Lajoie, J.J. and West, G.F. 1985b. Two selected field examples of EM anomalies in a conductive environment (Classic paper of the past 25 years). Geophysics, 50, 2213-2218.

Mayrand, L. and Chouteau, M. 1985. Performance evaluation of a microcomputer-based interpretation system for gravity and magnetic data. In: Microcomputer Applications in Geology, J.T. Hanley and D.F. Merriam (Editors), Computers and Geology, 5.

McGrath, P.H. and Henderson, J.B. 1985. Reconnaissance ground magnetic and VLF profile data in the vicinity of the Thelon Front, Artillery Lake map area. In: Current Research, Part A, Geological Survey of Canada, Paper 85-1A, 455-462.

Mwenifumbo, C.J. 1985a. Application of borehole geophysics in exploration for gold. SPWLA Twenty-sixth Annual Logging Symposium Transactions.

Mwenifumbo, C.J. 1985b. Mise-à-la masse mapping of gold-bearing alteration zones at the Hoyle Pond gold deposit, Timmins, Ontario. In: Current Research, Part A, Geological Survey of Canada, Paper 85-1A, 669-679.

Paterson, N.R. and Reeves, C.V. 1985. Applications of gravity and magnetic surveys: The state of the art in 1985. Geophysics, 50, 2558-2594.

Pitcher, D.H. 1985a. Night Hawk geophysical test range results, District of Cochrane. In: Summary of Field Work and Other Activities, 1985, J. Wood, O.L. White, R.B. Barlow and A.C. Colvine (Editors), Ontario Geological Survey, Miscellaneous Paper 126, 170-177.

Pitcher, D.H. 1985b. A correlation of airborne and ground electromagnetics with sonic drilling results in the Black River - Matheson (BRIM) area, District of Cochrane. In: Summary of Field Work and Other Activities, 1985, J. Wood, O.L. White, R.B. Barlow and A.C. Colvine (Editors), Ontario Geological Survey, Miscellaneous Paper 126, 334-340.

Reford, S.W. and Paterson, N.R. 1985. Testing and demonstration of interpretation software for magnetic, EM and spectrometry inversion. In: Exploration Technology Development Program of the Board of Industrial Leadership and Development, Summary of Research 1984-85, V.G. Milne and R.B. Barlow (Editors), Ontario Geological Survey, Miscellaneous Paper 125, 80-84.

Reford, S.W., Paterson, N.R. and Edwards, R.N. 1985. Inversion and SVD analysis of frequency-domain EM data. In: Expanded Abstracts, 1985 Technical Program, Society of Exploration Geophysicists, 251-254.

Schock, L.D. and Killeen, P.G. 1985. Establishment of coal logging calibration facilities: a progress report. In: Current Research, Part B, Geological Survey of Canada, Paper 85-1B, 459-462.

Sinha, A.K., Collett, L.S. and Bazinet, R. 1985. Geophysical analysis of the new intrablock grid at RA-4. In: The Geoscience Program. Proceedings of the Seventeenth Information Meeting of the Nuclear Fuel Waste Management Program, Atomic Energy of Canada Limited Research Company, Publication TR-299.

Spector, A. and Grant, F.S. 1985. Statistical methods for interpreting aeromagnetic data (Classic paper of the past 25 years). Geophysics, 50, 1951-1960.

Taylor, S.I. and Woods, D.V. 1985. Simple inversion methods to aid in the interpretation of borehole TEM data. In: Expanded Abstracts, 1985 Technical Program, Society of Exploration Geophysicists, 133-135.

Urquhart, W.E.S. and Strangway, D.W. 1985. Interpretation of part of an aeromagnetic survey in the Matagami area of Quebec. In: The Utility of Regional Gravity and Magnetic Anomaly Maps, W.J. Hinze (Editor), Society of Exploration Geophysicists, 426-438.

West, G.F. and Edwards, R.N. 1985. A simple parametric model for the electromagnetic response of an anomalous body in a host medium. Geophysics, 50, 2542-2557.

Woods, D.V. 1985a. 2-D horizontal magnetic field calculation. In: Manual of Geophysical Hand-Calculator Programs, Society of Exploration Geophysicists, TI volume, MAG 12.

Woods, D.V. 1985b. 2-D dipping dike interpretation using horizontal and vertical magnetic field profiles. In: Manual of Geophysical Hand- Calculator Programs, Society of Exploration Geophysicists, TI Volume, MAG 11.

Yamashita, M., Hallof, P.G. and Pelton, W.H. 1985. CSAMT case histories with a multichannel CSAMT system and near-field data correction. In: Expanded Abstracts, 1985 Technical Program, Society of Exploration Geophysicists, 276-278.

Yunsheng, S., Strangway, D.W. and Urquhart, W.E.S. 1985. Geologic interpretation of a high-resolution aeromagnetic survey in the Amos-Barraute area of Quebec. In: The Utility of Regional Gravity and Magnetic Anomaly Maps, W.J. Hinze (Editor), Society of Exploration Geophysicists, 413-425.

Zandee, A.P., Best, M.E. and Bremner, T.G.T. 1985. Sweepem, a new airborne electromagnetic system. In: Expanded Abstracts, 1985 Technical Program, Society of Exploration Geophysicists, 236-239.

XI ENGINEERING GEOPHYSICS

Compiled by: K. Howells

1. Université Laval (M.K. Séguin)

Géophysique du pergélisol à Kangiqsuallujjuaq et Koroc, Québec nordique

Les travaux géophysiques effectués en 1984 et 1985 dans les régions mentionnées ci-dessus ont pour but de délimiter l'extension du pergélisol discontinu en milieu littoral et en milieu terrestre et ce en une, deux ou trois dimensions dépendant de la nature du problème envisagé. Pour ce faire, nous avons procédé à des sondages de résistivité électrique et de polarisation provoquée en surface afin de déterminer les surfaces inférieure et supérieure du pergélisol dans la région est de la baie d'Ungava.

Afin de vérifier plus précisément l'interprétation des résultats obtenus, des forages de moyenne profondeur (15-25 m) ont été effectués, permettant ainsi un meilleur contrôle de ces sondages géophysiques. L'évolution du mollisol en fonction du temps est étudiée à l'aide de sondes thermiques, géophysiques (résistivité électrique, polarisation spontanée, polarisation provoquée, neutron, capacitancemètre dans le domaine fréquenciel) et de cylindres concentriques mesurant le déplacement différenciel du mollisol en période de gel et de dégel. Ces sondes ont une longueur variable entre 2 et 3 m. De telles mesures ont été faites dans des lentilles de permagel sur le schorre et la slikke en milieu littoral et dans des palses, buttes minérales cryogènes, tills, dépôts glaciels, dépôts fluvioglaciaires et autres en milieu continental.

L'isotherme 0°C obtenu à la surface inférieure du pergélisol grâce aux thermocables dans les trous de moyenne profondeur corrèle avec les résultats obtenus par sondages géophysiques de surface avec une précision relative de 10%. L'isotherme 0°C obtenu à l'interface: mollisol-pergélisol montre une excellente corrélation avec une décroissance de chargeabilité électrique. En général, l'augmentation rapide de résistivité électrique dans le pergélisol se situe légèrement en-dessous de l'isotherme 0°C. Une diminution importante du voltage en polarisation spontanée correspond à l'isotherme 0°C dans presque tous les dépôts mais elle est plus évidente dans les palses.

L'emploi de la sonde neutrons et du capacitancemètre dans le domaine fréquenciel permet la détermination du contenu relatif en eau et en glace dans le pergélisol. Ces données ont été calibrées de manière absolue par méthode calorimétrique adiabatique in situ. Lors des expériences calorimétriques, les pourcentages volumétriques de la glace, de l'eau et des solides, la densité de formation et des solides, la porosité et le pourcentage granulométrique ont été déterminés. Des mesures de micro-résistivité sur des carottes de forage du pergélisol ont permis d'établir une corrélation préliminaire entre la résistivité électrique, la température, le contenu en eau et le contenu en glace pour un matériau solide spécifique (argile, silt, sable et gravier).

2. Nova Scotia Research Foundation Corporation (A.G. McKay)

The success of other experimenters with out-of-phase dual P-wave vibratory sources as a method of stimulating horizontal S-waves prompted A. McKay to propose a method of measuring S-wave velocities in seabed sediments by using, on the seabed, two conventional sparkers fired with a controllable trigger delay. Experiments under an existing agreement with E.M.R. have

been confined to water of wading depth, the sparkers and receiving geophones being positioned by hand. Arrivals (identified by the customary method of identifying S-wave phase change on the reversal of the direction of first motion of the source) have been compared with arrivals obtained with a shearwave hammer source. While S-wave arrivals are less obvious than those obtained with the hammer source, the results are sufficiently encouraging to warrant further investigation of appropriate sparker power, firing delay and separation.

A cruise on the CSS Dawson to the Sable Island Bank area of the Scotian Shelf was undertaken jointly by the Geology Department of Dalhousie University (R. Boyd) and NSRFC (A. McKay) for surficial sediment investigations. In addition to obtaining excellent sub-bottom information with the NSRFC deep-tow profiler it was possible, as a result of a fortuitous spell of good weather, to obtain good profiles with a surface-towed system. These data complement one another and improve knowledge of the continuity of seismic stratigraphy from one side of the island to the other. A line run between Sable Island and Country Harbour encountered further evidence for possible glacial material as a lens or "tongue" within a sequence of finer marine sediments on the periphery of an intra-shelf basin.

3. Gartner Lee Associates Limited (D.D. Slaine)

A paper entitled "Geophysical Modelling and Mapping of Contaminated Ground Water Around Three Waste Disposal Sites in Southern Ontario" was submitted to the Canadian Geotechnical Journal in November, 1985. The paper is authored by J.P. Greenhouse, University of Waterloo and D.D. Slaine, Gartner Lee Associates Limited. The paper discusses the application of a predictive model for selecting EM equipment to perform a survey around a waste disposal site. These case histories of hazardous investigations are presented with the results of an EM geophysical survey, a hydrogeology and a geochemistry study at each site.

A seismic reflection survey was performed as a preliminary investigation to siting a hazardous waste site. The survey was 11 km in total length and the data are presently being processed for interpretation. Upon completion of the study, scientific paper(s) will be published by D.D. Slaine, Gartner Lee Associates Limited, P. Pehme, private consultant and J.A. Hunter, GSC.

4. Paterson, Grant and Watson Limited (N.R. Paterson, S.W. Reford)

The company has been investigating the mapping of a stratified earth using the airborne and ground electromagnetic (EM) methods since 1982. Software has been developed to invert frequency-domain airborne EM data to a two-layer earth model, and ground EM data to an n-layer earth model. This has particular application in the engineering geophysics field for mapping of overburden and bedrock, groundwater exploration, mapping the water table and mapping groundwater contaminants and salinity. The software has been extensively and successfully tested on synthetic and real data, and applied in production work. Research continues to allow processing of data from an increased number of frequency-domain systems. Future work will include adapting the software to time-domain EM data and investigating the possibility of joint EM/resistivity inversion. A paper on this research was presented at the 1985 Annual Meeting of the Society of Exploration Geophysicists in Washington, D.C. A manuscript is in preparation for publication. Some support for this research has been provided by the Energy Technology Development Fund which is administered by the Ontario Geological Survey.

5. Ontario Hydro (H.W. Asmis, J.R. Bowlby, R.J. Heystee)

(a) Accelerometer Systems

In 1985 an accelerometer system was installed in the city of Oshawa. This system comprises a borehole triaxial sensing head located on bedrock below 13.3 m of overburden, and a surface triaxial accelerometer located just above ground surface on the floor of a semi-abandoned transformer building. Two digital recorders complete the system. On January 31, 1986 this system recorded the first Ontario accelerogram of the Lake Erie earthquake, which had an amplitude of about 0.005 g on the E-W channel. The amplitude of the rock motions did not apparently exceed the 0.001 g trigger level.

(b) Seismometers

Ontario Hydro and Earth Physics Branch (EPB) have a co-operative program for seismic monitoring on the north shore of Lake Ontario. Seismometer outstation WEO is located near Welcome, Ontario, to the north of Port Hope. This station is funded by Ontario Hydro and operated by EPB in the Eastern Canada Telemetered Network. Digitized data are telemetered to EPB in Ottawa for analysis. Quarterly reports of activity are prepared and distributed by EPB.

Ontario Hydro provided support for the continued operation of the Queen's University three-station array in 1985. Some microseismic events are being detected within the array.

(c) Deep Drilling Program

Two deep boreholes have been drilled adjacent to the north shore of Lake Ontario in the Paleozoic rocks of Southern Ontario and into the Precambrian basement. The primary purpose of these boreholes is to define the hydrogeologic nature of thick sedimentary rock sequences; i.e., geologic features controlling groundwater flow, rates and direction of flow, and age and origin of groundwater. Investigative techniques that are being used include rock core logging, borehole geophysical logging, borehole hydraulic testing and the monitoring of a multi-level piezometer system. Hydrogeologic and geologic data are currently being collected and analyzed. Proposals to conduct studies in these boreholes or on the rock core can be entertained.

6. Queen's University

(a) Rockburst Investigations using Concurrent Tomographic Imaging and Acoustic Emission Techniques (R.P. Young, D.A. Hutchins, T. Urbancic, W.J. McGaughey, S. Falls, J. Towers)

This research project (funded by an NSERC Strategic Grant, 1985-1988) is aimed at providing much needed fundamental knowledge about rockburst phenomena, through a three phase investigation. During Phase I, rockbursts will be investigated in the laboratory using a hybrid acoustic monitoring system involving both active and passive techniques. The active technique will produce an acoustic velocity and alternative tomographic "movie" of the changing internal structure of the rock during deformation. Passive acoustic emission (naturally occurring sounds emitted by rocks under stress) will be used concurrently, to monitor acoustic transients emanating from propagating cracks during the deformation of the rock. In addition any precursor mechanisms in the tomographic and acoustic emission data will be investigated. The ultimate aim of this phase is to develop signal processing software and techniques which can eventually be transferred to the field situation.

Phase II will involve a study of what additional information can be extracted from mine microseismic data about the internal structure/integrity and state of stress of the rock mass through which the waves travelled. Seismic signal processing techniques, applied to three component data, will be utilised to provide information, in addition to source location maps already computed by the mining companies, about the source mechanisms of rockbursts.

Finally in Phase III, the potential of borehole seismic probing methods will be studied by initially carrying out a concurrent tomographic imaging and microseismic monitoring of mine pillars as a function of time, using the techniques and software developed in Phase I.

In the short term this research project aims to provide a greater understanding of rockburst phenomena and their triggering mechanisms which could lead to a better and more reliable early warning system. Prevention, however, is potentially a much more important long term research goal than prediction, as this may be the way to eliminate significant rockburst problems in the future. This could be achieved by probing ahead of the mine front, using borehole tomographic imaging techniques which will be developed in this research. This approach would allow fundamental information about the state of stress and fracture characteristics of the rock mass to be incorporated into the design of the mine or development of a new mine level. It would also enable destressing to be carried out on the identified high risk areas, thus significantly improving mine safety and reducing mining costs caused by rockbursts.

(b) Seismic Anisotropy Induced by Mine Blasting (R.P. Young)

Experiments have been carried out with a shallow downhole shear wave source and surface detectors, to determine the anisotropic effects of mine blasting on seismic velocity and attenuation of compressional and shear waves. The polarization of the shear wave source was rotated and seismic data were collected using three component detectors along seismic lines radiating from a central source borehole. These experiments were repeated before and after mine blasting. Orthogonal joint sets existed within the rock mass prior to blasting, although one set dominated the wave propagation effects. The blast pattern used induced new fractures parallel to two free surfaces (one horizontal and one vertical) in the rock mass, as well as opening up the existing orthogonal fractures. Particle motion diagrams were used to highlight the polarization directions of arriving waves, and spectral analysis of selected portions of the waves was carried out to study attenuation spectra as a function of wave propagation direction and source polarization. The results show that the shear wave data are sensitive to blast induced fissures and can be used to quantify the fragmentation efficiency and fracture anisotropy caused by mine blasts. The analysis highlights the increased resolution of S-wave data over compressional waves for the characterization of fractured rock masses. The attenuation spectral data provides evidence for several mechanisms of wavelength dependent attenuation and in some selected cases, amplification phenomena caused by the blasting process. Polar diagrams of shear wave attenuation and velocity as a function of wave propagation direction and source polarisation, are being used in an attempt to quantify these complex processes.

(c) Queen's Seismometer Array (D.V. Woods, R.P. Young, W.J. McGaughey)

The Queen's Seismometer Array (QSA) was established in 1982 with funding from Ontario Hydro to monitor low-level micro-seismicity in the immediate Kingston vicinity. The array consists of three remote seismometer stations equally spaced about 30 kilometres distant from Kingston and linked to Queen's University by standard telephone circuitry. A fourth station, in the basement of the Department of Geological Sciences, is used for continuous seismic monitoring. Events identified from the helicorder records were played back from the remote station tape recordings and were then used to make hypocentre location and magnitude estimations. Almost all of the events recorded to date in the Kingston vicinity are due to quarry blasting. Only three small events were recorded during the 1983-84 period which, because they occurred late at night in areas of no known quarry operations, can be assumed to be natural micro-earthquakes. The QSA is being upgraded with the development of a three-component seismic recording system in the basement of the Geological Sciences building.

(d) A Near-Surface, High-Resolution Seismic System (W.J. McGaughey, D.V. Woods, R.P. Young)

Data acquisition and processing techniques have been developed to carry out shallow seismic investigations for mineral exploration and geotechnical applications. An efficient method of gathering common depth point data with an engineering seismograph has been established, resulting in the ability to quickly acquire large volumes of data which may be sorted by computer into the common offset, common depth point, and refraction source-receiver geometries implicit in the CDP field data. A sophisticated microcomputer-based interactive processing system has been developed to sort the data and carry out refraction, reflection, and spectral processing. The viability and efficiency of the software has been proven through the analysis of various case studies from eastern Ontario.

7. Bibliography

Allard, M. et Seguin, M.K. 1985. La déglaciation d'une partie du versant hudsonien québécois: bassins des rivières Nastapoca, Sheldrake et à l'Eau Claire. Géographie physique et Quaternaire, 39(1), 13-24.

Dyck, A.V. and Young, R.P. 1985. Physical characterization of rock masses using borehole methods. Geophysics, 50(12), 2530-2541.

Seguin, M.K. et Allard, M. 1984a. Le pergélisol et les processus thermokarstiques de la région de la rivière Nastapoca, Nouveau-Québec. Géographie physique et Quaternaire, 38(1), 11-25.

Séguin, M.K. et Allard, M. 1984b. La répartition du pergélisol dans la région du détroit de Manitounuk, côte est de la mer d'Hudson, Canada. Can. J. Earth Sci., 21, 354-364.

Woods, D.V. 1984. Regional seismic monitoring: annual report of the Queen's Seismometer Array 1983. Ontario Hydro Report No. 85029.

Woods, D.V. 1985. A study of shallow reflection seismics for placer-time-reserve estimation and mining - a discussion. Geoexploration, 23, 291-292.

Young, R.P. and Hill, J.J. 1985. Seismic characterization of rock masses before and after mine blasting. Proceedings 26th U.S. Symposium on Rock Mechanics, Rapid City, 2, 1151-1158.

GUIDELINES FOR THE EDITOR AND REPORTERS
CANADIAN GEOPHYSICAL BULLETIN

1. The Canadian Geophysical Bulletin is an annual report of geophysical research and development activities in industry, government and universities in Canada. Its main purpose is to inform geophysicists in Canada and abroad of current projects, developments and publications in their own and related areas. At the same time, it provides an overview for those outside the earth science disciplines of the extent and directions of scientific research activity in this subject in Canada.

2. The Bulletin shall be made up of a collection of chapters authored by reporters named by the Editor, after consultation with the National Correspondents.

3. The Editor will review the chapter titles on an annual basis to ensure that together they continue to cover the full range of geophysical activities in Canada. He will then set a maximum length for each chapter after consideration of the following:
(i) the total length of the Bulletin, cover to cover shall not exceed 200 pages;
(ii) the importance of the chapter topic in both the national and international community;
(iii)the number and productivity of Canadian workers in the field.

4. Each chapter shall begin with an index, include a one-page summary written by the appropriate reporter, followed by a succinct account of current activities and conclude with a list of reports and papers that have appeared in print during the previous calendar year. Abstracts, current year material and material in press or preparation will not be listed. Scientific publications in a recognized government series and appearing in the year under review may be included in the list of references. Theses accepted as part of a recognized graduate degree program during the year under review should also be included in the list of references.

5. The accounts of current activities are listed in each chapter under headings for each reporting research group. Each of these items should include a brief statement of current activities. Lengthy statements of results obtained will not be allowed. The latter should be abbreviated to not more than two or three typewritten lines.

6. Copy-ready material will be prepared by the Earth Physics Branch of EMR from clearly presented text supplied by the Editor not later than March of the year following that covered by the Bulletin. Reporters should supply the Editor with final, complete chapters that have been proof read. The layout, headings, sub-headings, references, etc. should follow the style of CGB Volume 38. If possible, chapters should be prepared on a Wang word processing unit and a diskette of each chapter provided to the Editor.

7. The Bulletin will be published by the Earth Physics Branch of Energy, Mines and Resources Canada as early as possible in the year following that which the material covers.

DIRECTIVES POUR LE RÉDACTEUR EN CHEF ET LES RAPPORTEURS
BULLETIN CANADIEN DE GÉOPHYSIQUE

1. Le Bulletin canadien de géophysique est un rapport annuel des activités de recherche et de développement géophysiques de l'industrie, du gouvernement et des universités au Canada. Son but principal est d'informer les géophysiciens au Canada et à l'étranger des recherches, des développements et des publications en cours dans leur propre domaine ou dans des domaines connexes. De plus, il fournit à ceux oeuvrant en dehors des disciplines des sciences de la Terre une vue d'ensemble sur l'étendue et les directions de la recherche scientifique dans ce domaine au Canada.

2. Le Bulletin consistera en un ensemble de chapitres rédigés par des rapporteurs nommés par le rédacteur en chef après consultation avec les correspondants nationaux.

3. Le rédacteur en chef révisera les titres des chapitres sur une base annuelle afin de s'assurer que ceux-ci couvrent bien la totalité des activités géophysiques au Canada. Il fixera ensuite une longueur maximale pour chaque chapitre en tenant compte des considérations suivantes: (i) la longueur totale du Bulletin ne doit pas excéder 200 pages d'une couverture à l'autre; (ii) l'importance du contenu du chapitre tant sur le plan national que sur le plan international; (iii) le nombre et la productivité des travailleurs canadiens dans ce domaine.

4. Chaque chapitre commencera par un index, suivi d'un résumé d'une page écrit par le rapporteur approprié; résumé suivi des comptes rendus concis des activités en cours. Le chapitre se terminera par une liste des rapports et des articles qui ont été publiés l'année précédente. Les résumés, les références de l'année courante et les publications sous presse ou en préparation ne devront pas être mentionnés. Les publications scientifiques apparaissant au cours de l'année considérées dans une série reconnue du gouvernement pourront être incluses dans la liste de références. Thèses acceptées pendant la période considérée comme partie d'un programme de diplôme reconnu pourront également être incluses.

5. Les comptes rendus des activités en cours pour chaque chapitre seront accompagnés de titres se référant aux groupes de recherches rapporteurs. Chacune de ces rubriques devra inclure un bref paragraphe sur les activités en cours. Les longs exposés des résultats obtenus ne seront pas autorisés. Ceux-ci devront être abrégés afin de ne pas excéder une ou deux lignes dactylographiées.

6. Le matériel prêt à être reproduit sera préparé par la Direction de la physique du globe d'Énergie, Mines et Ressources Canada à partir du texte clairement présenté fourni par le rédacteur en chef pas plus tard que le mois de mars de l'année suivant celle couverte par le volume du Bulletin. Les rapporteurs doivent fournir des chapitres corrigés, complets et finals au rédacteur. Le style, les titres et les sous-titres doivent se conformer au style du BCG volume 38. Si possible, les chapitres doivent être préparés sur une machine à traitement de texte Wang et une disquette de chaque chapitre fournie au rédacteur.

7. Le Bulletin sera publié par la Direction de la physique du globe d'Énergie, Mines et Ressources Canada le plus tôt possible dans l'année suivant celle couverte par le Bulletin.

Canada