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**CANADIAN BULLETIN  
GEOPHYSICAL CANADIEN  
BULLETIN DE GÉOPHYSIQUE**

**Volume 39**

Editor/Rédacteur en chef P.B. Robertson

Published by the Canadian National Committee  
for the International Union of Geodesy and  
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## 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 considerable assistance of Ms. Irene Wilkes and Mrs. Kathy Magladry, Geophysics Division, Geological Survey of Canada, Energy, Mines and Resources Canada.

The Bulletin is produced and distributed to readers inside and outside Canada by the Geological Survey of 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:

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

P.B. Robertson  
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: Mme Irene Wilkes et Mme Kathy Magladry, de la Division de géophysique, Commission géologique du Canada, d'Énergie, Mines et Ressources Canada.

Ce bulletin est produit et distribué aux lecteurs du Canada et de l'étranger par la Commission géologique du 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:

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P.B. Robertson  
Rédacteur en chef



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 Geological Survey of Canada 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 Geological Survey of Canada 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 Commission géologique du 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 Commission géologique du Canada d'Énergie, Mines et Ressources Canada le plus tôt possible dans l'année suivant celle couverte par le Bulletin.



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## I(A) GEODESY

Compiled by: R.B. Langley

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15. University of Saskatchewan, Department of Geological Sciences
16. University of Calgary, Department of Surveying Engineering
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### 1. Summary

Geodesy is the science of determining the size and shape of the earth, including its gravity field, in four dimensional space-time. As such its major areas of activity are positioning, the description of the global gravity field, and the study of temporal variations in positions due to natural and engineered causes. In the subsequent sections, sixteen agencies and organizations in the government, university, and private sectors in Canada report on their geodetic activities in 1986. Significant accomplishments include the completion of the continental adjustment of North American horizontal control networks and the preparation for integrating secondary control into the system; the planning for trial adjustments of the North American vertical networks; the development of techniques and procedures for using the Global Positioning System (GPS) of satellites for geodetic control, crustal motion and deformation studies, and precise positioning of moving platforms; the testing of components of the Canadian Geophysical Long Baseline Interferometry system, the Electronic Chart Test Bed, and a suspended gyro-compass; and the completion of a new gravimetric geoid for Canada. These accomplishments were presented in the scientific literature and at several meetings held in 1986 pertaining to geodesy. Of particular note was the Fourth International Geodetic Symposium on Satellite Positioning held at the University of Texas at Austin at which no fewer than 10 Canadian papers were presented. Canadian expertise in GPS was also evidenced in the printing of the Guide to GPS Positioning (Wells et al., 1986) a 600-page book on all facets of GPS co-authored by a group of 11 scientists and engineers from all sectors of the geodetic research community.

### 2. Geodetic Survey of Canada

The continental adjustment of North American horizontal control networks (NAD83) was completed in July, 1986. Block adjustments of secondary control in Canada will be carried out during 1987 in cooperation with provincial agencies. Definition of NAD83 was made consistent with the Bureau International de l'Heure (BIH) Terrestrial System (BTS) and WGS84, the world geodetic system of the Defense Mapping Agency. Since January 1987, the GPS satellites have been broadcasting their positions in the WGS84 reference frame.

Automation of primary levelling data processing for the North American Vertical Datum (NAVD) project continued. Meetings were held with personnel of the United States National Geodetic Survey (U.S. NGS) for the purpose of exchanging research results, software, and data. Trial adjustments to assess various vertical datum alternatives are planned for 1987. A relational database for observations is being developed.

In 1986, GPS was used to increase the primary horizontal control density in the eastern part of the Northwest Territories (NWT). Fifty-nine points were positioned in this region which previously was served by a widely-spaced primary triangulation network. It is planned to continue primary positioning by GPS in this region in 1987. Other primary positioning by GPS was undertaken on Vancouver Island, and in the Great Slave Lake area of the NWT along the major roadways.

Further GPS positioning was completed on the Belcher Islands for mapping, and additional secondary positioning by satellite Doppler was provided in Alberta and Manitoba.

In the Yukon, inertial surveying was used to establish 132 horizontal and vertical control points to support gravity work by the Geophysics Division (formerly the Earth Physics Branch) of Energy Mines and Resources Canada (EMR).

Approximately 2900 km of precise levelling was completed in 1986. Most of this was releve-ling needed for the NAVD project, but about 300 km was for crustal movement study on Vancouver Island. About 540 km of new line was levelled, mostly in northern Saskatchewan and northern Alberta.

A major thrust of research in satellite applications was the continuing development of GPS models and software. Various GPS receivers were tested on the Ottawa three-dimensional test network, and software for the design of GPS networks was developed.

Work progressed on the design of an Active Control System and on the building of a proto-type station. This may eventually lead to a series of fully-automated tracking stations operat-ing around the clock for satellite orbit determination, differential corrections, and geodetic control.

A study was begun on modelling techniques for geodetic data that will result in a database of geodetic data which will support the mathematical maintenance of the Canadian Geodetic Net-work. The data will include field data observations, coordinates, and covariance matrices. Study was also begun on the application of optical disk technology to the management of geodetic data.

### 3. Geological Survey of Canada, Geophysics Division

In April, 1986, the Earth Physics Branch (EPB) of EMR was absorbed into the Geological Survey of Canada. The new Geophysics Division continues the activities related to geodynamics formerly carried out by the EPB.

Photographic Zenith Tube (PZT) observations from the geodynamic observatories near Ottawa and Calgary continued monitoring of the rotational time and the meridian component of polar motion. The observations have been reduced using MERIT standards and contributed weekly via the General Electric Mark III computer network to the BIH, Paris, and the International Polar Motion Service (IPMS), Mizusawa, Japan.

Canadian TRANET satellite Doppler stations collocated with the PZT instruments at the Ottawa and Calgary observatories carried out monitoring of the navigational and geodetic satel-lites to facilitate precise orbit and gravity determinations over Canada. Refraction channel output and dual receiver operation have been implemented in the new station controller and Doppler data real-time validation, station timing analysis, satellite orbit parameter updating, and daily data transmission to the U.S. Defense Mapping Agency Hydrographic/Topographic Center in Washington via the GE Mark III high-speed service are fully automated.

The geodynamics real-time multi-tasking distributed minicomputer network consisting of three HP-1000 systems has been upgraded to RTE-6/VM operation and connected to the DATAPAC com-puter communications network. An HP-A900 minicomputer using the RTE-A/VC+ operating system was connected to the distributed network as an application co-processor to enhance processing capa-bilities for GPS and very long baseline interferometry (VLBI) data reduction. GPS data reduction software packages DIPOP and PHASER have been installed and a new preprocessor is under develop-ment. In collaboration with the Geodetic Survey of Canada and the U.S. Geological Survey, GPS TI 4100 receivers were used to re-survey the first-order triangulation network across Juan de Fuca

Strait in order to determine the contemporary rates of strain accumulation in the area. GPS observing and data processing strategies for high-precision network measurements required for crustal dynamics applications have been studied. New approaches to satellite orbit calculations and related gravity field modelling have been investigated and a new method for compressed representation and reduction of satellite-to-satellite range and range rate measurements has been proposed.

The participation in the NASA Crustal Dynamics Project continued in cooperation with the Geodetic Survey of Canada and Canadian universities. As a result of NASA budget cuts, only the site at Whitehorse was occupied in 1986. Comparison of baseline lengths between 1984 and 1985 from observations at Penticton, Yellowknife, and Algonquin suggest east-west extension across Canada. Continuation of annual measurements along these baselines will be necessary to verify the significance of these early results.

The development of the Canadian Geophysical Long Baseline Interferometry (CGLBI) system has reached the experimental stage with three observing sessions on the Algonquin Radio Observatory-Dominion Radio Astrophysical Observatory (ARO-DRAO) baseline in 1986. These sessions were used to verify the newly developed CGLBI data acquisition and recording terminals. A CGLBI correlator and data processor has also been developed and operationally tested. Arrangements for the CGLBI system completion and commencement of regular observations on the ARO-DRAO baseline in 1987 are being negotiated between NRC and EMR.

#### 4. Canadian Hydrographic Service

All Canadian Hydrographic Service (CHS) horizontal control networks are being consolidated into a larger block to facilitate the transformation from NAD27 to NAD83. Transformation values, based on the Geodetic Survey of Canada primary control adjustment, are being prepared for all new charts under construction at present. A number of projects dealing with digital data and database systems have been successfully completed in the continuing development of a CHS data system.

A network of 117 permanent gauging stations continues to be operated along the coastal and inland navigable waters by the Tidal Divisions of the various regional offices of the CHS. In addition, tide and current surveys were carried out to better define tidal processes in Dixon Entrance, Hecate Strait, Baffin Bay, and Jacques Cartier Strait. Instrumentation development has resulted in portable tide gauge designs intended to provide reliable water table reductions for hydrographic survey parties. These have been successfully field tested and are being transferred to the private sector for manufacture.

Bedford Institute of Oceanography/CHS investigations into GPS concentrated on the problem of providing 2 to 5 m positioning in a survey launch in real time, with high probability of detecting errors through redundancy. Work in 1986 was done mainly by Nortech Surveys (Canada) Inc. with confirmatory checks by McElhanney Services. The technique used is carrier phase smoothing of C/A-code measurements, with differential correction. Road tests early in the year using reflector posts showed 5 m accuracy with both the TI 4100 and Trimble 4000A receivers. Rough weather tests in November on a small ship and on a launch showed field processed results of 15 m compared with dual Polarfix (laser range/bearing) and 4-range MiniRanger (microwave radar).

Loran lattice production for charts continues with the completion of coastline calibration of the Atlantic area, except for the North Shore of the Gulf of St. Lawrence. Nine new large-scale lattices were produced, and the data were extrapolated to lattice another eleven small-scale charts.

Work on the Electronic Chart Test Bed concentrated on data manipulation, with one major aim being to specify the form of the electronic chart database required. The test bed was changed to 32 bit word length, to define position worldwide to better than 1 m resolution. In a November sea test the contractor, Universal Systems Ltd. of Fredericton, demonstrated the ability to protect an official minimum dataset for safe navigation, to detect and signal over-scale display, and to enter chart corrections.



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

An inspection of 5781 control monuments and the placement of 202 new monuments was carried out in 1986. A project under contract with the University of New Brunswick (UNB) to review future control survey requirements resulting from the introduction of GPS technology was completed. The results of the project are published in Hamilton et al. (1986).

Eleven stations from the existing Maritime control network in New Brunswick were occupied by GPS receivers in July 1986. This campaign was part of a research project conducted by UNB with participation from LRIS, Canadian Engineering Surveys, and various New Brunswick Government departments. An analysis of the observations is currently underway.

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

During 1986, 928 new second- and third-order horizontal points were added to the network by Service de la géodésie du Québec (SGQ) as well as 151 km of second-order levelling. An entirely automatic process has been put into practice for horizontal data manipulation all the way from total station measurements to the final loading of coordinates into the geodetic data bank GEODEQ. Also, 3500 points (third and fourth orders) established by other organizations were mathematically integrated into the official Québec network by SGQ. Inspection activities dealt with 2000 points. In the matter of standardization, progress is quite important: two new calibration bases were established; new editions of specifications were completed for official horizontal and vertical networks and for urban complementary networks (available from SGQ); guides for utilization and maintenance of the network are in preparation; and two electronic tacheometers were tested. In microgeodesy, stability measurements of the Trois-Rivières bridge were carried out. A test of three Trimble 4000SX receivers was completed, mainly with a view to establishing field procedures and logistics as well as overall acquaintance with GPS measurements and computations within SGQ. Further preparation of second-order data was carried out for integration into NAD83 by the Geodetic Survey of Canada; an interface was developed for translating TOGAS to GHOST formats.

The research-development sector pursued or supervised several projects in analytical photogrammetry, GPS, gyroazimuths, and satellite laser ranging (SLR). Results from a joint Université Laval (UL)/University of Calgary contract show encouraging developments in photogrammetric optimization and qualification. In-house analysis of the GPS TI 4100 test of 1985 was completed and reported (Moreau, 1986); also UL personnel under contract pursued analysis of the same data, and completed the computations with the assistance of UNB; finally, the above-mentioned practical test of the Trimble 4000SX has generated sufficiently redundant observations for a quality analysis of results which will be completed in 1987. The work under a grant to UL has led to significant improvements in gyroazimuth computations (Jeudy, 1986). Under a recent contract, development is being continued on photo-electric registration of gyroazimuths. The planned SLR project of 1985 has progressed to an official Quebec/NASA agreement and the proposed "normal point procedure" is nearing completion through funding to UL. Also, the results of a previous project on laser profiling were published (Moreau et Jeudy, 1986). Both production and research staff contributed to the Canadian Institute of Surveying and Mapping (CISM) seminar on GPS held at UL. Finally, since the summer of 1986, a joint effort has been in progress toward the formulation of an official Québec policy regarding GPS.

7. Ontario Ministry of Natural Resources

A research contract has been let to study the impact of the GPS on Ontario control networks. Selected sub-networks within the province will be analysed using stress and strain techniques. This will give an indication of the nature and location of weaknesses in the nets. GPS observations will then be simulated to demonstrate their strengthening effect on the selected networks. The results should form a basis for a Ministry of Natural Resources (MNR) decision regarding the use of GPS in establishing new control networks as well as on strengthening existing ones.

Second- and third-order horizontal and third-order vertical municipal densification networks, established in 1985/86 were analysed for about 25 municipalities throughout the province. About 10 new point contracts have been let for second- and third-order horizontal and vertical

municipal control densification networks in 1986. These networks will support large-scale mapping and integrated surveys. In addition, horizontal and vertical control is being established by the MNR to support large-scale flood plain mapping. Five new control surveys for flood plain mapping are currently in progress.

Positional and associated observational data for about 1300 horizontal control stations have been stored in the Ontario control survey data bank COSINE in 1986. This gives a total of 42,300 stations complete with positional and observational data, currently residing in COSINE. COSINE is a control survey database 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.

In preparation for the forthcoming NAD83 readjustment, the MNR has successfully performed what may be the largest single, simultaneous, least-squares adjustment of horizontal control survey data in the world to date. Data for 38,856 free stations and 1124 fixed stations and involving 207,383 observations, almost the entire horizontal control network in Ontario, were adjusted in a single adjustment using program MANOR. The adjustment took 54 hours of CPU time on a dedicated DEC MicroVAX computer. The results of this adjustment have been used to further check, validate, and remove observational blunders and inconsistencies from the raw field data. Datum transformation software has been obtained which will allow relatively good NAD83 approximate coordinates to be computed prior to performing the readjustment computations. Additionally, a global geoid model based on GRS80 and associated software has been obtained for the computation of geoidal heights and deflections of the vertical. These data will be used in the generation of spheroidal heights in the NAD83 coordinate system for our control stations.

Twenty-three existing vertical control networks, involving about 1000 of the 3000 bench marks installed by MNR, have been processed, adjusted, and loaded into a temporary vertical control data bank. The total number of bench marks stored in the vertical data bank to date is about 1700. Station descriptions for nearly 2000 MNR bench marks have been stored in the data bank.

A precise calibration baseline for calibrating EDM equipment was constructed in Barrie, Ontario.

#### 8. Manitoba Department of Natural Resources, Surveys and Mapping Branch

Coordinate values for 174 inertial survey stations in southeastern Manitoba were obtained from the Geodetic Survey of Canada. This effectively completed a cooperative federal-provincial inertial surveys program which has seen inertial stations established at or near every township corner in southern Manitoba.

A second-order horizontal and third-order vertical network was established in and around the community of Churchill. This network tied in the majority of geodetic stations that existed in the area. In addition, many ties were made to the cadastral fabric to allow for the production of a cadastral overlay in subsequent mapping operations.

Over 800 km of third-order spirit levelling was carried out over a 50 township area north of and including the City of Winnipeg. A third-order horizontal and vertical network was established around the Oak Lake area in south-western Manitoba. This network was established to support the production of a controlled photo mosaic of the area. It also provides control for any future large-scale mapping.

Integration of the Dominion Land Survey System into the geodetic framework was accomplished at 20 locations.

The City of Winnipeg in conjunction with the province is densifying and upgrading the existing horizontal framework within the city limits to a density of 400 metres. Cadastral ties are being made to allow for production of cadastral overlays on large-scale city maps.

The adjustment program GHOST has been implemented on the Surveys and Mapping Branch's VAX minicomputer.

An update to the Control Surveys Index Map for the southern half of Manitoba has been published. Revisions to the northern index map are expected to be completed during 1987.

#### 9. Saskatchewan Central Survey and Mapping Agency

The data for Saskatchewan's 11 "Priority 1" networks, involving 770 stations, were assembled, evaluated, and transferred to the EMR Computer Science Centre in Ottawa, for inclusion in the NAD83 readjustment.

Survey control densification has been continuing in urban areas. Connections between the survey control system and the legal survey system were completed for 4 more cities and towns. Some 150 new control points were established. All property boundaries in the 4 communities are being coordinated from these connections.

The Dominion Land Survey System is being connected to the geodetic framework. The Survey Control Branch is computing coordinates of section corners connected by small networks to survey control points. The spacing of the connections is approximately 10 km north-south and 20 km east-west. Computations were completed for 925 connections. The Data Management Branch is producing coordinates for the remaining section corners mainly from plan information and has completed the process of converting the Township Plan distances and bearings to digital form.

The Saskatchewan Geodetic Database is operational within the Survey Control Branch. The database was implemented on the Tandy 6000 computer using the Unify database management system. The database currently contains data for all inertial survey system (ISS) and Doppler stations in Saskatchewan, as well as coordinates of section corners connected to survey control. The database is being used to manage data produced for the development of the provincial Rural Cadastral Database.

#### 10. Alberta Bureau of Surveying and Mapping

Two new EDM calibration baselines were completed this year with the Geodetic Survey of Canada doing the observational work. The new baselines are located in Lethbridge and Grande Prairie. Two GPS projects were also completed this past year with a total of 15 stations involved.

A vertical stability monitoring program has been ongoing for the Alberta survey control helix markers. The results of this study are expected to be completed early next year.

Data validation continues on survey control blocks in preparation for the NAD83 readjustment. Approximately 30% of this validation task is completed.

The interactive graphics network design package CANDSN was fully implemented early in 1986 and is currently in full production on an IBM PC AT graphics workstation.

The development of the Multipurpose Alberta Survey Control Operations and Tasks (MASCOT) computer system is well advanced with completion anticipated for mid-1987. This system will handle all the geodetic data processing for the Bureau as well as provide the access medium for geodetic information on survey control in Alberta.

#### 11. University of New Brunswick, Department of Surveying Engineering

Work on a gravimetric geoid for the whole of Canada, carried out for the Geodetic Survey of Canada, has been completed (Vanicek et al., 1986a). The geoid was compiled as the combination of long wavelength information obtained from satellite orbit analysis (GEM9) and short wavelength information contained in terrestrial/marine gravity using a modified Stokes's approach. Geoidal heights referred to GRS80 plus their standard deviations have been computed on a 10'x10' geographical grid (Vanicek and Kleusberg, 1986a) and are available on magnetic tape from either the Geodetic Survey of Canada or UNB. Work on geoid improvement through the incorporation of other kinds of data and through the application of various modified integral kernels continued (Vanicek and Kleusberg, 1986b).

A package of computer programs needed to test the quality of marine gravity data by means of satellite altimetry was developed for the Bedford Institute of Oceanography (Vanicek et al., 1986b). The idea behind the comparison is a two-dimensional filter applied to gridded satellite altimetry, the output of which is equivalent to truncated Stokes' convolution (spatial geoidal height). Various modes of display on a DIPIX ARIES-II system have been applied to resulting data sets.

A cooperative project on the improvement of modelling recent vertical crustal movements has been undertaken with the Swedish Royal Institute of Technology.

The UNB earth tides station continues to operate in an automatic mode collecting tilt, gravity, and atmospheric data. Analysis of newly acquired data is underway.

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, visco-elastic, compressible, heterogeneous, rotating, and self-gravitating earth. Anisotropies in the radial direction are considered.

Field tests on the implementation of trigonometric height traversing in geodetic levelling have been completed confirming the conclusions reported in 1985. An M.Sc. thesis by Kornacki (1986) gives additional information on the computerization of the motorized height traversing. The study on the influence of atmospheric refraction in trigonometric height traversing continues.

Work also continues on the implementation of UNB's generalized method for the analysis of deformation surveys (Chrzanowski and Chen, 1986; Chrzanowski et al., 1986a; 1986b; Faig et al., 1986), including the use of the method in designing deformation monitoring schemes (Chrzanowski et al., 1985). The generalized method has been used in the analysis of tectonic movements in the Huaytapallana mountain range in Peru (Chrzanowski and Welsch, 1986). A modular computer program DEFNAN for the generalized method (Chrzanowski et al., 1986a) is being documented for use on mainframe computers as well as on an IBM PC AT.

Work continues on deterministic modelling and prediction of deformations (Chen and Chrzanowski, 1986) with emphasis on the use of non-linear elastic finite element analysis. The computer program FEMMA has been developed and successfully used in the interpretation and prediction of ground subsidence in mining areas.

The project on the use of GPS in deformation surveys continues. A test network of nine stations with lines ranging from 600 m to about 30 km was established in the area of the Mactaquac power dam during the summer of 1986. TI 4100 and WM101 receivers were used in two independent survey campaigns. Preliminary results of the WM101 survey, which was conducted in cooperation with Usher Canada Ltd., have given average loop misclosures of 2 ppm for an average loop length of 40 km. The project on the use of GPS in ground subsidence in oil fields in Venezuela is at the stage of monumentation of the ground stations. The first field campaign is scheduled for April 1987. Use of instrumented balloons for improving the model of the effect of the troposphere on GPS measurements is being investigated for implementation in the Venezuelan project. Research on the integration of geodetic levelling with GPS in the subsidence studies is in progress.

Work has continued on the enhancement of the GPS relative positioning software package DIPOP (Langley et al., 1986). Different error sources in satellite positioning have been studied and first results regarding ionospheric delays of GPS signals have been published by Kleusberg (1986a). Other GPS static positioning work includes an analysis of prototype Macrometer II observations on long baselines (Okumu, 1986).

Research on the capabilities of GPS for precise kinematic positioning and navigation has been initiated (Kleusberg, 1986b; Kleusberg et al., 1986). Several applications have been studied (Kleusberg, 1986c; Kleusberg and Wells, 1986) and work continues on combining GPS with other position and orientation sensors. Further research regarding the reduction of biases and errors resulting from different sources is planned for the immediate future.

The UNB Satellite Doppler Receiving System (UNBSAT) consisting of a CMA-722B receiver interfaced to an Apple II microcomputer has been further developed (Quek and Langley, 1986a; 1986b).

The system allows established survey organizations to expand their Transit positioning capabilities by reactivating their moth-balled CMA-722B receivers, allows developing nations to carry out Doppler surveys economically, and provides an educational tool for training surveying engineers in satellite positioning techniques.

The standard procedure for computing secondary phaselag in the propagation of low frequency radiowaves has been improved by expanding the range of permitted conductivity and permittivity values and by introducing a useful interpolating formula (Mahmood, 1986).

#### 12. Université Laval, Département des Sciences géodésiques et télédétection

En métrologie appliquée à la géodésie, trois projets ont été complétés sous la direction de J. Jobin. Le premier a conduit au développement et à l'installation d'un système interférométrique de calibrage des mires invar et des rubans (Lhimeur et Jobin, 1986). Le deuxième projet a permis de faire l'évaluation de divers théodolites munis de télémètre du type station totale (Jobin et Plante, 1986). Le troisième projet a conduit au développement et à la mise au point d'un système de positionnement d'écrans optiques pour des études en balistique pour le compte du Centre de Recherche de la Défense de Valcartier (CRDV). Deux nouveaux projets ont été entrepris par J. Jobin, il s'agit d'une étude sur le comportement des fils de Kelvar servant au calibrage dans le tunnel balistique du CRDV et d'un projet concernant le calibrage des prismes utilisés lors des mesures de haute précision. Un troisième projet sur l'automatisation et l'amélioration de la précision du gyrocompas suspendu a démarré sous la direction de L. Jeudy. L'objectif est de développer une station entièrement automatique permettant d'obtenir l'azimut avec une précision de  $\pm 5''$  (Jeudy, 1986).

Dans le domaine de la géodésie spatiale, l'analyse et la comparaison des résultats obtenus avec différents récepteurs GPS sur le réseau de Sainte-Foy se sont poursuivies sous la direction de J.G. Leclerc. Une analyse des principaux modèles mathématiques est effectuée de même qu'une étude des effets de la réfraction ionosphérique en utilisant des modèles ionosphériques globaux. Le projet de recherche dans le domaine des mesures laser sur satellite développé en collaboration avec la NASA par L. Jeudy a progressé. L'implantation du logiciel GEODYN est en voie d'être complétée. Le projet sur l'utilisation des données Doppler du projet ADOS pour l'analyse du réseau géodésique marocain a été complété sous la direction de P. Gagnon (Ait Belaid et Gagnon, 1986).

Dans le domaine de la géodynamique, l'expérience de détermination de l'azimut gyroscopique développée par L. Jeudy a été poursuivie. Une précision de  $0.1''$  a été obtenue après une nuit d'observation (6400 mesures). Les dernières améliorations ont consisté à mesurer en continu la vitesse de rotation du gyroscope et à raffiner la méthode de détermination de la position d'équilibre de moment nul du raban de suspension. Des nouvelles formules plus précises pour le calcul des matrices de variances-covariances des paramètres ont été développées.

En hydrographie, J.G. Leclerc a poursuivi un projet sur le modelage du déphasage secondaire des ondes Loran-C occasionné par les variations des constantes géoélectriques ainsi que par la topographie le long du parcours de propagation. Un deuxième projet a été complété pour déterminer, pour la sécurité de la navigation, les hauteurs libres des fils de haute tension en considérant divers paramètres comme le vent et les charges de glace.

#### 13. University of Toronto/Erindale College, Department of Survey Science

Geodetic activities in 1986 included a research project on the impact of GPS on the horizontal control network for the province of Ontario. The research was supported by the Surveys and Mapping Branch of the Ontario Ministry of Natural Resources.

Research for a master's degree thesis on the accuracy of the forthcoming NAVD based on various adjustment constraining schemes is still underway.

Further studies for the long-term monitoring of the Ontario Hydro Cornwall Dyke were performed during the latter part of 1986.



A study of the bias induced in GPS positioning by improper weighting of data (Wassef, 1986) brought home the need to develop a processing methodology allowing for the deviation of GPS measurements from the Gaussian distribution and restricting the rejection of outlying observations. The theoretical deductions are being substantiated by analyses of data especially compiled for this research by the U.S. Defense Mapping Agency.

The comparative study of the methods of analysis and evaluation of levelling errors in the context of the task of the Special Study Group 1.74 of the International Association of Geodesy continues. The current work at Erindale aims to develop a reliable statistical technique to detect systematic errors in the presence of pseudo-systematic effects superposed on heterogeneous random variation using field data provided by the U.S. NGS. The results are expected to bear on the levelling network adjustments for the NAVD as well as on the use of levelling data in crustal movement studies.

Work has begun on the development of an improved image sensor with industrial and geodetic applications.

The perspectives of an integrated geodetic network in Africa and the prospects and fields of international cooperation to study recent crustal movements in Africa have been outlined.

#### 14. University of Manitoba, Department of Geological Sciences

Ocean bottom coupling processes are being studied using satellite altimeter data. An ocean-solid earth coupling study has been completed using Seasat altimetry data, over the Hudson Bay area of Canada and the East China Sea (Moon et al., 1986). The results obtained are planned to be refined using Geosat data, depending on its availability. Theoretical aspects of the coupling processes are also being investigated, including topographic effects.

Quantitative systematic study for the integration of satellite data with available geophysical data are being investigated and tested with localized data sets (Moon and Ushah, 1986).

#### 15. University of Saskatchewan, Department of Geological Sciences

Work continues on the response of the earth to sources of transverse stress at the surface. A paper showing how Green's functions for transverse stress may be computed has been published (Merriam, 1986) and work continued to apply these functions to the interpretation of tidal strain data.

Work done over the last two years has shown that there may be some potential for monitoring large-scale flows in the fluid core through geodetic observables such as the Jeffreys coefficient  $J_2$ , polar motion, and length of day. All of these imply that any decade-scale pressure anomalies associated with flow in the core must be less than  $10^4$  Pa.

As part of its budget for a new building to house the Department of Geological Sciences, the University of Saskatchewan has undertaken to build a new seismic vault on a site 30 km east of Saskatoon. The new vault will also operate as an earth tides station with separate piers and provision for three component long baseline (about 100 m) tiltmeters and strainmeters. Construction is due to commence in the summer of 1987.

#### 16. University of Calgary, Department of Surveying Engineering

Research continued on the use of inertial technology in geodesy and the real-time integration of inertial and satellite data. A survey of some open problems in inertial modelling was made on the occasion of the third inertial symposium (Schwarz, 1986a). First steps toward their solution have been discussed by Schwarz and Vassiliou (1986) using an eigen vector approach and by Schwarz (1986b) using analysis techniques developed in oscillation theory. A detailed report on postmission estimation of the anomalous gravity vector from the system output has been published by Forsberg (1986). A comparison of Kalman filtering and postmission adjustment techniques for gravity vector determination shows no significant difference in the results (Forsberg et al., 1986). A comparison of estimation procedures for inertial networks (Schwarz and Arden,

1986) summarizes the results achieved over the last few years. An extensive survey of accelerometer designs by Rueger (1986) was published as a companion volume to the existing one on gyroscopes by the same author. Results of the detailed studies on GPS/INS integration, made during the last two years, were confirmed by the analysis of actual data sets (Cannon et al., 1986). It appears that moving land vehicles and aircraft can be positioned with an accuracy of better than 0.5 m if no cycle slips occur in the GPS data. With present receivers and their cycle slip problems, the accuracy is at the level of 1 to 2 m (1 $\sigma$ ). If the GPS receiver in the integrated system is replaced by a precise radio-navigation system, accuracies of 3 to 5 m can be achieved under optimal conditions (Wong and McMillan, 1986). A new method of geoid determination using GPS/INS has been discussed by Schwarz (1986c). Research in this area will profit from the recent acquisition of an inertial strapdown system and two GPS receivers by the University of Calgary (U of C).

In gravity field approximation, the study of new numerical techniques has been further extended and a major contribution to airborne gradiometry has been made. Schwarz (1986d) has overviewed some unsolved problems in gravity field approximation. The high frequency spectrum of the anomalous gravity field has been investigated and associated modelling questions addressed. Sideris and Schwarz (1986b) have studied the effect of geopotential errors on local solutions and the best use of local data to reduce the effect of such errors. Problems of data combination have been addressed by Sideris and Schwarz (1986a) who have reconsidered the best use of satellite and terrestrial data for height datum definition. A comparison of numerical techniques for airborne gravity gradiometry has been given by Vassiliou (1986a) and a new computer-efficient method for the combination of second-order gravitational gradients has been proposed (Vassiliou, 1986b). The use of such techniques in geophysical prospecting has been discussed by Schwarz et al. (1986), whereas their contribution to geoid resolution has been considered by Vassiliou (1986c).

An automatic vehicle location group was formed by E.J. Krakiwsky in April 1986. The group is currently building a prototype system which comprises a Trimble GPS receiver interfaced with a Macintosh Plus microcomputer. An electronic map and relational database of routes in Alberta have been built, and an optimum route algorithm has been programmed.

A multi-station GPS software package is under continuous development at U of C.

The statistical and harmonic analyses of the Permanent Service for Mean Sea Level global tidal data are completed, and the estimates of eustatic sea level change and regional vertical crustal motion in Fennoscandia and North America have been reported (Nakiboglu, 1986a; 1986b). The earth's rotational response to ongoing eustatic sea level rise has been quantified and interpreted by Nakiboglu and Pointon (1986).

A thermo-mechanical model for sedimentary basins has been developed and used in studying the evolution of the Sverdrup Basin (Nakiboglu and Hastaoglu, 1986; Stephenson et al., 1986).

#### 17. Nortech Surveys (Canada) Inc.

A series of land kinematic tests was conducted to assess the accuracy and reliability of GPS in absolute and relative positioning modes. Both the P- and C/A-codes were tested. An algorithm was also developed to combine code and carrier phase measurements (Lachapelle et al., 1986b). The effect of receiver tracking bandwidth on positioning accuracy was studied. Baselines of up to 1000 km were used to assess the relative positioning mode (Lachapelle et al., 1986a). The accuracy obtained varied from 8 m for absolute positioning with the single frequency C/A code to 1 m for relative positioning using a combination of code and carrier measurements. The accuracy and reliability of the future 21-satellite GPS constellation were analysed as a function of parameters such as satellite geometry, receiver and antenna characteristics, atmospheric and multipath effects, positioning mode, and application type (Lachapelle, 1986; Lachapelle et al., 1986c). Field portable software was developed for accurate kinematic differential GPS positioning, both for postmission and real-time applications. Preliminary tests on selected data link types were conducted.

The accuracy of precise static GPS differential positioning was analysed over baselines of 10 to 500 km. Repeatabilities of 0.2 to 2 ppm were obtained using carrier phase data sets collected over successive days (Lachapelle and Cannon, 1986). These results were obtained with



U.S. NGS program PHASER using the non-difference mode. Subsequent to these tests, a program called NOVAS (NORtech Vector Adjustment Software) was developed for cost effective field applications. The double difference method is used. The program has been operational since mid-1986 and has been used satisfactorily on many large GPS surveys in many parts of the world.

Further enhancements to the Airborne Laser Terrain Profiling System (ALTPS) were made. ALTPS I was used operationally on a large mapping project in Indonesia. Development of ALTPS II, which contains major hardware and software improvements, was initiated. The system is expected to become operational in early 1987.

The Norstar Instruments Division continued development of its NORSTAR 1000 GPS receiver. Single point and differential software for kinematic applications was developed. The first units are expected to be available by mid-1987. The standard unit will be 5 channel, with a 7-channel option available for high reliability requirements.

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## I (B) GRAVITY

Compiled by: A.K. Goodacre

1. Summary
2. Geological Survey of Canada
3. Nova Scotia Research Foundation
4. University of Calgary
5. University of Laval
6. University of Manitoba
7. University of Newfoundland
8. University of Western Ontario

### 1. Summary

#### (a) Instrumentation

A new data logging system, termed CIBAL and developed at the Atlantic Geoscience Centre, was successfully tested on three production cruises and is ready for routine operation in 1987. The program to upgrade the free-fall absolute gravity meter for Canadian field conditions is continuing, with absolute determinations of gravity having been successfully made in Ottawa and Calgary as part of a plan to provide control for a future readjustment of the Canadian Gravity Standardization Net. An evaluation of the LaCoste and Romberg Model D type gravity meter for precise gravity surveys has been completed as part of an International D-meter Campaign undertaken jointly by the Geological Survey of Canada and Institutes in Japan and West Germany.

#### (b) Surveys

During 1986 about 2,500 static gravity observations were made on land, on ice and under-water and about 2,300 line kilometres of dynamic gravity data were logged at sea. The surveys were carried out in the Yukon, the Northwest Territories, The Arctic Ocean (Canada Ice Island), Prince Edward Island, and the Gulf of St. Lawrence.

One of the highlights of the gravity surveys is that the regional survey in the Yukon is, so far, the largest one of its kind to use the satellite-based Global Positioning System (GPS). High-precision gravity surveys, designed to study crustal stability, were carried out on Vancouver Island and in the Ottawa-Hull Region.

#### (c) Database and maps

Colour DNAG gravity maps of the Arctic Ocean and Innuitian Region have been compiled and printed by the Geological Survey of Canada. In addition, numerous Applicon colour maps have been produced in response to requests from staff of the Geological Survey of Canada and outside agencies. Four maps of the Canadian Geophysical Atlas and two sheets comprising the DNAG Gravity Map of North America are in the final stages of preparation.

#### (d) Interpretation

The interpretation of gravity data is continuing on several fronts.

Within the Geological Survey of Canada, maps of the horizontal gradient of gravity have been used to locate and examine tectonic features of North America, and a photograph of the horizontal gradient map subsequently appeared in July, 1986 on the front cover of the Transactions of the American Geophysical Union (EOS). The concept of "thermal isostasy" is being applied to the Canadian continental lithosphere. An integrated geophysical and petrological study of the deep crustal structure and tectonic history of the Kapuskasing uplift of Ontario was completed. On a more localized scale, gravity anomalies have been used to define the structure of gravity intrusions in southern Nova Scotia, western Ontario and the Sept-Îles region of the Gulf of St. Lawrence.

The Nova Scotia Research Foundation completed an interpretation of gravity data in the Windsor-Kennetcook area of the Minas sub-basin.

Both theoretical studies and field investigations are continuing in Canadian Universities. For example, the University of Calgary is involved in an evaluation of airborne gradiometry and the University of Manitoba is working on mathematical methods to combine geophysical data from different types of surveys. L'université de Québec à Montréal has established a gravity transect across the northern Labrador trough and specific geological features are being studied by staff and students at l'université Laval (e.g. Mont Megantic), the University of Manitoba (e.g. Falcon Lake granite stock) and the Memorial University of Newfoundland (e.g. Ackley granite). The University of Western Ontario is studying possible spatial correlations of seismic activity and horizontal gravity gradients.

## 2. Geological Survey of Canada

### (a) Geophysics Division

(i) Gravity Standards (R.K. McConnell). Inspection and updating of the Canadian Gravity Standardization Net was carried out on the east coast of Hudson Bay and on Vancouver Island. To provide absolute datum control for a future readjustment of the net, a plan was developed for absolute measurements at Ottawa, Winnipeg, Calgary, Yellowknife, Resolute Bay and Alert. Observations of absolute gravity were made successfully at Calgary and Ottawa. Problems with ground motion from nearby equipment spoiled measurements at Winnipeg but this experience provided valuable information to update site selection criteria.

(ii) Gravity Surveys (D.W. Halliday, R.V. Cooper and P.J. Winter). During 1986 about 2,500 static gravity measurements were made on land and in coastal areas. Approximately 2,300 kilometres of dynamic gravity data were logged at sea. Many of the surveys were made in conjunction with other GSC Divisions and other agencies. A summary is given below; details may be found elsewhere in the report.

Yukon. About 955 new gravity stations were observed to complete regional mapping north of latitude 64°N, from the Alaska-Yukon boundary east to the Dempster Highway.

Northwest Territories. In conjunction with a survey by the Canadian Hydrographic Service, 369 gravity stations were observed at a 6 kilometre spacing on the ice-covered surfaces of Com-mittee Bay and Pelly Bay.

A total of 63 gravity stations was observed along refraction seismic lines near the Canada Ice Island. In addition, gravity readings were logged along the drift path of the Ice Island.

In the District of Mackenzie, 337 gravity stations were observed on profiles across the Thelon Front in the area northeast of Artillery Lake.

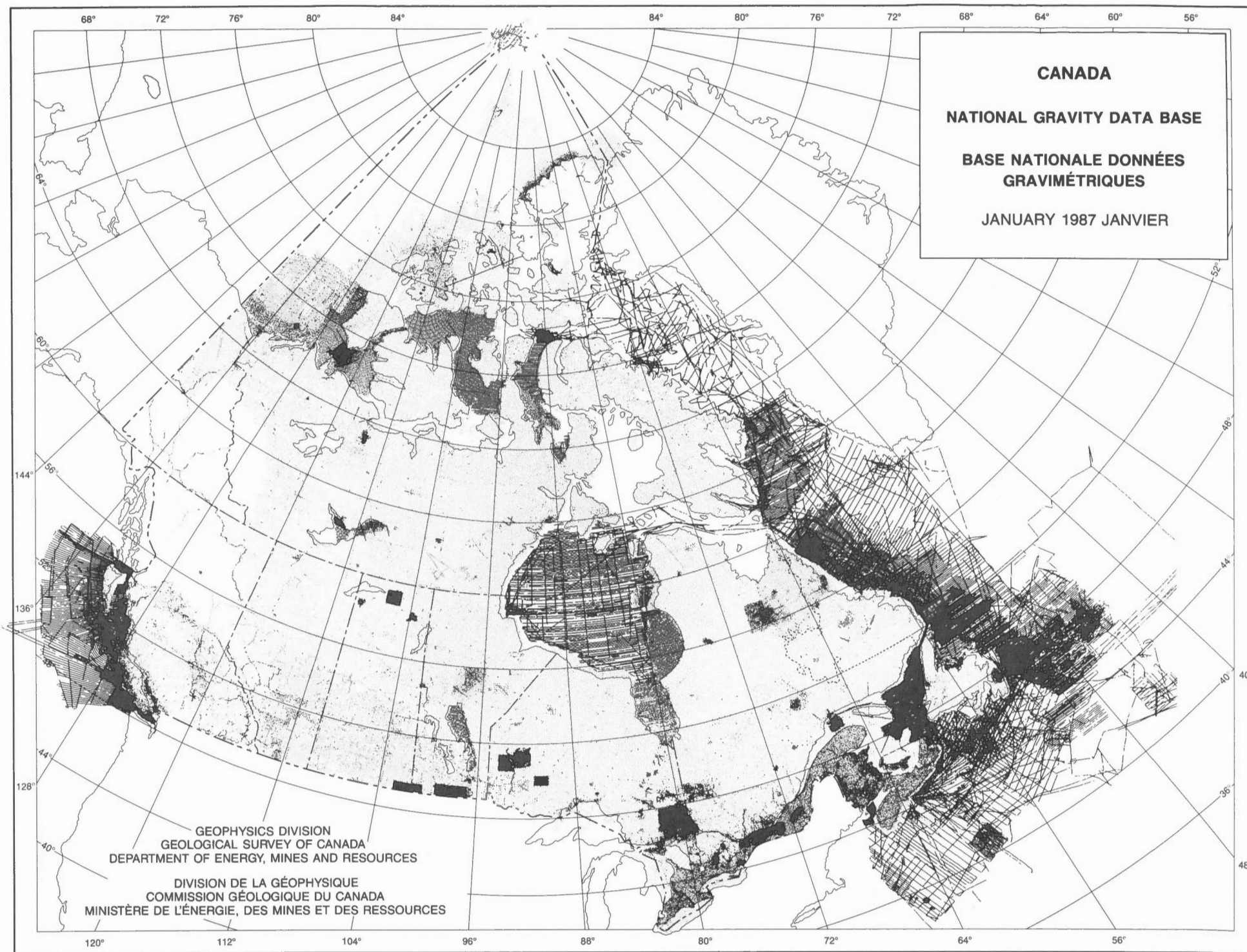
Eastern Canada. On Prince Edward Island, 329 gravity stations were observed at a 6 kilometre spacing.

In Newfoundland, 180 underwater gravity stations were observed in Trinity and Bonavista Bays and about 250 gravity stations were observed on the adjacent land areas. These surveys were performed in collaboration with Memorial University of Newfoundland.

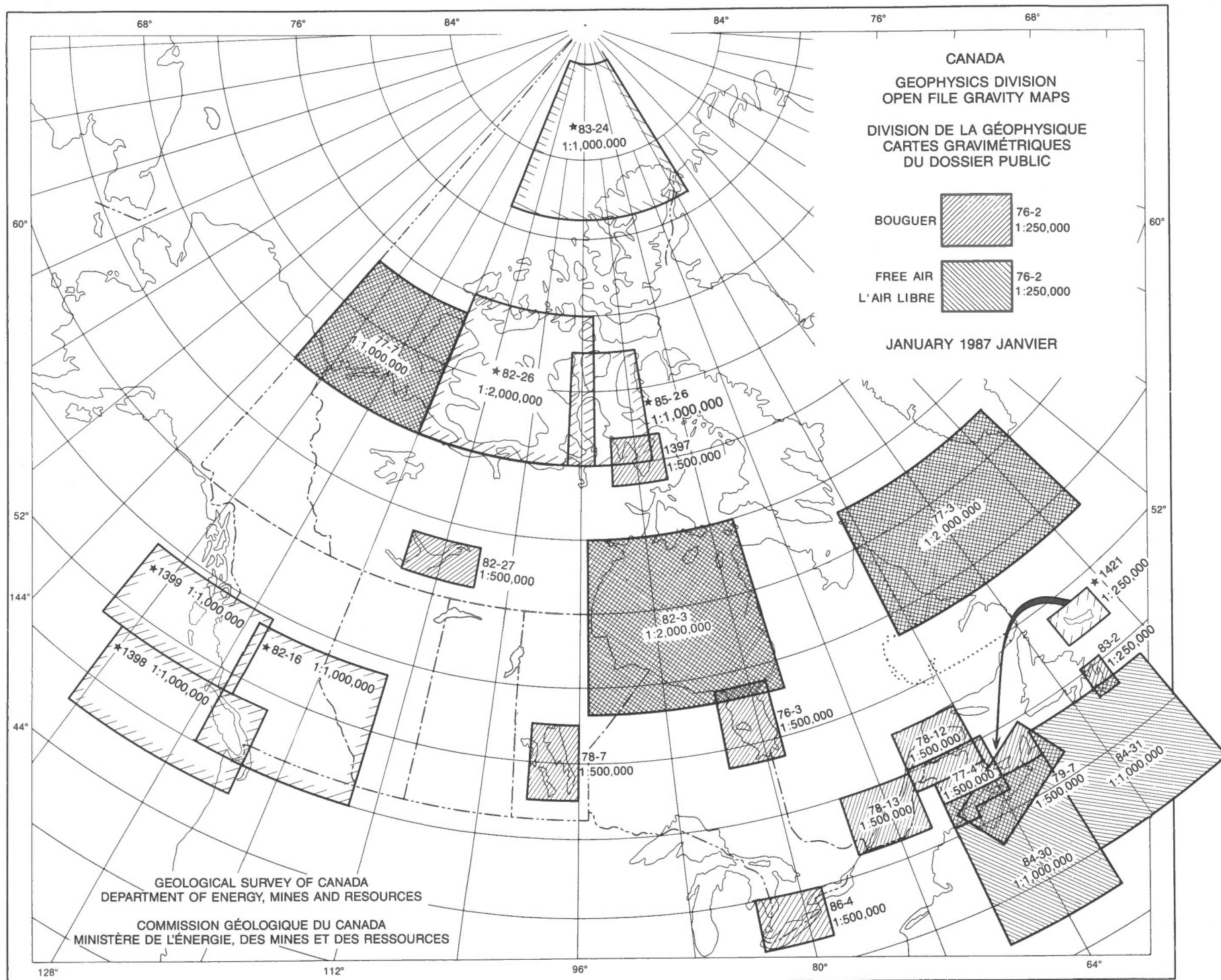
In the area south of Sept-Iles about 2,300 kilometres of dynamic gravity data were logged at sea. The survey was done jointly by the Geophysics Division and the Atlantic Geoscience Centre.

(iii) Gravity Data Base and Map Production (J.F. Halpenny, D.B. Hearty, L.A. Warren, J. Rupert, A.K. Goodacre and R.A.F. Grieve). Numerous Applicon colour maps were produced in response to internal and external requests. In addition to gravity data base data plotted at a variety of scales, projections and data formats (including anomalies and vertical and horizontal gradients), the same plotting programs were used with other datasets, such as a world topography database, detailed Canadian and US topography and some magnetic data.

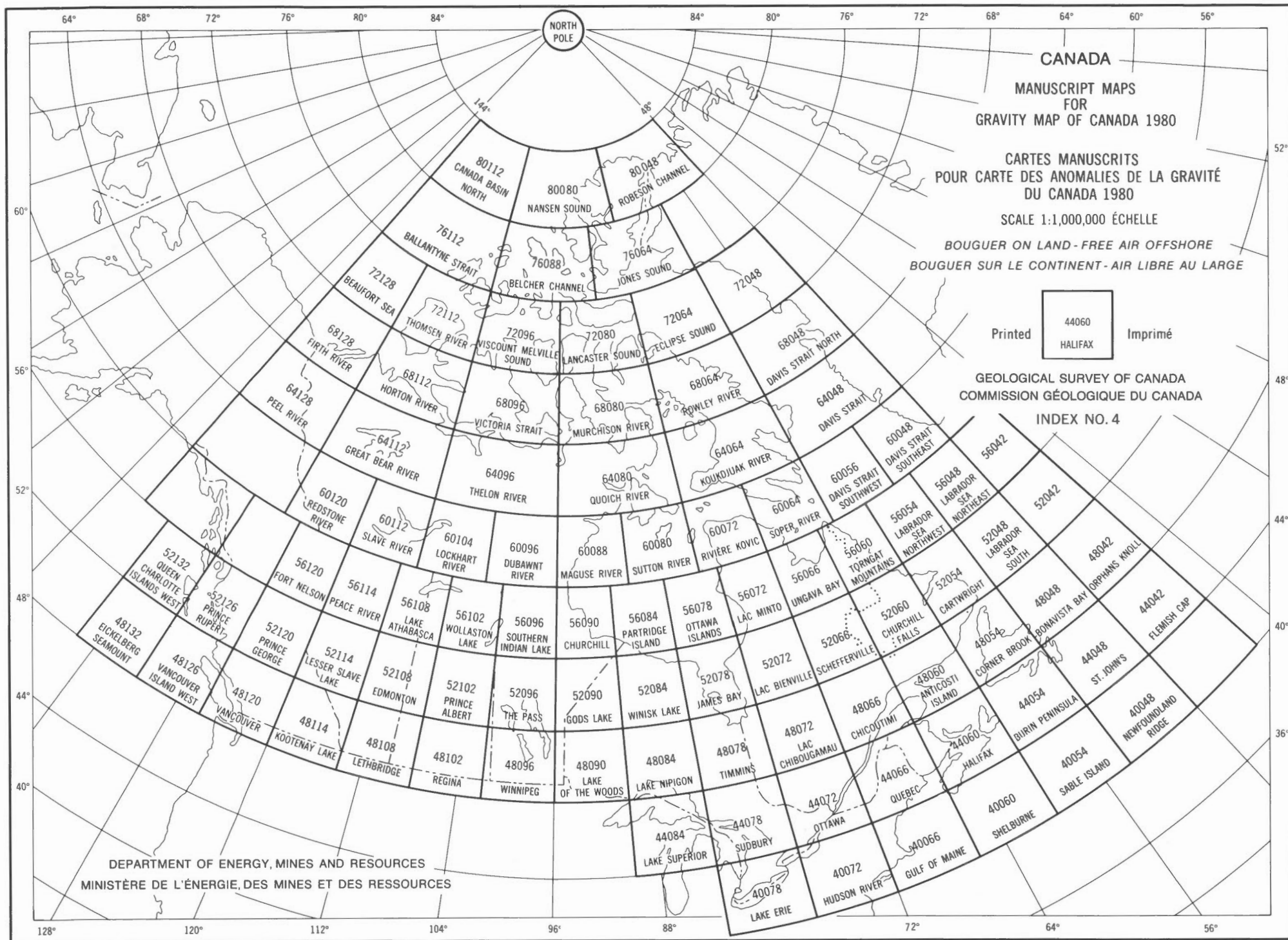








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In 1986 the Geophysics Division started using a new procedure to produce high-resolution colour separations ready for printing. This procedure employs the EMR Cyber computer and the Optronics film-writer at Environment Canada to produce dot-screen colour separation ready for press, thus bypassing much of the manual work in map preparation.

The Geophysics Division is involved in producing a number of gravity maps in the Decade of North American Geology (DNAG) series. The Arctic and Innuitian sheets were produced in conjunction with L.W. Sobczak of the Lithosphere and Canadian Shield Division. The East Coast sheet, prepared in conjunction with the Atlantic Geoscience Centre, is in the final editing stage.

Colour separations and text for four Geophysical Atlas Maps of Canada, (Free air, Bouguer, Isostatic residual and Bouguer horizontal gradient) have been prepared. A computer program exists to produce colour separations for the National Earth Sciences Series directly from the gravity data base, and two prototypes were prepared early in the year.

The Orca image processing system has been continuously improved with new software and hardware. The raster display software was speeded up, a Calcomp plotter driver (connecting to the Departmental CSC Calcomp plotter through a link to the Cyber) was installed, as were new character fonts. The system now employs a Unix V operating system, 8 megabytes of memory and 160 megabytes of disk storage. A major application of the Orca has been to study gravity data sets. An Orca shaded-gravity image was displayed on the cover of EOS, July 8, and various gravity images were used to study linear features and for displays. The system has also been used in investigations of Seamark ocean bottom images, and to produce displays of Radarsat and Venus topography images.

(iv) Precise Gravimetry (R. Bastien and A. Lambert). Three LaCoste and Romberg model D gravity meters were deployed to establish a local network of four high-precision gravity stations in Ottawa and the surrounding area to monitor secular changes of gravity as an aid to studies of crustal stability.

The analysis of gravity meter calibration data gathered during the International D-meter Campaign in 1983 was completed. The analysis was a joint undertaking by the Geological Survey of Canada and West German and Japanese institutions. The results provide a more reliable assessment of the accuracy of the LaCoste and Romberg model D gravity meter used in many geodynamic applications.

(v) Absolute Gravity (P.N. Courtier, A.K. Goodacre and J.O. Liard). Improvements to the laser optical system and associated electronics resulted in a significant (20 $\mu$ Gal) reduction of noise in readings attained from the absolute gravity meter on the gravity reference pier in the Geophysical Laboratory, Ottawa. A tentative location was chosen for the Canadian Absolute Gravity Service facility at the CCRS satellite tracking site north of Gatineau, Quebec. A multiple regression analysis of gravity observations and air pressure, temperature, well water level and humidity readings was carried out as part of a program to study the effects of environmental factors on gravity readings.

(vi) Instrumentation (R. Bastien, R.J. Beach and C. Gagnon). A pronounced annual variation in recording earth-tide gravity meter readings has been observed consistently for the past few years and an experiment has been initiated to determine the cause. Laboratory tests with a view to upgrading the free-fall absolute gravity meter for Canadian field conditions are continuing with absolute determinations of gravity having been made at Ottawa and Calgary.

(vii) Gravity Interpretation (R. Grieve, A. Goodacre and R. Gibb). A gravity trend map of the North American continent has been prepared from a horizontal gravity gradient map and subdivided into a number of gravity domains. Correlation of certain gravity domains with structural provinces defined largely on the basis of geological criteria demonstrates the utility of the gravity trend map for structural studies. One such study made with M. Thomas and V. Sharpton concludes that North America grew outward from the Archean, Superior and Wyoming Provinces by successive plate-tectonic accretion of microcontinents and island arcs.

Maps of horizontal gravity gradient have been used to locate and examine Precambrian structural province boundaries buried beneath the midcontinent region of North America. New interpretations have been proposed for the southern and western boundaries of the Superior

Province and for the eastern boundary of the Wyoming province. The latter boundary has been traced from southern South Dakota north to the Canadian Shield where it is proposed to lie near the northwestern margin of a 1900-1600 M yr magmatic belt. Major faults extending hundreds of kilometres are also evident in the gradient maps.

The gravity anomaly associated with the Eye-Dashwa Lakes granitic pluton was interpreted and a report submitted to AECL as part of the Canadian Nuclear Fuel Waste Management Program. Two-dimensional modelling suggests that the pluton has inward dipping contacts and reaches a maximum depth of 5 km. The pluton has been extensively studied by a variety of geophysical methods and is one of several plutons that occur in the Wabigoon subprovince of the western Superior Province.

(viii) Charlevoix Observatory (A. Lambert and J. Labrecque). A ten-year experiment to compare the performance of short-baselength, near-surface tiltmeters (GSC) with borehole tiltmeters (Dalhousie University) and a levelling array (l'Université Laval) was completed in 1986. The attenuation with depth of water level effects on tilt has been determined. All three methods were affected by water level variations; the water level effect varied from 1 microradian per metre at the surface to less than 0.1 microradian per metre at a depth of 110 m. The total r.m.s. noise level on tilt varied from 1-3 microradian for the new-surface installations to 0.2-0.3 microradian at 50-100m depths. The levelling array put a limit of 0.5 microradian/year on secular tilt from 1976 to 1986 at the Observatory.

#### (b) Lithosphere and Canadian Shield Division

(i) Canadian Shield Studies (P.J. McGrath and M.D. Thomas). In conjunction with the geological mapping programs carried out by GSC in the NWT along the Thelon Tectonic Zone, 334 gravity measurements were obtained at a nominal spacing of 2 km along five profiles which cross from the the eastern Slave Province into the North Keewatin Platform of the northwestern Churchill Province. The geophysical survey included in situ magnetic susceptibility determinations and density measurements of samples collected at gravity stations which occur on or close to basement outcrops. Gravity and magnetic anomalies over the Thelon Tectonic Zone will be modelled in order to extend surface geological information to depth and to provide a basis for the development of dynamic geological models.

An integrated petrological-geophysical study of the deep crustal structure and tectonic history of the northern Kapuskasing Uplift of Ontario was published. Interpretations of gravity and magnetic anomalies indicate that the Lepage Fault dips 60°-70°NW with 7-10 km of west-side-down displacement. Also, the northern Fraserdale-Moosonee block appears to be a pop-up structure having been uplifted 10-15 km along inward-dipping thrust faults. 2 1/2-D gravity modelling of Bouguer anomalies in the southern Central Metasedimentary Belt (CMB) in the Grenville Province suggests that most, if not all, of the gravity variations within the CMB can be explained by structures located within the uppermost 4 km of crust. Felsic intrusions can be divided into two categories on the basis of their depth extent: relatively thick intrusions (2.4 to 4.2 km) include the Weslemkoon, Elzevir, Northbrook and Mazinaw Lake bodies, whereas relatively thin bodies (0.2 to 1 km) include the Cross Lake, Mellon Lake, Addington and Deloro bodies. Belts of mafic and intermediate metavolcanics and gabbro intrusions are modelled as having depths of 3.4 and 2.6 km, respectively. The results of gravity modelling suggest that the crust below a depth of about 4 km under the CMB is laterally homogeneous and this may be an important constraint in evaluating models proposed for the development of the CMB.

(ii) Arctic Studies (L.W. Sobczak). In April and May, using the Canadian Ice Island as a base, 77 gravity and 61 water depth observations were made on the polar continental shelf off northern Axel Heiberg Island by J.R. Weber and L.W. Sobczak. The stations, positioned by a SYLEDIS navigational system, were located along the seismic lines established concurrently in connection with the 1986 Ice Island Seismic Refraction Survey.

Several papers and a map have been completed and accepted for publication in the forthcoming DNAG Arctic Volume, Transect Volume and Innuitian Volume.

(iii) Appalachian Studies (M.D. Thomas). 2 1/2-D gravity modelling of negative gravity anomalies associated with the Wedgeport granite and South Mountain Batholith, Nova



Scotia indicate that these intrusions have thicknesses of approximately 8 and 25 to 35 km, respectively. Regionally higher gravity values along the northwest flanks of the intrusions are attributed to a block of buried Precambrian crust composed of rocks similar to those exposed in the neighbouring Caledonia Highlands, Cobequid Mountains and Antigonish Inlier.

(vi) Interpretation Methods (E. Schwarz). An automatic modelling method for gravity data has been devised which is applicable to layered structures with or without within - layer sources. An initial solution is obtained using infinite horizontal plates, the depths of which are subsequently adjusted using a thin plate model. Tests show that conversion is rapid. The aim is to obtain a fast, flexible method for 2-dimensional data distributions.

(c) Atlantic Geoscience Center (J. Woodside)

(i) Gravity Surveys. In June, a detailed survey with a line spacing of about 2 km was undertaken jointly by the Geophysics Division and the Atlantic Geoscience Centre of the prominent gravity anomaly south of Sept-Iles, in the St. Lawrence estuary. The intention was to outline the offshore extension of the anomaly for analysis to determine if the source is an anorthosite complex similar to those observed to the northeast, or a large, layered mafic intrusion as proposed by T. Feininger.

(ii) Data Handling and Map Production. On 26 January, 1986, all AGC marine gravity data were released through open file EPB 85-32 along with a report on the integration of Atlantic Geoscience Centre Marine Gravity Data into the National Gravity Data Base. Approximately 339,000 5-minute data values with an internal consistency of  $\pm 1$  to  $\pm 5$  mGals and an overall accuracy of 2.5 mGals were added to the National Gravity Data Base. More than 2,000,000 1-minute data points were archived separately for future detailed study.

Five areas were selected for the production of gravity maps in the National Earth Science Series (NESS): NK-19 (Gulf of Maine), NK-20 (Shelburne), NN-21 (Cartwright), NN-22 (Labrador Sea South), and NO-21 (Labrador Sea Northwest). Editing of data for these maps was done at AGC and the Geophysics Division. Base map underlays have been created for some of these sheets and publication is scheduled for 1987.

Compilation of data was completed for a map to accompany a volume on the Geology of the Continental Margin off Eastern Canada as part of the AGC contribution to the Decade of North American Geology (DNAG). Data from American, Danish and French sources were merged with GSC data at the Geophysics Division. This map is also scheduled for printing in 1987.

Modelling of gravity data along transects across the continental margin of eastern Canada provided estimates of sedimentary and crustal thickness for use in compilation of a crustal thickness map to be published as a contribution to The Geology of the Continental Margin off Eastern Canada for DNAG.

A publication comprising 9 maps of the Labrador Sea including Free-air and Bouguer gravity maps was published. The maps were manually compiled and contoured on a scale of 1:200,000 on a Lambert Conformal projection (with standard parallels of 45 and 66 degrees north). Comparison of these gravity maps with those compiled digitally from adjusted gravity data in the Labrador Sea shows little difference.

(iii) Data Interpretation. Software development continued principally on the MicroVAX. During the summer, a student was hired to examine, modify, and test software developed at the Lamont-Doherty Geological Observatory for computing and modelling the admittance function for observed gravity and bathymetry profiles. By year end the programs were being tested on simulated gravity and bathymetric profiles.

Modelling software acquired from the firm of Paterson, Grant and Watson as part of a contract to process and analyse aeromagnetic data from the St. Pierre Bank region (see Chapter on geomagnetic surveys) was implemented on the VAX750 and used for modelling gravity in the Orpheus Graben area, the Sydney Basin, and south of the Avalon Peninsula, Newfoundland.

Compilation and interpretation of the 1985 aeromagnetic survey between Cape Breton and Newfoundland provided a new geophysical framework for the interpretation of gravity data.

Using the new data base described above, a new compilation was produced and results presented on Applicon colour maps at 1:1,000,000 scale. The main gravity features are the deep Orpheus Graben, the extensive Sydney Basin of Carboniferous age (which may have a graben-like 'root') and a gravity high, extending southwest from the Avalon Peninsula, which is bounded on the northwest by the Placentia Graben.

(iv) Instrumentation. In late 1985, two configurations of the Gss30 gravimeter were tested on a short cruise on board the CSS Quest. The two configurations were the Kss30 (the original platform delivered to the GSC in 1981) and the Kss31 (using a new platform with balanced gimbal supports). As expected, the new platform improves the accuracy of the gravity measurements by a factor of two. Further improvements in the Kss30's performance were achieved by incorporating a new on-line digital filter. A set of sixty 10-second readings is passed through a fifth-order recursive Bessel filter twice (in forward and reverse order) producing a zero-phase delay.

The new data logging system, CIGAL, was tested on three production cruises in 1986 and is ready to enter routine operation in 1987. The system will operate in the "hands-off" mode, requiring no intervention by an operator. The logged data are stored in bubble memory until a day-file is full, at which point the data are backed up on tape cartridge and dumped into the shipboard microVAX computer for further processing.

(d) Cordilleran and Pacific Margin Division (J.F. Sweeney)

(i) Gravity Surveys. In the Yukon Territory 824 new gravity observations were made under contract, at intervals of about 10 km. The regional gravity survey covered the area between the Dempster corridor and the Alaska border, and north from Dawson (about 64°N) to the Beaufort Sea. Satellite-based GPS was used for positioning. This gravity survey is to date, the largest of its kind in Canada to have used this new positioning system.

Detailed gravity traverses were also conducted in house, across the Richardson Mountains at about 66°30'N and across the Kaltag Fault and the Old Crow batholith along the Alaska border. Station spacing averaged about 1 km and 126 gravity observations were made.

A total of 142 additional in-house gravity observations were made; the first survey was over the Gun Pluton in collaboration with a geological mapping program in the Mackenzie Mountains, the second survey was along several inlets on the mainland coast in southern B.C. as part of ongoing, multi-parameter studies at PGC/UBC.

In conjunction with the Geophysics Division, four new gravity control stations were established in the central Yukon to facilitate the planned 1987 regional gravity survey. An additional gravity control survey also tied precise gravity stations on Vancouver Island to the National Base Network.

(ii) Data Handling. Terrain corrections were computed at the Pacific Geoscience Centre for about 100 Cordilleran gravity observations. These will be added to the national gravity data base.

(iii) Data Interpretation. A 2-D gravity modelling program was made user-friendly and given an interactive graphics capability. With some further refinements, now being completed, this software package will be open-filed in early 1987. A digital automated data acquisition system has been developed for use on-station during field surveys. At each station the system samples and stores barometric elevation, atmospheric temperature, humidity and the gravity meter dial reading. Each day these data are transferred electronically to field-computer memory for processing, thereby facilitating quality control while in the field.

Preliminary crustal density structure models have been prepared for (1) the LITHOPROBE profile across Vancouver Island and adjacent marine areas, (2) three profiles across the Tintina Fault in the Yukon and (3) the Frontier Geoscience Program deep reflection profile across the Mackenzie Delta.

D.S. Chapman has applied the concept of "thermal isostasy" as an important process governing the elevation of continents. Just as the subsidence of oceanic lithosphere accompanying

sea floor spreading can be explained as a cooling phenomenon, so can the change in elevation between various continental provinces be explained in terms of their respective thermal states, although effects are sometimes obscured by compositional heterogeneities on continents.

D.S. Chapman has initiated a geophysical study of seamounts along the Kiodak-Bowie seamount chain. Gravity profiles across the Denson, Davidson, Hodgkins and Bowie seamounts show clear gravity moats which are being modelled to study lithospheric flexure.

R. Riddihough (GSC), in cooperation with C. Finn (USGS) and R. Couch (Oregon State University) has interpreted regional gravity data in the state of Oregon. These data clearly show a zone of southwest-northeast lineations across Oregon that defines a major crustal lineament, the Klamath - Blue Mountain Lineament. Its existence is supported by geologic and geophysical data. Its correlation with the northwestern boundaries of the Klamath and Blue Mountain provinces suggests that these are continuous beneath the Cascade volcanic arc. The lineament may represent a pre-Tertiary, strike-slip continental margin which, from paleomagnetic evidence, later rotated clockwise into its present position.

(iv) West Coast Crustal Dynamics Studies. The program to monitor contemporary crustal deformation on Canada's seismically active west coast continued with its geographic focus on Vancouver Island. Shear-strain analysis of trilateration data from the Gold River and Johnstone Strait networks indicates a total engineering shear-strain rate of about 0.2 microradian per year for central Vancouver island over the most recent years, with the principal axes of compression lying in a northeast to east direction. A comparison of levelling surveys in 1946, 1977, and 1984 has established an apparent increase in the relative uplift rate from 1mm/yr to 5mm/yr for the Campbell River region. Long-term trends in relative gravity values at sites within this area are obscured by the presence of strong (10 to 20  $\mu$ Gal) seasonal variation. These data are currently being re-analyzed in an effort to extract the secular signal.

To determine the spatial extent of the deforming region, geodetic surveys carried out in the 1986 field season concentrated on the Parksville to Tofino corridor across Vancouver Island. Laser trilateration measurements were made among 15 horizontal control points within this corridor by personnel of the Geodetic Survey of Canada. A preliminary network adjustment of these survey data indicates a relative baseline precision of 0.5 parts per million. Special-order levelling was also carried out by the Geodetic Survey of Canada along the highway from Parksville to Tofino and Uclulet. Comparison with older surveys (1973 and 1978) shows significant changes in elevations; however, the older survey data have yet to be corrected for refraction and magnetic effects. Precise gravity measurements were also completed at 15 stations along the levelling route to establish possible gravity changes at stations since 1979. This data comparison will be carried out in 1987.

The use of GPS for regional deformation surveys on the west coast was also initiated this past field season. Ten of the control points within the Parksville/Tofino trilateration network were occupied with GPS receivers in order to investigate currently achievable GPS accuracies. This field work was carried out by the Geodetic Survey of Canada. Also, in co-operation with the Earthquake Hazards Study Group of the USGS at Menlo Park, a GPS survey of 22 control points spanning Juan de Fuca Strait was completed in September. These data will be analyzed independently by the Geodetic Research Laboratory at UNB as well as by the USGS.

### 3. Nova Scotia Research Foundation (K. Howells)

Gravity terrain corrections for stations in the Boisdale Hills-Boularderie Island areas of Cape Breton are in progress. An interpretation of a gravity profile across the Windsor - Kennetcook area of the Minas Subbasin of Nova Scotia was completed with new borehole data and geological mapping by the Nova Scotia Department of Mines and Energy being incorporated into the interpretation.

### 4. University of Calgary (K.-P. Schwarz)

At the University of Calgary, research concentrated on the processing of new gravimetric data types, namely airborne gravity gradiometer data and inertial gravity data.



The use of airborne gravity gradiometry opens new vistas in geodesy and geophysical exploration. A. Vassiliou has compared a number of methods to process large amounts of heterogeneous, noisy data and has proposed a new approach based on multiple input - single output filtering with applications to geoid determination. Applications of this technique to geophysical exploration have been outlined by K.-P. Schwarz and others. The integration of gravity gradiometer data with seismic and aeromagnetic data is under study and first results will be presented at the IUGG General Assembly in Vancouver in August, 1987.

The determination of the anomalous gravity vector from the output of an inertial survey system has been discussed by K.-P. Schwarz and a comparison of methods using some actual runs in a fast-changing local gravity field is discussed by R. Forsberg and others. R. Forsberg has completed an extensive report discussing model and data problems and K.-P. Schwarz has made a proposal to extract gravity information using an integrated INS/GPS system.

#### 5. L'Université Laval (M.-K. Seguin)

Some 250 gravimetric stations were obtained on and around Mount Mégantic. Samples were collected to obtain densities and ferrimagnetic susceptibilities of various lithological units. A simple Bouguer gravity map and a Bouguer anomaly map with topographic corrections were produced. Different techniques were used to obtain the regional anomaly map of this area. The regional field was approximated with (1) first and second degree polynomials, (2) moving average making use of two versions of mobile windows. A correlation of gravimetric, topographical, petrophysical and magnetic parameters has been undertaken.

A study of the Aylmer pluton, located in the Eastern Townships, has been carried out in cooperation with Prof. J.-C. Mareschal of the l'Université de Québec à Montréal. The centre of the intrusive is located some 8 km to the south of an important thrust fault. The Bouguer anomaly is positive in the centre of the intrusive. The small width of the anomaly indicates that the intrusion is shallow and could be truncated by the extension of the fault. If this interpretation is correct, the thrust fault occurred after the Devonian intrusive event.

#### 6. University of Manitoba (W.C. Brisbin, D.H. Hall and W. Moon)

W.C. Brisbin and his graduate students have made systematic gravity measurements in the Falcon Lake area (granite stock), and Chisel Lake area (igneous pluton), Manitoba. The objectives of these surveys are to reduce and interpret the data for subsurface structural geological studies. Interpretation of these data is currently in progress and more work is planned in the future for both study areas.

A new gravity survey to map the Precambrian basement topography under Paleozoic and younger sediments was started in the southwestern Manitoba. This is also being supervised by Prof. Brisbin.

A gravity survey in the Rainy River area of the Fort Frances district, Ontario was initiated in the summer of 1986 by D.H. Hall with the aim of expanding the survey in subsequent field seasons. The objective is to obtain data for gravity anomaly interpretation of the Sabaskong batholith over the area occupied by a prominent magnetic anomaly and a concentration of magnetization on the Sabaskong batholith in McCrossan, Trovill, and Dewart townships. Three gravity bases (from Fort Frances) and about 20 stations on Hwy. 621 were established as a beginning to the project.

Theoretical and numerical aspects of 2-D Hilbert transform are being studied with potential field data. Tests of the preliminary algorithm indicate that the method can be extremely useful in the integration of geophysical data, for example, airborne magnetic digital data and conventional ground gravity data.

A unified geodynamic equation is being solved for displacement fields in the core-mantle region. The main objective of this study is to extend current understanding of the possible topographic coupling at the core-mantle boundary.

7. Memorial University of Newfoundland (H. Miller)

In 1986, 250 land gravity stations were occupied on the Burin and Bonavista Peninsulas. These were collected in conjunction with a joint GSC Geophysics Division-Memorial University underwater gravity project in which 184 stations were occupied in Trinity and Bonavista Bays. The 1986 data collection is the final phase of a five-year Memorial University - GSC project which has resulted in the upgrading of the gravity coverage on land and in the nearshore region of the Avalon Terrane of Newfoundland.

Seventy-two gravity stations were occupied in the Ackley Granite Suite area of southern Newfoundland to provide additional data to supplement those collected in 1983 and 1985.

Interpretation continued on the underwater and land gravity results from the St. George's Bay area of western Newfoundland.

8. L'Université de Québec à Montréal (J.-C. Mareschal)

One hundred measurements were taken along a transect across the Northern Labrador Trough in the area of Leaf Bay (Quebec). The Bouguer anomaly profile is similar to profiles obtained across the central part of the Trough and shows a 20 mGal increase from the Superior to Churchill Provinces. A detailed interpretation is in progress.

9. University of Western Ontario (H. Schloessin)

R. Freel, has completed his Honors B.Sc. thesis studies on the subject of 'Interpretations of Gravity Data in the Gatineau Region of Quebec and Eastern Ontario'. These studies focus on possible correlations of the orientation, alignment and magnitude of horizontal gravity gradients with seismic activity as displayed by the distribution of epicentres in this region.

The existence of a Paleozoic, transcontinental, Florida-Montana, strike-slip fault had been postulated by Carey in 1976 on the basis of geological evidence, and by Kinsland in 1983 on the basis of visual inspection of the U.S. gravity anomaly map. F. Diamond and L. Mansinha are applying the methods of time series analysis to a study of the feature. The fault hypothesis is supported by a strong correlation peak at about 750 km strike-slip displacement. Additional supporting evidence is provided by changes in the amplitude spectrum.

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## II SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR

Compiled by: E.R. Kanasewich

1. Geological Survey of Canada
2. University of Alberta
3. University of British Columbia
4. University of Calgary
5. University of Manitoba
6. Queen's University
7. University of Saskatchewan
8. University of Western Ontario
9. Bibliography

### 1. Geological Survey of Canada

#### (a) Canadian Seismicity

Studies of Canadian seismicity are carried out in the Geophysics Division (GD), Ottawa, and the Cordilleran and Pacific Margin Division at the Pacific Geoscience Centre (PGC), Sidney, B.C.

J.A. Drysdale (GD), R.B. Horner (PGC) and M. Lamontagne (GD) have produced quarterly Provisional Earthquake Summaries for 1986. As of mid-December, provisional data have been analysed for more than 650 earthquakes in or bordering Canada during 1986. There were 37 events greater than or equal to magnitude 4.0, five of which were greater than magnitude 5.0.

The pattern of activity has continued to be similar to that of previous years and will be described in the 1986 Canadian Earthquake Catalogue (in the GSC paper series). Of significance in northern Canada was the continuation of activity in the Nahanni region of the MacKenzie mountains, Northwest Territories, which commenced October 5, 1985 with a magnitude 6.4 earthquake. The largest (magnitude 5.3) aftershock this year occurred on February 13.

In western Canada a magnitude 5.4 earthquake near Prince George, British Columbia (B.C.), was felt with maximum intensity VI at Willow River, Giscome, Upper Fraser and Sinclair Mills. A magnitude 5.3 earthquake off the west coast of Vancouver Island was felt over most of the Island and in high-rise buildings in Vancouver. The maximum intensity (IV) was experienced at Tahis and Estervan Point, B.C.

The most widely felt event in eastern Canada occurred January 31, near Cleveland, Ohio. This magnitude 5.0 earthquake was felt from Wisconsin to Maryland in the United States and felt widely throughout southwestern Ontario (intensity III-IV). Of significance also in eastern Canada, was the increase of activity following a magnitude 4.1 earthquake on October 17 in the Miramichi region of New Brunswick. Over 75 aftershocks occurred in the following 3 days. This activity subsided by the end of October. The largest earthquake in the lower St. Lawrence river zone since a magnitude 4.1 event on January 17, 1983, occurred November 9 and was also magnitude 4.1. It was felt on both the north and south shores of the St. Lawrence River.

Through analysis of the 1985-86 Nahanni, N.W.T., earthquake sequence the Geophysics Division aims to improve the assessment of seismic hazards in the eastern Canadian Cordillera. Under R.J. Wetmiller, the principal investigator, the two main shocks have been analyzed in terms of source mechanism, macroseismic effects, near-field strong motion and geological features. More than four hundred aftershocks, located by three separate field surveys, have been analyzed and define a 50 km N-S by 15 km E-W aftershock zone in the North Nahanni valley. The activity is not associated with any mapped fault in the epicentral area, but their spatial distribution suggests the existence of a buried or 'blind' thrust fault.

M.G. Cajka (AECL/GD) analyzed the records produced by five seismograph stations, supported by Atomic Energy of Canada Limited (AECL), which monitor northern Ontario. The increased coverage provided data to locate approximately six earthquakes in the 2.5-3.0 magnitude range,

which probably would have otherwise gone undetected. In addition, these data were used to detect and analyze the numerous rockbursts that occurred throughout northern Ontario. Twenty-three rockbursts with magnitude 2.5 or greater were located and confirmed in 1986.

J. Adams and A.E. Stevens (GD) are continuing the historical earthquake record in eastern Canada through a series of contracts for a systematic search of old newspapers and related documents for the four Atlantic Provinces and Quebec.

A new Canadian earthquake intensity questionnaire, prepared by A.E. Stevens and M.G. Cajka, has been used in draft form for three earthquakes of 1986. The bilingual questionnaire, to be available in early 1987, allows the respondent to reply in his/her own words to six basic questions, eliminating the ambiguities inherent in the former multiple choice questionnaire. It assumes that any significant damage will be investigated on the spot by qualified specialists. Detailed questions concerning damage or geological effects have been eliminated.

An intensity survey was conducted by Cajka and Stevens following the widely-felt, mb 5.0 earthquake of January 31, 1986 near Cleveland, Ohio. About 1200 replies were received from residents of southern Ontario following a media appeal. The analyzed data show the earthquake was perceptible in Ontario to epicentral distances of 400 km, with intensity IV experienced in southwestern Ontario from Toronto to Sarnia.

The Canadian (National) seismograph network, as of December 11, 1986, is made up of 15 standard stations, 43 regional stations, 20 eastern Canada telemetered (into Ottawa) stations and 18 western Canada telemetered (into Victoria) stations. Special networks include the Yellowknife Array, strong motion networks in eastern and western Canada, the Charlevoix Array and a digital station telemetered into Sudbury. Details of these stations are described in Canadian Seismograph Operations, which is published annually as part of the Seismograph Series of the Geophysics Division of the Geological Survey of Canada.

The western and eastern strong motion seismograph networks are operational with over 70 instruments. A temporary three element array was installed in the North Nahanni River area of the N.W.T., in October of 1985. The instruments were triggered by a large number of after-shocks, including a second large earthquake of Ms 6.9. Peak horizontal accelerations recorded were greater than 1 g and a vertical peak exceeded 2 g. The array was in place throughout 1986.

R.G. North and K.W. Beverley (GD) have made plans to replace the existing standard seismograph station network with a number of broadband stations. The new stations will use the Streckeisen instrument which is flat to velocity from 10 Hz to 360 seconds period. A detailed design document for the stations has been prepared and development of a prototype has begun. The first stations will be part of the Yellowknife array upgrade; a total of 4-8 stations elsewhere in Canada will be installed by 1993.

Funds have been obtained for a complete modernization of the array at Yellowknife, N.W.T., originally installed in 1963. This project, under the direction of R.G. North, includes replacement of the short-period array; addition of a 4-element broadband array; digital telemetry from all outstations to the Yellowknife control centre housed in a new building; real-time satellite telemetry of all the data to Ottawa; and provision of new data processing and analysis facilities in Ottawa. The upgrade will be completed early in 1989.

J.A. Lyons (GD) has continued to develop central site processor and software systems for the Canadian Digital Telemetered Seismic Networks (CDTSN's). A total of seven new PDP-11/73-based Mark IV processing systems have been developed and installed in all regional and local networks. These systems feature automatic transfer of all detected events from the primary processor to the central VAX.

C. Wong (GD) has continued to add new features to the Seismic Analysis Monitor (SAM) software system to support the current seismicity project on the in-house VAX. In addition, development has begun on a national Canadian Database using the INGRES Relational Database package. This database will incorporate:

1. all phase measurements, source parameters, and related information for all significant earthquakes occurring on or near the Canadian landmass since 1534;
2. similar information for significant teleseismic events needed to fulfill Canada's international role in global seismic monitoring, nuclear test-ban treaty verification and data exchange;
3. an index to all time series stored in the national archive, including Canadian seismicity, significant teleseisms, selected blasts and calibration recordings.

M. Andrew (GD) has coordinated the development of the expanded Sudbury Local Telemetered Network (SLTN). He has also modified the CDTSN software to provide for three components at variable sampling rates for the new portable seismic networks destined for the Charlevoix region of Quebec and the West Coast. Andrew continues to provide technical support for data communications as it relates to the transmission of digital seismic waveforms, both within Canada (e.g., the Yellowknife to Ottawa satellite link) and internationally.

#### (b) Theoretical Seismology

Studies of theoretical seismology are undertaken in the Geophysics Division (GD) and Lithosphere and Canadian Shield Division (LCSD), Ottawa.

R.A.W. Haddon (GD) is developing leaking mode theory for computing synthetic wavefields for plane-layered models and in axi-symmetric borehole problems. The method involves only modes and is in principle exact. It has the potential to require far less computing time than most other methods.

Haddon and F.M. Anglin (GD) have interpreted an anomalous set of signals recorded by the Yellowknife seismological array as the result of a shock wave produced by the passage of a meteoroid, rather than the impact of the meteoroid upon the earth. Modelling of the shock, P, S and Rayleigh waves, has produced a good fit to the altitude of the meteoroid set at 45 km.

C. Spencer (LCSD) and C. Thompson are investigating the use of Maslov amplitude calculations with two-point, three-dimensional ray tracing. They are examining both theoretically and numerically the problems such as caustics and multipathing in three dimensions.

#### (c) Experimental Seismology

Studies of experimental seismology are undertaken in the Lithosphere and Canadian Shield Division (LCSD) and Geophysics Division (GD), Ottawa, in the Atlantic Geoscience Division (AGC), Dartmouth, Nova Scotia, and in the Institute of Sedimentary and Petroleum Geology (ISPG), Calgary, Alberta.

Deep multichannel seismic reflection data were obtained by C. Keen (AGC) through a contract during 1985 across basins and margins of the Grand Banks. The crustal structure was successfully imaged down to the Moho. Basin bounding faults extend deep within the crust and little Moho topography is apparent beneath the basins. A reflective lower crust is present in much of the area. The oceanic Moho adjacent to the rifted margin appears to be strongly faulted.

Deep multichannel reflection data were collected on the Gulf of St. Lawrence across the Magdalen Basin by F. Marillier (AGC) through a contract during August, 1986. The work was designed primarily to study Appalachian structures. Processing is not yet complete but initial results show strong mantle reflections, significant Moho topography and major dipping structures within the crust.

Seismic refraction studies of Orphan Basin and the margin were carried out by I. Reid (AGC). The detailed refraction experiment in 1986 was carried out along the 1984 Lithoprobe reflection profile. The main objective of this is to resolve the nature of the lower crust and its variation and continuity across the basin and margin to learn more about the mechanics of crustal extension and rifting.

Geodynamic modelling by R. Boutilier (AGC) concentrated on extensional basins and comparisons with deep seismic data.



A.G. Green, P. Morel-à-l'Huissier, C.J. Spencer, I. Asudeh (LCSD) et R.C. Schieman (GD) ont participé à l'expérience de sismique réflexion/réfraction GLIMPCE menée conjointement avec des collègues des universités canadiennes et des collègues américains du USGS et des universités. Ce projet est destiné à une meilleure compréhension de l'évolution de la région mid-continentale. Lors de cette expérience, les nouveaux systèmes d'enregistrement de la Commission géologique du Canada furent utilisés avec succès pour la première fois. Les données ramassées sont d'excellente qualité et très prometteuses quant à leur interprétation.

Morel-à-l'Huissier, Green et C.J. Pike ont complété leur interprétation des données de sismique réfraction recueillies par le groupe COCRUST dans la région du bassin du Williston.

Morel-à-l'Huissier effectue présentement une compilation des levés de sismique réfraction et de sismique réflexion effectués au Canada. Cette compilation doit conduire à la réalisation de cartes (épaisseur de la croûte, vitesse moyenne des ondes sismiques dans la croûte, vitesse moyenne des ondes sismiques dans le manteau supérieur, etc.) devant faire partie d'un atlas géophysique. Une bibliographie des travaux concernés sera également fournie.

D.A. Forsyth, I. Asudeh, and L. Sobczak (LCSD), together with H.R. Weber, R. Schieman, M. Schmidt (GD), R. Stephenson (ISPG), R. Jackson (AGC), D. White (UBC) and R. Morris (Geodetic Survey) conducted the second successful seismic refraction program under the Frontier Geoscience Program from the Ice Island during April-May.

The ladder style survey grid established in 1985 was continued southwest offshore of Axel Heiberg Island. With the addition of the Mk 1 version of the new portable single channel recorders and a streamlined shooting operation, the 1986 survey effectively doubled the 1985 coverage. Development of system software to handle the new and larger volumes of data is in progress towards production of a GSC Open File on the 1986 program.

The Frontier Geoscience Program refraction program review meeting held in October decided to direct '87 efforts to a Mackenzie Delta survey due to the Ice Island's lack of net progress along the polar margin in '86.

Forsyth, Morel-à-l'Huissier, Asudeh and Green suggest that similarities between crustal structures of the Alpha Ridge and the Iceland-Faeroe Ridge region are due to mantle plume activity.

Forsyth, Jackson and L. Johnson (U.S.O.N.R.) have described geological and geophysical features derived largely from results of the CESAR '83 survey, which point to an oceanic origin for the Alpha ridge.

Asudeh and Spencer have designed several new software enhancement modules for the litho-probe Seismic Refraction System and are currently implementing them. This, and a commercial single trace analysis software package called VISTA already purchased, will provide complete in-field processing capabilities as well as industry standard SEG-Y format for data exchange.

B. Milkereit (LCSD) is conducting research in the areas of acquisition, processing and interpretation of P- and S-wave reflection and refraction data sets. He is developing new processing and inversion techniques for pre- and post-stack migration of noisy crustal seismic data, multitrace attribute processing, and the pre-stack separation of P-waves and converted S-waves. The new techniques are being applied to Lithoprobe reflection seismic data.

Green, Milkereit and C. Michaud (LCSD) are regressing the seismic reflection data collected across the southeastern Canadian Cordillera. Various pre- and post-stack processing steps are being applied to data collected across critical structures such as the Rocky Mountain Trench and the Kootenay Arc.

Forsyth has proposed a multidisciplinary program in the Lincoln Sea at the August meeting of the International Committee on the Lithosphere in Kiel, ERG.

Asudeh, Green and Forsyth have interpreted phase one of CESAR 1983, a Canadian seismic refraction survey of the Alpha Ridge complex.



C.R.W. Duff (GD) is determining the magnitude threshold, as a function of epicentral location and at a given probability level, for detection and location of seismic events in Canada. The Canadian earthquake bulletin is used as an indicator of a station's actual performance in the past, to give a detection threshold versus distance curve for each station. Detection threshold contours indicate a 50% probability of locating  $L_g$ -magnitude 3.0 events over most of Canada.

R.G. North (GD) is assessing the effects of various factors on earthquake magnitude. These include an analysis of instrumental effects upon  $mbLg$  (for Eastern Canadian seismicity) which have indicated over-estimation by up to 0.6 magnitude units for small events; a study to determine the relationship between present  $mb$  (near 1 Hz) and the older  $MB$  (broadband instruments); and an analysis of  $mb$  corrections for the Canadian seismograph network. The last has demonstrated that the corrections are strongly dependent upon source region and that this dependence varies greatly, even for close stations.

P.W. Basham (GD) and North represented Canada at the March and July sessions of the Geneva Group of Scientific Experts. A workshop in Ottawa on the exchange of digital waveform data, held in October, 1986 was attended by experts from 17 countries. Research into discriminant at regional distances, background noise spectra, and various analysis techniques, continued. W. Hanka from Hanover (West Germany) visited the Geophysics Division in October-December, 1986 to study event characterization using Vespagrams of Yellowknife array data.

#### (d) Physics of the Earth's Interior

Studies of the physics of the earth's interior are carried out primarily in the Geophysics Division (GD), Ottawa.

R.A.W. Haddon and G.G.R. Buchbinder (GD) have investigated an alternative to the lower mantle transition layer model proposed by Lay and Helmberger. By use of Kirchhoff wave theory they have shown that the pertinent data may be interpreted alternatively as an effect of wave propagation in an inhomogeneous lower mantle.

Under the supervision of J. Adams (GD), new focal mechanisms have been obtained for 18 eastern Canadian earthquakes using program FOCMEC derived by Arthur Snoke. Using ECTN digital data for P-wave polarities and  $S_p/P$  amplitude ratios (from stations within 100 km of the epicentre) mechanisms to data indicate thrust faulting dominates, but the compression direction inferred from the earthquake P-axes is very variable.

Adams has compiled crustal stress data for Canada and adjacent areas and has implemented the data using DATATRIEVE on the Geophysics Division VAX. There are currently 1029 entries, each representing a compression direction derived from earthquake mechanism, *in situ* testing (overcoring, hydrofracturing, oil well breakouts, etc.) or geological evidence. Canada east of the Cordillera appears to be compressed along the northeast-southwest azimuth, presumably in response to plate motions. In southern B.C. there appears to be a separate stress province (NE compression) above the subducting Juan de Fuca plate and another (N-S compression) just to the east. Data to 1985 are contained in Earth Physics Branch Open File 85-31, and an updated GSC open file will be issued early in 1987. This work is a contribution to the DNAG stress map of North America.

Admas is compiling data on neotectonic deformation in Canada as part of the DNAG Neotectonic map of North America. Excluding the effects of ice-loading, there has been little evidence for deformation in eastern Canada. Deformation in the Cordillera and western margin is more pronounced but still poorly documented. By contrast with the United States, the Canadian neotectonic map must therefore remain largely blank.

D.A. Forsyth, H.S. Hasegawa (GD) and R.J. Wetmiller have described seismotectonics in the Canadian Arctic archipelago for inclusion in DNAG Vol. E, Innuitian Orogen and Arctic Platform.

Hasegawa has compiled information on seismotectonics in eastern Canada and described neotectonic movements in Canada at the Helsinki conference on "Geologic problems related to the disposal of radioactive wastes in Precambrian formations".

(e) Geothermal Studies

Geothermal studies are undertaken in the Terrain Sciences Division (TS), Lithosphere and Canadian Shield Division (LCSD) and Mineral Resources Division (MRD), Ottawa, at the Institute of Sedimentary and Petroleum Geology (ISPG), Calgary, and the Pacific Geoscience Centre (PGC), Sidney, B.C.

A.M. Jessop has begun a program of accurate temperature measurement in wells in sedimentary basins at the Institute of Sedimentary and Petroleum Geology, with the objectives of: a) determining the reliability of the large files of industrial data, b) describing the detailed vertical profile in the sediments, and c) drawing inferences on hydrodynamic influence on heat transport within the sediments.

Jessop has analyzed temperature anomaly in a well used for disposal of waste brine to reveal a natural lateral flow of water in an aquifer near Regina. The method is used to estimate a flow rate, without recourse to pressures and Darcy's law, which is found to be 2.6 m/y., with an accuracy of about 20%

M.J. Drury (LCSD) has compiled heat flow data from the Canadian Appalachians. The concept of a heat flow province has been re-examined using global data sets to which reasonable estimates of uncertainty have been applied. The result is that the orthodox views of reduced heat flow and depth distribution of radiogenic elements must be tempered with caution. Thermal diffusivity of a large number of crystalline rocks has been measured and statistically analyzed. The heat flow and heat generation in some Canadian greenstone belts have been examined.

Thermal data have been collected by the University of Western Ontario, under contract to the Geological Survey of Canada (Drury, principal investigator), in the southwestern part of the Abitibi Greenstone Belt and close to the Kapuskasing Structural Zone, as the first phase of a project to study the thermal nature of the two structures. Earlier data from the Superior Province have also been analyzed.

Jessop and L.W. Vigrass have analyzed thermal, chemical and hydrological data from the well on the campus of the University of Regina to provide an account of the geothermal energy potential, the hydrodynamic character of the reservoir and other strata, and the thermal state of the sedimentary column at Regina. Heat flow in the Paleozoic strata is uniform and equal to 52 mW/m<sup>2</sup>, but heat flow in the Mesozoic strata varies with depth.

A. Judge (TS) examined the available data on the deep geothermal regime to 4 km, and the permafrost regime in the Mackenzie/Beaufort region. Underground temperatures and permafrost thickness appear strongly related to the recent sediment depositional history of the region and the Quaternary history in terms of glacial limits and sea-level.

A. Taylor (TS), Judge and V. Allen (TS) analyzed terrestrial heat flow results from 12 stations occupied during the Arctic Ocean Basin CESAR project. The topographically corrected mean heat flow of  $56 \pm 7$  mW/m<sup>2</sup> for the eastern Alpha Cordillera is higher than earlier observations on the western Cordillera by some 15%. The value constrains the age of the Alpha Ridge to 60-120 m.y. on the basis of plate models of a cooling ocean crust. Results are not inconsistent with a hot spot trace, but this requires detailed analysis of earlier data gathered during T3 as well as the present data set.

Taylor, Judge and Allen, in conjunction with Dobrocky Seatec and Panarctic Oils Ltd., completed a successful demonstration of the installation of a temperature scale in an abandoned offshore well located in 250 m of water. Data were transmitted by acoustic telemetry to a recorder unit on the sea-ice. The calculated equilibrium temperatures suggest lower gradients in a particular geological horizon in the offshore than adjacent onshore regions, which has important implications for arctic thermal crustal models.

P.T. LaFleche (TS), Judge and Taylor have summarized some of the recent experiences from thermal studies in mining areas with thick permafrost, demonstrating the importance of permafrost information and showing some applications of geophysics to permafrost delineation. Examples are drawn from studies of permafrost in the Mackenzie Delta where the EM-37 transient electromagnetic system has been used to detect and map up to 600 m of frozen ground.

J. Pilon (TS) has led the development by A-Cubed of a new ground probing digital radar system for the Permafrost Section of the Terrain Sciences Division. The system underwent extensive field testing in the summer of 1986 at a number of surface and underground sites in northern Canada.

Evaluation of the system to detect overburden thickness and to distinguish between frozen and unfrozen ground was completed in conjunction with Echo Bay Mines Ltd. at Contwoyto Lake, N.W.T.

M.M. Burgess (TS) and Pilon continued studies of the ground thermal regime at 23 sites along an 800 km north-south linear profile in conjunction with an INAC program to evaluate terrain performance of the Norman Wells oil pipeline. Evidence exists of a natural climate change at high elevation sites and deeper drilling is being conducted to evaluate the climate change aspects.

E. Davis, L. Law, D. Nobes (PGC), J. Franklin, W. Goodfellow, I. Jonnason (MRD), H. Villinger (AW Polar Institut), W. Ryan, E. Kappel (Lamont), and P. Ryall (Dalhousie) completed an integrated geophysical/geological study in the sedimented rift valley of the N. Juan de Fuca Ridge where sediment hosted sulfide deposits were discovered the previous season. A suite of over 500 heat-flow measurements was completed to map the regional pattern of hydro-thermal circulation, including locations of fluid recharge and discharge. Two currently active discharge sites were well characterized with the surface heat-flow measurements, and their structure at depth was imaged with ocean-bottom magnetometer receiver/controlled current source electrical resistivity soundings. The distribution of sulfide outcrop was mapped with a video (real-time) and still camera system. The site is proposed for an ODP drilling leg.

R. Hyndman (PGC), M. Langseth (Lamont Doherty) and R. Von Herzen (Woods Hole) reviewed all of the Deep-sea Drilling Project geothermal measurements, making revisions where necessary to values from the Initial DSDP reports, and assigning reliabilities. They found general agreement with heat flux values from shallow oceanographic probes, and no changes in heat flux with depth in well-sedimented areas. At a few sites vertical migration of interstitial water was suggested. At younger crustal sites, hydrothermal circulation was evident, but concentrated at shallow crustal depths. Hyndman and D. Roberts (BP Petroleum) calculated the heat flux in the rifted West Rockall Margin, and compared it to values expected from various extension models.

T. Lewis (PGC) found a large variation in heat flux along the Lithoprobe I line across Vancouver Island and its extensions seaward and landward across the Coast Plutonic Complex. The modelled subducting oceanic crust, constrained by the calculated temperatures above it, moves beneath a very thick, cool prism seaward of the large, abrupt heat flux transition 30 km seaward of the Garibaldi Volcanic Belt. Lewis prepared a description of the method and results of using a pulsed needle probe to measure the thermal conductivity of rock fragments. The technique was used to measure the thermal conductivity of cuttings from offshore wells, and showed promise in recovering the original formation porosity from the cuttings. W. Bentkowski (PGC) and Lewis prepared an open file describing the high heat flux in the Raft batholith and relating it to the high heat generation in the crustal rocks.

Lewis, Bentkowski, J. Majorowicz (U. of Alberta), Xia Kan Yuan and Chen Zhong Rong (South China Sea Ocean. Inst.) went on an initial cruise to measure the heat flux in the Queen Charlotte basin using an 11-m oceanic probe. Since the bottom water temperatures vary on the shelf, temperature recorders were moored, and cruises are planned for 1988 and 1989. Lewis and Bentkowski logged available mineral exploration boreholes in southern B.C. and Bentkowski and M. Burgess logged boreholes in the southern Yukon. Lewis and Bentkowski collected samples and determined the heat generation of the Bugaboos, Horsethief, Fry Creek and other bodies in southeastern B.C. The heat generation of samples provided by geologists from other intrusives from B.C. and the Yukon were measured and added to the UTHK data file.

D.S. Chapman (PGC) with Deming (U. of Utah) completed a study of Bottom-hole Temperatures in the Pineview field of the Utah-Wyoming thrust belt. Thermal conductivities were combined with estimates of temperature gradients to estimate heat flow for the field and to test an inversion procedure through a series of numerical simulations. Chapman and S. Willett (U. of Utah) continued their study of the temperature field within the Uinta Basin. BHTs were treated in a stochastic inversion to determine thermal gradients in five formations. Large lateral

variations in formation gradients are consistent with a modelled regional groundwater system driven by hydraulic head. Chapman and Brigaud (U. of Utah) compared the thermal conductivities of several hundred samples measured in the Uinta Basin with predicted values from suites of logs from three wells in the Basin.

## 2. University of Alberta

F. Hron, B.G. Mikhailenko (from the Computing Center of the Soviet Academy of Sciences, Novosibirsk) and P.F. Daley are working on new synthetic seismogram programs for complex three-dimensional structures based on the Alekseev-Mikhailenko method. The technique utilizes a hybrid method of computing synthetic seismograms in which finite integral transforms are used to reduce the spatial dimensionality of the problem, and then finite differences are employed to complete the solution. I. Psencik (from the Geophysical Institute of Czechoslovak Academy of Sciences, Prague) and Hron are adapting a program written by V. Cervený and Psencik based on ray method and Gaussian beam method. The method is suitable for studying the wave field in the vicinity of caustics and regions where diffracted events could be expected to be generated.

Z. Berkes and Hron have developed a geophysical-geological interpretation method to infer information of wedge-shaped strata on mature passive margins. Their kinematic method provides a better reconstruction of past tectonic events on passive margins. R. Chan and Hron have several new computer programs for seismic diffracted waves based on the Klem-Musatov work. Bao-Shan Zheng and Hron are exploring the use of higher order terms in the asymptotic ray series.

M. Shahriar, G.L. Cumming and Hron have used an iterative matrix inversion scheme on refraction and reflection data for horizontally layered models.

E. Nyland and Lawrence Le are using pattern recognition and other artificial intelligence techniques in seismology.

E.R. Kanasewich, C. Macrides, A. Vafidis are carrying out an analysis of seismic well-to-well data from the Cold Lake area. Finite difference algorithms for the CYBER 205 supercomputer are being written and tested for SH and P-SV wave propagation. Various high order finite difference methods are being written using the heterogeneous approach to the hyperbolic system of elastic wave equations. The (2,2) Lax-Wendroff scheme is being tested but a (2,4) MacCormack type splitting scheme is also being prepared. The seismic data, acquired by industry at 1 millisecond sampling from the Cold Lake steam injection pilot project, are of good quality for a zone before and after injection. Additional data on a new experiment have been obtained with a DFS-V seismic recording system, recording at 2000 samples/second, from a fixed downhole string of 24 hydrophones. The source was a downhole air gun operated at multiple depths at a pressure of 2300 Psi. The spacing at both sources and receivers was 3 m. The spectral ratio method, as well as the concept of average frequency, is being used in order to measure attenuation before steam stimulating the formation. Additional attenuation studies are being carried out by N. Keen and Kanasewich on vertical seismic profile data from Melville Island.

Kanasewich, S. Chiu and S. Phadke have written several programs for linear least squares inversion of crooked-line data from the LITHOPROBE DATA SET ON Vancouver Island. They are also investigating methods of imaging diffraction data in seismic reflection experiments and are able to locate and migrate diffracting centres using before-stack field data.

F.W. Jones, J.S. Rogers and P. Rouleau are carrying out experiments with mercury-level tiltmeters on the surface and in boreholes. Instruments are due to be installed in wells at the Leduc EDM seismic observatory and others will be at the AMOCO-AOSTRA-GLISP pilot near Grgoire Lake, Alberta.

C.M. Scarfe and E. Takashashi (Okayama University) have studied the melting of peridotite to 14 GPa and the genesis of komatiite. This study represents the first melting experiments on mantle peridotite above 40 Kbar (4 GPa). The major technological innovation was the use of the Okayama University uniaxial split-sphere apparatus. They showed that partial melts close to the solidus at 5-7 GPa are komatiitic and discussed a simple diapiric model for their genesis in the Archean.

### 3. University of British Columbia

R.M. Ellis and J. Cassidy, working with G. Rogers (PGC) have completed a reexamination of the 1918 ( $M_s = 6$ ) Vancouver Island earthquake. The source solution is in close agreement with a 1957 event and shows a predominantly strike-slip event along either a northeast or a northwest striking fault.

R.M. Ellis and C. Zelt are analyzing data from the Peace River seismic experiment. Preliminary results from a N-S refraction profile across the arch suggest that the crust may thin by about 5 km under the arch.

R.M. Clowes and S. Dehler have completed interpretation of data related to the Queen Charlotte Fault Zone and the associated offshore terrace. Clowes and C. Pike have completed interpretation of a sedimentary basin model below Hecate Strait. It shows significant lateral variations. Clowes is also collaborating with C. Yorath and R. Hyndman (PGC) on the analysis of more than 500 km of marine multichannel crustal reflection data acquired along a number of lines extending from the deep ocean to the west coast of Vancouver Island. There is also work by Clowes, D. White and C. Cudrak on 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. The data extend the results of LITHOPROBE on Vancouver Island. Clowes and J. Drew are also working on a reinterpretation of the 1980 Vancouver Island Seismic Project.

D.W. Oldenburg and J. Cabrera are developing a new method to image subsurface structure using common-shot gathers and plane wave processing techniques. The method, which assumes a straight-ray approximation, utilizes simple geometrical relations observed in the propagation of plane waves to produce an image of only those portions of the model interfaces illuminated by the field experiment. Oldenburg and Z. Gao have investigated the theoretical foundation of diffraction tomography and its applications to geophysical problems.

M. Yedlin and B. Narod have developed a zero-offset edge diffraction modelling experiment. Yedlin, B. Zelt and B. Seymour have continued work on truncated asymptotic expansions. One dimensional synthetic seismograms obtained with these methods are equivalent to those obtained using the WKBJ methods and the exact solution.

T.J. Ulrych and S. Leaney have developed a new approach to the correlation of well logs which is based on dynamic programming. They have also used median filtering on blocky signals. Ulrych and T. Matsuoka have developed an approach to predictive deconvolution of vibroseis data which does not require phase correction.

### 4. University of Calgary

F. Cook has obtained crustal reflection profiles in the Mackenzie River delta region of the western Canadian Arctic. Preliminary results indicate that a pre-Mesozoic compressional orogen lies buried beneath the Arctic Coastal Plain and that some of the Mesozoic and younger normal faulting associated with the formation of the delta reactivated old structures.

E.S. Krebs is continuing theoretical studies on seismic wave propagation in anelastic media. Reflection and transmission coefficients have been obtained in a linear viscoelastic medium.

### 5. University of Manitoba

W. Moon and N. Seongho are working on the problems of the tidal displacement field by solving vector spherical harmonic equations. The objective is to use these to study outer core processes. Moon and J. Morrish are developing a numerical algorithm to study the boundary layer phenomenon for various coupling processes in the solid-fluid core boundary.

A high resolution seismic survey has been undertaken across the north range of the Sudbury Basin by Moon and S. Mulu. Pre-stack processing software for velocity analysis and migration is being developed. Moon and C. Dilliston are carrying out seismic surface wave studies over



western Canada. Preliminary work on the earthquake surface data from selected standard stations is now complete.

#### 6. Queen's University

C. Thomson is carrying out research on diffraction and anisotropy of body waves. Boundary-layer theory is being used to find correction for diffraction effects in ray/Maslov seismograms at grazing and critical angles. Grazing ray corrections in laterally varying media are now known and show some interesting features. New projects concerning anisotropic media, in collaboration with R.P. Young, and 3D media, in collaboration with C.P. Spencer, are being initiated.

#### 7. University of Saskatchewan

Z. Hajnal and I. Kesmarsky are analyzing over 1000 seismic reflection records which were recorded on a floating ice island during the summers of 1985 and 1986. The aim is to map the subsurface geology of the continental margin along the coastline of the Canadian Arctic Islands. The records are heavily contaminated by near surface generated multiple events. A processing technique is being developed to suppress the coherent interference. Hajnal is also interpreting two 300 km long reversed crustal profiles from the central portion of the Peace River Arch in Northern Alberta. Detailed sonic log oriented analysis is in progress to establish the influence of the sedimentary section on the deep crustal events.

Hajnal conducted a high resolution reflection survey in the Athabasca Basin. The field observations show that reflections are generated at the basement sandstone contact but these events are highly contaminated by coherent noise. A digital processing method is being developed to eliminate the powerful surface-generated interference. A procedure is being developed for a selection of starting parameters when the reflectivity technique is used to compute synthetic seismic records. Once the earth model is defined, the procedure permits calculation of specific input parameters. This process eliminates lengthy experimentation and always leads to well defined, clean synthetic models.

Hajnal has obtained an 11 km, high resolution reflection profile on the western portion of the Haughton Impact Crater on Devon Island in the High Arctic. The final section maps several major faults, slide generated terrace features and major megablocks in the central portion of the crater. As a participant in the 1986 Great Lakes seismic experiment, 1200 records were observed with a 48 channel recording system near Terrace Bay, Ontario. One group of records represents the northerly extension of a north-south trending refraction profile. The second part of the data set is formed by a number of reflection records which were observed a few km northwest of the refraction survey site as a land extension of line 2B.

#### 8. University of Western Ontario

R.F. Mereu and T. Cox participated in the 1985 Geological Survey of Canada Arctic Ice Island seismic reflection experiment. A unique 119 station cross-arm array was set up on the drifting ice island which was located a few miles from Ellesmere Island. Various data processing methods are being used in the analysis to remove the strong water bottom multiples in the record sections. Data were also acquired by Mereu and E. Diurydhan in the 1986 Great Lakes seismic experiment (GLIMPCE) with a combined on-ship source to on-shore refraction equipment. Recording was on-shore on Michipicoten Island, the Bruce Peninsula and the east side of Georgian Bay. Over 6000 usable seismic records were obtained along the Georgian Bay - Lake Huron line which crossed the Grenville Front and the Parry Sound Shear Zones. A combined seismic reflection-refraction interpretation is being performed on the data at present.

Mereu continued with the interpretation of COCRUST refraction and wide angle reflection data from Vancouver Island, the Peace River Arch, the Williston Basin, the Superior-Churchill boundary zone, the Kapuskasing structural feature, the Ottawa graben and Grenville Front. Interpretation of these data sets is placing emphasis on the causes and nature of various signal complexities and how these may vary regionally.



A.E. Beck has made studies on the accuracy and resolution possible in temperature logging. An early investigation by Beck, P.Y. Shen and D. Wang showed that one-time probe measurements could lead to undetectable errors as high as 100% unless the temperature at the sediment-water interface was carefully monitored for at least 5 years before the probe experiment. Further work with two probe measurements spaced a few months apart shows that reasonable values can be obtained without monitoring water bottom temperatures.

H.H. Schloessin and C. Anderson have made investigations by X-ray topography and optical spectroscopy of colour centres in amethystine quartz crystals to identify precursory lattice defects. Theoretical studies were made of seismogenic perturbations of the fair-weather, air-field electric current. The electrification and luminescence of minerals were examined with determinations of the electric field in the air near the ground caused by transient changes in charge density, electrical conductivity and dielectric constant associated with waxing and waning elastic strain energy generated by an elastic inhomogeneity in a stressed section of the earth's outer shell.

Schloessin and R.A. Secco have carried out experiments with a cubic press utilizing a fluid encapsulation technique which provides excellent isobaric and isothermal conditions in relatively large volumes, thus permitting complicated experimental assemblages together with in situ calibration devices. Schloessin and P. Lenson have done modelling of the temperature field in a cube. They have also investigated the thermoluminescence and phosphorescence of  $\text{CaSiO}_3$  and the transmission properties of the mantle.

Hot creep of single crystals has been studied by Schloessin, R. Govindarajan and G. Ranalli (Carleton University). A 3-point bending apparatus with feed-back control in a high vacuum system is used to determine the strains and stresses as well as their time derivatives. X-ray diffraction topography of the bent single crystals, done with different Bragg reflections, permits the detailed analysis of the dislocation distribution and concentrations corresponding to different creep stages in crystals of different orientations. Pilot experiments have been performed upon enstatite, alpha-quartz and spinel.

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### III (A) GEOMAGNETISM

Compiled by: G. W. Pearce

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#### 1. Summary

In 1986 the reorganization of the Geological Survey of Canada and of the Earth Physics Branch were undertaken and are apparently still in progress. This process has caused some complication in the identification of the source of reports from the government agencies. The reporter attempted to retain the traditional divisions in both reporting agencies and topics for the present volume.

Magnetic surveys and charts occupy the attention of several Geological Survey of Canada (GSC) groups with continuing effort on a number of major compilations - the DNAG volume "Geology of the Continental Margin off Eastern Canada", the Marine Geophysical Atlas of the Northeast Atlantic and Labrador Sea between 50°N - 72°N, and 0°W - 65°W (both by Atlantic Geoscience Centre - AGC) and Magnetic Anomaly Map of North America (Geophysics Division). The AGC group has also made much progress in geological interpretation of aeromagnetic surveys obtained in cooperation with the Aeromagnetic Subdivision last year. They have, for example, discovered two new fracture zones south of the Charlie Zone. The Aeromagnetic Subdivision completed 262 aeromagnetic charts during the year including a helicopter-borne gradiometer survey in the Gaspé Peninsula. The University of Manitoba worked on several magnetic interpretation projects.

In the Geophysics Division, GSC (formerly the Geomagnetic Division, EPB) regular data collection, analysis and publishing of geomagnetic observatory data continued during the year. The Division also continued its work of originating and developing refinements in instrumentation and analysis with particular progress on projects to evaluate microcomputers for data collection, to model of the effects of HF radio adsorption on ionization in the lower ionosphere and to model external magnetic variation. The group also hosted an international workshop on observatory instrumentation.

The GSC, the Pacific Geoscience Centre (PGC) and three universities reported activity in electromagnetic induction studies during the year. GSC, University of Alberta and Queen's University personnel worked on EMSLAB, an international project to study the Juan de Fuca plate at depth. The first results from EMSLAB have appeared with papers submitted and several reports given at the Eighth International Workshop on Electromagnetic Induction in the Earth and Moon, held in August in Neuchâtel, Switzerland. Early results include a number of Fourier Transform maps and evidence that ocean water motions may be largely responsible for the

continental edge effect. The GSC also made progress on a number of regional surveys - Kapuskasing, Miramichi, Central Plains, Wopmay orogen - and on several theoretical studies - modelling of a buried inhomogeneity and developing of a logarithmic FT method for slowly decaying functions. University of Alberta continued work on its western surveys, in addition to EMSLAB, but also completed several theoretical studies - developing of a thicksheet model and of a technique for separation of internal and external sources in magnetovariation records. Queen's University staff worked on the interpretation of the Kapuskasing Structural Zone study and on the collection and analysis of EMSLAB data. At the University of Victoria, staff concentrated on theoretical studies - model calculations for the electric field over complex geological structures - and on analogue modelling, particularly in regard to ocean channels.

Paleomagnetism and rock magnetism remain very popular subjects in Canadian institutes and universities. GSC, Laval University, University of Toronto and University of Western Ontario reported on projects pertaining to the Precambrian. Prominent among these is the startup of the Kapuskasing Lithoprobe studies and many projects examining intrusive rocks. One might note the use of paleomagnetism for structural problems (e.g., by GSC in Nova Scotia/New Brunswick and in the N. Cordillera). Western Ontario has used the condition of volcanic glass as an indicator of the condition of the remanent moments in Keweenawan rocks. GSC, Alberta, Laval and Toronto report progress in Paleozoic studies, particularly in Eastern Canada (e.g., Appalachian projects of the GSC in Newfoundland and Nova Scotia). The GSC, Alberta and Toronto groups have Cenozoic studies in progress, with secular variation being the subject of the GSC's study of stalagmites and Alberta's study of sediments from Old Crow, N. Yukon. The GSC and Toronto are pursuing many rock magnetic studies, with the Toronto group being extremely active. They are examining CRM and VRM mechanisms as well as theoretical modelling. One notable development is the use of hydrothermally grown magnetite particles for analogues of natural material in a number of rock magnetic projects. Finally, in associated studies, Western Ontario has a project in progress to use the anisotropy of magnetic susceptibility as a tool for structural fabric analysis.

## 2. Geomagnetic Surveys, Charts and Interpretations

- (a) Geomagnetic Surveys and Interpretation, Earth Sciences - formerly reporting as Atlantic Geoscience Centre (B. Loncarevic, R. MacNab, S. Srivastava, J. Verhoeef)

### (i) Data Interpretation

Data acquired in 1985 during a high-resolution aeromagnetic survey between Newfoundland and Nova Scotia were interpreted to identify offshore structural trends and their relation to onshore magnetic trends. Magnetic zonation was used to identify lithofacies at several crustal levels. Magnetic terranes were defined by depth to magnetic basement contours and susceptibility contrasts. Some of the latter could be correlated with the known geological zonation of the Appalachian Orogen.

Aeromagnetic data collected over the western end of the Charlie-Gibbs Fracture Zone and east of the Grand Banks of Newfoundland have improved the definition of well-lineated magnetic anomalies on the shelf and in the deep ocean. Anomalies 24 to 34 can be recognized easily in the oceanic region. The presence of high amplitude anomalies across the Charlie-Gibbs Fracture Zone have enabled us to establish its westward continuation under the shelf and its relation to the tectonic fabric of the region. Dislocations of magnetic anomalies show the presence of two additional fracture zones south of the Charlie Fracture Zone. The southernmost fracture zone lies in line with the westward extension of the Faraday Fracture Zone. Reconstruction of the North Atlantic brings the Pastouret Ridge, a reactivated oceanic fracture zone across Goban Spur, in juxtaposition with this fracture zone across the Canadian margin.

The localized studies described above have been complemented by an analysis of all east coast marine magnetic data, which aims to study broad regional characteristics. The data set spans a wide geographic area, necessitating the development of new techniques for equal area gridding and for differential reduction to the magnetic pole. To date, downward continuation studies have been completed that yield estimates of magnetization of a layer of the upper crust whose top surface is approximated by the bathymetry.

(ii) Data Handling

The past year has brought a substantial improvement in our abilities to manipulate and display large sets of magnetic data. Computer programs for gridding, filtering, and merging data have been implemented on recently expanded computer facilities. These routines are complemented by other programs for statistical analysis and graphic display in colour and in black and white. The major effect of these developments is to make interaction with the data a far easier - and swifter - task for the geophysicist who can now concentrate on the information content of that data without being distracted by the mechanics of manipulation.

(iii) Maps

A major compilation effort has resulted in the assembly, editing, and merging of all available magnetic data for land and marine areas of the continental margin of eastern Canada. The primary objective of this was to prepare data for publication in a 1:5,000,000 magnetic anomaly map in AGC's forthcoming volume in the DNAG series: "Geology of the Continental Margin off Eastern Canada". The magnetic anomaly map is in an advanced stage of production, and has been displayed in prototype form at various meetings.

Data compilation has reached the final stages for the magnetic anomaly map of the Marine Geophysical Atlas of the Northeast Atlantic and Labrador Sea between 50°N - 72°N, and 0°W - 65°W. The Atlas is an international project involving workers from Canada, the US, Germany, and Denmark.

- (b) Geophysics Division, Geological Survey of Canada - formerly reporting as Earth Physics Branch, Ottawa (R.L. Coles, G.V. Haines, L.R. Newitt)

As part of a continuing study of geomagnetic secular variation, 11 repeat stations were occupied in Manitoba, Saskatchewan and the N.W.T. Six of these were done by contract. The routine occupation and observations are similar to those outlined in Canadian Geophysical Bulletin, 32, 60, 1979. Reduction of repeat station data has recently been simplified by using the same software as that used in the editing of AMOS data.

Investigations have been carried out on the feasibility of correcting repeat station data for transient variations using simple interpolation. Test results for polar cap stations are encouraging, but the complexity of transient variations in the auroral zone caused any simple method to fail.

- (c) Aeromagnetic Subdivision, Geological Survey of Canada, Ottawa - formerly reporting as Regional Geophysics Subdivision (P.J. Hood)

(i) Geomagnetic Surveys, Charts and Compilations

A total of 262 aeromagnetic maps were published by the Geological Survey of Canada during 1986. Of these 36 were 1:50,000 coloured total field pixel maps, 36 were 1:50,000 coloured vertical gradient pixel maps, 8 were 1:50,000 line contour maps and 182 were 1:25,000 (or 1:20,000) contoured field and vertical gradient maps.

The foregoing maps included the results of the first helicopter-borne gradiometer surveys flown in the Gaspé Peninsula area of Quebec and the Liverpool area of Nova Scotia by Les Relèves Géophysiques of Quebec City which were issued by the GSC on October 1, 1986.

The following progress was made in aeromagnetic surveys:-

A survey of the Georgia Strait area that extended over the adjoining Vancouver Island and coast of mainland B.C. was awarded to Questor Surveys Ltd. of Toronto on June 23, 1986. The 37,678 line kilometre survey was completed on November 8, 1986 using the Litton inertial navigation system LTN 72/76 (and visual fixes) as the prime navigation aid.



Three helicopter-borne aeromagnetic gradiometer/VLF EM surveys in Newfoundland, Nova Scotia and New Brunswick amounting to 53,828 line km were awarded on June 30, 1986 to Aerodat Ltd., Sander Geophysics Ltd. and Les Relevés Géophysiques (LRG) respectively. These surveys were funded under the appropriate Mineral Development Agreements and the field survey operations were still in operation on December 31, 1986. All the helicopter-borne gradiometer systems utilize inverted-T towed-bird systems. The Aerodat and LRG system utilized Scintrex cesium-vapour magnetometers whereas the Sander Geophysics system utilized Overhauser magnetometers designed by the company itself. Further details of these systems are given in the article by Hood and Teskey (1986).

In addition a fixed-wing aeromagnetic gradiometer survey of the Rice Lake, Hargrave River and Moose Lake area of northern Manitoba was awarded to Kenting Earth Sciences Ltd. on 26th August, 1986. The flying component of the 19,129 line kilometres was completed on October 5, 1986.

A 41,200 line km total field survey of Lakes Huron and adjacent St. Clair was completed by the GSC Queenair aircraft as a contribution to the GLIMPCE project during the period July-September, 1986. In addition, fill-in aeromagnetic surveys in the Waterloo area of Ontario and Camp Borden were completed amounting to 13,600 line km.

Considerable progress was made in the compilation of the first edition of the Magnetic Anomaly Map of North America as a contribution to the DNAG project. First the U.S. and Canadian data were reconciled across the common boundary to form the nucleus of the map. Then the peripheral areas such as Greenland, the Caribbean and other offshore areas were added. Committee meetings were held in Ottawa in May and at the SEG meeting in Houston in November, 1986 to review progress. The final map will be produced by the GSC in colour pixel form using an Optronics plotter and the colour interval will be 100 nT. The compilation of the Caribbean data was assisted considerably by the completion of a tie line survey of that area by the Convair 580 aeromagnetic survey aircraft of the National Aeronautical Establishment during March, 1986.

#### (ii) Instrumentation

The GSC aeromagnetic instrumentation group is progressing towards the fabrication of a four-sensor tri-axis aeromagnetic gradiometer system on the GSC Queenair aircraft. Pull-away tests and flight tests using a three-sensor stringer system have indicated the feasibility of such a gradiometer system which can measure the transverse, longitudinal and vertical gradients simultaneously in the survey aircraft.

(d) The University of Manitoba (Dr. D.H. Hall, Mr. R. Seabrook)

(i) A magnetic-gravity interpretation of crustal structure beneath the Aulneau and Sabaskong batholiths, Ontario has been completed.

(ii) A magnetic interpretation of structure beneath the Benue trough, Nigeria is in progress. Data have been reduced to the pole for modelling.

### 3. Magnetic Observatories and Instruments

(a) Geophysics Division, Geological Survey of Canada (R.L. Coles, G. Jansen van Beek, D.F. Trigg, J. Hruska, L.R. Newitt, M. Gervais, F. Plet, G. Brown, J.K. Walker, H.-L. Lam, G.R. Libbey).

#### (i) Magnetic Observatories

The Geomagnetism Section of the Geophysics Division continued its management of the Canadian Magnetic Observatory Network (CMON) consisting of the following 12 digital magnetic observatories: Alert, Mould Bay, 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. Glenlea, Manitoba was operated with limited absolute control in co-operation with the University of Manitoba in Winnipeg. A full description of the present network is given in the "Annual Report for Magnetic Observatories - 1985" (in press).

To assist the VIKING project, incremental tape decks gathering selected five-second data were in operation in the Fort Churchill and Baker Lake Magnetic Observatories throughout much of 1986. The recordings were discontinued on 31 December, 1986.

Evaluation of the declination and inclination data from the ELSEC 8200 vector PPM (acquired in 1984) against conventional absolute magnetometers continues.

In order to explore the use of a Personal Computer as a data collecting platform, an IBM PC was installed in Ottawa Magnetic Observatory and programmed to collect the 10-second data on floppy diskettes. The hardware was installed in July, 1986. Enhancement of the software continues.

The final 1985 digital magnetic observatory data which includes one-minute values, hourly means and hourly ranges were deposited in the World Data Center in Boulder, Colorado in June, 1986. Copies of magnetograms and digital data are available at cost plus 100% handling charge from:

Geophysics Division, Geological Survey of Canada, Dept. of Energy, Mines & Resources, 1 Observatory Crescent, Ottawa, Ontario, K1A 0Y3 - Tel. (613) 995-5474

Details of other services are listed in the Catalogue of Services for Seismology and Geomagnetism.

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. With the improved telephone service to Alert and Mould Bay, N.W.T., this file now includes the summary data from these far northern magnetic observatories as well.

Under the auspices of IAGA, a workshop on magnetic observatory instruments was held in the facilities of the Ottawa Magnetic Observatory during the period 30 July to 9 August, 1986. The purpose of the workshop was to enhance communications between instrument manufacturers and those that use these instruments. Vigorous discussions among the 41 international delegates as to observing techniques and instrument performance took place in an easy atmosphere of give and take. The proceedings of this workshop are in press.

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

The Geophysics Division issues regularly two types of forecast of geomagnetic activity. The three-zone, 27-day forecast is issued every three weeks and mailed on request. The 72-hour forecast is updated every working day and is available on automatic answering service - 613-992-1299. A new multizone 27-day forecast gives a daily estimate of a range parameter for each major zone (subauroral, auroral and polar cap) over Canada. The parameter (DRX) forecasted is the daily mean of twenty-four hourly ranges in the X component of the magnetic field. A prediction filter based on Wiener linear prediction theory has been developed and contributes to the routine three-zone 27-day geomagnetic forecast.

An Associate Regional Warning Centre (ARWC) has been established at the Geophysics Division, G.S.C. The Ottawa ARWC is part of the IUWDS (International Ursigram and World Day Service) Network, which provides a system for near-real-time exchange of solar and geophysical data and forecasts by means of coded messages - URSIGRAMS.

(iii) Radio Absorption, Upper Atmospheric Ionization, Conductances and Heating (J.K. Walker)

An expression has been determined (from recently calibrated riometer observations) for the ionization of the lower ionosphere as a function of the HF radio adsorption. The energetic particle heating can also be determined and the height-integrated values related to the adsorption with a quadratic expression. The Hall and Pederson conductivities are

calculated for the seven nominal nighttime models and these height-integrated values are also related to the absorption. Further, expressions for these conductances during distributed sunlit conditions are determined. These relations can be used in conjunction with simultaneous riometer and magnetic observations to determine the Hall and Pederson currents and the Joule heating. The temperature rate for the mesosphere is calculated for both the energetic particle models and for typical Joule heating conditions. It is  $\sim 10$  K/day at 75 km altitude for an 8 dB event.

(iv) Modelling External Currents and Their Magnetic Fields (J.K. Walker, G.V. Haines)

An improved method of modelling external magnetic variations and their associated currents is being developed. It is based on the new method of spherical cap harmonic analysis and models the vector magnetic field to any degree, order and level of statistical significance. At the same time the field is constrained so that the curl and divergence are zero. Preliminary tests for very disturbed conditions using the mean hourly values from the 13 Canadian magnetic observatories indicate the method can model  $\sim 95\%$  of the variation. The equivalent currents at 110 km altitude are also determined from the external coefficients and plotted on synoptic maps.

4. Electromagnetic Induction in the Earth

(a) Geological Survey of Canada, Ottawa (E.R. Niblett, J.A. Craven, J.C. Gupta, A.G. Jones, R.D. Kurtz, G.V. Haines)

As part of Lithoprobe, a major magnetotelluric survey was conducted across the Kapuskasing Structural Zone (KSZ) west of Timmins, Ontario. The profile extended over 100 km from the Wawa Gneiss Terrane to the Abitibi Greenstone Belt. The KSZ is an upthrust section of the Archean crust and provides the opportunity to examine crustal growth and structure. Modelling studies show a very resistive upper crust with a decrease of resistivity to 500-1000 ohm-m in the lower crust. There is little evidence for a conductive anomaly associated with the KSZ other than a probable near surface conductor coinciding with the Ivanhoe Lake Cataclastic Zone - the boundary between the KSZ and the Abitibi Greenstone Belt. This study suggests that increased conductivity observed in the lower crust in many regions is dependent on position rather than composition.

The Miramichi earthquakes in the north-central highlands of New Brunswick provided the impetus for the tensor and scalar magnetotelluric survey in 1983. The analysis of the data shows the presence of a resistive upper crust with a 2 to 3 km layer of about 10,000 ohm-m underlain by a layer of more than 50,000 ohm-m extending to a depth of about 20 km. Below 20 km the resistivity decreases to approximately 2500 ohm-m and then to about 400 ohm-m near the base of the crust. There is no evidence for a seismic fault plane in the magnetotelluric data. However the results indicate the presence of a north-south trending conductor several kilometres wide located in the upper crust a few kilometres east of the Miramichi survey area.

Work progressed on a fast approximation scheme for modelling the anomalous electromagnetic fields due to a buried inhomogeneity. The scheme is valid at periods where the body may be adequately represented as a line current in a conducting half-space. Initial results using a FFT algorithm were a factor of three faster than conventional numerical modelling (Jones, 1986b), however, an alternative approach using Logarithmic Fourier Transformation (LFT; Haines and Jones, 1987) was developed which promises to be at least two orders of magnitude faster. Possible future extensions of this approach will allow for an arbitrary-shaped body, and its shape will be determined from the surface observations using inverse theory.

Analysis of a 35 station MT dataset recorded over the North American Central Plains (NACP) conductivity anomaly for PanCanadian Oil Co. showed that the anomaly is in fact some 75 km further east of the location given by the magnetometer array studies conducted in the early 1970s (Jones & Savage, 1986). Modelling of the responses indicates that the body responsible for the observations is at a depth of some 10 km, and is thin and anticlinal in shape. The MT data were corrected for "static-shift" using a new technique developed by Jones (1986; paper presented at Neuchtel), and the corrected responses agree excellently with the known variation of the conductivity in the Williston sedimentary basin.

Data recorded across the Wopmay orogen have been reanalyzed, principally to reduce source-effect contamination from the estimated inductive response functions. Unfortunately, the data are only along a profile, permitting only a representation of the source in one horizontal direction, rather than both. Nonetheless, results using the new scheme, in which the normal field is approximated by a low order polynomial, shows far superior and stable results compared to the traditional method which does not remove source field effects from data recorded in the auroral zone.

The analysis of the land-based 10 magnetometer sites for EMSLAB run by GSC-LG is continuing. Jones is spending four months (Jan-April 1987) at IGPP, Scripps, in order to complete the analysis and begin collaboration with other scientists involved in this, the largest EM experiment ever conducted.

A new method, called Logarithmic Fourier Transformation, has been devised for determining a Fourier Transform of a function that decays slowly. The procedure involves logarithmic conversions of time and frequency (or, spatially, wavelength and wavenumber), multiplications by well-known elementary (exponential and gamma) functions, and two Fast Fourier Transforms. Since a Logarithmic Fourier Transform requires only a few hundred sampling points, whereas the usual linear Fourier Transform requires tens of thousands (for slowly decaying functions), the total computer time for computing a Logarithmic Transform is about 1000 times less than that for a linear Transform (Haines and Jones).

(b) Pacific Geoscience Centre, Sidney, B.C. (L.K. Law, J.M. DeLaurier, D.R. Auld)

The MOSES method, utilizing ocean - bottom magnetometer and controlled current source, obtained electrical resistivity soundings in the sedimented rift valley of the northern Juan de Fuca Ridge.

The monitoring of changes in apparent resistivity, related to the increase in tectonic strain in Central Vancouver Island, continued at the two established sites in the area. As well, measurements were started in 1986 at a third station located directly on the Beaufort Range Fault.

In cooperation with Dr. J.R. Booker, University of Washington, Seattle, Washington, a joint geomagnetic variation study was conducted in the Clear Lake area of northern California. An array of 18 three component magnetometers was deployed, in two stages, to delineate the conductivity structure beneath the North America lithosphere at the southern edge of the Gorda plate.

(c) University of Alberta

(D.I. Gough, D. McKirdy, Chen Guangming, Wang Xishuo, K. Wilson, M. Connors; V.R.S. Hutton, G.J.K. Dawes, J.Travassos, University of Edinburgh, Scotland; M.R. Ingham, Victoria University of Wellington, New Zealand; W.D. Parkinson, Dept. of Geology, Univ. of Tasmania, Hobart, Australia)

(i) Western Canada

The major study of conductive structures in western Canada, and of their tectonic and geothermal implications continued. Magnetotelluric (MT) soundings will dominate the program in the next few years. The strategy is to use broadband tensor MT to measure the depths and resistivities of the numerous conductive structures already mapped by the magneto-variation arrays.

Large-scale two-dimensional models of the Canadian Cordilleran Regional conductor, and its thickening under the Rocky Mountains Trench and Main Ranges in the latitude range 52-54°N, have been fitted to long-period magnetovariation responses. This work was reported last year, and a paper on it is now in press<sup>1</sup>. Magnetotelluric soundings of a few ohm metres at depths less than 10 km, were also noted in last year's report: that work, too, is in press<sup>2</sup>.

Mr. Chen is working on data from both the 1981B and 1983 magnetovariation arrays to study the Southern Alberta-British Columbia (SABC) conductive structure, the subject of his M.Sc. thesis. He has used many variation events, with varied external current geometries and polarizations, to obtain well determined transfer functions  $Z_H$  and has applied hypothetical fields to these to improve the isolation of the anomalous field of the internal conductor from non-uniform source fields. Chen has also used a technique developed by Mr. Wang (reported below) to separate internal from external fields in the wave-number domain, and has used downward continuation of the internal field to show that the induced currents can be placed with high probability in the lower crust. The conductive structure appears not to coincide with Kansewich's lower crustal rift valley.

(ii) Magnetotelluric field work

The MT study of the Rocky Mountains Trench near McBride, B.C., begun in 1982 in association with the University of Edinburgh, was continued in July by Drs. McKirdy and Gough and Mr. Connors. Twelve sites were occupied in the Holmes River valley and Chalko Creek, where preliminary results showed further indications of a good conductor beneath the main ranges of the Rockies. It was not possible to continue the traverse directly on the southwest side of the trench in the Cariboo Mountains on account of damage done to access roads by flash floods, but a further 5 sites were occupied in the vicinity of Quesnel, B.C., which constituted a widely spaced traverse running from Nazko in the west to the Cariboo Mountains near Bowron Lake.

Computer programs for reprocessing the data have recently been made to run successfully on the university's mainframe computer and on a personal computer, which may make it possible to carry out the reprocessing in the field.

(iii) EMSLAB

This large, international electromagnetic study of the lithosphere and asthenosphere, beneath the Juan de Fuca plate and the continent behind the subduction zone, began last year with data acquisition by means of magnetometer arrays on land and seafloor, magnetotelluric systems on both and pressure sensors on the ocean bottom. Scientists from universities and government laboratories in five countries took part. The U. of Alberta contribution consisted of the operation of the northern half of the land magnetometer array, with the southern half run by Dr. D.V. Woods and Mr. H. Geiger of Queen's University. As was noted last year, the process of reducing the very large quantity of data, much of it in analogue form, is protracted but preliminary results are appearing. For the land magnetovariation array, two whole days and two shorter sequences of data have been digitized and magnetograms and maps of Fourier transform (FT) parameters have been prepared for many events. A north-south elongated high in the east-west horizontal component, Y, shows the presence of a broad lower crustal conductor under the entire Cascades Ranges volcanoes, provisionally assumed to be partial melt. The vertical component, Z, shows a large continental edge anomaly in east-west polarized magnetovariation events, corresponding to induced current in the ocean and the oceanic asthenosphere. All Z maps show very low amplitudes in the southeastern part of the array, which lies on the northeastern corner of the Basin and Range tectonic province. This prominent anomaly in Z is assumed to be due to induced currents in partial melt in the upper mantle under the Basin and Range. FT maps were shown in a poster session of first EMSLAB results, during the Eighth International Workshop on Electromagnetic Induction in the Earth and Moon, held in August in Neuchâtel, Switzerland.

At that workshop, first results from a central east-west line of magnetotelluric soundings gave promise of detection of high conductivities at the top of the subducting oceanic plate. The seafloor sensors have so far yielded mainly some excellent results concerning tidal motions of the ocean water, both from  $\nabla \times \mathbf{B}$  electromagnetic signal and from pressure sensors. Parkinson vectors indicate that the continental edge effect is not mainly due to the thick sedimentary wedge off the coast, but to the ocean water and asthenosphere. As the effect of the water can be calculated, that of the asthenosphere will be discoverable. An article for submission to NATURE, giving first results from EMSLAB, is near completion.



(iv) Electromagnetic modelling and inversion

Dr. McKirdy has continued to develop the approximate 'thick-sheet' modelling scheme, based on a generalization of thin-sheet methods, so that more general models may be studied. The effects of topography and bathymetry can be examined by stacking two model layers of variable thickness, while thicker anomalies, up to six skin depths thick, can be modelled by stacking many layers. The results obtained by such an approximate method agree very favourably with those obtained by analytical and finite difference methods and examples were presented in a talk at the IAGA Workshop in Neuchtel (see also the EMSLAB section). The solutions obtained for simple two-dimensional test models will shortly be sent to Dr Zhdanov of IZMIRAN, Moscow as a contribution to the COMMEMI project.

Mr. Wang has completed a study of separation of magnetovariation data into parts due to internal and external currents, in the wavenumber domain<sup>3</sup>. The method makes use of the orthogonality of the external and internal parts of the observed field, and of a unified potential both in minimizing the curl of each horizontal component, and in the separation. A paper in press<sup>3</sup> gives the theory, and tests it by combining the analytically calculated fields of model line currents above and below a plane, separating the combined field, and comparing the separated parts with the original fields. While known effects limit the precision of separation of fields recorded by a finite array, satisfactory correlation coefficients were obtained between separated and original fields. The new separation technique has been applied to a variation event recorded in a recent array study in western Canada, and a prominent anomaly was shown to be caused by internal currents.

At the Neuchtel Workshop, mentioned in the EMSLAB part of this report, Mr. Wang gave a paper on the inversion of magnetovariation fields to plane sheet currents through an induction matrix formulation. This topic forms a major part of his Ph.D. thesis, now being written.

References

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- <sup>2</sup>Hutton, V.R.S., D.I. Gough, G.J.K. Dawes and J. Travassos, Magnetotelluric soundings in the Canadian Rocky Mountains, *Geophys. J.R. Astr. Soc.*, 1987 (in press).
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(d) Queen's University (D.V. Woods)

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

Magnetometer array data, collected during the summer of 1984 over the Kapuskasing Structural Zone (KSZ) area of north-central Ontario, has been analyzed using Fourier transform amplitude and phase maps and vertical-field transfer functions. The KSZ was found not to be anomalously conductive, even though it is composed of lower-crustal, high grade metamorphic rocks, and the lower crust in this part of the Canadian Shield is anomalously conductive. However, a northeasterly striking conductive zone in the upper crust has been interpreted in the southeast corner of the array. At its most southwesterly end, the conductor appears to be coincident with the Ivanhoe Lake Cataclastic Zone (ILCZ), the eastern boundary fault of the KSZ. To the northeast, however, it diverges from the ILCZ and aligns with a proposed westward extension of the Destor-Porcupine fault in the Abitibi greenstone belt. The size, position and depth of this conductive zone is not well resolved by the few, widely-spaced stations in the southeast corner of the KSZ array, and hence it should be investigated further by detailed electromagnetic surveys in the area.

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

The EMSLAB study is discussed elsewhere in this volume by our collaborators in the project: D.I. Gough and D. McKirdy at the University of Alberta. The primary effort of the



Queen's University group has been 1) data acquisition during the late summer and fall of 1985 from 30 Gough-Reitzel magnetic variometer stations in Oregon, northern California and Nevada, and western Idaho, and 2) data reduction from the entire set of EMSLAB land array stations using an innovative, microcomputer-based system to automatically digitize Gough-Reitzel film records. The digitizing system utilizes a high-resolution, grey-scale, camera digitizer and is capable of 0.5 nT precision digitization of three-component records at a rate of one record-day per hour. At this rate it will take about 2 person-years to digitize the entire Gough-Reitzel data set (65 days x 56 stations) from the EMSLAB experiment.

(e) University of Victoria (J.T. Weaver, H.W. Dosso)

(i) Theoretical Studies (J.T. Weaver, A.G. Agarwal, H.E. Poll)

Existing finite difference programs for modelling the TM mode of electromagnetic induction in 2-dimensional structures provide direct calculations of the induced electric and magnetic fields. In magnetotelluric field measurements, however, the "electric field" is measured as the voltage difference between separated electrodes divided by the distance between the electrodes, which is not the same as the true electric field in a region of surface conductivity anomalies, such as a geological fault, where the field may vary between the electrodes. In order to compare model calculations more accurately with field data, the finite difference program at the University of Victoria has been modified to calculate voltage differences rather than true electric fields. In collaboration with A.G. Jones (Ottawa) these calculations have been compared with field measurements made across the Gloucester fault in Ontario. A paper on this topic was presented at the 8th Workshop on EM Induction in the Earth (Neuchtel, Switzerland) in August, 1986.

As a contribution to the COMMEMI project, in which the results provided by various induction modelling programs developed at different institutions will be compared for a prescribed set of test models, a complete package of finite difference calculations for all the 2-dimensional test models has now been completed. The results have been published as a University of Victoria Report.

New integral boundary conditions for E-polarization solutions have been implemented in the 2-dimensional finite difference program in use at the University of Victoria.

Further work on calculations for 3-dimensional models using the thin sheet approximation is in progress and an extensive study of electromagnetic induction in the southern India region is planned for the near future with the aid of this technique.

An invited lecture on the mathematical solution of the geomagnetic coast effect was presented by J.T. Weaver at the special Conference on Applied Mathematics in honour of Professor A.A. Ashour at the University of Cairo, Egypt.

(ii) Analogue Studies (H.W. Dosso, W. Nienaber, J. Chen, W.B. Hu, Z.W. Meng)

Measurements for the west coast laboratory analogue model, that included a simulation of the subducting Juan de Fuca plate, are being used to compare with field measurements for both the LITHOPROBE and EMSLAB projects. The dipping subducting plate generally has the effect of attenuating coastal anomalies at short periods and enhancing anomalous fields large distances inland for a wide period range.

The analogue modelling facility is being further used to study the electromagnetic responses of idealized ocean channels, islands in an ocean, and submerged seamounts with the view to examining response maxima and periods at which maximum occur, as a function of model dimensions. It is noted that generally the quadrature responses mimic the in-phase responses but at a longer period. As well, the quadrature response is observed to change sign at the period for which maximum in-phase response is observed.

An analogue model of the Bohai Bay region of China has been constructed and model electric and magnetic field measurements are underway. It is planned to employ these model results as an aid in interpreting field station measurements for the Bohai Bay region.

## 5. Paleomagnetism and Rock Magnetism

### (a) Geological Survey of Canada, Ottawa

#### (i) Secular Variation Studies Program (A.G. Latham)

A secular variation record and its interpretation, from a Vancouver Island stalagmite, has been accepted for publication (Feb. 1987) in the Canadian Journal of Earth Sciences. Together with a sediment record from Bessette Creek (Turner, Evans, and Hussin, U. of Alberta), this provides an almost unbroken SV curve dating from 31 Ka to 15 Ka for Western Canada.

Another stalagmite, known to be Holocene in age, from Vancouver Island, is to be studied shortly in order to extend the W. Canadian SV Holocene record, started with stalagmite VCCL.

The earlier, 31 to 15 Ka SV curve appears to provide evidence for pulsating core - mantle boundary sources, whereas the Holocene SV curve shows mainly westward drift of the (non-dipole) field.

Other oriented stalagmites, now being prepared for NRM measurement, include two from eastern USA, two from Mexico and two from Tasmania (in collaboration with A. Goede, U. of Tasmania). Dating of these stalagmites is by the U-Th method and will be made after all magnetic measurements have been completed.

#### (ii) Canadian Nuclear Fuel Waste Management Program (A. Latham, K.L. Harding, P. Lapointe)

Work undertaken by the Rock Magnetic Properties Task group for AECL is now largely complete. Summaries for the URL site, Atikokan and East Bull Lake are in the final draft stage for the Level II, Concept Assessment Documents (CAD), and have been refereed internally by GSC and AECL personnel.

In addition, the Rock Properties CAD for the East Bull Lake gabbroic pluton is being edited, and is nearing completion.

No further experimental work or magnetic measurements will be carried out on AECL borecores, but statistical analyses of the available data for pluton characterization as outlined below will continue.

#### (iii) Studies in Magnetic Character and Alteration of Granitic Plutons (A. Latham, K.L. Harding, P. Lapointe)

This work is a natural follow-on from the magnetic studies done for the Nuclear Fuel Waste Program. Statistical analyses of granite borecore susceptibility data are being used as part of a larger program to study primary magma source (S-type, I-type, etc.), magnetic homogeneity, assimilation of xenoliths, wall- and roof-rock, etc, and fracture-induced weathering of the rock body. Two borecores from Nova Scotia and one from New Brunswick are being analyzed in conjunction with Morris Magnetics and the Nova Scotia Dept. of Mines. This work appears to confirm the supposed genetic relationship between the South Mountain Batholith and the nearby Wedgeport pluton, even though the latter is younger by about 70 Ma. The core from the St. George pluton of New Brunswick has at least 20 times the susceptibility of the Nova Scotia cores, and is pervasively altered to at least a depth of 370 m, as opposed to ~50 m for the other two.

In other granite alteration work, it has been (re?) discovered that the weathered granite samples (from Atikokan) display susceptibility, coercive force and saturation remanence variations which lie along the "main sequence" trend of the discrete grain-size studies of Dankers, Hartstra and Dunlop, for magnetites. Some of the most reddened samples then follow the hematite trend of Dankers in the same plot. This suggests, inter alia, that a distribution of grain sizes behaves like a discrete grain size (range) when using these parameters, and suggests an alternative way of quantifying alteration by rock-magnetic methods.

(iv) Technical Program (Gilbert Massie, Benoit St. Louis)

The automatic core-feeder and automatic core susceptibility data acquisition system has been completed and used several times on URL cores and a long core from Nova Scotia. Further work and development is in progress on a similar system, employing ring-core technology, to measure remanences of borecore sections. This is expected to be completed and tested soon, and together with the susceptibility system, will provide a rapid method for producing rock magnetic property data. Section 3 above highlights the desirability of these rapid, automated systems in opening up areas of research which would have been extremely tedious and time consuming using the older instruments.

(v) Precambrian Program

Work continues on late Precambrian units of the Cordillera of the Yukon and Northwest Territories. Analysis of the Coates Lake Group (Redstone River Formation, Thundercloud Formation) reveals several magnetic components, one of which suggests that the proposed hiatus between this group and the underlying Mackenzie Mountains supergroup is not as large as previously thought. This interpretation conforms to a recent geological interpretation. A paper is currently in preparation on late Proterozoic diabases from the Mackenzie Arc, showing that the arc is a primary feature, as suggested by some earlier structural studies.

(vi) Nipissing Diabase Sills of Southern Province

The paleomagnetic characteristics of Nipissing diabase sills are being studied in several broad regions of the Southern Province. This work demonstrates that Nipissing sills carry one of three distinct directions of magnetization. Each component has been observed in petrographically fresh diabase. Further work is being conducted in order to clarify their relative age and to determine which are primary and which secondary. Resolution of these questions is important for an understanding of the Early Proterozoic apparent polar wandering path of the North America.

(vii) Appalachian Orogen in Newfoundland

Recent models of the evolution of Appalachian terranes are controversial. They suggest that (1) a portion of Eastern North America (called Acadia) was located ~2,000 km south of its present location relative to cratonic North America until the Devonian or Mississippian, (2) the Appalachian orogen is composed of numerous suspect terranes which moved independently of one another, or (3) the orogen has been essentially coherent since the early Silurian. Several geological units of Paleozoic age in Newfoundland are being studied paleomagnetically to test these models. Results will be compared with units of similar age elsewhere in Appalachian terranes and from cratonic North America.

To date a stable magnetization direction has been obtained for early Silurian red beds and rhyolites of the King George IV Lake area of southwestern Newfoundland. This work is being carried out in collaboration with J.P. Hodych of Memorial University of Newfoundland, St. John's.

(viii) Paleomagnetic Studies in the Appalachians

a) The Meguma Terrain. Studies in Nova Scotia are aimed at unravelling the tectonic history of the Meguma Terrain in the context of the Appalachian Orogen.

Overprints from the Mavillette Intrusion, a Middle Paleozoic continental tholeiite, bear some similarity to remanences observed in the Shelburne Pluton, and the greisenized Davis Lake Pluton at East Kemptville. Experimental work on the greisenized granite is in progress.

A feasibility study is in progress on the potentially mineralized members of the Liscomb Complex. More sampling is scheduled for the upcoming field season.

b) The Maritime Sedimentary Basin. Field work was carried out on the Magdalen Islands in order to investigate the hematization process of the Cap aux Meules Permian redbeds. Hematite was preferentially leached out of some horizons, thereby explaining why some sites of this collection give discordant results.

(ix) Paleomagnetic Studies on the St. Lawrence Platform

The goal of this program is to complement Appalachians studies by defining the Lower Paleozoic reference path from the stable part of the craton. This is necessary for proper interpretation of results from the Appalachian foldbelt.

A study of the Cambrian layered mafic intrusion at Sept-Îles has yielded a well-dated Cambrian pole. Results were presented at the latest meetings of the GAC, and are nearing publication. The development of the Sept-Îles 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. Therefore, a study of the dyke swarm that crosscuts the Sept-Îles intrusion is planned to commence in the upcoming field season.

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

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

Work is now completed on the large collection (760 samples) of sediments taken from the banks of the Old Crow River between latitudes 67° and 68°N. The resulting data form the basis of Michael Hedlin's recent M.Sc. thesis, and have been accepted for publication in the Geophysical Journal of the Royal Astronomical Society. One of the original goals of this study was to locate and investigate the so-called Blake Event which is generally regarded as a global interval of reversed polarity which occurred about 100,000 years ago. Apart from its intrinsic geomagnetic interest, this polarity event has considerable potential as a regional stratigraphic marker and is consequently of interest to a broad spectrum of scientific disciplines. Indeed this project enjoys the active collaboration of John Matthews (Geological Survey of Canada), John Westgate (Department of Geology, University of Toronto), Owen Hughes (Institute of Sedimentary Petrology, Calgary), and Charles Schweger (Department of Anthropology, University of Alberta).

With the exception of a single sample (whose behaviour during AF demagnetization suggests the presence of an underlying reversed magnetization) no reversed interval was found, however the secular variation (SV) pattern observed was of considerable interest. This reveals the type of pattern which can be attributed to a standing source. Westward (or eastward) drifting sources generally produce symmetrical SV patterns in the form of open loops, whereas a stationary source which suddenly grows and decays leads to a linear perturbation involving an 'outward' and a superimposed 'return' trajectory. A simple magnetostatic model consisting of a radial dipole just below the core-mantle boundary is remarkably successful in explaining the observed perturbations. It is found that a subsidiary dipole with an amplitude as low as 8% of that of the main central dipole is adequate; if such a source is allowed to vary sinusoidally (half-rectified) the main SV features are readily reproduced. Earlier work on a sequence of sediments from southern British Columbia produced evidence of similar behaviour which may be due to the same source. If this is so it raises the intriguing possibility that stationary sources of this kind - which may correspond to the "static flux bundles" recently recognized by Bloxham and Gubbins in their novel analysis of historically recorded SV - may have lifetimes of  $10^5$  years or more.

We plan to extend the data base of this project with further collections to be made in the summer of 1987.

(ii) Archeomagnetism (M.E. Evans, M. Mareschal (Ecole Polytechnique, Montreal), G.S. Hoye, W.I. Gough, V. Frnoch)

Samples collected from archeological sites around the Mediterranean are yielding good archaeomagnetic results and work to date has been summarized in a series of three papers, details of which can be found in the Bibliography section. These refer mostly to Italian sites, whereas samples from Greece and North Africa are still being investigated in the laboratory. Good results ( $k > 200$ ) have so far been obtained from three Roman sites in Morocco (Sala, Banasa and Thamusida), from the Roman town of Tipasa in Algeria, and from several Punic features in Tunisia (Carthage and Kerkouane). In Crete good results have been obtained from Roman kilns at Knossos and Khalo Chorio, while on the mainland promising data

are forthcoming from Argos and Corinth. These data will help define the secular variation pattern both in space and time and may provide important clues for the dating of certain sites.

Another archaeomagnetic study involves the detailed thermal demagnetization behaviour of several samples drilled from a large tile fragment (about 20 cm long) taken from the wall of a 1st century A.D. kiln. The data so far obtained clearly reveal the presence of two magnetic vectors, one dating from the original firing, the other being a later overprint. This indicates that it should be possible to deduce the reheating temperature profile throughout the fragment and thus determine the firing temperature used when the kiln was in production. Magnetothermometry of this kind therefore offers a useful addition to the scientific tools as the disposal of the archeometrist.

- (iii) Permian paleomagnetism (M.E. Evans, J.-M. Maillol (Université des Sciences et Techniques du Languedoc, Montpellier, France), V. Frnoch, W.I. Gough)

A paleomagnetic investigation of a 16 m sequence of redbeds recovered from a long core (drilled for uranium exploration in France) has been completed and the results have been published. A corresponding collection of fully oriented surface samples has been made and is currently being studied in the laboratory. In addition, several coherent core segments on the order of a metre in length have been obtained in order to determine any high-frequency content in the SV pattern. This project will be extended and accelerated in 1987 when J.-M. Maillol arrives to continue graduate work at the University of Alberta.

(c) Université Laval (Maurice K. Seguin)

Projects in progress:

(i) Quebec.

- 1 - Ordovician-Silurian boundary of the upper St. Lawrence Lowlands on Anticosti Island.
- 2 - Devonian sedimentary units in the eastern Gaspé and Chaleur Bay region in the Andean margin of the northern Appalachians.
- 3 - Carboniferous diabase dykes from the eastern Gaspé area.
- 4 - Ordovician sedimentary units (Black River, Utica, Trenton, Chazy and Beekmantown) from the central St. Lawrence Lowlands.

(ii) Newfoundland.

- 1 - Late Hadrynian basalts in the Harbour Main Group of Eastern Newfoundland (Avalon Zone).
- 2 - Late Hadrynian rhyolitic sills in the Cape St. Francis area of northeastern Newfoundland (Avalon Zone).

(iii) Nova Scotia. The Nova Scotia Paleomagnetic research is a joint project of Laval University (M.K. Seguin and K.V. Rao) and Memorial University of Newfoundland (E.R. Deutsch).

- 1 - Late Hadrynian Fourchu gabbro intrusives in the Louisbourg, Baleine Cove and Cape Breton areas of southern Cape Breton (Avalon Zone).
- 2 - Late Hadrynian Fourchu ultrabasic dykes in the same area as 1.
- 3 - Late Ordovician to Devonian dykes and Devonian sediments from the Torbrook Formation in northwestern Nova Scotia (Meguma Terrane).
- 4 - Devonian Fisset Brook Formation (red beds and volcanics) from northwestern Cape Breton Island (Avalon Zone).

- 5 - Late Devonian and Lower Carboniferous granitic to granodioritic intrusives from central Nova Scotia.
  - 6 - Lower Silurian volcanics from the Dunn Point Formation, northeastern Nova Scotia (Avalon Zone).
  - (iv) Andes of South America. In collaboration with T. Feininger and E. Tanczyk from the Geological Survey of Canada.
    - 1 - Cretaceous igneous and sedimentary rock sequences from coastal Peru.
    - 2 - Precambrian to Tertiary rock units from allochthonous terranes of Ecuador.
  - (v) Scandinavian Countries. In collaboration with G. Bylund (Univ. Lund, Sweden) and Pieter Nystueen (Gothenburg Tech., Norway).
    - 1 - Cambrian, Ordovician and Silurian platform sequences (sedimentary rocks) of southern and central Sweden.
    - 2 - Late Hadrynian and Cambrian sequences (sedimentary rocks) of central eastern Norway.
- (d) University of Toronto (D.J. Dunlop, H.C. Halls)
- (i) Chemical Remanent Magnetization (CRM) Studies (O. Ozdemir, D.J. Dunlop)
 

The CRM of synthetic single-domain maghemite carrying initial anhysteretic remanence (ARM) has been determined during inversion to hematite in a 0.5 Oe field perpendicular to the ARM at temperatures of 300, 410, 505 and 555°C. The total remanence and its coercivity spectrum after each run can be approximately simulated by combining, orthogonally, results from purely CRM and purely ARM thermal runs (i.e. experiments in which either CRM=0 or ARM=0). Thus, to a first approximation, CRM forms independently of pre-existing remanence in the parent phase. However, CRM intensity increases sharply as the hematite content grows and average coercivity also increases. Some degree of coupling between the parent and daughter phases may be indicated by these observations.
  - (ii) High-temperature Viscous Remanent Magnetization (VRM) Studies (O. Ozdemir, D.J. Dunlop)
 

These experiments have been undertaken to test the hypothesis that much of the CRM observed in high-temperature runs in magnetite and titanomagnetite oxidation or maghemite inversion forms by a VRM mechanism, i.e., blocking is principally a result of time rather than volume change. Single-domain (0.04  $\mu\text{m}$ ) magnetites have been given 3-hour VRMs in a 0.5 Oe field at temperatures of 300, 400, 450, 500 and 550°C. After zero-field cooling, the VRMs were AF demagnetized in 21 steps to 1000 Oe. Average coercivity increases for higher temperature VRMs, and the coercivity spectra do resemble those of "CRMs" produced at the same temperatures.
  - (iii) Hydrothermally Grown Magnetite Crystals (F. Heider, D.J. Dunlop, N. Sugiura (U.B.C), S.L. Halgedahl (Lamont))
 

Narrowly sized magnetite crystals were grown from 1  $\mu\text{m}$  to 1000  $\mu\text{m}$  in size. The hysteresis properties of these crystals continue the size trends of submicron magnetites over 3 decades of larger grain diameters, following a power law as expected theoretically. Hysteresis properties of millimetre size magnetite crystals are similar for hydrothermally grown and natural crystals. Dislocation densities estimated from etch pit counts were similar also in the two types of crystals. Magnetic domain patterns were observed using the Bitter technique with both optical and scanning electron microscopes. The samples were first polished with an atom mill to remove the stressed surface layer resulting from mechanical polishing. Hydrothermally grown crystals, like natural crystals, show fewer domains than expected from micromagnetic calculations.



- (iv) High-temperature Susceptibility and Coercive Force of Titanomagnetites  
(D.J. Dunlop, O. Ozdemir, R.J. Enkin)

A method proposed by J. Hodych for determining demagnetizing factor was tested using high-temperature susceptibility and coercive force data of fine-particle magnetites and titanomagnetites. Unfortunately, the coercive force data were much affected by thermal fluctuations and the method seems to work well only for below-room-temperature data. A new method of thermal fluctuation analysis was developed to treat the case of mixed crystalline and shape anisotropies. It gave encouraging results in analyzing the titanomagnetite data.

- (v) Micromagnetic Calculations of Internal Fields in Ferromagnetic Crystals  
(R.J. Enkin, E. Tjan, D.J. Dunlop)

Using equilibrium one-, two- and three-domain structures calculated for magnetite by a sophisticated micromagnetic method (see last year's report), the resulting distribution of internal demagnetizing fields  $H_i$  has been determined.  $H_i$  has a much more complicated pattern of directions and intensities than the magnetization distribution which is its source. However, at the geometric centre of the particle, the demagnetizing factor (the ratio between  $H_i$  and the magnetization) has the theoretically expected value (e.g.,  $-1/3$  for a uniformly magnetized cube). Most of the patterns and field lines can be explained in a natural way by considering the analogous problem of the electric field distribution between the plates of a parallel-plate capacitor whose plate dimensions are comparable to the plate spacing.

- (vi) Paleotemperature Determination by Paleomagnetism and  $^{40}\text{Ar}/^{39}\text{Ar}$  dating  
(H. Hyodo, D.J. Dunlop, D. York)

The method of obtaining paleotemperatures by paleomagnetism and  $^{40}\text{Ar}/^{39}\text{Ar}$  dating was described in previous years' reports. One of our study areas is 100 km west of Mattawa, Ontario on Hwy. 17. Syenitic gneiss is intruded by a mafic dike associated with the Ottawa graben. The paleomagnetically estimated temperature of the country rock is about 200°C, corresponding to a depth of about 7 km if the present geothermal gradient is used. Another study area is near Gowganda, Ontario, where Nipissing diabase is cut by a mafic dike with Abitibi (ENE) trend. Here a paleotemperature of 250-280°C at the time of intrusion is indicated. We are also analyzing a baked contact on Whiteface Mountain in the Adirondacks (New York State), where overprinting and host magnetizations coexist over a broad zone compared to the dike width of 0.9 m. A general warming of the anorthosite country rock, perhaps due to multiple dike intrusions or hydrothermal heat transport, seems to be indicated. Further study of these baked contacts is continuing using  $^{40}\text{Ar}/^{39}\text{Ar}$  age spectra.

- (vii) Paleomagnetism in the Kapuskasing Structural Zone (Lithoprobe Project)  
(V. Costanzo, D.J. Dunlop)

Extensive resampling was undertaken last summer in the southern lobe of the KSZ to obtain more information about the three magnetic components isolated previously. Specifically we wished to improve the statistical resolution of the A, B and C components, to obtain if possible an unrotated A component from the adjacent Michipicoten belt to refine our previous structural correction for the KSZ, and to study the relationship between carbonatite rift intrusions (e.g., the Lackner Lake carbonatite) and the thermochemical overprints B and C in anorthosite samples.

Our ultimate goal is to determine a paleomagnetic cooling history for the KSZ. To this end, we have designed sampling schemes to overcome some of the problems in our original strategy (non-parallelism with regional metamorphic gradient, heterogeneity of rock types and blocking temperature spectra). The new traverses are along Hwy. 11 between Timmins and Kapuskasing and along Hwy. 101 west of Chapleau. Sampling is restricted to mafic phases in the tonalitic gneisses.

- (viii) Paleomagnetism in the Red Lake Greenstone Belt (V. Costanzo, P.W. Layer, D.J. Dunlop)

A new joint paleomagnetic and  $^{40}\text{Ar}/^{39}\text{Ar}$  study in the Red Lake greenstone belt (Uchi subprovince, NW Ontario) is the first such work in this 2.94-2.73 Ga metavolcanic-

metasedimentary terrain with its associated 2.74-2.69 Ga granitic batholithic plutonism. Paleomagnetic sampling of the Hammel Lake, Little Vermillion Lake, Trout Lake, Dome Stock and Killala-Baird batholiths has been carried out. The magnetic studies will link with ongoing U/Pb and  $^{40}\text{Ar}/^{39}\text{Ar}$  geochronological studies on the batholiths and metavolcanics, in an attempt to unravel the age of gold mineralization and its relationship with shear deformation, contact thermal metamorphism and intense hydrothermal alteration. Preliminary paleomagnetic results show a novel high-coercivity magnetic component with a southward, intermediate upward direction. The corresponding virtual geomagnetic pole falls between well-established groups of poles about 2.5 and 2.65 Ga in age respectively. An age of 2.6 Ga is also consistent with preliminary hornblende and mica  $^{40}\text{Ar}/^{39}\text{Ar}$  ages.

- (ix) Paleomagnetism of Oriented Drillcores into Precambrian Basement (O. Ozdemir, D.J. Dunlop, B. Reid)

A virtual geomagnetic pole at  $4^\circ\text{S}$ ,  $92^\circ\text{W}$  ( $dp=3^\circ$ ,  $dm=4^\circ$ ), based on AF cleaned data from 25 fully oriented samples from an 8-m section of a Pan Canadian Petroleum Co. drill core into the granitic basement of southern Alberta, falls on the established apparent polar wander path for North America around 1850 Ma. The method holds promise for dating basement cores and mapping the extensions of Precambrian province and subprovince boundaries under later cover.

- (x) Shaw-method Paleointensity and Thermal Alteration Studies (D.J. Dunlop, B. Reid, H. Hyodo)

We have restudied samples of the 19th-century Jordan brick kiln near Niagara Falls, Ontario using the Shaw method, in which anhysteretic remanences (ARMs) are compared before and after heating samples to induce thermoremanence (TRM) to monitor alteration in the quantity and texture of magnetic minerals. Previous Thellier paleointensity results were anomalous, presumably because of alteration between pairs of heating steps. In many cases, the coercivity spectrum of TRM could be successfully corrected for alteration on the basis of corresponding changes in the ARM coercivity spectrum, and a more reasonable paleointensity estimate was obtained.

- (xi) Paleomagnetism and Structure of Precambrian dykes, eastern Lake Superior region and their use in estimates of crustal tilting (H.C. Halls and E.G. Shaw)

Using paleomagnetic and structural data on 2.6 Ga-old Matachewan dykes along the east coast of Lake Superior, a westward crustal tilt of about 60 degrees can be estimated. This tilting is associated with crustal subsidence along the 1.1 Ga Central North American rift system. The potential of using dykes as deformation indicators is that estimates of crustal tilting can be obtained on a regional basis without reliance on the few isolated patches of Keweenaw supracrustal sequences.

- (xii) Paleomagnetism and geochemistry of Middle Precambrian dykes from northwestern Ontario and Minnesota (H.C. Halls, D.L. Southwick (Minnesota Geological Survey))

A primary magnetization about 2.1 Ga old is found in a NW-trending dyke swarm that passes through Kenora, Ontario. It is especially well preserved in sites at the NW end of the swarm, which are the farthest away from the Penokean fold belt that truncates the dyke swarm at its southern end. The primary nature of the remanence is demonstrated using geochemistry to correlate individual dykes over distances in excess of 300 km. The remanence direction varies between dykes but remains constant along a dyke, sufficient proof that it was formed during initial cooling of the intrusion. A weak longitudinal increase in hydrous alteration, MgO content and degree of magnetic overprinting is found towards the southeast and may reflect increasing proximity to a Precambrian margin that underwent rifting, sedimentation and deformation during the time interval 2.2 to 1.6 Ga. The results illustrate for the first time the potential of dyke swarms as sensitive indicators of how shield terrains may respond to events occurring around their margins. The dykes were derived from a single magma type which was tapped at two stages: an early stage when the magma contained 7.6% MgO and 0.9%  $\text{TiO}_2$  and a late stage when the magma contained 5.5% MgO and 2.2%  $\text{TiO}_2$ .

- (xiii) Paleomagnetism of the Keweenaw Powder Mill Group, Michigan and Wisconsin (H.C. Halls, H.C. Palmer (Western Ontario))

Reversely magnetized sites from the eastern end of the Powder Mill volcanic range, where dips are shallow, yield a pole that lies at the apex of the Logan Loop. Near-vertical strata toward the west, if rotated to horizontal about presently observed strike, yield a pole that lies on the eastern arm of the Logan Loop. A stratigraphic change from reversed to normal polarity near the base of the sequence, originally reported by Books (1972) is not confirmed. Normal flows have been found at two localities, only one of which is at the base of the sequence. A higher metamorphic grade of normally magnetized rocks suggests that their remanence is secondary. A major conclusion is that only a single reversed-to-normal polarity change characterizes southern Lake Superior Keweenaw volcanic sequences, in agreement with findings along the north shore.

- (xiv) Paleomagnetism of mafic intrusive rocks from the Sverdrup Basin, Axel Heiberg and Ellesmere Islands (H.C. Halls and K.C. Jackson (Imperial College, London, UK))

Detailed thermal and AF demagnetization performed on about 500 samples from more than 100 sites collected from sills, dykes and lava flows in the Sverdrup Basin yield high quality paleomagnetic data. Results suggest that igneous activity was confined to the Cretaceous and that a displacement of the pole from the Mesozoic APW path indicates an anti-clockwise movement of the terrain of less than 25 degrees. Much of this movement accompanied deformation during the Tertiary Eureka Orogeny when Greenland rotated to open the Labrador Sea. The results can accommodate an earlier (Upper Cretaceous?) anticlockwise movement which is also suggested by paleomagnetic results from Spitzbergen.

- (xv) Paleomagnetism of the Matachewan dyke swarm and its bearing on the evolution on the Kapuskasing Structural Zone (H.C. Halls and H.C. Palmer (Western Ontario))

Beginning with the initial study by Ernst and Halls (1984) and continuing with detailed sampling traverses along the White River-Hearst Road (Halls, 1984), Missinaibi Lake and Elsas CN rail line (Halls, 1985) and Chapleau area (Halls and Palmer, 1984, 1985) a total of 41 sites from 2.6 Ga-old Matachewan dykes and 15 sites from 2.0 Ga-old Kapuskasing dykes have been paleomagnetically measured. Major conclusions are that all dykes in the vicinity of the Kapuskasing Zone are relatively stable magnetically and petrologically fresh compared to those of the same trend and probable age that are farther away. A marked anomaly, that may reflect inadequate sampling or some tectonic relationship with the KSZ, is that Matachewan dykes in the vicinity of the KSZ are normally magnetized whereas those outside are for the most part reversed. Work is continuing in an effort to delineate the extent of the normal swarm and its age relative to those of reversed polarity.

- (xvi) Aeromagnetic interpretation of dyke swarms in Tanzania (H.C. Halls, K. Burns, P. Batterham, S. Bullock (latter two formerly with Geosurvey International, London, U.K.))

A spectacular series of north-trending magnetic anomalies extends southwards from Lake Victoria for a distance of 500 to 800 km and continues for a further 500 km through Zambia. The anomalies are caused by dykes of two or possibly three distinct ages, some of which are major intrusions having widths of more than 200 m and lengths of 400 to 800 km.

- (xvii) Paleomagnetism and geochemistry of NW-trending dykes in the Barberton Mountain Land of South Africa (H.C. Halls and D.R. Hunter (University of Natal, South Africa))

Paleomagnetic and geochemical samples were collected from 14 dykes of a major swarm that cuts Archean rocks of Swaziland and neighbouring South Africa. Paleomagnetic measurements and an aerial photo study of the swarm are presently underway.

- (xviii) Paleomagnetism of the Marathon dyke swarm, northern Ontario (H.C. Halls)

A long-term project is an accumulation of paleomagnetic data from a rather ill-defined dyke swarm approximately centred on Marathon, Ontario, that trends in a northerly direction for several hundred km. About 20 sites collected from the Hemlo, Marathon, Geraldton

and O'Sullivan Lake areas have been measured. The data are generally of good quality with both normal and reversed dykes being present. The reversed dykes have directions similar to those of the Kenora-Kabetogama dykes farther west.

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

- (i) Michipicoten Island-Paleomagnetism and Age (H.C. Palmer and D.W. Davis, Royal Ontario Museum)

The Mamainse Point Formation and the overlying Michipicoten Island Formation on Michipicoten Island, Lake Superior have been re-studied paleomagnetically. Normal polarity poles from each formation have been obtained (186°E, 38°N; 175°E, 26°N) respectively. A quartz-feldspar porphyry intruding the Mamainse Point Formation, but overlain by the Michipicoten Island Formation, was sampled for U-Pb analysis of zircon. The zircons define an age of emplacement of  $1086.5 \pm 1.3 / -3.0$  Ma. This age, combined with previously published U-Pb ages, indicates a time span of about 22 Ma for most Keweenawan igneous activity. A paper describing this work has been accepted for publication by Precambrian Research.

- (ii) Michipicoten Island-Precambrian Glass (H.C. Palmer, K. Tazaki, W.S. Fyfe, and Z. Zhou, all at U.W.O.)

Several of the members of the Michipicoten Island Formation still preserve optical volcanic glass (Annells, 1974). By a combination of x-ray diffraction, electron diffraction and transmission electron microscopy we show that by all techniques known to us, this material is still true glass. A paper describing these results and possible reasons for its amazing survival has been submitted for publication. The documentation of this material as being true glass enhances the belief that the remanence recovered from the Michipicoten Island rocks is primary; secondary overprints can be excluded.

- (iii) Archean Gabbros-Magnetic Fabric Studies (H.C. Palmer and R.H. Sutcliffe, Ontario Geological Survey)

Oriented samples from both the Mulcahy Gabbro and the Lac des Iles Complex, district of Kenora have been examined for their low field anisotropy. Where these rocks are visibly layered or foliated, the AMS data faithfully reflect the orientation of megascopic layering and/or foliation. In addition the AMS data provides, at many localities, a direction of magnetic lineation which cannot be observed in outcrop. The lineation data probably reflect magmatic flow directions. Planar magnetic fabrics, not mimicked by visible layering or foliation, may aid in the distribution of occult stratiform sulfide deposits. To date only some of the samples have had their remanence examined; preliminary conclusions are that the Mulcahy remanence is pre-tilting in age and that the remanence in the Lac des Iles Complex has been variably reset by nearby sheets of Logan diabase.

- (iv) Matachewan Dykes of Ontario (H.C. Palmer and H.C. Halls, Univ. of Toronto)

See entry by H.C. Halls, University of Toronto

- (v) Felsic Volcanic Rocks, East Central Nevada (H.C. Palmer and W.D. MacDonald, SUNY, Binghamton)

Through a study of the spatial distribution of felsic volcanic rocks of 43-34 Ma age in east-central Nevada, we have identified 4 possible eroded volcanic caldera structures. By a combination of the techniques of paleomagnetism and anisotropy of magnetic susceptibility (AMS), we are reconstructing paleoflow patterns and attempting to confirm the locations of eruptive centres. On the larger scale of structural geology and tectonics, these data are used to assess the role of block rotations accompanying Basin and Range extensional tectonics and rotations as a consequence of possible strike-slip motion along the Oregon Nevada lineament.

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### III(B) AERONOMY AND SPACE PHYSICS

Compiled by: D. Venkatesan

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#### 1. Introduction

The following represents the highlights of the research activities in the areas of Aeronomy and Space Physics in Canada during 1986; this is based on the DASP/CAP newsletter edited by R. Koehler, York University, Toronto (ON).

A milestone in the year was the launching of the Swedish Satellite Viking in February, 1986; this carried onboard the Canadian Ultra Violet Imager (UVI) with C.D. Anger, University of Calgary, as the principal investigator and the following co-investigators, composed mainly of scientists from a number of institutions across Canada: G. Rostoker (Univ. of Alberta), L.L. Cogger, J.W. Haslett, J.S. Murphree and D. Venkatesan (Univ. of Calgary), E.H. Richardson (Dom. Asph. Observatory), A.L. Broadfoot (Univ. of S. Calif.), A. Vallance Jones, G. Creutzberg, R.L. Gattinger and F.R. Harris (Herzberg Inst. of Asph.), E.J. Llewellyn and D.J. McEwen (Univ. of Sask.), G. Gustafsson (Uppsala Iono. Observatory), G.C. Shepherd and J.C. McConnell (York Univ.).

Considerable credit goes to J.S. Murphree, Calgary, who has been primarily responsible for setting up the ground station in Kiruna, Sweden and co-ordinating the field operations, and also producing the necessary software. He spent a number of months at Kiruna before and after launch. Co-investigators spent varying periods during specific campaigns. A number of scientific papers using Viking data have recently appeared in the April 1987 issue of Geophysical Research Letters published by the American Geophysical Union.

The Viking UVI experiment attests to the cooperation and team spirit of a number of scientists, and its successful operation over 1986 brings credit to the entire Canadian community involved in the same. The studies of the Auroral Oval by the Viking UVI and its predecessor on the ISIS-2 satellite are standing monuments of the Canadian contribution to Auroral Physics.

#### 2. Division of Aeronomy and Space Physics/Canadian Association of Physicists (DASP/CAP)

The Executive of DASP/CAP for 1986-87 are R. Lowe, University of Western Ontario, London (ON) - Chairman, J. Samson, University of Alberta, Edmonton (AB) - Vice-Chairman, R. Koehler, York University, Toronto (ON) - Secretary-Treasurer, and L.L. Cogger, University of Calgary, Calgary (AB) - Past Chairman.

The following provides a summary of the letter from Chairman, R.P. Lowe, to the DASP members, issued in March, 1987. The year 1986 had a high level of scientific activity for DASP members, with particular involvement in major projects and campaigns. The announcement of the formation of a new Space Agency is likely to have an important bearing on the research activities of the DASP membership.

The DASP annual meeting scheduled for June, 1987 at the University of Toronto will provide a lively forum for scientific and organizational matters. The invited speakers include; J.S. Murphree, A.S. Vallance Jones, and G. Shepherd, who will provide updates on Viking, Canopus, and Wamdi/Windii projects, respectively. A.E. Collina is expected to talk about the status and directions of the new Space Agency. The acceptance of the DASP Newsletter Editorship by R. Koehler at short notice, and producing the newsletter for year 1986 is appreciated.

3. Minutes of the DASP Annual Meeting at the CAP Congress June 24, 1986, at the University of Alberta, Edmonton (AB).

The following provides the essential summary of the minutes: About 20 members (out of 70 as of 04-30-86) were present; G. Sofko was appointed Acting Secretary, in the absence of the regular Secretary, R. Koehler. The financial report from the Secretary/Treasurer revealed the following: Brought forward \$2734.00, Membership revenue \$412.00, Expenditure \$345.49 and thus Balance on 04/30/86 = \$2800.41. The highlights of the Chairman's Report are as follows: CAP Congress: There are 18 regular papers (17 from Universities) and 2 invited papers from Herzberg Institute of Astrophysics/National Research Council (HIA/NRC), Ottawa. DASP holds only an oral paper session for the contributed papers in contrast to the poster sessions held by many other Divisions of CAP. There was no motion for a change from this procedure. Chairman Cogger on behalf of DASP felicitated Ian McDiarmid Director, Canadian Centre for Space Science, NRC, Ottawa, on his retirement. The DASP Division declined an invitation to organize a DASP/Industry Symposium at the CAP Congress. D.J. McEwen said that many universities are developing archival collections on a permanent basis; he suggested that perhaps DASP should retrieve its archival material (currently held by Agnes Kruchio), for incorporation into a University Archive. Nate Gerson's suggestion to CAP for establishing an F. Davies Scholarship in optical processing was discussed at length; no clear course of action emerged. A motion not to take action at this time was passed. The physics Building at Saskatoon has a permanent plaque and an area for Davies/Balfour Currie memorabilia.

IUGG: The upcoming IUGG Meeting (Vancouver, August 9-22, 1987) has an excellent program, with 7 days on magnetospheric physics (Nishida) and 7 on aeronomy (Gadsden). The two Canadian members on the National Committee for IAGA are D.J. McEwen (DASP) and R. Coles (Canadian Geophysical Union). A new DASP member has to be elected to replace D.J. McEwen whose term expires after IUGG meeting.

The members at present on NRC Associate Committee for Space Research are G. Sofko and R. Burrows. There is need to check on the status of these two, and to suggest new ones when necessary.

The past 4 editors for DASP newsletter have been Lyon (Western), Llewellyn (Saskatchewan), Horita (Victoria) and Gattinger (HI/NRC) for the past 3 years. The obvious choice for a new DASP Newsletter Editor is from York University; perhaps it could return to Western. The matter has been left to the DASP Executive to decide.

The question of holding a separate winter workshop was discussed; a move for holding one this year, in view of IUGG at Vancouver in August, was unsuccessful; it was suggested that DASP still participate in the CAP Annual Congress at Toronto and publicize the Viking results, setting the stage for further papers at the IUGG in Vancouver.

4. University of Alberta; Institute of Earth and Planetary Physics and Department of Physics/Space Science Group

This year the emphasis has shifted from interpretation of ground based magnetometer data to several other projects (VIKING imager data analysis, and modelling and computer simulations of magnetospheric processes). Note still active involvement in the CANOPUS ground-based array set-up; analysis of data is planned for the future.

An important result of the VIKING imager data is the observation that the so-called westward traveling surges do not, in fact, travel but remain stationary over the region of initial breakup of the auroral substorm.

G. Rostoker and W. Kamocki (grad. student) are studying the particle populations and magnetic field configuration in the magnetotail using ISEE 1 and 2 data, to determine the various magnetospheric current systems which contribute to the magnetic field Y-component in the magnetotail.

The completed study of G. Rostoker and NSERC summer student D. Savoie shows that the response of the directly driven magnetosphere-ionosphere currents depends on the levels of magnetospheric activity prior to the southward turning of IMF.

G. Rostoker and M. Jeremy's analysis of the space physics group's magnetometer array data aims to explore if many day-side, low frequency pulsations (1-5mHz) arise from a superposition of impulsive bursts and are not composed of continuous wavetrains. This has consequence for the possible generating mechanisms, particularly the Kelvin-Helmholtz instability (KHI) at the low latitude boundary layer (LLBL)/central plasma sheet (CPS) interface, and this is also studied.

G. Rostoker still explores the boundary layer model of magnetospheric substorms which considers substorm expansive phase outbursts as a manifestation of a KHI at the interface between the LLBL and the CPS; with M. Connors he is constructing magnetotail computer models to demonstrate that field lines emanating from the auroral ionosphere can map to distances of tens of Earth radii in the magnetotail.

G. Rostoker, is co-Chairman of the VIKING Imager Science Definition Team.

J.C. Samson continues as P.I. for the magnetometer and riometer experiments (MARIA) in CANOPUS. Despite slow progress, the instrumental design concepts have been proven as acceptable. Most riometers and telluric instruments are in place; a large number of magnetometers should be by summer, 1987.

J.C. Samson and B.J. Fraser (Univ. of Newcastle, Australia) have completed numerical simulations and experimental measurements of the convective growth rates of proton cyclotron instabilities in a multispecies, magnetospheric plasma. The experiment used particle and electric and magnetic field data (ISEE 1 and 2) to study the propagation and spectra of ion cyclotron waves near the oxygen cyclotron frequency. With J. Manual (grad. student) he is working on the numerical simulation of the nonlinear KHI in the LLBL. Test of a hydromagnetic code with flux-corrected transport in systems with reasonable geometry has progressed. He and W. Rozmus (Physics Dept.) have begun studies in the simulation of nonlinear wave-wave interactions and stochastic heating of electrons in magnetospheric plasmas, in parallel with studies of stimulated Raman and Brillouin scattering, and Langmuir turbulence in high density laser-produced plasmas.

5. University of British Columbia; Aeronomy Group (T. Watanabe, T.W. Koleszar, B. Chapel, S. Capelle and J. Criswick)

Magnetic pulsation is the main interest of the group. The enhanced data analysis capabilities (IBM PCAT Computer with newly added A/D converter, completed software, etc.) and availability of F. Greutzberg's induction magnetometer data from Cape Parry (Winter 1981, 4 weeks) have initiated a quest for a break in pulsation activity near local noon (reported in cusp auroral data). Some examples have been seen. The objective is to correlate these Pc 3 events with cusp auroral, solar wind parameters and mid-latitude Pc 3 to understand cusp Pc 3 behaviour, and its generation mechanism(s). We participated in a cooperative project to acquire data of magnetic pulsation and related phenomena in December, 1985 to January, 1986; 30 out of 50 world-wide sites were set up in Canada. The participants were four universities in Japan and those of Oslo, Norway; Victoria and British Columbia.

Pi 2: The induction magnetometer data from Pulsating Aurora Campaign (February 1980) is under analysis by T. Koleszar (Ph.D. student) to study characteristics of IPDP pulsations (i.e., polarization, fine spectral structures and their changes with latitude and longitude). The Pi 2 data from 4 stations within 61°-67° magnetic latitudes (acquired during 1983 summer campaign organized by University of Saskatchewan) is under analysis by S. Capelle (M.Sc. student) to study spectral and polarization characteristics and their latitude dependence. Note some Pi 2 signatures in radar echos discovered by G. Sofko.



## 6. University of Calgary; Department of Physics

### (a) Aeronomy

The Trailer Airglow Observatory (operation collaboration with University of Michigan) was moved during summer from the Rothney Astrophysical Observatory site (50 km SW) to new site (10 km NW of Calgary). The site, darker especially for northward viewing, is also easier to reach. D. Giers (Ph.D. student) is currently in charge of the airglow trailer. The rotational temperature maps of the sky obtained from the OH photometer enables the study of mesospheric dynamics. The Fabry-Perot interferometer with new etalon plates and hence a better image plane detector awaits routine operation in the automatic mode. The third instrument, a 1-m spectrometer is yet to function. Analysis of all the acquired OH data so far has been completed by R. Elphinstone; manuscript is under preparation.

The CCD-based ALL-Sky Imager for the CANOPUS program was essentially constructed by S. Babey; it is operating at Gillam, Manitoba since November, 1986 and transmits 16 by 25 superpixel images at 4 wavelengths every 20 sec to the DAN computer in Ottawa. R.A. King, J.S. Murphree and L.L. Cogger are involved in preliminary planning to place a Viking-like UV Imager on the 'Interball' satellite program currently under development (Soviet Union and eight other countries). Canadian participation is not yet approved either by the Intercoms Council or by the Dept. of External Affairs. Decision is being awaited. Launch of the two main satellites and two subsatellites is scheduled for summer, 1990.

### (b) Heliospheric Physics

The ongoing analysis of Cosmic Ray data from spacecraft Voyagers 1 and 2 and earth satellite IMP-8, (collaborators: D. Venkatesan and R.B. Decker, and S.M. Krimigis, Johns Hopkins University/Applied Physics Laboratory, Laurel, MD) is enhancing our understanding of the 3-dimensional heliosphere. The steady decrease in the Cosmic Ray radial gradient since 1981, as the Voyagers proceed farther away from the sun and as the solar cycle of activity approaches the minimum, raises the question of the location of the heliospheric boundary. Furthermore, note Voyager 2, (in ecliptic plane) registers a greater intensity, since mid-1985, than Voyager 1 (at higher heliolatitudes); this establishes a steady latitudinal gradient. The solar activity-controlled nature of the outer heliospheric regions is discussed in terms of the absence of co-rotating shocks, as revealed by the low energy data on the same two spacecraft (see recent publication JGR, April, 1987). Further work is in progress.

### (c) Magnetospheric Physics

The Conjugate study program (Collaborators D. Venkatesan and J.F. Bamber, and A. Wolfe and L.J. Lanzerotti, AT & T Bell Labs., Murray Hill, NJ), using ground-based magnetometers at Frobisher Bay, N.W.T. and South Pole, Antarctica continues. J.F. Bamber obtained his M.Sc. in August, 1986 on High-Latitudinal Magnetospheric Modelling. Bamber, after a few months in Max-Planck Institute for Aeronomie at Lindau-Harz, Germany will join the Ph.D. program at UCLA (CA) from Sept., 1987. Work on ULF Geomagnetic Power at Cusp Latitudes in Response to Upstream Solar Wind Conditions by A. Wolfe et al. and Comparison of the Modified Region of Open Field Lines with the Observed Poleward Boundary of Auroral Electron Precipitation by Bamber et al. have been completed; the former is published in JGR (Jan., 1987). The collaborative project continues.

### (d) Auroral Physics

The completion of analysis of Bremsstrahlung X-ray data from balloon-borne detectors launched from Cold Lake, Alberta has resulted in the award of Ph.D. degree to L. Varga in Sept., 1986. Varga continues as a part-time P.D.F. and part-time sessional lecturer, at Calgary.

### (e) Ionospheric Absorption

The study of the ionospheric absorption data from the South Pole riometer in Antarctica and the interplanetary ion data from IMP-8 is completed and indicates for the first time the contribution of interplanetary ions to ionospheric absorption. This study of the specific event (day 35, 1983) results from collaboration of D. Venkatesan and undergraduate student

D. Hudon, of Calgary; T.P. Armstrong and C.M. Laird, Univ. of Kansas, Lawrence, and S. Krishnaswamy and T.J. Rosenberg, from the Univ. of Maryland, College Park.

(f) High Energy Balloon X-Ray Astronomy

This relates to the collaborative project between D. Venkatesan and D.A. Leahy Calgary, and S. Narayan, S.V. Damle, P.K. Kunte and B.V. Sreekantan (Tata Institute of Fundamental Research, Bombay). A paper on the Hard X-Ray Observations of Quasar 3C 273, relating to the launch on December 12, 1983 of balloon-borne detectors (20-120 Kev) from Hyderabad, India has been completed. Prof. Narayan from TIFR was a University of Calgary Visiting Scientist during Nov.-Dec., 1986.

(g) Climate Study

Analysis of the time series of temperature data from a number of Canadian stations by D. Venkatesan and L. Nkemdirim, Dept. of Geography, has dealt with the Urban-Induced Increase in the Length of the Freeze-Free Season and its Environmental Implications.

(h) Other Activities

D. Venkatesan presented an invited paper at COSPAR-STP Meeting, Toulouse, France in June, 1986 on cosmic ray intensity variations in the 3-dimensional heliosphere.

D. Venkatesan also organized at Calgary, the Canadian Corporation for University Space Science (CCUSS) sponsored seminars on gravity waves by Prof. Colin Hines (Adj. Prof., York Univ.). D. Venkatesan also organized a two day Calgary visit (Public Lecture, Seminar and Workshop) of Prof. Alfred Bork, Univ. of California - Riverside Dr., Irvine (CA) relating to computer-assisted learning.

7. Geological Survey of Canada; Geophysics Division (GSC/GD)

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

The Geomagnetic Observatory Unit/Geophysics Division of the Geological Survey of Canada continues to manage the Canadian Magnetic Observatory Network (CMON) of the following 12 digital magnetic observatories: Alert, Mould Bay, Resolute Bay, Cambridge Bay, Baker Lake and Yellowknife (NWT); Fort Churchill (MAN); Poste-de-la-Baleine (QUE); Meanook (AB); St. John's (NFLD); Ottawa (ON); and Victoria (BC). Glenlea (MAN) operated with limited absolute control in co-operation with the Univ. of Manitoba, Winnipeg. For details about network refer to "Annual Report for Magnetic Observatories - 1985" (in press).

To assist the VIKING project, data over selected five-second intervals were also collected at the Fort Churchill and Baker Lake Observatories throughout much of 1986.

Evaluation of the declination and inclination data from the ELSEC 8200 vector PPM (acquired in 1984) against conventional absolute magnetometers continues. A Personal Computer (IBM PC) as a data collection platform has been used in the Ottawa Magnetic Observatory and programmed to collect the 10-second data on floppy diskettes; hardware installed (July, 1986); software enhancement continues. The final 1985 digital magnetic observatory data including one-minute values, hourly means and hourly ranges were submitted (June 1985) to the World Data Center, Boulder, Colorado. For data, contact us by phone (613) 995-5474 or at Dept. of Energy, Mines and Resources, 1 Observatory Crescent, Ottawa ON, K1A 0Y3 (cost plus 100% handling charges). Other services are listed in the Catalogue of Services for Seismology and Geomagnetism. Note a computer file with summary of the magnetic variations and the operation of the AMOS MKIII is updated each day. With the improved phone service to Alert and Mould Bay, N.W.T., this file now includes the summary data from them as well.

Under IAGA auspices a workshop on magnetic observatory instruments was held at the Ottawa Magnetic Observatory (30 July to 9 Aug., 1986) to enhance communications between instrument manufacturers and users of instruments. The proceedings of this workshop of 35 international delegates relating to observing techniques and instrument performance are in press.

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

Two types of geomagnetic activity forecasts are issued by GSC/GD: (a) the three-zone, 27 day forecast every three weeks (mailed on request), (b) the 72 hour forecast, updated every working day, and available on automatic answering service from Ottawa (613) 992-1299. A new multi-zone 27-day forecast (DRX) forecasts daily estimate of a range parameter for three zones (subauroral, auroral and polar cap) over Canada; it is the daily mean of 24-hourly ranges in the X-component of the magnetic field. A prediction filter based on Wiener linear prediction theory has been developed and contributes to this forecast.

An Associate Regional Warning Centre (ARWC) established at GSC/GD, Ottawa, is part of the IUWDS (International Ursigram and World Day Service) Network, which provides a system for near-real-time exchange of solar and geophysics data, and forecasts by means of coded messages - URSIGRAMS.

(c) Radio Absorption, Upper Atmosphere Ionization, Conductances and Heating (J.K. Walker)

From recently calibrated riometer observations an expression is determined for the lower ionosphere ionization as a function of the HF radio absorption. The energetic particle heating is also determined and the height-integrated values related to the absorption with a quadratic expression. The Hall and Pedersen conductivities are calculated for the 7 nominal night-time models and these height-integrated values are also related to the absorption. Further, expressions for these conductances determined during sunlit conditions can be used with simultaneous riometer and magnetic observations to determine the Hall and Pedersen currents and the Joule heating. The temperature rate for the mesosphere is calculated for both the energetic particle models and for typical Joule heating conditions. It is  $-10^{\circ}\text{K/day}$  at 75 km altitude for an 8dB event.

(d) Modelling External Currents and their Magnetic Fields (J.K. Walker and G.V. Haines)

An improved method of modelling external magnetic variations and their associated currents is being developed, based on the new method of spherical cap harmonic analysis. It models the vector magnetic field to any degree, order and level of statistical significance. At the same time the field is constrained so that the curl and divergence are zero. Preliminary tests for very disturbed conditions using the mean hourly method can model 95% of the variation. The equivalent coefficients and plotted on synoptic maps.

8. Herzberg Institute of Astrophysics; Planetary Sciences Section

(a) Photometry of Aurora and Airglow (F. Creutzberg, R.L. Gattinger, F.R. Harris, A. Vallance Jones and S. Wosniak)

The analysis of H-beta and 5577A data from the IMS period with the Churchill-Thompson-Swan River chain of meridian scanning photometers has been resumed. This examines the average intensities as a function of geomagnetic time and latitude for difference AE ranges and fits a simple model to the averaged data. The model permits the average H-beta intensity to be reproduced for AE up to 400. A similar model was fitted to the precipitated energy flux derived from the 5577A intensity.

(b) CANOPUS (A. Vallance Jones)

This system has operated for a year; two magnetometers at Gillam and Eskimo Point almost continuously and a third at Rankin Inlet partially. The automatic meridian scanning photometer at Gillam (operating well during March-June) was removed for warranty updates; redeployed in Sept. it has run well since then. The BARS radars gave some data in spring. Some problems existed until around the end of 1986. Following attention to the radar operating software it is operating well, although some further software debugging can be anticipated. The All Sky Imager (tested in Oct.) is giving continuous data. The ground net extended to Dawson City now includes stations on the western line through Fort Smith; these produce riometer data. Procurement of magnetometers and the solution of some problems with the earth current measurements are anticipated. The Data Analysis Network is in operation, but all data at present are stored in "campaign mode" pending software installation.

(c) CANOPUS-Viking Studies (R.L. Gattinger, F. Creutzberg, F.R. Harris and A. Vallance Jones)

Moonlight affected manned ground campaign (March) aimed to compare with VIKING observations. The automatic meridian scanner and magnetometers on the Churchill line got good data later. Possibly, valid comparisons can be made on various occasions. P. Prikryl (Univ. of Sask.) has begun analysis for one occasion when images with a bright oval centered near to Gillam and good optical data from scanner were available; the results are submitted for publication. The ground-satellite comparison provided a relation between imager signal and N2+ band intensity applicable to IBC 2 aurora to take advantage of the ratios of signals from the two VIKING cameras.

The image processing system at HIA programmed to display VIKING UVI images with geographic and geomagnetic grids is used in a number of collaborative studies.

A global array of low latitude and auroral zone magnetograms, including MARIA data, is being collected for the early VIKING time period to study the substorm-associated magnetospheric perturbations. These along with CANOPUS optical data will be used to look for substorm-associated longitudinal perturbations in geomagnetic time, to relate the results to existing substorm models for both proton and electron aurora and to study and compare the dynamics of the substorm longitude sector boundaries for both optical emission and current systems.

(d) STARE (D.R. McDiarmid)

A STARE (and SABRE) observed monochromatic Pc 5 pulsation exhibiting a time-varying Doppler-shifted frequency is under analysis; the last feature is new. Interesting magnetospheric cold plasma density structure seems necessary for every explanation.

(e) Pre-BARS Studies (D.R. McDiarmid, A.G. McNamara and J. Waterman)

Studies (collaborators: Sofko and Koehler) are planned using data from Saskatoon-initiated Pre-BARS campaigns. These include the dependence of (a) the Doppler shift of types I and II echoes on the magnetic aspect angle, (b) the backscatter cross section of each of these echo types on the magnetic aspect angle and, (c) the impact of mixtures of types II and III backscatter on the interpretation of BARS data. All this work is required to achieve a proper understanding of BARS data.

(f) Meteor Research

Halley's Comet Observations: About 20 observatories are intensely studying the Comet Halley meteor shower - the Eta-Aquarids in May and the Orionids in October. The Meteor Studies Discipline (International Halley watch) coordinates data collection and archiving. As expected, the comet passage caused no increase in meteor activity, but helped unique world-wide study of the structure and evolution of the Comet's particle stream.

The Ottawa (Springhill) 20-kilowatt radar will contribute about 1000 hours of observations of the Eta-Aquarid and Orionid meteor showers. During intervals in 1986 of Earth passage through Comet's plane, the 2-megawatt radar's search for small particles outside normal periods of the showers proved negative.

A study of a number of Orionid spectra meteors from Halley's Comet covers 3400 to 8700 Å. The peak brightnesses indicated masses of some tens of grams, and confirm that comets large particles survive long enough in space to encounter the Earth. Perseid meteors spectra are very similar to these.

The theoretical model for the dynamic evolution of the Halley meteor stream developed by McIntosh and Hajduk explains successfully observed showers' features. Numerical integration of the gravitational perturbations on 500 meteor particles over a period of 3000 years by Jones and McIntosh confirms the model features in more detail. Departing from earlier theory, the present calculations show that the fine structure observed in the showers develops in a few millennia. Particles observed now in the Orionid shower must have been released from the Comet more than 1000 years ago.

Radar observations of the Lyrid meteor shower in 1982 showed unusual and unexpected activity on April 22. The enhancement was ~ten times the normal rate. It peaked at 06:59 UT and lasted for only fifty minutes. The hypothesis that this might be a 'young' concentration of meteoroids, usually indicated by non-random pairings in the stream, was not proved.

(g) Springhill Meteor Observatory (B.A. McIntosh and I. Halliday)

After 30 years of contributions to meteor astronomy, this has been closed.

(h) Meteorite Research (I. Halliday)

Further reductions of fireballs from the meteorite camera network revealed a meteorite-dropping event on February 6, 1980 near Ridgedale, Saskatchewan, exactly 3 years after Innisfree meteorite fall; the two had identical orbits except for minor differences due to Earth perturbations. Clearly they represent two fragments from a relatively recent collision and provide the first evidence for such an association among meteorite events. Searches to locate this object will continue in 1987.

Geminid meteors are believed to penetrate unusually deep into the atmosphere. More than a dozen fireballs from it are under study to assess their physical properties relative to other meteorites and other shower meteors. The Geminid meteors are fragments of a peculiar object discovered by the IRAS satellite, and appear telescopically as an asteroid but may be an extinct comet.

(i) Comet Research (I. Halliday and B.A. McIntosh)

Halley's and other comets were observed with the Canada-France-Hawaii telescope (1984, 1985 and once in February, 1987). A unique correlation has been established between the ion features in Comet Giacobini-Zinner and the magnetometer data (ICE spacecraft encounter in September, 1985). Comet Halley exhibits an extremely sharp central peak of intensity within the coma. Efforts to model this behaviour with data from the various Halley spacecraft encounters are in progress.

(j) Nomenclature for Planets and Satellites (P.M. Millman)

The Working Group for Planetary System Nomenclature (WGPSN) of the International Astronomical Union (IAU) has unanimously recommended that the Voyager 2-discovered Uranian small satellites in order of increasing distance from Uranus, be named Cordelia, Ophelia, Bianca, Cressida, Desdemona, Juliet, Portia, Belinda and Puck after characters from plays of Shakespeare and the poem "The Rape of the Lock" by Alexander Pope. This follows the tradition of the previous naming of five large Uranian satellites discovered during 1787-1948.

The WGPSN has also recommended naming the seven closely grouped craters in the multiple ringed basin Apollo, on the far side of the moon after the late seven astronauts of Space Shuttle tragedy on January 28, 1986. These provisional names need official acceptance by IAU.

Again, the seven Minor Planets, Nos. 3350 to 3356, have been officially named after the above noted astronauts, by the Minor Planet Center (M.P.C.) of the IAU at the Smithsonian Astrophysical Observatory, Cambridge, Mass. (Reference M.P.C. pages 10549-10550).

## 9. University of Lethbridge; Department of Physics

### Infrared Astronomy/Aeronomy (D.A. Naylor and A.A. Schultz)

A versatile compact high resolution Fourier transform spectrometer optimized for mid-infrared astronomical observations has been under development for several years. This was tested at the NASA Infrared Telescope Facility on Mauna Kea in April, May and August, 1986. In May our primary goal was to observe Comet Halley in 10 micron atmospheric window. Jupiter and Saturn and a few galactic HII regions were also observed. Solar observations were also made under the direction of T. Clark (University of Calgary), at the 20 micron atmospheric window as we searched for previously undetected transitions in Rydberg atoms. Preliminary analysis of these results encouraged us to return in August to undertake a more detailed



survey of solar emission in the 20 micron window. These data are under analysis. This year Arvid Schultz (Dept. of Physics, Lethbridge) joined the infrared astronomy group, took part in both campaigns and is now involved with data reduction; these observational results should come out in 1987.

#### 10. University of Saskatchewan; Institute of Space and Atmospheric Studies

##### (a) Auroral Studies (D.J. McEwen, D. Steele, Y. Zou, W. Zhang and D. Strauss)

Continued activity in 1986 involved ground-based photometric measurements and satellite electron influx measurements at Rabbit Lake ( $\lambda = 58^\circ\text{N}$ ) station during most dark moon winter periods in conjunction with HILAT and DMSP overpasses. Comprehensive studies of latitudinal distribution of energy influx and the spectral characteristics of inverted-V events are well underway using the electron data (20 eV-22 keV). Cloudy weather, however, restricted data collection somewhat. Using simultaneous electron and optical measurements during Rabbit Lake overpasses D. Steele (M.Sc. student) has calculated optical intensity ratios as a function of electron energy and electron excitation efficiencies for  $\text{N}_2^+$  and OI emissions. Y. Zou has extended this work using a 1/2 metre spectrometer capable of examining emission features in the infrared. HILAT electron data now being received from Tromso station extend the database for potential intercomparison with simultaneous Viking passes at greater altitude.

The secondary electron fluxes (1-100 eV) measured during two rocket flights through aurora (1984 Aries auroral campaign) have been fully processed and interpreted by W. Zhang (M.Sc. just completed); the study reveals some interesting results on the direct excitation of OI emissions by electron impact. The calibration of the electron spectrometer below 20 eV is challenging; this work continues.

The July images of the whole auroral oval (UVI, VIKING, 1986) for extended periods when the satellite was near apogee, show a dayside activity from a perspective not previously available. Detailed morphological studies and comparisons with ground and particle measurements are just beginning.

##### (b) Solar UV Balloon Measurements (D.J. McEwen, H.T. Meredith and D. Strauss)

A 0.25 m double monochromator flown in May-June, 1985 on AES balloons from Palestine, Texas produced good solar spectra in the region 1950-2300Å. Data reduction has begun to derive ozone densities above the balloon.

##### (c) Atmospheric Dynamics (A.H. Manson and C.E. Meek)

A.H. Manson, C.E. Meek and J.B. Gregory (Group Founder, Emeritus Professor) were active with Middle Atmospheric Programs. Focus has been on winds data from the Medium Frequency Radar (2.2 MHz) providing real time profiles (5 min. resolution) from 60/80-100 km (Day/Night) continuously. Note comparisons with data from Global Radar Network and satellites are becoming more important.

The group studies solar and lunar tides. A video of daily wind-field contours was prepared with a year's data of hourly mean winds, 60-110 km. The wind oscillations associated with the 12-, 24-h tides were readily seen, and were consistent with Fourier and harmonic analyses. Detailed comparisons of planetary wave fields at Monpazier, France ( $45^\circ\text{N}$ ) and Poker Flat, Alaska ( $65^\circ\text{N}$ ) were completed. At  $45^\circ\text{N}$  great similarities exist especially in the 12-h tide: long wavelengths in summer, short in winter, with rapid transitions. Even at  $65^\circ\text{N}$  a similar wind and tidal field were discerned; both responded strongly to STRATFORMS. A mid-, high latitude tidal climatology is now emerging; the lunar tide (12.42h) is difficult to measure and a long data is needed: its value is that model comparisons can be made, which have well-known (gravitational) forcing functions. Monthly amplitude and phase profiles have been produced and published for the first time. Winter amplitudes and summer wavelengths are largest, both at variance with models. The solar and lunar tides remain unresolved as the best models do not match the now available excellent observations.

Individual profiles were analyzed for Gravity wave (GW) wavelengths and amplitudes. Regions of high shear, "wind corners" were found, as in rocket profiles. Annual contours of



GW amplitudes, Eddy diffusion, wind shears, and turbulent energy dissipation were compared: there are annual (winter maxima) and semi-annual variations (equinoctial minima) below 90 km, and annual above winter maxima. Radar scattered power contours are consistent with turbulence and ionization variations. New prevailing winds from the Global Radar network were assimilated into sets under preparation for CIRA-1987. Comparisons with CIRA-72, and the satellite radiance-derived geostrophic winds from Nimbus 5, 6 were completed: satellite-winds appear erroneous at high latitudes. Results were presented at COSPAR (Toulouse). Finally, adjusted data sets are to be published.

The middle atmosphere's response to solar activity was completed. Mean winds, tides and GW were compared and correlated with local and planetary indices (Ap; Kp). The tidal amplitudes (90-105 km) decreased (10%) and GW increased (5-10%) during disturbances; this is consistent with more limited studies with European radars. Responses to solar activity (10.7 cm) at 13 and 27 days were found (collaborators, A. Evel and colleagues, Univ. of Cologne).

Finally, the MF radar was used as an interferometer; this technology is to be elaborated into a signal averaging/Doppler radar capable of horizontal and vertical wind measurements. Cross-spectral analysis at 3-spaced antennas and angle-of-arrival determinations allow Doppler velocities and scatter locations to be found. These velocities compared well with the normal spaced-antenna wind determination. GW phase velocities and momentum deposition ( $50 \text{ ms}^{-1} \text{ hr}^{-1}$ ) were measured from Doppler velocity fluctuations in a unique analysis.

The preparation of a portable MF-radar receiving/real-time analysis system to operate at Tromsø, for the MAC/SINE (summer studies) and turbulence projects, is planned for 1987.

#### 11. University of Victoria; Department of Physics

Plasma waves, proton cyclotron echoes and spurs from Alouette topside sounder ionograms and ISIS satellites were classified based on their apparent range and shape; scheme involves the apparent range related to the proton gyrofrequency at the satellite location. The results with discussion and comparison with available theories for these phenomena are contained in a manuscript. Another paper deals with analysis of counterstreaming ion (CSI) events in the magnetosphere observed on the ISEE-1 satellite. Other studies on intersatellite propagation, transionospheric propagation, micropulsations, etc., are in progress.

#### 12. University of Western Ontario (UWO)

P.A. Forsyth, J.A. Fulford, and J. MacDougall participated with M. Mendillo (P.I.) Boston Univ. and P. Bernhardt of Los Alamos in the SPINEX-2 chemical release rocket launch (April, 1986), from Wallops Island. The UWO two-frequency, differential phase system measured the electron depletion in the ionospheric "hole" with considerable accuracy. This information plus Millstone Hill radar data suggests that the sulphur hexafluoride was remarkably efficient in attaching electrons.

G.F. Lyon, P.A. Forsyth, and J. Davies (summer student) investigated scintillation data from Sach's Harbour (using NNSS satellites) and from Churchill (using the HILAT satellite); sheetlike ionospheric irregularities reported in early Alaskan scintillation studies. Despite our large database and use of various statistical tests, we see no clear evidence of these irregularities. Forsyth secured late 1985, a number of angle-of-arrival measurements at Churchill. These should reveal the sheetlike irregularities, if present, on individual satellite passes. The tedious analysis of about half the passes are completed; these again reveal no indications of the irregularities. J.A. Fulford and E. Buller (grad. student) used the 1985 Churchill recordings in a statistical study of the scintillation producing irregularities to extend earlier work of Fulford and Forsyth.

Forsyth and R. Niciejewski (grad. student) have intercompared auroral optical emissions as measured from ground (at Churchill) with a two-barrel photometer swept back and forth along the satellite track (~45 min.) before the satellite path, to build up an emission history.

Using photometer data as measure of particle flux and energy, one can relate the short term changes in electron content to aurorally induced ionization in both E- and F-regions.

The HILAT/POLAR BEAR archives will exist at UWO for at least another year. With availability of POLAR BEAR images from Churchill (April, 1987) useful extensions of the scintillation and optical/radio studies will be possible.

A mid-latitude scintillations study resolved an old problem namely, why the vertical dimension of the irregularities experimentally measured along the magnetic field are usually only a few kms, while one expects dimensions of tens of kms comparable with vertical ionospheric scale sizes.

A special array of receivers measured the irregularity lengths using signals from the NNSS moving satellites. The array had both a small spacing and a large spacing on the axis which would measure the irregularity length. An initial array setup was aborted after some receivers and antennas disappeared completely under snowbanks in January. In April, however, when the receivers reappeared from the snowdrifts, the array soon proved what might have been anticipated: the irregularity length calculated using the large array spacing came out to be tens of kms as expected, while for the same irregularity using the smaller array spacing the calculated length was only a few kms. Thus the answer to the old problem is that statistical errors when using a too-small receiving array tend to underestimate the irregularity length.

### 13. York University

#### (a) WINDII Project

The engineering model under construction will be finished during summer 1987. A. Gault dealt with specialized aspects of the optical design. B. Solheim collaborated with the local computer centre to bring the WINDII VAX on line, and R. Wiens looked after some aspects of data processing. W. Ward (thesis almost completed) has joined Hierogram Associates, Ottawa, who support NRC on the WINDII project. UARS may be launched in 1991; Y. Rochon (M.Sc. student) is working on inversion methods for WINDII data.

#### (b) WAMDII Project

SED systems are constructing the flight model; mission planning is underway. Goddard Space Flight Center will integrate WAMDII onto a pointing system, and is supporting the mission; L. Cogger, D. Gattinger and G. Shepherd are to make arrangements. Analysis of the WAMDII developmental model field results (Wiens) beginning by least squares fitting a uniform wind field to the 9,000 pixels in an all-sky image is encouraging; further work is being done in Saskatoon under Paulson's direction. P. Kosteniuk is modelling the WAMDII dark current, and E. Yee has discovered a good method (to appear in Applied Optics) of tomographic analysis of WAMDII data.

#### (c) Other Studies

J. Bird (Ph.D. project) has assembled a polarizing Michelson interferometer (PAMI) which uses a photomultiplier detector, and an input mirror for sky scanning. This instrument easily changes the path difference by rotating a polaroid. The instrument is almost ready for field measurements. S. Piotrowski (M.Sc. student) is looking at alternative optical Doppler configurations. F. Hamade's M.Sc. thesis (almost completed) on the observation of the 8446Å emission twilight is an interesting study being intimately related to the dayglow emission of the 1304Å line, about which there has been some controversy. The measurements were made with a low resolution Fabry-Perot spectrometer.

Colin Hines is currently in Arecibo. His paper with D. Tarasick on Division waves in airglow is awaiting publication. E. Griffioen (Ph.D. student) is starting analysis of Viking data.

The new computer-controlled, scanning wide-angle interferometer system (Jun Lu's Ph.D. project) has progressed well. Two papers are submitted for publication, another is to be presented at the 14th Congress, International Commission for Optics. Prof. Liang has returned

to China after participation in our research program. Laboratory tests with the interferometer system are progressing and field tests lie ahead.

The study of the EUV dayglow, begun several years ago by R. Gladstone (LASP), R. Link (Berkeley and York), S. Chakrabarty (Berkeley) and J. McConnell, has come to fruition. Three papers have been submitted on analysis of satellite observations of the OI EUV dayglow, re-analysis of rocket measurements of the ultraviolet dayglow, and modelling of the OI989 to 1173Å ratio in the terrestrial dayglow. These suggest that the laboratory data and modelling capability are such that one can quantitatively model the dayglow in the EUV, certainly for the cases studied; these also point out calibration problems with earlier rocket measurements of solar and EUV airglow emission.

The antarctic ozone hole observed in spring is a topical problem; it is still unclear whether the ozone depletion is due to chemistry, dynamics or both. The article by W. Evans (A.E.S. & York), G. Henderson, B. Boville and J. McConnell (Nov. special issue, GRL) suggests dynamics as the major role.

The assumed composition of outer planetary ionospheres is  $H^+$  for lack of an efficient recombination process for  $H^+$ . However, new laboratory results suggest  $H_3^+$  also recombines very slowly. Calculations of T. Majeed and J. McConnell on " $H_3^+$  in the Jovian Ionosphere" (in press, JGR) suggest that  $H_3^+$  is the major ion and that electron temperatures are much higher than had been thought.

The strong EUV dayglow emissions from the outer planets ("electroglow") poses a problem in terms of an energy source. In the "Dependence of the Electroglow on Solar Flux" (submitted to JGR), R. Yelle, W. Sandel, and L. Broadfoot (U of Ariz.) and J. McConnell present some new data and some speculations about some of the dayglow sources. Consequent to successful Voyager 2 Uranus encounter we have taken up our chemical modelling efforts on the outer planets to understand the giant planet reflection spectra: G. Henderson with the chemical aspect and J. McConnell with the radiative transfer. Our new collaborative project is with J. Caldwell (newly joined professor). His very interesting reflection spectra (1700-2000Å) of Uranus and Neptune from IUE, and the Voyager 2 spectra (600-1700Å) will provide an important database to understand the structure of the stratosphere, mesosphere and thermosphere of these planets.

The project of A. Holubec (newly joined) is to produce a high energy electron deposition code for use in auroral modelling. C. Parkinson has started on the radiative transfer of resonance line for applications to Earth and planets.

I. Hare has been developing a chemical-dynamical model to investigate the generation of NO during nuclear device detonation to characterize more accurately the amount and location of the input of NO into the stratosphere during the early 60's (period of heavy testing). This work will have an important impact on the apparent lack of the global O3 database.

#### IV VOLCANOLOGY

Compiled by: Raymond Goldie

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2. Geological Survey of Canada
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4. Ontario Geological Survey
5. Nova Scotia Department of Mines and Energy
6. University of British Columbia
7. University of Manitoba
8. University of Western Ontario
9. Université de Montréal and McGill University
10. Université Laval
11. Saint Mary's University
12. Acadia University
13. Bibliography

##### 1. Introduction

Twenty-nine reports have been submitted from twelve institutions: two federal government agencies, two provincial government agencies and eight universities. The reports mostly concern field studies which are supplemented by laboratory work. Of the thirty-six studies which concern rocks of a particular age, nine are of Cenozoic rocks, one is of Paleozoic rocks and sixteen are of Precambrian rocks.

##### 2. Geological Survey of Canada

###### (a) Pb and Sr Isotopic Study of the Anahim Volcanic Belt, B.C. (Mary Lou Bevier)

This is a terminating study. I am carrying out a Pb and Sr isotopic study of Miocene-Quaternary alkaline and peralkaline volcanic rocks of the Anahim Volcanic Belt, south-central British Columbia. Individual centres studied include: Bella Bella, King Island, Rainbow Range, Ilgachuz Range, Itcha Range, Nazko and Wells Gray-Clearwater. My objectives are to: (1) determine the nature of the mantle source for these volcanoes; (2) assess the extent, if any, of crustal contamination in their genesis; (3) determine the extent of sub-oceanic mantle beneath the accreted terranes of British Columbia. So far, I have determined approximately 48 each of Pb and Sr isotopic ratios on fresh, whole-rock samples of Anahim belt volcanoes and associated sub-volcanic plutons. Results indicate that depleted, sub-oceanic mantle of plume-type (i.e., ocean island basalt source) is present beneath all accreted terranes beneath the Anahim belt. Wells Gray-Clearwater lavas show evidence of crustal contamination by a Precambrian component. My research plans are to continue assessing the extent of plume-type sub-oceanic mantle beneath accreted terranes in B.C. by initiating isotopic studies of additional volcanic belts in British Columbia.

###### (b) Pb and Sr isotopic study of the Stikine Volcanic Belt of British Columbia and Yukon Territory (Mary Lou Bevier and Jack G. Souther)

This is a new study. We are carrying out a Pb and Sr isotopic study of Miocene-Quaternary alkaline and peralkaline volcanic rocks of the Stikine Volcanic Belt, northwestern British Columbia and southern Yukon. Individual centres studied include Mt. Edziza, Heart Peaks and Level Mountain, as well as smaller and unnamed centres along the entire length of the Stikine Volcanic Belt in order to (1) determine the nature of mantle source for these volcanoes; (2) assess the extent, if any, of crustal contamination in their genesis; and (3) determine the extent of and type(s) of mantle beneath the accreted terraces of northwestern British Columbia and southern Yukon Territory. Approximately 30-50 samples of fresh, whole rock volcanic rocks will be analyzed for Pb and Sr isotopes. Our plans are to continue assessing the extent of plume-type sub-oceanic mantle beneath accreted terranes in northern British Columbia, through Pb and Sr isotopic evidence from young volcanic rocks.

(c) Manganese and Ocean Mineral Deposits (Gordon A. Gross)

This is a continuing study. I am studying the geochemistry of recent sea floor and ancient metalliferous sediments in order to determine the origins of metalliferous sediments.

3. Indian and Northern Affairs Canada

(a) Hope Bay Volcanic Belt (Walter A. Gibbins)

This is a continuing study. I am mapping an Archaean volcanic belt situated in the north-east corner of the Slave geological province between Bathurst Inlet and Cambridge Bay, NWT. My objectives are to outline the structure, petrology, geochemistry and economic geology of this belt. So far, I have completed mapping of the northern third of the belt. A geochemical and petrological study of komatiitic peridotites is partially complete. My plans are (1) to do more field mapping as soon as resources are available; (2) to continue petrological and geochemical studies; (3) to attempt to construct a metallogenic model and exploration criteria for the area; and (4) to assess its carving stone potential.

(b) Mapping of Hope Bay (Walter A. Gibbins)

This is a continuing study. I am mapping supracrustal belts at 1:50,000, volcanic belts in more detail, and I am preparing a 1:250,000 compilation of NTS map areas 760/14E and A/4SE of the Archaean Slave Structural Province. My objectives are to provide modern geological map coverage to assist mineral exploration and to provide insight into the relations of volcanic rocks of the Slave Province to the enclosing rocks. So far, I have completed mapping of one sheet, and a map for 760/14E A/14 SE is in preparation for the EGS series.

(c) Mapping of Kathawachaga Lake Area 76/L (Val Jackson)

This is a continuing study. I am mapping supracrustal belts at 1:50,000, volcanic belts in more detail, and I am producing a 1:250,000 compilation map in NTS map area 76/L of the Archaean Slave Structural Province. My objectives are to provide modern geological map coverage to assist mineral exploration and to provide insight into the relations of volcanic rocks of the Slave Province to enclosing rocks. I have completed mapping of three sheets. Maps in the EGS series have been released for NTS 76L/10, 15 & 16, EGS 1986-14. Field work will continue in 1987.

(d) Hepburn Island 76M (Val Jackson)

This is a continuing study. I am preparing a final 1:250,000 map, accompanied by a report. The map provides insight into the setting of volcanic belts in the northern part of the Archaean Slave Province. My objectives are to provide modern geological map coverage to assist mineral exploration and to provide insight into the relations of volcanic rocks of the Slave Province to enclosing rocks. Preliminary maps at 1:30,000 and 1:50,000 scale have been released in the EGS series for the whole area. EGS 1986-6 contains six maps at 1:30,000 (also available at 1:50,000) for NTS 76M/1,2,8,9,15,16. My plans are to compile petrological, geochemical and geochronological studies in order to produce a final 1:250,000 map.

(e) Russell Lake Region Mapping (Val Jackson)

This is a continuing study. I am preparing detailed 1:50,000 scale maps of the volcanic belt and its environment, and more detailed maps of the volcanic rocks and adjacent iron-formations in NTS map areas 85J/12 O/14 and adjacent areas (Russell Lake supracrustal belt) of the Archaean Slave Structural Province. My objectives are to provide modern geological map coverage to assist mineral exploration and to provide insight into the relations of volcanic rocks of the Slave Province to enclosing rocks. I have completed reconnaissance, and have produced one preliminary map (EGS 1986-11). Field work will continue in 1987.

(f) Yellowknife Volcanic Belt Project (W.A. Padgham)

This is a continuing study. I am studying rocks in the Yellowknife volcanic belt, concentrating on turbidite-sill-pillowed flow sequences at the top of the Kam Group (Archaean). My objectives are to subdivide the Yellowknife Bay Formation (which hosts the shear zone gold deposits at the Con and Giant Mines). A "Guide to the Yellowknife Mining District" is to be published by August, 1987. It will concentrate on the Yellowknife volcanic belt.

(g) Mapping of southwest end of Yellowknife Volcanic Belt (Karen Pelletier)

This is a continuing study. I am mapping the southwest end of the Yellowknife Volcanic belt at a scale of 1:10,000 in an area which is part of NTS map areas 85J/7&8 of the Archaean Slave Structural Province. My objectives are to provide modern geological map coverage to assist mineral exploration and to provide insight into the relations of volcanic rocks of the Slave Province to enclosing rocks. I have completed mapping (EGS series release 1986-12).

(h) Mapping of Southeast End of Yellowknife Volcanic Belt (C. Relf).

This is a continuing study. I am preparing a map of volcanic rocks at a scale of 1:2,000 in an area which is part of NTS map areas 85J/1,2,7 & 8 of the Archaean Slave Structural Province. My objectives are to provide modern geological map coverage to assist mineral exploration and to provide insight into the relations of volcanic rocks of the Slave Province to enclosing rocks. I have completed my field work, and intend to complete my M.Sc. thesis (on petrology, stratigraphy and shear zones) this year. The following maps in the EGS series have been released: West Mirage Islands EGS 1986-5; East Mirage Islands EGS 1986-15.

(i) Bimodal volcanism along Tintina Trench, Yukon Territory (Monica J. Pride: funded by a contract from Indian and Northern Affairs)

This is a new study. I am carrying out a mapping project to study in more detail the stratigraphy, petrography, geochemistry, mineralization and geochronology of the Tertiary bimodal basalt-rhyolite volcanic suite located along Tintina Trench in south-central Yukon. My aim is to establish the volcanofacies of the Tertiary volcanic rocks in Tintina Trench and their relationship to epithermal precious metal mineralization. I am currently writing a progress report. My plans are to do more detailed work on petrography and geochemistry concentrating more on the volcanological features than on economic features.

4. Ontario Geological Survey

(a) Blackwell and Laurie Townships (M.W. Carter)

This is a new study. I am carrying out geological mapping in Archaean volcanic rocks in Blackwell and Laurie Townships in the Thunder Bay area of Ontario in order to characterize the volcanic suites present, their stratigraphic relationship and the relationships of any ore deposits to stratigraphy, lithology or structure. So far, my mapping has shown that there is a progression from komatiitic-tholeiitic volcanic rocks through calc-alkalic to alkalic (shoshonitic) rocks at the end of the volcanism. My plans are to use these data to establish the setting of the volcanism. My views are that the volcanism represents mature island-arc volcanism, possibly related to a subduction zone.

(b) Hawaiian Studies (R.M. Easton)

This is a terminating study, carried out in conjunction with the U.S. Geological Survey. I am studying the stratigraphy of Kilauea volcano, Hawaii and the general geology of the Hawaiian Islands. My objectives are to revise the stratigraphy of Kilauea in accordance with the Code of Stratigraphic Nomenclature, and to produce a geological road guide to the geology of the Hawaiian Islands. Revision of Kilauea stratigraphy has been completed for inclusion in



USGS Prof. Paper 1350. The Hawaii Road Guide has been updated and published. Trace element and isotopic studies of the Hilina Basalt were completed and are in the publication stage.

(c) Facies Study of the Apsley Formation, Grenville Province (R.M. Easton)

This is a new study. I am conducting a facies study of the Apsley Formation in order to evaluate its origin and mineral potential. There has been controversy over whether the Apsley Formation is of sedimentary or of volcanic origin. I have recognized a number of facies in the Apsley Formation, which indicate, along with earlier chemical evidence, that part of the formation is volcanic. The sequence probably represents a volcanic sequence which was deposited subaqueously. I am carrying out geochemical studies to link the facies with chemical changes in the formation.

(d) Volcanism in the Central Metasedimentary Belt of the Grenville Province of the Canadian Shield (R.M. Easton).

This is a new study. I am attempting to provide a better understanding of the environment and facies of volcanic systems in the Central Metasedimentary Belt (CMB) of the Grenville Province in order to determine the tectonic setting of the CMB and to improve stratigraphic correlation in this belt. All of the above will assist in mineral exploration. Mapping to date has indicated that, in places, carbonate sedimentation and volcanism were contemporaneous, thus aiding in stratigraphic mapping in carbonate basins in the Grenville Province. I plan to continue mapping in volcanic terrains in the Grenville Province.

(e) Geochemical Classification of Archaean Volcanic Rocks (R.M. Easton, E.C. Grunsky, P.C. Thurston, L.S. Jensen, J. Howe)

This is a new study. We are attempting to devise a classification scheme for Archaean volcanic rocks based on chemical analyses, taking full advantage of modern statistical techniques. Our objectives are to better classify Archaean volcanic rocks in Ontario and to better compare Archaean and modern volcanic rocks. So far, we have largely completed compilation of a data base, and have begun an analysis of komatiitic rocks.

5. Nova Scotia Department of Mines & Energy - (also St. Mary's University, Royal Ontario Museum, St. Francis Xavier University and the Scottish Universities Reactor Centre)

Metallotectonic Map of Nova Scotia (J.D. Keppie, J. Dostal, J.B. Murphy, T.E. Krogh, R.F. Cormier, A.N. Halliday)

This is a continuing study. We are carrying out a study of petrography, geochemistry, metallogeny, tectonic setting and Rb/Sr and U-Pb ages of mineral occurrences throughout Nova Scotia. Areas sampled and mapped so far are the Antigonish Highlands and southern Cape Breton Island. We are now turning our attention to northern Cape Breton Island and the Cobequoid Highlands.

6. University of British Columbia

(a) Isotopic and petrochemical study of Cordilleran volcanic rocks (R.L. Armstrong and students, and co-workers from the GSC and B.C. Ministry of Energy, Mines and Petroleum Resources)

This is a continuing study. For details see the review of isotope research in Chapter V of this Bulletin.

(b) Crystallization and Vesiculation of Basalt Magmas (J.K. Russell)

This is a new study. I am carrying out a petrologic study of the lava erupted in 1984 from Mauna Loa, Hawaii, and I am attempting to construct thermodynamic models of crystal-

lization and vesiculation processes. I have modelled the ascent and eruption of the 1984 Mauna Loa lava in three stages. Stage 1 is the pre-eruptive magma; Stage 2 is the ascent of the magma and Stage 3 is the eruption. The solution illustrates that in order to reproduce the observed mineralogy, shallow level vesiculation is required before sufficient crystallization can progress.

#### 7. University of Manitoba

Geology of the Mt. Skukum Volcanic Complex, Yukon Territory (Monica J. Pride; funded by Indian and Northern Affairs and the University of Manitoba)

This is a terminating study. I have carried out a mapping project that includes work on stratigraphy, petrography, geochronology, geochemistry, structure and alteration of the Mt. Skukum volcanic complex located about 60 km south south-west of Whitehorse, Yukon Territory. My objectives are to understand the nature, size and shape of the individual volcanoes of this complex and the nature of its vents, to establish distal and proximal facies, to determine the history of the volcano and to elucidate the relationships between mineralization and alteration in vent areas. I have completed field and laboratory work and am writing my thesis.

#### 8. University of Western Ontario

Precambrian Glass (H.C. Palmer, K. Tazaki, W.S. Fyfe and E. Zhou)

This is a terminating study. A paper has been submitted to "Nature" which documents through electron microscopy and electron diffraction that material with the optical properties of glass, reported by Annells (1974) from the Michipicoten Island Formation, Michipicoten Island, is indeed true glass.

#### 9. Université de Montréal and McGill University

- (a) Cenozoic Volcanism, Yukon and North-central British Columbia (John Ludden - U. de M. and D. Francis - McGill)

This is a continuing study of the St. Claire volcanic rocks of the Kluane region, Yukon; of Mt. Edziza in northern British Columbia; of Alligator Lake, Yukon; and of Itcha Mt. and Anahim in central British Columbia. We intend to study petrogenesis, age relationships and mantle evolution. Two Ph.D. students and 2 M.Sc. students are involved in the project. 40 isotope analyses for Sr, Nd and Pb are complete and nodule studies are in progress. Our research plans for 1987 are to return to the Anahim and Fort Selkirk (nephelinite) localities.

- (b) Volcanogenic Origin of the Onaping Formation (John S. Stevenson - McGill)

I am continuing field and laboratory studies of middle Proterozoic rocks at Sudbury, Ontario in order to gather further pertinent data on the origin of the Onaping Formation, to help in deciding whether the Sudbury structure is endogenic or due to meteoritic impact. In my opinion, all data assembled to date, including studies of structural states of Onaping feldspars and comparative field studies of late Cenozoic pyroclastic rocks in the Taupo Volcanic Zone, New Zealand, support the volcanogenic origin of the Onaping Formation. I plan further detailed studies of both Onaping and Taupo volcanic rocks.

#### 10. Université Laval

Volcanic Rocks of the Dunnage Zone, Quebec Appalachians (Roger Laurent and Rejean Hebert)

This is a new study. A detailed petrological, stratigraphic and structural investigation of the Ordovician volcanic rocks associated with tectonic melanges and sedimentary sequences, mainly flysches from the Magog Group and the Ascot and Weedon Formations, has begun. We aim to reconstruct the primary relations between the volcano-sedimentary facies representing typical paleotectonic zones of an arc-trench system.

## 11. Saint Mary's University

- (a) Geochemistry of Volcanic Rocks of French Polynesia (J. Dostal - St. Mary's and C. Dupuy - CNRS, Montpellier, France)

This is a continuing study. We are carrying out comprehensive geochemical studies of oceanic island basalts from several Plio-Quaternary volcanic chains in French Polynesia using major element, trace element and isotopic data to sort out the effects of various magmatic processes on the evolution of the basalts and to define the characteristics of their mantle sources. We have completed major and trace element studies on basaltic rocks from the Marquesas and Society Islands. These islands are composed of alkalic, transitional and tholeiitic basalts which were derived from different upper mantle sources. The sources of these magmas were enriched in incompatible elements and were similar in trace element chemistry to the oceanic mantle below Hawaii. We plan to document the major, trace and isotopic (Sr, Nd and Pb) composition of the Austral and Cook Island volcanic rocks and to supplement the data on the Marquesas and Society Islands with additional isotopic analyses. We will evaluate the relationship among the various rock types and their petrogenesis.

- (b) Geochemistry of Continental Tholeiites (J. Dostal, C. Dupuy and W.R.A. Baragar - Geological Survey of Canada)

This is a continuing study. We are carrying out geochemical and petrological studies of Mesozoic continental tholeiites from Nova Scotia, Morocco, Liberia and Madagascar, and Precambrian basalts from Coppermine River and Natkusiak (N.W.T.) in order to define and quantify the fractionation process, to identify the role of crustal contamination during the genesis of continental tholeiites, to examine the differences in composition among continental tholeiites and to characterize the source of their parental magmas. We have completed geochemical studies on suites of continental tholeiites from the Coppermine River, Natkusiak, Nova Scotia and Morocco. The results show that these suites were probably derived from an upper mantle source very similar to that of MORB. The relatively high content of K and related elements in many of these rocks, together with their characteristic distribution of incompatible trace elements, appears to be due to crustal contamination. We intend to continue to study several individual provinces in detail through the use of major and trace element and Nd, Pb and Sr isotope data, and then discuss and synthesize the findings. We hope that we can eventually refine models for the petrogenesis of continental tholeiites, put constraints on their mantle sources and evaluate their geodynamic implication.

## 12. Acadia University

Field relations and petrology of the Coldbrook Group, southern New Brunswick (S.M. Barr)

This is a continuing study. I am mapping and studying the petrology of the metavolcanic and metasedimentary rocks of the Late Precambrian Coldbrook Group and associated granitoid rocks in the Caledonian Highlands of southern New Brunswick, in order to clarify the stratigraphy, structure, chemical affinities and tectonic history of these rocks. After two summers of field work, I have tentatively constructed a stratigraphic column. A strong metamorphic and cataclastic overprint makes recognition of primary igneous features of the rocks difficult to interpret. Both volcanic and granitoid units appear to have formed in a volcanic arc environment. My plans are to continue mapping in the central part of the Caledonian Highlands, followed by petrological studies and radiometric age dating.

- (b) Field Relations and Petrology of the Fourchu Group, Southeastern Cape Breton Island, Nova Scotia (S.M. Barr, M.J. Thicke)

This is a continuing study. We are mapping and studying the petrology of the Late Precambrian Fourchu Group in southeastern Cape Breton Island, Nova Scotia, in order to clarify the stratigraphy, structure, chemical affinities, tectonic setting, and economic potential of these rocks. Thicke is completing a MSc thesis on metavolcanic and associated granitoid rocks of the East Bay Hills and Coxheath Hills. His work shows that the volcanic rocks are calc-alkaline, formed in a volcanic arc environment, and that the region has good potential for

gold and base metal mineralization. We plan further mapping and petrological studies of the Fourchu Group.

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## V ISOTOPE STUDIES AND GEOCHRONOLOGY

Compiled by: J.C. Roddick

1. University of Alberta
2. University of British Columbia
3. University of Calgary
4. Dalhousie University
5. Geological Survey of Canada
6. McMaster University
7. Queen's University
8. University of Saskatchewan
9. University of Toronto
10. University of Waterloo
11. University of Windsor
12. Other Institutions
13. Bibliography

### 1. University of Alberta, Dept. of Geology (H. Baadsgaard)

Four main lines of research are being pursued: Geochronology of ancient Archean rocks of west Greenland; Geologic time-scale calibration; Isotope geology of salt deposits, and Timing and paragenesis of the sandstone-hosted uranium deposits of northern Saskatchewan.

The multi-method (U-Pb, Rb-Sr, Nd-Sm, Pb-Pb) dating of rocks and minerals of the Isua supracrustal belt and intrusive Amitsoq gneisses has produced a definite time sequence of emplacement of major lithological units. The genesis of these units heavily involves pre-existing crustal rocks, either as sources or as contaminants (Baadsgaard et al., 1986a, b, c). Time scale calibration of the K/T boundary has been completed, and a multi-method (U-Pb, Rb-Sr, K-Ar), multi-mineral age determination on three different bentonite sites yielded a weighted mean age of  $64.3 \pm 0.4$  Ma. The Campanian-Maestrichtian boundary, a Silurian bentonite site in Sweden and the Kinnekulle (Caradocian) bentonite in Sweden are also being studied. Isotope studies of the potash horizons of the Prairie Evaporite Formation in Saskatchewan have reached a stage where the time of major diagenetic recrystallization has been established at 100-50 Ma ago, and very late local recrystallization has occurred at sporadic locations in Pliocene-Pleistocene time. Isotope studies on the Milwest uranium deposit in northern Saskatchewan revealed a primary age of pitchblende deposition at  $1328 \pm 17$  Ma with remobilization at  $1110 \pm 28$  Ma to form secondary pitchblende and coffinite. Pb-Pb isotope ratios indicate three isotopic classes of Pb present in the Milwest deposit, yielding a model in which radiogenic additions to galena have occurred in two different events (Worden et al., 1985).

Other projects have involved the crystallization of the Big Spruce Lake Precambrian carbonatite (Cavell and Baadsgaard, 1986), petrogenesis of some Peruvian rocks (Kontak et al., 1986), and Sm-Nd dating of rocks from the Ukrainian and Omolon shields (USSR) (Bibikova and Baadsgaard, 1986).

### 2. University of British Columbia, Dept. of Geological Sciences (R.L. Armstrong)

#### (a) Coast-Cascade Belt

Peter van der Heyden is in the middle stages of his Ph.D. thesis project which will provide regional coverage of U-Pb zircon dates for the Coast Plutonic Complex between  $53^\circ$  and  $54^\circ 40'N$ . During this past year many months were spent preparing and calibrating  $^{205}Pb$  spike which will greatly enhance productivity.

In the Stewart area D. Alldrick (Ph.D. thesis on regional Geology) and D. Brown (M.Sc. thesis focusing on the Silback-Premier mine and its surroundings) have completed U-Pb, K-Ar and Rb-Sr studies of igneous and metamorphic rocks. The major events dated are Early Jurassic volcanism, plutonism, and mineralization, mid-Cretaceous regional metamorphic overprint and deformation, Eocene plutonism, and some younger lamprophyre dike emplacement. Preliminary results are reported in Alldrick et al. (1986).



(b) Intermontane Belt

R. Friedman has finished Ph.D. thesis field work and U-Pb, Rb-Sr and K-Ar geochronometry in the Tatla lake metamorphic core complex which lies northeast of the Yalakom transcurrent fault at 52°N and is on the western edge of the Intermontane Belt. A generally horizontal, but folded, ductile shear zone 1 to 2 km thick separates a higher-grade migmatitic core from low grade Jurassic (?) volcanic rocks. This structure, of Eocene age, can be interpreted as a metamorphic core complex, related to Shuswap and Cascade deformation of the same age.

Where the new Coquihalla highway crosses the Needle Peak and Eagle-Mount Lytton plutons C. Grieg has begun work on a M.Sc. thesis, in cooperation with J.W.H. Monger of the GSC. Field work is complete, U-Pb, K-Ar, and Rb-Sr analyses are in progress.

N. Mortimer, a UBC Killam postdoctoral fellow, has completed his work on Nicola volcanic rocks (chemical petrology) and Cache Creek-Pavillion Group geology (mapping, new fossil and isotopic ages).

(c) Yukon

Vicki Hansen (Ph.D. in progress at UCLA) has completed a Rb-Sr and K-Ar dating project on schists from the Teslin suture zone. Early Jurassic dates give a younger limit on multiple strain episodes, in agreement with unpublished K-Ar data in Alaska (G. Cushing, M.Sc. thesis, SUNY, Albany, 1984). A familiar mid-Cretaceous resetting event affects some localities.

Samples of blueschist from the Orchee Lakes area (provided by P. Erdmer, U. of Alberta) give Permian Rb-Sr and K-Ar dates, supporting a single K-Ar date of 255 Ma for blueschist/eclogite from Faro, previously done by the GSC.

(d) Omineca Belt

Rb-Sr mineral isochrons with Proterozoic ages have been obtained for two more ultramafic nodules from the West Kettle River locality. This complements previous work by Min Sun which produced ages up to mid-Proterozoic for nodules brought to the surface by Pleistocene basaltic eruptions at several localities in the Omineca Belt. We believe these are pieces of ancient mantle lithosphere, presumably autochthonous, that underlies the Mesozoic-emplaced allochthons, including much of Quesnellia.

(e) Nd Isotopes

E. Agyei, CIDA fellow from the University of Ghana, prepared Sm-Nd spikes and standards, programmed the mass spectrometer for Nd and spiked Sm-Nd runs, and debugged lab procedures so that we can now use this system for geochronometry and petrogenesis. He completed measurements on a number of samples of basement rock from Ghana - Early Proterozoic shield, and even older rocks reworked in Pan-African mobile belt.

Nd whole-rock model dates are also planned to supplement R. Sun's Sr isotopic study of Archean rocks in North China, and the first work on B.C. rocks will be Nd model dates for Vaseaux, Grand Forks, and Monashee gneisses - all known, or suspected, Proterozoic (or older) basement in the Omineca Belt.

3. University of Calgary, Departments of Physics (H.R. Krouse, C.J. Bland, A. Ueda, C. Yonge). Geology (F.A. Campbell, I. Hutcheon, A. Levinson, J. Nicholls, L. Goldenberg, A. Oldershaw, R. Spencer). Geography (S. Harris). Biology (E. Laishley, D.M. Reid). Chemistry (R. Roche, T. Swaddle). Chemical Engineering (D. Bennion, G. Moore). Archaeology (A. Katzenbert). Kananaskis Centre for Environmental Research (A. Legge). Arctic Institute of North America (J. Holdsworth, R.O. van Everdingen). Short term visitors: J.R. Richards, ANU and H. Herbert, University of Queensland, Australia.

(a) Fossil fuels

(i) Gas and oil wells in Alberta, northeastern British Columbia, and eastern offshore. C and H isotope compositions of separated gases and oil fractions were used to identify source rocks.

(ii) Sour gas reservoirs, Alberta. S and C isotopes have been used to relate H<sub>2</sub> generation to reduction of anhydrite by light hydrocarbon gases (joint project with Shell Canada).

(iii) In situ heavy oil recovery operations. C-isotope monitoring of CH<sub>4</sub> and CO<sub>2</sub> at recovery wells served as an indicator of how well underground steam or combustion drives were functioning. The progress of combustion fronts can be mapped.

(iv) Coal. H-, C-, and S-isotope compositions are used to decipher depositional environments at various sites in western Canada.

(v) Pyrolysis studies of terrestrial organic matter. The isotope compositions of H<sub>2</sub>S, CO<sub>2</sub>, and CH<sub>4</sub> evolved during linear temperature programmed pyrolysis of coal and bitumens were used to decipher organic sulphur geochemistry. Samples of bitumen from Pine Point, NWT, proved interesting in that H<sub>2</sub>S evolved at high temperatures had a sulphur isotope composition similar to the Pb-Zn sulphide ore bodies, whereas a lower temperature component was significantly depleted in <sup>34</sup>S.

(b) Carbon and sulphur isotopic evolution of the oceans.

(i) Permian carbonates in the Sverdrup Basin, Yukon, and Northern B.C. (thesis project of B. Beauchamp). Higher enrichments of <sup>13</sup>C in shallow water carbonates which increase with latitude have been interpreted in terms of anoxic preservation of <sup>13</sup>C-depleted organic matter in the Sverdrup basin with a corresponding enrichment of <sup>13</sup>C in carbonate dissolved in shallow waters. These waters mixed surficially along the eastern margin of the paleopacific to give the latitude trend.

(ii) Trace sulphate and sulphide in marine carbonates. The sulphur isotope compositions of Phanerozoic marine carbonates determined by the in vacuo Kiba extraction technique of Ueda and Sakai are consistent with data from anhydrite. Data from Precambrian carbonates imply that excursions in  $\delta^{34}\text{S}$  values for Precambrian oceanic sulphur were as large as in the Phanerozoic.

(c) Meteorology, hydrology

Studies of precipitation and ice cores in the Arctic continued in collaboration with M. Jeffries, University of Alaska. H and O isotope data proved particularly useful in deciphering the freezing process in ice dammed fiords. H, O, C, and S isotope data were obtained for an additional ice covered stratified lake on Ellesmere Island. Studies continued on snow and ice cores from Mt. Logan (J. Holdsworth). The origin of SO<sub>4</sub><sup>2-</sup> in ground waters of southern Alberta continues in collaboration with J. Hendry of Alberta Agriculture, Lethbridge.

The O isotope composition of SO<sub>4</sub><sup>2-</sup> in mine waters is being compared to that of the water (R. van Everdingen).

An 18 month detailed record of H and O isotope compositions of precipitation at Calgary has been obtained along with a few S and O isotope data on dissolved sulphate. The S isotope data are consistent with emissions of SO<sub>2</sub> from natural gas refining. A traverse of springs from Vancouver to Calgary has also been conducted (L. Goldenberg). On a  $\delta\text{D}$  versus  $\delta^{18}\text{O}$  plot, the data from both Calgary and the traverse show significant departures from the generally accepted "meteoric water line".

(d) Environmental: food web, medical, bacterial isotope selectivity, and pollution studies

(i) Sulphur isotope studies of the environment near sour gas processing plants. Under the Acid Deposition Research Program (A. Legge), the sulphur isotope compositions of

particulates and  $\text{SO}_2$  have been monitored as a function of wind direction at one site near a processing plant and a site remote from industry. Under this program, a review of environmental sulphur isotope investigations in Alberta has been prepared.

(ii) Great Barrier Reef. In collaboration with Dr. H. Herbert, University of Queensland, carbon and sulphur isotope investigations have been carried out on flora and fauna on Heron Island. The  $\delta^{34}\text{S}$  values of the environment were markedly consistent near +18 ‰. In contrast, carbon isotope data for bird feathers varied significantly dependent upon marine versus continental food sources, and for the latter, the elevation of vegetation consumed.

(iii) Medical studies. Isotopic studies of kidney stones have been extended to include S-isotopes in trace sulphide and sulphate. These data and C-isotope data have been compared to hair of patients in an attempt to better understand the formation of these biological minerals. The oxygen isotopic composition of  $\text{SO}_4^{2-}$  in body fluids was found to correlate to that of the fluids, implying that some water oxygen was involved in oxidation of organic S. This has implications for the tracing of pollutants in groundwater near feedlot operations.

(iv) Food webs. Carbon and sulphur isotopes have been measured in flora and fauna in the Arctic. Continental and marine food webs can be clearly distinguished. Such data are relevant to the global cycling of sulphur in the Arctic.

Hair and nails of animals, including humans, have been compared with respect to diets in the City of Calgary (including the zoo), a Hutterite farm, a Koala and Kangaroo sanctuary in Australia, and a small island in the Philippines. Students in Archaeology are pursuing a number of topics including bison bones at jump sites (N. McKinnon) and human skeletal remains.

(v) Turtle Mountain Spring, Crowsnest, Alberta (R. van Everdingen). The S, C, O, and H isotope geochemistry of this spring and surrounding vegetation have been studied. Algae mats have incorporated dissolved sulphide rather than more abundant sulphate. Surrounding conifer needles display the sulphur isotope composition of sulphide rather than sulphate.

(vi) Bacterial isotope selectivity. In a collaborative study with K.M. Semple and D.W.S. Westlake, University of Alberta, sulphur isotope fractionation by Pseudomonads isolated from oil field fluids during sulphite reduction was found to display inverse kinetic isotope effects similar to those found previously with Clostridia.

#### (e) Rocks, Minerals, and Ore Deposits

A number of collaborative studies on ore bodies have been carried out with colleagues at other universities. Projects at the University of Alberta (A. Changkakoti, J. Gray, R. Morton) include Archean metasediments, Bullmoose Lake, NWT (S. Swatton) and Deer Trail Pb-Zn-Ag, NE Washington (D.W. Fluet).

Sulphur isotope data have been obtained for the Dolly Varden Silver Camp, Alice Arm Area of Northwestern British Columbia (B.D. Devlin and C.I. Godwin, UBC).

C and O isotope data for carbonates and  $\delta^{34}\text{S}$  data for trace sulphur have been obtained for concretions west of Lansing, Michigan (G. Giles and D. Long, Michigan State University). These occur in the organic rich Upper Devonian Antrim Shale with or without a pyrite shell and range up to metres in size. Most  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  values cluster near -10 and -60 ‰ PDB respectively, whereas trace sulphide ranges from 0 to -120 ‰ and trace sulphate  $\delta^{34}\text{S}$  values range from +10 to +500 ‰.

Ranges of -17 to +1, -8 to +10 (PDB), and +2 to +10 ‰ were found for C and O in carbonates and S isotopes in sulphide minerals of Pb-Zn deposits in the Pucara Basin, Peru (collaborative study with Ian Lange, University of Montana). There was a strong preference for  $\delta^{34}\text{S}$  values near +7 ‰ for which the associated  $\delta^{13}\text{C}$  values were +1 ‰. The more extreme  $\delta^{34}\text{S}$  values corresponded to the very negative  $\delta^{13}\text{C}$  values.

Most pyrite and pyrrhotite samples identified with a Devonian submarine island, Mt. Hayes Quadrangle, Alaska had  $\delta^{34}\text{S}$  values near +8 ‰ (Ian Lange).

$\delta^{34}\text{S}$  values around -30 ‰ have been found for framboidal pyrite in the Lower Cretaceous Harmon Shale, Fort St. John, B.C. (thesis project of John Block, University of Calgary).

Trona deposits from the Denison Trough of Australia, Greece, and the Green River Shale of Wyoming were examined by H. Herbert. In the case of the latter, the  $\delta^{18}\text{O}$  values shifted positively by 10 ‰ in going from older to younger beds. Whereas this is consistent with a progressively evaporative environment, this must be reconciled with the intervening shale deposits which imply freshwater fluxes to the basin. Trace S in the trona was quite enriched in  $^{34}\text{S}$ , consistent with values found previously for bitumens in the Uinta Basin.

For samples from Sullivan, B.C., about 300  $\delta^{34}$  analyses were conducted on very thin consecutive slices (H. Herbert). In addition to elucidating ore deposition, this study provides a yardstick to which microsampling techniques such as laser extraction and secondary ion emission mass spectrometry, e.g., SHRIMP, Australian National University, might be compared.

#### 4. Dalhousie University, Department of Geology (P.H. Reynolds)

Two mass spectrometer systems are in routine operation: for argon analyses, a modified MS10, now fully computer controlled; for carbon/oxygen analyses, a VG micromass 602D which is equipped with an on-line carbonate extraction system.

In the argon lab, in addition to conventional resistance-type extraction furnaces, we now have a (Nd L YAG) 'laserprobe' system. The latter extends the capabilities of the lab by permitting analyses of mineral phases which are intergrown and hence difficult to separate by conventional techniques.

##### (a) Argon and Fission Track Geochronology

Graduate student, Peter Elias (supervised by Reynolds and G.K. Muecke) has completed his Ph.D. study on the dating of metamorphic and intrusive rocks from southwestern Nova Scotia by the  $^{40}\text{Ar}/^{39}\text{Ar}$  and fission track methods. The study has revealed a complex and protracted tectonothermal evolution. Only localized windows record the onset of the Acadian orogeny ~390 Ma ago. Post-tectonic peraluminous granitoids (~370 Ma old) initiated major overprinting or argon systems. Renewed overprinting occurred ~300 Ma ago particularly in the southern portion of the terrane where K-feldspars were completely reset and the mica clocks were at least partially reset. An inferred episode of  $^{40}\text{Ar}$  loss from K-feldspars ~220 Ma ago reflects the formation of the aborted Fundy Rift system. The mean apatite fission track age (180 Ma) records final cooling of the terrane below 100°C. This study makes clear the usefulness of argon (mica, feldspar) and fission track (apatite) chronometers in determining low temperature thermal history.

Graduate student Heather Plint (principally supervised by R.A. Jamieson) has completed an M.Sc. thesis on a suite of metamorphic rocks in western Cape Breton. The  $^{40}\text{Ar}/^{39}\text{Ar}$  age data obtained will be incorporated into a P-T-t path and compared with predictions of an overthrust model. Our work in Cape Breton is progressing towards the determination of the cooling history of the several identifiable structural blocks and subsequently a tectonic interpretation.

##### (b) Stable Isotope Studies

Graduate student, Casey Ravenhurst (supervised by Reynolds and M. Zentilli) has completed a Ph.D. thesis on the genesis of ore deposits which rim Nova Scotia's Shubenacadie Basin. We have assembled a large amount of stable isotope data on these deposits, specifically, isotopes of hydrogen, oxygen, carbon and sulphur. The principal deposit at Gays River has a distinctive isotopic fingerprint. We have had some success in determining the physio-chemical conditions prevailing during deposition at Gays River. For example, it is clear that the carbon budget was dominated by oxidized carbon from a (nearby?) carbonate source ( $\delta^{13}\text{C} = 2$  ‰). The isotopic data base provides useful constraints on mathematical models developed to explain the genesis of the deposits.

5. Geological Survey of Canada (O. van Breemen, J.C. Roddick, R.R. Parrish, J.K. Mortensen, W.D. Loveridge, R.W. Sullivan, P.A. Hunt, M.L. Bevier, Geochronology Section)

A second Finnigan-MAT 261 multicollector mass spectrometer, to be dedicated to U-Pb analysis, was received in October. It will free the original 261 for applications and development of other radiogenic techniques. The bulk of the laboratory's work continues to be U-Pb dating of zircon and similar phases. A number of improvements in chemical processing (in a new clean air laboratory) and mass spectrometry now permit routine analysis of microgram quantities of zircon with amounts of zircon Pb as small as 50 picograms. Precise calibration of an electron multiplier used simultaneously for  $^{204}\text{Pb}$  measurement, while the major Pb isotopes and spike  $^{205}\text{Pb}$  are collected in faraday cups, permits rapid (10 minute) and precise analyses of radiogenic Pb. A similar procedure, with faraday cups only, also permits rapid U determinations (8 minutes). Rigorous error analysis, using numerical procedures, is now applied to all analyses. The ability to analyze very small zircon quantities has permitted more selective sample preparation. Grain polishing and etching techniques have been used to document the detailed internal structure of complex zircons from shear zones and geologically complex granulite terranes.

R.R. Parrish with the assistance of personnel from the geochronology Laboratory, Atomic Energy of Canada and Tom Krogh (Royal Ontario Museum) synthesized and purified 100  $\mu\text{g}$ m of  $^{205}\text{Pb}$  for use as an isotopic tracer for U-Pb geochronology. This material has been distributed to over 50 world laboratories.

Procedures for common Pb isotopic analyses were established in early 1986. The technique is being applied to isotopic tracer studies and common Pb corrections to U-Pb sphene dating. Blank corrections to whole rock and mineral separates are maintained at <0.1%.

Rb-Sr geochronology is in routine operation. Sm-Nd dating, employing REE separations by a combination of standard cation exchange chromatography followed by high pressure liquid chromatography on commercially available equipment, is currently being set up. Initial tests, in cooperation with Atomic Energy of Canada Ltd. (Chalk River), have shown that element separations are excellent and the blanks are low (Cassidy et al., 1986).

Conventional K-Ar dating is performed using a computer controlled AEI MS-10 mass spectrometer on line to the extraction system. For the first time rocks as young as 0.5 Ma have been analyzed in this laboratory. The construction of a  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  step-heating system is near completion. It consists of a Jessberger style 2-stage vacuum furnace on line to a modified MS-10 with computer controlled data acquisition.

In addition to providing age determinations for the Geological Survey of Canada more extensive projects are:

- (a) Thelon Tectonic Zone, Taltson Magmatic Zone (O. van Breemen, W.D. Loveridge, J.B. Henderson, P.H. Thompson and H.H. Bostock)

A major structural lineament involving the Thelon and Taltson Zones extends from the Arctic Ocean to the Alberta border. U-Pb zircon and monazite dating demonstrate that magmatism in these belts is confined to the time interval of 2.0 to 1.9 Ga. Structural studies combined with internal zircon morphological evidence show that most of the plutons are syntectonic. In the adjacent Slave Province, tectonism with extensive plutonism took place at 2.6 Ga.

- (b) Abitibi Greenstone Belt (J.K. Mortensen)

A U-Pb dating study of the evolution of supracrustal sequences in the central and eastern Abitibi greenstone belt was initiated in 1985. Approximately 25 ages obtained thus far demonstrate that greenstone belt volcanism occurred episodically over a period of at least 100 Ma, and that the bulk of the deformation and metamorphism, related to the Kenoran orogeny, occurred immediately after the cessation of volcanism.

- (c) Ashuanipi terrane, northeast Quebec and Labrador (J.K. Mortensen and J.A. Percival)

Granulites of the Ashuanipi terrane are being studied by U-Pb methods. The objectives of this project are to place constraints on proterolith ages, to determine the timing and duration of granulite facies metamorphism, and to investigate processes of formation of metamorphic zircon and monazite in high grade metamorphic terranes.

- (d) Keewatin in the Baker Lake - Wager Bay Region, N.W.T. (J.C. Roddick and A.N. LeCheminant)

U-Pb zircon dating has been used to constrain the extent and nature of magmatic events in the northwest Churchill province. An Archean terrane, of 2.8 to 2.6 Ga was variably reactivated in the early Proterozoic. Zircon data and initial Nd results suggest Archean crustal contamination in the southern region while zircons from calc-alkaline plutons in the north show no contamination. Further Nd work is in progress.

- (e) Trans-Hudson Suture Zone, Manitoba and Saskatchewan (P.A. Hunt and T.M. Gordon)

U-Pb zircon and K-Ar dating has been used to determine the nature of crustal development in this major orogenic zone. The formation of a juvenile crustal segment took place over about 75 Ma. The earliest magmatism occurred in two episodes at approximately 1900 Ma and 1875 Ma. Metamorphism and anatexis of sediments began during the waning stages of magmatism and continued to about 1800 Ma.

- (f) Southwestern Grenville Province (O. van Breemen and A. Davidson)

U-Pb studies are being used to examine the tectonic evolution of a complex metamorphic terrane in the Central Gneiss Belt. Dating of zircon and baddeleyite from coronitic gabbros is in progress. Adjacent to the Grenville Front, 1740 Ma and 1470 Ma zircon ages, for granites and porphyries are correlated with the Proterozoic igneous terranes of mid-continental North America. In the Central Metasedimentary Belt zircon ages on syenite and granitic intrusions range from 1240 Ma to 1980 Ma.

- (g) New Brunswick granitoids (M.L. Bevier)

U-Pb and common Pb studies are being employed to define the age and evolution of the crust in New Brunswick. Preliminary U-Pb dating indicates that the Trousers Lake Complex orthogneiss is mid-Ordovician and not Precambrian as previously proposed. Common Pb isotopic determinations suggest that Avalonian or older basement may be present beneath north-central New Brunswick.

- (h) British Columbia granitoids (J.C. Roddick and R.R. Parrish)

A combined Sr-Nd-O isotopic study is in progress on granites from south-central B.C. The aim is to constrain the importance of crust and mantle as sources of the granitic magmas and relate them to terrane boundaries. Twenty-five plutons have been sampled and whole rock and mineral separates prepared. Age constraints on the plutons are provided by U-Pb and K-Ar dating.

- (i) Yukon-Tanana terrane (J.K. Mortensen)

The evolution of polydeformed metamorphic rocks of the Yukon-Tanana terrane in south-eastern and west-central Yukon Territory is being studied by U-Pb, Rb-Sr and K-Ar dating techniques. U-Pb ages for meta-igneous rock units in this terrane range from Late Devonian to mid-Permian. Subsequent episodes of deformation and granitoid intrusion range from Late Permian to Eocene in age.



(j) Valhalla Complex B.C. (R.R. Parrish, S.D. Carr and M.L. Bevier)

Comprehensive U-Pb, Rb-Sr and K-Ar geochronology in conjunction with mapping has elucidated the late Cretaceous to Eocene structural and tectonothermal evolution of the Valhalla core complex consisting of both compressional and extensional processes. Common Pb isotopes demonstrate a Precambrian upper crustal component in the major units of the complex and that orthogneiss sheets within the complex are isotopically distinct. New tectonic models for the region have been proposed.

(k) Shuswap Complex (R.R. Parrish)

Recent U-Pb zircon studies indicate that late Cretaceous and Paleocene metamorphic zircons are present in the metamorphic Shuswap complex. It seems clear that they have crystallized under amphibolite conditions without partial melting in alkaline, pelitic and amphibolitic gneisses. These studies will help to determine the usefulness, origin and significance of metamorphic zircons in general.

(l) Anahim Volcanic Belt, B.C. (M.L. Bevier)

Pb and Sr isotopic ratios indicate that depleted mantle similar to the source for Juan de Fuca plate seamounts is widespread beneath all accreted terranes in southern B.C. and that a Precambrian crustal component is only present in Kootenay terrane.

6. McMaster University, Departments of Geology and Chemistry

(a) Stable isotope research (H.P. Schwarcz, Department of Geology)

(i) Paleodiet studies. We have continued to use  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  measurements to determine the major components in diet, through analysis of human bone collagen. Study of a Mayan site in Belize, in cooperation with Christine White of Trent University, showed that there were marked changes in the consumption of maize through the various stages of occupation, corresponding to changes in organization of society. Studies at the Mesolithic/Neolithic boundary in coastal sites of Portugal (with D. Lubell, U. of Alberta) showed decrease in consumption of fish vs terrestrial foods as the agricultural era began.

(ii) Trophic level studies. Mytilid clams from an estuary in Nova Scotia have been studied to test for the contribution of terrigenous foods, using  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$ ; there is a distinct gradient toward the sea, but a plateau is reached well before the mouth of the estuary, suggesting that marine sources are dominant, and are preferentially selected by the organism. Further studies with hydrogen isotopes should help to resolve the continental contribution (with C. Leblanc, M.J. Risk).

(iii) El Niño studies. Stable carbon and oxygen measurements of corals from a reef in Costa Rica show strong warming signals that coincide in time with the onset of El Niño in the 1982-83 season. This method will now be applied to older deposits (with J. Carriquiry, M.J. Risk).

(iv) Acid rain studies. The variation in  $\delta^{18}\text{O}$  and  $\delta^{34}\text{S}$  in sulphate in rain has been measured over the eastern U.S. and Canada, using a set of collecting stations erected last summer. We are beginning to observe trends in the areal distribution of these parameters which will allow us to trace sources of the sulphate, and to understand the mechanisms by which the isotopic signals are generated. In general,  $\delta^{18}\text{O}$  of sulphate is correlated with  $\delta^{18}\text{O}$  of the rainwater, suggesting that there is rapid, local generation of sulphate from a portable "pool" ( $\text{SO}_2$ ?) (with J.R. Kramer).

(b) Dating studies (H.P. Schwarcz)

(i) U-series dating. Various archaeological sites in Europe have been investigated. In Italy we have dated the travertine coating of a neanderthal skull from the cave of Monte

Circeo, showing it to be  $51 \pm 3$  ka old. Other travertine deposits in the Roman district have anomalously high  $^{230}\text{Th}$  contents, which makes it impossible to date them by conventional U-series methods.

(ii) Electron spin resonance dating. The ESR method has been applied to the dating of tooth enamel from archaeological sites in Europe, and vertebrate sites in Alberta and Saskatchewan. The age range for the method seems to be greater than 2 Ma. Models for the calculation of dose rates have been developed, taking into account the uptake of U by the enamel, and the growth into equilibrium of the U-series daughter isotopes (with R. Grun).

(iii) Radioactive waste site studies. Previous studies of U-series disequilibrium in granitic rocks from the Canadian Shield have shown that the  $^{234}\text{U}/^{238}\text{U}$  ratio is generally lower than unity, and that the  $^{234}\text{Th}/^{238}\text{U}$  ratio may be higher than 1.0 in some visibly altered rocks, showing that the time of alteration has been less than 10,000 y. We have now developed a general model to use such isotope data to estimate the rate of chemical transport of uranium through the rock; these estimates generally give much higher transport rates than could have been sustained for the lifetime of the rock near its present erosional level, and suggest marked disturbances during the late Pleistocene, accompanying glacial loading and unloading (with A.G. Latham, Geological Survey of Canada).

(c) Sulphur and Carbon Isotope Geochemistry (H.G. Thode, Department of Chemistry)

(i) Archean gold ores and bedded barites (H.G. Thode, J.H. Crocket and T. Ding (Beijing University, People's Republic of China)). Distribution patterns of  $\delta^{34}\text{S}$  and  $\delta^{13}\text{C}_{\text{CO}_2}$  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 all questions to be answered.

(ii) Environmental studies [H.G. Thode, M. Dickman (Brock University) and S. Rao, M.E. Thompson and A.S. Fraser (C.C.I.W., Burlington)]. Investigation of sulphur content, isotope ratios and microbiota populations in soft water lake waters and lake sediments are being carried out in an attempt to identify natural and anthropological sources of sulphur, and from down core profiles, follow environmental changes over the past century.  $\delta^{34}\text{S}$  profiles both for the water columns and sediment cores for merimictic, seasonally stratified and aerated lakes at different sulphate loadings are obtained.

(d) Radiogenic Isotopic Research (R.H. McNutt, Department of Geology)

(i) Development of the ICP/MS for isotopic measurements with application to Ca-isotopes (medical project), Pb isotopes in air particulates, rain and snow and Os isotopes with application to ore deposits is proceeding. In addition, we are developing analytical protocols to the abundance determination. We have found that the use of a Rh internal standard works very well for a number of elements (R.H. McNutt, A.P. Dickin, J.H. Crocket).

(ii) Comparison of Rb/Sr, zircon U/Pb and Sm/Nd geochronology in high grade metamorphic terranes (R.H. McNutt, A.P. Dickin).

(iii) Sr and Pb isotopic geochemistry of brines and groundwaters from the Precambrian Shield and from the Michigan Basin (R.H. McNutt with S.K. Frape and P. Fritz, University of Waterloo). An extension of this work is the use of Sr isotopes and the U-Th disequilibrium method to study open system behaviour in detail at a radioactive waste repository test site (R.H. McNutt, H.P. Schwarz).

(iv) Pb, Sr, Nd isotope analysis of Neogene volcanics from the Rio Grande rift in Colorado, in order to identify mantle sources and measure the extent of crustal contamination (A.P. Dickin with R.N. Thompson, Durham).

(v) Nd isotope analysis of Colorado Mineral Belt stocks in order to distinguish a crustal or mantle source for the magmas (A.P. Dickin with C. Rice, Aberdeen).

(vi) Nd isotope analysis of Tertiary igneous rocks from Arran, western Scotland to determine petrogenesis (A.P. Dickin).

(vii) Pb, Sr, Nd isotope analysis of basic igneous rocks from Blackstones complex, western Scotland to study intense crustal contamination processes (A.P. Dickin, R.H. McNutt).

(viii) Pb and Nd isotope analysis of igneous rocks from the Grenville of southern Ontario to search for hidden older basement (R.H. McNutt, A.P. Dickin).

(ix) U-series dating by mass spectrometry (A.P. Dickin, H.P. Schwarcz, R.H. McNutt).

7. Queens University, Department of Geological Sciences (E. Farrar, J.A. Hanes, D. Archibald, S. Clark, R. Langridge, S. Heinrich, P. Chaurisiri, M. Gerasimoff, L. Wong)

The argon extraction system has been rebuilt and is used on-line (to a modified A.E.I. MS-10 mass spectrometer) for conventional K-Ar dating and with a Lindberg furnace for high-resolution  $^{40}\text{Ar}/^{39}\text{Ar}$  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, southeastern 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 origin (the Zongo-San Gaban zone) has been identified.

(ii) An isotopic (K-Ar) and petrologic study (L.F., M.Sc. 1985, E.Farrar) of Neogen 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 magnetization 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 southern Peru that support the previously determined counter-clockwise rotation. The timing of 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,  $^{40}\text{Ar}/^{39}\text{Ar}$  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. Archibald, E. Farrar) continues. The study comprises conventional K-Ar dating as well as  $^{40}\text{Ar}/^{39}\text{Ar}$ , U-Pb (with T. Krogh, R.O.M.), zircon dating and Rb/Sr studies (with R.L. Armstrong) and fission track dating of apatites of selected plutons. This study has succeeded in elucidating the thermal and tectonic history of the southern Kootenay Arc and Purcell Anticlinorium from Precambrian to Eocene time. A  $^{40}\text{Ar}/^{39}\text{Ar}$  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 miogeoclinal.

(c) Other Studies in the Canadian Cordillera

(i) An  $^{40}\text{Ar}/^{39}\text{Ar}$  study (D. Archibald) of the west flank of Frenchman's Cap dome from the core zone to the Anstey pluton: Biotite and muscovite yielded concordant or nearly concordant K-Ar dates between 45 and 55 Ma. In contrast, hornblende yielded mid-

late-Cretaceous K-Ar dates (117 to 88 Ma).  $^{40}\text{Ar}/^{39}\text{Ar}$  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.

(ii) An  $^{40}\text{Ar}/^{39}\text{Ar}$  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.

(iii) A K-Ar and  $^{40}\text{Ar}/^{39}\text{Ar}$  study (D. Archibald) of metamorphic rocks near the Purcell thrust (Canoe River map area).

(iv) An isotopic study (K-Ar and  $^{40}\text{Ar}/^{39}\text{Ar}$  step-heating and fission track dating) of selected intrusive bodies in the Selwyn Mountains north and east of Cantung, NWT (D. Archibald).

(d) Studies of Ore Deposits

(i) An isotopic study of the Lake George antimony deposit (D. 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. An  $^{40}\text{Ar}/^{39}\text{Ar}$  study of these samples is in progress.

(ii) An  $^{40}\text{Ar}/^{39}\text{Ar}$  study of the Mt. Pleasant Sn deposit is in progress (D. 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. Archibald, E. Farrar) of selected W mining districts in Korea is in progress. K-Ar dates (80 to 1700 Ma) and  $^{40}\text{Ar}/^{39}\text{Ar}$  age spectra suggest a complex thermal history for these areas.

(iv) In cooperation with A.H. Clark, a  $^{40}\text{Ar}/^{39}\text{Ar}$  study (P. Chaurstri, E. Farrar) of W mining districts in Thailand has been initiated.

(e) Precambrian Studies

(i) An ongoing  $^{40}\text{Ar}/^{39}\text{Ar}$  thermochronometric study (J. Hanes, S. Clark) of the Grenville Elzevir trondhjemite in southeastern Ontario has demonstrated the suitability of Grenville muscovite as a thermochronometer. Results from plagioclase and K-feldspar cast doubt on earlier models of protracted cooling for the Grenville, and also indicate a low temperature Ordovician hydrothermal event. This work will be extended as a  $^{40}\text{Ar}/^{39}\text{Ar}$  thermochronometric transect of the Grenville Front from Montreal to Val d'Or (with J. Martignole, U. de Montréal). Electron microprobe studies of the mineral phases dated will be related to the  $^{40}\text{Ar}/^{39}\text{Ar}$  age and diffusion data.

(ii) In a study (J. Hanes, L. Wong) on the tectonothermal history of the Archean Abitibi greenstone belt,  $^{40}\text{Ar}/^{39}\text{Ar}$  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, GSC).

(iii)  $^{40}\text{Ar}/^{39}\text{Ar}$  geochronology (J. Hanes, D. 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) An  $^{40}\text{Ar}/^{39}\text{Ar}$  study (D. Archibald, E. Farrar, J. Hanes with J. Percival, GSC) of the sheared eastern margin of the Kapuskasing structural zone 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  $^{40}\text{Ar}/^{39}\text{Ar}$  study of the Kapuskasing structural zone and western Abitibi greenstone belt as part of a Lithoprobe transect.

8. University of Saskatchewan, Department of Geological Sciences (T.K. Kyser)

(a) Instrumentation

A MAT 261 thermal ionization mass spectrometer with 5 variable collectors and an automated MAT 251 isotope ratio mass spectrometer have been obtained as complements to our MM 602C isotope ratio machine. Excellent results have been obtained from both the new mass spectrometers and Sr, Nd, and Pb analyses are now routine.

(b) Radiogenic and Stable Isotope Studies

(i) Mafic lavas, ultramafic xenoliths, and the mantle. The oxygen isotopic composition of the mantle, as reflected by the  $\delta^{18}\text{O}$  values of modern mafic lavas and ultramafic xenoliths, is variable, ranging from about +4.5 in deep portions of the mantle to +7 in very refractory portions. Boninites, which are high-Mg lavas associated with subduction zones, have among the highest values and, in conjunction with their Nd, Sr and REE patterns, are derived from melting refractory portions of the mantle and a subducted component. In contrast to the variable isotopic composition of oxygen in the mantle, the hydrogen isotopic composition is relatively constant with most variations in mafic lavas resulting from processes such as outgassing or seawater alteration.

(ii) Hudsonian metamorphism. Several mafic intrusions in the Churchill Province of Saskatchewan and Manitoba yield mineral Sm-Nd ages near 1.85 Ga and Rb-Sr mineral ages that record a younger Hudsonian event near 1.7 Ga.  $\epsilon_{\text{Nd}}$  values range from -0.7 to +3.8, with the low values indicating the incorporation of Archean crust in some of these magmas and the high values indicating derivation from the same depleted source as the associated mafic volcanic rocks.

Within the Hanson Lake Block, a 2.5 Ga terrane in northern Saskatchewan, the O, Sr, and Nd isotopic systematics of almost all minerals were reset to varying degrees during the Hudsonian Orogeny. Sm-Nd compositions of the minerals indicate that partial melting occurred at about 1.8 Ga whereas biotite closure temperatures for Rb-Sr occurred near 1.67 Ga.

(iii) Archean komatiites. H, O, and Sr isotopic compositions of komatiites and associated lavas from the Barberton, Belingwe, and Abitibi Greenstone belts indicate that all these lavas have been altered to varying degrees by seawater during their eruption, and metamorphic and meteoric waters since their emplacement.  $\delta^{18}\text{O}$  values of unaltered olivine and chromite from the komatiites are similar to those of modern mafic lavas in that there is a substantial range in the values of some areas (such as Belingwe) but more restricted ranges and different average values from other greenstone belts. As with Nd isotope results, the primary  $^{18}\text{O}/^{16}\text{O}$  ratios are compatible with derivation of the komatiites from depleted mantle sources.

(iv) Gold deposits. Auriferous quartz veins in Proterozoic intrusive rocks of the Western Shield have oxygen isotopic compositions that indicate formation from high-temperature (ca. 500°C) metamorphic or magmatic fluids associated with emplacement of nearby plutons. In contrast, auriferous and non-auriferous quartz veins in metavolcanic rocks of the Western Shield formed primarily from mixtures of metamorphic and submarine-hydrothermal fluids at lower temperatures of 350°C. Although similar to the temperatures and fluids associated with Archean gold-lode deposits, the Proterozoic deposits are much smaller because they are related to less intense events involving more crustal material.

(v) Unconformity-type uranium deposits. M. Wilson has used the chemical and isotopic composition of clay minerals associated with unconformity-type uranium deposits to trace the fluid history of these deposits. The results suggest that the deposits originally formed from the mixing of basinal brines with distinct basement fluids released along graphitic shear zones during loading of the basement gneisses. Further, the shear zones are still active as conduits for surface waters which have interacted with and modified the deposits throughout their history.

(vi) Paleoclimate Studies. Carbon and oxygen isotopic compositions of fossil mollusks from the coast of California indicate that the seawater temperatures in this area during the

last interglacial stage at 125 Ka were cooler rather than warmer than at present. Similar analyses of Pliocene carbonates in the Amargosa desert indicate that dolomites and Mg-clay minerals resulted from evaporative concentration of calcite-saturated groundwaters.

Stable and radiogenic isotope analyses of Cretaceous nano- and micro-fossils and sediments from the Western Interior Basin of Canada reveal a complex paleohydrology for the ancient seaway. Paleotemperatures are impossible to calculate because the isotopic composition of the seaway was continually altered by influxes of meteoric water and modified pore waters.

#### 9. University of Toronto, Departments of Physics and Geology

- (a) IsoTrace Laboratory; Physics (A.E. Litherland, R.P. Beukens, L. Kilus, W.E. Kieser, R. Cresswell); Geology (J.C. Rucklidge, G.C. Wilson)

The 2MV accelerator mass spectrometer at IsoTrace was acquired in 1982 for the purpose of a) providing high precision  $^{14}\text{C}$  measurements on milligram-sized samples of carbon, and b) performing research into the technique of accelerator mass spectrometry with the aim of applying to a wider range of isotopes, both long-lived radioactive and stable.

(i) Radiocarbon dating. The successful demonstration of the quality and accuracy of the radiocarbon facility was completed in 1984. The contractual obligation to date 50 "Crown Samples" was fulfilled by April, 1985, and a radiocarbon dating service began to be offered to the geological and archaeological research communities. In 1985 and 1986, 317 dates were produced for over 50 users in Canada and the USA. All dates are the average of at least two targets analyzed on different occasions, and results are corrected for natural, Rayleigh and sputter fractionation. Including standards and backgrounds, over 900 targets were analyzed in 1986.

For samples younger than 10,000 years BP a precision of 1% or better is usually obtained. The preferred sample size is 5 mg, although smaller samples can be dated with the risk of lower precision. The machine background is equivalent to an age of 85,000 years; optical quality calcite processed through the sample preparation line yields an age of 50,000 years. Materials analyzed include wood, bone, shell, charcoal, iron artifacts (from which the carbon is extracted) and meteorites.

(ii) Research activities. The phenomenon of isotope fractionation due to sputtering is being studied, since this is believed to set the ultimate limit in accuracy obtainable for radiocarbon dating using a sputter ion source.

The details of the tails higher and lower in energy than the main peak from a sputter ion source are also being studied in connection with the effort to use the equipment for heavy element work. In the case of carbon the high energy tail extends 6keV above the mean ion energy, and although the intensity drops to  $10^{-10}$  of the main peak it can still constitute a source of background for rare heavier isotopes unless adequate energy filtering is performed.

With the support of the Department of Energy, Mines and Resources progress has been made in using IsoTrace facilities to measure  $^{129}\text{I}$  at levels down to  $10^{-14}$ . This isotope has a potential use in the dating of sediments, ice cores and even petroleum reservoirs.

- (b) Lead and Hafnium Isotopic Studies (R.M. Farquhar, Department of Physics)

(i) Archean rocks (P.E. Smith and R.M. Farquhar). An investigation of Hf isotopic variations and Lu-Hf concentrations in meta-volcanics, granitic and dioritic intrusives in the vicinity of two adjacent greenstone belts (Gamitagama and Michipicoten) in the southern part of the Superior Province has been completed. Hf isotope measurements were made on well-dated zircon, in which Hf is concentrated, thus giving initial  $^{176}\text{Hf}/^{177}\text{Hf}$  ratios directly on whole rocks for which corrections were made for radiogenic  $^{176}\text{Hf}$  on the basis of the Lu concentration and known age of the rocks. For the older rocks, mafic volcanics are enriched in  $^{176}\text{Hf}$  ( $\epsilon_{\text{Hf}} +10$  relative to chondrites), rhyolites and granitoids have  $\epsilon_{\text{Hf}}$  values of  $-1$  to  $+1$ , while intermediate rocks lie between these extremes ( $\epsilon_{\text{Hf}} \approx +1$  to  $+4$ ). We attribute the



high  $\epsilon_{\text{Hf}}$  in the mafic rocks to their derivation from a depleted (low Hf/Lu) mantle, and the low  $\epsilon_{\text{Hf}}$  in the granites and rhyolites to a source in the upper crust. The intermediate rocks may be derived from a third distinct source, or may be mixtures of inputs from upper crust and depleted mantle. Later intrusives show roughly time-correlated increases in  $\epsilon_{\text{Hf}}$ , from +1 to +6.

This study has been extended by measurement of Pb isotope ratios and Pb, U and Th concentrations in two basaltic rocks from the same belts. The basalt contains small amounts of sulphides having relatively large concentrations of Pb, with an isotopic composition substantially different from that in the rock matrix. Acid leaching removes the sulphides, and Pb isotope ratios in the residues lie on isochrons which give ages in reasonable agreement with those derived by other geochronological methods.

(ii) Caledonide basalts of southeastern Norway (J. Fox and R.M. Farquhar). We have analyzed Pb in a group of sulphides from stratabound deposits in the Ordovician Upper Nappe sequence of basaltic-sedimentary rocks. Pb is a minor constituent in the sulphides and the Pb isotope ratios indicate mixing of Pb derived from mantle and crustal reservoirs during deposition of the sulphides. The initial Pb isotopic ratios in unmineralized basalts from the sequence are variable and conform to the trend observed in the sulphides, suggesting that the host basalts have also interacted with crustal material during deposition.

(iii) Silurian sedimentary rocks. Pb isotopic ratios of galena found in voids and veins in dolomites of the Middle Silurian Lockport formation in the Niagara escarpment are variable, and define trends which intersect values for Pb in K-feldspars from western Appalachian intrusives. The data are consistent with a derivation of the Pb from a source within the Appalachian Basin, transport toward the margin of the basin, and redeposition. A sample of galena from rock of similar age in the Michigan Basin has significantly different isotopic characteristics reflecting differences in the source beds from which the Pb in the galenas in the two basins have come.

#### 10. University of Waterloo, Department of Earth Sciences (P. Fritz)

##### (a) Canadian Shield studies (with S.K. Frape, UW)

To date we have documented that across the Canadian Shield deep groundwaters are extremely saline and have an unusual isotopic composition inasmuch as they plot above the meteoric waterline in a  $^{18}\text{O}/^{2}\text{H}$  diagram. We interpret these fluids as low temperature fluids which may have higher temperature precursors, that is, retrograde equilibration appears important. At present we concentrate on associated gases and have documented that methane is also ubiquitous. It has a low-intermediate temperature isotopic signature and was most likely generated within the rock masses in which it is found. This does not exclude some migration but we have no evidence that we are dealing with mantle gas. Nevertheless, we are looking at the rare gases at present (with J. Welhan, Memorial University) to substantiate or refute this interpretation.

##### (b) Paleoclimate research

In collaboration with Quaternary geologists at Waterloo we have investigated climatic and environmental changes in southwestern Ontario and northern New York during the past 15 Ka or so. We have been able to document on the basis of isotope analyses that not temperature but humidity changes were responsible for some of the most pronounced 'climatic' shifts. Research on modern molluscs and their carbon isotope controls is in progress.

##### (c) Geochemistry of the Sulphur System

A number of studies on the sulphur cycle in soils and shallow groundwater, in acid rain, and groundwaters in the rocks of the Canadian Shield are in progress. We hope to present an experimental study on sulphate oxidation/reduction processes.

(d) International Hydrology

A major study of the groundwater resources of Oman has been completed. Environmental isotope analyses were essential to establish age and flow relationships for different groundwater regimes.

A cooperative project with Mexico is in progress in collaboration with R.N. Farvolden (UW). Again isotope analyses are used in groundwater studies both at the water supply and contamination end.

11. University of Windsor, Department of Geology (A. Turek et al.)

U-Pb zircon age determinations for the Port Coldwell Complex, Ontario and the Island Lake greenstone belt in Manitoba have been completed and reported. A geochronology study of the Rice Lake greenstone belt in Manitoba is in progress. geochronology studies in the Wawa area of Ontario will be continued with some work in the Michipicoten greenstone belt proper and the Mishubishu greenstone belt to the southwest which is currently being mapped by the Ontario Geological Survey.

Perhaps the most significant item of progress to report is the completion of the mass spectrometer at Windsor. A 25 cm, 90°, solid source mass spectrometer designed and built by the GSC was purchased as government surplus equipment. It has been rebuilt, rehabilitated and computerized and is now fully operational.

12. Other Institutions

A number of departments within the contributing institutions and other separate institutions are known to be conducting active research, but chose not to submit reports this year. For completeness, the separate institutions are listed below.

Carleton University (Geology)  
McGill University (Geological Sciences)  
Memorial University (Geology)  
Royal Ontario Museum (Mineralogy and Geology)  
Université de Montréal (Geology)  
University of Ottawa (Geology)  
University of Western Ontario (Geology; Geophysics)

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## VI METEOROLOGY AND ATMOSPHERIC SCIENCE

Compiled by: E.J. Truhlar

1. University of British Columbia
2. Simon Fraser University
3. University of Alberta
4. Western Research
5. Saskatchewan Research Council
6. University of Windsor
7. McMaster University
8. University of Toronto
9. Ontario Ministry of the Environment
10. Communications Research Centre
11. McGill University
12. Ministère de l'environnement du Québec
13. Agriculture Canada
14. Canadian Forestry Service
15. Atmospheric Environment Service
16. Bibliography

### 1. University of British Columbia, Department of Geography

Research activities in meteorology and atmospheric science continue as follows:

#### (a) T.R. Oke

- Energy and water balances of suburban terrains;
- Energy balance and microclimate of an E-W oriented urban canyon;
- Canyon climate and street design;
- Numerical modelling/validation of a heat island model;
- Research for a book on the urban boundary layer and 2nd edition of "Boundary Layer Climates".

#### (b) D.G. Steyn

- Sea-breeze dynamics in the Lower Fraser Valley, with further collaboration of AES, BCMOE and GVRD, and on 3-D numerical modelling in collaboration with Dr. I.G. McKendry and scientists at Colorado State University;
- View factor determination (now completed);
- Urban energy balance studies;
- Urban heat island modelling;
- Mixed Layer Depth Modelling, in collaboration with BCMOE (revival of previous work);
- Mesoscale windfield modelling;
- Oxidants in the Lower Fraser Valley, BC.

### 2. Simon Fraser University, Department of Geography (W.G. Bailey)

Research was conducted on:

- The climates of shade used in the commercial production of American ginseng in the arid interior of British Columbia;
- The radiation, energy and water balance regimes of Alpine tundra on Scout Mountain in south-central British Columbia.

### 3. University of Alberta, Meteorology Division and Institute of Earth and Planetary Physics (K. Al-Jumily, D. Ball, R. Blackmore, E. Chan, R.B. Charlton, K. Finstad, F. Hopper, W.-W. Jiang, E.P. Lozowski, A. Nowak, E.R. Reinelt, C. Sackiw, C. Schneider, G. Strong, K. Szilder, D. Yiu, P. Zakrzewski, Y. Zhuang)

Measurements of mean wind speed and turbulence were carried out behind two sections of a 50% porous fence differing only in their vertical distributions of porosity. A numerical model, using a second-order turbulence closure scheme, simulates shelter flow by parametrizing the fence as a localized momentum sink.

Several atmospheric icing models have been reviewed and operational rime-icing models for cylinders and airfoils have been developed, including one that takes into account the effects of internal heat conduction. Studies are under way on the heat transfer coefficient of rough cylinders, and on the accretion of ice on fishing vessels resulting from the splashing effects of wave-generated, freezing spray.

Experiments in marine ice accretion have been carried out in a small outdoor wind tunnel. Related work involved experiments on icicle growth, and calorimetric studies of sponginess in accreted ice. Monte Carlo methods have been applied to the modelling of the diffusion of spray droplets in the marine boundary layer, in order to predict the variation of liquid content with height. These results have been incorporated into a model of ice accretion on offshore drilling platforms.

A simple model claimed to give useful predictions for snowfall in the Colorado Rockies has been tested in the Alberta Rockies. Studies continue on the synoptic-mesoscale interactions and dynamics of severe convective storms and on the sea surface temperature effects of the 1981/82 El Nino.

The distribution and frequency of cloud patterns associated with fronts and cyclonic systems are being re-examined with a view to providing a more detailed climatology of cloud cover in Western Canada.

Various aspects of the hydrometeorology of ice jams in northern rivers are under investigation, in particular the spring break-up of the Athabasca River. The morphology of a heavy spring snowstorm in Calgary, and the evolution of the weather patterns responsible for the extensive flooding in the Edmonton district in July, 1986 are being studied by integrating a comprehensive set of satellite, radar and surface observations. A catalogue of vertical wind and temperature profiles has been compiled for specific sites within the boreal forest regions of Northwestern Canada.

Two related studies on the composition of Arctic haze and on urban visibilities at low temperatures have been completed.

A cooperative study with the Weather Radar Group has found that the correlation between two circularly polarized components of the radar echo is a better indicator of the presence of hail than previously believed. A related project deals with the relationship between in-cloud measurements of raindrop and ice-particle size distributions and simultaneously received radar echoes. This work concentrates on the differences between showers and continuous precipitation.

#### 4. Western Research, Division of Bow Valley Resource Services Limited

Detailed studies were completed into the effects of forested Foothills terrain upon horizontal and vertical wind fluctuations. Work continued on quality assurance for air quality and meteorological data collected as part of the jointly funded Alberta Government-Industry Acid Deposition Research Program (ADRP). Input data were assembled on behalf of the Atmospheric Environment Service for application of three statistical models for the long-range transport of air pollutants to Western Canada. Consulting services were supplied to industries regarding climatology, the effects of stack emissions on air quality and the extent of hazard zones created by sour gas escapes from well blowouts and pipeline ruptures.

#### 5. Saskatchewan Research Council

In spray drift trials with Canada Agriculture several different commercially available sprayers were tested for off-swath droplet drift and pattern uniformity.

SRC operates a benchmark climate station on the University lands; a significant part of the program development has involved the Atmospheric Environment Service. The climate station is being automated by the Handar system. Eleven years of evaporation data were compiled and analysed for a selected series of four atmometers installed at the SRC Climatological Reference Station. The Class A pan continues to provide a reliable stable record for evaporation at Saskatoon.

Research continues on the effect of climate on prairie lakes with the primary emphasis being on hydrometeorological processes. Other activities dealt with acid deposition, surface hydrology, and pesticide flux to the atmosphere.

A major program in conjunction with several other agencies has been the study of the effects of climate change on agriculture in Saskatchewan.

The SRC monitoring services to industry and government organizations continued (see CGB, 1984).

#### 6. University of Windsor

##### (a) Department of Geography

Under a grant from the Donner Canadian Foundation the impact of possible future climatic change on Great Lakes levels and flows is being studied.

##### (b) Department of Physics

A wide variety of experiments have dealt with the interaction of electrons and photons with atomic and molecular species, with particular emphasis on the impact excitation of  $O(^1S_0)$  and  $^1D_2$ ; and low energy, heavy-particle collisions involving atmospheric species.

#### 7. McMaster University, Department of Geography

##### (a) Radiation Studies (J.A. Davies)

Spectral optical depth measurements at Alert are being analysed to determine aerosol optical depths and particle size distributions of Arctic haze. Surface albedos are being determined from Nimbus-7 satellite data. Several other projects, (i), (ii) and (iii) have continued (see CGB, 1985).

##### (b) Hudson Bay Lowlands Studies (W.R. Rouse)

In a continuation of energy-balance studies in the Hudson Bay Lowlands the advective effect of Hudson Bay on the climate of the adjacent lowland is being studied along a traverse from the shore inland in the vicinity of Churchill, Manitoba. All relevant ground-based energy-balance measurements are being taken at 4 stations spaced along an 18-km transect across lat, wet-sedge terrain. At the shoreward and landward ends of the traverse, simultaneous tethersonde data will be gathered to the top of the boundary layer, to study the effects of the entrainment of heat and moisture on boundary-layer characteristics and development during onshore and offshore wind episodes.

##### (c) Associated research

- Above- and below-ground plant biomass development, and stomatal and canopy resistance as related to climate during the growing season;
- Small-scale advection between tussock hummocks, which can dry out and heat up in overall wet terrain conditions, as one factor in the surface control over the latent heat flux through surface resistance to or enhancement of evapotranspiration.

## 8. University of Toronto

### (a) Department of Physics

(i) Cloud Physics. Radiometric microscope measurements of growing hailstones (in gyrational and rotational modes) in the pressure-controlled icing tunnel allowed detection of surface temperatures of thin water films of  $-5^{\circ}\text{C}$ . These films covered spongy ice deposits with temperatures of  $0^{\circ}\text{C}$ . At the same time, pole temperatures were recorded even closer to the air temperatures. Together with the measured shedding this should lead to a new non-isotropic theory of hailstone heat and mass transfer.

The growth of low-density graupel particles in the icing tunnel led to a new parametrization of the growth and density evolution of these particles, which are the key elements of rain in our latitudes.

A warm rain experiment was carried out in Penang jointly with the Malaysian Meteorological Service. The ground measurements with a Joss Disdrometer (rain drop diameter range  $100\text{ }\mu\text{m}$  up) and a PMS 2-D laser spectrometer (diameter range  $15\text{--}960\text{ }\mu\text{m}$ ) produced the first-ever observed characteristics of rain in the tropics in those scales. In particular, it was possible to prove the existence of triple peak spectra, with peaks at fixed diameters - as proposed by the laboratory-based numerical models by List, Donaldson and Stewart (JAS, 1987). Another mechanism was also found that produces other peaks. Of particular interest is the finding of a signature of breakup in rainshafts. The new insights into warm rain from warm clouds (or "cold" ones with freezing levels at about  $5\text{ km}$ ) will help in the future explanations of cold rain in our latitudes or the warm rain evolution parallel to the hail growth in the cold regions of cumulonimbus clouds.

(ii) Mesoscale Atmospheric Dynamics. Dynamics of rainbands, polar front cyclogenesis, Kelvin-Helmholtz instabilities, cloud-mean flow interactions, melting-induced mesoscale circulations.

(iii) Geophysical Fluid Dynamics and Paleoclimatology. Ongoing research in geophysical fluid dynamics has focused on the problems of the transition to turbulence in stratified parallel flows, on the dynamics of intense downslope windstorms dominated by breaking internal waves, and on the origin of frontal cyclones, polar lows, and comma clouds.

In paleoclimatology, efforts continued on refining a new version of the astronomical theory of the origin of ice ages that includes the glacial isostatic adjustment process; analyses of observed present-day variations of relative sea level have been performed which allow secular sea level bands to be filtered so as to remove the isostatic adjustment contribution. Work also continued on the theory of mantle convection and continental drift and on the inverse problem for mantle viscosity using earth rotation and global gravity data as well as relative sea-level information. All of this work is closely connected to the new ICSU program on Global Change.

(iv) Middle Atmosphere Composition and Radiative Transfer. Results from our own stratospheric balloon instrument have been analysed to give simultaneous profiles of  $\text{CO}_2$ ,  $\text{CH}_4$  and  $\text{O}_3$ . In addition an upper bound on formaldehyde concentration has been obtained.

A multi-gas, multi-layer general line-by-line spectral modelling program has been developed for atmospheric radiative transfer calculations with particular application to limb-scanning in the middle atmosphere.

### (b) Institute for Environmental Studies

The Institute's interdisciplinary programs focus on problem-oriented research on the quality of the environment and on environmental management. Specific recent studies have dealt with the impacts of climate variability and change, the atmospheric deposition of heavy metals, the modelling of environmental pathways of organic contaminants, the effects of acid rain on a boreal ecosystem, the role of atmospheric pollution in sugar maple decline and the use of lichens as biomonitors of atmospheric deposition.

9. Ontario Ministry of the Environment, Air Resources Branch

Statistics on the Lagrangian model trajectories have been calculated and incorporated in the statistical model thus allowing it to simulate more realistically the sulphur deposition to Canadian receptors.

A revised modelling package including the state-of-the-science concepts has been recommended for regulatory applications within the Ministry of the Environment.

The transport wind for the heavy gas model has been modified by including realistic variations of the surface wind within the depth of the slumping heavy gas cloud.

Routine monitoring continued across the province for acid rain related compounds, as well as trace metals, in air and precipitation. Plans for upgrading the provincial network, as part of the North America Eulerian Model Evaluation Field Study, were completed, and the work to accomplish this is in progress. Monitors for a number of toxic organics in air and precipitation have been developed, and a small network of samplers is being installed in the Great Lakes Basin.

10. Communications Research Centre

The Radio Propagation Laboratory at CRC has continued its study of meteorological influences on radiowave propagation. Current interests include the nature and magnitude of the temporal variation in short duration precipitation statistics, the influence of raingauge integration time on perceived intensity statistics, and the importance of low-level atmospheric ducts and superrefractive layers on terrestrial communications systems.

11. McGill University

(a) Department of Meteorology

The main areas of research are (1) dynamic meteorology, including studies of planetary waves and numerical weather prediction; (2) climate research, with emphasis on interannual variability, teleconnections and ocean-atmosphere interactions; and (3) physical meteorology, including theoretical and observational research on mesoscale cloud systems.

(b) Macdonald College, Department of Renewable Resources

Research activities continued on:

- Laboratory simulation of heat and mass transfer between vegetation and the atmosphere, both in air and by electrochemical simulation
- Field studies on nitrogen loss through volatilization of ammonia from manure, using the Lagrangian simulation models developed at Guelph University
- Acid deposition to foliage (wet and dry) including field observations at Mt. Tremblant and laboratory studies on adsorption of isotope-labelled  $\text{SO}_2$
- Aircraft-based, eddy-correlation flux measurements (in cooperation with Agriculture Canada and the National Aeronautical Establishment), which involved the expertise of the McGill Physics Department and McGill Weather Radar Observatory for the statistical and conceptual analysis of flux imaging problems
- Further exploration of the uses of the beta-gauge for plant water relations (evaporation from and condensation on leaf surfaces) and other environmental problems
- Ecological behaviour of insects, studied by radio(isotope) labelling

12. Ministère de l'environnement du Québec, Direction de la météorologie

Les travaux se sont poursuivis pour permettre la publication d'une "Climatologie du Québec méridional". L'originalité de ces travaux réside dans le caractère synthétique des résultats. Ces travaux se terminent en 1987.



Une étude a été mise de l'avant avec la collaboration du Bureau de la statistique du Québec pour analyser les corrélations et les relations existant entre les ions majeurs composant les précipitations dites acides. Des résultats préliminaires montrent pour le Québec un comportement différent de celui de l'Est des États-Unis sous certains aspects. L'étude a été faite à l'échelle saisonnière. En collaboration avec l'Institut National de la Recherche scientifique (INRS-Eau), une analyse basée sur le krigeage ordinaire des concentrations et dépôts humides saisonniers des substances acidifiantes contenues dans les précipitations a permis d'en évaluer la variabilité spatiale de même que la précision relative des valeurs moyenne spatiales estimées.

De plus, des travaux visant l'amélioration et l'étalonnage d'un modèle de transport à grandes distances des polluants atmosphériques (les  $\text{SO}_x$ ) se sont poursuivis. Les données météorologiques mesurées en altitude de même que les données chimiques (sous forme de  $\text{SO}_4^{--}$ ) recueillies par le biais du réseau d'échantillonnage des précipitations (REPQ) sont utilisées à cette fin.

### 13. Agriculture Canada

#### (a) Crop Environment Assessment

A data acquisition system is being developed to measure  $\text{CO}_2$  and water-vapour flux densities for assessing biomass growth and evapotranspiration over large areas. A high degree of reproduceability of results was obtained. Detailed analyses of Landsat data were carried out at the Carberry (Manitoba) test site using Thematic Mapper imagery of six bands. The use of the two extra bands (0.45 and 10.5  $\mu\text{m}$ ) combined with the 30-cm resolution area improved the capability to correctly classify the variety of special crops as compared to the standard Landsat MSS data for the same region. Using daily meteorological data from 76 observation stations in the Prairie Provinces, the production of cereals was estimated for cereals seeded on fallow and on stubble land.

#### (b) Agroclimatic Resource Assessment

Research continued on achieving a better understanding of the relationships between plant physiological processes and crop growth and development under varying environmental conditions. Algorithms were derived that describe the photosynthetic response to irradiance of eight maize varieties during development, estimate maize leaf area from readily available climatic variables and predict barley phenology as a function of temperature and photoperiod. Interactions between water stress, photoperiod and the development rate of barley were evaluated.

Historical data on daily snow depth are being archived for the Atlantic region in cooperation with Environment Canada AES, for input into regression-based soil temperature models. Procedures for sampling and analysing soil temperatures for soil climate classification were evaluated. With a sampling frequency of 14 measurements per year, 3 years of data produced reasonably accurate estimates of soil climate parameters used in classification for the 20- and 50-cm depths under grass cover. A Fourier series model with a second harmonic provided an improved fit to the seasonal soil temperature curve compared with a 2-variable model.

Average optimum seeding dates of winter wheat were highly correlated ( $r = 0.998$ ) with average air temperature during fall in various regions of Canada. The optimum seeding period for winter wheat in the Vernon-Armstrong region of British Columbia and in southern Ontario was estimated from climatic normals.

A climatic index based on winter temperatures was computed to help assess the risk of outbreaks of Stewart's bacterial disease in corn in all regions of southern Ontario. Index values suggested that even in areas of southern Ontario where the disease is most probably found, the probability of severe outbreaks is relatively low (about 5%, or 1 year in 20).

Improving estimation of soil water content was achieved using a diffusion-based soil water model. Two different root water uptake functions were incorporated into the model. Using only root depth gave a better correspondence than using root densities. Soil water content simulations were within 10% of the measured values.

(c) Operations Management

Current weather conditions and derived soil moisture were monitored weekly and monthly for the Prairie Provinces. Current computer weather data files for Ontario and the Prairie Provinces continue to be updated on a weekly basis for use by regional researchers (see CGB, 1985).

The evaluation of a soil moisture budget using data from Quebec for a range of soils and crops was completed. A user friendly version of the budget was implemented on a microcomputer for near real-time monitoring of soil moisture and for irrigation scheduling for potatoes for individual farms. Derived soil moisture was monitored weekly for two soil textures for Smithfield, Ontario in relation to orchard crop management. Areal estimates of evapotranspiration in Quebec were compared with measurements of water vapour flux obtained using an aircraft.

Field testing of the new low-cost leaf wetness sensor, a sonic snow depth sensor and an electrical frost probe continued. A new data logging system using radio telemetry was implemented for automatic recording and retrieval of data from a weather site at Ottawa.

14. Canadian Forestry Service

(a) Newfoundland Forestry Centre, St. John's

The following studies are continuing (see CGB 1985):

Research on the impact of wind on forest stand dynamics dealing with processes that maintain wave-generated balsam fir stands on the coastal plain of the Great Northern Peninsula has produced a method of estimating windflow in hilly terrain from tamarack deformation. The ENFOR energy balance system has been operational on a bare-soil site prepared for a willow plantation. The peatland afforestation experiment on drained bog and fern is studying black spruce performance and larch survival and growth relative to above-ground climate, hydrology and fertility. The impact of acid rain on forest soils is being assessed from data in the Acid Rain Early Warning System (ARNEWS).

A new study has been set up in a mature stand and adjacent clear-cut to measure air and soil temperatures, relative humidity, and water potential to characterize microclimate and soil temperatures on a black spruce site following site preparation.

Another study on production processes in balsam fir stands includes measurements of ambient CO<sub>2</sub>, light interception, and photosynthesis and respiration rates.

(b) Maritimes Forestry Centre, Fredericton

LRTAP studies are continuing in order to determine the impact of the atmospheric deposition of SO<sub>x</sub> compounds on tree growth and soil fertility processes.

The ARNEWS monitoring also continues. A special set of plots was established to monitor ozone and to collect fog water for chemical analysis in order to relate white birch decline along the Bay of Fundy to air pollution parameters. Projects completed included: the multivariate analysis of meteorological data for Prince Edward Island and Nova Scotia; and the examination of LRTAP effects on the dendrochronology of red spruce and sugar maple in south-eastern Quebec and the Maritimes.

(c) Laurentian Forestry Centre, Ste. Foy

The studies reported in CGB 1985 are continuing. Microclimatic and climate data are being used to assess the relationship between air temperature, relative humidity, total radiation, rainfall and soil temperatures and tree crown architecture; to characterize the sites where genetic provenance trials are being carried out on white spruce, white pine and Norway spruce; and to study floral induction and conservation of grafted stock during winter.

(d) Petawawa National Forestry Institute, Chalk River

Several studies are continuing (see CGB 1985): analysis of wind data already obtained; research on the drying of various forest fuels; and measurement of rainfall in remote areas using satellite, radar and automatic raingauge data.

Work completed included a final report on the relationship of area burned by wildfire to meteorological variables; two case studies - an escaped experimental burn and a northwestern Ontario wildfire; a project to monitor forest fires using the AVHRR instruments carried by NOAA-6 and -7; and a review of the causes of climate change. Drought persistence at Canadian stations is receiving greater attention because of intriguing results from a study of rainfall statistics for 43 stations. This study was a spin-off from the research on area burned by wildfire. New studies deal with the cause and control of firewhirls at prescribed burns, and the role of atmospheric stability on fire behaviour (in cooperation with GLFC); and the effect of air pollution and climate on the growth of trees.

(e) Great Lakes Forestry Centre, Sault Ste. Marie

In addition to the uses for weather and climate data reported in CGB 1985, such data are also used for evaluating and calibrating the Canadian Forest Fire Danger Rating System for use in Ontario; and for conducting and analysing experimental fires to develop a Fire Behaviour Prediction System for Ontario forests.

(f) Forest Pest Management Institute, Sault Ste. Marie

Weather data and forecasts are used for developing and evaluating field applications of insecticides and herbicides; testing of insecticide and herbicide efficacy; evaluating the environmental impacts of chemical and biological pesticides; timing aerial pesticide applications and determining spray drift and effectiveness; and studying the effect of weather on insect population dynamics.

(g) Northern Forestry Centre, Edmonton

Twenty-four years of monitoring meteorological and hydrological data on the Marmot Creek watershed ended on December 31.

Results from snow evaporation studies in small clear-cuts at the James River site were used to modify water yields predicted by the USFS WRENSS procedure. This procedure has been used to simulate potential water yield for a proposed pilot water shed management area and the Eastern Slopes watershed of the Saskatchewan River.

Research on the effect of microclimate on the growth of trees, and of climatic extremes on regeneration in harvested areas has been carried out. Study of climatic trends in the three major subregions of the boreal forest showed highly significant and slightly increasing temperature and precipitation trends from 1871 to 1981 for the forest subregion, and a similar though lower temperature increase but a slight precipitation increase for the forest-tundra subregions.

The air and soil climate of three different peatlands (see CGB 1985) are being monitored before and after drainage in order to model the moisture and temperature regime of drained peatlands having ditches spaced at various distances.

Soil moisture and temperature measured on plots south of Grande Prairie are being related to the movement and breakdown of the herbicide, pronone.

Research during the winter on a juvenile stand of lodgepole was aimed at determining the time required for aerodynamic closure of a clear-cut through regrowth of planted lodgepole pine. Field data has revealed that snow evaporation in the stand was 1/2 to 1/5 of that in the open.

The CFS/Alberta Forest Service experimental project continued in northern Alberta with three successful burns and included measurements of weather data over a 10-week period.

Weather and climate data were used to evaluate the microclimate of Saskatchewan fire weather stations, resulting in the establishment of 29 automatic stations over the past two years; and to study the microclimates of clear-cuts near Hinton, Alberta.

Several research studies produced maps of the wetlands and the ecoclimatic regions of Canada. Work continued on the climatology of atmospheric conditions related to extreme forest fire behaviour in west-central and northern Canada (University of Alberta).

(h) Pacific Forestry Centre, Victoria

Climate affects the following studies as well as those continuing studies reported in CGB 1985: the decomposition of surface organic layers; site disturbance following logging; development of the black-headed budworm; dispersal of the black army cutworm; effectiveness of pathogens for controlling mountain pine beetle.

New studies under the Canada/B.C. Forest Resource Development Agreement having a significant climate component are:

- The effect of prescribed fire on soil moisture and temperature on two ecosystem associations in the Sub-boreal Spruce Biogeoclimatic Zone.
- Site preparation and planting procedures to minimize temperature and moisture adaptation of forest planting stock.
- Optimum climatic and edaphic conditions for Engelmann spruce fall planting in the Kamloops forest region.
- Autecology of weed species on northern interior backlog NSR lands.
- Testing of planting stock for drought resistance.
- Seasonal course of the water loss from conifer leaves, with emphasis on the period between bud-burst and leaf maturation.
- Soil-water relationships and hydrology of the Wedene River floodplains in relation to several stand conversion alternatives.
- Cold hardiness of conifer roots.
- Effect of *Agrobacterium rhizogenes* on root development and drought avoidance in interior Douglas-fir bareroot planting stock.
- Daylength and drought effects of shoot-root growth in container-grown interior Douglas-fir.
- Climate monitoring to assess the effects of site preparation in the Cariboo Region.
- Production of handbooks describing guidelines for assessing soil temperature and moisture conditions at forest sites.

15. Atmospheric Environment Service

(a) Meteorological Services Research Branch (MSRB)

(i) Forecast Research. Continuing studies on the Donelan Lake Wave Model included improvements in its drag formulation, exhaustive tests using wind and wave data from Great Lakes buoys, and tests for application to the Beaufort Sea. A personal computer version of the real-time oil spill trajectory forecast model is being developed.

The Canadian Atlantic Storms Program (CASP) provided an opportunity to make real-time tests of (1) spectral wave models for Canadian operational wave forecasting, (2) the storm surge model which was expanded to make forecasts for the east and south coasts of Nova Scotia, (3) a freezing spray model based on the Kachurin nomogram using spectral model data as input, and (4) a set of eight statistical forecast products supplied to the CASP operational forecast desk in graphics format. The Regional Ice Model was adapted to operate over (1) the Gulf of St. Lawrence area in order to use detailed CASP data to produce case studies and (2) the coastal waters east of Labrador in preparation for the Labrador Ice Margin Experiment (LIMEX). Studies continued on an iceberg rolling model to aid in forecasting rolling during towing, and on the micro-mechanics approach to sea-ice modelling. A comparison of the Perfect Prog and Model Output Statistics (MOS) methods showed not much difference in accuracy, either for continuous predictands or for categorized predictands. MOS forecast equations for surface

wind and temperature were developed for the sites of the Calgary winter Olympic games. The 1986/87 winter forecasts are being used to assess whether the equations can discriminate mesoscale differences in winds based on input from a synoptic-scale model. Other work in progress includes (1) adapting a thunderstorm-forecasting procedure based on the expert system approach to AES operational needs and incorporating AES expertise (a contract with MacDonald Dettwiler and Associates and the Alberta Research Council), (2) development and testing of procedures to enter and edit graphical weather depiction charts that are based on charts either manually entered or received from the Canadian Meteorological Centre, and (3) testing of procedures based on natural language algorithms to automatically draft worded marine and public forecasts from these weather depiction charts.

(ii) Numerical Prediction Research. A version of the analysis program was tested having increased horizontal resolution and using a large number of predictors to calculate the analysed value at each grid point. This version used the  $180 \times 45$  hemispheric Gaussian transform grid of the spectral model which drives the assimilation cycle as the analysis grid, and allowed the use of up to 24 predictors to calculate an analysed value. Compared with the operational analysis program this version gave stronger, better-defined jets and more intense vorticity fields. A scheme that uses high-resolution GOES satellite data to enhance the moisture analysis was implemented operationally.

Two projects aimed at increasing analysis accuracy included one to calculate and periodically update the correlations and other statistics required by the analysis program, and another to implement an expanded data file containing significant level data and additional mandatory levels in the stratosphere. These will increase the vertical as well as the horizontal analysis resolution. A high-resolution regional version of the analysis program is also being developed.

Experiments on a few cases of explosive cyclogenesis during CASP showed model sensitivity to various sub-grid scale parametrizations. The simulations indicated the importance of (1) a realistic convection scheme to connect with the turbulent Planetary Boundary Layer (PBL) fluxes (a Kuo-type scheme including a simplified treatment of shallow convection gave better results than a Manabe-type convective adjustment scheme), (2) a PBL scheme capable of redistributing the large surface fluxes from the ocean (superiority of a turbulent kinetic energy (TKE) scheme over a bulk-aerodynamic formulation), and (3) a realistic SST analysis (with a horizontal resolution consistent with the model resolution). Improving the TKE PBL scheme in the operational finite-element regional model (more general formulations for the eddy mixing length, dissipation length and PBL height) continues and includes shallow convection in the TKE scheme. A boundary-layer scheme with low sensitivity to vertical resolution has been developed in a column model and is being tested in the operational spectral model. The scheme relieves models from the necessity of carrying a level very close to the surface.

Research on improved numerical methods continued. As a second step in the application of the semi-Lagrangian time integration scheme to spectral modelling, three semi-implicit models of the momentum (U,V) form of the shallow water equations were constructed. The first model is Eulerian; it has been validated by its results, which are identical to those produced by a corresponding model for the conventional vorticity-divergence form of the shallow water equations. The second and third models use interpolating and non-interpolating semi-Lagrangian treatments of advection, respectively. For short-term forecasts the semi-Lagrangian schemes produce stable, accurate integrations with time steps that far exceed the stability limit of the Eulerian scheme. Preliminary results for medium to long-term integrations are also encouraging. Work also continued on the two-time-level version of the semi-Lagrangian scheme that maintains second-order accuracy in time without relying on operator splitting. This method was formerly tested in a shallow water regional finite-element model. A version for the baroclinic primitive equations has been formulated and analysis indicates that it should be stable and accurate. To evaluate the feasibility of using a spectral model to test this version, Ritchie's three-time-level interpolating semi-Lagrangian spectral model of the shallow water equations has been converted to a two-time-level scheme, and preliminary results indicate that this approach is viable for shallow water spectral models. A slight reformulation of the implicit normal mode initialization scheme has permitted inclusion of some of the "beta" terms in the linear system that defines the implicit normal modes, leading to a better initialization at the largest scales and in the tropics. This has also clarified and improved the treatment of lateral boundary conditions for the finite-element regional model. A version of an initialization scheme due to Tribbia has also been incorporated; it



generalizes the usual Machenhauer scheme to higher order in time and enables the implied model balance condition to take into account the time tendency of the non-linear forcing of the gravity modes. Prime factor Fast Fourier Transform algorithms written in CAL for CRAY computers have been thoroughly tested on both the CRAY-1 and X-MP, and experiments have demonstrated worthwhile gains in both speed and storage requirements in comparison with the conventional FFT package.

(iii) Aerospace Meteorology. The Satellite Data Laboratory continued to provide satellite data on an operational basis to AES and DND forecast offices as well as to a wide variety of specialized users. The read-out/processing equipment in the laboratory handles the A/VHRR, TOVS and DCP data from the NOAA polar-orbiting satellites and the VISSR data from the geostationary satellites of the US GOES series. A DCP capability for the GOES satellites is also now in operation. Much of the laboratory's equipment is being replaced, and the antenna system is being refurbished. The VISSR systems at Downsview and Vancouver have been converted to the new Mode AAA format. A new Mode AAA facility is being developed for the Satellite Data Laboratory to support R & D activities. VIEWFAX, the soft-copy satellite image display device developed with Muirhead Canada, continues to be used in the DND weather office in Halifax. Research continues on using weather radar data to ground-truth satellite data from geostationary satellites (RAINSAT) to produce rain analyses and forecasts. The main effort was centred on algorithm evaluation using a large data set. To evaluate the system's value in forecast operations, demonstration products are transmitted in real-time to the Quebec Weather Centre in Montréal. The initial reaction of the forecasters has been sufficiently favourable, so that these transmissions will continue. To assist in this evaluation a new display system was developed. Unfortunately, the quality of the products was lower than expected because of the failure of GOES (East) and the resulting degradation of coverage over Eastern Canada. A closely related project uses RAINSAT products for initializing NWP models at CMC. A processing system was developed to obtain three-dimensional mesoscale temperature and humidity fields from the data received from the TOVS instrument flown on the NOAA satellites. A new technique using empirical orthogonal functions to carry out simultaneous physical retrievals was also developed. Statistical retrieval software was implemented at the Arctic Weather Centre in Edmonton. In the research to obtain surface wind speeds and directions from microwave scatterometer data, the collaborative program with JPL, NASA Goddard and UCLA continued. In the Askervein Hill Project, data from the full-scale experiments were analysed and published in collaboration with Risø National Laboratory, the Danish partner. Results from further wind-tunnel simulations carried out at Oxford University and from the University of Canterbury (New Zealand) were compared with those from the AES. The AES tunnel also studies the flow over a vertically-exaggerated model of the hill to determine the impact of such scale-exaggeration on the quality of the simulations produced.

(b) Atmospheric Processes Research Branch (APRB)

(i) Cloud Physics Research Division. The Chemistry of High Elevation Fog (CHEF) program began measurements of the vertical and horizontal variability of ozone concentrations in southern Quebec. These are in addition to the on-going fog and precipitation chemistry and meteorological measurements.

The field phase of the Canadian Atlantic Storms Program (CASP) was conducted from January to March, 1986. The data analysis phase of CASP has proceeded in earnest. Major new software has been developed for displaying and merging data from satellites, radar, rawinsondes, and surface stations. Preliminary analyses have revealed that East Coast storms are typically characterized by both a surface and a mid-level cold front. Freezing rain is highly localized near the rain/snow boundary as is heavy snowfall. Modelling of the storm and mesoscale features has commenced.

Studies on the techniques and applications of Doppler radar data to increase the understanding of severe storm development and growth and to assist in the recognition and prediction of hazardous weather conditions, were based on real-time and archived data from a continuously operating Doppler radar. Analysis using radial velocity, spectral width, VAD, multimoment and wind shear displays revealed the presence of mesoscale patterns, greatly increased our power to observe the complex dynamics and structure of southern Ontario storms, and contributed to a significant improvement in providing timely severe storm warnings. There appear to be significant differences between these storms and those in the United States



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Midwest. Lightning location and radar data have been integrated into a severe storm map. An interactive multidisplay system for manipulating 4 hours of real-time and archival data is under development.

The cloud chemistry program had 2 studies that involved collecting samples of aerosols, trace gases, cloud and precipitation for chemical analysis: 1) in storms off the East Coast during CASP; and 2) in polluted air near Cambridge, Ontario between 21 October and 1 November, inclusive. The National Research Council (NRC) Twin Otter and the Canadian Centre for Remote Sensing DC-3 were used for sample collection during CASP; the NRC Twin Otter was used for sampling at Cambridge. An additional goal of the Cambridge study was the development of new instruments for aircraft pollution monitoring. Among the new instruments tested were a Canadian device for the monitoring of  $\text{NO}_2$ , and a Canadian-built version of a device for the real-time monitoring of carbonaceous particles. These instruments were found to work well and will continue to be used. Data analysis continues on both studies.

As part of the Canadian Arctic Haze study, the NRC Twin Otter was flown to and operated out of Alert, NWT, between April 4 and 22, 1986. The aircraft was outfitted for detailed microphysical measurements of aerosols and ice crystals. Vertical profiles up to 6 km MSL revealed the presence of polluted layers throughout the troposphere. Data are being analysed in conjunction with extensive ground-based measurements made at Alert and data collected by the US Arctic gas and sampling program during this period.

(ii) Experimental Studies Division. The STRATOPROBE program successfully made measurements of ozone and other stratospheric gases in parallel with the NASA SAGE II measurements on the ERBS satellite. Besides validating the satellite results, the data should help to increase our understanding of the chemistry of the ozone layer.  $\text{N}_2\text{O}_5$  was measured before dawn at Ainsworth, Nebraska, as part of the Laramie overpass experiment for the ground-truthing of SAGE.

In collaboration with York University, several numerical 1-D model experiments were carried out to simulate the behaviour of the Antarctic ozone "hole" in order to account for the observed downward trend in October.

Modernization of the Canadian ozone network continues (see CGB, 1985). The Canadian Brewer network was expanded during 1986 with the installation of a new instrument at Churchill. Fully automated, scheduled operation is now being implemented at five Canadian and seven foreign stations. The Brewers are manufactured by SCI-TEC of Saskatoon; serial number 30 is now in production.

The ground-based nitrogen dioxide Brewer continues to monitor  $\text{NO}_2$  at Toronto. Tropospheric  $\text{SO}_2$  overburden is also being monitored with the ozone Brewers.

Three Brewer instruments from Canada, Germany and Greece participated in the ground-based ozone spectrophotometer intercomparison at Arosa in August.

Preparations to fly a Brewer spectrophotometer on a NASA Get-Away Special (GAS) package on a future Shuttle flight continued. This project is being supported by Bristol Aerospace Limited.

To study ozone depletion, the UV-B flux was monitored with a modified Brewer and with a Smithsonian instrument at Toronto. The correlation between UV-B flux and total ozone is being investigated experimentally.

A research monitoring observatory, specifically designed to measure the greenhouse radiation for the radiatively active gases (RAGS), was established at Asquith, Saskatchewan, in January.

The National Atmospheric Radiation Centre (NARC) continued participating in (and leading) international programs for the improvement of radiation measurement (WMO, ISO, IEA). Work on the measurement of long-wave thermal irradiance was accelerated in response to needs expressed in the meteorological and solar energy fields. Routine NARC calibrations were made on 130 radiometers about half of which were owned by organizations outside the AES. Sky radiance studies in several wavebands continued at Toronto.

(c) Air Quality and Inter-Environmental Research Branch (AQRB)

(i) LRTAP. Using the Lagrangian model to compute sulphur dioxide and sulphate atmospheric concentrations, a model was developed to simulate the transport of sulphur into and out of the Arctic basin. The model showed a strong late-winter inflow from Eurasia and a Canadian Arctic concentration maximum in March-April.

The summer field study of atmospheric nitrogen near Nobleton, Ontario, showed that the night-time formation of aerosol nitrate often occurs simultaneously with nitrogen dioxide maxima. This occurs probably as a result of the conversion of nitrogen dioxide to aerosol nitric acid.

Measurements from the Chemistry of High Elevation Fog (CHEF) program have shown that the pH values for precipitation are considerably higher than for fog water. Typical mean pH values for precipitation at two sites were: 4.25 compared with 3.82 for fog water at 860 m; and 4.32 compared with 3.71 for fog water at 970 m. For 3 sites at the same altitude (approximately 900 m) but at different latitudes, ozone measurements have shown that, during the growing season from May to September, the mean percentages of hours with concentrations greater than 50 parts per billion (ppb) were 20, 14 and 7% and the corresponding seasonal means were 40, 34 and 30 ppb. There is a regional uniformity in the occurrence of ozone episodes in southern Quebec, but the mean duration of the episodes and the mean magnitude of the concentrations decrease from the most southern site to the most northern.

(ii) Toxic Chemicals. The Gas and Particle sampler was used during two field studies to determine the gas-phase and particle-phase distribution coefficients of selected toxic organochlorine compounds. In the first study at Niagara-on-the-Lake, Ontario, measurements were made to investigate compound concentrations as a result of off-shore and on-shore breeze conditions. Compound concentrations were very low and in the region of sub-nanograms per cubic metre. In the second study in the Turkey Lakes region of Ontario, measurements of the same target compounds were made; the data should yield a washout ratio for the compounds.

The Dunphy (New Brunswick) field trials of spray drift were completed for a variety of wind speed, stability and aircraft-height scenarios. The total deposition (and hence drift) was strongly correlated with the "effective" release height of the spray cloud as determined by the aircraft height and the vortex lifetime. The lidar capabilities were enhanced to allow for the rapid mapping of the spray cloud from release to eventual deposit. The rapid-fire scanning lidar system is capable of giving a 4-m vertical by 1-m horizontal resolution of the spray cloud up to 1 km downwind from the spray line.

(iii) Climate Change. Canada's first permanent research station for continuous monitoring of background air pollution was opened at Alert, N.W.T., on August 29, 1986 as one of the stations in an international network for the study of the long-term effects of pollution on the atmosphere. The concentrations of pollutants that may originate from major North American industrial regions will be measured as well as their changes with time.

The weekly carbon dioxide flask sampling data from Alert, Sable Island and Cape St. James yielded an average annual increase in carbon dioxide concentration of about 1.3 parts per million (ppm) and an average 1985 concentration of about 345 ppm.

The Arctic Gas and Aerosol Sampling Program at Alert during April studied the transport of pollutants into the Arctic. The first measurements of Arctic haze showed haze levels that were higher than those measured in 1985 and that were continuously increasing during the four-week study.

(iv) Core Research. The Differential Absorption Lidar (DIAL) for measuring vertical profiles of ozone and sulphur dioxide has been extensively tested in order to optimize its sensitivity, which is 10 parts per billion (ppb) in 200-m increments to 2.4 km.

A technique using long-path spectroscopy was devised to measure nitrous acid in parts per billion (ppb). The method has a sensitivity of about 10 ppb and work to improve this is in order, since ambient levels are expected to be about 10-100 times less than this.

(v) Air Quality Services. A workshop on "Air Quality Response to Accidental Releases of Hazardous Substances" was organized to review the state-of-the-art in modelling for nuclear accidents and for heavy gas dispersion, response packages for chemical spills, acquisition of weather and air quality data and emergency preparedness.

(d) Canadian Climate Centre

(i) Hydrometeorology. The application of micro-electronics to improve hydro-meteorological data collection methods continues. Unattended operation of the AES standard rain gauge (type B) proved feasible but prototype testing determined the need for improved robustness. A potentiometer-based weighing precipitation gauge interface to an on-board data logger was successfully tested.

Various satellite rainfall estimation techniques were evaluated for their ability to determine daily, weekly and monthly precipitation. Current emphasis is on combining satellite, radar and conventional climatological station data to give better estimates of climate parameter fields.

Procedures for estimating probable maximum precipitation (PMP) and particularly applicable to Canadian conditions and datasets were developed.

Work in marine icing and winds, funded through the Panel on Energy Research and Development (PERD), included development of a vessel icing dataset for Canadian waters containing over 7000 reports, development of an icing model suitable for drilling platforms and offshore structures, and monitoring of icing on east coast drilling units. Wind gusts and profiles over oceans, and the spatial and temporal coherence of marine wind observations were studied.

In marine climatology, contracted studies funded by PERD produced a comparative climatology of 11 offshore drilling areas throughout the world, along with climate variability off the Canadian East Coast. Marine climatological atlases were produced for the Great Lakes and for the Canadian West Coast. A comprehensive review of procedures for extreme value analysis was also funded. A handbook containing descriptions of meteorological and oceanographic conditions associated with typical East Coast storms was produced as a guide to mariners and people involved in offshore operations.

Surge and wave models were adapted and implemented on a PC to assist in forecasting Great Lakes water levels.

Development of an ultrasonic snow depth sensor for use at remote or unmanned stations neared completion; field tests indicate that its accuracy is  $\pm 2$  cm compared with the conventional ruler's accuracy. Arrangements are being made to license its production. The sensor is being tested for application to the water level measurement of streams.

Three test sites were installed as part of the WMO Solid Precipitation Measurement Intercomparison in which fifteen countries are participating. Canadian methods of measuring snowfall (both manual and automatic) will be tested against an international standard.

The production of national maps and tabulations of water budget parameters and drought indices continued for the weekly monitoring of hydrometeorological impacts. Studies were completed on the development of snowmelt equations for specific regions and on the feasibility of estimating evapotranspiration from satellite data.

Continuing projects include: automating hydrometeorological measurements; measuring snowmelt and snowpack chemistry at Dorset, Ontario; and testing algorithms for determining snow water equivalent/depth from microwave passive data (see CGB, 1985).

(ii) Climate Applications and Impacts. New work included implementation of CLASP, a system for analysing historic climate data and development of a microcomputer-based system for modelling wind flow over specified terrain features.

Reports of studies published included several on the impacts of climate change on the Great Lakes and on energy consumption, a catalogue of storms affecting offshore areas,

analyses of a variety of proxy climate datasets in the Hudson Bay area, an analysis of the relationship between weather patterns and forest fire hazard, and a bibliography of publications dealing with offshore climate.

(iii) Monitoring and Prediction. Subjective monthly and seasonal experimental forecasts of temperature and precipitation anomalies continue to be produced routinely. An objective method has been developed to produce a hemispheric 50-kPa monthly height anomaly field (and the associated surface temperature anomaly field) from a specification of the anomaly at a small number of points at arbitrary locations. The method is based on the application of historically derived empirical orthogonal functions to define spatial relationships. It will help to prevent the prediction of improbable patterns and is expected to lead to an improvement in forecast scores. A hindcast experiment is being carried out to see if the experimental forecasts for 1985-86 would have been improved if the real-time subjective 50-kPa prognoses had been processed through this special spatial filter.

Empirical forecast models, based on the Entropy Minimax method, are being developed for monthly temperature and precipitation forecasts through searches for patterns in historical data that are associated with the highest probabilities of particular outcomes. The optimization method that is used to identify the patterns maximizes the outcome probabilities (based on maximum entropy probability estimates) while minimizing the global entropy of the pattern classification. The dependent data set consists of 50- and 100-kPa geopotential height fields, sea surface temperature fields, Canadian surface weather data, and the Southern Oscillation Index, together with derived fields, such as thickness, thickness advection, vorticity, principal component amplitudes, and Fourier amplitudes, all for the period 1946 to 1972. A statistical experiment involving forecasts for a small number of predictands is being carried out. Verification statistics for all the predictands will be produced for the independent data period from 1973 to the present.

(iv) General Circulation Modelling. Major changes to the CCC GCM for simulations of doubled CO<sub>2</sub> is under way including more levels, a higher top at 1 mb, new solar and infrared radiation schemes, interactive clouds, new cumulus parametrizations, a modified gravity-wave drag parametrization and a new hydrology package.

(v) Radiative-Photochemical Climate Modelling. Participation in the ICRCCM (Inter-Comparison of Radiative Codes for use in Climate Models) study continued (see CGB, 1985) to improve the solar and the long-wave radiative transfer codes in the 1-D and the 2-D climate models.

Sensitivity experiments were carried out with a 1-D radiative-convective and photochemical diffusion model to assess the possible effects of anthropogenic trace gas emissions and volcanic aerosols on atmospheric thermal and chemical structures and surface climate by taking into account the thermal inertia of the oceans.

Experiments with a stratospheric 2-D radiative-photochemical-dynamical model were also performed to simulate the anomalous ozone and temperature variations in the southern polar regions during spring.

(vi) General Circulation Diagnostics. The simulated January and July climates that are obtained when the solar forcing and prescribed sea surface temperatures follow annual cycles was compared with those obtained when these quantities are fixed at perpetual January and July values. It was found that the "annual cycle" mode and the "perpetual" mode climates of the model are significantly different.

Results from a study of potential predictability of simulated climate indicated that the model does exhibit "potential predictability" owing to purely internal dynamical mechanisms. A subsequent predictability experiment showed that the major event contributing to this "potential predictability" could be forecast with some skill for an extended period.

Newly developed statistical techniques that look for the "recurrent" component of the model's response were used to analyse the model's sensitivity to El Nino boundary forcing. For both positive and negative El Nino anomalies, the model's recurrent component of the response is confined to a narrow band centred on the equator.



A study of the linearity of the response of the atmosphere to external El Nino forcing based on GCM results indicated that the atmospheric response could not be considered to be linear if the linearization was taken about the zonally averaged state.

The distributions of surface fluxes and stresses over the oceans developed in 12 non-interactive GCM's have been compiled and compared.

The winter and summer season cyclone climatology of the GCM was determined for both the Northern and Southern Hemispheres from a five-year simulation. The results show that the model produces too few cyclones in total. In the Northern Hemisphere, there are too few weak cyclones, too many intense cyclones and roughly the right number of moderate cyclones. In the Southern Hemisphere, there are too few moderate cyclones and the correct number of weak and intense cyclones. Lee cyclogenesis is very weak in the GCM and the movement of lows is not impeded by mountain barriers.

Five years of NMC global operational analyses were compared with five years of ECMWF/WMO data to examine the utility of these data for climate diagnostic purposes. The results suggest that these datasets are able to provide useful data in the extratropical Northern Hemisphere and in the mid-latitudes of the Southern Hemisphere.

A study of the vorticity budget of the Southern Hemisphere based on both GCM output and FGGE data indicates a topographic source of cyclonic vorticity associated with Antarctica and a balance with the more equatorward regions through transient transport.

Nineteen months of global NMC data were archived, spectrally analysed and diagnosed in terms of the zonal and the two-dimensional wavenumbers.

(e) Central Services Directorate

Ice Branch. Ice reconnaissance, data handling and ice forecasting continued substantially as reported in the CGB, 1982; regular iceberg surveillance was commenced in preparation for a future iceberg information service, Ice information services have been enhanced through better use of HF radio facsimile, both for data telecommunications and for the dissemination of information to users. The new Dash-7 was successfully commissioned for operational ice reconnaissance.

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## VII OCEANOGRAPHY

Compiled by: F.M. Boyce

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2. Dalhousie University, Department of Oceanography
3. Bedford Institute of Oceanography, Atlantic Oceanographic Laboratory
4. Bedford Institute of Oceanography, Marine Ecology Laboratory
5. Université du Québec à Rimouski, Département d'Océanographie
6. Oceanographic Sciences Directorate, Fisheries and Oceans
7. National Water Research Institute, Environment Canada
8. Canadian Hydrographic Service, Arctic and Central Region, Fisheries and Oceans
9. National Hydrology Research Institute, Environment Canada
10. University of British Columbia, Department of Oceanography
11. Institute of Ocean Sciences, Fisheries and Oceans
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16. Bibliography
17. Addresses of Reporting Institutes

### 1. Memorial University, Newfoundland Institute for Cold Oceans Science (NICOS)

A four-year gravity mapping program in cooperation with Earth Physics Branch (now Geophysics Division, Geological Survey of Canada), Ottawa, was completed in the waters off the Avalon Peninsula. Quaternary geology and geochemistry, including the structure of complex modern food chains, are becoming a focus of the NICOS earth scientists.

Two major ecosystem studies were launched. The question of the high fish production of cold oceans is the focus of COPE (Cold Ocean Productivity Experiment). This field and laboratory program, with both biological and physical aspects, will concentrate on food chain dynamics as a function of temperature in Conception Bay. Project OPEN (Oceanographic Processes off Eastern Newfoundland) is a multidisciplinary project between physicists, biologists, the seabird group, and earth scientists which will look at the relationship between physical oceanographic parameters and the fishery of northeastern inshore Newfoundland.

Mathematical modeling efforts continued in both physics and biology. Particular focus and success has been in the area of Labrador Current dynamics, coastal circulation, sea ice motion, spatial variation and patchiness in seabirds, plankton and benthos across the Grand Banks, and a paleo-problem involving diffusive loss of seawater and chemical composition in an ancient lake.

### 2. Dalhousie University, Department of Oceanography

During a winter experiment in 1986, a field station was maintained for three months at Martinique Beach, N.S. in order to obtain nearshore measurements at the time that both the meteorological conditions and offshore wave environment were being intensively monitored as part of the Canadian Atlantic Storms Project (CASP) (A.J. Bowen). A substantial data set was obtained.

Analysis from the two Canadian Coastal Sediment Study field experiments continued. J. Doering has been studying the non-linear coupling between waves as seen in the bispectrum. R. Tatavarti has been looking at problems of reflection across all frequency bands and J. Haines has been examining the low frequency motion.

A survey of sediment transport models that might be applicable to the Scotian Shelf has been completed and we have been looking at data taken by the Atlantic Geosciences Centre (Dr. C. Amos) to try to further evaluate the adequacy of existing models.

Main interests include the dynamics of flow through straits and deep ocean mixing problems (C. Garrett).

M. Bormans, Garrett and K. Thompson continued their study of the flow through the Strait of Gibraltar. B. Toulany (BIO), B. Petrie (BIO) and Garrett have completed their interpretation of flow fluctuations in the Strait of Belle Isle. D. Gilbert and Garrett are calculating the rate of vertical mixing in the deep ocean due to the breaking of internal waves reflected off a sloping bottom. J. Shepherd (Lowestoft) and Garrett have completed their analytical study of radioactive waste dispersal from a deep sea source, allowing for geochemical scavenging. M. Bowers (BIO) and Garrett have proposed a survey of the scientific and other issues related to deep-sea dumping of radwaste. Y. Andrade is working with B. Topliss (BIO) and Petrie on the analysis of I.R. imagery from satellites. P. Galbraith is working with D. LeFaivre (DFO, Quebec) on the analysis and interpretation of oceanographic current meter and thermistor chain data from the St. Lawrence Estuary. K. Drinkwater (BIO) has submitted a Ph.D. thesis on the response of St. Georges Bay to meteorological forcing.

Research centred on nearshore processes and on near bed turbulence and currents on the continental shelf. Both topics involve study of sediment motion as well as water motion (D.A. Huntley).

Analysis of turbulence measurements from within 0.5 m of the sea bed in depths of 25 m and 45 m on the continental shelf off Nova Scotia has suggested a new technique for estimating sea bed stresses, and shows that the bottom stress due to a mean flow is greatly enhanced by the presence of waves. Although the results are in fair agreement with existing theoretical predictions, there is evidence that the theory underestimates the influence of waves even in the relatively mild conditions studied.

D. Hanes (U. Miami) and David Huntley are using new suspended sediment sensors to study sediment suspension by waves in the nearshore zone and the resulting sediment transport. Initial results from the first C<sup>2</sup>S<sup>2</sup> experiment at Pte. Sapin in 1983 used an optical sensor, and analysis is now underway using data from an acoustic profiling sensor which was deployed at Stanhope Lane during the second C<sup>2</sup>S<sup>2</sup> experiment in October, 1984. These sensors are revealing unexpected features in the processes of sediment suspension, as well as providing confirmation of previously untested hypotheses.

The influence of low frequency edge wave motion on nearshore beach shape is likely to depend strongly on the degree of coupling between the edge wave modes. D. Huntley finds strong evidence for mode coupling in some of the U.S. Nearshore Sediment Transport Study data. J. Haines is developing an objective analysis technique which should quantify this mode coupling from the second C<sup>2</sup>S<sup>2</sup> experiment at Stanhope Lane, P.E.I.

An analysis of low-frequency variations of the Labrador Current, evident in long current meter records from the seaward side of Hamilton Bank, and the role of Ekman pumping over the North Atlantic has been completed (Thompson, Lazier and Taylor, 1986). Plans are currently underway to obtain more reliable estimates of transport variability using bottom pressure gauges during a joint BIO/DAL field program to be mounted in the Labrador Sea, July, 1987 - July, 1988 (K.R. Thompson).

J. Middleton and Thompson have now completed the development of the method for estimating return periods of extreme events from short spans of data (Middleton and Thompson, 1986). Work also continued on sea surface temperature variability along the eastern seaboard of U.S. and Canada and its relationship to fish recruitment variability (see references).

F. Schwing and Thompson are studying subtidal circulation variability on the Scotian Shelf and have started to analyse data from CASP (Canadian Atlantic Storm Program). Thompson has also developed some simple models to elucidate the addition of time dependent, wind-driven shelf circulation to the arrested topographic wave solution of Csanady.

S. Todoroff is completing an analysis of BIO bottom pressure data from the Labrador Shelf in an attempt to understand the role of wind forcing on shelf circulation in this region.



### 3. Bedford Institute of Oceanography, Atlantic Oceanographic Laboratory

#### (a) Ocean Circulation Division

Many hours of humidity flux data using a Lyman-Alpha system were collected throughout October and November, 1986, as part of a major international program in the North Sea aimed at collecting high quality atmospheric boundary layer data for parameterizing humidity flux over a wide range of atmospheric conditions (HERMAX) (S. Smith).

A new observational program in the Newfoundland Basin was initiated in April/May with a joint Ocean Circulation (A. Clark)/Chemical Oceanography (P. Jones and D. Wallace) cruise to investigate the circulation of the waters in this region. A large scale grid of hydrographic stations was occupied to collect temperature, salinity, oxygen, alkalinity, total carbonate, nutrient and freon data in order to trace the southward flow of North Atlantic Deep Water from Flemish Cap through the Newfoundland Basin and around the Southeast Newfoundland ridge into the North American Basin. In addition, seven current meter moorings were set across the axis of the North Atlantic Current near the Newfoundland Seamounts (A. Clarke). These moorings were to be recovered in summer and fall of 1987 and should provide estimates of the mean and eddy statistics of the velocity fields in this region. Finally, the frontal zones between the North Atlantic and Labrador currents were mapped using the Batfish system. This mapping will be repeated in winter and fall of 1989 in order to compare the frontal structures during periods of low and high fresh water content of the Labrador Current.

During a one-month cruise of the R.V. Endeavor (University of Rhode Island) a microstructure probe (EPSONDE) was used to collect temperature and velocity microstructure data in the upper 200 m of the water column, as part of a multi-vessel, multi-institutional investigation of the response of an oceanic front to atmospheric forcing (FASINEX) (N. Oakey). The preliminary analysis of similar microstructure data collected in the Canary Basin during 1985 for the study of a decaying MEDDY has shown that a vertical nitrate flux estimated from EPSONDE turbulent dissipation estimates is consistent with that estimated from biological uptake requirements.

The Labrador Ice Buoy Program was continued for a second winter (G. Symonds). A few days after the first set of beacons had been deployed in a line running offshore of Nain, a period of offshore winds moved all the beacons and the ice into the central Labrador Sea where the ice quickly melted and the beacons failed. Following this event, it took several weeks for the ice to refreeze to a sufficient distance offshore to make a second deployment of beacons feasible. It is processes of this type and their effect on the annual ice extent that this program seeks to describe and understand. At present, a Hibler type ice model driven by observed meteorological fields and an imposed heat flux into an upper mixed layer is being used to look at both the seasonal cycle of ice distribution and its interannual variation (M. Ikeda). A two layer coastal circulation model driven by wind stress and buoyancy flux is being developed for the Labrador Shelf and this will eventually be coupled to the ice model (M. Ikeda).

The Hamilton Bank current meter line was expanded this year to include a large scale bottom pressure array which will be used to examine the response of the shelf waters to meteorological forcing (D. Wright). The multi-year temperature and velocity records collected since 1977 are giving valuable information on the annual and inter-annual variability of transport and water properties (J. Lazier). This information and its interpretation was particularly valuable in a study this year aimed at understanding the variation of inshore cod catches in northeast Newfoundland.

A pilot program to determine the processes that result in anomalously warm waters in summer over the Southeast Shoals on the Grand Banks of Newfoundland was started during 1986 (J. Loder). Moorings were set and recovered to monitor the water temperature and currents at a few levels and locations over the heating season. A number of hydrographic surveys were also carried out over the shoals by AOL, MEL and Newfoundland Fisheries.

An extensive wave array was deployed as part of the Canadian Atlantic Storms Program (CASP) (F. Dobson and W. Perrie). The wave data obtained from these deployments will be valuable for the development of new wave models. WOTANS (Wind Observing through Acoustic Noise) were also deployed during this experiment in order to evaluate their potential as wind speed measuring instruments.

Finally, an exploratory mooring and hydrographic program was continued in Baffin Bay for describing circulation and quantifying its strength and variability in this region (C. Ross).

#### (b) Coastal Oceanography

A field survey in the Hibernia region of the Grand Banks was completed; the data are being analyzed to study mixed-layer development and current variability (C. Tang). A new project to study the marginal ice zone off the Labrador coast was initiated jointly with scientists from RADARSAT, C-Core, Scott Polar Research Institute, Jet Propulsion Laboratory and Alfred Wegener Polar Research Institute (C. Tang). Two articles based on data from the Canadian Arctic were completed. One deals with Barrow Strait and the seasonal variation of transports through the Strait while the other deals with the nutrient flux for ice biota during the spring bloom (S. Prinsenberg).

The oceanographic component of the Canadian Atlantic Storms Program (CASP) was conducted on the Scotian Shelf east of Halifax from December, 1985 through March, 1986. Measurements include moored current meter and bottom pressure, coastal sea level along the Nova Scotian coast, directional wave spectra, marine surface winds and aerial surveys of the boundary layer. Preliminary editing and archiving of the data have been completed. In addition, analysis of cross-shore variations in the near-surface wind field at the land-sea boundary has been published (P. Smith). Surface current fields were also measured by HF radar near the N.S. coast during CASP. From a preliminary examination of data from only one storm, on average the surface current directions were to the right of the wind, but by  $60^\circ$  which is considerably greater than the  $20^\circ$  used in many of the simpler drift models. It appears possible to simulate the surface current amplitude by using about 2% of the wind speed (D. Lawrence).

The in situ particle characteristics in Bedford Basin, Nova Scotia Shelf and Slope and Skagitt Bay have been investigated. Plankton Camera photographs have confirmed the universal importance of large, fast settling, aggregated particles including macro-flocs of diatoms (K. Kranck).

Studies of the climatology of the Gulf of St. Lawrence have continued. Variations in the temperature of the deeper waters of the Gulf appear to be related to events at the edge of the continental shelf. The annual Gulf ice forecast cruise continued one of the longest unbroken oceanographic time series available for the Gulf area (G. Bugden).

Numerical modelling has been developing on several fronts. A model of the Newfoundland Shelf and Flemish Cap shows how the barotropic Labrador Current interacts with topography. An idealized two layer model indicates how stratification plays a part in guiding the current along the shelf edge. A two dimensional model with imbedded interactive profile is being used to model CASP currents (D. Greenberg).

Time development of a model of the tides on the Newfoundland Shelf during 1986 has been completed. Computations were made for the five principal constituents  $M_2$ ,  $S_2$ ,  $N_2$ ,  $K_1$ , and  $O_1$ , with excellent agreement for the amplitude and phase of the tidal elevation and currents where data availability allowed intercomparison (B. Petrie).

The AOL image analysis system was fully operational and received software upgrades of both its software systems. Up to twenty different users (excluding demonstrations) have been using the system for oceanographic studies; the NOAA imagery archive has been maintained and now covers the period up to the end of 1986. Regional studies of the optical properties of the open Atlantic, Arctic regions and Newfoundland Banks have also been completed. Satellite images of high sediment areas were processed and used for optical model development (B. Topliss).

An analysis of the stability properties of the Nova Scotian Current has shown it to be susceptible to baroclinic instability. Model results have been successfully compared to satellite IR imagery for length scale, propagation speeds and growth rates of wavelike features seen in the coastal temperature front (B. Petrie).

Collaboration with European and American research groups on development of next generation wave models continued, with actual implementation of BIO in early 1987. The shallow water

extension to a Canadian wave forecast model from the 1970s was shown to be competitive with European models in comparisons using real and hypothetical data. Theory for nonlinear transfer due to wave-wave interactions and wind input energy continues, guided by the outstanding data set obtained in the Canadian Atlantic Storms Program (W. Perrie).

#### (c) Chemical Oceanography

A new project, based on laboratory experiments and field surveys, on metal behaviour in Nova Scotian estuaries was started in 1986 as part of a larger international effort to investigate the processes influencing metal distributions in estuaries (P.A. Yeats and J.A. Dalziel). Chemical analysis of trace metal samples from the 1985 cruise to the Scotian Shelf is underway and some initial interpretation of the results has been done. The accumulated knowledge on trace metal distributions in eastern Canadian coastal waters has been summarized with the intention of describing the general distribution of metals in our coastal waters (P.A. Yeats and J.A. Dalziel). Work on trace metal samples from the Fram 3 and CESAR ice camps has been completed and additional samples were collected at an ice island in the Arctic Ocean (P.A. Yeats).

An intercalibration exercise for trace metals in marine sediments has been completed for, and on behalf of, the International Council for the Exploration of the Sea (ICES) (D.H. Loring). This exercise was designed to evaluate the suitability of various dissolution/extraction procedures used for determining the total, partial, and weakly-bound metal concentrations in marine sediments, and to assess comparability of analytical results among 24 laboratories in Europe and 16 in North America. A study indicated that the inability of the participants to reach inter-laboratory agreement on total metal concentrations appears to be due mainly to the use of inadequate atomic absorption procedures and the failure of most laboratories (>50%) to use reference materials for intra-laboratory quality control.

The first of three cruises in the Newfoundland Basin was undertaken to investigate mixing between the Labrador Current and the North Atlantic Drift and to determine the age of water in the Western Boundary Undercurrent using several tracers. During this cruise freons were measured for the first time using a new semi-automated analytical system (E.P. Jones and D.W.R. Wallace). The shelf region north of Ellesmere Island was again studied through measurements made from an ice island (E.P. Jones). Preliminary interpretation of the data indicate the water column to be similar to that at the same depths in the central Arctic Ocean. The aggregate results point to a degree of mixing between the halocline water and the underlying Atlantic layer, suggesting the water north of Ellesmere Island is older than that in the central Arctic Ocean. Interpretation of data from the CESAR Ice Camp and various cruises in Fram Strait (between Greenland and Svalbard) has led to an assessment of the atmosphere-ocean CO<sub>2</sub> transfer as well as of the ventilation of the deep water and of total new biological production in the Arctic Ocean basin (E.P. Jones).

Investigations of technetium-99 and caesium-134 were continued in the West Greenland current in order to determine both the progression of the radionuclide plume from the Sellafield Reprocessing Plant in the U.K. and the consequences of Chernobyl fallout on radionuclide inventories in the North Atlantic Ocean (J.N. Smith and K.M. Ellis). Analyses of sediments have been completed in the study of the dispersion and in-sediment mixing of plutonium accidentally released into the environment at Thule, Greenland. The Point Lepreau Environmental Monitoring Program continued and included investigations of a small leak at the station in early 1986. Studies of Chernobyl fallout were also conducted to distinguish between fallout from the Chernobyl accident and local releases from the Pt. Lepreau Nuclear Generating Station (J.N. Smith and K.M. Ellis). A dynamic model was developed for the transport of particle-associated radioactivity through the Saguenay drainage basin that can be applied to many chemical substances (J.N. Smith and K.M. Ellis). A detailed depositional record for the 19th Century has been resolved from Pb-210 and particle size analysis of sediment piston cores. The vertical distribution and chemical identity of PAHs in dated sediment cores from the Saguenay Fjord has also been examined (E.M. Levy and J.N. Smith). The results clearly demonstrate the major inputs have been from the aluminum industry with both riverine and atmospheric processes involved in dissemination of the PAHs.

Measurement of Pb-210 and fallout radionuclides in sediment samples collected in arctic and west coast fjords continued and are used in conjunction with a model predicting suspended particle transport and deposition in a fjord (J.N. Smith and K.M. Ellis). Projects on fluxes and temporal variability of elemental and isotopic composition of organic carbon from the St.

Lawrence River (F.C. Tan and R. Pocklington) and on stable isotope paleoclimatology of Lake Melville, Labrador (F.C. Tan) have been completed.

Other work has included studies of organic matter transport from the Rhone River into the northwest Mediterranean (R. Pocklington) and activities related to the development of international regulations and safety assurance of sea dumping of radioactive and other wastes (J.M. Bowers).

(d) Ocean Technology

The Laboratory continued an active program in the development of sensors and related platforms (A.S. Bennert, J.G. Neisureault), Survey and positioning systems (N. Cochrane, D. McKeown), and sampling methods (G. Fowler).

4. Bedford Institute of Oceanography, Marine Ecology Laboratory

Investigations continued into the physical oceanography of Hudson Strait and Ungava Bay with a detailed field program undertaken to study the water mass characteristics in Ungava Bay (K.F. Drinkwater). The observed vertical stratification of the water will be compared with predictions from a published numerical tidal model to determine the effects of tidal mixing and the possible importance of local freshwater runoff. In central Hudson Strait a current meter and subsurface tide gauge array was deployed which will be recovered in late 1987. The year long time series will be used to investigate the variability in the outflow from Hudson Bay and Foxe Basin.

Archived temperature and salinity data from the Grand Banks region off Newfoundland have been compiled and monthly averages by sub-areas have been determined. A similar undertaking for the Scotian Shelf region off Nova Scotia is underway (K.F. Drinkwater and R.M. Trites).

An overview of environmental conditions in the Northwest Atlantic during the previous year was prepared for the Scientific Council of NAFO to aid in the interpretation of fisheries and related biological data. In addition, an examination of the monthly means at a station at the mouth of the Bay of Fundy was undertaken (K.F. Drinkwater and R.W. Trites).

Studies on the dynamical response of St. Georges Bay, Nova Scotia, to wind forcing are nearing completion. They have shown a strong coherence of both along-bay currents and temperature in the near-bottom waters with local wind stress estimates. A description and interpretation of the Bay's response to particular wind events have also been undertaken (K.F. Drinkwater).

Analysis of current meter, CTD, turbulence and nutrient data from an experiment on Georges Bank conducted in 1985 is continuing (E. Horne). A strong nitrate-temperature correlation was found from the water samples collected on the cruise. This correlation was used to predict the nitrate flux onto Georges Bank using the temperature and velocity data from the current meters. The magnitude of this flux is consistent with levels of primary production found on Georges Bank.

In order to determine the extent to which results from boundary layer experiments can be used to model turbulence processes at the ice-water interface, an experiment was conducted at Resolute in April to measure for the first time turbulence spectra and mean velocity profiles to within a few millimetres of the ice-water interface (E. Horne). Preliminary analysis of the mean velocity profiles from a subset of the data indicates that, at times, the nondimensional thickness of the linear region of the velocity profile is considerably larger than predicted from laboratory studies of neutrally buoyant, smooth-walled boundary layer flows. Initial results from spectral analysis suggest that spectra of horizontal velocity fluctuations in the viscous sublayer at the ice-water interface contain considerably less energy than expected from studies of laboratory flows.

Field investigation in 1986 on the role the Gulf Stream system plays in the entrainment, transport, and diffusion of larval and juvenile short finned squid, Illex illecebrosus, was focused on the area off the east coast of Florida where major spawning is thought to occur (R.W. Trites).

Studies on sea surface temperature variability in the Northwest Atlantic, using 30 years of archived data from the Climate Analysis Center, Asheville, North Carolina, have continued. Effort was directed as well to an investigation of the role that fresh water discharge may play in modifying sea surface temperature and salinity (R.W. Trites in cooperation with K. Thompson, Dalhousie University, and R. Loucks, Loucks Oceanology Ltd.

##### 5. Université du Québec à Rimouski, Département d'Océanographie

###### (a) Hydrodynamique des estuaires et des zones côtières

Quelques 150 images thermiques prises par les satellites NOSAA-7 et NOAA-9, entre mai et septembre, 1984 et 1985, ont été traitées et analysées pour une étude synoptique détaillée de la variabilité spatio-temporelle des phénomènes physiques rencontrés dans l'estuaire maritime et la partie ouest du golfe du Saint-Laurent. À l'interprétation, les images révèlent une grande complexité de structure thermique à la surface dans la région d'étude. Ceci est particulièrement vrai pour les zones plus fermées ou étroites tels les détroits, les baies, ainsi que dans l'estuaire maritime. Lorsque confrontées avec des données de vent, de phases de lune et de débits d'eau douce, les données-images nous permettent d'associer les zones de remontées d'eau froide, les fronts et l'évolution des différentes nappes d'eau avec des processus météorologiques ou astronomiques (Lavoie et al., 1985; Lacroix et al., 1985).

À l'aide des images satellites, de mesures de courants et de CTD, M.I. El-Sabh a continué en 1985-86 son programme de recherche sur la dynamique et les processus de mélange dans l'estuaire maritime du Saint-Laurent. En effet, les résultats obtenus démontrent que l'estuaire est sujet à de larges perturbations à l'échelle de 10 à 16 jours et alterne entre deux modes de circulation. Le premier mode est caractérisé par la présence de deux nappes d'eau froide à chacune de ses extrémités, une nappe d'eau plus chaude dans la zone au large de la péninsule de Manicouagan et par plusieurs gyres et fronts de densité latéraux dont le front froid de Pointe-des-Monts. Le second mode dénote deux masses d'eau distinctes séparées par un front longitudinal à mi-estuaire. La moitié sud de l'estuaire apparaît plus froide que la moitié nord. Le front à l'embouchure de l'estuaire, avec une périodicité d'environ 11 jours, résulte d'une remontée d'eau froide induite par des vents à traits dominants de l'ouest le long de la côte entre Pointe-des-Monts et Pointe-aux-Anglais.

Au cours des deux dernières années, M.I. El-Sabh, en collaboration avec madame B. Côté de l'INRS-Océanologie, ont amorcé une étude des caractéristiques physiques et biologiques de la région sud-ouest du golfe Saint-Laurent, faisant partie du plateau madelinot. Les objectifs de ce programme de recherche sont d'étudier les fluctuations d'abondance et de composition des larves de poissons en relation avec les caractéristiques physiques et trophiques du milieu. Dans cette perspective, deux thèmes de recherche retiennent notre attention. D'un côté, il s'agit de définir les caractéristiques physiques et biologiques à moyenne échelle (spatiale et temporelle) du milieu qui déterminent l'environnement écologique global où se trouvent les larves. En particulier, l'existence de structures physiques "dissipatives" auxquelles sont associées des hétérogénéités biologiques retient notre attention.

Pour la première fois, nous avons pu observer directement l'impact de l'arrivée de la crue printanière du fleuve tant sur le système biologique que sur le système physique (Côté et al., 1986). L'arrivée d'eau douce produit la formation d'un front dont les caractéristiques physiques sont bien définies. Associé à ce front, nous avons trouvé une hétérogénéité biologique aussi très marquée. Nos résultats suggèrent fortement que l'impact écologique de l'arrivée de la crue printanière du fleuve se manifeste par des effets très directs (e.g., création de fronts) en plus des effets indirects (e.g., influence trophodynamique).

En 1985-1986, notre étude s'est poursuivie par un travail de terrain visant à comparer de part et d'autre d'un système frontal, la trophodynamique larvaire. Étant donné que les caractéristiques physiques à moyenne échelle du milieu définissent l'environnement global où se trouvent les larves, leurs proies et leurs prédateurs, il est important d'étudier à l'intérieur de ces différents environnements les interactions trophodynamiques susceptibles d'affecter la survie des larves. Ainsi, au cours de la mission de juillet 1985, suite à une étude à grande échelle qui consistait à faire des prélèvements à dix stations positionnées le long d'un transect préétabli, deux stations fixes ont été choisies pour leurs caractéristiques hydrographiques différentes (zone mélangée versus zone stratifiée) et une étude comparative de



la structure verticale des communautés planctoniques (phyto-zoo-ichtyoplanctoniques) des deux stations fut entreprise. Nos résultats suggèrent également que les tempêtes de courte durée peuvent augmenter la mortalité larvaire en réduisant d'une part, la disponibilité de nourriture et, d'autre part, en transportant les larves dans un environnement moins approprié pour leur croissance. La fréquence de tels événements, en conjonction avec la phase du cycle larvaire à laquelle ils se produisent, pourrait être responsable de la variabilité locale du succès reproductif des populations de poissons.

(b) Méthodes statistiques appliquées à l'océanographie

L'objectif de ce programme poursuivi par J.P. Chanut est de développer des méthodes optimales de collecte d'analyse et de modélisation de données expérimentales et de les appliquer au milieu marin.

Les recherches portent sur: (1) les méthodes d'échantillonnage considérées comme prérequis à toute analyse conséquente des données; (2) les analyses statistiques multidimensionnelles dans un but essentiellement descriptif; (3) la modélisation des séries chronologiques dans un but prévisionnel.

L'élaboration de plans d'échantillonnage aléatoires optimaux en milieu stratifié améliore considérablement l'estimation des caractéristiques du milieu et de leur distribution spatiale. Les méthodes optimales en analyse statistique multidimensionnelles ont permis de mieux faire ressortir la structure, généralement complexe, les interrelations et, dans plusieurs cas, l'évolution des caractéristiques du milieu marin contenues dans de grands ensembles de données. La modélisation stochastique des séries de données océanographiques, dans le domaine temporel, a permis de prendre en compte des variations non cycliques et a fourni des modèles ayant une interprétation physique immédiate et utilisable directement pour la prévision.

6. Oceanographic Sciences Directorate, Fisheries and Oceans, Ottawa

The Ocean Sciences Affairs Branch provides a focus for the establishment of national and international policies, programs and priorities for the physical and chemical oceanography and marine contaminants programs of the Department of Fisheries and Oceans. In 1986, staff participated in Federal R & D programs such as the Energy R & D Program, the Canadian Climate Program, the Northern Oil and Gas Action Plan, the Unsolicited Proposal Program and the Environmental Studies Revolving Fund. National coordination of the DFD Science Subvention Fund which supports university research in the marine sciences was also provided, and the Branch continued to administer the Ocean Dumping Control Act Research Fund which supports R & D for problems related to the disposal of wastes and dredge spoils at sea.

The Branch continued to provide assistance for the technological development of the Fluorescence Line Imager (FLI). Aircraft-deployed FLI evaluation trials have demonstrated the instrument's capability to monitor chlorophyll concentrations in the ocean, and more data will be gathered in 1987 for input to the west coast salmon survival project linking primary productivity with fisheries management. The FLI is now on loan to Canadian industry for applications development and marketing, both nationally and internationally.

On the international side, the Branch provided coordination for DFO participation in the Intergovernmental Oceanographic Commission. Of particular interest to Canada are the Commission's programs in ocean climate, marine pollution, and ocean sciences. With regard to ocean sciences for example, the Canadian input of real-time subsurface temperature and salinity data to the Integrated Global ocean Services System (IGOSS) approached 2500 messages in 1986, representing an increase of 1300 over the past two years. In addition, the Branch continued to be the focal point for DFO participation in the London Dumping Convention, where such matters as the international control of the disposal of low-level radioactive wastes at sea and the incineration of wastes at sea are currently under debate.

The Marine Environmental Data Service (MEDS) archives oceanographic data collected off Canada in the northeast Pacific, Arctic and northwest Atlantic Oceans and carries out wave climate studies in support of offshore industrial development. MEDS has also been designated as the responsible National Oceanographic Data Centre for the collection and archiving of global drifting buoy data. This will be an increasingly important function over the next



decade as the major global oceanographic experiments of the World Climate Research Program come on stream.

The Information and Publications Branch (IPB) provides the national focus for fisheries and oceans scientific and technical information. It produced and distributed about 14,000 printed pages last year including the widely-read monthly Canadian Journal of Fisheries and Aquatic Sciences. IPB is also the input centre for the Aquatic Sciences and Fisheries Information System sponsored by the Food and Agriculture Organizations (FAO) and the Intergovernmental Oceanographic Commission.

## 7. National Water Research Institute, Environment Canada

### (a) Physical Limnology of Connecting Channels

Lake St. Clair, the western end of Lake Erie (influenced by the Detroit River), and the entrance to the St. Lawrence River, have been the sites of intensive field experiments in 1985 and 1986. These studies were coordinated with U.S. investigators. In addition to delineating the flow fields, the experiments focussed on sediment resuspension and transport. In Lake St. Clair, the background sediment flux is about  $18 \text{ mg m}^{-2} \text{ s}^{-1}$ . Daily averages of this transport during storm events are as high as  $200 \text{ mg m}^{-2} \text{ s}^{-1}$ , while peak transports during severe storms may attain values of  $20 \text{ mg m}^{-2} \text{ s}^{-1}$ . Surface wave-induced orbital motion is thought to be the principal agent of resuspension (P.F. Hamblin, F.M. Boyce, C.R. Murthy).

Numerical model calculations based on Ekman theory for finite water depth were performed on Lake St. Clair in order to assess the relative effects of wind-driven and hydraulic flow. These were tested against vertical profiles of current, fixed current meter moorings, and satellite-tracked drifters (P.F. Hamblin, W.M. Schertzer, T.J. Simons). Modifications to the conventional Ekman formulation were introduced to provide more realistic simulations of current near the bottom. A novel, efficient verification procedure compared hydrodynamic model output against the output of a Box-Jenkins type statistical model (T.J. Simons, W.M. Schertzer).

Hydrological water balance calculations were conducted on Lake St. Clair to determine the magnitude of the major exchanges with other parts of the system. A numerical hydrodynamic model was used to compute changes in water level, and various formulations of wind stress and bottom stress were evaluated (T.J. Simons and W.M. Schertzer).

Simultaneous measurements of waves, suspended solids, and sedimentation rate were collected on Lake St. Clair (M. Skafel, P.F. Hamblin, F.M. Boyce). The wave measurements were used to test some commonly employed statistical wave models (W.M. Schertzer). Wave forecasts will be input to a resuspension model as part of an overall simulation of sediment transport in Lake St. Clair (P.F. Hamblin, W.M. Schertzer).

### (b) Reservoir Modelling

A one-dimensional dynamic simulation model has been further (and successfully) tested on data from Lake Laberge, a typical example of a large northern storage reservoir. The model has been extended to include suspended sediments and dissolved oxygen and applied to a large Central European lake (P.F. Hamblin).

### (c) Canadian Climate Program

Climate effects on lake stratification cycles were investigated as part of the NWRI commitment to the Canadian Climate Program. Models of the surface energy balance components and one-dimensional temperature distributions were developed and applied to Lake Ontario and Lake Erie over the climatological period 1953 - 1983 (W.M. Schertzer).

### (d) Niagara River

Based on extensive modelling and field experiments it is shown that the one-way transport across Lake Ontario is ten times as large as the hydraulic flow induced by the Niagara River - St. Lawrence River throughout. Assuming that the Niagara River water mixes thoroughly with

the eastward moving stream, then it follows that 90% of its inflow must be recirculated in Lake Ontario. Based on average flow speeds and the dimension of the basin, the recirculation timescale is 60 days. The distribution of contaminants in the sediments of Lake Ontario confirms these circulation features (C.R. Murthy and T.J. Simons).

(e) St. Lawrence Estuary

Four, 36-hour anchor stations were carried out in the upper estuary of the St. Lawrence River during which measurements of current, temperature, salinity and suspended sediment concentrations were made. Analysis of the data revealed that the principal mechanism for upstream suspended sediment flux that contributes to the estuary's turbidity maximum is through the action of tidal pumping which is counter to the bottom advective flux. A numerical model of the suspended sediment concentration over depth and several complete tidal cycles indicated that asymmetry in the vertical diffusion of sediment due to the presence of the salt wedge in the flood is the main contributing factor to the tidal pumping mechanism (P.F. Hamblin).

(f) Waves and Air-Water Interactions

The joint NWRI Woods Hole Oceanographic Institution project on breaking waves and wave-generated turbulence completed a second phase in December, 1986. The analysis of selected cases has been reported (Donelan and Kahma, 1986). Particular emphasis is being placed on exploring the differences between observed velocities and those induced from wave height through linear theory (see also Connecting Channels Study).

In the second phase, an additional observational system was incorporated by scientists from the U.S. Naval Research Laboratory (Washington, D.C.). The system consisted of four microwave scatterometers in the C, Ku, and Ka bands that measure the radar reflectivity of the wind-roughened water surface as a function of wind direction (relative to the radar pointing direction), water temperature, wind speed, and the slope of the long waves.

A third and final phase of the experiment is planned for the fall of 1987 (M.A. Donelan, M. Skafel, I. Tsanis).

The shallow water wave experiment of 1985 in Lake St. Clair has yielded an excellent data base for examining the effects of bottom dissipation. This experiment was conducted jointly by NWRI, the Atmospheric Environment Service and the U.S. National Oceanic and Atmospheric Administration (Great Lakes Environmental Research Laboratory). The data have been analysed to produce frequency and frequency direction spectra and various schemes for interpreting these results are being followed by a team from the three organizations (M.A. Donelan, M. Skafel).

Laboratory investigations of vapour transfer of various environmental contaminants (or suitable surrogates) are being planned. The design of a 32 m by 0.6 m by 1.0 m closed wind - water tunnel is complete and construction will begin in 1987. Vapour transfer experiments will begin in late 1987. The role of breaking waves in augmenting this transfer is of particular interest (M.A. Donelan, N. Merzi).

(g) Instrumentation

A current and temperature profiler intended for shallow water dominated by wave orbital motions was tested. The electromagnetic current meters proved to be insufficiently accurate to provide estimates of current shear, possibly due to progressive biological fouling. A second profiler, employing vector-averaging acoustic current meters is under evaluation. These instruments have been equipped with a microprocessor that calculates the variance and covariance of the two components and the number of zero crossings in each measurement period, in addition to the conventional vector-averaged components (J.A. Bull).

8. Canadian Hydrographic Service, Central and Arctic Region, Fisheries and Oceans

Under contract with private industry over the past three years, the Canadian Hydrographic Service (CHS), Central & Arctic Region, has developed a Through Ice Bathymetry System (TIBS). TIBS is a helicopter mounted system, towing a boom, which contains electromagnetic transmitting and receiving coils, 30 metres above the ice or water surface. The equipment measures the

points where the conductivity changes, in particular the air/ice, the ice/water, and the water/bottom sediment interfaces, by measuring the amplitude and phase shift of a secondary electromagnetic (EM) field induced by the transmitting coil.

The airborne electromagnetic (AEM) system can rapidly and accurately cover a larger survey area, can work over ice or open water, is not constrained by optical qualities of the water column or bottom sediment, and can measure maximum depths in excess of 100 metres.

The 1987 CHS program will use a second generation TIBS system for a bathymetric survey in Pelly Bay, N.W.T. area, during April (G. Macdonald).

#### 9. National Hydrology Research Institute, Environment Canada

The two branches of the National Water Research Institute in the west, the Western and Northern Region group and the Pacific and Yukon Region group, have been amalgamated. They now form part of the National Hydrology Research Institute which was relocated to Saskatoon in 1986. Physical limnology research is conducted as part of the activities of the Surface Water Division.

The experimental work on sediment transport and under-ice physical processes in Lake Laberge, Kluane Lake and other lakes in the Yukon has been completed. Analysis and synthesis of the data collected are continuing (E. Carmack).

The study of sediment resuspension in shallow prairie lakes has continued. Current emphasis is on mixing processes and the further development of the horizontal suspended sediment sampler for use in riverine systems (B. Kenney).

#### 10. University of British Columbia, Department of Oceanography

##### (a) Physical Oceanography

Studies of the dynamics of fjord estuaries, led by S. Pond, are continuing; recent work has focussed on the generation and propagation of internal tides in Knight Inlet (A.J. Webb, Ph.D. thesis, 1986) and on the role played by the internal tide in deep water exchange in Indian Arm (B. deYoung, Ph.D. thesis, 1986). A major program of numerical modelling and measurements funded under the NSERC Strategic program, which will build on the above results, is now underway.

The circulation in the Strait of Georgia has been the object of intensive study and the results from an array of moorings have shed new light on the dynamics and vorticity balance of fluctuations in the periods of days to months. A study of deep water renewal in the Strait of Georgia and of its interannual variability has also been completed by P.H. LeBlond and M.Sc. student F. Doherty.

Research on the larger scale circulation in the North East Pacific is being conducted by numerical methods by L.A. Mysak, W. Hsieh and Ph.D. student P. Cummins. The generation of Rossby waves by fluctuating winds in that area has also been investigated numerically (Cummins et al., 1986). Relations between mesoscale variability and salmon migration routes have also been sought (Hamilton and Mysak, 1986; Mysak et al., 1986). W. Hsieh is using a three-dimensional finite difference model forced by windstress and surface heat fluxes to study interannual variability and its influence on sockeye salmon returns. Observational studies of North East Pacific circulation are planned by W.J. Emery and P.H. LeBlond, using deep-drogued drifters. M.Sc. student J. Ukita has studied in some detail the statistics of a previous set of drifter tracks.

Ongoing wave studies led by P.H. LeBlond include theoretical work with Ph.D. student D. Masson on the growth of a wind wave spectrum in a field of scattered ice floes, using a third generation wave growth model. M.Sc. student D. Egles is working on the development of a self-propelled, sun-powered instrumental buoy and its performance in a realistic wave field. This work is performed with Sea-Buoy Ltd. of Sydney, B.C.

The ocean remote-sensing laboratory, led by W.J. Emery, has continued to be very active, with application to the analysis of sea-ice motion (Ninnis et al., 1986), the computation of advective surface velocities from infrared satellite imagery (Emery et al., 1986) and the relation between phytoplankton distribution and hydrographic properties (Thomas and Emery, 1986). Images have been provided to government and industry scientists in a number of collaborative projects.

Collaboration with the Institute of Ocean Sciences goes on in a variety of projects. S. Pond and Ph.D. student S. Hill are collaborating with D. Farmer on the use of acoustic techniques for measuring directional wave spectra. P. LeBlond co-supervises Ph.D. student R. Dewey with W. Crawford on instrumental studies of turbulence in the bottom boundary layer, and M.Sc. student B. von Hardenberg with D. Topham on small scale modelling of circulation induced by salt rejection during ice formation.

(b) Chemical Oceanography

S. Calvert is conducting a survey of the chemical variability of ferromanganese nodules and crusts from throughout the Pacific. The rare earth element geochemistry of nodules from two small survey areas of the northern equatorial Pacific has been shown to be governed by the balance of metal supply from diagenetic and bottom water sources (with D.Z. Piper, USGS, Menlo Park, CA). The work on the geochemistry of Black Sea sapropels has been extended to include accelerator radiocarbon measurements of several cores in order to derive carbon accumulation rates and a refined chronology of sapropel formation, and the determination of the organic carbon isotope composition to identify carbon sources. Detailed chemical studies of some Mediterranean sapropels have also started (with M. Fontugne, Centre des Faibles Radioactivités; Gif-sur-Yvette, France). The settling and burial fluxes of organic carbon are being measured in two B.C. inlets using moored arrays of particle settling traps in order to compare and contrast the preservation of organic matter under oxic and anoxic conditions. A study of the diagenetic mobility of molybdenum from buried mine tailings in Alice Arm, B.C. is nearing completion (A. Loshner). Work on the relationship between the solid-phase and pore-water behaviour of metals in coastal sediments has continued (C. Jones) and studies of the role of the humic fraction of nearshore sediments on the geochemistry of the halogens, sulphurs and trace metals are nearing completion (R. Francois).

T.F. Pedersen's research interests include diagenetic reactivity of mine tailings in marine and lacustrine environments, diagenesis of halogens and trace metals in hemipelagic sediments, sulphur speciation and pyrite formation in meromictic lakes, and palaeoceanography, specifically using isotopic ( $^{13}\text{C}$  and  $^{18}\text{O}$ ) and geochemical measurements to study the Quaternary history of circulation and productivity, largely in the eastern equatorial Pacific.

B. Boudreau joined the department this fall as a University Research Fellow. He is doing mathematical modelling of geochemical systems, with emphasis on sediment-water exchange and mass transport in porous media.

11. Institute of Ocean Sciences, Fisheries and Oceans

(a) Fjords and Narrow Channels

The main activity in this area is concentrated on improving understanding of mixing and its relation to flow and stratification. Field work combining direct microstructure measurement techniques with acoustic velocity mapping was carried out in both vertically mixed and stratified situations. A new acoustic technique for measuring total transport across a channel was developed and tested and commercialization begun.

(b) Continental Shelves

An array of 16 current meter moorings (operating over the past year) covering the outer continental shelf in the Beaufort Sea was recovered, but many of the current meters had failed to record properly. A numerical model of vertically integrated currents on the Beaufort Sea shelf was completed. It provides results which are consistent with available observations of the current system response to atmospheric forcing. Strong westerly winds set up a coherent pattern of flow towards the east, with a concentrated jet flowing into Amundsen Gulf east of

Cape Bathurst. When the wind stops, the flow breaks down into an incoherent regime of small scale features. An exploratory field program was conducted in the inshore Beaufort Sea, in preparation for a 1987 NOGAP study of the transport and behaviour of natural hydrocarbons entering with Mackenzie River water.

Field work on the Pacific continental shelf was limited to several surveys and a few moorings in a 10-year project to study interannual variability of ocean conditions on the La Perouse Bank area and related variations in biological systems. In addition, a number of satellite tracked drifting buoy deployments were made in cooperation with the Canadian Coast Guard, to improve understanding of the drift of disabled vessels and/or survivors. The B.C. Shore Station program of daily samples for climate monitoring also continued. Interpretation of earlier data covered all parts of the coast. Numerical models showed that tidal rectification could account for the semi-permanent, eddy-like features found in Dixon Entrance and west of Cape St. James. Satellite images relayed to research vessels in near real-time were used to direct biological sampling programs to the edges of fronts and jets.

(c) Open Ocean

Four climate monitoring cruises to the site of Ocean Weather Station P (50° N, 145° W) were conducted. Winter surface and mixed layer temperatures in the central Gulf of Alaska were approximately three standard deviations above the 25-year mean in both 1985-1986 and 1986-1987. XBT and CTD data received in near real-time over the IGOS net were used to produce monthly maps of temperatures at the surface and several layers, and a synthetic monthly North-South section for the 140° W - 150° W longitude band.

An array of current meter moorings, sediment traps and transmissometers was installed around the hydrothermal vent field on Endeavour Ridge over the winter of 1985-1986 and a single mooring maintained over 1986-1987, in cooperation with Oregon State University. The plume of warm water from the vent field can be detected on both moored and profiling instruments.

Work continued on the development of ocean basin scale models, including the representation of small scale features. Simplified models were used to study methods of assimilation of data, and to design sampling arrays for large scale experiments.

In collaboration with several U.S. laboratories, a field program was conducted in Gibraltar Strait to examine the processes controlling the exchanges between the Mediterranean and Atlantic, which are different only in scale from those controlling the exchange between a B.C. fjord and the adjacent ocean. The IOS moorings and acoustic survey techniques were important in making this the most successful study of the region.

(d) Upper Layer Processes

Work on the hydrodynamic drag of pack ice pressure ridge keels was continued through a program of laboratory modelling aimed at reproducing the range of phenomena observed in the 1985 field program. Together with the Beaufort Sea current studies, this is aimed at improving prediction of ice motion in the Beaufort Sea.

Wave breaking and bubble dynamics were studied acoustically in local waters and as part of the international FASINEX experiment.

(e) Forecast Development

In cooperation with the Atmospheric Environment Service, Canadian Coast Guard and U.S. National Oceanic and Atmospheric Administration, a meteorological buoy was moored 360 km SW of Vancouver Island. Four buoys are being constructed by a local firm to permit permanent occupation of three sites.

One contractor completed a study of the conditions giving rise to the ten highest sea state events recorded on the B.C. coast which indicated that nearshore modification and intensification of the wind field could not be neglected in any predictive models. Another contractor developed a technique for calculating the effect of currents on the wave field, and combined this with a tidal model to demonstrate that tidal currents would have a significant effect on the wave climate of the Queen Charlotte Sound-Hecate Strait region.



(f) Observational Methods

Passive and active acoustic techniques continued to be explored. Ambient noise measurements obtained under the Arctic pack ice showed a dramatic change in character as breakup approached. Ambient noise wind speed sensors were tested in the CASP experiment and a small, relatively inexpensive ambient noise sensor was developed for use on drifting buoys. A cross channel flow measurement technique was successfully tested and is being commercialized. Acoustic techniques are being used to study wave breaking and bubble behaviour, and mixing processes.

The prototype airborne imaging spectrophotometer or Fluorescence Line Imager was evaluated. It was able to measure water depth, map macro-algae, and determine phytoplankton chlorophyll levels successfully. The prototype has been lent to the company which developed it for demonstrations in North America and Europe.

(g) Tidal and Current Surveys

A study of circulation on the continental shelf off the west coast of Vancouver Island revealed an eddy which traps surface water for periods of a week under favourable wind conditions. Analysis of temperature data from satellites and drifter positions over periods of several days has revealed that the pattern of temperature gradients, rather than the temperature field itself, can be used to determine the surface current field over a very wide region, if images can be obtained over periods of several days. This method is valuable in regions of coastal waters where the cloud cover does not obstruct the images of infrared radiation from the sea surface. (W. Crawford and W.S. Huggett, Institute of Ocean Sciences and W. Emery, University of B.C.).

A Lagrangian modification of an existing one-dimensional model of the Fraser River and its delta has been developed to forecast the motion and residence time of contaminants. For more accurate representation of the current profiles in the lower reaches of the river, the behaviour of the salt wedge is being incorporated into the model. (A. Ages, Institute of Ocean Sciences).

A lightweight, low-power, self-contained tide gauge was designed, built and successfully tested in 1986. This unit is expected to replace the older, antiquated model used at present by hydrographic survey parties. It is a bubbler-type design, stores data internally in solid-state memory, is very rugged and waterproof, and will record data every fifteen minutes for up to six months without attention. A separate radio transmission module may be used to transmit the data to the survey party. (M. Woodward and F. Stephenson, Institute of Ocean Sciences).

A tide gauge being tested at present in the Queen Charlotte Islands uses a meteorburst communication system to transmit the data to the Institute of Ocean Sciences. This system has sufficient range to cover all tidal waters in the province. (F. Stephenson, Institute of Ocean Sciences).

The highest tides ever predicted in the 85 years of existence of the Tide Tables for the port of Victoria, B.C. occurred in December, 1986.

(h) Oceanographic Data Information System

In 1981, IOS began to develop a computer directory for all known oceanographic data in selected Canadian Arctic and B.C. marine waters. The need for this geo-referenced, menu-driven directory has been well established. ODIS (Oceanographic Data Information System) now exists as a geographical information system on the Institute's Sperry 1100/60 using System 2000 Database. A secondary repository for rapid interactive access is an Applications Database on a dedicated MicroVax II computer. On-site and off-site users of terminal and appropriate communications software are encouraged to use ODIS, although a Tektronics 4107 or 4014 terminal is required for map plotting features. The system allows any user to select data stations by geographic area, data type, water depth, year, month, instrument type and data quality rating. The station locations can be plotted on a computer map, and/or the station attributes (collection agency, sampling methods and materials, reference citations, measurement types, concurrent data, etc.) printed as a dataset summary report. At present (January, 1987), ODIS offers directories to Beaufort Sea and Northwest Passage data, including ocean currents, temperature,



salinity, water levels, hydrocarbons, trace metals, nutrients, marine and anadromous fishes; over 12,000 stations can be sorted, mapped and queried for dataset details. In addition, ODIS contains an inventory of 18,000 stations with measurements of currents, temperature, salinity, water levels or waves for Hecate Strait, Queen Charlotte Sound, Dixon Entrance and all other offshore waters to 200-mile limit. These, and other data catalogues published but not yet keypunched into ODIS, are available upon request to those involved in research planning, impact assessment, regulatory review, marine engineering or resource management.

(i) Canadian Hydrographic Service, Pacific Region

Horizontal control networks to support hydrographic surveys were established in the Tofino area, Cumshewa Inlet, the Gulf Islands and along the north coast of Vancouver Island. Several C.G.S. and Provincial monuments were recovered in these areas and new data will be incorporated in the various geodetic data banks.

Differential G.P.S. horizontal control methods were utilized by Terra Surveys Ltd. for the contract surveys of the southern MacKenzie River and the Lidar (airborne laser bathymetry) project conducted in Simpson Strait and Requisite Channel, N.W.T.

Further G.P.S. (Global Positioning System) research, on Optimal Estimators and Receiver Design, was carried out in conjunction with Nortech Surveys Ltd., the University of New Brunswick and the Bedford Institute of Oceanography.

12. Gore and Storrie Limited, Water Resources Division

The Water Resources Division provides research and development of mathematical models and computer programs in areas of water quality assessment. The computer programs are used to assist in the management of water quality and pollution abatement programs (M.D. Palmer).

Recent projects in water quality assessment have required the development of new computer models or modifications of existing code and have included:

(a) Discharge Event Model

One-dimensional and two-dimensional models have been developed to predict the receiving water quality in rivers, resulting from discharges/spills. The program accepts multiple discharges which can vary independently in flow rate and/or concentration.

(b) River Mixing Zone

A computer program has been developed to predict the mixing zones within rivers of both nearshore and offshore diffuser outfalls.

(c) Stochastic River Model

A one-dimensional steady state stochastic river water quality model has been developed to compute the mean values and standard deviations of dissolved oxygen, biological oxygen demand and nitrogenous oxygen demand at any point in a river. The model considers randomness in the initial conditions, sources, rate constants and other model parameters, as well as randomness in each of the modelled processes. At present the computer model is being upgraded to consider nutrients.

(d) RAND Model

Conversion of the RAND 2-Dimensional Dynamic Water Quality Model from its original main-frame version to a user-friendly personal computer version has been completed. In consultation with the original author, the program has been upgraded to allow for three open boundaries and second order advection term. The model has been applied and calibrated for several organism density studies along Lake Ontario beaches.

(e) Current Meter Data Processing Program

A user-friendly program has been developed to process recording current meter data on personal computers. The program performs various time series analyses such as: temperature and speed-direction frequency tables, time series plots, autocorrelation functions and power spectral density distributions.

(f) Drogue Tracking Program

A computer program has been developed to process the data collected from Lagrangian drogue tracking surveys. Displays of the drogue trajectory, dispersion estimates and probable dilution analyses are provided on micro-computers.

(g) Sediment Transport Model

A sediment transport model for the near-shore zone of lakes is under development.

13. Martec Limited

(a) Coastal Processes

A study was conducted for Environment Canada to determine the effects of a 1 m rise in mean sea level on the City of Saint John and surrounding areas, and the consequences for the flooding that occurs each spring in the lower reaches of the Saint John River system.

Studies have been conducted to investigate the hydrographic and oceanographic feasibility of various potential shipping terminals in the Bay of Fundy. Ice obstructions to shipping have been considered during this study as well as vessel draft requirements and tidal influences.

An investigation into the erosion of the banks of the Annapolis Tidal Power headpond (the Annapolis River) has been conducted. Site investigation, analysis of aerial photos, land surveys and analysis of aerial mapping have been employed to estimate past, present and future erosion rates along the river banks in detail.

(b) Seabed Processes

A numerical model of sediment transport, developed for the Atlantic Geoscience Centre, has been employed to compare observed and predicted sediment transport rates. The observed rates were obtained from the radioactive sand tracer study conducted for the Environmental Studies Revolving Funds (ESRF) in 1984-1985. In addition, modifications and improvements to the predictive model have been made and are part of ongoing activity in the area of sediment transport modelling.

During the Canadian Atlantic Storms Program (CASP), under sponsorship of the Environmental Studies Revolving Funds (ESRF), four measurement sites were located along the CASP transect line. The objective of the study was to measure nearbottom residual currents, conduct near-bottom time lapse photography and monitor/measure depth of disturbance indicators which were the main quantitative measuring devices. These consisted of a measuring rod driven into the sea bottom, onto which was placed a washer assembly to monitor variations in sediment behaviour throughout the measurement period. Also, visual observations and photographs taken by divers were a major component of the field work. The sites were located at 20 m depth on sand, 30 m depth on sand, 30 m depth on gravel and 37 m depth on sand. Measured values of erosion throughout the monitoring period were small at all sites. The maximum measured erosion was 97 mm and the maximum accretion was 129 mm. An additional point of interest is that during the monitoring of the measurement sites, divers observed large anomalous depressions in the sandy seafloor that were 10 to 30 m wide and 0.8 to 2.4 m deep with near vertical walls. Photographs and measurements were taken of these interesting and apparently rare features.

(c) Ocean Technology and Other Oceanography

A system has been developed, SUB-C-DAS, which will allow underwater data to be easily recorded and stored in digital form. The heart of the system is a hand-held programmable cal-

culator or computer in a waterproof housing. Data are entered by using a specially designed fibre optic scanner to read bar codes, thus avoiding the problems of manipulating a conventional button keyboard underwater. The principal application is to aid scientific and commercial divers in data acquisition and subsequent data analysis.

Numerical dispersion models have been developed and operated to predict the behaviour of drilling mud injected into the water column. Both steady-state and batch injection of drilling mud and cuttings were investigated for various rates of injection. This study was conducted for Texaco Resources Canada Limited.

#### 14. Oceanchem Group

In the marine environment much of our work involves the environmental aspects of dredging and dredged material disposal. This work is related to applications for permits to dispose under the Ocean Dumping Control Act. The samples are collected by coring and analyzed for Cd, Hg, Cu, Zn, Pb, particle size, oil and grease, carbon, PCB, and DDT's. In 1986 we conducted major pre-dredging evaluations in Saint John/Courteney Bay (NB), and Sydney (NS), as well as post-use disposal site monitoring and evaluation at Georgetown (PEI). Smaller-scale pre-dredging evaluations were conducted at many other sites. All our reports are on file with Public Works Canada, Atlantic Region office of Marine Design and Construction.

In 1986 we continued work on the "Field Verification of Sediment Sampling Guidelines for Pre-Dredging Evaluations", a study being undertaken for Mr. J. Karau, Ocean Disposal Activities Office, Environment Canada, Ottawa.

In late 1986 we began a study of the distribution of pyrethroid pesticides in harbour and estuary sediments of Prince Edward Island for the Habitat Protection Branch, Fisheries and Oceans, Gulf Region (Moncton, N.B.). We have also begun a tabulation and review of all data related to dredging and ocean disposal of sediments from Atlantic Canadian harbours under the management of Transport Canada.

#### 15. Ph.D. Associates Inc.

Ph.D. Associates Inc. specializes in scientific computer application for receiving, interpreting and displaying remote sensing data.

Ph.D. Associates Inc., in conjunction with the Ice Research and Development Branch of the Atmospheric Environment Service (AES), has been conducting research activities into utilizing passive microwave satellite data for the remote sensing of sea ice. The Scanning Multichannel Microwave Radiometer (SMMR) onboard the U.S. NASA NIMBUS-7 satellite has provided the passive microwave data to monitor sea ice on a 24-hour, alternate day, nearly all weather basis.

Over the period 1980-84 sea ice algorithms and accompanying computer generated ice map products (hardcopy and electronic) were developed. Having achieved sufficient confidence in the sea ice algorithms, the need arose to validate the products in various regions at different times of the year and, if possible, to demonstrate the operational use of the product. To achieve this goal, a near real-time data collection, analysis, display and distribution system functioning in an operational mode was developed by Ph.D. Associates Inc. as part of AES contracts.

One of the most promising remote sensing techniques measures winds over the open ocean using granine microwave radiometry from a satellite.

The integration of passive microwave satellite imagery with other data products has the potential of becoming a vital tool for the weather forecaster. The intent of Ph.D. Associates Inc. is to continue to progress this relatively new imagery through the research environment into the applied operational mode. The ongoing development of SMMR algorithms to deduce wind speeds over the open ocean is yielding positive results. Storm tracking using passive microwave data has been verified against weather charts produced by the Atmospheric Environment Service (AES). The possibility of a three hour turnaround time for wind maps makes such an operational wind product system feasible.

The data system described above would still be in full operation today except that the SMMR data are no longer available in near real-time (effective October 1, 1984). However, the SSM/I (Special Sensor Microwave Imager - a radiometer similar to SMMR) is due to be launched on a U.S. meteorological DMSP Satellite in late 1986 or early 1987, and the near real-time data system is planned to become once again fully operational. Upgrades are scheduled to be made to the system to handle the increased data volume (wider sensor swath width of about 1400 km, additional dual polarized 8.5. GHz frequency with increased resolution of 15 km square and daily operation). The SSM/I data may be available on an orbit-by-orbit basis, and by utilizing upgraded hardware the final product should be delivered to the user within three hours of the instrument viewing the geographic region of interest.

The requirements of individual users and the incorporation of their in situ data can be accommodated in the presentation of the final product. Additionally, it should be stressed that hindcast and validation studies using existing user-provided ground-truth data can easily be undertaken since over ten years of historical satellite passive microwave data reside at Ph.D. Associates Inc. These archived SMMR data, combined with existing historical climatological information, represent a wealth of research material which can be used to improve our understanding of air-sea interactions on a global scale. The satellite oceanographic measurements provide researchers with numerous observations from areas not easily studied by traditional measurements.

#### 17. Addresses of Reporting Institutes

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## VIII GLACIER STUDIES

Compiled by: P.G. Johnson

1. Summary
2. Polar Continental Shelf Project and Terrain Sciences Division, Energy, Mines and Resources
3. Surface Water Division, National Hydrology Research Institute
4. Karl E. Ricker Ltd. and Associates
5. University of British Columbia (Queen's University, University of Western Ontario)
6. University of Calgary
7. Memorial University of Newfoundland
8. University of Ottawa
9. Université de Sherbrooke
10. Trent University
11. Waterloo University
12. Wilfrid Laurier University
13. E.T.H. Eidgenössische Technische Hochschule, Zurich
14. Bibliography

### 1. Summary

The routine mass balance studies which for nearly two decades have provided good regional coverage of glacierized regions in Canada have virtually been eliminated due to changes at the National Hydrology Research Institute and at B.C. Hydro. Records which had been one of the world's best continuous sets of information, with increasing value in climatic change studies and resource management, have been seriously interrupted.

Principal investigators of most of the other projects reported over the last few years continued to pursue glacier studies, with some expansion of interest through association with the University of British Columbia (Queen's University and University of Western Ontario) and the return to glacier studies at the University of Toronto (project commencing 1986-1987).

Research on fast glacier flow, glacier hydrology, ice core analysis, glacier fluctuations and rock glaciers has continued, particularly in the Arctic and in the Yukon Territory.

### 2. Polar Continental Shelf Project, and Terrain Sciences Division (GSC), Energy, Mines and Resources. (B.T. Alt, J. Bourgeois, D. Fisher, A. Koerner, M. Parnandi and N. Reeh)

#### (a) Laboratory Work

All the mass balance results for Meighen, Devon & Melville South Ice Caps have been organised for micro-computer storage. Programs have been written to calculate for missing data and to compute basic statistics. All results have been sent to an international glacier data bank. Preliminary work was completed on calculating the mass balance of a theoretical Queen Elizabeth Islands Maximum Ice Cap using present-day values in 3 of the past 25 years that the ice cap would have had a positive balance.

Several samples collected for us by other field parties and expeditions on the Ward Hunt Ice Shelf and the Arctic Ocean were analysed for particulates, chemistry and pollen concentrations in a continuing study of High Arctic air mass circulation and snow chemistry. Bulk samples from a borehole on Agassiz Ice Cap, Northern Ellesmere I., were analysed for pollen concentrations and the results studied with a view to distinguishing between glacial and interglacial ice.

A computer model of the Laurentide Ice Sheet was completed and shows the importance of possible deforming beds. A model study of the ice flow down a ridge leading to a borehole site on the Devon Ice Cap was completed. The study indicates a highly variable depth/deformation relationship along that ridge. The volcanic stratigraphy of 3 Agassiz Ice Cap cores was used to accurately align and date the oxygen isotope and summer melt feature time series.

Borehole closure rates in the 3 holes were related to the degradation of the volcanic signatures in 'dirty' Wisconsin ice.

The regional congruence of present-day vegetation and summer climate patterns in the Queen Elizabeth Islands was studied in cooperation with S. Edlund (GSC) as part of an ongoing evaluation of climate-related variables used in paleoclimate reconstructions. A laser device for measuring microparticle concentrations in 1 ml samples was developed.

(b) Field Work

The mass balance of 4 High Arctic ice caps was remeasured. Samples were collected from the margins of Devon and Agassiz Ice Caps and from the Tuto and Nuna ramps on the Greenland Ice Sheet for oxygen isotope and chemistry analysis. The purpose was to investigate ice flow characteristics by comparison of these results with those from borehole at the top of the flow line at borehole sites. Two further bulk (50 l) samples were melted at depth in an old borehole for pollen analysis. Borehole diameters were remeasured in a hole drilled to bedrock on Agassiz Ice Cap in 1984. Microparticle concentrations in snow and ice meltwater were measured in the laser device noted above. A new strain net was set up to cover all three boreholes on Agassiz Ice Cap in Northern Ellesmere Island. A pilot study was made of wind pumping in the snow at the same locality. Samples were collected in three 2-3 m snow pits to attain a complete view of pollen, particulate and chemistry variations from season to season and from year to year. A levelling profile was made across a small ice cap close to the northwest edge of Devon Ice Cap; when repeated in several years time it will serve to quantify ice cap shrinkage or expansion. This was the third such profile made in three years on different ice caps.

3. Surface Water Division, National Hydrology Research Institute (M. Demuth, G. Holdsworth, A. Letreguilly, O. Mokievsky-Zubok and C.S.L. Ommanney)

Following the move of the NHRI to Saskatoon the glacier research programme has been severely curtailed. Three staff members were lost as a result of the move and their positions were reassigned. A fourth remained in Ottawa. The glacier inventory project has been shelved and glacier field investigations, now limited to three field sites, may be further reduced. All glacier records accumulated over the last 20 years were transferred to Saskatoon, and it remains to be seen what access will be provided to them.

Research on the Mount Logan ice core focused on the extraction of climatic and other atmospheric process information from an oxygen isotope time series covering almost the last 300 years. Data will be included from 1980-1986 as soon as samples are analysed. These were collected in summer 1986, at which time the borehole was relocated for logging purposes. Some preliminary results indicate that volcanic events and the  $S^{18}O$  signature associated with them have climatic implications.

Acid anions have been measured through major volcanic events and significant lags between nitrate, sulfate and the halides were noticed. These data have implications for the study of acid precipitation: acid gas loading in the atmosphere also has repercussions vis à vis climate change scenarios. Analyses are being undertaken by H.R. Krouse and E. Peake of the University of Calgary.

A project on ice core chemistry, in conjunction with D. Raynaud and R. Delmas of CNRS, Grenoble, complements and overlaps with the above. A detailed ion balance was carried out on a section of core to help interpret the chemistry of the core in general. The carbon dioxide content of air bubbles was measured at various depths (ages). Reports on this work will be published in 1987. Major anion analyses, through selected volcanic events, are being carried out by P. Mayewski of the University of New Hampshire. Comparison with Greenland ice core data is planned. Analyses of  $^{210}Pb$  and  $^{10}Be$  are being done by M. Monaghan of the University of Chicago to study the flux of these isotopes and to use them for dating if possible. Sampling includes sites other than Mount Logan.

Although mass balance measurements were discontinued this year on three glaciers in the Bridge River watershed, a Data Collection Platform (DCP) below Bridge Glacier continued its operation, providing meteorological and hydrological data.

Mass balance measurements continued on both Sentinel and Helm glaciers. Although only 10 km apart, within the same elevation range and with the same aspect, mass balance results are persistently different. Sentinel Glacier had a negative balance of -0.32 while Helm Glacier had -1.33 m H<sub>2</sub>O. Meltwater flow measurements at Sentinel Glacier were not renewed after the gauging station was washed away by an October flood in 1984.

Measurements of winter and summer balances and meltwater flow continued on Place Glacier. A slightly below average winter accumulation and a warm summer produced a strongly negative mass balance of -1.31 m H<sub>2</sub>O. This is the tenth consecutive year that Place Glacier has recorded a negative mass balance.

The winter, summer and net mass balances and equilibrium line altitude of three glaciers (Peyto, Place and Sentinel) were compared to meteorological data from neighbouring stations for 1966-1984. Peyto mass balance is almost entirely related to summer temperature, Sentinel mostly to winter precipitation and Place to both. The equilibrium line altitude of the three glaciers has the same correlation with met data as the mass balance. A number of visits were made to Peyto Glacier in 1985 and 1986 to determine the mass balance and to survey the glacier tongue geometry.

#### 4. Karl E. Ricker Ltd. and Associates

- (a) Wedgemount Lake and Glacier, Northern Garibaldi Park, Coast Mountains, B.C. (Karl Ricker; W.A. Tupper, B.C.I.T.)

The phototheodolite survey of the lower reaches of the glacier was repeated at the end of the 1986 melt season. Pronounced recession on the north side of the snout had taken place, whereas the south side continued to hold a near constant position, with calving of icebergs into the lake. The northeast (or Mt. Weart) arm of the glacier was now completely separated from the main arm due to excessive ice melt, and the warm August temperatures produced a higher than normal equilibrium line on the main arm. The entire glacier was phototheodolite re-surveyed from its head from atop Wedge Mountain, on August 15, 1986 thereby replicating the original 1928 survey. Targets set to monitor velocity on the lower glacier were replaced with drilled-in stakes this year so that the ablation could be measured directly as well. The results of the annual surveys are published in each yearly edition of the Canadian Alpine Journal.

- (b) Overlord Glacier, Central Garibaldi Park, Coast Mountains, B.C. (Karl Ricker; W.A. Tupper, B.C.I.T.)

This glacier lies near the resort of Whistler and is easily reached by a well built trail. In 1986 monuments were established to position its snout. A substantial advance of 175 metres from a 1951 position was calculated, of which 76 metres of growth occurred since 1972. Moraines around the glacier were mapped, and age studies of them will be carried out in conjunction with the next snout survey in 1987.

- (c) Tchaikazan Glacier, Pacific Ranges, Coast Mountains, B.C. (Chilcotin District) (Karl Ricker; J. Lixvar, Alpine Club of Canada)

The snout of this glacier was remeasured this year showing yet another large withdrawal of 100.5 metres since the 1982 survey. Adjacent Friendly Glacier was not visited.

- (d) Fyles Glacier and Ape Lake, Purgatory Glacier; Pacific Ranges, Coast Mountains, B.C. (Bella Coola District). (Karl Ricker; Joe Desloges, U.B.C. Geog; British Columbia Forest Service and Ministry of Environment)

On August 2nd, 1986, immediately after Ape Lake had re-filled to full pool level, the second jökulhlaup occurred bringing yet more downstream damage to roads, bridges, forest reserves and salmon spawning beds, as well as debris to litter the oceanic waterway - South Bentinck Arm. The second event took less than 20 hours to again drain the lake to the same low levels as in the first event, and river water levels were distinctly higher during this event which was monitored by a pressure recorder implanted into the lake only two weeks before the outburst. Pilot observations coupled with the notes of downstream logging camp

inhabitants suggest that peak discharge occurred when only 40 to 60% of the total discharge or emptying had taken place. The entire lake and river water course, as well as the silt plume in South Bentinck Arm, was aerial photographed at 1:20,000 scale near the conclusion of the event on the afternoon of August 2. Sedimentological studies of the lake basin were concluded this season and a paper has been submitted by Desloges for publication on this part of the study. Purgatory Glacier, which oscillates wildly at its snout, has again advanced 65 metres between the Oct. 31/84 and Aug. 2/86 observation dates.

- (e) High Runoff Fjords - Suitability for Salmon Net Pen Farming, British Columbia (Karl Ricker; Ministry of Environment, Victoria; Entech Consultants)

In 1986, the success of Norwegian Salmon farming created an "avalanche" of applications for Salmon net pen farm sites for the similar fjord-indented coastline of British Columbia. Rapidly, outer coast accessible sites were taken, more often than not by subsidiaries or joint ventures with Norwegian companies, thereby leaving only other less desirable sections of the coastline for the late comers. In several areas sites were "staked" in major glacier fed "high runoff fjords" bringing about concerns as to their suitability for farm sites because of excessive summer surface water dilution and turbidity. The most critical fjords, where great hopes had been raised by local politicians and entrepreneurs alike, are the Portland Canal - Observatory Inlet area to the north of Prince Rupert, and the Dean Burke Channel system to the west of Bella Coola. Both areas have large ice fields at their heads and both are periodically disrupted by jokulhlaups emanating from Summit and Ape Lakes at present; but by others (as well as potential new ones) in the case of the Portland Canal area. For the Portland Canal system the scant oceanographic data coupled with the spotty river hydrograph records were examined to determine the possible duration, steadiness, and depth of the dilute zone. Follow up field t/s and turbidity measurements supported this cursory analysis, but it was concluded that the discharge of Summit Lake would have an unpredictable, more adverse impact which needed detailed up and down channel as well as river gauge monitoring. Until this is carried out it was recommended that salmon farming should not be undertaken as a commercial venture.

In the case of the Burke-Dean Channel area, the Ape Lake jökulhlaup was monitored by aerial photography (black and white), but because the event occurred during the high runoff season this technique was not totally successful. Further, for days after the event, up inlet winds tended to hold up the down inlet diffusion of dilute turbid water. Future work is in the planning stages.

##### 5. University of British Columbia, Department of Geophysics and Astronomy

- (a) Glacier Studies - Yukon Territory (G.K.C. Clarke, E.W. Blake, F.H.M. Jones, (GPHYS/UBC); J. Shaw (GEOG/Queens); C.C. Smart (GEOG/UWO))

Trapridge Glacier last surged around 1945 and its next surge is expected to occur within several years. The aims of the field study are to determine the cause and mechanics of surging. In 1986 the glacier was resurveyed, 68 holes drilled to the bed, subglacial water pressure was measured, basal and outflow water was analyzed for the presence of a Rhodamine WT tracer, subglacial material was sampled, a new impulse radar was tested, ice structures formed by previous surges were examined and the "slurry till" layer exposed in the lower part of Trapridge basin was analyzed.

- (b) Ice-dammed lakes - Yukon Territory (J. Schmok and G.K.C. Clarke, GPHYS/UBC)

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: (1) Lake Alsek phase (varved silts and clays); (2) Lake Alsek flood deposits (sands and gravels); (3) Normal (organic horizons). This sequence is repeated many times within a single core. Schmok recently completed an M.Sc. thesis on the sedimentology of these cores and the implied lake-filling chronology.

- (c) Radio Echo Sounding - Yukon Territory (F.H.M. Jones, G.K.C. Clarke and B.B. Narod, GPHYS/UBC)

Jones successfully tested a prototype of a digital impulse radar system on Trapridge Glacier in 1986. The system is fully back portable and records sounding results on digital cassettes. Five lines were surveyed for glacier depth. At one site, instrumented with a bottom water pressure transducer, soundings were automatically taken every 20 minutes for 60 hours. Using principal component analysis, Jones is attempting to detect temporal variations in reflection character and relate these to water pressure changes. To guide interpretation of the radar data, Jones has developed a linear system model to study how varying basal debris and water content affect the shape of the bottom-reflected pulse.

- (d) Radio Echo Sounding - Alaska (G.M. Cross, G.K.C. Clarke, and B.B. Narod, GPHYS/UBC)

Research involved a radioglaciological investigation of the ice-filled summit caldera at Mt. Wrangell, Alaska. In April, 1982 the UBC ice-sounding radar was employed along 21 air-borne traverses of the caldera. A well defined vertical sequence of radio-reflections was recorded. The radar stratigraphy is attributed to high-acidity layers deposited during past eruptions at Mt. Wrangell and suggests a significant extension of the volcanic history.

- (e) Isotope Glaciology (M.G. Maxwell, R.D. Russell and G.K.C. Clarke, GPHYS/UBC)

M.G. Maxwell is studying 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  $^{18}\text{O}/^{16}\text{O}$  for ice samples taken from Backe and Trapridge Glaciers, Y.T. The results suggest that: (1) Basal freezing from a permeable substrate leads to accretion of basal ice which is isotopically variable due to basal water isotopic variations or fractionation process variations. (2) Basal and bulk ice have different relationships between oxygen and hydrogen heavy isotopes, but it is not always possible to distinguish between bulk and basal ice if only a few samples are analyzed. (3) Bulk ice is isotopically altered during evolution from precipitation to ice.

## 6. University of Calgary, Department of Geography

- (a) Rock Glacier Study (S.A. Harris and W. Blumstengel)

Rock glaciers are masses of rock debris showing ridges, furrows and lakes. When active, they contain ice in their interior and move down-slope at varying speeds. A vegetation-covered active rock glacier is found on the east side of the Slims River valley six kilometres from the Alaska Highway. It extends from the mountain side to the Slims River and must be traversed by the proposed access road to the Kaskawulsh Glacier. Parks Canada, therefore, requested a study to establish the source of the ice and rate of movement of the rock glacier in order to determine the probable impact of the landform on the road.

In 1984, a long-term study of the rock glacier was begun. It involves using isotopic and neutron probe techniques to determine the origin and dynamics of the upper icy layer, thermistor strings to measure the ground temperatures of the upper two metres, and a survey grid to monitor the state of movement of the lowest part of the rock glacier.

In the summer of 1985, observations were made of the ground temperature and moisture regimes every two weeks. The survey grid was re-surveyed in August, and four short late fall and winter trips were made to obtain further data on temperature and moisture content.

In 1986, temperature and moisture observations were made periodically during the field season while the survey grid was partly re-surveyed. The combined results suggest that the upper layer of interstitial ice is of meteoric origin. The rate of movement is highest in the fronts of the lobes where it may be over 10 cm per year. This is corroborated by live trees being split, by trees being tilted and pushed over, by tilted trees on its surface, and by fresh fissures up to 90 cm in width developing behind the steep 40° front.

Unfortunately, the emplacement of the ground temperature and moisture access tubes involved digging pits and placing tubes in slots cut in the corners. As a result, the thermal



and moisture regimes have not yet recovered to equilibrium with their surroundings and it will probably require two more years of observations to be sure of obtaining a reliable measure of the actual conditions.

- (b) Ice Shelf and Ice Island Studies, (H.R. Krause and M.O. Jeffries, Geophysical Institute, University of Alaska)

Stable isotope analysis of Arctic ice shelf and ice island ice cores continued in collaboration with the Geophysical Institute, University of Alaska. Particular emphasis was on ice cores from an ice island that calved from the east side of Ward Hunt Ice Shelf in 1982-83. Oxygen isotope values show that the entire ice island, and by implication the east ice shelf, is composed entirely of freshwater ice with a mean  $\delta^{18}O$  value of almost  $-30.0\text{‰}$ . This strongly contrasts with the west ice shelf where extensive saline ice strata have  $\delta$  values close to zero (SMOW). This contrast is probably due to variations in water circulation and ice accretion below the ice shelf.

7. Memorial University of Newfoundland, Department of Geography

Torngat Mountain Glaciers (R.J. Rogerson)

The last surface measurements on Superguksoak, Minaret, Abraham and Hidden Glaciers, south of Nachvak Fiord in the Torngat Mountains of Northern Labrador ( $59^{\circ}N$ ), were made in 1984. In each of the years 1981 to 1984, mass balances were negative in most cases (Rogerson 1986: J. of Glaciology, Vol. 32, No. 11, 208-218), and by the end of the summers little snow remained on the glaciers. A helicopter flight over the glaciers in September, 1985 revealed that snowcover from the previous winter was still extensive, right down to the terminus in the case of Abraham Glacier. Mass-balance year 1984-5 would be undoubtedly positive for all the glaciers. A brief visit to the glaciers late in July, 1986 revealed continuous snowcover even over the areas where camps had been established on alpine meadows early in July in previous years. Very large snowfalls may have occurred the previous winter. Summer, 1986 was very warm, but it remains likely that mass balances were also positive for 1985-6. In view of the fact Abraham Glacier continued to readvance from 1981 to 1984, despite negative balances, the mass balance years 1981-4 may not have been typical of recent decades; what has followed may be more typical.

8. University of Ottawa, Department of Geography

- (a) Glaciological and Glacier Hydrological Contrasts & Kaskawulsh Glacier Basin, SW Yukon (P.G. Johnson)

Three small alpine glaciers in a sub-basin of the Kaskawulsh have marked contrasts glaciologically. One is currently surging, one is downwasting and has an extensive ice-cored moraine system, and the third is downwasting without an extensive moraine system. Geological and morphological contrasts between the glacier valleys, causing differences in glacier bed conditions and accumulation/ablation patterns, are being investigated as the possible causes of the glaciological contrasts. Discharge regimes from the three systems are different but are all highly variable. Water release from the surging glacier, disrupted by the highly crevassed nature of the ice, occurs in pulses as channels open through the glacier. Discharge regimes from the ice-cored moraine glacier are dominated by course changes through the moraine, with outburst floods caused by tunnel collapse and course reorientation. The regime of the third glacier is more regular but experiences variability in the early ablation season as the drainage system develops.

- (b) Rock Glacier Formation, Dalton Range, SW Yukon (P.G. Johnson, Diane Lacasse)

All the east-facing cirques and valleys of the Dalton Range have well developed glacier ice-cored rock glaciers. These had a number of periods of activity in the pre-recent period, which it has not been possible to date, and have a number of surfaces which are of recent date, probably from the Neoglacial and Little Ice Age. A 'modern' date has been established for wood from one of the surfaces. There is no evidence from the two rock glaciers studied in detail for any synchronicity of advances.



- (c) Glacier Ice Dammed Lake, Kaskawulsh Glacier, SW Yukon (P.G. Johnson, Jennifer Kasper)

An annually draining ice dammed lake on the margin of the Kaskawulsh Glacier has a history of late summer draining. The lake is filled from the Kaskawulsh Glacier and from a small basin containing three glaciers. The heavy sediment laden water from the basin forms turbidity flows along the lake bed producing sequences of rhymite deposits. Fossil deposits indicate a lake history for the last few hundred years. The lake drains subglacially by floating of the glacier margin. Drainage occurred in September, 1986 over a period of five days.

9. University of Sherbrooke (P. Bail, P. Bigras, A. Champoux, J.-M.M. Dubois, Q.H.J. Gwyn, A. Larocque, G. Larocque, A. Morissette, C.S.L. Ommanney, M. Parent and L. St-Pierre)

Au niveau des glaciers quaternaires, il y a trois sous-projets: Cantons de l'Est, île d'Anticosti et îles de la Madeleine. Dans les Cantons de l'Est, Jean-Marie M. Dubois, Michel Parent, Q.H.J. Gwyn et Pierre Bail (Université de Montréal) étudient la stratigraphie et la géochronologie des lacs proglaciaires ainsi que le comportement de la calotte appalachienne en fonction de la calotte laurentidienne. Deux étudiants au doctorat de l'Université de Montréal y participent, MM. Armand Larocque et Gérard Larocque, ainsi qu'une étudiante à la maîtrise, Madame Anne Morissette, dans la région de Coaticook-Malvina. Une attention particulière touche le lac pré-Champlainien Vermont, spécialement la phase Fort Ann. A l'île d'Anticosti, Jean-Marie Dubois, Q.H.J. Gwyn, Luc St-Pierre et Patrice Bigras terminent une étude sur le comportement des glaciers et des niveaux marins reliés depuis 85 000 ans. Aux îles de la Madeleine, Jean-Marie Dubois et Michel Parent commencent une étude du comportement des glaciers au moins depuis 35 000 ans, mais spécialement lors du dernier englacement.

Au niveau des glaciers actuels, une étude sur la variation du volume des glaciers du parc national de Glacier en Colombie-Britannique est terminée. Un dernier article synthèse, rédigé par André Champoux, Jean-Marie Dubois et C.S.L. Ommanney, sera publié sous peu. Cette étude montre l'évolution des glaciers depuis le Petit Age Glaciaire et leurs caractéristiques physiologiques.

10. Trent University, Department of Geography

White Glacier, Axel Heiberg Island, NWT (P. Adams, P. Doran and M. Ecclestone)

Mass balance measurements were conducted on the lower part of the White Glacier in late August/early September, 1986. All stakes were redrilled to 3 m or more and the measuring cables were cut 1 m above ice surface. The upper half of the glacier will be completed during spring, 1987.

11. University of Waterloo, Department of Geography

- (a) Avalanche Hydrology and Hazard, Kaghan, Pakistan Himalaya (F. deScally and J. Gardner)

The research continued work begun in 1985 under the joint Canada-Pakistan Snow and Ice Hydrology Project to estimate snow/water yields from numerous large avalanche deposits in the Himalayan front range area of Kaghan. In addition to estimation, the research focusses on the development and evaluation of methods for estimation. Data collection includes inventories of avalanche occurrence and monitoring of meteorological conditions. Field mapping of avalanche hazard areas and the development hazard identification criteria for the Himalayan environment continued.

- (b) Hilda Rock Glacier, Canadian Rockies (I. Bajewsky and J. Gardner)

Monitoring of discharge from the Hilda rock glacier continued in the summer of 1986. In addition, suspended sediment load and total dissolved solids were monitored. Together, these data and related meteorological data are being used to make inferences about the internal structure of the rock glacier and the role of the rock glacier in local erosion rates and patterns.

- (c) Rakhiot Glacier, Punjab Himalaya, Pakistan (J. Gardner, E. Mattson and N. Jones)

Research continued during June, July and August, 1986 on margin fluctuations, surface velocities, ablation rates, and sediment yield rates at the Rakhiot Glacier. The research is partially supported by the joint Canada-Pakistan Snow and Ice Hydrology Project. Data from 1986 indicate that the Rakhiot is in a recessional state at present (ca. 5m/yr) and that ablation zone debris cover produced by surface meltout of englacial debris has a strong conservative impact on ice loss. The principal focus of the 1986 research was relationships between ablation, debris cover, and meteorological conditions.

- (d) Snowline and Glacier Margin Fluctuations, Canadian Rockies (J. Gardner, P. Howarth and E. LeDrew)

The purpose of this research is to test the utility of Landsat imagery (hard copy and digital) in mapping extent and fluctuations of high elevation snowcover and glacier margins as surrogate indicators of short-term climatic variability and medium-term climatic variability and change, respectively. Test areas have been chosen in the Canadian Rockies. MSS and TM data are being utilized.

## 12. Wilfrid Laurier University, Department of Geography

Upper Indus Basin Project [K. Hewitt, C. Wake (WLU) and C. David, University of Ottawa]

The upper Indus Basin Project has applied objectives in hydroelectricity development and irrigation water supply, and has involved detailed mass balance, snow study and hydrometeorological observations on a number of glaciers in the Pakistan Karakoram Mountains.

13. E.T.H. Eidgenossische Technische Hochschule, Zurich [H. Blatter (E.T.H. Geog.), M. Funk (E.T.H. Geog.), W. Greuell (I.M.O.U. Utrecht.), G. Kappenburger (E.T.H. Geog.), P. Kasser (E.T.H. Hydraulics, retired), J. Oerlemans (I.M.O.U. Utrecht.) and A. Ohmura (E.T.H. Geog.)].

Analysis and publication of data obtained from the Canadian Arctic continued. Monopulse radar has demonstrated the possible existence of pockets of stagnant ice in bedrock depressions beneath the accumulation zone of White Glacier. Temperature profiles indicate an extended layer of temperate or near temperate ice close to the bedrock near the terminus, and that the temperature distribution is not in steady state. Measurements from the Laika Ice Cap are being used to model the evolution of englacial temperature distributions at a non-temperate location on a glacier.

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## IX HYDROLOGY

Compiled by: E.M. Nicolson

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### 1. Introduction

This report is a compilation of activities on hydrology for the approximate period of August, 1985 to August, 1986. It covers both the research and operational aspects but does not include glacier studies - this being the subject of Chapter VIII of this bulletin. Hydro-meteorology activities are also addressed separately.

#### (a) Major Concerns

Toxic chemical pollution, directly from industry and from landfill sites, continues to be a major concern. Agreement has been reached with the U.S. on the need to reduce toxic contamination of the Niagara River. Discussions with the U.S. on acid rain achieved a breakthrough when President Reagan formally recognized the severity of the problem and agreed to work towards a bilateral accord on transboundary pollution.

#### (b) Major Hydrologic Events

On August 1, 1986 it was announced that the Governments of Canada and the United States have forwarded to the International Joint Commission, a Joint Reference requesting the Commission to examine and report on ways to deal with the problems caused by fluctuating water levels in the Great Lakes-St. Lawrence River Basin. The Joint Reference is in response to the serious problem of flooding in the Great Lakes region that has resulted from an extended period of abnormally high precipitation. The Commission has been asked to examine and evaluate all possible measures, to address the problem of fluctuating water levels on both a short and long-term and to recommend to governments the most practicable means of alleviating the problem. The upper Great Lakes basin received greater than average rainfall during much of the year resulting in the levels of Lake Superior, Michigan, Huron, St. Clair and Erie being all-time highs for the period 1900-1985. Outflows from Lake Ontario have been the maximum possible during this period, giving due regard to the principle of providing "no less protection" to the downstream riparian interests. In contrast, persistent low flows occurred on both coasts during the spring and summer periods. Significant flooding occurred in the central Prairies when the North Saskatchewan River experienced its highest recorded flow.

#### (c) Legislative Initiatives

In 1982, the United States National Conference of Commissioners on Uniform State Laws and the Uniform Law Conference of Canada adopted the "Transboundary Pollution Reciprocal Access Act". Ontario is the first Canadian Province to introduce the elements of this act into its legislation. In February, 1986 the Ontario legislature passed its own "Transboundary Pollution Reciprocal Access Act, 1986". For the first time persons outside of Ontario will have the same rights to relief with respect to injury, or threatened injury from pollution, in the courts of Ontario as an Ontario resident.



(d) Policy Initiatives

In September, 1986 the federal Environment Minister released a national Marine Parks Policy that set the stage for selecting, establishing and managing marine parks in Canada. The long-term goal of the policy is to represent each of Canada's 29 marine natural regions in the national parks system. There are 10 marine regions in the Arctic Ocean, nine in the Atlantic, five in the Pacific and five in the Great Lakes. The policy was approved after several years of research by Environment Canada, and extensive consultation with other Canadian federal and provincial government agencies, the academic community and special interest groups, including commercial fishermen. National marine parks will be established to protect and conserve representative examples of marine environments. They will also offer recreational opportunities to the public and emphasize education programs about the marine environment. The policy permits commercial fishing according to each specific marine park management plan. Navigation and commercial shipping will also continue in accordance with international convention. Environment Canada is currently conducting studies to determine the feasibility of establishing national marine parks in four locations in Canada: the West Isles in the Bay of Fundy, New Brunswick; the junction of the Saguenay and St. Lawrence Rivers, Québec; Lancaster Sound in the Eastern Arctic and South Moresby in the Queen Charlotte Islands, British Columbia.

The federal Fisheries Minister has approved a new policy for the management of fish habitat, which has the objective of increasing the productive capacity of the wetlands and waterways that provide the breeding grounds for Canadian fish stocks. The policy provides a comprehensive framework for the conservation, restoration and development of fish habitats, and presents strategies for the implementation of the various components. The specific objective of the new policy is the achievement of an overall Net Gain of habitat productivity. The fisheries department will strive to balance unavoidable habitat losses with habitat replacement on a project-by-project basis, thus preventing further reductions to Canada's fisheries resources.

(e) Significant Studies

The Science Council of Canada has undertaken an 18 month study on water research policy under the direction of a committee chaired by Dr. R.O. Fournier, Assistant Vice-President of Research at Dalhousie University. The study will determine the key water resource problems facing Canada in 20 to 30 years, consider the research required to address these problems and examine policy and management alternatives.

(f) Federal/Provincial Agreements

The Canada-Ontario Agreement respecting Great Lakes Water Quality was renewed in March, 1986. The 6-year agreement commits each government to providing \$9.6 million for surveillance and \$1.4 million for phosphorus control. Funding for the upgrading and construction of new sewage facilities is also included. The federal government will provide \$9.7 million, Ontario \$14.2 million and municipalities \$25.2 million.

As part of the Canada-Ontario agreement, the federal and Ontario agricultural ministers have agreed to a \$30 million, 5 year Soil and Water Environmental Enhancement Program (SWEEP) with the purpose of reducing phosphorus input to Lake Erie from agricultural runoff by 200 tons/year by 1990. This is in response to a 1983 amendment to the 1978 Canada/US Great Lakes Water Quality Agreement which commits Canada to reducing its phosphorus "input to Lake Erie by 300 tons/year. The remaining 100 ton reduction will come from industries and municipalities. The US is required to reduce its phosphorus loadings by 1700 tons/year.

(g) Publications

Canada's first State of the Environment report was published in May, 1986. It sets out the condition of the farmlands, forests, water, wildlife and other resources, and identifies major factors that will change those conditions. A companion document "Canada's Environment: An overview", summarizes the salient points. It highlights such serious problems as acid rain and the proliferation of toxic chemicals in the environment.

A report on Groundwater Use in Canada was released by the federal Environment Minister in September, 1986. As the first in-depth study of groundwater use across the country, the report is one of a series of steps either already underway or about to be taken to assess and protect

the quality of groundwater supplies. These steps include a follow-up report on sources of groundwater contamination in Canada, initiatives concerning the surface or underground storage of chemicals, co-operative undertakings with the provinces to protect groundwater supplies, and the development of a Canadian groundwater assessment and protection strategy.

The Canadian Council of Resource and Environment Ministers approved publication of the first edition of Canadian Water Quality Guidelines. It will be published in early 1987. As in the United States, Australia, Britain, France and other countries, Canada manages the quality of its water resources by the use of water quality objectives. This new compendium of guidelines will provide a uniform basis for formulating these objectives throughout the various Canadian jurisdictions involved.

#### (h) Research

A centre of excellence for water research has been established by the Canadian Environment department in Saskatoon. The National Hydrology Research Centre will concentrate on problems that are of importance for water conservation and development in the four western provinces and in the Territories. The eastern provinces, and in particular the Great Lakes basin, are serviced by Environment Canada's other world class research institute at Burlington, Ontario; the National Water Research Institute.

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") and two technical subcommittees on specialized areas of hydrology ("Glaciers" and "Hydraulics of Ice Covered Rivers").

The 1985/86 National Lecture Tour, cosponsored by the Canadian Water Resources Association, was conducted by Mr. G.H. Mackay of Manitoba Affairs, PFRA, Winnipeg, on the topic "Hydrology of Droughts".

The 1986 Canadian Hydrology Symposium on "Drought: The Impending Crisis?" held jointly with the Canadian Meteorological & Oceanographic Society at the University of Regina, was very successful and well attended. The Proceedings are available from the NRC Publications Office.

The Design Flood Guide project is scheduled for completion by summer 1987.

The Subcommittee on Hydraulics of Ice Covered Rivers held a fourth workshop in Montreal. The Subcommittee has currently one Working Group - River Ice Jams, and three active Task Forces - Optimal Operation of Hydro Plants During the Winter Ice Regime, Numerical Modelling of River Ice Processes, and Physical Modelling of River Ice Problems.

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). D. MacLeod, Chairman of ACH, will represent Canada on the IHP Intergovernmental Council for a 4-year term. ACH has prepared a four-part report on Canadian participation in IHP III Projects.

ACH is organizing 5 symposia and 8 workshops for the IAHS/IUGG General Assembly in Vancouver, August, 1987. A final program listing all papers, and the Proceedings of the 5 symposia, will be prepublished.

## 2. Federal Government Departments

An Inquiry on Federal Water Policy was appointed in January, 1984 because of a perception that the federal government was not fully equipped to deal with federal aspects of several emerging water issues. These issues include: growing interjurisdictional complexities; the proliferation of toxic chemicals and their impact on various water uses, including drinking water; rapidly increasing water demands in water deficient regions of the country; the deterioration of municipal infrastructure; climatic change; mounting interest in interbasin transfers; and the matter of water export. Following extensive public consultation and

research, the Inquiry concluded that some upgrading of federal legislation, institutions and approaches was called for. It presented 55 specific recommendations in its final report, "Currents of Change", released in September, 1985.

A Federal Interdepartmental Water Policy Task Force was set up to provide the federal Environment Minister with advice on the 55 recommendations and advise on the "scope and nature" of an appropriate federal water policy. The Task Force presented its final report to the minister in July, 1986.

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/Lands Directorate (IW/LD) 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. IW/LD'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 use; and maintains inventories relating to the quantity and quality of surface and ground waters. Much of IW/LD'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.

(i) National Hydrology Research Centre. The \$16.4 million National Hydrology Research Centre was officially opened in October, 1986 by Dr. Gary Gurbin, the then Parliamentary Secretary to federal Environment Minister Tom McMillan. Canada's newest water research facility brings together many of Environment Canada's research units from across the country under one roof, as a centre of excellence for water research. One of the main reasons Saskatoon was chosen as the site for the new centre was the large research community dedicated to water studies already located at the University of Saskatchewan and the importance of water research in Western Canada. Research at this facility will concentrate on those problems that are of importance for water conservation and development in the four western provinces and in the territories.

The new centre houses the National Hydrology Research Institute, formerly located in Ottawa, Winnipeg, Calgary and Vancouver; the regional Water Quality laboratories of Environment Canada, formerly located in Calgary; and the Meteorological Inspection Office of the Atmospheric Environment Service, formerly located near Saskatoon airport. Because of the disruptive nature of such a major relocation a complete specific activity report is not available for the 85/86 fiscal year.

The Institute has three scientific divisions - Surface Water, Groundwater and Limnological Research.

The Surface Water Division focuses on three main areas: watershed (hydrologic cycle) research; river ice research; and glaciological research.

**RIVER ICE BREAK-UP AND ICE JAMMING:** Field studies of break-up and ice jamming along the Liard and Mackenzie rivers have continued. The physical characteristics of thermal and mechanical break-ups have been identified and an ice jam stage-discharge relationship has been defined for the Liard River mouth using the theory of floating equilibrium jams. The importance of hydrothermal heat flow to the decay of ice jams has been established and an analysis is continuing of the importance of atmospheric heat flows to ice melt and decay.

**HYDROLOGY OF MACKENZIE DELTA LAKES:** A lake hydrology study to determine the relative importance of the processes controlling lake levels is continuing in the Mackenzie Delta, N.W.T. The lakes studied span a wide range of sill elevations and therefore different hydrologic regimes. Recent progress has been made on understanding the flow pattern into, out of and through low sill elevation lakes; on determining the sill elevations of a large number of lakes; on quantifying the relationship between hydrologic regime and sill elevation; and on developing a model to predict lake levels. Water balance work has indicated that the high sill elevation lakes are dependent on flooding. Without it they would disappear.

**LAKE REGIMES, MACKENZIE DELTA, N.W.T.:** From 1980 to 1985, baseline data on the hydrologic cycle of lakes and channels throughout the Delta were collected to assess the potential environmental impact of regulation of the main stem of the Mackenzie River. Preliminary analysis suggests that spring break-up is the most significant event. Ice jams, and the resultant backwater flooding during break-up, are essential to the replenishment of the delta lakes. Indications are that regulation would increase the land-to-water ratio and create problems similar to those in the Peace-Athabasca Delta.

**WATER TEMPERATURE AND HEAT FLUX IN ICE-COVERED RIVERS:** Work is continuing on determining the processes controlling water temperature in ice-covered rivers and developing a model predicting both cross-channel and temporal changes in temperature. The convective heat flux from the water to the overlying ice cover has been determined. A number of techniques for calculating heat flux were compared. A major conclusion is that an ice roughness term is required and that the Colburn analogy method was in closest agreement to the measured heat flux.

**SNOW PROPERTIES:** Stereological and topological parameters were derived from sections and serials prepared in seasonal snow samples collected from mountain snowpacks. Computer algorithms were developed to describe specimen microstructure using parameters that correlate with electrical, optical, mechanical and thermodynamic properties. Theoretical models of snow metamorphism and sintering were developed in terms of the section and serial parameters.

**SNOW MANAGEMENT AND MELTWATER INFILTRATION ENHANCEMENT:** A study was initiated in October, 1986 to improve the application and efficiency of snow management techniques for soil water augmentation by increasing infiltration into frozen soils through the use of deep tillage and subsoiling practices.

**LIMITATIONS OF FLOOD FREQUENCY ANALYSIS:** Shortcomings of current practice were described and documented by examples. Results were presented at the International Symposium on Flood Frequency Analysis and Risk, Baton Rouge, Louisiana in May, 1986.

**HYDROLOGIC TECHNOLOGY TRANSFER:** During the past year a number of papers and talks were prepared and presented. They included the following - Hydrological research and the global water supply problem; a possible scenario for the project "Large International Rivers", stochastic hydrology in search of hydrologic content; drought prediction - a hydrological perspective; frustrations at the interface between scientific studies and water resources planning; risk and uncertainty - differences between hydrological and water resources perspectives; and hydrologic aspects of flood frequency analysis.

**HERBICIDE, NUTRIENT AND WATER DRAINAGE FROM AN IRRIGATED FIELD:** A project was initiated in 1986 to determine the amount of irrigation and subsurface drainage following each rainfall and irrigation event. The quality of surface and subsurface drainage water with respect to nutrients and herbicides is being investigated as is the irrigation efficiency with respect to the application of water, nutrients and herbicides. The impact of drainage on downstream flows and water quality is being studied. The project should reveal opportunities for the re-use of irrigation drainage water and the effect of application techniques of herbicides on loss.

The principal research thrust of the Groundwater Division concerns contaminant transport in the subsurface. This is necessarily based on an understanding of the physics of flow through porous media, which is, therefore, a secondary but essential part of this division's research activities.

The Limnological Research Division has been principally concerned with water quality deterioration in lakes and rivers, either as a result of eutrophication or due to the introduction of contaminants, such as mercury or agricultural pesticides and herbicides. Research extends to the examination of the role played by sediments in immobilizing or remobilizing contaminants and to the effects of contaminants on river-dwelling organisms.

(ii) National Water Research Institute (NWRI). The research accomplishments of the NWRI, Inland Waters Directorate, Environment Canada, for the fiscal years 1984/85 and 1985/86 are summarized. The Institute, located at the Canada Centre for Inland Waters in Burlington, Ontario, undertakes original research on freshwater issues of national significance to Canada. The knowledge and expertise derived from its research are communicated to Environment Canada, the Canadian water management community and the general public for use in resolving aquatic environmental problems.

Historically, research at NWRI has been conducted by five research divisions, each with a particular disciplinary or functional role (contaminants, hydraulics, ecology, lake physics, analytical methods). To enhance the integration and flexibility of the Institute's research programs and to maintain economy and efficiency in a time of restraint, a comprehensive Project Management System was implemented in late 1985. Research activities were organized into a series of multidisciplinary projects, each addressing an issue of scientific and managerial importance. Projects will be the focus for planning and managing future research, for developing internationally recognized expertise and for communicating results and their implications to users.

A summary follows of the research and communication highlights of major, "flagship" projects during the review period. New projects, or groupings of projects, which have been implemented for 1986/87 are also briefly summarized. Together, they comprise the core research program that NWRI will undertake over the next several years. Research results from the Western and Northern and Pacific and Yukon regional detachments of NWRI are included here for the last time. Effective April, 1986 these two groups were reorganized as the Limnology Division of DOE's National Hydrology Research Institute, Saskatoon.

**FATE AND EFFECTS OF TOXIC CONTAMINANTS.** To develop control strategies and predictive capabilities for management purposes, the properties, pathways, fate and biotoxic effects of toxic chemicals are being systematically characterized through ongoing laboratory and field experiments. Highlights from the review period include the following:

Research on the fate of chlorophenols in the North Saskatchewan River was undertaken. Anaerobic dehalogenation was shown to be a critical pathway for chlorophenol degradation in this and other systems.

The rate of mercury methylation in sediments of the Qu'Appelle Basin of Saskatchewan was shown experimentally to be controlled, not by the availability of inorganic mercury, but primarily by trophic conditions.

Studies of factors affecting methylation, demethylation and bioaccumulation of mercury by fish in northern Manitoba showed that elevated mercury levels are to be expected following flooding by northern hydroelectric reservoirs.

Toxicity tests using Microtox and octanol-water partition coefficients were found to parallel each other for a wide range of organic chemicals, including chlorophenols, anilines, benzenes, nitrobenzenes and pyridines.

A study to evaluate organic and inorganic contaminant pathways in the Mackenzie River was initiated in response to native concerns and recognized water data deficiencies. Water, suspended and bottom sediments and biological samples were collected under summer flow conditions.

Deformities in Chironomus larvae are being developed as in situ bioindicators to assess the ecological impact of contaminants in the Saskatchewan River Basin.

Formation of organic coatings by colloidal fibrils in lake water was investigated. These fibrils are important for metal specification changes in lake water.



The effects of specific heavy metals on the metabolic activities of natural bacterial populations were evaluated, using populations from Hamilton Harbour.

**CONTAMINATED SEDIMENTS.** To aid the development of site rehabilitation guidelines, the availability, biogeochemical pathways and effects of sediment contaminants from the Great Lakes and smaller systems are being determined. Long-term contaminant release from bottom sediments, which can slow recovery following point-source control, will also be quantified. Highlights include the following:

Bioconcentration factors for chlorinated hydrocarbons by aquatic worms varied with chemical structure and sediment type. The worms selectively accumulate chemicals from the sediments in which they live; this has important implications for fish predators.

Historical changes in the accumulation of pollutant metals since 1910 were determined using  $^{210}\text{Pb}$  dating of lake sediments. Metal deposition rates in lakes from Nova Scotia, eastern Ontario and upper New York State were comparable.

Discontinuities were found in the vertical distribution of suspended sediments in Lake Manitoba. The results have important implications for redistribution of sediment contaminants in large, shallow lakes.

**UPPER GREAT LAKES CONNECTING CHANNELS STUDY.** This ongoing project is developing the knowledge and expertise needed to assess the magnitude of toxic contamination of the upper Great Lakes connecting channels. Contaminant and nutrient sources are being identified and quantified, biological toxicity is being assessed, and models to predict contaminant distribution will be developed. Highlights from the past two years include the following:

A multidisciplinary NWRI team collaborated with the Ontario Ministry of the Environment in an emergency study to determine the nature, chemical composition and specific source of contaminant "puddles" discovered on the St. Clair River bottom near Sarnia, Ontario. The identity and source of the puddles, other contaminant sources along the river and the extent of contaminant transport across the border were determined. As a result, Dow Chemical removed the sediment puddles, eliminated the plant source and developed procedures to minimize future seepage to the river.

A special issue of the Journal of Great Lakes Research was published dealing with pollution of the St. Clair River, Lake St. Clair and the Detroit River. Many toxic chemicals, such as HCBD, HCB and OCS, were identified in the papers. Sources were suggested and pathways of movement, both spatially and into food webs, were resolved. The sources, pathways, fate and effects of tributyltins, alkylleads, many persistent and bioaccumulated organochlorines and volatile organics were also described.

**ST. LAWRENCE RIVER REHABILITATION.** The degree of hazard posed to aquatic biota and humans from toxic contaminants in the St. Lawrence River (and upper estuary) is unknown and the expertise needed for restoration planning had not been developed. Research is undertaken to determine the magnitude, distribution, loadings, principal pathways, fate and biological effects of toxics in the river, as well as the ecological impacts of contaminants at the mouth of the estuary. Highlights from the early phase of work include the following:

An initial cruise from Lake Ontario to Quebec city was made to collect sediment and water samples for a preliminary assessment of contaminant types, distribution and fate.

The surface sediments of Lake St. Louis were surveyed and maps showing the extent and size-distribution of the sediments prepared.

An intensive microbiological study of Lake St. Louis for toxicants and bacterial biomass distributions was undertaken. Over 80% of surface sediments were found to contain toxicants, as determined by the Microtox test.

**LONG RANGE TRANSPORT OF AIR POLLUTANTS.** To improve the information base, expertise and scientific credibility for effective national and international management of LRTAP, a major research effort is in progress to quantify the biogeochemical processes which control the response of lakes and rivers to the deposition of acids and other contaminants in eastern



Canada. Improved expertise in the design, conduct and interpretation of acid rain monitoring programs is also being developed. Highlights include the following:

Sulphur stored in the sediments of the Turkey Lakes was determined, by stable isotope techniques, to occur in the reduced form, mostly as organosulphur compounds. Reduction of pollutant sulphur was shown to be the most important process for the generation of buffering alkalinity.

Low pH stress on natural lake bacteria adversely affects their cellular surface structure, metabolic rates and ability to decompose organic matter.

Waters in the Atlantic Provinces were shown to be the most sensitive in eastern Canada to acid rain.

During spring, short-term acidification of surface waters was shown to be strongly influenced by rainfall. In addition, nitrate deposition was found to be as important as sulphate deposition in influencing acidity during snowmelt.

International Acid Rain Conference at Muskoka Ontario 1985.

Watershed acidification models were developed to assess the aquatic impacts of acid precipitation and to predict geographical areas at risk.

Sphagnum moss was found to be an effective biomonitor of atmospheric metal deposition. The technique is now in use in representative areas across Canada.

**WATER QUALITY METHODS DEVELOPMENT.** In this ongoing project, new and improved analytical methodologies for the measurement of chemical and biological parameters in water, sediment and biota are developed and transferred to Inland Waters/Lands Directorate operational (and research) laboratories. Review period highlights are the following:

Institute staff organized and chaired two international symposia related to microbiological methodology: the International Symposium on Aquatic Microbial Ecology and the Second International Symposium on Toxicity Testing Using Bacteria.

Assistance was provided to the International Development Centre, Ottawa, to design and evaluate a three-continent study on the use of coliphage as an indicator of microbial water quality.

A new method for solubilizing and measuring polychlorinated dibenzo-p-dioxins (PCDD) by a radioimmunoassay technique was calibrated, standardized and used for PCDD screening.

A flow-injection/atomic absorption method for Ca and Mg was developed and transferred to operational use.

A flow-injection/colorimetric method for the simultaneous determination of ammonia, nitrate, nitrite and phosphate was developed and transferred to operational use. This is more efficient and cost-effective than previous techniques.

The traditional molybdate "geo-P" method for analyzing sediment phosphorus was modified to prevent iron (III) interference and to permit estimation of the bioavailable phosphorus fraction by chemical extraction.

A large-volume, continuous-flow extractor was developed to concentrate organic contaminants which occur at extremely low levels in environmental samples. Units are now operational in both the field and the National Analytical Laboratory.

**WATER QUALITY MONITORING AND MODELLING RESEARCH.** Improved methods of data collection, interpretation, synthesis and prediction are required for national water quality assessment. In this project, improved chemical and biological monitoring strategies, data interpretation protocols and water quality simulation models are developed for Inland Waters/Lands Directorate operational use and for interpretation of Great Lakes Surveillance data. Project highlights include the following:

A fundamental new strategy for monitoring and interpretation of toxic chemicals in rivers was developed and transmitted to operational programs in Canada and the United States.

A comprehensive statistical assessment of the Great Lakes Surveillance Program was completed.

A numerical model was modified to assess various phosphorus management options for the control of eutrophication in the four Qu'Appelle fishing lakes.

An atlas of the optical properties of the Great Lakes (photic depth, PAR, etc.) was prepared.

**LAKE AND RIVER RESTORATION.** Federal and provincial water managers require expert assistance in rehabilitating the Great lakes and other regional lakes and rivers from the effects of nutrient eutrophication and macrophyte infestations. Applied, site-specific research is undertaken to establish cause-effect relationships and develop specific remedial plans. Project highlights are the following:

In a joint Inland Waters/Lands Directorate-Industry study of eutrophication in the Thompson River, B.C., experimental flowing troughs were used to determine the combined effects of physical conditions and nutrient flux rates (P and N) on periphyton growth. New generalizations on organic production in rivers, with major implications for water quality management, were formulated.

Sediment dialysis samplers ("peepers") were used to measure regeneration and internal loading of soluble phosphorus to Lake Erie. Fifty percent of the non-apatite sediment phosphorus is potentially regenerated.

Experiments with sediment traps showed that large quantities of phosphorus can be made available by natural resuspension of sediments in the Great Lakes.

Experimental lime treatments to restore eutrophic Frisken and Chain lakes (B.C.) were successful.

Cladophora, a filamentous nuisance alga affecting Lakes Ontario, Erie and Huron, was found to have declined about 50% between 1972 and 1983, due to phosphorus reductions.

Harvesting experiments to control Eurasian milfoil in Buckhorn Lake, Ontario, were completed, and procedures to minimize adverse treatment effects developed.

Analysis of historical data on the recovery of Kootenay Lake, B.C., following severe phosphorus pollution, indicated only slight declines in phytoplankton and no changes in zooplankton, apparently as a result of nitrogen limitation and Mysis grazing. Controversial provincial plans to fertilize the lake by aircraft in an attempt to restore declining fish stocks were thus abandoned.

**NEAR-SHORE; OPEN-LAKE INTERACTIONS.** Point-source pollutants are usually discharged or advected into the near-shore zone of large lakes, a zone that is physically distinct from the open lake. In this project, the physical and sedimentological processes controlling the movement of contaminants between the coastal and offshore zones of the Great Lakes are identified, quantified and modelled. Highlights of this project, which is nearing completion, include the following:

A comprehensive review and several synthesis reports were published on water circulation in Lake Ontario, with emphasis on near-shore coastal zone dynamics and the transport and fate of toxic contaminants in Lake Ontario from the Niagara River plume.

A major monograph on effluent transport and diffusion models for the coastal zone of large lakes was published.

**WATER RESOURCES AND MODELLING.** Management of water resources in its various aspects requires knowledge and understanding of the movements and mixing processes of water, as well as its interactions with land and air. In this project, simulation models are developed to predict

the physical effects of man-made or natural alterations in the environment. Review period highlights include the following:

The MOBED river model was modified to deal with non-uniform sizes of bed material and now simulates "paving" effects. MOBED was applied to Qu'Appelle River data to predict the response of the river to the removal of meander loops.

The RIVMIX model was modified to predict downstream concentrations of some classes of non-conservative pollutants, such as water-soluble, but volatile compounds.

The flow component of the HSPF model was installed on the NWRI computer, calibrated, and used to evaluate the effects of urbanization on water quality and quantity in the Waterford River basin.

**INTER-BASIN WATER TRANSFER.** To develop the interdisciplinary expertise and departmental credibility for effective assessment of future diversions, this new project will systematically identify, and, if feasible, generalize about the physical, chemical and ecological effects of large-scale inter-basin water transfers. The initial focus is on physical processes. Highlights from this subject area are the following:

A five-year study was completed to determine the environmental sensitivity of the large, deep, ice-covered, riverine headwater lakes of the Yukon River to future hydroelectric impoundments and diversions. Baseline descriptions were provided of important physical, chemical and microbiological processes, with emphasis on circulation patterns and ice formation during winter.

Available information on the effects of diversions on river regimes was analyzed and reviewed. Research to develop better models of river dynamics, lake erosion and ice behaviour was recommended.

**FLOODING AND ICE.** To improve ice-jam flood management, this ongoing project will acquire the knowledge needed to develop ice-jam forecasting methods using data on formation, transport and distribution of frazil and anchor ice. Highlights include the following:

Field measurements of ice growth and decay, frazil dam formation and midwinter streamflow in the Yukon River were obtained in collaboration with the Water Resources Branch. Specific factors which may control ice-jam formation and spring breakup were identified.

An improved turbulence model to predict flood levels was developed. The model takes into account changing bed roughness as well as overbank flow.

A mathematical model of ice-jamming was improved so that it can be applied to channels of changing width.

**FRASER RIVER REHABILITATION.** The Fraser River Estuary in British Columbia is an area of environment degradation. In particular, the effects of chemicals used in wood processing require investigation. Pathways of transport, degradation and bioaccumulation of chlorinated phenols and related contaminants in the estuary will be determined and used as "benchmark" models for other contaminants. The knowledge will aid in the design of monitoring programs and the formulation of water quality objectives within the framework of the Fraser River Estuary Management Program.

**AIR/WATER CONTAMINANT EXCHANGE.** This project will determine the extent to which atmospheric loading of toxic contaminants may prolong the recovery of the Great Lakes following point-source control. Data on precipitation already reveal the importance of this pathway. Air/water contaminant flux rates will be determined from laboratory and field experiments and novel simulation models to predict aerial loadings will be developed.

Concentrations of PCBs, alpha-BHC and lindane in rainfall were found to be relatively uniform across southern Canada, east of the Rocky Mountains.

**FATE AND EFFECTS OF PESTICIDES.** This project will systemically determine the pathways, fate and effects of important diffuse-source pesticides. Both laboratory and field experiments, primarily in eastern Canada, will be carried out.

A national survey of the extremely toxic, anti-fouling pesticide, tributyltin, in water and sediment showed its occurrence is related to boating and shipping activities, mainly in harbours and marinas. Sunlight and bacterial degradation are the main factors controlling the persistence of tributyltin, which has a half-life of several months under Canadian conditions.

**NUTRIENT-CONTAMINANT INTERACTIONS.** This new project will evaluate whether the processes of bioaccumulation, biodegradation and sedimentation of toxic contaminants in lakes are controlled by the nutrient status and biological productivity of the system. An understanding of these complex interactions, which could determine the vulnerability of a particular lake to toxic pollution, will be important in the development of future contaminant action plans.

**GROUND-WATER CONTAMINATION.** More knowledge and expertise are required for the effective management of eastern Canadian ground-water supplies contaminated by toxic wastes and biocides. Better sampling, analytical and modelling techniques will be developed to determine the physical and chemical processes controlling the migration and fate of ground-water contaminants. This new project will focus on dump-site contamination in international reaches of the Great Lakes connecting channels and on potential contamination of potable ground-water supplies in the Maritimes.

(iii) **Water Resources Branch.** 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 and Calgary develop and maintain 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 2,100 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 historical streamflow and water level summaries, and an annual series containing sediment data.

It has long been recognized that water data is essential to sound water management and that the efficiency of data collection programs is enhanced significantly by combining networks and by 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 whereby 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. Thence, 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, Environment Quebec 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, 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 5-year program to install satellite data

collection platforms (DCPs) at selected sites to improve monitoring and to provide timely data; to date, 330 DCP's 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 analyse 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 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 Hydrology Division headquarters 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.

(iv) Water Quality Branch. The Water Quality Branch 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, analysing 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. The Branch develops, promotes and provides technical guidance on water quality objectives. A water quality objective is expressed either as a concentration of a constituent or as a description of the body of water. The Branch has recently completed the first report on "Canadian Water Quality Guidelines" for the Canadian Council of Resource and Environment Ministers. It contains recommendations on the levels of water quality suitable for such uses as: aquatic life, raw public water supply, agriculture, recreation and 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. 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.

(v) Water Planning and Management Branch. The Water Management Systems Division of the Water Planning and Management Branch is currently completing calibration of the one-dimensional hydro-dynamic model for hydraulic forecasting of water levels on the Red River between Emerson and Winnipeg. Other applications, such as extending the operational model for the Fraser River below Port Mann, and model construction of the Mackenzie Delta, have been initiated. The development of the Mackenzie Delta model has been in response to a request from the Department of Fisheries and Oceans to obtain the timing and volume of fresh water reaching the Beaufort Sea on all sides of the delta. Collection of calibration data has begun in both cases.

A major part of the development of the Qu'Appelle Water Management Model has been completed. A further review was undertaken of several other similar models that are employed to meet the diverse water management demands in basins such as the Great Lakes and Lake of the Woods.

The Modelling Section has also participated in water quality modelling for the Saint John River. A review of several other water quality models is being carried out with emphasis on applications throughout Canada. Other services include providing comments on model development, such as the unsolicited research proposal for modelling the North Thompson River. The Section is also involved in formatting the use of models and disseminating modelling information. It provides in-house models such as the hydrodynamic model on the PC and mainframe and is consolidating ideas and code in order to produce a non-proprietary ice-regime model.

The Engineering and Development Division undertook a study of the annual runoff in the English River basin.

A number of scenarios related to restoring portions of the canal wall to their original positions on the Richelieu River in the town of Saint-Jean, Quebec, were modelled. The impact on Lake Champlain water levels was determined for one of the scenarios using the Richamp routing model.

A multi-phase research project, directed by the Socio-Economic Division and financed by the Federal Energy R&D program, was initiated in 1981 to investigate the potential water resources impacts of large expansions in the energy sector. Its overall objective is to provide a quantitative assessment of emerging water use-supply imbalances in critical drainage basins within Canada. The results are consistent with the needs of a headquarters-regional Water Use Analysis Program. As part of this project, a river-basin based simulation model of water uses and supplies (Water Use Analysis Model - WUAM) was developed that is capable of identifying the effects of population and economic growth, technological changes and other factors governing future water use and supply conditions. The model covers all water use sectors; municipalities, manufacturing, mining, agriculture and instream uses. Among other features, a sub-model for evaluation of the temporal and spatial variations of irrigation water requirements, based on crop, climatic, soil, operational and other parameters, was also developed. Experimental analytical routines to examine the impacts of price changes on industrial and municipal water uses and the addition of a reservoir simulation component further enhanced the WUAM. Since electric energy generation is another major water use, the present development phase of WUAM considers the construction of a sub-model solely dealing with this activity. This sub-model will analyze and project water needs for electric energy production by hydro and thermal power plants. The WUAM is currently being adapted for use in all regions for examining trends in water use in various river basins and comparing the projected future use to available water supplies.

Implementation of the national Flood Damage Reduction 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, 1986 maps prepared and designations made covered 319 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.



During the year, the Atlantic Region was involved in a wide variety of hydrological activities and a number are in progress again this year. A report overviewing flooding in New Brunswick during the period 1969 to 1985 was prepared. Total annual flood damages were in excess of \$6 million and during the period in question there have been at least 45 lives lost due to flooding. A user's manual documenting procedures to estimate flood flows for Newfoundland was completed based on the Regional Flood Frequency Analysis published in December, 1984. A video on flooding in Nova Scotia was produced and has been used extensively for public presentations.

In view of the importance of groundwater resources in the region and the significant threats to the resource, considerable emphasis has been placed on groundwater hydrology. A report documenting issues surrounding agricultural pesticides and groundwater in Atlantic Canada was prepared. The report prioritizes pesticides based on toxicity, use and mobility in groundwater and provides a basis for future activities in this area. A baseline study of the quantity and quality of groundwater in transboundary aquifers in the Saint John River Valley was completed. The report summarizes the state of our knowledge about the groundwater resources of the area and provides the basis for further work required to obtain strategic information. A report identifying groundwater-surface water interactions in the Winter River Basin, PEI was prepared. The report documents that, while groundwater provides base flow in the Winter River, pumping stresses can induce surface water into the groundwater aquifer.

Three water treatment processes; chemical precipitations, ozonation, and ultra-filtration, were assessed for the Channel-Port-aux-Basques (NFLD) Water Improvement Agreement. The least costly alternative was chemical precipitation, especially when annual operating costs were considered.

The Steering Committee of the Canada/Ontario Flood Damage Reduction program commissioned three major studies under the Other Measures component of the Agreement. One study is in support of developing guidelines for snow hydrology in general, and northern hydrology in particular. Ontario, in the past years, funded a five-phase project addressing various aspects of snow hydrology. This guide will attempt to consolidate the available information and provide the hydrologist with a working tool. The other studies are in support of the Streamflow Forecasting Centre of the Ontario Ministry of Natural Resources. A study was initiated for the development of an Antecedent Precipitation Index (API) to better estimate rainfall excess and flood volumes above a threshold similar to the methods developed by the United States National Weather Service for the northeastern States. A complementary study on drainage basin categorization was also commissioned. The objectives are to perform a literature survey of models used by various agencies, test selected models and make recommendations on their use based on the categorization procedures.

Comprehensive hydrology studies have been initiated for the Niagara region and the Nottawasaga drainage basin for the estimation of design flows at ungauged locations.

Another project commissioned by the Steering Committee was a Regional Frequency Analysis for Ontario Streams. This three-part study was done by Branch personnel in the Region. Volume I, the results of single station analyses and regional analyses using the Index Flood Method, was published in February, 1986. Two additional volumes presenting the results of the multiple regression analyses and the documentation of the single station analyses are to be published in early 1987.

(vi) Conservation and Protection Service. DOE's Conservation and Protection Service is also involved in developing and maintaining the knowledge base necessary for both assessing the significance of environmental threats and devising balanced strategies for preventing and correcting environmental problems. Strategies involve economic measures, public consultation and advocacy and regulatory activities.

(vii) Lands Directorate. The Lands Directorate of Environment Canada has completed a series of case studies providing a national synopsis of wetland loss across Canada. Studies in the Fraser Delta, Montreal area, and the St. Lawrence region are published, and reports are in preparation for Southern Ontario, the Tantramar Marshes of Nova Scotia and for southern Saskatchewan. A national fact sheet was published in November, 1986 and over 16,000 copies have been distributed indicating the significant public interest in wetland conservation issues.

The Directorate has also copublished with the National Atlas of Canada (EMR), a folio of two maps on wetland regions and wetland distribution, entitled Canada's Wetlands, available for sale from the Canada Map Office. The author group for these maps is the National Wetlands Working Group of the Canada Committee on Ecological Land Classification (CCELC). Lands provides the National Secretariat to the CCELC, a federal-provincial steering committee. The CCELC is currently developing for publication a national reference book, The Wetlands of Canada, a national report on The Canadian Wetland Classification System, and a symposium on Wetland Ecology and Conservation, all for completion by August, 1987.

The Lands Directorate has also completed for publication in 1987, two reports on the sensitivity and interaction of wetlands with acid precipitation. A national acid precipitation sensitivity map relating soil and bedrock characteristics with aquatic ecosystems is at press. These activities contribute to the federal-provincial Acid Rain (LRTAP) Program and complement joint Inland Waters/Lands Directorate research on the Cation Denudation Rate model for acid rain effects on watersheds. Acid precipitation sensitivity maps and reports for Quebec and Ontario are at press. A joint Lands-Gov't NWT report for the Northwest Territories has been published.

(viii) Canadian Wildlife Service (CWS). CWS carried on activities to preserve endangered waterfowl habitat (wetlands) in cooperation with provinces. Together they developed a rating system tailored to the needs of the provinces and CWS mandated responsibility. Wetlands were mapped, rated and the data were computer stored for use by agencies involved in planning and environmental assessment. The data were also used in the design of waterfowl surveys to increase federal and provincial efficiency in conducting the programs. CWS also conducted research and surveys on the effects of air and waterborne pollutants on aquatic ecosystems. On the prairies a pilot wetland monitoring program was carried out in cooperation with DOE Lands and the US Fish and Wildlife Service. In British Columbia a feasibility study was conducted in cooperation with Lands to determine the use of LANDSAT imagery in monitoring wetland changes. Sites chosen for the study were the Fraser River estuary, the Columbia River and the interior pothole country. A multi-disciplinary study of the St-Lawrence River resources was initiated and CWS (Quebec) provided info to the studies.

(ix) Parks Canada. 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. As of September, 1986, 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. Designations covering a total of 387 km have been made in Ontario (French River), the Yukon (Alsek River) and in Saskatchewan (Cleanwater River). Another 1,783 km have been nominated for designation.

(x) Atmospheric Environment Service. Activities of the Atmospheric Environment Service (DOE) are reported in Chapter VI, Meteorology and Atmospheric Science.

### 3. Newfoundland

The St. John's office of Acres International Limited continued flood handling studies as a follow-up to 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 were realistically simulated.

### 4. New Brunswick

The Water Resources Planning Branch, Dept. of Municipal Affairs and 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.

In an effort to protect water supply watersheds, the Water Resources Planning Branch is again involved with the production of digital maps covering the watersheds used by Rothesay, Petit Rocher, St-Jacques, St.-Stephen, and Perth-Andover. These maps will be produced by the Maritime Resource Management Service by interpreting aerial photos at a scale of 1:10,000. Various land use characteristics, such as property, infrastructure, forest agriculture, etc., will be identified on these maps. Several studies will be undertaken to prepare the documentations required to designate some water supply watersheds as protected areas under the Clean Environment Act.

An update of the flow duration analysis was carried out at various hydrometric stations throughout the Province. Low flow analysis is not being undertaken at stations with 20 years or more of hydrometric records.

Under the Canada Works program, several projects and final reports have been completed. These include: a review of the 1902 ice jam event in the Province; historical review of ice jam events along the Nashwaak River; extensive survey of cross-sections along the Nashwaak and Tay Rivers; and the development of a watercourse alteration data base.

In the groundwater field, several reports have been commenced dealing with the collation of data and information on nitrate, nitrite and pesticides in relation to groundwater. A study of the surface and groundwater interaction is near completion.

The Branch, in consultation with the Water Well Advisory Board and the Well Drillers Association, has recommended the amendment of the Water Well Regulation to increase the minimum well diameter in order to improve the drought resistance of wells and water supplies. This recommendation was approved and the Regulation was successfully amended.

Activities under the Federal-Provincial Flood Damage Reduction Program continued with flood forecasting activities along the Saint John River.

The airborne monitoring program of snow water equivalent within the Saint John Basin was again carried out. 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 soil moisture content were also performed over several calibration lines.

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.

The New Brunswick Subcommittee on River Ice has been established with members from the N.B. Departments of Municipal Affairs and Environment, Transportation plus Environment Canada and the N.B. Electric Power Commission. The Subcommittee reports to 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 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 comprising university researchers and government representatives.

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 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.

(b) University of New Brunswick

The Civil Engineering Department continued its concentrated efforts in the areas of resistance to flow under ice covered rivers and other river ice processes, including river breakup. Research in the field of river engineering and fluvial geomorphology also continued. Work has been carried out in the field of unsteady flow in estuaries and in association with dam breaks. Most recently, work has begun on the problem on developing and applying suspended sediment rating curves at a particular hydrometric station site.

5. Nova Scotia

The Centre for Water Resources Studies at the Technical University of Nova Scotia completed the fifth year of the Halifax Urban Watersheds Program with monetary support and assistance from NSERC, the Technical University, and cooperating government agencies. A complementary study on the chemistry of bulk deposition and watershed processes was begun with funding from the Donner Canadian Foundation and will continue for three years. Projects regarding chloride inputs to lakes, the effectiveness of erosion and sedimentation control measures, and lake/groundwater interactions were continued during the past year. Research was carried out on water quality in roofwater cisterns, both in Nova Scotia and the Caribbean. Research was also begun on the relative contributions of acidity to surface and groundwater by pyritifous slates. Advisory panels on research and education related to on-site waste treatment, erosion and sediment control, water quality management, and roofwater cisterns were active in preparing research proposals during the past year.

6. Québec

(a) Gouvernement du Québec

Dans le cadre du programme de cartographie de zones inondables le ministère de l'environnement a effectué les études hydrologiques des bassins versants des rivières suivantes: Beaurivage, Jacques Cartier, Malbaie, Du Sud, Bras Saint Nicholas, Batiscan, Ontaritz, Saint-Charles, et ses affluents. Pour le bassin de la rivière Saint-Charles, un modèle régional a été développé et les résultats sont comparés à ceux obtenus par le modèle déterministe du type pluie-ruissellement (HYMO).

Fleuve Saint-Laurent: les études hydrologiques ont été effectuées afin de déterminer des niveaux de récurrences 2, 5, 10, 20, 50 et 100 ans pour les tronçons "Lac Saint-Louis-Varennnes" et "Grondines - Sainte-Anne-des-Monts".

D'autres études hydrologiques qui sont en cours, permettront de développer des modèles régionaux des débits de crue instantanés et les rapports de pointe au sud du fleuve Saint-Laurent.

(b) Laval University

The Geological Engineering Research Group, Department of Geology, has been involved in the following areas:

Groundwater Contamination: field and laboratory studies related to road-salting, sanitary landfill and toxic wastes disposal; monitoring techniques for contaminant transport in saturated and unsaturated zones; mathematical modeling of solute transport in groundwater; micro-computer applications of flow and transport models.

Groundwater Hydrology: groundwater-lake interactions; neutron-probe monitoring of infiltration; geothermal investigation of flow through lake beds; mathematical modeling of flow through frozen and thawing soils; aquifer modeling and management; groundwater resources evaluation; hydraulic properties of unsaturated zone. Salt-water intrusion in coastal aquifers.

The following studies are also reported by the Geophysics and Geochemistry Group in collaboration with the Geolog-Eng-Group:

Acid Rain Studies: buffering capacities of natural soils; evolution of groundwater quality in a flow system; field instrumentation and monitoring.

Permafrost Studies: mapping and properties of the active layer; groundwater in areas of discontinuous permafrost.

## 7. Ontario

### (a) Ministry of Natural Resources

In February, 1986, the Ontario Ministry of Natural Resources, through the Conservation Authorities and Water Management Branch, issued Technical Guidelines for Flood Plain Management in Ontario to assist the private sector in the computation of flood flows and delineation of flood plains in Ontario. During the preparation of the Guidelines document, several technical working papers were prepared by the private sector and government agencies. These include:

- Regional Flood Frequency Study, by Cumming-Cockburn and Associates Ltd.
- Hydrologic and Hydraulic Models, by MacLaren Plansearch Inc.
- Rainfall Analyses by M.M. Dillon Ltd.
- Flood Levels Caused by Ice Jams by MacLaren Plansearch Inc.
- Schedule B and C of Canada/Ontario Flood Damage Reduction Agreement.
- Regional Flood Frequency Analyses by Environment Canada.

During 1985/86, the private sector also conducted, on behalf of the Ministry, a number of research and development projects, including the Development of Flood Depth-Damage Curves for Residential Homes in Ontario; Flood Plain Roughness Characteristics Study; Ice Jams on Small Rivers, Remedial Measures and Monitoring; Dynamic Wave Flood Routing Sensitivity Study; Snow Hydrology Study; and Agricultural Land Drainage Modelling Study. A total of 23 technical reports had been completed as of July 31, 1986.

### (b) University of Guelph

The Departments of Land Resource Science and Environmental Biology have undertaken an interdisciplinary investigation as to whether the practice of spray irrigation of landfill leachate into a forest ecosystem is an environmentally-sound and cost-effective means of treatment of such wastewaters in Ontario. A case study at the Muskoka Lakes sanitary landfill has included investigations of site hydrology and leachate volume reduction, soil attenuation capacities, ecosystem stresses from leachate irrigation, and physico-chemical pre-treatment prior to land disposal.

### (c) Queen's University

Hydrological research in the Department of Civil Engineering involves the following projects: real-time flood forecasting for flood damage reduction and for reservoir regulation using stochastic and dynamic models; urban runoff measurement and modelling 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.

### (d) Trent University

Most hydrologic research at Trent University is undertaken in conjunction with the Watershed Ecosystem graduate program offered jointly by the Geography and Biology Departments.



Current work has focussed 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 hydrometeorology of the Canadian Climate Centre's general circulation climate model.

(e) York University

In the Department of Geography, hydrological research is currently being undertaken both by graduate students and faculty. Current research interests focus on the biochemistry of stream ecosystems; Arctic land and lake evaporation; the hydrology of wetlands and freshwater lake ice cover. 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. Wetland hydrology research is examining the inflow and outflow groundwater of isolated and headwater wetlands and the redistribution of water within mire complexes of regional wetland systems. The final research area is concerned with the thermal and structure influence of snowcovers on the growth of freshwater lake ice.

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.

(f) Acres International Limited

The Niagara Falls office carried out work on the following hydrology/water resources projects and studies:

Water Supply Constraints to Energy Development - This ongoing study for the Inland Waters/Lands Directorate of Environment Canada has resulted in the development of a Water Use Analysis Model. This model has recently been enhanced in the areas of reservoir modelling, price elasticity effects, and minimum flow apportionment. The model was applied for the Saskatchewan-Nelson River Basin and is being used to evaluate the future water supply/demand balance in the Prairie Provinces.

Proposed Magpie River Development - A proposed hydroelectric development comprising three plants with a total installed capacity of 43 MW was studied for Great Lakes Power Limited. Hydrologic work included the analysis and extension of hydrological records, flood frequency and low-flow frequency analyses, sedimentation/erosion studies, ice observations and numerical ice modeling. A probable maximum flood study including rain and snowmelt modeling was also completed. The model DWOPER was used to address problems related to the operation of three hydroelectric plants located along 30 km of the Magpie River.

8. Prairie Provinces (General)

The Federal Department of Agriculture's Prairie Farm Rehabilitation Administration (PFRA) is involved in hydrology and hydrology-related activities covering a broad spectrum including the conception, planning, design, construction and operation of water resource projects. PFRA provides hydrologic assessments and advice in the management of groundwater and is also involved in hydrology activities that 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 experience and expertise, special studies have been carried out 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 obtaining pertinent hydrologic information and developing practical solutions in the areas of water development and soil conservation and reclamation.

Surface water development projects vary in scale and complexity and include small projects serving farming units, community projects (including town water supplies), and large multiple water use projects involving dams on major streams.

Hydrology studies for both water supply and flood potential involve state-of-the-art technology as well as innovative analytical techniques in data-sparse areas, and are carried out in conjunction with hydrogeological assessments to optimize development opportunities. Due to human intervention over time in the natural hydrological regime of streamflow, 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 performed as required to meet the needs of PFRA and other water resource agencies.

An important and difficult aspect of project design for earthfill dam facilities is the selection of a design flood for determining spillway size and type. PFRA has developed preliminary guidelines for the selection of a project spillway design flood based on embankment height, reservoir storage and hazard potential (consequences of dam failure). The final project spillway design flood also takes into account general and site-specific considerations. However, the guidelines specify flood potential considerations in terms of various flood frequency and/or probable maximum flood events.

Due to the high variability of 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 farms. In the past year, several surface water supply projects supplemented by groundwater have been designed or constructed. Also, water supply systems composed 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 regards to reducing damages. The effects of such activities on erosion are currently being studied from both a practical and a research perspective. Research into the runoff processes causing soil erosion is being undertaken by the Soil and Water Conservation Service of PFRA.

The drought of the last few years has heightened awareness of the importance of availability of surface and 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. Studies have been conducted separately for each of the three prairie provinces. Reports on these studies have been completed for Alberta and Saskatchewan while the report for Manitoba is nearing completion.

PFRA participates in and supports several activities that relate to research and/or development of analytical techniques. These activities are:

(i) 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 area maps are published and circulated to concerned provincial and federal water resource agencies.

(ii) 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.

(iii) 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.

(iv) Field investigation and analysis leading to an understanding of 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.

(v) 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 1986 and distributed to concerned provincial and federal government agencies.

(vi) 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.

(vii) PFRA has developed prairie-wide drought sensitivity models to evaluate both the economic impacts of drought and drought-mitigating measures. These evaluations are being used to help formulate policies and programs for short and long-term drought strategies in the use and conservation of water. Economic models are also being used in conjunction with benefit-cost and hydrologic analytical tools to assess the economic feasibility and impact of various irrigation, water development and soil conservation proposals.

## 9. Manitoba

The Manitoba Department of Natural Resources, Water Resources Branch continued streamflow simulation studies under the Canada-Manitoba Agreement Respecting Flood Forecasting. This Agreement is part of the Canada-Manitoba Flood Damage Reduction Program. The HSPF model was calibrated on three smaller tributary watersheds of the Assiniboine River and the Souris River in southwestern Manitoba. While results were relatively good, difficulties were encountered in simulating spring streamflows. Errors were attributed to inadequacies in input data, to shortcomings in the model and to a lack of sufficient experience in effectively applying the model. Inadequacies in input data included unreliable estimates of initial basin soil moisture, basin precipitation, basin temperature, dew point, wind and radiation. Errors in the snowmelt energy balance inputs resulted largely from the need to use data for somewhat distant mainline meteorological stations. Shortcomings of the HSPF model included its inability to adequately simulate phenomenon such as infiltration of melt water into partially frozen soil, losses to depressional storage and soil cracking and the albedo of the snow. Attempts were made to improve the infiltration component of the model using research findings of the Division of Hydrology, University of Saskatchewan and the snowmelt component using findings of a snowmelt hydrology study performed by MacLaren Plansearch for the Ontario Ministry of Natural Resources. While these changes improved simulation results somewhat, the spring runoff simulations were not significantly better than those obtained with the index model used at present. A report outlining experiences with the HSPF model in detail is being prepared.

In order to improve hydrometeorological data availability for streamflow forecasting, the Manitoba Flow Forecast Centre, under the Canada-Manitoba Flood Forecasting Agreement, is participating with Environment Canada's Atmospheric Environment Service in a project to determine the feasibility of using Telidon weather radar for precipitation mapping. Additional nipher-shielded snow gauges and recording precipitation gauges with real-time data transmission are also being installed under this Agreement. In cooperation with Environment Canada's Water Resources Branch, additional data collection platforms are being installed at river locations where the Forecast Centre has the greatest need for continuous real-time water level data. Wherever possible, real-time hydrometric and meteorologic stations are co-located to make maximum use of data transmission facilities.

The Manitoba Water Resources Branch is continuing to cooperate with the National Hydrology Research Centre in Saskatoon with respect to the Domain-Mannes project in Manitoba. The objective is to determine the effects of agricultural drainage on runoff volumes and peak flood flows. This is a pressing issue in Manitoba where the government is facing increasing complaints from farmers, towns and Indian bands claiming that agricultural drainage has increased the frequency and magnitude of flooding of their properties.

The Manitoba Water Resources Branch is also cooperating with the Atmospheric Environment Service and the United States National Weather Service on studies of the remote sensing of soil moisture and snowcover using gamma, microwave and radar systems, either by aircraft or satellite. Specific projects are still in the planning stage.

Hydrogeological activities in Manitoba were concentrated in four functional areas including aquifer data, aquifer definition, aquifer capacity and aquifer modification. The main thrust of aquifer data activities was to convert manual files to computer files within the limits of the available computer facilities. One of the projects under development was a computer file of all groundwater monitoring stations in Manitoba including station name, number, year of establishment, design, parameters measured and method of measurement. Another project under development was an annual publication on Manitoba Groundwater Statistics and Information.

Aquifer Definition activities included publication of a series of groundwater availability maps for the Selkirk Map Sheet Area and the Kenora Map Sheet Area and preparation of a similar series of maps for the Dauphin Lake Map Sheet Area. A report was prepared on aquifer definition investigations under the Canada-Manitoba Interim Subsidiary Agreement on Water Development for Regional Economic Expansion and Drought Proofing which terminated March 31, 1986. A paper on the Hydrogeology of the Winnipeg Formation in Manitoba was presented at the Third Canadian Hydrogeological Conferences, sponsored by the Canadian Chapter of the International Association of Hydrogeologists.

Aquifer Capacity activities included preparation of a report on aquifer capacity investigations under the Canada-Manitoba Interim Subsidiary Agreement on Water Development for Regional Economic Expansion and Drought Proofing. Data generated from these aquifer capacity investigations were organized for use in developing computer models of selected aquifers to aid in the development of aquifer management strategies.

Aquifer Modification activities included preparation of a report on aquifer enhancement investigations under the Canada-Manitoba Interim Subsidiary Agreement. Evaluation of an aquifer modification project associated with the agricultural drainage system in the Brokehead River Watershed was carried out, in addition to monitoring the performance of previously completed aquifer modification projects of a similar nature in the Wavy Creek and Manning Canal Watersheds.

## 10. Saskatchewan

### (a) Saskatchewan Water Corporation

The Hydrology Service of the Saskatchewan Water Corporation comprises three working sections: surface water, groundwater and operation planning. The Hydrology Service is responsible for conducting hydrologic and hydrogeologic investigations associated with basin planning studies, watershed development proposals and environmental impact assessments, planning the operation of reservoirs and river systems in the province, streamflow forecasting, administration of federal-provincial hydrometric agreements and representing Saskatchewan and providing support in administering interjurisdictional water resources.

The Surface Water Section completed a study of the magnitude and frequency of flood peaks and volumes in Saskatchewan. The study results provide a data base for conducting hydrology studies for project feasibility and preliminary design investigations. Ongoing support services to the Corporation's Planning Branch were provided in conducting flood routing and reservoir operation modelling for the proposed Rafferty and Alameda Reservoirs in the Souris River basin.

The Hydrology Service will co-operate with the Canadian Centre for Remote Sensing and Saskatchewan Research Council in conducting a demonstration project in the use of remote sensing techniques in water resources evaluation. Projects were undertaken to evaluate depressional storage areas and artificially drained lands. The demonstration project phase is scheduled to be completed by March 31, 1987. Numerous other hydrology studies were undertaken, including a study of Kenosee Lake water levels and the impact of increased water usage from the lake, a study to determine natural lake levels on Reindeer Lake, a natural flow study of the Birch River basin in northeast Saskatchewan and studies to determine the hydrology of the Saskatchewan portion of the Mackenzie River basin.

The Groundwater Hydrology Section initiated work towards implementing an aquifer management plan for the Regina Aquifer. It is hoped that the plan will provide the information needed to efficiently and effectively manage the resources of the aquifer, as well as provide a model for aquifer management plans in other areas of the province. Other activities included groundwater

assessments and reviews with respect to mining developments at Key Lake, deep well injection at Lloydminster in conjunction with a proposed heavy oil development, and the proposed Rafferty Reservoir and its impact on the groundwater regime of the area. The Groundwater Hydrology Section is also responsible for groundwater data acquisition in the form of electric logs, water well records, maps and profiles. An electric-logger accreditation clinic is held annually to ensure that quality geologic information is collected and to ensure that only accredited loggers are used in connection with provincial groundwater assistance programs.

The Operation Planning Section was involved in the ongoing operation of the province's major reservoirs and river systems. A highlight of the year was the July, 1986 flood on the North Saskatchewan River. A rainstorm over the headwaters of the basin upstream of Edmonton resulted in the highest recorded flow at Edmonton since 1915, and also the second highest summer flood peak at Prince Albert. Lake Diefenbaker rose to its full supply level for the first time since 1981.

Considerable advancement was made in automating the Service's Forecast Centre activities through computerized remote data acquisition and data processing and display.

(b) Crippen Acres Saskatchewan Limited

The design, construction supervision and commissioning of the Nipawin hydroelectric project on the North Saskatchewan River were completed. This development comprised 252 MW of installed capacity. Hydrologic work included a probable maximum flood study. The project recently won an award of merit from the Canadian Engineer magazine and the Association of Consulting Engineers of Canada.

11. Alberta

(a) Alberta Department of Environment

The River Forecast Centre (RFC) is continuing its work in cooperation with the University of Saskatchewan at Saskatoon to improve the snowmelt modelling routines used in the SSARR (Streamflow Synthesis and Reservoir Regulation) hydrologic computer model. The work for 1986/87 involved the development of a daily snowmelt amount estimation technique based on solar radiation data for application to spring snowmelt runoff flood forecasting in the plains and parkland areas of Alberta.

The RFC has also continued its 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 capability for forecasting the water supply and streamflow from the mountainous areas in Alberta.

The network of real-time weather stations developed and managed by the River Forecast Centre in conjunction with the Survey Branch of Alberta Environment did not expand during the past year. This network now consists of 47 stations. Slow growth of this network is expected in the years to come. Most of the stations in the network are telemetered using the GOES satellite system. The rest are telemetered using the telephone system.

Emphasis for the collection of real-time hydrometeorological data for streamflow forecasting has shifted to river, canal and lake level data in the past year. Such data are becoming more important in the day-to-day management of southern Alberta's limited water resources, particularly for irrigation operations. A total of 52 streamflow gauging stations are telemetered by the RFC in cooperation with Water Survey of Canada, Environment Canada. Data from another 77 stations telemetered by other agencies are available in real-time to the Centre.

The Hydrology Branch has developed a Storage Effective Drainage (SED) Runoff Model as a tool to aid in the research objectives of the Spring Creek Experimental Watershed Project. The SED model accounts for normal changes in storage conditions of a watershed, and is capable of accurately modelling runoff and hydrograph reconstitution.

A Probable Maximum Flood Workshop was jointly sponsored by the Hydrology Branch and the University of Alberta. The workshop was in two parts: Part I on Probable Maximum Precipitation, was presented by John F. Miller formerly with the United States National Weather Service, and W.D. Hogg of Environment Canada. Part II on Probable Maximum Flood - SSAAR Hydrologic Modeling, was presented by Don Kuehl and David Rockwood, formerly with the United States Army Corps of Engineers.

The Hydrology Branch prepared a report entitled The Northwest Alberta Regional Hydrologic Study. The hydrology prepared for the report provides hydrologic estimates for the entire study area. The estimates are provided for the 1:2 to the 1:25 year return period floods, and include the instantaneous peak discharge, mean daily discharge, and runoff volumes for both the annual and summer flood events. A dimensionless hydrograph computer program is also provided in the report that relates runoff volume to the peak discharge. The dimensionless hydrograph used in the program is developed from recorded hydrometric data within the study area.

The Hydrogeology Branch of the Earth Sciences Division's observation well networks have been steadily expanded from 200 observation wells to approximately 250 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 processes on heavy oil production.

The Hydrogeology 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, the 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.

(b) Acres International Limited

The Calgary office of conducted a feasibility study of mathematical and physical modeling methods to be used in selecting flood reduction measures as part of a major program of investigation, planning and construction to alleviate flooding in the metropolis of Bangkok, the capital of Thailand. Situated on the low-lying delta of the Chao Phraya River, Bangkok is subjected to seasonal flooding which has become a serious problem in terms of flood damage.

12. British Columbia

(a) British Columbia Ministry of Environment and Parks

The Hydrology Section continued development on standard procedures to provide peak flow estimates on ungauged streams. These procedures were used to provide a large number of peak flow estimates of varying return periods for floodplain management and preliminary hydraulic design purposes. A wide range of hydrology studies was carried out for government, including water supply, peak flow, low flow, network planning, major basin studies and land use impact studies.

The network of automated snow survey stations using the GOES Data Collection System now totals 13 stations, a number of which are operated under a cooperative arrangement with B.C. Hydro. One new station, a high-elevation location in the Similkameen River basin, will be used for flood forecasting and reservoir operation in that part of the Province. Further network expansion in the Squamish River and Coquihalla River basins is anticipated.

The manually operated snow course network now totals 269 active stations, a decrease of nine since the previous year. A historical summary of all snow course measurements in the province, 1935 to 1985, was published.

The Fraser River flood forecast model was highly successful in predicting flows and water-levels throughout the basin during the 1986 freshet. The peak flow observed was the 10th highest in 75 years of record.



The Groundwater Section maintains a network of 145 observation wells to monitor water levels and water quality fluctuations in unconsolidated and bedrock aquifers. Groundwater investigations related to water supply, water quality, drainage and waste disposal problems were completed. Investigations commenced on the occurrence of high nitrate groundwaters and sea water intrusion in these areas of the Province.

(b) Simon Fraser University

Research is being conducted in the Department of Geography into the energy and water balances of mountain terrain in south-central British Columbia. Emphasis is directed towards: a) atmospheric and surface control on heat and mass transfer, and b) role of radiative and advective energy contributions to spring snowmelt.

Four years of research have been completed on the use of shade and surface mulch on soil water conservation in the arid interior of British Columbia. Results indicate that the surface modifications maintain high soil water, thereby limiting the requirements of irrigation. These principles may have expanded application in other arid locales.

(a) University of Victoria

The Department of Geography is conducting research into the impact of water quality on health, using Canadian, U.S. and British data. In particular, possible links between trace and bulk elements and cancer, cardiovascular disease, multiple sclerosis and amyotrophic lateral sclerosis are being examined.

(d) Acres International Limited

The Vancouver office carried out work on the following hydrology/water resources projects and studies:

Osoyoos Lake Control Structure - The design and construction supervision of a four-gate control facility at Oroville, Washington was completed. This work included examination of flood frequency and flood levels on the Okanogan River and a major downstream tributary, the Similkameen River. River profiles were analyzed to determine dredging requirements upstream from the structure. Erosion control works were designed to reduce the redeposition of sediments.

Waneta Generating Station Expansion - The feasibility of a significant expansion of the peak capacity of the Waneta Generating Station was examined. Various options for different combinations of additional unit sizes were evaluated.

Beatrice Generating Station - The feasibility of 24MW of new generating facilities was reviewed.

Shuswap Generating Facilities - The feasibility of 60MW of new generating facilities, including a basin diversion and two generating stations, was reviewed.

(e) Ward & Associates

One winter of field testing has been completed for the solar powered ice control pump developed on behalf of the Fisheries Branch, BC Ministry of Environment. The pump, known as the WARDUN SUNSTIRRER, performed satisfactorily for three months of the test program, and demonstrated that adequate energy to drive a circulator pump could be obtained from photovoltaic solar panels in winter at latitude 51 degrees North. The target flow rate of 25 litres/s was reached and an ice free area of 25 to 400 m<sup>2</sup> was developed on the Lake. Plans are underway to enlarge the flow delivered and for detailed monitoring of dissolved oxygen during next Winter.

A Lotus 123 based water temperature model suitable for small to medium lakes in Spring and early Summer was prepared for the Fisheries Branch, BCMOE. The model was required to predict the effects of changing the level at which water leaves a lake in the western Rockies (Alces Lake, BC) to determine whether it would be possible to improve (lower) the outflow temperature. The model, which was one dimensional, included several physical processes, namely: heat gain from short wave solar radiation; heat losses from evaporation; heat (coldness) addition from



inflows; plume plunging and entrainment; and vertical dispersion of heat. The model was calibrated with field data from the 1986 season. The model, known as TEMP-123, constitutes a breakthrough in low cost temperature simulation of lakes and required only a modest number of man-days to prepare, encode, run and calibrate.

### 13. 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 was not available for 1984/85 because of the reformatting of the WATDOC bibliographic database. An update to the 1984 Bibliography will be prepared in 1987 using the AQUAREF database. Online access to AQUAREF is now available on the CAN/OLE system.

For more information on WATDOC contact:

WATDOC

Inland Waters/Lands Directorate

Environment Canada

Ottawa, Ontario

K1A 0E7

Tel.: (819) 997-1238 or 997-2324

## X MINING GEOPHYSICS

Compiled by: D. James Misener and Stephen W. Reford

### 1. Introduction

#### INDUSTRY

2. A-Cubed Incorporated, Mississauga, Ontario
3. Aerodat Limited, Toronto, Ontario
4. Dighem Surveys and Processing Incorporated, Mississauga, Ontario
5. Geoterrex Limited, Ottawa, Ontario
6. Noranda Exploration Co. Ltd., Ontario
7. Paterson, Grant & Watson Limited, Toronto, Ontario
8. Sagax Géophysique Incorporated, Montréal, Québec

#### GOVERNMENT

9. Geophysics/Geochemistry Section, Ontario Geological Survey, Ministry of Northern Development and Mines, Toronto, Ontario
10. Ministère de l'énergie et des ressources du Québec, Québec, Québec

#### UNIVERSITIES

11. Department of Geophysics and Astronomy, University of British Columbia, Vancouver, British Columbia
12. Department of Geology and Geophysics, University of Calgary, Calgary, Alberta
13. Département de Géologie, Université Laval, Québec City, Québec
14. Department of Geological Sciences, Queen's University, Kingston, Ontario
15. Department of Geophysics, University of Western Ontario, London, Ontario
16. Bibliography

### 1. Introduction

Fourteen organizations reported research in mining geophysics in 1986. A further four organizations reported no current research activity in mining geophysics for this year. A total of eighteen responses were received from eighty-one organizations contacted. As in previous years the apparent level of effort is distorted by a lack of information submitted in the private, university and government sectors. Total research and development expenditure reported by the fourteen organizations for 1986 was \$3.72 million, comprising \$1.51 million from industry, \$1.8 million from government and \$0.41 million from universities. These figures exclude the millions of dollars spent on airborne survey work by the federal and provincial governments. Since no information was reported by some of the larger companies and university/government organizations, it is likely that total expenditure is a factor of two or three higher than indicated.

The reported level of effort in industry has decreased to 37% of the level reported in 1985. This dramatic drop is due, in part but not completely, to the lack of figures from major companies. Given the limitation of our sample, the results are nevertheless a sobering reflection of the decrease in research in mining geophysics being carried out in Canada by the private sector.

The dollar amounts reported by the government have remained approximately equal to those for 1985 and, if the amounts expended by the Geological Survey of Canada were included, would probably indicate an increase. The university amounts are also understated; the level of expenditure reported, however, indicated a decrease to 66% of the 1985 level.

Research is underway in all areas of instrumentation, survey methods and interpretation. Of particular interest in 1986 was the diversification of applications into the fields of surficial geological deposits and groundwater exploration.

## INDUSTRY

2. A-Cubed Incorporated, Mississauga, Ontario (A.P. Annan, J.L. Davis, D.C. Labbatt, G. Black, C.J. Vaughan, S. Cosway)

The company continued initial airborne tests of the PROSPECT 1 airborne electromagnetic system. Data processing algorithms for real-time and post flight analysis were in development during 1986.

Field tests of the new pulse EKKO III radar system, development of new data processing algorithms and design of the pulse EKKO IV radar system were initiated in 1986.

Development also continued on the OUTPUT programs for re-processing of Airborne electromagnetic data to extract maximum or geological structure as well as separating and identifying metallic conductors. The OUTPUT process is now commercially available and has been used successfully on existing INPUT and HEM and geotem data.

3. Aerodat Limited, Toronto, Ontario (S. Hogg, M. Granovsky)

A "multi-geometry, broadband" helicopter electromagnetic system is being developed by Aerodat Limited and preliminary flight testing began in March, 1986. The transmitter consists of two concentric coils, 6 m in diameter; one with its axis vertical, the second with its axis in the direction of flight. The receiver, located at the centre of the transmitter loops, consists of 3 orthogonal coils to measure secondary magnetic field strength as well as direction. Both the transmitter and receiver are mounted in a bird towed 30 m below the helicopter. The two transmitter loops are energized with a transient pulse on a time shared basis to provide contrasting inductive geometries of the primary field with the underlying geology. The mark/space ratio as well as the pulse length of the primary field transient, is controlled digitally to provide a variable bandwidth.

4. Dighem Surveys and Processing Incorporated, Mississauga, Ontario (D.C. Fraser, S.J. Kitty, P.W. Strandberg)

The development of the microprocessor-based digital receiver console for the Dighem<sup>III/IV</sup> helicopter EM system was virtually completed during 1986. The system accumulates data at the rate of 100 samples per second, removes spherics, and smooths and compresses the data. This project was partially funded by the Ontario Geological Survey's Exploration Technology Development Fund.

The Dighem<sup>IV</sup> system with four coil-pairs was perfected in 1986. This included the evaluation of the dielectric effect at 56,000 Hz, integration of the 56,000 Hz data into the inversion technique, along with hardware and software redesign.

5. Geoterrex Limited, Ottawa, Ontario (P. Millette, M. O'Connell, S. Thomson)

In 1986, Geoterrex introduced the Geotem (Geoterrex Time Domain EM) system. Geotem is the first fully digital airborne EM system in production. Significant effort has been applied to refining the system and to the development of appropriate data processing techniques to handle the data.

The company has continued to modify the GMAPS (Geoterrex Ground, Marine and Airborne Processing System) software package to generate new products as required, and to improve the quality and efficiency of data processing.

6. Noranda Exploration Co. Ltd., Toronto, Ontario (R. Pemberton, D. Carrier, B. Graves)

The company carried out a number of field tests using a variety of geophysical instrumentation.

The CSAMT method was tested over a number of areas exhibiting deep conductive overburden; in particular, the Isle Dieu Pb-Zn deposit in Quebec and an area south of Carlin Nevada were surveyed.

Galvano-magnetic surveying utilizing a low frequency EM system was carried out over regional fault zones in northeastern Ontario. A grounded dipole current source was employed to enhance current flow in conductive bedrock features. Dip and strike measurements of the magnetic field were made, interpretation and evaluation of the method are continuing.

7. Paterson, Grant & Watson Limited, Toronto, Ontario (N.R. Paterson, D.J. Misener, I.N. MacLeod, S.W. Reford, E. Baranyi, R. Hearst, D.C. Gresham)

The company continued the development of a comprehensive software library for both internal and commercial interpretation applications. The development work on the SPECMAP method for ternary colour mapping of three element radiometric or geochemical data was brought to the final testing stages and the program was applied successfully to two large radiometric/geochemical data sets; one from South America and one from Africa.

In the field of electromagnetics, the development of the GEMINV and AEMINV programs was completed and tests were carried out on representative ground and airborne data sets. Work continued on the use of airborne electromagnetic inversion (AEMINV) with current application of the program to the Val Gagné, OGS test site. The results of the AEMINV processing will be compared directly to recent drilling and shallow seismic results in the test area.

Development work on a comprehensive mapping system, including profile plotting, gridding, and contouring, was completed by GEOSOFT Inc., the computer software division of the company. The complete mapping system, (GEOSOFT 2-D Mapping System) has been fully tested on all types of ground and airborne geophysical data. Development of the fully interactive 2 and 2 1/2 dimensional magnetic modelling system (MAGMOD) was also completed during the year.

8. Sagax Géophysique Inc., Montréal, Québec (R. Bazinet, J. Legault, P. Bérube, A. Lachapelle)

The company carried out research on a number of projects during 1986. A phase and coherency detector was developed, tested and installed on the Sagax SAMT<sup>TM</sup> (Scalar audio magnetotelluric) instrument. Several test surveys were carried out to demonstrate the performance of the SAMT<sup>TM</sup> scalar audio magnetotelluric method over deep oil and mining targets. The program was successful and demonstrated that SAMT<sup>TM</sup> will detect targets up to 1 km in depth. The project was financed by MERQ. A final report will be published in 1987.

The company is also developing an interactive 3D Induced Polarization and simulation program. The computation algorithms are fully operational and final packaging is near completion.

9. Geophysics/Geochemistry Section, Ontario Geological Survey, Ministry of Northern Development and Mines, Toronto, Ontario (R.B. Barlow, J.E. Hanneson, R.S. Huxter, V.K. Gupta, D.R. Wadge, A. Nakashima)

The Geophysics and Geochemistry Section of the OGS carried out research and field testing over a number of specific geophysical/geological environments in Ontario.

During the 1986 field season, the Night Hawk geophysical test range near Timmins, Ontario, was utilized for testing, research, and instruction purposes by personnel from industry, universities, and government. Section staff carried out field work using the UTEM III electromagnetic system based on a standard (1 by 1 km) fixed source transmitter loop.

A project to investigate the potential for detecting and tracing conductive strata in Precambrian rocks overlain by thick Huronian stratigraphy in the Moose Lake sub-basin area west of Cobalt has been initiated. In this area, conductive horizons are largely contained within the interflow sediments, which are in turn stratigraphically positioned within mafic volcanic rocks of Precambrian age. Techniques which would enable the tracing of these conductive horizons in the basement rocks beneath substantial thicknesses of Huronian sediments are of

interest, both from a geological and an exploration viewpoint. Firstly, modeling of electromagnetic responses could reveal the depth of the Huronian sequence such that basement topography could be realized. Secondly, in some cases there appears to be a spacial relationship between the interflow sediments and the contained conductive strata in basement rocks, with cobalt-silver occurrences in the lower sequence of Huronian sediments above the unconformity. The study incorporates computer modeling of layered earth responses and plate-like targets, as well as the testing of field methods.

A gravity survey of the Lac des Iles area (1400 km<sup>2</sup>) was carried out during the 1986 field season to aid in the regional geological interpretation of the mafic and ultramafic intrusive rocks in the area. The largest intrusive complex in this area is located approximately 80 km northwest of Thunder Bay, and is host to significant palladium-platinum mineralization. Some detailed gravity profiles were established in order to map specific features of several intrusions in the area.

10. Ministère de l'énergie et des ressources du Québec, Québec, Québec (H. Church, R. Boraks, R. Boivon, D.L. Lefebvre, D.J. Dion)

During 1986, MER carried out a number of ground surveys and airborne projects. Seismic surveys were completed in the Harricana-Grasset region in order to establish a regional structural model and as an aid in mapping surficial deposits. Research was initiated into non-destruction acoustic methods that would facilitate the definition of anisotropy in granite. Both field and laboratory studies are continuing.

Two areas of Quebec (the Magog group in the Appalachians and the Archean Terrane west of the Labrador Trough) were identified as prospective zones for gold exploration, and two airborne geophysical surveys, comprising airborne electromagnetics, spectrometer and magnetics, were carried out in these areas under MER auspices.

#### UNIVERSITIES

11. Department of Geophysics and Astronomy, University of British Columbia, Vancouver, British Columbia (W.F. Slawson, T. Watanabe, S. O'Brien)

Research continued on the utility of powerline harmonics in geophysical exploration. A spectrum analyzer was modified to display only 60 Hz harmonics by rebuilding the active filters to increase selectivity and adjusting gains to equalize output.

12. Department of Geology and Geophysics, University of Calgary, Calgary, Alberta (K. Duckworth, C. Cummins, D. O'Neill, T. Calvert)

Interpretation methods for use with the Turam electromagnetic exploration system in difficult exploration environments has been developed. Physical modelling using the Turam system in conductive and free space environments, with emphasis on the comparative performance of conventional and parallel line modes of operation over a variety of target types has been completed.

Research is continuing into the characteristics of sulphide minerals under permafrost conditions. An extensive suite of mineral specimens will be investigated by means of complex resistivity methods over a temperature range extending down to -20°C using the Cole-Cole model to characterize the behaviour of the specimens.

13. Département de Géologie, Université Laval, Québec, Québec (M. Seguin, J. Frydeckz, S. Roy, J. Vachon, B. Hanley)

A research project has been carried out on the gravimetric signature of the Mount Mégantic anomaly. This study includes the data acquisition, data processing and interpretation of the Mount Mégantic Cretaceous intrusive in the Quebec Appalachians. Data include over 300 gravity readings and 50 density determinations, as well as topographic corrections. Different techniques, including polynomial fits; moving average of a square surface, etc., were used to obtain

different regional gravity contour maps. The residual gravity map and the following interpretation is indeed entirely dependent on the quality of the regional map. A depth of 7 to 10 km is obtained for the base of the cone shaped cylinder.

14. Department of Geological Sciences, Queen's University, Kingston, Ontario (R.P. Young, A.V. Dyck, C. Thomson, D.V. Woods, D.A. Hutchins, W.J. McGaughey, T. Urbancic, S. Falls, J. Towers, M. Marchand, D. Krentz)

Seismic experiments are being undertaken in underground hard rock mines and the results are being used to obtain geotomographic images of anomalous ground conditions. Interpretation of seismic tomographic images during different stages of mining, and source mechanism studies of mine-induced seismicity, are being used concurrently to understand rock-burst phenomena in Canadian hard rock mines. The research is sponsored jointly by NSERC and Canadian mining companies.

Research is continuing on seismic diffraction modelling using boundary-layer theory. Ray theory fails for grazing and critical angles of incidence because it does not account for interference between the primary and secondary waves. A boundary layer is created at the point of incidence and the correct local solution can be found by coordinate stretching. We have been applying and extending the boundary-layer method for this problem in order to model more correctly the effects of shadow boundaries, interference head waves, etc.

A study is underway to correlate, on a detailed level, drill-hole EM anomalies with known occurrences of massive-sulphide mineralization. Detailed drilling information and pulse EM surveys from the Ruttan Mine in northern Manitoba are being utilized for this investigation. Construction of a modeling facility is being undertaken to study the effects of multiple conductors and odd-shaped bodies.

15. Department of Geophysics, University of Western Ontario, London, Ontario (A.E. Beck, L. Mansinha, D. Marcotte)

A suite of computer programs has been developed to process three component high sensitivity gradiometer data in contour maps of total magnetic field. The complete processing package includes error recognition and correction capabilities, as well as gridding routines that use the horizontal gradients in order to interpolate the total magnetic field between flight lines. Calculations based on synthetic data have shown that the inclusion of the horizontal gradient information into the interpolation process yields a more accurate total field and reduces the effect of random noise.

Research is also continuing in the design of short forward filters for resistivity measurements and into inversion methods using singular value deconvolution.

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## XI ENGINEERING GEOPHYSICS

Compiled by: K. Howells

1. Université Laval
2. Nova Scotia Research Foundation Corporation
3. Gartner Lee Associates Limited
4. Ontario Hydro
5. Geological Survey of Canada: Terrain Sciences Division
6. Geological Survey of Canada: Atlantic Geoscience Centre
7. Dalhousie University
8. Bibliography

### 1. Université Laval (M.K. Séguin)

Basic and applied aspects of discontinuous permafrost geophysics were investigated in the Kangiqsualujjuaq area of Northern Quebec at the southeastern edge of Ungava Bay. Construction in a discontinuous permafrost environment requires a knowledge of active layer thicknesses, lateral and vertical distribution of permafrost, bedrock topography and the groundwater regime. Geomorphology, surface and borehole geophysics as well as water jet drilling allow determination of the lateral and vertical extents of permafrost. Seismic refraction and geothermometry are most useful to outline the active layer. Electrical resistivity, electromagnetic soundings, induced polarization and seismic refraction are the most efficient surface geophysical methods to determine the thickness of permafrost, whereas electrical resistivity, seismic refraction and gravity methods are adequate tools to estimate the depth to bedrock. In this fashion, the sub-permafrost water flow section can be obtained in an indirect manner. The thickness of the active layer ranges from 0.6 to 2.1 m, that of permafrost from 1.5 to 27 m, that of the unfrozen layer beneath permafrost from 5 to 40 m and the depth to bedrock from 7 to 65 m. The lateral distribution of permafrost represents approximately 45% of the area. The physical properties (electrical resistivity, charge ability, seismic velocity and density) are obtained for different geological units (e.g., clayey silt, sand, till, dry sand and gravel, wet sand and gravel) in both frozen and unfrozen states. These geophysical data are helpful for the choice of soils less sensitive to permafrost in problems of construction. Neutron probe measurements, installation of heavymeters, borehole geophysics (electrical resistivity, induced polarization, self potential, salinity and temperature) as well as in-situ adiabatic calorimetry, are useful tools to monitor the water and ice content in the active layer and permafrost. Invasion of salt water in the supertidal environment at high tides is monitored by specific electrical surveys. Ground ice is lenticular in clayey silt and intergranular in sand and gravel. A correlation of the morphometric parameters of the permafrost mounds (e.g., length, width, elevation) with their thickness allows a prediction of this thickness with a relative degree of certainty. A model of evolution of permafrost in cryogenic mounds is under investigation. This model takes into account the thickness of permafrost, elevation of the mounds, isostatic rebound and dendro-chronologic results.

### 2. Nova Scotia Research Foundation Corporation (A.G. McKay)

Since last year's report on the development of a dual sparker source for shear wave generation, further field trials have been carried out under an existing research agreement with the Department of Energy, Mines and Resources. These trials were again conducted in water only a few centimetres deep, but sparker energy and voltage were increased and results have been obtained for the velocity of a phase-reversed seismic arrival. These results agree with values obtained by other workers for shear wave propagation in sands. On the basis of these findings, additional work is proposed for a test of this method in water depths of up to about 50 metres.

### 3. Gartner Lee Limited (D.D. Slaine)

Gartner Lee Limited have carried out various geophysical surveys for numerous hydro-geological studies during 1986. These are briefly described as follows:

(a) Seismic refraction surveys to define the continuity and thickness of a sand layer in southeastern Ontario and the overburden thickness of a PCB disposal/storage site in southern Ontario.

(b) Seismic reflection surveys to map a buried bedrock valley in southwestern Ontario; buried valleys for a groundwater supply investigation near Newmarket, Ontario; and eleven kilometres of line used for a site selection investigation for completion of a draft report for the Ontario Waste Management Corporation.

(c) Electromagnetic surveys to map ten buried, abandoned landfills in southern Ontario and a buried trench containing fungicide in the Maritimes.

(d) Magnetic surveys to map buried, abandoned hazardous waste storage tanks in central Ontario and buried steel barrels at a waste disposal site in southwestern Ontario. Geophysical modelling and mapping of contaminated groundwater waste disposal sites described in Greenhouse and Slaine (1986): see Bibliography.

#### 4. Ontario Hydro (R.J. Hetstee)

Two deep boreholes (76 mm diameter; 243 and 390 m long) have been drilled adjacent to the northshore of Lake Ontario. They intersect a thick sequence of sedimentary rock (shale and/or limestone) and penetrate the Precambrian basement rock. Core logging, geophysical logging and hydraulic testing have been completed in both boreholes. The data that are available to-date indicate that few relatively permeable zones are intersected by these boreholes and the hydraulic conductivity of the rock units is generally less than  $1 \times 10^{13}$  ms. Large formation fluid/gas pressures have been measured at depth in the boreholes. This may indicate the upward movement of groundwater towards Lake Ontario. A multiple-level groundwater pressure and groundwater sampling system has been installed in both boreholes. The interpretation of high quality fluid pressure measurements and the analysis of groundwater samples from this system may yield more information on groundwater flow patterns in these rock masses.

#### 5. Geological Survey of Canada, Terrain Sciences Division (J.A. Hunter)

Research on the application of high resolution reflection seismology under the direction of Dr. S.E. Pullan, was conducted in two field areas in Canada. In Val Gagné, Ontario, 10 km of reflection seismic was shot to map the overburden-bedrock interface and to detect the presence of till as an aid in overburden drilling for gold. In the Fraser Delta area, 10 km of seismic reflection data were acquired to map shallow structure as an aid to understanding the development of the modern delta.

Under the direction of Dr. J.A. Hunter a deep-towed seismic refraction system for mapping the presence of ice-bonded permafrost in the Beaufort Sea was extensively tested this season. The system can be towed in water depths of 100 m and can detect permafrost lenses to depths of 20 m below sea-bottom with depth accuracies of 10% and a velocity accuracy of 3%.

The Ice Island Seismic Reflection Program, funded by the ISPG as part of the Frontier Geoscience Program, was started in 1984 to study the unknown geology along the continental margin of the Canadian Arctic Islands. Some 2500 reflection soundings have been recorded along convoluted sedimentary sequences with a total thickness of a few hundred metres, overlying a high velocity (5300 m/s) basement under the drift path. The reflection signatures of the sedimentary sequence are concealed by the large amplitude direct signals travelling through the water layer, and by smaller amplitude, rapidly decaying reverberations between the top and the bottom of the water layer. It is expected that the reflection signatures will become more predominant as the ice island drifts toward the southwest traversing thicker sediments. Meanwhile, the GSC is sponsoring two research contracts, one with the University of Western Ontario, the other with the University of Saskatchewan, to study data processing methods to enhance the signal-to-noise ratio on these records. The program is under the direction of Mr. A. Overton.

#### 6. Geological Survey of Canada, Atlantic Geoscience Centre (R. Parrott)

The Atlantic Geoscience Centre performs regional geophysical mapping programs to determine the distribution, character and genesis of seafloor sediments and features on the continental

margins of eastern and Arctic Canada. These regional programs provide a framework for the interpretation of surveys performed for the solution of site-specific engineering and scientific problems.

Projects are also underway to provide a better understanding of the physical and acoustic properties of marine sediments through development of:

- A computer assisted system for on-line determinations of near-surface seismic velocity using wide-angle reflection seismic techniques.
- a system for measurement of the velocity and attenuation of sound in sediment cores (with Dalhousie University).
- a digital system for single-channel seismic data acquisition and on-line processing and display, and model experiments for determining the effect of permafrost on seismic data (with the University of Calgary).
- a technique for the inclusion of acoustic reflectivity measurements produced on-line from sub-bottom profiler data into a data base with navigation and other concurrently collected data such as gravity, magnetics and bathymetry.
- a cone penetrometer for use with a PISCES class submersible to allow detailed study of the bearing strength of the top metre of marine sediments to be correlated with studies of the acoustic properties of the sediments.
- a collection of cores and seismic data in representative depositional environments to study diagnostic correlations between the acoustic and physical properties of marine sediments.
- a directional hydrophone for performing seismic surveys in shallow water and ice leads.
- assessment of available techniques and equipment for the acquisition of seismic profiles on, through, or below the permanent polar sea ice.
- techniques and equipment for collection of continuous acoustic data on seabed sediments through leads in the permanent polar ice cover.

Geophysical surveys for engineering property evaluation have been performed in the following locations:

- Grand Banks of Newfoundland to determine iceberg scouring rates, and to study the nature and genesis of some of the large sand bodies present.
- Scotian Slope to study the effects of the 1929 earthquake and resulting sediment failure.
- Sable Island Bank and Banquereau to study sediment transport.
- Hudson Bay to study the distribution of surficial sediments and shallow bedrock geology.
- Arctic Islands for regional geological and geotechnical data for assessment of sediment stability, and engineering and other constraints.
- Beaufort Sea to complete regional shallow seabed surveys for engineering property zonation.

For a published description of activities, see Bibliography.

#### 7. Dalhousie University (L. Mayer)

- (a) High resolution acoustic profiling and remote sediment property determinations with a broad-band profiling system

Since 1981 we have been sponsored by the U.S. Office of Naval Research to develop a new, deeply towed sub-bottom profiling system (The Chirp Sonar). This system uses a long 2.5 -

8 kHz swept FM pulse to provide the bandwidth and energy output necessary for high resolution with substantial penetration. Because of the long pulse, the returned echoes must be processed to achieve the resolution predicted by the bandwidth. This processing involves matched filter correlation (to compress the long Chirp into a spike) and correction for amplitude degrading factors such as spherical spreading loss and sediment attenuation. The resulting sub-bottom profile is hopefully a quantitative image of sub-bottom structure that can provide the basis for statistical studies of the physical and acoustic properties of marine sediments.

A shallow-water prototype was successfully field-tested in Narragansett Bay (R.I.) late in 1982 (Mayer and LeBlanc, 1983). We then concentrated our efforts on digital acquisition techniques and on the development of algorithms that would use the bandwidth of the system to estimate sediment attenuation and reflectivity. In our most recent work we have used a computer designed "optimized" outgoing pulse to compensate for the impulse response of the entire system. This technique results in extremely high resolution ( $< .25$  msec) and high signal/noise ratio ( $> 10$  dB) records that produce exceedingly stable estimates of acoustic attenuation (Shock, LeBlanc and Mayer, 1986). Using our optimized pulse and newly developed, high-speed processing algorithms, we have collected and produced, in near real-time, attenuation profiles across Narragansett Bay that display values that are quite consistent with our knowledge of the sub-surface sediment types and that vary in a geologically sensible manner.

We have also begun to apply our processing techniques to other, broadband shallow water seismic sources (boomers). In particular, we have digitized and processed ORE GEOPULSE data collected from Narragansett Bay and Hunters DTS data from Emerald Basin off Nova Scotia. In each case the processing has produced reasonable attenuation estimates (though more variable due to the lower signal/noise ratio and greater pulse-to-pulse variability of the boomer). Most intriguing are our results from gas-charged sediments in Emerald Basin. These reveal a frequency-dependent resonance and may provide a means of estimating the size distribution of bubbles in the sediment (Mayer, 1986 - DREA Rept.).

#### (b) Laboratory and In Situ Analysis System

In order to verify the remote measurements described above, we have constructed a computer-controlled digital analytical system for the measurement of compressional sound-wave speed and attenuation on laboratory samples. This system uses four, orthogonally arranged probes, inserted into a sediment core and an extremely high-speed A/D converter (20 MHz) to measure the time of flight of a sound wave through the sediment and to digitize the entire wave form for the calculation of acoustic attenuation (by a spectral ratio technique). Measurements can be made at any sample interval resulting in an automatic and nearly continuous profile of sound speed and attenuation. This system has been field tested on cruises to the Grand Banks and Emerald Basin and has produced excellent velocity data and reasonable (based on comparison to values in the literature) attenuation number. In order to collect in situ velocity and attenuation data we have also constructed a remote probe system that can be deployed from a submersible. This system has successfully been deployed from the Canadian Navy SOL submersible operating in the Arctic.

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