Energy, Mines and Resources Canada
Geological Survey of Canada

Énergie, Mines et Ressources Canada
Commission géologique du Canada

CANADIAN GEOPHYSICAL BULLETIN

BULLETIN CANADIEN DE GÉOPHYSIQUE

Volume 40

Editor/Rédacteur en chef P.B. Robertson

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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 compliers or as researchers responding to the requests for information issued by the compliers. During 1981 a sub-committee of the CNC/IUGG prepared a set of guidelines to aid compliers and individual contributors in preparing their reports. The compliers 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 editorial assistance of Louise Simpson and Margaret Joseph.

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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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 maniére à ce que ce bulletin ne dépasse pas 200 pages, limite fixée par des contraintes financières. Cést avec non moins de reconnaissance que nous tenons à souligner l'aide de la rédaction apportée par Louise Simpson et Margaret Joseph.

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

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 intenational 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. 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 using WordPerfect and a diskette of each chapter provided to the Editor.

7. The Bullitin 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 RÉDACTEUREN 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 governement 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 aprés 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 matérial 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 utilisant WordPerfect 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

1. Summary

Fifteen organizations from government, university and private sectors in Canada report on their geodetic activities in 1987 in the contributions below. Although the reports cover the whole spectrum of geodesy, what is perhaps most notable is the significant increase in work with the Global Positioning System (GPS) over the past year. All 15 organizations report developments in the use of GPS . They include the completion of the NORSTAR 1000 GPS receiver, the design and construction of a prototype station for the Canadian Active Control System, the study of the effects of the troposphere and orbit errors on GPS-derived positions, development of improved processing software, and the coding of specifications and procedures for urban GPS surveys. The contributors report that GPS is being developed as a tool in a wide variety of areas including mapping control, aerial photography and photogrammetry, deformation monitoring, geoid profiling, heave estimation, hydrographic positioning and marine navigation.

Other significant accomplishments in 1987 include detecting the first fringes from the new Canadian Geophysical Long Baseline Interferometry system, the improved description of the geoid in Canada, test adjustments of secondary control networks into the NAD83 system, and the development of an automatic vehicle location and navigation system. Many other important contributions are documented below.

Geodesy is the oldest of the geosciences, whether one dates its birth from the earliest geodetic investigations of the ancient Greeks or from the early 19th century when Bessel and Gauss made their significant contributions. As an organized international endeavour, geodesy dates from 1862 when 15 European countries agreed to cooperate on better determining the size and shape of the earth. They met in Berlin two years later for the first International Geodetic Conference. That European council was the origin of the International Association of Geodesy (IAG), one of seven member associations of the International Union of Geodesy and Geophysics (IUGG) [A list of the seven member associations and their Canadian representatives is given on pages ii and iii - ed].

In 1987 Canada hosted the 19th General Assembly of the IUGG. Held in Vancouver from 9 to 22 August, the Assembly provided an opportunity for geodesists and geophysicists from around the world to discuss the latest developments in their fields. The IAG convened three symposia, three scientific meetings and five section meetings, as well as co-sponsoring various Union lectures and interdisciplinary symposia. Canadians made significant contributions to these meetings. Some of those contributions are documented in the following reports.

2. Geodetic Survey of Canada

Following the NAD83 adjustment of primary horizontal control networks in 1986, preparations began for the integration of secondary control networks in cooperation with the provinces. About one hundred thousand secondary points are being organized by regions, and considerable progress has been made in formatting and validating the data. In the northern regions, a test adjustment of 10 000 stations was successfully completed. A 41 000-station test adjustment was also completed by the Province of Ontario and their data will be forwarded to us early in 1988. Data for 22 000 points in Québec and the western provinces have also been formatted and evaluated; these will be sent to us early in 1988 for blocking, testing, and processing. In addition, an evaluation of the 2000-station Canadian Doppler net was completed.

Maintenance of the 7500-station Canadian primary framework continued with the integration of recently completed projects including a 50-station survey in Metropolitan Toronto. Currently the Geodetic Survey is establishing about 400 station positions annually using GPS.

Progress continued on the North American Vertical Datum (NAVD) project. At the end of 1987, more than a million data records had been

processed through validation programs, and data from more than 7700 field record books had been extracted and stored in computer files. Field levelling data for the project is complete except for a few lines which may have been affected by systematic errors caused by the earth's magnetic field on the instruments used. These lines will be relevelled in 1988.

Observed data for a network of levelling lines along the St. Lawrence River and along the Great Lakes to Thunder Bay were prepared and sent to the U.S. National Geodetic Survey to be included in their International Great Lakes Datum analysis.

Positioning by GPS increased in 1987. In the Northwest Territories and the Yukon, 197 points were positioned by this method. GPS was also used on two crustal movement surveys 11 points in the Charlevoix region of Québec, and 4 on Vancouver Island. GPS also provided mapping control in Alberta, Québec, Cape Breton Island, and Newfoundland. High precision survey measurements were also made at several special interest locations to monitor earth movement or structure deformation; 465 measurements were made.

Inertial surveys provided vertical and horizontal control on 126 points in Québec, and 536 vertical control points in the Northwest Territories for gravity surveys being undertaken by the Geophysics Division of the Geological Survey.

Precise levelling in 1987 (5380 km total) was done mainly by contract with the exception of about 600 km of special-order work. Most of the special-order work took place on both sides of the St. Lawrence River to the east of Québec City, required by the Geophysics Division. Of the remaining 4780 km, 1660 km was new work; the balance was relevelling of older lines.

Development of the new National Geodetic Information System began in 1987. The scope and requirements of the system were defined and development of a prototype system was started.

Work continued on the development of the Canadian Active Control System; an active control point prototype was designed and tested successfully.

A GPS monitor site was established at Yellowknife at the start of 1987 and operated throughout the year as part of an international satellite tracking network.

New gravimetric geoid solutions were compiled, plotted for analysis, and verified against GPS levelling-derived geoidal heights. A GPS field survey project was undertaken using benchmarks coincident with the primary levelling network. The purpose of the project was to control gravimetric geoid solutions.

A software package (NETAN) was developed by contract to provide strain analysis, with graphics, of one-, two- and three-dimensional geodetic networks.

Work continued on developing GPS processing and modelling software. A detailed analysis of GPS software requirements was completed.

3. Geological Survey of Canada, Geophysics Division

Photographic zenith tube (PZT) observations from the geodynamics observatories near Ottawa and Calgary continued monitoring of rotational time and the meridian component of polar motion. The observations have been reduced using the MERIT standards and contributed weekly via the General Electric (GE) Mark III computer network to the Bureau International de l'Heure, Paris and the International Polar Motion Service, Mizusawa, Japan to the end of 1987.

Canadian TRANET satellite Doppler stations collocated with the PZT instruments at the Ottawa and Calgary observatories recorded data from the navigational and geodetic satellites to facilitate precise orbit and gravity determinations over Canada. Real-time data 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 has been maintained using a distributed computer system.

A fully-automated GPS monitoring and data acquisition system based on a Texas Instruments TI 4100 receiver and an HP-A900 computer has been developed. GPS data reduction programs DIPOP, GPS22, and PHASER have been implemented on the Geodynamics Sections' HP-A900. In conjunction with the University of New Brunswick, a GPS preprocessor has been developed and enhanced tropospheric refraction modelling has been incorporated in the DIPOP software. The 1986 Port Alberni GPS data set has been reduced using this software package providing results which agree with the high precision terrestrial survey at the 0.4 ppm level. Capabilities and limitations of GPS for geodynamical studies have been analyzed.

A new approach to processing satellite-to-satellite observations has been proposed. This approach could increase data processing efficiency in a future satellite geopotential mission. A method to use power series expansion to evaluate the mutual potential of gravitating bodies with finite size has also been studied.

The first comprehensive crustal motion survey of the Charlevoix seismic zone was carried out in 1987 jointly with the Geodetic Survey. It is planned to repeat the survey at about four year intervals to study strain accumulation and release in the zone. The survey consisted of over 200 km of special-order levelling, 30 special-order line length measurements, and 35 precise gravity ties referred to an absolute gravity datum. The line length measurements carried out by meteorology-corrected laser techniques were also observed using GPS for comparison.

The development of the Canadian Geophysical Long Baseline Interferometry (CGLBI) System continued with six observing sessions on the Algonquin Radio Observatory (ARO) - Dominion Radio Astrophysical Observatory baseline in 1987. The Data Acquisition and Recording Terminal (DART) and the COrrelator and DAta Processor (CODAP) systems have been debugged and first fringes have been obtained. Arrangements to make ARO available for regular CGLBI observations are under negotiation with the National Research Council and other possible users. The size of the 46m ARO main radio telescope is particularly important for facilitating the use of small field systems for establishment of fiducial VLBI reference points for precise control network and crustal dynamics studies in Canada.

4. Canadian Hydrographic Service

The Canadian Hydrographic Service (CHS) horizontal control networks are being prepared for transformation from NAD27 to NAD83. This event will happen following the completion of the secondary adjustment of the federal-provincial horizontal control networks.

To date, approximately 40 new CHS charts have been compiled on NAD83 with notes being added to allow transformation of data referenced to NAD27. Transformation notes for an additional 50 charts have been published for plotting data referenced to NAD83 on the existing data base.

A network of 119 permanent gauging stations continued to be operated along the coast and inland navigable waters by the tidal divisions of the regional offices of CHS. In addition, tide and current surveys were carried out in North Channel (Georgian Channel), Hudson Bay, St. Lawrence River at Cornwall, Passamaquoddy Bay, Grande-Anse (Saguenay River), Vancouver Harbour, and Tofino. Current surveys in the Stuart Island area, Whirlpool, Green and Arran Rapids, as well as Sulphur Passage, Seymour Narrows, and Hayden Passage were also carried out. Temporary tide gauges at Kelsey Bay, Nanose Bay, and Gold River were operated to support a joint project involving the study of crustal movement on Vancouver Island.

Loran-C lattice production continued with the publication of 10 latticed charts. Loran-C time differences were measured at surveyed positions in Lake Erie and the results added to the Additional Secondary Factor (ASF) data base. Atlantic Region has extended their process of deriving adjustments to predicted ASF by comparison with quite widely dispersed observations over the entire continental shelf to the 200 mile limit. It is intended that all computed ASF results will be published in Radio Aids to Marine Navigation in the form of ASF contour maps.

In support of the electronic chart, considerable progress has been made in international standard setting through the International Hydrographic Organization (IHO) and internally in the U.S.A. by the Radio Technical Commission Maritime Services. International efforts in supplying common format digital chart data will be tested in the IHO North Sea project in October, 1988.

The CHS program in GPS continued its investigative work in determining the most critical factors for success in GPS operations. This year a software package called 'HYDROSTAR' was developed and tested. The software (currently running on an HP 200 computer) is used for real-time differential kinematic operations. The program is designed to operate with a number of different receivers. The algorithms used apply the 'accuracy insurance' philosophy whereby system operators are told when the results fail to achieve certain pre-set standards for accuracy. The system operates using single channel C/A-code with integrated carrier phase aiding and has demonstrated ± 3 m accuracy under typical conditions.

5. Ministère de l'Energie et des Ressources du Québec, Domaine territorial

Geodetic production comprised 933 new second- and third-order horizontal points and 358 second-order vertical points. Also 1858 points were inspected of which 12 were replaced. The integration into the official Québec networks of 4000 points established by other organizations was completed, and 3500 such points were classified. One new calibration baseline was installed at Port-Cartier, and another was extended at Université Laval. Stability verification was pursued on the Trois Rivières bridge. The second-order data of Québec was prepared for simultaneous adjustment with the primary network in view of NAD83. On this latter topic, a consultation seminar was held and various preparations are under way.

In the research sector, tests were conducted on two electro-optical instruments, the Geodimeter 440, and the Wild DI/OR-3000. A grant to Université Laval permitted advances in instrument calibration procedures and the processing of satellite laser ranging data. A major project for evaluating kinematic GPS as applied to aerial photography was completed. Publications in 1987 concerned geodetic observation preprocessing [Larivière, 1987] and GPS [Moreau, 1987].

6. Ontario Ministry of Natural Resources, Surveys, Mapping and Remote Sensing Branch

A research contract was let to the Centre for Surveying Science, University of Toronto, to review the available theoretical and practical studies of factors influencing the geodetic accuracy of GPS and to analyse actual GPS data with a view to (1) assessing actual deviations from the assumptions underlying the available GPS software, (2) examining the validity of current methods of rejection of outliers, (3) proposing appropriate amendments to the existing software, and (4) making recommendations on data banking GPS observations and related quantities. The results of this research should assist the Ministry in its decision regarding the capabilities and limitations of GPS in establishing new control networks in Ontario as well as strengthening existing ones.

Forty-five second- and third-order horizontal and third-order vertical municipal densification networks established in 1987 were analysed for quality control and compliance with Ministry specifications. About 30 new contracts have been let for work on second- and third-order horizontal and vertical municipal control densification networks in 1987. These networks will support large-scale mapping and integrated surveys. In addition, horizontal and vertical control is being established by the Ministry to support large-scale flood plain mapping. Three control surveys for flood plain mapping were completed in 1987.

With respect to the forthcoming NAD83 readjustment, the Ministry is preparing data previously adjusted into the NAD83 system for inclusion in the Canadian NAD83 secondary integration adjustment proposed to be carried out by the Geodetic Survey of Canada.

Work is progressing slowly on the preparation of vertical data for the forthcoming NAVD88 vertical redefinition and readjustment. There was little progress in 1987 in the processing of past vertical networks. However, about 45 new networks have contributed nearly 300 new benchmarks to the vertical data bank.

7. Alberta Department of Forestry, Lands and Wildlife, Land Information Services Division

Development of Phase I of the Multipurpose Alberta Survey Control Operations and Tasks (MASCOT) computer system was completed. This system will handle all of the geodetic data processing for the Land Information Services Division (LISD) as well as provide the access medium for geodetic information on survey control markers in Alberta. In developing MASCOT, relational tables defining observational, positional, and project (network attributes) data were constructed. MASCOT Phase II, which will enable handling of the readjustment on NAD83, is expected to be completed early in 1989.

User seminars on the new MASCOT system were held in Edmonton and Calgary. The seminars detailed geodetic and information system concepts, as well as provided information on the new products and services available through MASCOT [Barnes et al., 1987].

EDM calibration baseline publication values were revised on 1 December, 1987 for the Edmonton baseline due to suspected movement of pillars. This has resulted in the adoption of the concept of 'dynamic' baseline values for all provincial EDM calibration baselines. It is important to note that these baselines serve as the basis for scale control in conventional terrestrial geodetic surveys in Alberta.

Support was provided by LISD to the jointly funded City of Edmonton, Alberta Transportation research project to develop urban GPS specifications. Results of this project are expected to result in refinement of the LISD survey control "Standards, Specifications, and Guidelines" document [Rapatz et al., 1987].

8. British Columbia Ministry of Environment and Parks, Surveys and Resource Mapping Branch

A large GPS control project was carried out under contract in 1986 and 1987 in support of the 1:20 000 mapping program. A total of 584 stations was surveyed, including 93 old horizontal control stations and 25 benchmarks. They cover approximately 36, 1:250 000 map sheets in eastern and northern British Columbia. The projects were carried out by two companies using Trimble and Wild-Magnavox receivers.

Data preparation for the NAD83 secondary integration project continued. Data for 13 000 stations are at varying stages of preparation.

High density urban control networks with monuments at spacings of 100 to 300 metres are being established under the Integrated Survey Area Program. Work during 1986 and 1987 continued with the additions of Prince George, Saanich, and Victoria, and substantial additions to Delta, North Saanich, Kamloops, Burnaby, Vancouver, and Tumbler Ridge. There are now 33 integrated survey areas that have been officially declared by Order-in-Council, and 10 others are at various stages of development, comprising over 16 000 monuments.

9. University of New Brunswick, Department of Surveying Engineering

A computer program for the analysis of one-, two- and three-dimensional geodetic networks using strain and strength techniques, in addition to the traditional covariance analyses, has been developed under contract for the Geodetic Survey of Canada [Craymer et al., 1987]. The resulting program, NETAN, operates in an interactive graphics environment utilizing sequential adjustment techniques. Sequential methods for the maintenance of geodetic networks have also been developed. These methods allow for changes in observation values, weights, a priori coordinate constraints and densification without expensive recomputation of the entire network.

The novel use of altimetry for studying crustal density anomalies has been studied further. The study of the impact of temporal deformations on geodetic positioning was concluded. Pertinent findings have been published [Vanicek et al., 1987a]. A first attempt has been made to exploit the geophysical information content imbedded in the shorter wavelength component of the UNB December, 1986 detailed gravimetric geoid. Digital image analysis techniques have been employed to enhance the display and interpretation of the data. Visual correlations with gravity, magnetic and tectonic features were successfully made.

Variations in the angular momentum budget of the global ocean have been quantified using as input mean seasonal dynamic topography fields. These fields have been obtained from recent analysis of global specific volume data compiled by the U.S. National Oceanographic Data Center.

The conversion of GEOAIM, a VLBI data reduction program, to the J2000 system of constants and coefficients continues.

A new version of DIPOP, UNB's widely-used GPS relative positioning software package, was completed and released for distribution.

A fully-automated, proof-of-concept GPS tracking station has been developed under contract for the Geodetic Survey of Canada and Meridian Surveys Ltd. [Quek et al., 1987]. This active control point station, which consists of a Texas Instruments TI 4100 receiver interfaced to a MicroVAX II computer, is capable of controlling, monitoring and down-loading software into the receiver; capturing, interpreting, recording, editing, and validating data output by the receiver; extracting data from an interfaced weather station; managing local data storage prior to transmission; transferring data from the station to a remote computer using a communications network; and being monitored from a remote site.

Procedures and specifications for urban GPS surveys have been prepared for the City of Edmonton [Rapatz et al., 1987].
GPS measurements of a deformation network across the Juan de Fuca Strait have been analysed for the determination of precise inter-station baseline vectors [Kleusberg and Wanninger, 1987]. Work has continued on investigating the capabilities for the use of GPS measurements for the determination of platform position, velocity and acceleration in airborne gravimetry.

A study on the influence of refraction in trigonometric height traversing has been completed and evaluated in an M.Sc.E. thesis by Kharaghani [1987]. Previous conclusions, which were based mainly on simulations and test surveys, have been substantiated using real field data from a 400 km levelling line with observed gradients of temperature.

Work on the implementation of UNB's generalized method for deformation analysis continues with projects on dam deformations for the New Brunswick Electric Power Commission [Chrzanowski and Secord, 1987] and on deformations of a 40 km-long earth dyke for the petroleum industry in Venezuela [Chrzanowski, 1987]. A strategy for detection of outlying observations has been developed as a part of the generalized method [Chen et al., 1987].

A project on the use of GPS in local deformation surveys continues. Three campaigns (April and October, 1987, and May, 1988) have been completed in oil fields in Venezuela to study ground subsidence. WM101 receivers were used in all three campaigns in cooperation with Usher Canada Ltd. A preliminary evaluation of the results indicates that ground subsidence can be determined with GPS with standard deviations of about 3 cm when using baselines up to 18 km in length. The influence of tropospheric refraction seems to be the main source of error in the hot and humid study area. A balloon system for tropospheric profiling has been developed, giving results which indicate significant discrepancies with respect to the Saastamoinen and Hopfield models.

Research on the integration of GPS with geodetic levelling in ground subsidence studies continues using the aforementioned generalized method for deformation analysis.

Work continues on the use of non-linear elastic finite element analysis in deterministic modelling of deformations. A successful method for predicting ground movements in mining areas has been developed [Chrzanowski and Szostak-Chrzanowski, 1987] and implemented in mining areas in Canada, the U.S.A., China, and Poland.

A study to evaluate the three-dimensional positioning requirements at high latitudes has been completed [Wells et al., 1987]. Improvements in the reliability and robustness of real-time position determination through Kalman filtering of heterogeneous data is being investigated. A number

of algorithms have been developed, a software package written, and tests performed using real data known to have reliability problems. Comparisons of several methods for deriving position and velocity from a combination of GPS code and carrier phase measurements, both in real-time and post-mission are underway.

10. Université Laval, Département des Sciences Géodésiques et de Télédétection

Dans le domaine de l'instrumentation, des recherches théoriques [Jeudy, 1987] ont permis, sous la direction de L.M.A. Jeudy, la réalisation d'une station gyroscopique automatique basée sur le gyrocompas Wild GAK-1.

Dans le domaine de la géodynamique, l'expérience de détermination de l'azimut gyroscopique dirigée par L.M.A. Jeudy a été complétée et les résultats sont en cours d'analyse. J.G. Leclerc poursuit un projet sur l'application de la géostatique à des problèmes d'interpolation en gravimétrie et en géologie pour déterminer les structures géologiques internes de la croûte terrestre. La région de Charlevoix est utilisée comme zone expérimentale. La même théorie est appliquée pour l'interpolation des mesures gravimétriques. On prévoit développer l'algorithme pour l'étude et la détermination du géoïde en combinant plusieurs types de données.

Dans le domaine de la géodésie spatiale, le progiciel GEODYN a été installé sur l'ordinateur IBM 4381 de l'Université Laval et les mesures laser effectuées sur le satellite LAGEOS pendant le mois d'octobre 1983 ont été traitées. Les résiduels ont été analysés par analyse spectrale par moindres carrés. J.G. Leclerc a complété l'analyse des données GPS observées sur le réseau de Ste-Foy. Les données ont été ajustées avec le programme DIPOP. Une précision interne relative aux mesures GPS supérieure à 0.5 mm a été obtenue pour l'ensemble des lignes du réseau de 2e et 3e ordres. Le traitement des données a été réalisé en mode relatif [Leclerc, 1987].

Dans le domaine de la théorie du traitement des données par moindres carrés, des formules améliorées pour les matrices de variance-covariance ont été dérivées.

Dans le domaine de la géodésie et de l'astronomie, R.N. Sanchez a réalisé des éphémérides astronomiques à l'intention des arpenteurs-géomètres pour des observations expédiées d'azimut, latitudes, et longitudes [Sanchez, 1987]. R.N. Sanchez, M. Larose, et Y. Thériault ont complété un travail sur le développement d'une méthode de calculs géodésiques sur l'ellipsoïde de révolution. La méthode économise les séries de Legendre par l'application de la relation de Clairaut. Finalement, R.N. Sanchez a entrepris un projet sur le transfert de l'altitude géodésique à des distances de l'ordre de 20 km. La méthode s'appuie sur une généralisation de la méthode Sanchez proposée à l'Université de Vienne dans les études doctrales de Rosenthaler en 1982 et Wunderlich en 1984.

11. University of Toronto/Erindale College, Centre for Surveying Science

The comparative study of the methods of analysis and evaluation of levelling errors in the context of the task of Special Study Group 1.74 of the International Association of Geodesy was completed and discussed at the XIX General Assembly of the International Union of Geodesy and Geophysics in Vancouver.

An investigation of possible constraints for the definition of the 1988 North American height network was submitted for a master's degree [Tetreault, 1987].

The study of the southern California relevelling network continued, and an extensive program for the analysis of the Canadian levelling network for the NAVD was initiated with support from the federal Department of Energy, Mines and Resources.

The first season's geodetic measurements for the monitoring of the Ontario Hydro dam on the St. Lawrence River were made [Gunn et al., 1987].

Work continued on the development of an improved image sensor with industrial and geodetic applications, with support from the Natural Sciences and Engineering Research Council.

The study of the impact of GPS on surveying and mapping in Ontario continued with support from the Ontario Ministry of Natural Resources (OMNR).

A study on digital elevation models was carried out for OMNR [Wassef, 1987].

12. University of Calgary, Department of Surveying Engineering

Major progress has been made in gravity field approximation, including geoid determination, and in the development of kinematic methods for positioning and gravimetry. A study on the high frequency behaviour of the gravity field was made by Vassiliou and Schwarz [1987a]. Based on the analysis of actual data, common features of the anomalous gravity spectrum in different areas were discussed, and conclusions were drawn on data spacing for precise geoid and deflection determination and on covariance modelling for airborne gravimetry and gravity gradiometry. Sideris and Schwarz [1987] questioned whether or not the use of a high degree geopotential model can resolve the medium and high frequencies of the gravity field better than local or regional gravity anomalies. Results for geoid computations showed that it is preferable to truncate the model to lower degrees and supplement it by more local gravity data. A comprehensive study of frequency domain methods for gravity field approximation was undertaken [Sideris, 1987a]. The very efficient numerical methods resulting from this approach have been applied to Stokes's and Molodenskij's problem, as well as to a number of different terrain reduction methods, including topographic-isostatic approaches [Sideris, 1987b]. Geoid determination by spectral methods was compared to two other standard methods, namely, least-squares collocation and a combined integration-collocation approach [Schwarz et al., 1987]. Results show an agreement of 2-3 ppm with the 'ground truth' obtained from GPS-derived ellipsoidal heights and levelling-derived orthometric heights. In general, spectral methods were several times faster than space domain methods and also showed a slightly better accuracy. A similar study is currently in progress for mountainous regions. A new method of continuously profiling the geoid has been proposed [Schwarz, 1987a]. It uses the difference in trajectories obtained from kinematic GPS and from inertial survey systems. The implementation of the method is under investigation. Methods to solve the inverse gravimetric problem by combining gravity with other geophysical data have been discussed by Vassiliou and Schwarz [1987b]. Numerical comparisons are planned.

Kinematic methods of positioning and gravimetry were studied for a number of different cases, considering data from GPS, inertial systems, gravimeters, and gravity gradiometers. Cannon [1987] compared different methods of kinematic GPS positioning using pseudorange and carrier phase data. The analysis of almost three hours of data showed that problems due to cycle slips and interpolation are serious. However, the analysis also indicated that, even in the presence of cycle slips, positioning accuracies of better than 1 m are possible if good data density and good time tagging are available. Goldfarb [1987] studied inertial navigation system-GPS integration for photogrammetric applications. His results showed that aerotriangulation without ground control is clearly feasible for mapping scales down to 1:20 000 and perhaps beyond. Aircraft positioning accuracies at the level of 0.2 to 0.3 m can be achieved by using a simple strapdown inertial system for cycle slip correction and interpolation. The use of the Ferranti inertial system as the basis for an integrated positioning and navigation system has been discussed by Hagglund [1987]. A strategy for comparing different approaches to kinematic geodesy has been developed. Observables coming from GPS, inertial systems, dynamic gravimeters, and gravity gradiometers have been considered. Further work in this area is planned.

Research into Automatic Vehicle Location and Navigation (AVLN) began in 1986. Existing AVLN systems were studied and reviewed by Krakiwsky et al. [1987]. Research into electronic maps and AVLN systems has been undertaken. The application of expert systems in AVLN has been discussed by Karimi et al. [1987], and best routing algorithms for AVLN systems have been reported by Harris et al. [1987].

13. Nortech Surveys (Canada) Inc.

Shipborne navigation experiments were conducted to assess the performance of GPS in relative positioning mode for hydrographic surveying applications. Two vessel types were used, namely, a 10 metre survey launch and a 38 metre hydrographic vessel, to test thoroughly both equipment and methodology under different motion dynamics. TI 4100 GPS receivers were used in various combinations of P-code, C/A-code, and different 'user dynamics' modes. Code and carrier measurements were combined using a filter suitable for real-time utilization [Lachapelle et al., 1987a; 1987c]. The experiments were conducted successively in sheltered waters and in the open sea to provide the wide range of conditions necessary for a realistic analysis. An external horizontal position accuracy of 4.5 m at the 95% confidence level was achieved. Initial tests of a low-cost attitude sensor to measure roll and pitch motion was conducted. The estimation of heave motion with GPS was also attempted. The results of these experiments were reported by Lachapelle and Casey [1987].

The development of NOVAS (NOrtech Vector Adjustment Software), an automated program suitable for the precise reduction of GPS static carrier phase data, was completed and the program was used extensively for high-precision surveys around the world [Jones and Wanless, 1987]. The program, which is IBM AT compatible, is based on the double difference method and uses an adaptive Kalman filter for the efficient determination of integer ambiguities over short baselines. A sequential adjustment model allows for the robust and automatic detection of cycle slips and observation noise.

GPS positioning technologies were utilized successfully in many areas of the world for a wide variety of positioning and navigation applications [Colman et al., 1987]. The impact of GPS on geographic information systems was studied [Lachapelle et al., 1987d].

The Norstar Instruments Division completed the development of its C/A-code based NORSTAR 1000 GPS receiver and several production units were built and delivered. A real-time relative kinematic land test was conducted to demonstrate the capability of the system [Fenton et al., 1987]. External real-time accuracies of 2 m were confirmed. The Division is currently designing other advanced C/A-code and P-code based GPS hardware and software products.

14. Usher Canada Limited

Investigations related to the use of GPS static relative positioning in the monitoring of ground subsidence continued in cooperation with the University of New Brunswick. A second-epoch WM101 observation campaign was completed in April on the UNB Mactaquac test network. This work followed upon a similar, first-epoch campaign, completed in October 1986. First- and second-epoch observation campaigns were also completed in May and October in Venezuela in conjunction with geodetic levelling, to investigate the use of GPS in determining the extent and rate of ground subsidence induced by oil extraction in the vicinity of Lake Maracaibo. A preliminary analysis of the GPS results indicates that accuracies of better than 1 cm + 2 ppm of baseline length have been attained. A more detailed analysis, including a comparison with geodetic levelling, is currently underway.

A study of GPS static differential data processing methodologies and software was undertaken on behalf of the Geodetic Survey Division, Energy, Mines and Resources Canada, in collaboration with UNB, the University of Calgary, and Nortech Surveys (Canada) Inc. A report is being prepared for delivery in early 1988.

Research on the use of geoidal modelling in the adjustment of GPS networks was initiated. Geoidal modelling software based on the University of Calgary FFT approach and the GEM10B geopotential model has been implemented on an HP 1000 series A700 computer for this purpose. This software has subsequently been employed in the adjustment of several GPS networks observed on the prairies and in central Canada. Preliminary results indicate a significant improvement in results as evidenced by a marked reduction in the a posteriori variance factor.

A 2.5-year program of research and development in precise engineering and deformation surveys, to be undertaken in collaboration with UNB, was initiated in December under the National Research Council's IRAP program. The goal of this project is the development of a unified methodology for the measurement and analysis of crustal and structural deformations, based on the UNB generalized method. Areas to be addressed include precise GPS, terrestrial geodetic, and geotechnical measurement techniques for crustal and structural deformation survey applications; the optimal design of integrated deformation networks; and the geometrical analysis and physical interpretation of deformations by empirical and deterministic (finite element) methods.

15. McElhanney Geosurveys Ltd., Marine and Geodetic Services Division

The commitment to GPS surveying technology was further enhanced by the acquisition of four additional Trimble 4000SX receivers, bringing the total GPS receiver complement to nine units. These receivers were used extensively throughout North America and South East Asia on various projects such as mapping control, highway realignment, fibre-optic route location, and marine navigation.

An integrated analysis program was developed to predict system deformations using survey, geotechnical and structural data, and a finite element model for solution. The program was tested in a practical application in Alberta at the site of a buried gas pipeline river crossing. GPS and conventional methods were used to obtain survey data and direct comparisons between the two were made.

In excess of 200 new survey stations were established using GPS in support of the B.C. Government's Terrain Resource Inventory Management program. All stations were targeted for aerial photography, which was achieved with a 70 mm Hasselblad camera mounted through the floor of a helicopter.

Site surveys were undertaken for the new Short Range Radar locations along the coast of Labrador using GPS, conventional, and hydrographic surveying methods.

A major monitoring and deformation analysis project was continued in the Revelstoke area of British Columbia.

A purpose-built IBM compatible computer was designed for navigation use. This portable DC-powered computer is designed for both airborne and marine navigation, and data acquisition.

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I (B) GRAVITY

Compiled by: A.K. Goodacre

1. Summary

(a) Instrumentation

The Geological Survey of Canada (GSC) Gravity Instrumentation Group has conclusively demonstrated that a large, spurious annual signal in the output of their LaCoste and Romberg ET-12 recording Earth-tide gravity meter is due to seasonal variations in humidity. Tests are now underway to quantify the effect and the manufacturer has recommended replacement of internal seals in the instrument.

Tests with the GSC absolute gravity meter indicate that gravity changes related to post-glacial rebound should be observable after only a few years of monitoring at selected sites in the Hudson Bay region.

The University of Saskatchewan has purchased an electrostatic feedback nulling system for their LaCoste and Romberg Model G gravity meter. The substantial improvement in the instrument's sensitivity will permit its use for micro-gravity surveys.

The Computer Integrated Geodata Acquisition and Logging system (CIGAL), reported in last year's Canadian Geophysical Bulletin (Vol.39), is now fully operational. An associated suite of computer programs (SHIPAC) which checks, corrects and formats geophysical data logged by CIGAC is also in operational use.

(b) Surveys

During 1987 more than 3,800 gravity observations were made by the GSC to support studies in: the Arctic (Polar Continental Shelf, Axel Heiberg and Ellesmere Islands), British Columbia (Lithoprobe lines and Department of National Defence requirements) and Ontario (Lake Huron, Algonquin Park). One of the highlights was the use of an inertial survey system at high-latitudes (above 72° N) to provide elevations for Arctic gravity observations. Precise gravity surveys by GSC employees in the Ottawa-Hull region revealed the presence of small (on the order of 5 to 10 microGals) secular changes in observed gravity at some points of the precise gravity network.

The Ministère de l'Energie et des Ressources (Québec) carried out a detailed gravity survey in the Chibougamau region and the Nova Scotia Research Foundation Corp. added further detailed gravity coverage to the Cumberland Basin.

Université Laval made further detailed gravity measurements over Mont Megantic. Université du Québec à Montréal established detailed profiles in the Rouyn-Noranda regions. The Université du Québec à Montréal also carried out gravity surveys in the northern Labrador Trough.

(c) Database and maps

Colour Separations and text for the first five maps (Observed Gravity, Free Air, Bouguer, Isostatic and Horizontal Gradient) for the Canadian Geophysical Atlas have been completed. The maps will be printed in early 1988.

In response to requests from workers both within the GSC and outside in industry and university, numerous gravity maps (many in colour) at various scales, projections, etc. were produced during 1987. These maps included several maps for the Labrador Sea Basin Atlas.

The Yukon gravity data set has been prepared for GSC open file.

(d) Interpretation

Within the GSC, the following studies have been made:

(i) Three-dimensional modelling of the Sept-Iles mafic intrusion shows that this feature can be represented by an inverted-cone structure with density increasing with depth. The axis of the structure is tilted south away from the Grenville Province, possibly reflecting lithosphere bending during the Appalachian Orogeny.

(ii) An "enhanced" isostatic anomaly map of the Canadian Arctic essentially eliminates regional variations in gravity due to rock-water interfaces, continent-ocean boundaries, etc. and outlines areas of volcanism and intrusion, oceanic or continental crust, and recently tectonically active regions. Higher seismicity and heat flow values are often related to positive isostatic anomaly areas in transitional regions.

(iii) Recent measurements in the Queen Charlotte Islands (B.C.) define a possible zone of Karmutsen Formation mafic volcanics between Skidegate Inlet and Masset Inlet and a possible seaward extension of siliceous volcanic rocks in the Masset Inlet-Rennell Sound area.

An interpretation of gravity data from the Kapuskasing Structural Zone has been completed at the University of Western Ontario. Quasi-vector fields derived from horizontal gravity gradients have been particularly useful in resolving lithological boundaries, faults and discrete intrusive bodies.

Gravity anomalies in central Newfoundland have been utilized at the Memorial University of Newfoundland in the interpretation of the mode of emplacement of the Ackley batholith.

Studies at the University of Calgary indicated that a suitable scheme for geoid computations is to truncate high-degree geopotential models and supplement these models by local gravity data.

At the University of Toronto, studies are underway for improved computer interpretation methods of gravity (and magnetic) data. One procedure under investigation is an "extremal" method based on a "complexity" norm. Numerical tests on synthetic models are encouraging.

2. Geological Survey of Canada

(a) Geophysics Division

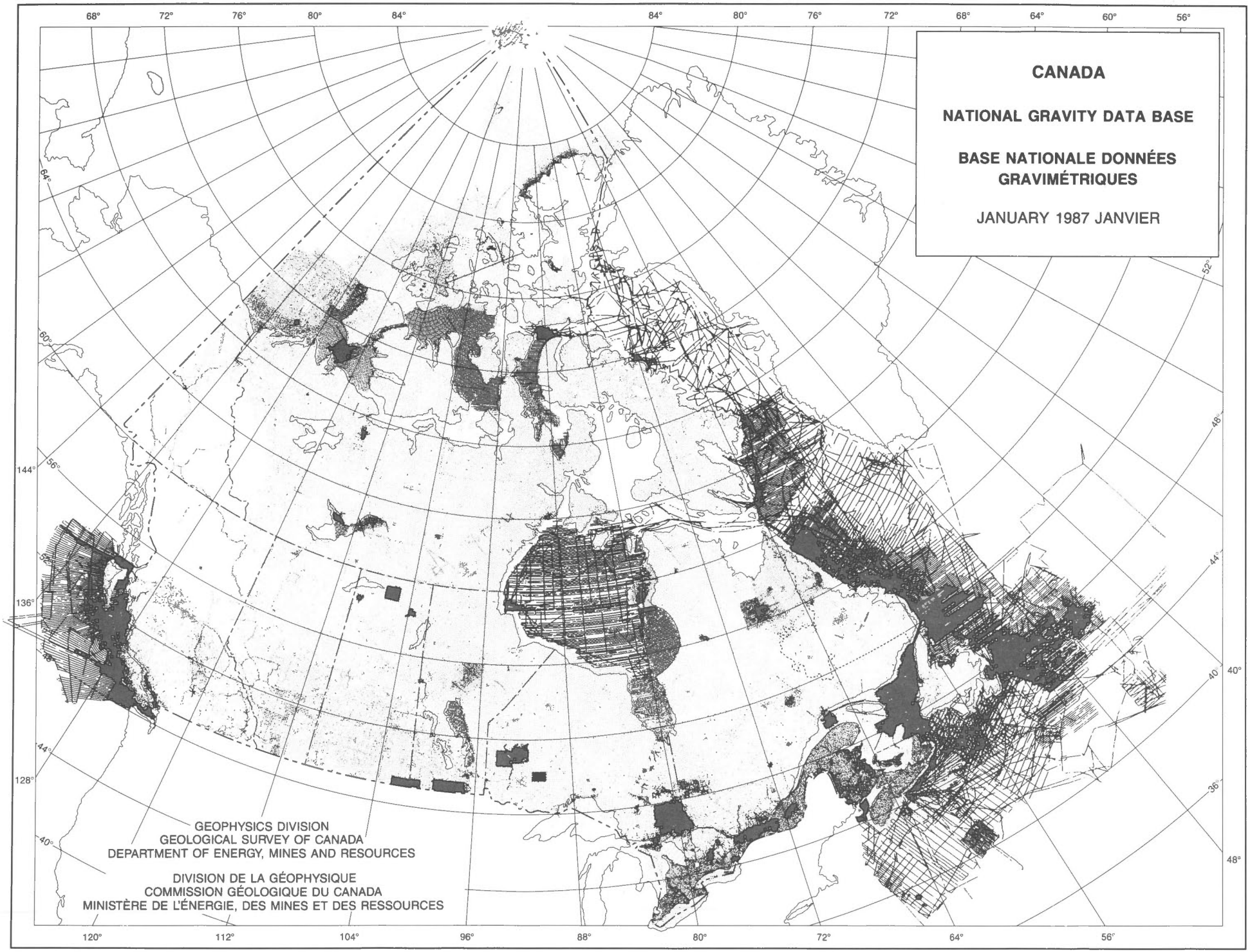
(i) Gravity Standards (P.N. Courtier, J.O. Liard, R.V. Cooper and R.K. McConnell). Absolute gravity measurements, in support of the Canadian Gravity Standardization Net, were carried out at Ottawa, Pinawa (near Winnipeg), Priddis (near Calgary) and Victoria. Measurements at Fredericton and Halifax are planned for 1988 to support the eastern portion of the Net.

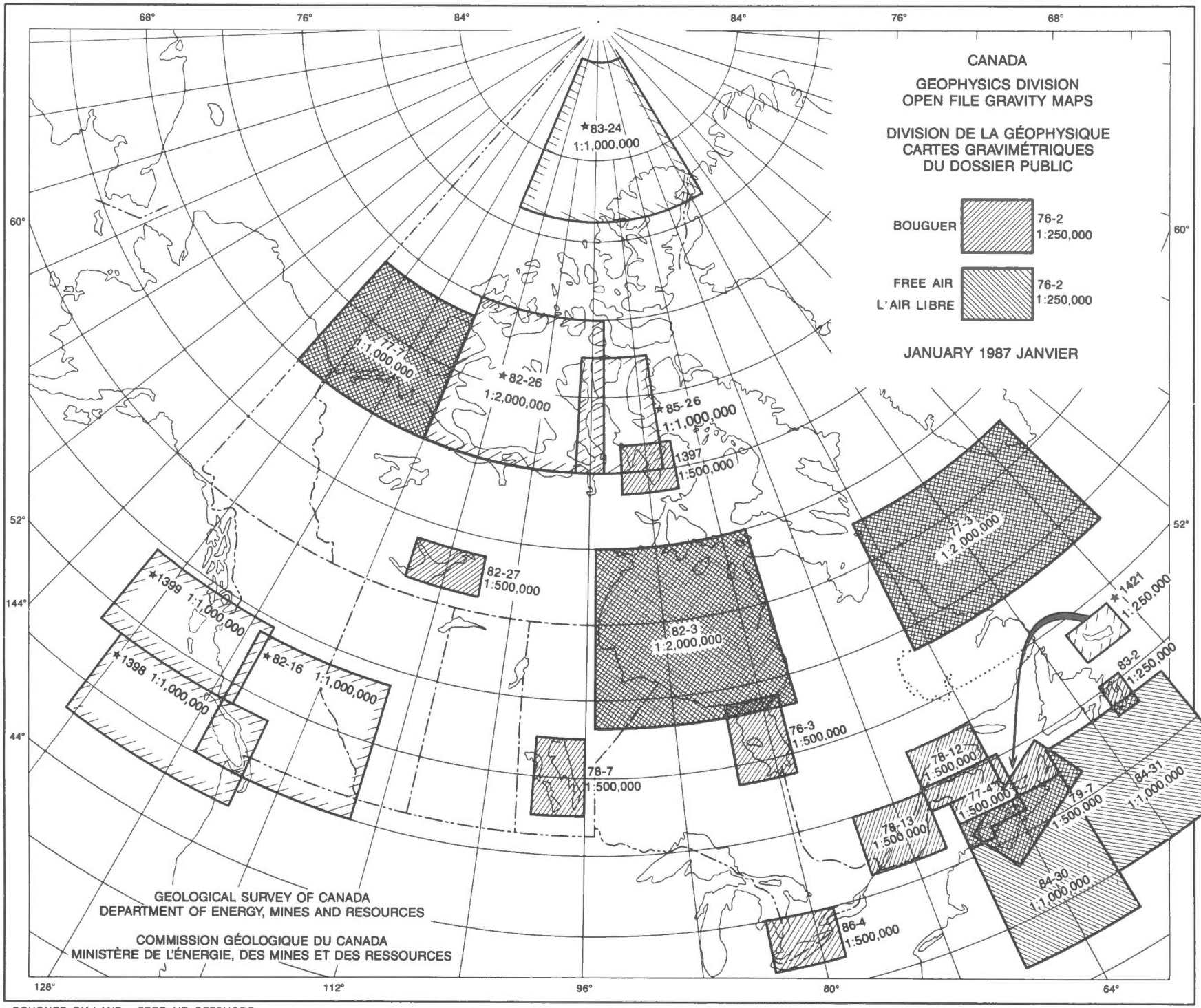
(ii) Gravity Surveys (D.W. Halliday, R.V. Cooper and P.J. Winter). During 1987 more than 3800 new gravity stations were added to the national gravity data base. Many of the surveys were made in conjunction with other GSC Divisions and other outside agencies. A summary is given below; details may be found elsewhere in the report.

Polar Continental Shelf - Using the Canadian Ice Island as a base for operations and in co-operation with the Canadian Hydrographic Service, more than 1900 gravity and bathymetry stations were established from the frozen surface of the Arctic Ocean. The survey filled the last remaining gap in the gravity coverage of the polar shelf from the Beaufort Sea to the Lincoln Sea, representing 25 years of surveying.

Axel Heiberg and Ellesmere Island - In response to a request from the Institute of Sedimentary and Petroleum Geology (GSC) two traverses were made across Axel Heiberg Island and the northwestern part of Ellesmere Island, with gravity stations placed 3km apart. A highlight of the survey was our first use of a Litton Inertial Survey System (LASS II) north of latitude 72°N to provide elevations for the gravity stations. The system was operated by the Geodetic Survey of Canada.

British Columbia - In response to a request from the Lithosphere and Canadian Shield Division, more than 250 gravity observations were made along Lithoprobe seismic lines. 230 new gravity observations were made in conjunction with the Department of National Defence in the southwestern portion of the province to augment existing regional gravity coverage.


CANADA
NATIONAL GRAVITY DATA BASE
BASE NATIONALE DONNÉES GRAVIMÉTRIQUES
JANUARY 1987 JANVIER
GEOPHYSICS DIVISION
GEOLOGICAL SURVEY OF CANADA
DEPARTMENT OF ENERGY, MINES AND RESOURCES
DIVISION DE LA GÉOPHYSIQUE
COMMISSION GÉOLOGIQUE DU CANADA
MINISTÈRE DE L'ÉNERGIE, DES MINES ET DES RESSOURCES



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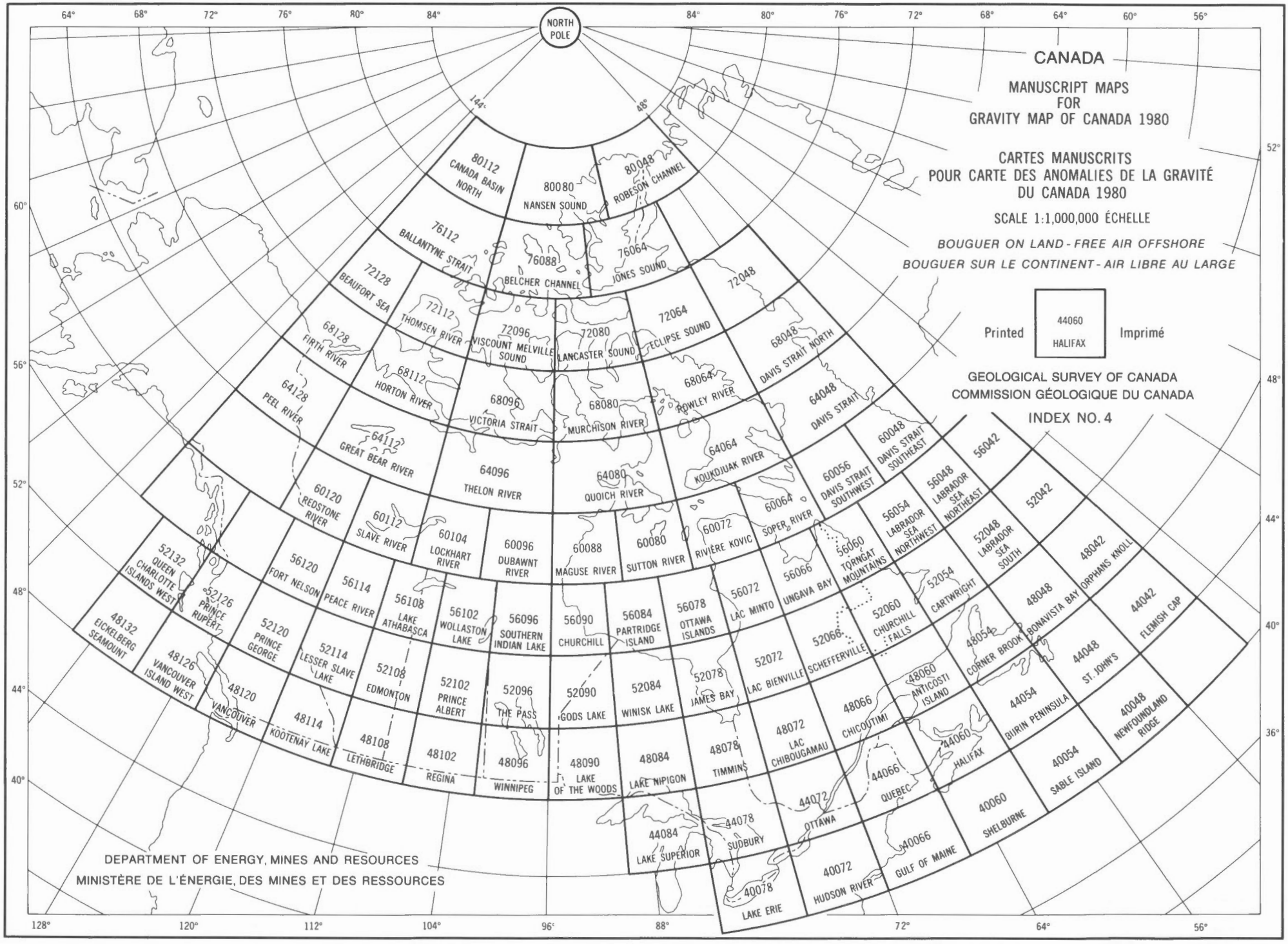
CANADA
MANUSCRIPT MAPS
FOR
GRAVITY MAP OF CANADA 1980
CARTES MANUSCRITS
POUR CARTE DES ANOMALIES DE LA GRAVITÉ
DU CANADA 1980
SCALE 1:1,000,000 ÉCHELLE
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COMMISSION GÉOLOGIQUE DU CANADA
INDEX NO. 4
DEPARTMENT OF ENERGY, MINES AND RESOURCES
MINISTÈRE DE L'ÉNERGIE, DES MINES ET DES RESSOURCES
NORTH POLE
80112 CANADA BASIN NORTH
80080 NANSEN SOUND
80048 ROBESON CHANNEL
76112 BALLANTYNE STRAIT
76088 BELCHER CHANNEL
76064 JONES SOUND
72128 BEAUFORT SEA
72112 THOMSEN RIVER
72096 VISCOUNT MELVILLE SOUND
72080 LANCASTER SOUND
72064 ECLIPSE SOUND
72048
68128 FIRTH RIVER
68112 HORTON RIVER
68096 VICTORIA STRAIT
68080 MURCHISON RIVER
68064 ROWLEY RIVER
68048 DAVIS STRAIT NORTH
64128 PEEL RIVER
64112 GREAT BEAR RIVER
64096 THELON RIVER
64080 QUOICH RIVER
64064 KOUKDJUAK RIVER
64048 DAVIS STRAIT
60120 REDSTONE RIVER
60112 SLAVE RIVER
60104 LOCKHART RIVER
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60088 MAGUSE RIVER
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60072 RIVIÈRE KOVIC
60064 SOPER RIVER
60056 DAVIS STRAIT SOUTHWEST
60048 DAVIS STRAIT SOUTHEAST
56042
52132 QUEEN CHARLOTTE ISLANDS WEST
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56120 FORT NELSON
56114 PEACE RIVER
56108 LAKE ATHABASCA
56102 WOLLASTON LAKE
56096 SOUTHERN INDIAN LAKE
56090 CHURCHILL
56084 PARTRIDGE ISLAND
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56072 LAC MINTO
56066 UNGAVA BAY
56060 TORNGAT MOUNTAINS
56054 LABRADOR SEA NORTHWEST
56048 LABRADOR SEA NORTHEAST
52042
48132 EICKELBERG SEAMOUNT
48126 VANCOUVER ISLAND WEST
52120 PRINCE GEORGE
52114 LESSER SLAVE LAKE
52108 EDMONTON
52102 PRINCE ALBERT
52096 THE PAS
52090 GODS LAKE
52084 WINISK LAKE
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52066 SCHEFFERVILLE
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48042 ORPHANS KNOLL
48120 VANCOUVER
48114 KOOTENAY LAKE
48108 LETHBRIDGE
48102 REGINA
48096 WINNIPEG
48090 LAKE OF THE WOODS
48084 LAKE NIPIGON
48078 TIMMINS
48072 LAC CHIBOUGAMAU
48066 CHICOUTIMI
48060 ANTICOSTI ISLAND
48054 CORNER BROOK
48048 BONAVISTA BAY
44084 LAKE SUPERIOR
44078 SUDBURY
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44066 QUEBEC
44060 HALIFAX
44054 BIRIN PENINSULA
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44042 FLEMISH CAP
40078 LAKE ERIE
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40060 SHELBURNE
40054 SABLE ISLAND
40048 NEWFOUNDLAND RIDGE
144°
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84° 80° 76° 72° 68° 64° 60° 56°
52° 60° 56° 48° 52° 44° 48° 40° 44° 36° 40°
128° 120° 112° 104° 96° 88°
72° 64° 56°

Ontario - Local gravity surveys were made on the eastern and northern shores of Lake Huron and in Algonquin Park in response to requests by the Lithospheric and Canadian Shield Division and by the Mineral Resources Division, respectively.

(iii) Gravity Data Base and Map Production (J.F. Halpenny, D.B. Hearty, L.A. Warren, R.A.F. Grieve and A.K. Goodacre). In cooperation with the United States Geological Survey, the Geological Society of America and various other institutions and organizations, aeromagnetic total field and Bouguer on land, Free Air offshore gravity maps of North America were complied and printed. These are at a scale of 1:10 million and are a contribution to the Decade of North American Geology. Fifty-one coloured 1:1 million magnetic anomaly maps of areas in Canada, as part of the National Earth Science Series of Canada, were published. The fifth edition, the first all digital, 1:5 million Magnetic Anomaly Map of Canada was also published. Approximately 600 requests for digital data or analog products were filled from the National Gravity Data Base, which is now combined with aeromagnetic data activities in the renamed Geophysical Data Centre.

Colour separations have been completed for the first five maps (Observed Gravity, Free Air, Bouguer, Isostatic and Horizontal Gradient) of the Canadian Geophysical Atlas, and the maps are ready for printing.

(iv) Precise Gravimetry (R. Bastien). Quarterly surveys using four LaCoste and Romberg model D gravity meters on the local Ottawa crustal stability network revealed the presence of secular changes in observed gravity of the order of 5 to 10 microGals at some points of the network.

(v) Absolute Gravity (P.N. Courtier, J. D. Liard, R.V. Cooper and A.K. Goodacre). Absolute gravity measurements in support of vertical crustal motion studies were made at Churchill, Man., Kuujjuaarapik (Great Whale River), Que. and Schefferville, Que. using the GSC SKYVAN for transportation. These results, with the GSC absolute gravimeter, have demonstrated that a precision of better than 2 microGals can be expected under non-laboratory conditions. At this level of precision the expected post-glacial rebound signal of 2-4 microGals/yr should be measurable in just a few years of monitoring, provided that local corrections for groundwater, atmospheric pressure and ocean tides can be made to the same precision as the instrumental error.

(vi) Instrumentation (R. Bastien, R.J. Beach and C. Gagnon). It has been demonstrated conclusively that large annual signals in recording earth-tide gravity meter readings are due to seasonal variations in humidity in the rooms in which the instruments are operated. The effect of a weak, unwanted mode in the operation of the laser used in the GSC absolute gravity meter is currently being investigated. D.R. Bower and J.F. Halpenny completed a study on the technical feasibility of airborne gravity measurements (Geophysics Division Internal Report 87-3).

(vii) Gravity Interpretation (R.A.F. Grieve). Interpretation of the horizontal gradient of Bouguer gravity over North America led to a series of publications dealing with its utility in defining crustal structure, the assembly history by collision tectonics of the major cratonic blocks of North America and the basement geology, structure and evolution of the Central Plains. The digital data set of gradient values for North America gridded at 5km was made publicly available. Digital data used in the preparation of five 1:5 million maps of Canada: Observed Gravity, Free Air, Bouguer, Isostatic and Horizontal Gradient of Bouguer were also made available.

(viii) Charlevoix Observatory (D.R. Bower). Tidal and coseismic water well level observations carried out at the Charlevoix geophysical observatory during the period 1979-1986 were summarized in a Geophysics Division Internal Report (87-2).

(b) Lithosphere and Canadian Shield Division

(i) Appalachians (M.D. Thomas). Preliminary results have been obtained for 2 ½D modelling of a detailed gravity profile (1km spacing of stations along greater part) extending from the vicinity of Port au Port Bay to Burgeo in southwestern Newfoundland. A crustal block between the Long Range and Victoria Lake faults is interpreted to consist in large part of mafic igneous rocks, including those of the Main Gut and Annieopsquotch complexes, that extend to a uniform dept of about 6km. The sides of the block are near-vertical, suggesting that the two bounding faults have a similar steep inclination and extend to at least the same depth. Granitic bodies to the southeast of the Victoria River fault, such as the Burgeo granite, are estimated to be about 4km thick with steep lateral contacts.

(ii) Artic Studies (L.W. Sobczak). Free-air, Bouguer and isostatic gravity maps, together with a new type of gravity map - an enhanced isostatic anomaly (EIA) map - were evaluated for their utility for geologic studies. The EIA map was judged most useful. It enhances variations in gravity related to geological structure, while at the same time it suppresses regional variations related to continental-oceanic crustal boundaries, water-rock interfaces and topography/bathymetry and associated isostatic roots/antiroots. Generally speaking, the zero contour delimits, variously, areas of mafic volcanism and intrusion, oceanic or continental crust, and regions tectonically active during the last 100 Ma. Within an oceanic region negative anomalies may indicate older (> 100 Ma) oceanic crust or pieces of continental crust, whereas positive anomalies indicate newer crust (< 100 Ma). Within a continental region, positive anomalies correspond with recently (< 100 Ma) active areas as indicated by mountains, volcanism, intrusions and sedimentary deposits, whereas negative anomalies indicate (> 100 Ma), more stable areas. Within a region transitional between continental and oceanic crust positive anomalies relate to newer (< 100 Ma) areas whereas negative anomalies relate to older areas. High seismicity and heat flow values are usually associated with areas of positive anomalies.

(iii) Canadian Shield. Ongoing gravity studies in the Quoich River Map Area (International Map of the World, NQ-15/16/17), NWT have included regional imaging of Bouguer anomalies and 2 ½D and 3D modelling of Archean and Aphebian granites adjacent to the Amer shear zone.

(iv) Interpretative Methodology. A new method has been developed to interpret gravity anomalies associated with two-dimensional geological boundaries, e.g. plate edge, which separate rock masses of different density. Upward continuation of first and second horizontal derivative profiles is used to determine the dip and vertical extent of such boundaries. Limitations of the method have been established through tests with theoretical plate models. The method has been applied to real data using a gravity profile extending across the boundary between the Kisseynew gneiss belt and the Baldock batholith in the Trans-Hudson orogen.

(c) Atlantic Geoscience Centre (J. Woodside)

(i) Gravity Surveys. Marine gravity measurements were made during the Hudson 87-019 cruise, principally along deep seismic reflection Lithoprobe East lines 85-2, 3 and 4, shot across the continental margin of Newfoundland. The data were collected in support of seismic refraction experiments on the Lithoprobe lines, and to provide some additional cross lines for previous surveys over the eastern margin of the Grand Banks.

(ii) Data Handling and Map Production. Software systems CIGAL and SHIPAC both underwent successful field trials during the Hudson 87-019 cruise. They are now considered to be fully operational. CIGAL is a Computer Integrated Geodata Acquisition and Logging system which facilitates the logging, documentation, and transfer to a data processing computer of any designated parameters to be recorded as a time series during the course of a cruise; SHIPAC is the suite of computer programs which checks, corrects, and formats geophysical data logged by CIGAL, calculating anomalies and storing the data.

Gravity data have been compiled for several maps in the Basin Atlas Series which is scheduled for publication during the next few years. Work for the Labrador Sea Basin Atlas was completed and a start made on the Scotian Shelf Atlas and Grand Banks Basin Atlas.

(iii) Data Interpretation. Three-dimensional gravity modelling of the Sept-Iles intrusion has shown that a layered intrusion can be adequately modelled with an inverted cone structure in which the density of the layers increases with depth. The axis of the cone is tilted southward away from the Grenville Province. This tilt may reflect lithospheric bending during the Appalachian Orogeny.

Various areas are being investigated with the help of gravity modelling. A study of the Gulf of St. Lawrence is underway in connection with the interpretation of several deep seismic reflection profiles acquired through the Lithoprobe East project. As a contribution to the Frontier Geophysics Program (Basin Atlas), gravity data along four margin transects are being used to constrain and model the crustal framework. A comparison of the geophysical signatures of these diverse margins is in progress in an effort to understand variations in their development.

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

(i) Gravity Surveys. During the months of August and September, 1987, Geoterrex Limited, Ottawa, under contract to the GSC, collected 650 gravity stations (at 12km intervals) in the Yukon and Northwest Territories. The region covered extends from 64° to 66°N latitude and from 127° to 137°W longitude. For accurate positioning of the gravity stations, Global Positioning System (GPS) receivers were employed in the differential mode. Nortech Surveys Limited, Calgary, provided the GPS equipment and operators. Regional gravity coverage is now complete in the Yukon everywhere north of 64°N.

During July, 1987, 135 gravity observations were made on and near Graham Island (in the Queen Charlotte Islands). Besides filling in the regional anomaly field at a 10 to 12km spacing, two detailed transects were completed along Skidegate and Masset Inlets, oriented approximately normal to regional crustal trends.

(ii) Data Handling. The Yukon gravity anomaly field will be displayed as a GSC Open File in early 1988.

(iii) Data Interpretation. The new measurements define a 10km by 20km northwest-trending Bouguer anomaly high (residual amplitude about 20 mGal) along a gravity gradient between Skidegate and Masset Inlets. A northeast-trending low of similar dimensions (residual amplitude about 10 mGal) is present between Rennell Sound and Masset Inlet. The former anomaly (high) could be caused by Karmutsen Formation mafic volcanics in the subsurface adjacent to an apparent east-facing basement scarp, and associated eastward thickening of sediments within the Queen Charlotte Basin. The latter anomaly (low) is associated with an area of exposed siliceous volcanic rocks up to 1km thick.

3. Ministère de l'Energie et des Ressources (D.L. Lefebvre)

Un levé gravimétrique détaillé (avec en plus une prise d'échantillons géochimiques des sols) a été effectué à l'automne 1987 dans la région de Chibougamau. Quelque 1 500 stations sont réparties sur les 2 feuillets SNRC 32 G/15 et 32 G/16. Les voies terrestres, les voies d'eau et l'utilisation d'un hélicoptère ont permis une densité de mesures relativement régulière de 0,75 station par kilomètre carré. De plus, un profil NE-SW détaillé a été effectué dans cette région sur une longueur de 120 kilomètres. Quelque 40 stations de gravimétrie sont espacées d'environ 300 mètres le long de routes pur ce profil. Des cartes de l'anomalie de Bouguer et du gradient vertical seront publiées au cours de 1988. Aussi, travail d'interprétation sera entrepris le long du profil au cours de 1988.

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

A north-south gravity profile was constructed across the Cumberland sedimentary basin in northern Nova Scotia. Terrain corrections have been estimated along the gravity profile and various model interpretations will be produced with the aid of increasingly complex geological cross-sections utilizing available borehole, seismic, geological and density information.

Terrain corrections were estimated for gravity survey data over the western part of the Sydney coal basin. These will be used to complete the contoured Bouguer gravity map coverage of the basin at a scale of 1:50,000. Interpretations of the gravity maps will follow.

5. University of Calgary (K.-P. Schwarz)

A study on the high-frequency behaviour of the gravity field was made by A.A. Vassiliou and K.-P. Schwarz. Based on the analysis of actual data, common features of the anomalous gravity spectrum in different areas are discussed, and conclusions are drawn with regard to appropriate data spacing for precise geoid and deflection determination, and on covariance modelling for airborne gravimetry and gravity gradiometry.

The question of whether the use of a high-degree geopotential model can resolve the medium and high frequencies of the gravity field better than local or regional gravity anomalies was studied by M.G. Sideris and K.-P. Schwarz. Results for geoid computations showed that it is preferable to truncate the geopotential model to lower degrees and supplement it by more local gravity data.

6. Université Laval (M.-K. Seguin)

Gravity coverage on Mount Megantic, one of the Monteregian Hills, was supplemented by additional measurements over the granitic, dioritic and gabbroic units. Regional and residual gravity maps were prepared and rock densities derived from these data.

Estimation of the regional gravity field in the La Malbaie area was carried out using Matheron's generalized variable theory.

7. Memorial University of Newfoundland (H. Miller)

During 1987, rock samples were collected for physical property determinations from eastern Newfoundland. These data will be used with additional gravity and sample data to be collected in 1988 to continue the interpretation of Avalon Terrane gravity and magnetic data collected since 1980.

Interpretation continued on gravity data from western and central Newfoundland, especially on data from the Ackley Granite Suite. The gravity anomalies have been utilized in interpreting the mode of emplacement of this batholith.

8. Université du Québec à Montreal (J.C. Mareschal)

Gravity measurements were made in the northern Labrador trough, near Leaf Bay, north of Kuujjuaq, Québec. The data were collected along Leaf River, in the Superior Province, west of the trough, and along the shore of the Ungava Bay, in the Churchill Province, east of the trough. These data will complete a profile across the trough. Additional data were collected along the Koksoaq river, west of Kuujjuaq.

Gravity measurements were also made in the vicinity of Rouyn-Noranda, Québec, with closely spaced data (1km) being collected along the Lithoprobe seismic transect.

9. University of Saskatchewan (J.B. Merriam)

An electrostatic feedback nulling system was purchased for our LaCoste and Romberg Model G gravity meter. The prototype system arrived in September, 1987 and was tested during the fall. The electrostatic nulling system substantially improves the sensitivity of the meter, within a continuous 3 mGal range, and affords a slight improvement over a much larger range. The improvement in sensitivity will permit us to do microgravity and gradient surveys.

J. Merriam and D. Gendzwill intend to investigate the performance of the instrument in examining the geology near potash mine openings, and in several applications to coal mines in the south of the province.

10. University of Toronto (R.C. Bailey)

S. Reford and R. Bailey worked on improved computer interpretation of gravity and magnetic data. Modern, automatic, computer-based gravity- and magnetic-modeling methods which do not require operator intervention or a priori specification of the topology of the model are almost always "extremal" methods, and do not generally produce geologically "reasonable" models. Bailey and Reford, therefore, proposed an "extremal" method based on a "complexity" norm for density (or magnetization) models; namely, the mean value of the magnitude of the density (or magnetization) gradient. On the basis of analogous work done in unidimensional seismic-inversion problems, minimization of this norm, subject to fitting both the gravity (or magnetic field) measurements and the density (or magnetization) values obtained by direct sampling at the surface or underground, should lead to simple (reasonable) models. Numerical tests on synthetic data generated for simple, two-dimensional test structures (e.g. a tabular sill, a dipping thick dike of finite depth extent) indicated that this is the case.

11. University of Western Ontario (H.H. Schloessin)

A gravity analysis with interpretation of the region bounded by the meridians 72° to 85°W and parallels 45° to 52°N, is being done by P.F. Lenson as a B.Sc. Honours thesis entitled "Gravity analysis of the Kapuskasing Structural Zone". Bouguer anomalies, free-air anomalies, horizontal gravity gradients and second derivatives have been determined. Downward continuations have been made using and comparing one of Elkins' methods and a frequency domain filter method. Contour maps of all of these have been produced. Results from the horizontal gravity gradients have been presented as (a) magnitude contour maps and (b) quasi-vector fields showing both magnitudes and directions. The latter give high resolution of all known lithological boundaries, faults and discrete intrusive bodies. Moreover, they provide refinement on the position, outline and probable continuation at depth of these as well as new identifications of smaller coherent lithological sub-units. The horizontal gravity gradient features are well supplemented by the second derivative maps.

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II SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR

Compiled by: H.S. Hasegawa

1. Geological Survey of Canada
2. Physics of the Earth's Interior
3. Bibliography

1. Geological Survey of Canada

(a) Canadian Seismicity

J. Drysdale, M. Lamontagne, R. Horner and M. Plouffe have produced quarterly Provisional Earthquake Summaries for 1987. As of March, 1988 provisional data have been analyzed for 885 earthquakes in or bordering Canada during 1987. There were 34 events greater than or equal to magnitude 4.0, five of which were greater than magnitude 5.0.

The pattern of activity was similar to that of previous years and will be described in the 1987/1988 Canadian Earthquake Catalogue. Of significance in northern Canada was a magnitude 5.4 earthquake on December 13, 1987 south of Resolute Bay in Barrow Strait, near the top of Somerset Island. It was felt in Resolute Bay on Cornwallis Island, in the Polaris Mine on Little Cornwallis Island, and at Arctic Bay on Baffin Island. There were many aftershocks in the couple of months following that still require analysis. On March 30, 1987 a magnitude 5.5 earthquake occurred in the Beaufort Sea. Aftershocks of the magnitude 6.6 October 5, 1985 and December 23, 1985 Nahanni earthquakes continued to the end of the year. The largest was magnitude 4.1 on January 10, 1987.

Two magnitude 5.2 earthquakes located in southwestern Alaska, one on November 14 and the other on November 17, 1987, were felt strongly in the southern Yukon Territory. Thirteen magnitude 4.0 - 4.6 earthquakes were recorded from the active area west of Vancouver Island.

A magnitude 4.9 earthquake on June 10, 1987, centred near Lawrenceville, Illinois, was felt widely in the U.S., and in southern Ontario as far north as Owen Sound and east to Toronto. This event was followed by several aftershocks during the next few months. Four other earthquakes with magnitude greater than 4.0 occurred in the eastern offshore during the year. These included a magnitude 4.2 event on the Laurentian slope on June 26, 1987, a magnitude 4.6 earthquake off Labrador on December 14, 1987, and magnitude 4.4 and 4.5 events in the northern Labrador Sea/Hudson Strait area on March 7 and May 15, 1987.

The analysis of Nahanni aftershock data collected by the September, 1986 field survey under supervision of R. Horner has been completed and provides important evidence for the existence of high-angle splay faults that formed during December, 1985 M 6.9 main-shock rupture. Many of the unusual features of the Nahanni earthquakes are likely due to these splay faults. The splay faults seem to represent a failure of a major barrier in the hanging wall above the main seismic rupture which, in turn, produced the additional moment release, increased complexity and strongly focused the strong ground motion that was observed for the main shock. The report on the data collected by the October, 1985 and January, 1986 field surveys (Wetmiller et al.) has just been published in the April, 1988 issue of the Bulletin of the Seismological Society of America. Reports on the work have also been described in GEOS and presented at the IUGG Symposia in Vancouver and the Canadian Conference of Earthquake Engineering in Ottawa.

Analysis of 1987 records from the strong-motion network has been completed and figures of all seismic traces have been prepared. Work is proceeding to produce an open-file report of all data in the coming year.

M. Cajka is monitoring the seismicity of northern Ontario as part of the Canadian Nuclear Fuel Waste Management Program.

M. Plouffe is monitoring the seismic activity of the Sudbury mining area as part of the Canada-Ontario-Industry Rockburst Project.

(b) Canadian Seismograph Networks

The Canadian (National) Seismograph Network (CSN), as of April 1, 1988, consisted of 13 standard (photographic) stations, 50 regional (pen and ink or hot-pen) stations, 20 Eastern Canada Telemetered Network (ECTN) stations (to Ottawa) and 18 Western Canada Telemetered Network (WCTN) stations (to Victoria). Specialized networks include the Yellowknife Array and the Sudbury Array. For further details concerning these arrays, the reader is referred to Canadian Seismograph Operations, which is published annually as part of the Seismograph Survey of the Geophysics Division of the Geological Survey of Canada.

The project to completely modernize the Array located near Yellowknife, N.W.T. is proceeding on schedule and will be completed by the early summer of 1989. Tunnel vaults have been constructed to house the four broad-band, 3-component seismometers, and the new building is essentially complete. Development of a 21-bit digitizer for the broad-band seismometers is proceeding. A contract has been let to provide all the data acquisition and routine processing software; this includes data transfer over a 56 kilobaud satellite link and data archiving on optical disk.

F. Anglin has developed code to automatically analyze and classify automatic detections on the ECTN as being real (of seismic character) or artificial (telemetry spikes, dropouts, calibration pulses, etc.) in character. This has proved so reliable that it has been implemented on the real-time data acquisition system, and has reduced the number of false detections by up to 50%.

As part of the Yellowknife Seismic Array upgrade, J.A. Lyons supervised a major software development contract to produce code for the Yellowknife Control Centre and Ottawa-based acquisition computer systems. He continued to maintain and update the Canadian Digital Telemetered Seismic Network (CDTSN) software, and manage the Seismology and Geomagnetism computer network facility.

M.D. Andrew has modified the CDTSN software to support the higher dynamic range Mark III outstation package and provide programmable sampling rates for the Charlevoix and Pacific portable networks. He continues to develop expertise in data communications.

C. Wong has completed work on the Current Seismicity relational database which is now in daily use by the Seismicity group, and has designed the table structure for, and started populating the comprehensive Canadian (National) Earthquake Database. She continues to maintain and enhance the in-house Seismic Analysis Monitor (SAM) software.

The local network in Sudbury (Sudbury Local Telemetered Network) was completed in May, the part-time CANMET-seconded analyst (Plouffe) was appointed in September and the network data were completely integrated into the regular seismicity analysis by December. The Sudbury network now provides very detailed reliable coverage of seismic activity at all the mines in the basin. Data analysis is carried out without delay and information on seismic events is provided to the various mining operators in a timely fashion. Since September the network has documented more than 93 rockburst in the Sudbury mines, including many that would otherwise have gone undetected.

A new quarterly report on mining-induced seismic activity was started, and information has been issued on 128 rockbursts documented by the project since January, 1985.

The seismograph station at Eldee, Ontario, supported by AECL, was completely refurbished in this period. The comprehensive report, by Wetmiller and Cajka, on the seismic activity detected in northern Ontario by the AECL network has been accepted for publication by the Canadian Journal of Earth Sciences.

P.S. Munro and Wong have completed the expressions of the system transfer functions for all classes of instrumentation used routinely in the Canadian Seismograph Network. A master calibration table has been created and is updated after each calibration trip.

2. Physics of the Earth's Interior

R.A.W. Haddon and G.G.R. Buchbinder have investigated deep mantle structures consistent with observational data on long period S-waves. Haddon continued work on leaking modes.

A.G. Green, B. Milkereit, C. Spencer and colleagues from the United States Geological Survey are completing the processing and interpretation of GLIMPCE deep seismic reflection data collected across the Mid-Continent rift system and Grenville Front.

Green, Milkereit and colleagues from universities and Provincial Surveys involved with LITHOPROBE have collected regional and high resolution seismic reflection data across the Kapuskasing Structural Zone and the Abitibi granite-greenstone belt. Preliminary brute stacks show outstanding data across the Ivanhoe cataclastic zone and across several important structures in the granite-greenstone terrane.

Spencer, Green, P. Morel-à-l'Huissier, Milkereit and colleagues from the United States Geological Survey have completed an interpretation of the seismic refraction and reflection data collected in Quebec as part of the joint Quebec-Maine project.

Green, Milkereit, R. Parrish, R. Price, C. Patenaude and colleagues from universities have completed an interpretation of LITHOPROBE deep seismic reflection data collected across the southeastern Cordillera.

Milkereit and Spencer have developed a new multi-attribute image processing scheme based on the combination of both single trace attributes, such as reflection strength and instantaneous frequency, and also multi-trace attributes such as slowness and semblance. For migrated

reflection data this technique facilitates the analysis of complex structures and indicates possible lithological boundaries. This technique can also be applied to the inversion of seismic refraction data.

Milkereit and L. Mayrand have developed a new efficient algorithm for quality control and automated trace editing of seismic reflection data; this technique has been extended to handle near surface velocity variations and static corrections.

Morel-à-l'Huissier and Green have attempted to derive a structural/velocity model that is consistent with the multichannel seismic reflection and refraction/wide-angle reflection data collected along GLIMPCE line A in Lake Superior. Initial ray-tracing results suggest that the model derived from the seismic reflection data is broadly consistent with refraction arrival times. The velocities of the deep Keweenawan volcanic rocks were not as high as the 6.9km/s quoted in previous work.

Through in-house developed software, Milkereit, Spencer and Morel-à-l'Huissier calculated the maximum depth for the origin of the energy recorded during the GLIMPCE seismic refraction survey in Lake Superior. The results obtained along line A are in relatively good agreement with the model produced by analyzing the seismic reflection data. Positive correlations were also made between variation in the amplitude of the seismic refraction data and the occurrence of major geological structures in the reflection model.

Morel-à-l'Huissier, Green et Milkereit ont mis sur pieds une exposition sur les données de GLIMPCE (réflexion et réfraction) et leur interprétation. Cette exposition dont le but essentielle était de faire connaitre le programme GLIMPCE à la communauté scientifique a été montrée à différentes conférences dont le GAC/MAC à Saskatoon, la réunion annuelle de l'IUGG à Vancouver et la réunion annuelle du GSA à Phoenix, Arizona. Il est estimé qu'environ 1500 à 1700 personnes ont visités cette exposition.

Morel-à-l'Huissier a coordonné la mise en format et la distribution des données de sismique réfraction recueillies lors de l'expérience GLIMPCE. Le groupe est composé de membres de la CGC, du USGS et d'universitaires canadiens et américains. Le format choisi (SEGY) a nécessité le développement de nouveau logiciels. Il a cependant l'avantage de permettre l'utilisation de logiciels de sismique réflexion pour la manipulation des données. Certaine données essentielles comme celles des OBS n'ont pas encore été réduites en format SEGY.

K. Rohr and G. Horel designed and implemented a system to record seismic reflection data digitally; the system runs on a personal computer and can handle the amount of data acquired in a typical single channel reflection survey.

Rohr recorded high resolution single channel seismic reflection data over three areas of the accretionary wedge west of Vancouver Island; preliminary results were presented at the Fall AUG meeting, 1987.

Rohr, G. Spence and D. Chapman collected seismic reflection data across Davidson and Bowie seamounts west of the Queen Charlotte Islands to study lithosphere flexure. Preliminary results were presented at the Fall AGU meeting, 1987.

C. Woodgold has completed a study of (Lg) coda Q across Eastern Canada and finds Q_0 (1Hz) values ranging from 480 in New Brunswick to 770 in Western Quebec, with frequency dependence of the form $Q = Q_0 f^{0.43}$

H.S. Hasegawa, Wetmiller and D.J. Gendzwill have summarized possible ways in which mine-induced seismicity in Canada can occur.

Hasegawa has identified regions where tectonic processes are the major contributor to neotectonic movements in Canada and other regions where postglacial rebound predominates.

P.W. Basham and R.G. North represented Canada at the March and July sessions of the Geneva Group of Scientific Experts. Basham was appointed by this Group to be the principal Coordinator of a large scale international data exchange and analysis experiment, tentatively scheduled for 1990. In co-operative work with a New Zealand colleague, North has identified 4 previously unannounced nuclear explosions at the French test site in the South Pacific. North has also calibrated the Eastern Canadian Telemetered Network (ECTN) in order to estimate the yield of nuclear explosions at the various test sites, and finds remarkable differences in amplitude variations across the ECTN for small changes in source location at the Nevada test site.

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III (A) GEOMAGNETISM

Compiled by: G. W. Pearce

1. Summary

The report on geomagnetism is smaller than usual this year and has fewer reporting groups. However, there was activity in all sections of the subject.

Two groups reported on regional surveys, with the Atlantic Geoscience Centre (AGC) being very active in the Atlantic region. They have completed a 1:5,000,000 magnetic anomaly map for the Decade of North American Geology (DNAG) project, with improved data interpretation based on a new differential reduction to the pole method.

Two groups reported abundant activity in induction studies. The Geological Survey of Canada (GSC) reported on progress from five large current survey projects -the Southern Cordilleran LITHOPROBE line, the Trans-Hudson Orogen and the North American Central Plains conductivity anomaly, Kapuskasing, Miramichi and Wopmay - as well as progress in theoretical studies in data reduction techniques. The University of Victoria has worked on model studies and theoretical problems.

Five groups reported on paleomagnetism with studies of a wide range of ages and localities. The GSC worked primarily in the Atlantic region and in the Precambrian Shield; the University of Alberta in the Quaternary sediments of the Yukon and in archeological material from the Mediterrean; Université Laval worked in South and Central America, the Baltic and Eastern Canada; the University of Western Ontario was concerned with the Precambrian and the Cordillera, while the University of Windsor covered a wide range of topics in student projects.

2. Geomagnetic Surveys, Charts and Interpretation

(a) Atlantic Geoscience Centre (J. Woodside)

(i) Magnetic Surveys. Marine magnetic measurements were made during Hudson cruise 87-019, principally along deep seismic reflection Lithoprobe lines 85-2, 3, and 4, shot across the continental margin of Newfoundland. A short detailed survey of two dykes inferred from aeromagnetic results south of the Avalon Peninsula (the Avalon Dykes) was made to trace the dykes eastward between longitudes 54°W and 55°W. Only the southernmost of the dykes could be followed to the east, probably because the northern of the two appears to bend northward at the eastern edge of the Laurentian Channel / St. Pierre Bank aeromagnetic survey area.

Two aeromagnetic surveys were carried out south and east of Newfoundland. These two surveys were designed to bridge the gap in coverage between previous surveys over St. Pierre Bank and the Laurentian Channel and over the northeast Newfoundland continental shelf and the adjacent Orphan Basin, and to follow structures and trends identified in the earlier surveys. An aeromagnetic survey over Whale Basin (roughly 44° N to 46.75°N and 48.5°W to 55°W) was completed by Geoterrex as a 4 km by 10 km grid of lines. A survey conducted under an agreement with the U.S. Naval Research Laboratory (NRL) provided reconnaissance lines over the continental margin and Newfoundland Basin as far east as 36°W, and at a line spacing which increased from about 18 km over the inner shelf to 36 km at the eastern extremity.

(ii) Data Management. A major compilation of all aeromagnetic and marine magnetic data over the eastern Canadian region from Georges Bank to the Arctic was completed. The primary marine data set consisted of about 2.9 million observations collected over nearly one million line kilometres on 91 cruises during the period 1963-84. An analysis of the problems encountered in applying the International Geomagnetic Reference Fields led to the conclusion that there is still some time-dependency left in the reference fields. Derived anomalies for given epochs in certain areas are therefore inaccurate.

The data were used to produce a map of magnetic anomalies at a scale of 1:5,000,000 in Lambert projection for a forthcoming publication in the DNAG series. All the data are being sent to Open File, and an accompanying report documenting the procedures used and data analysis performed in the compilation has been prepared for release in early 1988 as GSC Open File 1504.

(iii) Data Interpretation. Results from the magnetic survey over the Laurentian Channel and St. Pierre Bank have been analysed and interpreted both under contract at Paterson, Grant, and Watson Ltd. in Toronto and at AGC. In a subsequent contract the Laurentian Channel data were merged with earlier GSC surveys from the southern tip of Nova Scotia to the northern tip of Newfoundland. The complexities exhibited in this new compilation illustrate the difficulties in tracing Appalachian zonations from Cape Breton to Newfoundland. Magnetic data suggest that additional suspect terranes may have been involved during the closing of the Iapetus Ocean.

The data from the 1985 Orphan Basin aeromagnetic survey have been used to better constrain the evolution of sea-floor spreading in the North Atlantic, by better defining the magnetic lineations of the oldest oceanic crust (anomalies 24 to 34)(Srivastava et al., 1987). Three additional fracture zones were identified south of Charlie-Gibbs fracture zone, the southernmost being in line with the western extension of the Faraday fracture zone. Reconstruction of the North Atlantic brings the Pastouret Ridge, a reactivated fracture zone across Goban Spur, into juxtaposition with this fracture zone. A large amplitude magnetic anomaly landward of anomaly 34 on both sides of the Atlantic marks the ocean-continent boundary: the juxtaposition of highly magnetized oceanic crust against weakly magnetized continental crust causes the anomaly on both sides of the Atlantic. Poles of rotation derived for this anomaly show that it forms an isochron spanning the period 100-110 Ma during the Cretaceous Magnetic Quiet Period. Active sea-floor spreading between Flemish Cap and Goban Spur began 110 Ma ago; however, further north spreading from 100 Ma ago was presaged by stretching of the continental crust by 25%. More data from the European side of the Atlantic are being obtained for further analysis with the GSC data.

Using a recently-developed differential reduction to the pole method, all AGC marine magnetic data between 40°N and 70°N were reduced to the pole and converted to crustal magnetization contrasts by a generalized inversion technique which takes into account the variations in basement topography and crustal thickness (Arkani-Hamed et al., 1987). The resulting magnetization contrasts better resolve the magnetic anomalies. There is a close correlation between the magnetization contrasts and geological features associated with the tectonics of continental margins.

As a means of obtaining broad exposure for the new compilations of magnetic and gravity data, a review has been initiated of the geology and tectonics of eastern Canada which are directly correlatable with the potential field data. The resulting GSC Paper, now in preparation, is intended to be a key both to the geological framework of the region and to studies which have been published or are in progress using the data. The paper will be a companion to the 1:5,000,000 gravity and magnetic anomaly maps prepared as part of an AGC contribution to the DNAG Project.

An investigation is currently underway of the detailed magnetization and structure of the oceanic crust of the Labrador Sea. Modelling software has been used to examine the thickness and magnetization of magnetically normal and reversed blocks which are generated automatically from the reversal history and from the digitized basement topography.

(iv) Instrumentation. Both CIGAL and SHIPAC underwent successful field trials during the Hudson 87-019 cruise, and are now considered fully operational systems. (CIGAL is a Computer Integrated Geodata Acquisition and Logging system which facilitates the logging, documentation, and transfer to data processing computer of any designated parameters to be recorded as time series during the course of a cruise; SHIPAC is the computer system which checks, corrects, and formats geophysical data logged by CIGAL, calculating anomalies and storing or displaying the data.)

(b) Geophysics Division, Geological Survey of Canada (G.V. Haines, L.R. Newitt)

(i) Surveys. As part of the continuing study of geomagnetic secular variation, 12 repeat stations were occupied in the Atlantic Provinces, Quebec and the Northwest Territories. Six of these were done by contract. The routine occupation and observations are similar to those outlined in the Canadian Geophysical Bulletin, 32,p.60, 1979.

(ii) Reference Field. The Canadian Geomagnetic Reference Field has been revised and updated on the basis of the latest available magnetic observatory and repeat station data. The new version is denoted CGRF 1987.5. The model is resident on a microVax computer and may be accessed directly by telephone. A personal computer version of the software is also available.

(iii) Field Modelling. Computer programs for carrying out a spherical cap harmonic analysis, with accompanying discussion, are being published in Computers and Geosciences. The programs permit the modelling of three-component data or geocentric vertical data from a potential-gradient field; or the modelling of data from a general surface field. In the case of potential-gradient fields, causative sources may be

internal, external, or both. A paper has also been written on choosing the correct basis functions for modelling geophysical fields by Fourier series and rectangular harmonic analysis. It is shown that series expansions using periodic basis functions are not uniformly convergent, result in ringing at the boundaries, and cannot in general be differentiated term by term. The correct basis functions are given for the problem of modelling a differentiable field with arbitrary values and derivatives on the boundary.

3. Magnetic Observatories and Instruments

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

(i) Magnetic Observatories. The Geophysics Division, GSC, operates the Canadian Magnetic Observatory Network of 13 digital magnetic observatories: Alert, Mould Bay, Resolute Bay, Cambridge Bay, Baker Lake and Yellowknife in the Northwest Territories; Fort Churchill in Manitoba; Poste-de-la-Baleine, Quebec; Meanook, Alberta; St. John's, Newfoundland; Ottawa, Ontario; Victoria, British Columbia; and Glenlea, Manitoba (this last in cooperation with the University of Manitoba). An ELSEC 8200 vector proton magnetometer has been thoroughly evaluated. It has low temperature coefficients and excellent long-term stability, and has been incorporated into the routine operation at Ottawa magnetic observatory. A Jena 010B non-magnetic 1" theodolite has been acquired for the Ottawa magnetic observatory for use in a declination and inclination magnetometer. It permits a more precise calibration of instruments, and is being used to investigate potential sources of error in observatory measurements.

(ii) Forecasts of geomagnetic activity. The Geophysics Division issues regularly two types of forecast of geomagnetic activity. A three-zone, 27 day forecast is issued every three weeks and mailed on request. A 72-hour forecast is updated every working day and is available on an automatic answering service (613) 992-1299. Recent research has shown relations between the occurrence of very quiet magnetic intervals and several solar wind parameters. A new development is the application of AI Expert System techniques to the problem of routine short-term forecasting of geomagnetic activity.

(iii) Forecasts of occurrences of magnetic pulsations. Various spectral components and local time variations of the long-period magnetic pulsations under different geomagnetic conditions have been studied with respect to the DRX index, a parameter routinely forecast by the Geophysics Division of the GSC. The pulsational activity can be linearly related to DRX, thus enabling the future levels of pulsations to be inferred from the forecast DRX.

(iv) Spherical cap harmonic modelling of high latitude magnetic activity and equivalent sources. Data from 13 Canadian magnetic observatories during the February 6-8, 1986, magnetic storm were used to model the perturbation fields and their internal and external equivalent currents. Because the network is sparse, the mean hourly values are used to reduce the spatial aliasing of the short period variations. Both the spatial and temporal variations of the three components of the field were modelled from the vector observations. The harmonic degree and order of the modelling were optimized for the analysis and computation. The standard deviation of fit was less than 10 nT during less active periods of the storm, and 20-50 nT during the peaks of the storm (500-1300 nT). Errors ranged from 5 to 25 nT when both the spatial and temporal variations were modelled during the first day of activity (<360 nT). Large scale features of both regular and irregular magnetic activity, and the equivalent sources, can be well modelled using this technique.

4. Electromagnetic Induction in the Earth

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

(i) Southern Cordilleran LITHOPROBE MT study. In a joint collaborative venture, funded partly through GSC's resources and partly through a LITHOPROBE grant to Prof. D. Oldenburg of UBC, a contract was let to PHOENIX Geophysics of Toronto to undertake a magnetotelluric (MT) survey along the LITHOPROBE seismic lines 2,3,4 and 5. The survey was operated in an "active" mode in that the MT responses were monitored in real-time to decide where the following sites should be located. During the four weeks of the survey, measurements were made at nineteen distinct locations and the data quality is very high with typical standard errors < 1%. The MT profile begins on the east near the Rocky Mountain Trench above autochthonous North American basement, which is overlain by deformed and transported cover, traverses across the Purcell anticlinorium, the Kootenay arc, the Nelson batholith, and ends on the west side of the Valhalla gneiss complex west of the Eocene Slocan Lake normal fault. Stations close to Kootenay Lake respond to a major near-surface conductivity anomaly that is probably due to either graphitic schists or to an extension of the silver-bearing mineralization found further north in the Bluebell Mine. The data across the Nelson batholith are highly complex and exhibit 3D regional features that are beyond current abilities of numerical programmes to model. However, the data from the two sites on the Valhalla complex are reasonably 1D. Inversions of these data yield 1D models that, when compared with the seismic reflection results, indicate electrical structure in the region marked as of uncertain seismic interpretation by Cook et al. (1987, 1988). Interfaces in electrical conductivity are found at depths that agree with an increase in the number of reflectors at about 9 km, the "base of layered reflections" at about 22 km, and the Moho at about 35 km. Of major significance to our understanding of the current composition and state of the lower continental crust is that, although for the Valhalla complex there are few reflections below about 8 sec, the MT responses indicate that the zone is conducting. This is the only location known to the authors where the lower crust is seismically transparent but electrically conductive. A research note on these results has been submitted to Geophysical Research Letters.

(ii) Trans-Hudson/NACP MT profiles. The geometrical relationship, if any, between the Trans-Hudson Orogen and the North American Central Plains conductivity anomaly (NACP) is of foremost importance to any evolutionary tectonic model proposed to explain the collision of the Superior and Churchill Provinces in the Hudsonian. Any model that does not include a mechanism for the generation of this anomaly is obviously untenable. In order to map better the trend of the NACP in Saskatchewan, two magnetotelluric (MT) profiles were conducted over the NACP previously defined by magnetometer arrays and profiles. The more northern of the two, at a latitude of approximately 53°N, was of sixteen ten-component MT sites (local and remote-reference) between longitudes 101°-109° W, whereas the other profile, of eighteen ten-component sites, was at a latitude of 51° N between 99.5° - 105.5° W. Data from these two, together with an earlier MT profile just north of the U.S./Canadian border, suggest that the NACP is not a continuous feature, but rather that it exhibits a definite break at a latitude of 51° N. If a second MT anomaly mapped to the northwest of this break is, in fact, a manifestation of the same geological structure, then one possible interpretation is for a massive NW-SE trending sinistral fault in the deep crust, previously undetected, with a movement of some 100-150 km along strike. A paper describing the dominant results from these data, and their correlation with gravity, magnetics, seismic and heat flow data, has been submitted to Physics of the Earth and Planetary Interiors.

(iii) Kapuskasing LITHOPROBE electromagnetic induction studies. The Kapuskasing Structural Zone (KSZ) extends approximately 500 km from Lake Superior north-northeast to James Bay, and is characterized by high grade metamorphic rocks that cut the more or less east-west structural grain of the Archean Superior province. The eastern boundary of the KSZ is a major fault, the Ivanhoe Lake Cataclastic Zone(ILCZ), across which the metamorphic level drops abruptly to the east in the Abitibi Greenstone Belt. The KSZ is interpreted as an upthrust section of the Archean crust and provides the opportunity to examine crustal growth and structure. Interpretation of magnetotelluric data from 26 stations collected in 1986 suggests a remarkable uniformity along an east-west profile (except in the immediate vicinity of the ILCZ). This suggests that increased conductivity observed in the lower crust in many regions is dependent on position rather than composition. Lamontagne Geophysics conducted a contract UTEM survey in December, 1986 to resolve the static shift problem in the MT data, and to investigate in more detail the proposed surface strike of the ILCZ. The results support the MT crustal model and identified a weak conductor at approximately 3 km depth, dipping gently to the west, that is likely associated with the ILCZ. The area seems to be free of major upper crustal geoelectric features and thus provides a 'window' to the electrical structure of the lower crust and upper mantle. The electrical structure is typical of old continental regions, with a very resistive upper crust overlying a less resistive (<1000 Ohm m) lower crust. The anisotropic behaviour observed at long periods at a majority of the MT stations can be modelled as a conducting slab in the lower crust striking north-northeast. Eight long-period MT stations, located to test the conductive slab model, recorded data for two months in 1987 from which the geomagnetic transfer functions are currently being analyzed. The data also extended and confirmed the long period MT coverage of the 1986 survey.

(iv) Miramichi, New Brunswick MT study. The occurrence of four earthquakes with magnitudes ranging from 5.0 to 5.7 in early 1982 prompted a detailed magnetotelluric survey of the epicentral region in north-central New Brunswick. Scalar audiomagnetotelluric (AMT) measurements, spaced at 100 m intervals or less along a 7.5 km east-west profile, detected two conductors, but no anomaly associated with the proposed fault plane located by the earthquake hypocentres. The 150 AMT measurements, combined with broadband tensor soundings at eleven sites in a small region (6 by 7 km), provided an opportunity to study the distorting effects of near surface anomalies and also to determine the regional conductivity structure. The apparent resistivity and phase curves from all tensor stations, calculated in the coordinate system suggested by two low skew stations, were remarkably similar (except for static shift of the apparent resistivity curves) to those derived from the rotationally invariant Berdichevsky determinant averages. These averages appear to be very effective for deriving a first order estimate of the conductivity strucutre in areas for which near surface anomalies are a problem. The crustal resistivity values are considerably larger than those in other regions in the Appalachians of North America.

(v) Wopmay Orogen GDS/MT survey. The final manuscript on the electrical conductivity results, obtained from the 1982 data collected on a east-west line across the Wopmay Orogen, has been written and submitted. It compares transfer function results with those obtained recently from a re-analysis of the data when source-field effects have been minimized. The results show the presence of a 20 Ohm m conductive body about 30 km wide, and 2km thick near the allochthonous shelf margin at the eastern edge of the Hepburn Batholith. This body correlates spatially with graphitic pelites of the Odjick Formation, a unit of deep-water facies interpreted as continental slope-rise deposits.

(vi) Theoretical studies. A generalized representation of electromagnetic fields is being developed with the aim of developing adequate numerical inversion schemes for the interpretation of controlled source EM data in complicated environments. Two important advances have already been realized as a result of this work. It has been shown that the Fréchet kernels required for numerical inversion of EM data are adequately approximated by very simple (and analytical) functions. This means that computing the forward model becomes the rate limiting step in EM interpretation procedures, whereas previously the Fréchet kernel calculations were the dominant computational expense. In fact, many current interpretation methodologies are based on the assumption that the number of Fréchet kernel calculations should be minimized to reduce the expense of the computations. With this novel approximation scheme, these methodologies certainly need to be reassessed. It has also been demonstrated that the EM Green's functions for three dimensional modelling and interpretation can be factored into two functions. One of these functions is strictly dependent on the geometry of the source/receiver and any scattering features in the earth and is an extremely difficult function to understand. The other function describes the basic interaction of the EM fields with conductivity distributions and is extremely regular and predictable. The computational burden of 3D modelling can thus be reduced by factoring the calculation into these two components and computing them separately. This result, when combined with the approximations for Fréchet kernels should also make 3D inversion much more feasible.

(vii) MT recording systems. Three prototype long period MT data recorders have been developed at the Geomagnetic Laboratory and use three component ringcore fluxgates as magnetic field sensors. The recorders feature a CPU which may be programmed to suit specific requirements. The basic unit will be capable of sampling up to 16 channels of data at a maximum rate of 60 Hz and storing the data on 3 megabytes of DRAM. Field tests are planned for the summer of 1988.

(b) Dept. of Physics, University of Victoria (H.W. Dosso and J.T.Weaver)

Measurements of EM responses for the west coast laboratory analogue model, that includes a simulation of the subducting Juan de Fuca plate, have been compared with some field measurements in collaboration with R.D. Kurtz, J.M. DeLaurier, and J.C. Gupta (Geological Survey of Canada). There is excellent agreement at periods of 5 to 60 min for central Vancouver Island, while for east and west coast sites agreement is seen only for periods greater than 20 minutes. Departures of the observed responses from those of the model at the shorter periods may be the result of crustal inhomogeneities not simulated in the model. The analogue model results are consistent with a geophysical model of a subducting plate dipping beneath Vancouver Island. Further model measurements are being carried out to examine the effect of an inland horizontal conductor butting to the dipping subducting plate.

The analogue model facility has also been used to examine the EM response of a flat-topped cylindrical seamount in a deep ocean. Empirical curves were developed to predict the period for maximum response, the magnitude of the response at this period, and the period for sign reversal as functions of overburden depth.

An analogue model study of the Bohai Bay region of China has been carried out and the results are being compared with field measurements for the region. A second model, using a larger length scaling factor to include the Japan Islands and the deep ocean trenches, has been constructed and measurements are planned.

The thin sheet program developed at the University of Victoria for modelling the electromagnetic response of near surface 3-dimensional conductivity structures has been used to examine and interpret both daytime and nighttime geomagnetic variations recorded at various stations in India. For nighttime variations the inducing field is assumed to be uniform, but for daytime variations an equatorial electrojet, represented by a Gaussian distribution of ionospheric currents, has also been included in the model. The widely-used finite difference program for solving two-dimensional problems in electromagnetic induction in the earth is being rewritten in a more efficient form with automatic grid generation. It is hoped that this program will eventually be incorporated in a full two-dimensional inversion program. The generalization of the finite difference method to three-dimensional problems is in progress.

5. Paleomagnetism

(a) Geological Survey of Canada

(i) The Meguma Terrain. Paleomagnetic studies are in progress on a number of Paleozoic intrusive bodies in the Meguma Terrain in Nova Scotia. The aim is to investigate the accretionary history of the terrain, and the structurally controlled mineralizations that were associated with the tectonic event. Among the intrusions being studied are the Mavilette Intrusion, the Davis Lake Pluton, the Shelburne pluton and the Liscomb Complex. Based on an encouraging feasibility study, extensive sampling of the gabbroic phases of the Liscomb Complex was undertaken in the summer of 1987. A dyke, believed to be an offshoot of the gabbroic intrusions, was also sampled.

(ii) The Maritime Sedimentary Basin. Results from the Cap aux Meules redbeds of the Magdalen Islands indicate a tectonic rotation in the Gulf of St. Lawrence. The paleomagnetic evidence was recorded by the lengthy hematization process. A detailed mineralogical and paleomagnetic analysis revealed a systematic correlation between the type of hematite and the characteristic remanent magnetizations.

(iii) The Paleozoic Platform. Paleozoic rocks on the platform are being studied for comparison with the Appalachian mobile belt. The field area is the Cambrian Sept-Iles intrusion which is crosscut by younger dykes. A paleomagnetic study in the intrusion was completed and published in 1987. Interest in the area continued in view of the younger dykes, which could yield a pole significant in Appalachian reconstuctions. A new field program, jointly with Memorial University of Newfoundland, took place in the summer of 1987. Remanent magnetization studies on the sampled dykes are now being carried out at Memorial. A concurrent investigation of the anisotropy of magnetic susceptibility (AMS) is underway at the Geological Survey. AMS can shed light on the emplacement history of the dykes, and assist in the interpretation of the magnetic remanence.

(iv) Precambrian. A study of the Upper Precambrian Coates Lake Group of the Mackenzie Mountains in the Northwest Territories has proved to be complex, partly due to complexities in the geology and partly due to the complex, multicomponent magnetizations present. It is now apparent that the units of this Group, deposited in a rifting environment, have been subject to block rotations. Another study, now complete, on Precambrian diabases from about the Mackenzie Arc confirmed that the arc is a primary feature, not a structure imposed by later tectonic forces. The diabases from older units in the outer arc do not appear to have undergone the block rotations apparent in the Coates Lake Group from the inner arc.

(v) Other work. Paleomagnetic data indicate three distinct ages of intrusion for the gabbro sills of the Southern Province which are generally known as the Nipissing Diabase. Three paleopoles have been isolated and each is believed to be primary on the basis of baked contact tests. Superposition of two magnetization components at some localities indicates that secondary overprinting has occurred in certain areas.

A stable paleomagnetic remanence for Early Silurian redbeds and volcanics of the King George IV Lake area of the Central Mobile Belt of Newfoundland indicates a near-equatorial paleolatitude for this portion of the Appalachian Orogen. A positive fold test shows that the remanence

was acquired before Acadian (Devonian) deformation. A positive conglomerate test demonstrates that the remanence was acquired at the time of formation.

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

(i) Quaternary Magnetostratigraphy. (M.E. Evans, K.P. Gillen, V. Frnoch, W.I. Gough). The results of the first extensive collection of samples from the Old Crow Basin, Yukon Territory have now been published (Hedlin and Evans, 1987). Although these data revealed a very interesting secular variation (SV) pattern, no reversed horizons were discovered. One of the prime objectives of this continuing project is to locate and investigate the so-called Blake Event. This study will greatly facilitate stratigraphic correlation and provide much needed observational constraints on the actual geomagnetic behaviour involved. To improve the correlation between the different sections studied in the first collection initial susceptibility of all 760 samples has been measured. It is found that this provides a sensitive stratigraphic parameter that, when used in conjunction with geological field observations and the SV magnetograms themselves, allows improved correlation. A follow-up paper describing this new work has been submitted for publication. The most marked SV features found in the earlier work take the form of two westerly shallow perturbations. The new results indicate that the same perturbations have been recovered from a section which is about 1 km away. This greatly supports the reality of these features which are attributed to stationary flux sources in the outer core.

A second sampling trip was carried out in the summer of 1987 and yielded a further 650 samples collected from four new stratigraphic sections. Laboratory processing of this material is well advanced. The results will be the focus of K.P. Gillen's M.Sc. project.

(ii) Archeomagnetism (M.E. Evans, M. Mareschal [Ecole Polytechnique, Montreal], G.S. Hoye, V. Frnoch, W.I. Gough). Work on a large collection of archeological samples from a variety of sites around the Mediterranean Basin is continuing and a summary paper describing results from Italy is currently in press. The results are basically compatible with shape of the British limnomagnetic secular variation pattern, but the archeological data imply a more westerly extremum. In this context, we note that our samples are fully orientated by solar bearings, whereas the lake cores are essentially unconstrained in azimuth. It seems that a combination of the potential continuity of lake cores, coupled with the accurate orientation of archeological features, will be necessary to properly define the behaviour of the geomagnetic field over the last few millenia.

Laboratory measurements of samples from Greece are now complete and the data are being prepared by publication. Three time intervals are represented - Roman, 4th Century B.C., and Minoan. The Roman sites yield results that are compatible with the secular variation pattern for the first few centuries A.D. deduced by Thellier from numerous sites in France. The 4th century B.C. features (two kilns at Corinth, one at Cnossus) yield steep, westerly magnetic vectors which are consistent with our own contemporaneous data from southern Italy. Detailed comparison suggests that the Cnossus kiln is the same age as one of the Corinth kilns, and that the other kiln at Corinth was last fired some 50-100 years earlier. The Minoan data have some bearing on the Cretan destruction controversy. Earlier interpretation is based on the inclination angles only. If the full vectors (including declination) are taken into account then a smooth continuous clockwise loop is observed, very reminiscent of the behaviour of the field in historic times. There is no compelling need to claim any causal connection between volcanic activity and destruction of settlements on Crete.

In the summer of 1987 a preliminary survey of Roman kilns in southern Spain was made and permission was obtained to collect samples from two of these. Excellent results have been obtained from both and the prospects for future work are therefore very promising.

A paper is in press analysing the recently published paleointensity data for Japan and Bulgaria with a view to seeking evidence for the persistence of the westward drift. These two sites have comparable latitudes but are separated by 110° in longitude. There is indeed a marked similarity in the observed patterns, but a time lag is involved which suggests a westward drift rate of about 0.3% per year, which is in reasonable agreement with estimates obtained from historic data.

(iii) Permian Paleomagnetism (M.E. Evans, J.-M. Maillol, V. Frnoch, W.I. Gough). A new collection of fully-oriented surface samples was made in the summer of 1987 to increase the coverage of lowermost Saxonian horizons which should correlate with the 66 stratigraphic metres spanned by the long-core data already published. We now have a total of 66 samples (spanning about 70 m stratigraphically) to compare with the 43 samples in the original study of the core itself (Evans and Maillol, 1986). Measurements of natural remanent magnetizations are now complete and these define a planar distribution between the present and Permian field directions. Laboratory demagnetization studies will be undertaken in the near future now that J.-M. Maillol has commenced his graduate studies here.

(c) Université Laval (M.K. Seguin)

(i) Ecuador and Coastal Peru. Paleomagnetic investigations aimed at a better understanding of the formation of the Andean mountain chain were carried out in sedimentary, volcanic and granitic rocks of Cretaceous and Tertiary age from Coastal Peru, and in different metamorphic and unmetamorphosed terranes ranging from Precambrian to Eocene from the Sierra, Oriente and Costa regions of Ecuador, (collaborators are T. Feininger and E.I. Tanczyk, GSC, Ottawa).

(ii) Costa Rica. Tertiary and Quaternary volcanic and sedimentary rocks were collected in 1987 for paleomagnetic and geochemical investigations in different parts of Costa Rica.

(iii) Baltic Shield (Norway, Sweden and Baltic Islands). Paleomagnetic studies continued of tillites of Vendian age and most of the Cambrian, Ordovician and Silurian sequences of the Baltic platform sedimentary units. (collaborators are P. Nystueen [Norway] and G. Bylund [Sweden]).

(iv) Newfoundland-Avalon Zone. Paleomagnetic studies include Late Precambrian rhyolite flows and tuffs from Cape St. Francis and Bauline areas (collaborators: J. Jessop and E Gahé), and Cambrian Brigus Shale Formation (collaborator: K.V. Rao).

(v) Nova Scotia. Many paleomagnetic studies were undertaken in collaboration with Memorial University of Newfoundland. The following is an incomplete summary: Devonian Fisset Brook Formation (collaborators: M.A. Audet and E.R. Deutsch); Late Precambrian Fourchu Formation (volcanics) (K.V. Rao and E.R. Deutsch); Late Precambrian Fourchu gabbro (D. Vermette and K.V. Rao); Late Precambrian to Early Cambrian Fourchu dykes (D. Vermette and K.V. Rao); Cambrian Antigonish alaskite and Eden pluton (K.V. Rao and E.R. Deutsch); Cambrian Bourinot Formation (S. Barr); Ordovician Torbrook Formation (J. Langlois and E.R. Deutsch).

(vi) Quebec. The various investigations include: Paleomagnetism of Archean rock units (lavas, gabbros, ultramafics, granodiorites, tonalites, granites and tuffs) from the Troilus-Frotet greenstone belt (collaborators: A. Simard, E. Gahé and D.T.A. Symons); detailed paleomagnetic study of Ordovician rock units from the St. Lawrence Lowlands-Chazy, Black River, Beekmantown and Utica formations; paleomagnetic investigation of Devonian sedimentary units of southern Gaspé Peninsula; paleomagnetic sampling of Silurian dioritic and syenitic intrusions and country rocks from the St. Lawrence Lowlands (S. Kumarapelli and R. Boiselle); Late Precambrian (Hadrynian) basic and ultrabasic dykes from the north shore of the St. Lawrence River (Grenville Province) (J. Rondot).

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

(i) Precambrian dykes and the Kapuskasing Structural Zone (H.C. Palmer and H.C. Halls, University of Toronto). Approximately 75 dyke localities in the vicinity of the Kapuskasing Structural Zone have been examined for structural, petrographic and paleomagnetic information. Field work for this joint study was conducted during the summers of 1984 and 1987. A progress report can be found in the document: Project Lithoprobe, Kapuskasing Structural Zone Transect, Workshop, 16-17 February, 1988, University of Toronto, pp. 23-25.

(ii) Felsic Volcanic Rocks, East Central Nevada (H.C. Palmer and W.D. MacDonald, SUNY, Binghampton). The first summary of this work can be found as an abstract in the 1988 Spring Meetings volume of the American Geophysical Union (EOS) under the title "Interpretation of volcanic and tectonic history from magnetic data: Indian Well Formation, NE Nevada" by W.D. MacDonald and H.C. Palmer.

(iii) Paleomagnetism applied to the tectonic development of the Stikine Terrane (T.A. Vandall and H.C. Palmer). Paleomagnetic sampling in British Columbia was carried out from late July to mid-August, 1987. The Telkwa Formation was sampled in an area approximately 50 km east of Terrace and the Ootsa Lake volcanics were sampled along the Whitesail Lake shoreline approximately 80 km SW of Burns Lake. The stability of these samples is currently being assessed by alternating field and thermal demagnetization experiments.

(e) University of Windsor (Dr. D.T.A. Symons)

Four MSc. theses have been completed since the last report. D. Dunsmore studied three gabbro plutons near Lynn Lake. He found that the plutons were emplaced and mineralized with Cu-Ni ore at ~1890 Ma. He also found from the analysis of 1800-1900 Ma poles that the Slave and Superior cratons were ~40° further apart than at present as they began moving together to form the Trans-Hudson Orogen. R. Deklerk studied felsic plutons in the Kootenay Arc region, and found that the Eocene plutons show no motion, whereas the Cretaceous/Jurassic plutons show ~75° of clockwise rotation and ~7° of northward translation. T. Vandall studied well-dated Archean felsic plutons in the Wawa Subprovince. Poles determined for rock units between 2630 and 2700 Ma are concordant with coeval Abitibi Subprovince poles indicating no significant translation or vertical-axis rotation on the KSZ. D. Coyle studied a Pleistocene chalk diamicton from Hvideklint, Denmark using pebble-orientation and AMS/remanence methods. He concluded that folding in the unit was caused by ductile flow in response to lateral stresses from the re-advance of overriding Late Weichselian ice. M. Lewchuk is currently studying the Proterozoic Clay-Howells and Archean Squaw Lake alkalic-carbonatite complexes for his MSc. thesis.

Three BSc. thesis projects also bear reporting. M. Lewchuk completed a study of the Mississippian HP Pipe in the Front Ranges of the Rocky Mountains, and obtained a concordant pole implying that these rocks are part of the stable craton of North America. R. Bormann studied the Triassic Fundy Group red beds of Nova Scotia and found evidence for post-depositional rotations associated with rift formation in the Bay of Fundy. M. Wellings is currently studying the Eocene Kamloops group volcanics of British Columbia. His preliminary finding is that this part of Terrane I has not been rotated nor translated since extrusion. Three other studies are currently underway on Port Coldwell complex, Ontario, with the co-operation of W. Robertson, Lackner Lake, Seabrook Lake and Sturgeon Narrows carbonatite complexes in Ontario, and Archean volcanics near Wawa, Ontario.

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III (B) AERONOMY AND SPACE PHYSICS

Compiled by: D. Venkatesan

1. Division of Aeronomy and Space Physics/Canadian Association of Physicists
2. DASP Annual Meeting
3. APRX Research
4. Herzberg Institute of Astrophysics, NRC
5. University of Alberta
6. University of British Columbia
7. University of Calgary
8. University of Lethbridge
9. University of Victoria
10. University of Western Ontario
11. York University
12. Solar Terrestrial Physics Laboratory
13. L'Observatoire de Besancon

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

OFFICERS 1987-88: Past Chairman: R. Lowe, University of Western Ontario, London, Ontario; Chairman: J. Samson, University of Alberta, Edmonton, Alberta; Vice-Chairman: G. James, Communication Research Centre, Shirleys Bay, Ottawa, Ontario; Secretary/Treasurer: R. Koehler, York University, Toronto, Ontario.

2. Minutes of the DASP Annual Meeting/CAP Congress, June 17, 1987, Toronto, Ontario

Chairman's Report: Bob Lowe reported that Art Collins was unable to address DASP due to a prior commitment.

A DASP brief was submitted at the parliamentary hearing in Toronto of the House of Commons Standing Committee on Research, Science and Technology; a copy was also sent to CAP.

Secretary/Treasurer's Report: Roy Koehler noted that membership of DASP stood at 68 as of April 30, 1987, with a financial balance of $3124.41.

DASP Newsletter: J. MacDougall (U. Western Ontario) is the new DASP Newsletter editor. This information is essentially taken from the DASP newsletter, recently compiled by J. MacDougall and refers to the research work done over the year 1987.

Membership on CNC/IUGG: Don McEwen mentioned that a glossy report, summarizing 1983-1987 activity in Canada, was earmarked for the IUGG meeting in Vancouver (August 1987). A. Vallance Jones and R.P. Lowe were suggested to NRC for IUGG membership.

Student Papers Prize Winners: E.F. Donovan won this year's student prize. Don Wallis pointed out no award had been made last year although the papers were judged. He asked that the Executive Committee consider awarding it retroactively.

Other Business: Agnes Kruchio said the 'DASP book' will be a history of DASP and a reflection on Canadian Space Science. Agnes commented about problems with the previous publisher. She is still looking for illustrative material and has top priority now for this much delayed publication. Agnes also talked about her Canadian Space Gazette activities and the need to preserve historical papers and documents dealing with Canadian Space Science.

Don McEwen's motion (seconder J. Samson) "commending Harry Sullivan and Peter Forsyth who were involved in setting up DASP, and sending letters of appreciation" was carried unanimously.

The motion of John MacDougall/Don McEwen that "The Executive of DASP be charged with organizing a 1988 Winter Workshop and others in future years, as deemed appropriate" was carried.

The new executive is as follows: Past Chairman: Bob Lowe, Chairman: John Samson, Sec/Treas: Roy Koehler, New Vice Chm: Gordon James.

3. APRX Research

The second phase of the Canadian ozone experiment (CANOZE 2), designed to study the effect of the Arctic polar vortex on the ozone layer, took place in February and March, 1987 at Saskatoon. Two STRATOPROBE balloon flights, February 27 and March 19, were coordinated to determine the distribution of nitric acid, dinitrogen pentoxide, nitrogen dioxide, water vapour, methane, chlorine nitrate, as well as ozone. Brewer spectrophotometers were used to measure the altitude profiles of ozone and nitrogen dioxide from the ground. An interferometer was set up at the RAGS site near Saskatoon to obtain the overburden of hydrochloric acid, methane, water vapour and nitric oxide.

To study long-period trends in chlorofluorocarbons, nitric acid, nitrogen dioxide, dinitrogen pentoxide and chlorine nitrate, and to develop new instruments for monitoring these gases, two STRATOPROBE balloon payloads were launched from teh new site at Vanscoy near Saskatoon on August 15 and 22. Ground-based Brewer measurements of ozone and nitrogen dioxide were also made.

By December preparations for CANOZE 3 were well under way. CANOZE 3 will extend the observations made by CANOZE 2 in 1987, but wil include additional measurements at Alert. The balloon flights also provide a test for the new light-weight mini-radiometer now under development.

As part of the balloon campaigns, ozone sondes have provided ozone, temperature and pressure profiles. Ozone data obtained by processing TOMS imagery has been used to supplement ground-based measurements.

To improve spatial coverage in the Canadian ozone network, a Brewer instrument was installed at Alert (82.5xN). By observing the sun and night time moon, total ozone measurements are being obtained.

4. Herzberg Institute of Astrophysics/National Research Council, Ottawa

(a) Planetary Sciences

(i) Auroral Photometry: (R.L. Gattinger, F. Creutzberg, A. Vallance Jones and F.R. Harris). The optical group obtained good data in the Feb. 1987 CEDAR campaign at the Sondrestrom Radar Laboratory in Greenland in simultaneous optical and radar measurements in the magnetic zenith. The optical measurements with the 15-channel twin detector filter-wheel photometer covered emission features from the ultraviolet to the near infrared and with the 0.5m spectrometer. The quick-look plots of the intensities of the N2+ 4278Å, OI 5577Å, 6300Å and 8446Å emissions reveal many episodes of strong aurora as well as several passages of transpolar arcs. The former results are being compared with mean electron energies (from the electron density profiles inferred from the radar). These will include values of the ratios I(6300)/I(4278), I(8446)/I(4278) and N2+ rotational temperatures.

The completed study on the average distributions of proton and electron aurora (1978 IMS dataset) has been submitted for publication. This is now being extended with a separate analysis of the latitude distribution of proton aurora obtained with a 3-in filter wheel photometer operated for several seasons from a station near Ottawa. This will extend the geomagnetic latitude coverage of the earlier study by a further 7° equatorwards. Work is continuing on a study of spectral ratios in substorms from this dataset.

Another study in progress involves variations in the [NI] 5200Å emission obtained with the echelle spectrograph during a night with auroral activity. These measurements show an interesting build-up of intensity during the night. The echelle instrument provides unambiguous characterization of the [NI] emission.

(ii) CANOPUS; General: (A.G. McNamara, D.R. McDiarmid and J. Watermann). The CANOPUS system has now been in partial operation for over two years. The BARS radar system operated well in 1987 until near early Sept. when both radars suffered various multiple damages presumably by power failures, transients, and a transmitter tube blow out. Radars have been restored since February 8. Four Meridian Scanning Photometers are operating now, three on the Churchill line and the fourth in the Alberta sector at Ft. Smith. The All Sky Imager provided some excellent results in the High Resolution mode in January. At present it is not operating; improved magnetometers are to be installed. Magnetometers are now working properly at the four central stations of the Churchill line. We hope to get some good data during the spring maximum of auroral activity.

The software for data handling and analysis are improved although the contractor-written database system is awaiting final corrections. Examination of summary files and recovering data for particular events within a few hours after a "campaign", are now possible with "home-made software".

(iii) BARS: The data for intervals of equatorward drifting bands in the BARS latitude-intensity-time (LTI) plot has been examined, to establish if they really correspond to geomagnetic pulsations. The pre-BARS spectral studies will shift to BARS data when the radars begin producing high resolution Doppler spectra.

(iv) CANOPUS-VIKING Studies: (R.L. Gattinger, F. Creutzberg, F.R. Harris and A. Vallance Jones). The analysis of CANOPUS-VIKING simultaneous observations is progressing slowly. A further period of simultaneous observation during the growth phase of substorm has been identified for April 15, about 1 hour before the beginning of a period in which the southern oval was viewed by the DE-1 imager and during which the PROMIS spacecraft were obtaining data. The CANOPUS meridian scanner was well situated to observe the active part of the oval and there were radar echos from the two BARS radars as well as good magnetometer data.

For convenience in scanning, VIKING UV images of the first 400 orbits have been reproduced on 35mm colour film. This is inexpensive and will be done for the whole mission when the remaining tapes become available. These films can be made available to university team members on request; they are also welcome to visit HIA.NRC, Ottawa.

A procedure has been developed for presenting colour-coded ratio images from the two cameras and this has been used in a study of the variation of these ratios in images showing sun-aligned arcs.

(v) Radio Aurora Studies; Pulsation Theory: (D.R. McDiarmid). Collaborative work with W. Allan (Physics and Engineering Laboratory, Dept. of Scientific and Industrial Research, New Zealand) examines the predictions of the Allan et al. (PSS, 34, 371, 1986) model. The consequences of varying the equatorial mass density distribution, the position and structure of the plasmapause and the latitudinal variation of the damping decrement are being investigated. Also a published impulsively generated pulsation event is being simulated with the model to see if the state of the magnetosphere can be determined more completely. Further work will include the simulation of the ground magnetic and auroral radar (BARS) signatures of the Allan et al. model responses.

(vi) Pre-BARS Studies: (J. Watermann, D.R. McDiarmid and A.G. McNamara). The collaborative work with Drs. Sofko and Koehler examines the Doppler shift dependence and spectral width of types I and II echoes on magnetic aspect angle. The Doppler shift of type I echoes is only weakly dependent on the aspect angle (3% per degree) in the interval 1.5 to 6 degrees and shows that the spectral width did not vary in any consistent way. The data did not permit the Doppler aspect sensitivity of type II echoes to be determined, although they indicated that the dependence could not have been strong. The spectral width of type II echoes was found to increase with magnetic aspect angle. Work is continuing with type III echoes. J. Watermann, D.R. McDiarmid and A.G. McNamara

(viii) Comet Research: (I. Halliday and B.A. McIntosh). The program is to determine the physical properties of comets from high-resolution CCD images of the Canada-France-Hawaii telescope. Images taken through spectral filters provide colour and brightness variations of bare nucleii, or of the spatial distributions and time variabilities of the dominant gas species and dust. Direct analysis, modelling, and correlation with ground-based and spacecraft data, where available, are employed to deduce the desired physical information, namely, the morphology, kinematics, and production rates of gas and dust.

An extensive series of observations of Halley's comet, and a lesser number of observations of six faint comets including Giacobini-Zinner at the time of the ICE encounter, are under analysis. Progress has been made on the general calibration and reduction of the images at JPL, Victoria, and Ottawa. The data on Giacobini-Zinner were used in a collaborative study of the ICE spacecraft results. Current and future analysis has been divided specifically into four areas - onset of coma development in comet Halley; Comet Halley near opposition, November 1985; Analysis of dust in P/Giacobini-Zinner; and Comet Halley at large heliocentric distance: both pre- and post-perihelion. Other studies may include our observations of several faint comets covering a wide range of activities near the cometary nucleus.

(viii) Meteor and Meteorite Research: (I. Halliday). Geminids: A study of Geminid meteors photographed with the fireball camera network has been completed and submitted for publication. There appears to be no possibility that appreciable fragments could survive as meteorites. Geminids penetrate the atmosphere more deeply than other meteor shower members but not as well as suspected meteorites. A comparison of photometric and dynamic mass estimates leads to a mean density near 1.0 for Geminid meteoroids. This appears to prohibit association with known classes of asteroids but is near the upper limit of currently accepted densities for cometary material.

Fireballs: The geometrical reductions have been completed for 367 fireballs, including a subset of 215 objects suitable for estimating the flux of bright meteors. A study of about 40 events believed to have dropped at least a small meteorite in western Canada is nearing completion. Details of the orbit, luminosity, and atmospheric trajectory will be available if any of the objects are located in the future.

Halley Comet Meteors: (B.A. McIntosh). Approximately 720 hours of radar observations of the two comet-Halley meteor showers, the Eta Aquarids (May) and the Orionids (October), have been submitted to the International Halley Watch for archiving.

The model for the dynamical evolution of the Halley meteor stream has been extended to include perturbations by Saturn. As expected, this increases the particle shifts, demonstrating that particles observed now in the Orionid shower must have been released from the comet more than 4000 years ago. A paper has been submitted for publication.

(b) National Research Council/Space Science Division: (G. Atkinson)

Atkinson has studied substorms and discrete arcs. From an experimental study last year, he had determined an onset criterion for expansion (intensification) and other quantitative relationships involving auroral velocities and current intensities, which are unaccounted for by existing theories. His new theory of substorms explains these relationships. Processes in the tail are very similar to the older theories, but are controlled by physical processes in the dipolar region. Atkinson, Creutzberg and Gatting have found that the complicated structure and behaviour of discrete arcs in two substorms and in DMSP observations could be explained if it was assumed that discrete arcs are the mapping along field lines of X lines. Rapidly moving arcs, equatorward on the nightside and poleward on the dayside, could be explained as X line - 0 line pairs trapped in dipolar fields.

D. Kendall is involved in optical space instrumentation - specifically the WINDII and WAMDII programmes and with further developments in space- based ultra-violet auroral imagers. Data from the All Sky Imager (ASI) of the CANOPUS project are being archived and reduced in order to be made available to the scientific community. Several collaborative projects are being initiated involving the ASI and other ground-based or space-based instruments. Processing of the OGLOW data set obtained from teh STS 41-G mission is continuing to obtain further data on atmospheric emissions of interest in the WINDII and WAMDII programmes.

5. University of Alberta; Space Physics Group (G. Rostoker, J.C. Samson, P. Goldstein, X.-S. Wang and D. Webster)

Involvement has been over a wide variety of projects over the last year, including computer simulations, and the VIKING and CANOPUS experiments.

G. Rostoker, with the assistance of two NSERC summer students, D. Vavoie and T.D. Phan, has now completed a study of the response of the magnetosphere-ionosphere system to changes in the interplanetary magnetic field (IMF). An interesting discovery was that polarity of the IMF Bz component normally fluctuates on a time scale of less than 30-40 min.

M.G. Connors and G. Rostoker have completed the first phase to develop an "ad hoc" model of the magnetotail current systems conforming to as many details of tail magnetic field observations as possible.

Further studies of the VIKING images by G. Rostoker are progressing slowly as new hardware has been acquired by the group to handle the data set, and new software is being developed.

G. Rostoker has also become involved in the GISMOS coordinated study which involves the merging of coherent radar data, ground magnetometer array data and VIKING imager data, together with additional supporting data, in an effort to define the precise locale of the events leading up to the substorm expansive phase.

D. Webster, J.C. Samson, and G. Rostoker have finished an analysis of the transient plasma waves (Pi2s) and field aligned currents of the expansive phase. This study is based on data from the AFGL and Alberta magnetometer arrays.

J.C. Samson continues as the principal investigator in the MARIA (magnetometer and riometer array) component of CANOPUS. We expect that the bulk of the magnetometers will be installed by the summer of 1988. As part of this experiment, Xi-shuo Wang is developing algorithms and software for the analysis of the magnetotelluric data from the MARIA array. In addition, Xi-shuo Wang and J.C. Samson are looking at multivariate methods for identifying channeled currents in magnetovariational data.

The computer simulations program has two distinct, but complementary projects. J. Manuel, (PhD student with Dr. J.C. Samson) is developing a hydromagnetic code for the study of the formation of field-aligned currents in the nonlinear Kelvin-Helmholtz instability. The second project centres around studies of the dynamics of nonlinear plasma waves and the interaction of charged particles with these waves. This work is being carried out by P. Goldstein and J.C. Samson in collaboration with W. Rozmus.

6. University of British Columbia; Aeronomy Group (T. Watanabe, T.W. Koleszar, S. Capelle and I.A. Weemes)

(a) ULF Magnetic Variations (magnetic pulsations)

Two field projects were carried out: a multi-national project on auroral dynamics, VLF radio emissions and ULF magnetic variations; and one of simultaneous observations of ULF magnetic variations at a pair of conjugate points, Kuujjuaarapik (Great Whale River), Quebec and Vinson Base, Antarctica. Data analysis of Pc 1, Pc 3-4 and Pi 2 have been underway.

(b) Multi-National Project

Fifteen scientists from nine universities participated in the multi-national project (four from Japan, one from U.S.A. and Norway each, and three from Canada (UBC, U of Vic. and U of Sask.)). The project was proposed and organized by the Univ. of Tokyo. UBC aeronomy group observed the magnetic pulsations. About fifty world-wide magnetic stations were set up, thirty in N. America, mostly in Canada. The UBC group operated four out of ten stations it set up. Over Dec. '85 to Feb. '86 analysis of data is in progress. The initial results (see next subsection) were presented to the Vancouver IAGA meeting (August, 1987). The observation at the Great Whale-Vinson Base conjugate pair was done in cooperation with the instrumentation research team of R.D. Russell (Geophysics/Astronomy Dept., UBC). A fluxgate magnetometer and an induction magnetometer operated at each station (approx. 2 weeks, Dec. '86).

The project will be repeated in the future with an enhanced scale. There was no high latitude station from the southern hemisphere in the last multi-national project (Dec. '85 - Feb. '86).

(c) Conjugate Study

A few IPDP events were investigated during the multi-national project with the induction magnetometer data at 30 stations in N. America, 3 from Svalbard, Norway and 1 from Greenland. An IPDP event delineates a zone of enhanced activity; this is semi-spiral in shape when mapped onto the equatorial plane out in space. The spiral form begins at about L=4 at 21h local time meridian, gradually stretches outward and westward, and ends at about L=7 in a late afternoon meridian. IPDP activity front was found to advance westward. The highest velocity observed was 4°/min. which corresponds to magnetic drift velocity of 40 kev protons. We believe this is the first time that evolution of any type of Pc 1 over a continental scale was elucidated with this fine space/time resolution.

The spiral form of the enhanced activity zone indicates that IPDP is generated on the plasmapause, in agreement with the recent theoretical investigation of T.W. Koleszar (Ph.D. candidate, UBC). His computer simulation used 3 most popular models to produce frequency-time trend of IPDP. A common feature of all these models is slow-mode hm waves generated by non-thermal substorm protons through the ion cyclotron instability process. However, the difference is the region of IPDP creation. One theory (R.E. Horita) assumes that IPDP's are generated as azimuthally drifting protons meet the plasmapause. The two other models consider no special boundary in plasma distribution for the source region. Koleszar's results showed how the frequency-time trend should appear on a north-south line of observation sites. Two IPDP events recorded at five N/S chain of Saskatchewan stations spanning geomagnetic latitudes 60°-67° (during the Pulsating Aurora Campaign, 1980) give the best fit for the Horita model.

Induction magnetometer records from Cape Parry, N.W.T. and Maple Ridge, B.C.(geomag. lats. 74° and 55°) were compared to examine similarity/dissimilarity in daytime Pc 3-4 activity between a high latitude region and a middle latitude one. Their geomagnetic longitudes are nearly equal. Analysis of about ten days data found that Pc 3-4s at the two sites are only sometimes simultaneous; yet their waveforms are generally dissimilar. Note however that the activities at both sites are influenced by the direction of IMF (IMPJ and ISEE3). These findings indicate that Pc3-4s at both stations, if simultaneous, are essentially similar. Presumably Cape Parry is located near the boundary of the polar cap region; on occasion it gets into the same magnetospheric domain as the mid-latitude site, and at other times into the polar cap region.

Two Pi 2 events acquired by induction magnetometer at four stations on a N/S line (geomagnetic latitudes, 60°-67° were analyzed. It was found that both (lasting approx 15 mins, acquired during Saskatchewan Summer Campaign, 1983) were actually a sequence of 3 or 4 Pi 2 occurrences and that the centre of activity moved northward from one occurrence to the next. Identification of the activity centre was made possible through a finding that polarization changed its sense crossing the centre on the N/S line, from clockwise in S to counter-clockwise in N. The analysis was carried out by S. Capelle (MSc. project). Studies of Pi 2 continue. Other substorm-related pulsations of Pi 2 should be studied simultaneously. Besides the well known concurrent Pi burst with Pi 2, a third pulsation type exists (seen from induction magnetometer records obtained in several past field projects). The period of this third type falls in the range of Pc 2 (5-10 sec). Our induction magnetometers are capable of detecting all three types of pulsations, which are generally much smaller than Pi 2 in amplitude.

7. University of Calgary

(a) VIKING UV Imager

The data from the Canadian Ultraviolet Imager (UVI) on the Swedish satellite Viking has produced a wealth of data over the period February 1986-January 1987. The Calgary group has analysed intrinsically our own UV imager data and also compared data from the other experiments onboard; most involve auroral emissions but others involve the dayglow. The UV imager has provided observations of the dayside 1304 and LBH airglow from space.

Our UVI data point out the dynamic nature of the dayside aurora for the first time, with a temporal resolution of 1 minute and occasionally 20 seconds, in contrast to the temporal resolution of 12 minutes of the previous Dynamic Explorer. Historically, temporal studies of the aurora have been confined to a large extent to the nightside because of the difficulty of viewing the auroral emissions in daylight. Some of the results of our studies are as follows: 1) the existence of such variations (primarily in the afternoon sector) indicate acceleration processes operating in the Low Latitude Boundary Layer (LLBL) on the dayside. 2) the relationship between the dynamics on the day- and night-side substorm processes can for

the first time be assessed on a global scale. If IMF changes initiate substorm processes then it is conceivable day-side ramification of this will be noticed first. D. Venkatesan and his graduate student H. Vo are actively pursuing this question. 3) the dayside emissions normally constitute a well defined spatial region connected to the nightside distribution; however, observations also indicate generally magnetic latitude-aligned features at higher latitudes on the dayside. These features may represent the effects of merging between the IMF and magnetotail lobe during northward IMF. The study is being carried out by J.S. Murphree and L.L. Cogger. Dr. J.S. Murphree is the present PI to the UVI project.

Papers were presented at the following meetings: AGU, U.S.A.; European Geophysical Society, Strassbourg, France; Viking Workshop in Uppsala, Sweden; IAGA, Vancouver, Canada; and CAP congress, Toronto, Canada. Visitors to Calgary included Drs. T.P. Armstrong (Kansas), T.A. Potemra and A.T.Y. Lui (Laurel, Maryland), I. Sandahl, B. Hultqvist, L. Block and C-G. Falthammar (Sweden) and G. Rostoker (Edmonton, Alberta) to name a few.

Approval and funding has been obtained for the next Canadian Imager to go on the USSR satellite, Interball in 1990. U. Calgary is involved with the instrument design assistance, ground station development and future data analysis.

(b) CANOPUS

U. Calgary has provided assistance in the design and specifications of an All-Sky Imager (ASI) stationed at Gillam, Manitoba throughout 1987 for the Canadian Auroral Network for the Open Program Unified Study (CANOPUS).

(c) Rothney Astrophysical Observatory (RAO)

The recently acquired new 72" lightweight glass blank is expected to be turned into an optical-quality new main mirror. The precision grinding and polishing need to be done. Eventually the new telescope will provide a dedicated infrared facility, besides being one of the 3 largest telescopes.

Present work on the infrared telescope at RAO began a new phase with the dedication and formal opening of the facility. The telescope is pointing and tracking satisfactorily. Four papers were presented at the combined American and Canadian Astronomical Societies' meeting (Vancouver, June, 1987).

(d) Infra-red Astronomy

The data from the two 1986 field campaigns by T.A. Clark (collaborators: D.A. Naylor and A. Schultz, Univ. of Lethbridge) at Mauna Kea, Hawaii to measure the infra-red spectra of Halley's comet, Jupiter, Saturn and the Sun using the NASA Infra-red Telescope Facility have been under analysis. One manuscript has been published by T.A. Clark and R.B. Boreiko (now at Berkley, CA). The planning and design work of the balloon-borne solar telescope payload (with support from Space Division/NRC, Ottawa) is in progress.

(e) Radio Astronomy

The very large array telescope facility in New Mexico, U.S.A. is used by S. Kwok in continuing a five year project (initiated in 1983) to conduct a comprehensive radio survey of stellar planetary nebulae.

(f) Variable Stars

Milone, Fry and colleagues continued their studies of variable stars with observations at the DAO, Victoria and at Mt. Lemmon Infrared Observatory, besides observations at the Rothney Astrophysical Observatory. The study of Milone and Schiller (at South Dakota State University from September, 1987) has been completed on two eclipsing binary systems.

(g) X-Ray Astronomy Balloon Program

The study of celestial X-ray sources by balloon-borne payloads from Hyderabad, India in collaboration with the Tata Institute of Fundamental Research, Bombay, India continues. (collaborators: D. Venkatesan, D.A. Leahy, and H. Graumann, U. Calgary and S. Naranan, S.V. Damle, B.V. Sreekantan and P.K. Kunte, India) Three papers have been published. These relate to the payload, observation of Hard X-ray observations of the quasar 3C273 and the 2.93-ms pulsations in Scorpius X-1 which has appeared in IAU telegram.

(h) Airglow and Auroral Studies at Spy Hill, Calgary

Collaboration between the University of Calgary (L.L. Cogger, J.S. Murphree and H. Graumann) and the University of Michigan (P.B. Hays and J.W. Meriwether) is a program to measure winds, temperatures and emission rates in the upper atmosphere. A computer controls the three instruments and a scanning photometer. (New location near Spy Hill, Calgary)

(i) Multi-Spacecraft Studies of the Heliosphere

Continuing collaboration between U. Calgary (D. Venkatesan) and The Johns Hopkins University/
Applied Physics Laboratory, Laurel, MD (S.M. Krimigis and R.B. Decker) relating to analysis of data from 3 spacecraft, Voyagers 1 and 2, and IMP-8, has produced some vital results regarding cosmic ray modulation and the extent of the heliosphere boundary. Results were presented at the International Cosmic Ray Conference, Moscow, USSR during August, 1987. A paper has also been presented at the Solar Wind 5 Conference held in Boulder (CO) during August 1987. An invited paper to the Astrophysics and Space Science special issue to commemorate the 80th birthday of Prof. Hannes Alfven has been published. The article is by S.M. Krimigis and D. Venkatesan on the acceleration of charged particles and cosmic ray gradients in the outer heliosphere.

(j) Conjugate Studies of the Magnetosphere

Collaboration has continued between U. Calgary (D. Venkatesan) and AT & T Bell Labs., Murray Hill, NJ (A. Wolfe and L.J. Lanzerotti) on conjugate study. The comparison of magnetometer data from Iqaluit (Frobisher Bay) NWT and its conjugate station at South Pole, Antarctica continues. A paper on ULF observations at Iqaluit has been published. Another paper on Pc 3 pulsations with R. Slawinski (NSERC Undergraduate Summer Aide) is nearing publication.

(k) Study of Particle Precipitation in the Polar Regions

Collaboration between U. Calgary (D. Venkatesan), U. Kansas (T.P. Armstrong, E. Briggs) and U. Maryland, College Park (T.J. Rosenberg and S. Krishnaswamy) continued related to the correlative study of ion fluxes from earth-orbiting satellite IMP-8 and cosmic noise absorption data from a riometer in Antarctica. Part of this work was presented at the International Cosmic Ray Conference, Moscow, USSR during August, 1987.

(l) New Satellite Proposal

T. Mathews, (principal investigator) and R.B. Hicks, C.J. Bland and D. Venkatesan (co-investigators) submitted a proposal for a satellite experiment to study Forbush decreases in cosmic ray intensity. M.A. Shea and D. Smart, the Air Force Geophysical Research Laboratories, Cambridge, MA, W.R. Webber, U. New Hampshire, Durham, NH and John Ormes, NASA, Goddard Space Flight Center, Greenbelt, MD are also involved in this proposal. Futher development of this project is anticipated.

(m) Other News

The new addition to the group is A.R. Taylor (NSERC Fellowship - Asst. Prof.) who joined U. Calgary in August, 1987 and whose interest is Radio Astronomy. His research actively involves the study of high spatial resolution radio continuum and line observations of stars and related objects, using a variety of instruments at various places such as Very Large Array, U.S.A.; Multi-Element Radio Linked Interferometer, UK; and James Clark Maxwell Telescope, Hawaii among others. He has collaborators from U. Toronto (E.R. Seaquist), Smithsonian Astrophysical Observatory (S.J. Kenyou), National Radio Astronomy Observatory (W.M. Goss and R.M. Hjellming) to name a few. He gave an invited lecture at the IAU Colloquium 103 in Torun, Poland during August, 1987.

Committees (1987): A partial listing of committee involvements is given here: T.A. Clark continued as Member of NRC Associate Committee on Space Research; also a member of the NRC Space Astronomy Sub-Committee; also a Director of Westar representing U. Calgary. S. Kwok continued as a member of the NRC Associate Committee on Astronomy and of the Optical and Infrared sub-committee of the NRC Associate Committee on Astronomy. He continued as a member of the Theoretical Sub-Committee and as a member of the NSERC Space and Astronomy Grant Selection Committee. E.F. Milone was elected to the Organizing Committee of International Astronomical Union Commission 25 (Photometry and Polarimetry). D. Venkatesan continued as Chairman of the Space Science Group of the University of Calgary. T.A. Clark and E.F. Milone continue to be Co-Directors of Rothney Astrophysical Observatory. L.L. Cogger and D. Venkatesan continue to be members on the Board of Directors of the Canadian Corporation of University Space Science (CCUSS) and also were respectively, Secretary-Treasurer and Vice-President again for the year 1987-88.

The Canadian Undergraduate Physics Students Conference was held in Calgary in October, 1987. Four papers from U. Calgary were presented by students associated with Dr. D. Venkatesan, namely, D. Cukulin, G. Van Bavel, R. Slawinski and B. Austin; the latter was awarded a third prize in the competition for papers presented.

8. University of Lethbridge; Department of Physics (D.A. Naylor)

D.A. Naylor spent his sabbatical at the University College London, England working on the Infrared Space Observatory's Long Wave-length Spectrometer (ESA). He has continued with development of an infrared FTS for astronomy. During the first part of 1987 he concentrated on the problem of channel fringe elimination from data obtained with the University of Lethbridge FTS. New criteria for the optical train in the spectrometer were set. Two publications and a conference paper resulted.

9. University of Victoria; Department of Physics (R.E. Horita)

Work is continuing on counterstreaming ion (CSI) events in the magnetosphere observed on the ISEE-1 satellite. More recent studies in collaboration with W.K. Peterson and H.L. Collin (Lockheed Space Science Laboratory) and A.W. Yau (NRC) involved data from the lower-altitude DE-1 satellite which show good CSI events correlated with wave activity.

Participation in the Global Auroral Dynamics Campaign (December, 1985-February, 1986) with T. Watanabe (UBC), T. Oguti (U. Tokyo) and colleagues from four Japanese universities, U. Oslo, State Univ. of N.Y. at Albany, etc. has been a fruitful endeavour. The analyses of the vast quantity of data acquired are beginning to produce significant results on many phenomena. Important results have been obtained on the IPDP (intervals of pulsations of diminishing periods) phenomenon, the object of previous studies at the University of Victoria, which will lead to a better understanding of the generation mechanism and source dynamics for IPDP.

10. University of Western Ontario (R. Lowe)

A problem for users of the hydroxyl airglow has been that the set of transition probabilities most widely in use is inconsistent with airglow observations, particularly for the strongest bands in the near infrared. D. Turnbull (Ph.D., 1987) provided a new set of transition probabilities based on an electric dipole moment function for the molecule; this he obtained by combining very precise laboratory measurements with the dipole moment in the lower vibrational states with band ratios from airglow measurements. These new TP's should be valuable in rotational temperature evaluation and in the determination of the details of the excitation/quenching mechanisms. To check the validity of Turnbull's transition probabilities, A. Ali has just built a laboratory OH source and it awaits being put into operation. The source may be useful in the phase calibration of the WINDII instrument.

The UWO vintage Fourier transform spectrometer, which took its first near infrared airglow spectrum in 1966, has been repackaged in 1987 for campaign use. Now it can take a spectrum of the region from 1000 to 1700 nm in 14 s with a S/N of about 200 on the (3-1) band of OH. Software was written in 1987 for the automatic reduction of the large volumes of data gathered in the campaign at Poker Flat (1986), which was to explore any correlation between the hydroxyl rotational temperature and the occurrence of noctilucent clouds (observed by M. Taylor, Southampton University, from a site 200 km south of Poker Flat). The result was negative.

The newly formed Institute of Space and Terrestrial Science is operational. UWO, though a minor partner, will equip the Delaware Observatory for ground-based airglow studies of the effects of gravity waves of the mesopause region.

11. York University; Michelson Interferometer (R. Koehler)

J. Lu successfully completed her PhD. Two papers, one theoretical and one experimental, on the computer-controlled, scanning wide-angle interferometer have been published. A paper on the interferometer system was presented at the 14th Congress of the International Commission for Optics. Lu is now working at Canadian Marconi in Montreal. J. Litwin (new PhD student) has joined the interferometer project.

12. Solar Terrestrial Physics Laboratory (G. Shepherd)

The major news at York University is the start-up of the Institute of Space and Terrestrial Sciences (ISTS) jointly with the Universities of Toronto, Waterloo and Western Ontario, along with sixteen companies. This non-profit corporation will be involved in earth-observations, space-geodynamics and astrophysics, human performance in space, space technologies, and atmospheric physics, as well as electro-optics and microwave technologies. The DASP component of this lies primarily in the Solar Terrestrial Physics Laboratory, a joint enterprise between the Universities of Western Ontario and York. The remainder of this report consists of the York University activity that will become part of the Solar Terrestrial Physics Laboratory within ISTS.

W. Gault is project leader for laboratory instrumentation, in which prototype optical systems will be developed. The first undertaking here is to be S. Piotrowski's PhD thesis, on a version of WAMDII/WINDII that is immune to source intensity variations.

R. Wiens is project leader for observatory observations, where the prototype instruments will be tested on the ground, and where some continuous observations will be conducted. R. Peterson is assisting him in this, and the first project is F. Hamade's PhD thesis on atomic oxygen 7774 and 8846 Å emissions in twilight. This will be followed soon by a CCD device for measuring 02 rotational temperatures, and for airglow imaging.

B. Solheim is project leader for computer systems, to develop hardware for field data acquisition and for subsequent data analysis. He and T. Ivanco will be coming up with some novel systems.

In addition, Wiens is project leader for the WAMDII project (launch in 1990?). The WINDII project is supported by Gault on the hardware side and Solheim on the software side. This project, due for launch in 1991 on the Upper Atmosphere Research Satellite (UARS) is proceeing on a tight schedule. It has produced some excellent test results with the optical test model. For the WINDII project, Y. Rochon has taken responsibility for development of the inversion algorithms (part of his PhD thesis) and C. Hersom (a part-time student employed by Canadian Astronautics Ltd.) has responsibility for instrument characterization (PhD thesis).

The WINDII project has been assisted by having Piotrowski work for a few months for the prime contractor, AIT, and having W. Ward spend one year with Hierogam Associates. Ward plans to proceed to Cambridge with an NSERC PDF to work with M. McIntyre, replacing T. Shepherd who returned to Canada to take up a position at the University of Toronto.

At the fall convocation, Piotrowski, Rochon, Hamade and R. Van Es received MSc degrees.

13. L'Observatoire de Besancon (J. McConnell)

The work, started several years ago, when R. Link and R. Gladstone were at York University, has finally resulted in the publication of a very interesting set of papers on the UV airglow of O and N2 lines in the terrestrial dayglow. The results show the possibility to use theoretical calculations to quantitatively estimate UV dayglow intensities, and perhaps even use the estimates as secondary or tertiary calibration standards. This latter aspect is being pursued by E. Griffioen, J. McConnell and G. Shepherd at York University. The results of the dayglow calculations also cast doubt of the accuracy of the EUV fluxes measured by Hinterreger at solar minimum.

Work has continued on the atmospheres of the outer planets. New laboratory work on recombination continues and further confuses the issues regarding plasma behaviour in their ionospheres.

The "electroglow", a recent source of interest in the atmospheres of the outer planets is under study by J. McConnell with R. Yelle (U. Arizona). A couple of seminal papers have resolved some issues. The work presented at the DPS, Pasadena, has been submitted to GRL.

The electroglow problem may also impact the ionosphere since it appears that the source of the electroglow will also result in substancial pumping of the vibrational levels of H2. T. Majeed is working on these problems in the outer planets ionospheres and has given several presentations at meetings. The work is being written up.

C. Parkinson has been working on radiative transfer problems on the outer planets and has presented some of his work at the AGU. He will be looking at some interesting perturbation methods for application to planetary problems for his thesis.

A. Holubec has been making progress on the application of new techniques for the solution of the electron transport equation. The main code is available for general use, and the results will be published soon.

Details of our chemical model for the lower (80 km) atmosphere have finally been published. Results on the interaction between C1X and NOX compounds are included. The model has also been applied to study the Antarctic ozone problem and a paper has appeared in a special GRL (1986) issue. Recent results on the model and its application to minor constituents in the Antarctic vortex were presented at the AMS; papers will be submitted to a special issue of the Can. J. Phys. and to GRL.

J. Kaminski has joined our group and will be working on the development of a 3-D transport model for application to the stratospheric ozone problem. His model will also be applicable to interesting problems of PAN in the troposphere.

We have also been working on tropospheric chemistry with special reference to PAN production, and hope to submit several papers on acetone, acetaldhyde, and PAN.

IV VOLCANOLOGY

Compiled by: T.S. Hamilton

1. Introduction

In February, 1988, the annual survey of volcanological research was conducted on behalf of the Volcanology Division of the Geological Association of Canada (GAC) in order to compile this report. More than 300 mailings were sent to the list of Volcanology Division members, to potential contributors at provincial and federal government departments and to geoscience departments at Canadian universities. Responses were received from 71 researchers representing: 2 federal government agencies, 4 provincial government agencies, 18 Canadian universities and 3 in the U.S.A. Despite the number of active mines and exploration companies interested in volcanic-hosted and volcanogenic mineral deposits, only 2 replies were received from the private sector. The total number of projects thus reported was 81, including joint research projects and projects pertaining to a single individual. Several researchers indicated that their attention was divided among 2 or more projects. This compilation has been augmented by some of the contributions to the Annual GAC Meeting in St. John's and verbal reports of other investigations of note.

2. Overview

As in previous years, the body of this report consists of a simple compilation by department of active research projects. The post card questionnaire facilitated response and provided a consistent format of information about the projects. The increased number of replies and level of information about the research projects justifies a few general comments in review. To this end, the projects have been sorted and classified to provide profiles which give a sense of the directions in current Canadian volcanological research. Statistics refer to the % of projects reported.

(a) Project Status

New	Ongoing	Completing
18.4%	65.8%	15.8%

This profile reflects the 2 to 3 year lifespan of most projects and a steady state or small growth in interest and activity in volcanic research. The prognosis is one of general health against an overall climate of diminishing funding.

(b) By Region

Shield	-	28.1%
Cordilleran	-	22.8%
Foreign	-	14.0%
Appalachian	-	12.3%
Offrshore	-	12.3%
Other	-	10.5%

By Age

Cenozoic	-	38.5%
Precambrian	-	29.2%
Paleozoic	-	12.3%
Mesozoic	-	12.3%
Other	-	7.7%

By Funding

University	-	48.6%
Federal	-	32.4%
Provincial	-	12.2%
Foreign University	-	4.1%
Private Industry	-	2.7%

As most studies are geographically or temporally (formation) restricted, the research projects have been classified by region and age of volcanic unit. About one third of the studies pertain to Precambrian volcanic belts or formations in the Canadian Shield and are directly administered by federal or provincial agencies. While information concerning actual funding amounts was not solicited, it is readily apparent that whether a part of a federal department's budget, the federal-provincial Mineral Development Agreement (MDA) program or the federal university granting system, the funding for volcanological research derives from the federal tax base. Considering that economic assessment and aid to exploration is frequently given as the justification for regional synoptic studies, it seems unusual that the mining and exploration community does not take a more active role by providing direct sponsorship, particularly to graduate students and university faculty researchers.

More than a third of the projects deal with Cenozoic suites, including most of the Cordilleran, Offshore and Foreign projects. This level of interest is out of proportion with respect to their overall abundance and economic prospects; but justified for academic studies of physical-volcanic processes requiring areal exposure or research into the fundamentals of petrochemical processes requiring analyses of fresh rocks.

(c) By Topic

(i) Regional mapping in areas with a predominant volcanic component, studies tied to specific volcanic centres, formations or belts: physical, economic, structural, paleomagnetic or volcanic geology. 79.1%

(ii) Geochemical/analytical studies of volcanic rocks: major elements, trace elements, rare earths, mineralogy, isotopes, dating. 77.9%

(iii) Volcano-tectonic synthesis, interpretation of a particular formation or volcanic unit to constrain its setting or to constrain models of regional geological evolution. 47.7%

(iv) Processes: volcanic-petrogenetic, physical-volcanology, volcano-tectonic. 19.8%

(v) Mathematical-Statistical-Computer Analysis/Modelling: description of physical, chemical, physical-chemical processes and fitting of real data, statistical geochemical discrimination and classification. 8.1%

(vi) Metallogeny: genetic studies relating a style of volcanism to the formation of economic ore deposits, eg. hydrothermal alteration of ridge/seamount lavas and seafloor sulfides, Andean calderas and epithermal systems. 7.0%

(vii) All-Rounders: Studies containing 3 or more components from the above list, most commonly (i+ii+iii). 48.8%

The emphasis of the first 3 topics is the workmanlike application of volcanology/petrology research tools to regional problems in volcanic geology. Approximately half of the studies (topic vii) constitute a pragmatic application of volcanological skills to other problems. By contrast, only about a third of the studies (topics iv, v, vi) focused on processes or the development of generalizable models and methods that would be of international interest. Given the widespread map oriented mindset, more appropriate to the explorationist than the research scientist, and the non-research constraints and missions under which much research is funded, this is quite a good report card. To Canadian academic and government researchers alike there is a clear challenge to pursue high quality research topics and to salvage them from missions or programs with different boundary conditions, to ensure the future health of volcanological research.

(d) Among the hot topics currently being pursued, are:

(i) Crustal scale volcanic processes in modern oceanic environments and analogous older examples preserved in the continental record of the Canadian Shield and continental margins. (Ocean Drilling Program and other international marine geology programs, conventional land-based field studies.)

(ii) Petrogenetic hypothesis testing with normalized "Pearce Element Ratios".

(iii) Interpretation of mineral zonation patterns in volcanic phenocrysts and the use of the Laser-Nomarski imaging tool.

(iv) The development of thermochemical models for magma evolution.

(v) Volcano-tectonics, discriminant schemes and testing of Quaternary-Cenozoic models against older volcanic geology.

The Canadian strength remains in regional studies which examine entire volcanic formations or belts. These multicomponent studies tend to be geological and map sheet oriented. Typically they include aspects of regional, economic and volcanic geology, physical volcanology, geochemistry and paleotectonic interpretations. Essentially these are case studies of volcanic suites, either to understand the suites, or as a vehicle to understand volcano-tectonic evolution or the regional relationship of volcanic to economic geology. The 2 most recent recipients of the Volcanology Division's "Gelinas Award" for the best thesis, C. Roots and G. Nixon, submitted studies which exemplify this all-round perspective. It cannot be overemphasized that strong, highly valued research of this type is only possible given sufficient funding, support and project longevity. Many Canadian volcanological researchers, in contrast, are attempting to pursue quality research topics by salvaging them from programs with boundary conditions or missions which are different than the advance of research per se.

Among the synoptic studies there are strong traditional efforts by the Precambrian groups of the Geological Survey of Canada and the Ontario Geological Survey. In addition, there are several new initiatives under joint Federal-Provincial/Territorial funding. While these 2-3 year programs exist from B.C. to Newfoundland, the majority of those reported come from joint programs of DIAND and the NWT EMR Secretariat in Yellowknife.

(e) Publications

In previous years, the number of reported publications has been roughly half the number of projects. This year by contrast, the ratio of bibliographic items to projects is higher than 1. Correcting for newly initiated projects that have no data yet to report, the value of the ratio is between 1 and 2, suggesting this to be the steady state level of productivity for the average volcanological research project.

(f) Workshops and University Programs

J.K. Russell (UBC) reported to Geoscience Canada on the 2nd annual Canadian Inter-University Workshop on Igneous Petrology held at Queens University. The 3rd conference, scheduled for August, 1988 at UBC, is organized in conjunction with a field trip to Meagher Mountain. Directions of VGP research at Canadian Universities reflect interest in the Pearce Element Ratio method for testing petrogenetic hypotheses, thermochemical modelling for matching observed mineral compositions and following liquid lines of descent, in addition to traditional suite-oriented petrological investigations. There have not been any profound topical workshops in the VGP venue since the short course on Silicate Melts at the 1986 GAC Meeting in Ottawa.

(g) Meetings

During the past year, Canadian volcanologists have taken the opportunity to publicize their activities and to participate in several national and international meetings including: IUGG-Vancouver 1987, the 1987 Circum-Pacific Conference, the annual GSA and AGU meetings and the Conference on How Volcanoes Work-Hawaii 1988. At the GAC Annual Meeting - St.John's, Newfoundland, there were a number of papers and sessions of volcanological interest. Of all the papers and posters presented 8% had a volcanic component. While most of those occurred on the first day, a quarter of the sessions had 2 or more such papers. The highlight of the meeting was the special session on "Volcanic Regimes in Past and Present Oceanic Environments".

Upcoming meetings with topics of interest include: the Italian volcanoes trip in conjunction with the 1989 Montreal GAC, continental volcanism at the 1989 Santa Fe IAVCEI meeting and the 1990 Vancouver GAC meeting, with Cascades and Cordilleran themes in addition to special sessions and volcanic field trips.

(h) Canadian Involvement In International Projects: Oceanic Volcanism

Under the Ocean Drilling Program, P.T.Robinson (Dalhousie) was co-chief scientist on Leg 118 to the Atlantis II Fracture Zone. There, he and R. Hebert (Laval) were involved in the drilling of oceanic layer 3. Material obtained on that cruise should be instrumental in testing models for magma chamber processes and magma supply beneath ridges. Canadians remain involved in ODP, with membership on international committees and participation in various legs (eg. Leg 120 - Kerguelen Plateau, Leg 121 - Broken Ridge) and future proposals, including the drilling planned for the Northeast Pacific. Also on the international scene, S.D. Scott (U.of T.) and R.L. Chase (UBC) have also been active with their participation in the PACLARK cruises to Western Woodlark Basin. There, ocean ridge style tectonics and volcanism occur in the attenuated and foundered continental crust of a marginal basin. This provides a more relevant model for the Precambrian greenstone belts of the Canadian Shield and their metallogeny than that available from classical MOR settings. Under the Cyprus Crustal Study Project W.R.A. Baragar (GSC) investigated sheeted dykes and pillow lavas of the Troodos Ophiolite, obtaining useful information about primary and secondary processes in oceanic crust at various crustal levels.

(i) Future Research Opportunities:

There are some areas of volcanological research which are under-represented with respect to potential contributions and represent tremendous research opportunities.

(i) Critical review of volcanic environments from the Canadian rock record, to demonstrate the problems in and to improve upon volcano-tectonic evaluations.

(ii) Development of general volcanological facies models from cross sectional exposure of older volcanic belts.

(iii) Develop integrated volcanic-metallogenic models of volcanic-hydrothermal ore systems based on modern offshore systems in ridge and seamount settings and older Canadian occurrences.

(iv) Investigation of Paleozoic and Mesozoic Volcanic Units of the Cordilleran, Appalachian and Arctic regions to provide tectonic constraints on assemblage of allochthonous terranes and volcanotectonic information about continental margin evolution.

(v) The Tertiary to recent volcanism of Western Canada affords an excellent laboratory to study volcanism in: arc, back-arc, within plate and leaky transform settings, and to evaluate crust-mantle processes integral to developing more robust tectonic models.

Studies like these can make a lasting contribution to the science of volcanology, and should be targeted by granting bodies and private industry as high priority - high return topics to fund. Given the vast amount of Canadian volcanic real estate and associated mineral potential, the need for fundamental studies of physical volcanology and volcanic geology remains great.

3. Research in Federal Government Departments

(a) Geological Survey of Canada (EMR)

(i) R.G. Anderson (GSC, CD/CPDM, 100 W. Pender St., Vancouver, B.C., V6B 1R8; [604] 666-2693).

PROJECT: ONGOING

Paleozoic to Recent volcanology, NW Stikinia, Iskut River Area NTS 104B.

OBJECTIVES: Determine nature, age, geochemical and isotopic analyses on Devonian, Permian, Triassic, Lower Jurassic and Recent volcanics.

METHODS: Mapping, physical volcanology, geochronometry, Sr and Nd isotopic studies.

FINDINGS: Field studies indicate facies changes from E to W for Upper Triassic Volcanics and S to N for Lower Jurassic.

PLANS: More field mapping and further geochronology and geochemistry.

CONTRIBUTIONS (1987-1988): None

(ii) S.B. Ballantyne (GSC, MRD, 601 Booth Street, Ottawa, Ontario, K1A 0E4; [613] 995-4836).

PROJECT: ONGOING

Remote sensing study, Landsat-5 TM Imagery of Ruby Mountains Cinder Cone Field, Atlin Mining District, northern B.C.

OBJECTIVES: Compare and quantify features, Neogene cinder cones and older gossans.

METHODS: Landsat-5 TM image processing, field relations, geochemistry

FINDINGS: Quantification of oxidized scoria character on TM as an identifier and baseline for exploration.

PLANS: Continuing study.

CONTRIBUTIONS (1987-1988): None.

(iii) W.R.A. Baragar (GSC, LCSD, 588 Booth Street, Ottawa, Ontario, K1A OE4; [613] 995-4864).

PROJECT 1: COMPLETING

Investigations in sheeted dykes and pillow lavas under the auspices of the Cyprus Crustal Study Project, International Crustal Research Drilling Group.

OBJECTIVES: To correlate chemical and petrological data on the sheeted dykes with the other elements of The Troodos Ophiolite; pillow lavas and plutonic complex. To study the effects of sea floor weathering and hydrothermal alteration on composition at various crustal levels.

METHODS: Perform detailed sampling and analyses, determine structural and stratigraphic relationships.

FINDINGS: Compositional range and variation in sheeted dykes matches that of pillow lavas but unlike the latter shows no break in composition between depleted (Mg-rich) and non-depleted suites and no systematic age preference. More than one magmatic source. Alteration consistent with hydrothermal influence in lower part of pillow lavas and sheeted dykes, weathering in upper 300-400 m of pillow lava sequence.

PLANS: Completion.

CONTRIBUTIONS: Baragar, W.R.A. et al., 1987

PROJECT 2: ONGOING

Volcanics of the Circum-Superior Belt of Eastern Hudson Bay.

OBJECTIVES: To determine the source characteristics, the origin, the tectonic significance and compositional variations of komatiitic and tholeiitic suites of the volcanic assemblage.

METHODS: Trace and major element characteristics and stratigraphy-related variability.

FINDINGS: Much of short-range stratigraphic variability attributable to fractionation in the surface conduits; long-range variability to major subsurface magma reservoirs.

PLANS: Examination in detail of geochemistry and petrology of spinifex-textured flows.

CONTRIBUTIONS: Baragar, W.R.A. and Scoates, R.F.J., 1987.

(iv) M.L. Bevier (GSC, LCSD, 601 Booth Street, Ottawa, Ontario, K1A OE8; [613] 995-4805).

PROJECT: ONGOING

A radiogenic isotopic study of Stikine Volcanic Belt, B.C.

OBJECTIVES: To discern nature and composition of the mantle beneath accreted terranes and North America Craton in northern B.C.

METHODS: Pb-Sr-Nd isotopic ratios of young, mantle-derived volcanic rocks.

FINDINGS: Slightly depleted suboceanic mantle (like source for seamounts in Juan de Fuca plate) is widespread; older more radiogenic mantle beneath the craton is hinted at.

PLANS: Analyses on referred samples from additional centres.

CONTRIBUTIONS (1987 -1988): Bevier, M.L., 1988.

(v) S.S. Gandhi (GSC, MRD (NWT-MDA), 601 Booth Street, Ottawa, Ontario, K1A OE8; [613] 995-4642).

PROJECT: ONGOING

Metallogeny of magnetite-rich differentiates of quartz monzonite intrusions in the Great Bear-Great Slave Lakes regions.

OBJECTIVES: Study of metallogeny and resource potential of the magnetite-rich veins, pods and breccia-fillings associated with quartz monzonite intrusions and related volcanic sequences. (U, Cu, Precious metals).

METHODS: Fieldwork, whole rock chemical analyses, petrographic study, multi-element-analyses of mineralized samples; U-Pb pitchblende dating.

FINDINGS: Initial work in the southern Great Bear magmatic zone (Aphebian).

PLANS: Continuation of mapping/metallogenic study of the Faber Lake volcanic belt (andesite-dacite-rhyolite) in southern Great Bear magmatic zone.

CONTRIBUTIONS (1987-1988): Gandhi, S.S., 1988.

(vi) T.S. Hamilton (GSC, PGC/CPGD, 9860 W.Saanich Rd., Sidney, B.C., V8L 4B2; [604] 356-6423).

PROJECT 1: ONGOING

Tertiary volcanism in the Queen Charlotte Islands.

OBJECTIVES: Understand petrogenesis and tectonic setting of the Masset Formation.

METHODS: Dating, petrography, mineralogy, stratigraphic and regional petrochemistry: majors, trace, REE, and modelling.

FINDINGS: Mantle derived T-MORB parental to Eo-Oligocene two pyroxene, calc alkaline suite and Miocene bimodal suite. Incipient rifting in ridge proximal, ridge-transform, continental margin setting.

PLANS: Additional petrochemistry and preparation of journal articles.

CONTRIBUTIONS (1987-1988): Cameron and Hamilton, 1988; Dostal and Hamilton, 1988; Hamilton, T.S., 1988a and 1988b.

PROJECT 2: ONGOING

Petrology of seamounts at the Southern Terminus of the Kodiak-Bowie Seamount Chain.

OBJECTIVES: Characterization of seamount petrogenesis and relationship to NE Pacific tectonics.

METHODS: Dating, Petrochemistry.

FINDINGS: Sampled main edifice of seamounts: Bowie, Graham, Oshawa and a small unnamed seamount between Oshawa and Moresby Island. Dredged: basalts, diamictons, Mn encrustations and benthic communities.

PLANS: Petrography, whole rock major, trace and isotope geochemistry on 1987 dredged basalts, radiometric dating.

CONTRIBUTIONS (1987-1988): Chapman et al., 1987.

(vii) T.S. Hamilton[1], B.E.B. Cameron[1], M. Fowler[2] and L. Snowdon[2] (GSC, [1]PGC/CPGD, 9860 W. Saanich Rd. Sidney, B.C., V8L 4B2; [2]ISPG, 3303 - 33rd St. NW, Calgary, Alberta; [604] 356-6423) or [403] 284-0425).

PROJECT: COMPLETING

Organic geochemistry of bitumen seeps from Masset Volcanics, Queen Charlotte Basin.

OBJECTIVES: Report and characterize oil showings in Neogene volcanics, source typing, degradation and maturation studies.

METHODS: Organic and Inorganic Geochemistry, SFGC, GCMS.

FINDINGS: There are multiple oil sources in L. Jurassic, Cretaceous and Tertiary strata. Maturation and migration post-dated the eruption, emplacement and deformation of the Tertiary volcanics. The basin has conventional hydrocarbon sources but volcanic hosted accumulations are related to the influence of volcanic heat and young structural deformation.

PLANS: Characterize oil seep samples collected from Masset Volcanics in 1987 and publication of results.

CONTRIBUTIONS (1987-1988): Hamilton, T.S. and Cameron, B.E.B., 1988; Fowler, M.C. et al., 1987; Snowdon et al., 1988.

(viii) T.S. Hamilton and P.J. Wynne ([604] 356-6423).

PROJECT: ONGOING

Paleomagnetic Studies of Tertiary (Masset) and M. Jurassic (Yakoun) Volcanics in Queen Charlotte Is.

OBJECTIVES: Tectonic and structural history of region, magnetostratigraphy.

METHODS: Paleomagnetism, dating, stratigraphy.

FINDINGS: Composite reversal stratigraphy for U.Eocene - L. Miocene of Queen Charlotte Islands. Neogene block faulting and tilting with structural domains a few km wide. Displacement of Wrangellia from southerly latitude.

PLANS: Publications in prep., Wynne and Hamilton (1988).

CONTRIBUTIONS (1987-1988): None

(ix) C.J. Hickson (GSC, CD/CPGD, 100 W.Pender St., Vancouver, B.C., V6B 1R8; [604] 666-3955).

PROJECT 1: COMPLETING

Quaternary volcanism in the Wells Gray - Clearwater region, east-central British Columbia.

METHODS: Field mapping, geochemistry.

FINDINGS: Alkalic basalts, primitive, deep mantle sources, not related to Anahim Volcanic Belt.

PLANS: Completion of three papers in preparation/press.

CONTRIBUTIONS (1987-1988): Juras, S.J. et al., 1987.

PROJECT 2: NEW

Structure and Stratigraphy of the Tertiary Masset Formation, Queen Charlotte Islands.

OBJECTIVES: Physical volcanology, geographic extent, structure, relationship to offshore stratigraphy.

METHODS: Field mapping 1:50,000 scale, portions of NTS:103 F,G,K

FINDINGS: In Current Research, Part E, 1988.

PLANS: Complete field mapping on Graham Island.

CONTRIBUTIONS (1987-1988): Hickson, C.J., 1988.

(x) C.J. Hickson, and W.H. Mathews (GSC, and Dept. of Geol.Sci., U.B.C., Vancouver, B.C., V6T 2B4; [604] 666-3955).

PROJECT: NEW

Geochemistry of the Chilcotin Basalts.

OBJECTIVES: Looking at age and locality related variations in trace and major element chemistry.

METHODS: Geochemistry.

FINDINGS: In progress.

PLANS: Manuscript: with Mathews, W.H. - Geochemistry of the Chilcotin Basalts.

CONTRIBUTIONS (1987-1988): None

(b) Department of Indian and Northern Affairs and EMR Secretariat, Government of NWT

(i) D. Atkinson and W.A. Padgham (EMR Secretariat, Government of NWT, P.O.Box 1320, X1A 2L9, and Geol. Div., DIAND, P.O. Box 1500, Yellowknife, NWT, X1A 2R3; [403] 920-3347).

PROJECT: NEW

Geology of the Yellowknife Volcanic Belt, Mining District 85J/E.

OBJECTIVES: Determine relationship of volcanics to metallogeny.

METHODS: Detailed mapping, stratigraphy and structure in shear zones of belt.

FINDINGS: New MDA project

PLANS: Project life 1988 - 1990.

CONTRIBUTIONS FOR (1987 -1988): None

(ii) W.A. Gibbins and J. Giebert (Geology Division, DIAND, Box 1500, Yellowknife, NWT, X1A 2P2, and EMR Secretariat, Govt. of NWT, Box 1320, Yellowknife, NWT, X1A 2L9; [403] 920-8216).

PROJECT: ONGOING, MDA: 1985-1989

Geology of the Hope Bay volcanic belt:76 N/SW,76 O/NE and 77 A/S.

OBJECTIVES: Complete mapping of southern 2/3 of belt, evaluate mineral showings and assess economic potential.

METHODS: Field mapping - Geochemistry/Geochronology

FINDINGS: First komatiitic peridotite rocks reported from Slave Province in 1986.

PLANS: Complete mapping and compile results.

CONTRIBUTIONS FOR (1987 -1988): Gibbins, W. A., 1987.

(iii) W.A. Gibbins and others, as above

PROJECT: ONGOING, 1988 - 1990

Geology of the Central Baffin Island volcanic belt, 37/W.

OBJECTIVES: Mapping of portions of belt at 1:30,000. Provide overview of regional and economic geology for exploration.

METHODS: Field mapping, geochemistry and geochronology.

FINDINGS: First komatiitic peridotite rocks reported from Slave Province in 1986.

PLANS: Complete mapping and compile results as maps and open file reports.

CONTRIBUTIONS FOR (1987 -1988): None.

(iv) S. Goff and J.L Griep (EMR Secretariat, Govt.of NWT, Box 1320, Yellowknife, NWT, X1A 2L9, and Geology Division, DIAND, Box 1500, X1A 2P2; [403] 920-3347).

PROJECT: ONGOING (MDA: 1988 - 1990)

Geology of Archean volcanics: Pistol Bay - Mistake Bay (Kaminak Belt), Rankin - Ennadia Terrane.

OBJECTIVES: Geologic mapping of portions of belt at 1:50,000 or more detailed, volcanic stratigraphy, volcanic - sedimentary facies relations, geochemistry, petrology, regional and economic geology related to volcanics.

METHODS: Field mapping, geochemistry and geochronology.

FINDINGS: New project.

PLANS: Perform mapping and compile results as maps and open file reports.

CONTRIBUTIONS FOR (1987 -1988): None.

(v) V.A. Jackson (INAC, NAP Geology Division, BOX 1500, Yellowknife, NWT, X1A 2R3; [403] 920-8552).

PROJECT: ONGOING

1.) Geology of the Russell Lake Area (85 0/4)
2.) Geology of the Kathawachaga Lake Area (76L).

OBJECTIVES: Areal mapping at 1:30,000 or more detailed of supracrustals including metavolcanics and metasediments.

METHODS: Field mapping

FINDINGS: New areas of high-grade volcanic rocks (in 76L) previously mapped as granitoids and gneissic rocks.

PLANS: Geochemistry and petrological studies.

CONTRIBUTIONS FOR (1987 -1988): Jackson, V.A., 1987a and b.

(vi) J. Morgan, and W.A. Padgham (EMR Secretariat, Government of NWT, P.O.Box 1320, X1A 2L9, and Geol. Div., DIAND, P.O. Box 1500, Yellowknife, NWT, X1A 2R3).

PROJECT: NEW (MDA: 1988-1990)

Indin Lake Volcanics (Supracrustals) 86 B/SW

OBJECTIVES: Volcanology, stratigraphy, structural geology, mineralization and exploration

METHODS: Detailed field mapping

FINDINGS: New project.

PLANS: Preliminary geological reports and open files, NWT geology division.

CONTRIBUTIONS FOR (1987 -1988): None.

(vii) M. Stubbly and W.A. Padgham (EMR Secretariat, Government of NWT, P.O.Box 1320, X1A 2L9, and Geol. Div., DIAND, P.O. Box 1500, Yellowknife, NWT, X1A 2R3).

PROJECT: NEW (MDA: 1988-1990)

Geology of the Carp Lake - Tundra Area (75 M/W, 76 D/SW and 85 P)

OBJECTIVES: Detailed mapping of supracrustal rocks (including volcanics) at 1:50,000. Elucidate geologic history and precious metal potential.

METHODS: Mapping, geochemistry

FINDINGS: New project

PLANS: as above.

CONTRIBUTIONS FOR (1987 -1988): None.

4. Provincial Geological Surveys and Departments of Mines

(a) British Columbia Geological Survey Branch

(i) N. Massey (B.C. Geological Survey Branch, M.E.M.P.R., Parliament Buildings, Victoria, B.C., V8V 1X4; [604] 356-2828).

PROJECT: ONGOING

Geology of Sicker Group volcanics and sediments (≈Devonian)

OBJECTIVES: To understand the stratigraphy and structure of the Sicker Group of the Cowichan Uplift, S. Vancouver Island.

METHODS: 1:50,000 Field mapping.

FINDINGS: (2) - Field seasons to date (1986, 1987) - (2) 1:50,000 maps published.

PLANS: 1 more field season (1988); 1 writing year (1989).

CONTRIBUTIONS FOR (1987 -1988): Open file map sheets.

(b) Ontario

(i) J. Ayer (Ontario Geol. Surv., 77 Grenville St., Toronto, Ont., M7A 1W4; [613] 832-2751).

PROJECT: ONGOING

Synoptic Survey of Lake of the Woods, Kenora District, Ontario.

OBJECTIVES: Stratigraphy, geochemistry and volcanology of the Lake of the Woods Greenstone Belt.

METHODS: Field mapping, petrography, geochemistry.

FINDINGS: New project.

PLANS: As above.

CONTRIBUTIONS FOR (1987 -1988): Ayer, J., Preliminary Maps and Open File Report for the Ontario Geological Survey.

(ii) M.W. Carter (Ontario Geol. Surv., 909-77 Grenville St., Toronto, Ont., M7A 1W4; [416] 965-4817).

PROJECT: NEW

Alkalic Volcanic Rocks, Thunder Bay Area.

OBJECTIVES: Study stratigraphy, geochemistry, and petrology.

METHODS: Mapping, volcanological, chemical

FINDINGS: Alkalic volcanism occurs in both Keewatin-type and Timiskaming-type rocks.

PLANS: Detailed study of stratigraphic relationships and petrography and chemistry.

CONTRIBUTIONS FOR (1987 -1988): Carter, M.W., 1987.

(iii) R.M. Easton (Ontario Geol. Surv., Precambrian Geology Section, 77 Grenville St., Toronto, Ontario, M7A 1W4; [416] 965-4817).

PROJECT: ONGOING

Volcanism in the CMB, Grenville Province, Ontario.

OBJECTIVES: Understand volcanic environments and facies in Central Metasedimentary Belt.

METHODS: Geology and facies mapping, stratigraphy, geochemistry, and multivariate statistics.

FINDINGS: Presence of alkaline volcanics in Minder area, Ontario.

PLANS: Study the effect of carbonate alteration on volcanic rock chemistry in Grenville Province. Stratigraphic synthesis of CMB.

CONTRIBUTIONS FOR (1987 -1988): Easton, R.M., 1987a; 1987b; Easton, R.M. et al., 1987.

(iv) R.M. Easton, E.C. Grunsky, L.S. Jensen, P.C. Thurston and J. Howe (Ontario Geological Survey, as above; [416] 965-4817).

PROJECT: ONGOING

Geochemical Classification of Archean Volcanic Rocks.

OBJECTIVES: Devise a chemical classification scheme for Archean volcanic rocks, utilizing modern statistical techniques.

METHODS: Geochemistry, multivariate statistics.

FINDINGS: Komatiite reference database of 1786 analyses prepared, various ternary plots tested for comparison/distinction.

PLANS: Continue work on Archean suites: tholeiitic, calc-alkaline and alkaline.

CONTRIBUTIONS FOR (1987 -1988): Grunsky, E.C. et al., 1987a and 1987b; Howe, J. et al., 1987.

(v) P.C. Thurston, A.L. Cortis, D.W. Davis, (Roy. Ont. Mus.) and L.D. Ayres (U. of Man.) (O.G.S., 928-77 Grenville St., Toronto, Ontario, M7A 1W4; [416] 965-1827).

PROJECT: NEW

Volcanology and sedimentology of Archean platform sequences.

OBJECTIVES: Characterization of environment of shallow water quartzites-komatiites.

METHODS: Mapping, geochemistry, geochronology

FINDINGS: Ten new occurrences found in Sachigo Subprovince, excellent preservation of primary structures such as hummocky cross bedding, recrystallization (vapour phase) in subaerial tuffs.

PLANS: Volcanology, U/Pb geochronology

CONTRIBUTIONS FOR (1987 -1988): Thurston, P.C. et al., 1988.

(c) New Brunswick

(i) R.A. Wilson (N.B. Dept. of Natural Resources and Energy, Geological Surveys Branch, P.O. Box 6000, Fredericton, N.B., E3B 5H1; [506] 453-2206).

PROJECT: COMPLETING

Geochemistry and tectonic significance of Siluro-Devonian mafic volcanic rocks of the Tobique/Chaleur belt of northern NB.

OBJECTIVES: To document the geochemistry of these volcanic rocks, and to use these data to constrain the eruptive environment and possible tectonic models for the evolution of the Appalachian Orogen during the Siluro-Devonian.

METHODS: Whole rock geochemistry; pyroxene microprobe analysis.

FINDINGS: The overall chemistry of The Tobique/Chaleur mafic volcanics is consistent with an anorogenic environment although calc-alkaline major and trace-element signatures are present, as for active continental margin settings. A tectonic environment like present-day Iran-Turkey is inferred.

PLANS: Paper on these results in preparation with J. Dostal of St. Mary's University. Further analyses and interpretation of the lithogeochemistry and metallic mineral potential of the Tobique/Chaleur belt.

CONTRIBUTIONS FOR (1987 -1988): Wilson, Reginald A., 1988.

(d) Newfoundland

(i) G.A.G. Nunn (Department of Mines, Box 4750, St. John's, NFLD.; [709] 576-2769).

PROJECT: COMPLETING

Regional geology east of Michikamau Lake, Labrador.

OBJECTIVES: Regional mapping programme. Volcanics minor.

METHODS: Regional mapping.

(ii) H.S. Swinden (Dept. of Mines, P.O. Box 4750, St. John's, NFLD.)

PROJECT: ONGOING

Pb isotopes in volcanogenic massive sulfides from N. Appalachians.

OBJECTIVES: Genetic study of Pb isotopes from volcanogenic massive sulfides.

METHODS: Pb isotopes, geology, tectonics

FINDINGS: Pb isotope fingerprint of galenas from volcanogenic massive sulfides provide integrated estimates of their source leads which correlate to distinctive tectonostratigraphic terranes.

CONTRIBUTIONS FOR (1987 -1988): Swinden, H.S. et al., 1988.

5. Universities

(a) University of Alberta

(i) R. St. John Lambert, V. Chamberlain, I. Marsh and G. Goles (Geology Dept., University of Alberta, Edmonton, Alberta, T6G 2E3, and Idaho, Oregon; [403] 432-3265).

PROJECT: ONGOING

Rare Earth and Isotope Geochemistry of Columbia River Basalt (andesites).

OBJECTIVES: Petrogenesis.

METHODS: REE and Isotope Work.

(ii) S. Prevec (Geology, University of Alberta, Edmonton, Alberta, T6G 2E3; [403] 432-4749).

PROJECT: NEW

An isotopic and geochemical investigation of the genesis of mafic intrusive and volcanic rocks of the basal Huronian near Sudbury, Ontario.

OBJECTIVES: Age, origin-effect of low and high T alteration, contamination on geochemistry: Rb/Sr, Pb, Sm/Nd systems, and implications regarding southern-superior province contact.

METHODS: Geology, Geochemistry and Radiogenic isotopes.

FINDINGS: Sampling to commence in summer 1988.

PLANS: as above

CONTRIBUTIONS FOR (1987 -1988): None.

(b) University of British Columbia

(i) J.F. Allan (Dept. of Geological Sciences, UBC, Vancouver, B.C., V6T 2B4; [604] 288-2646).

PROJECT: NEW

1.) Petrology of Lavas from Tuzo Wilson Knolls
2.) Petrology of Lavas from Explorer Seamount

OBJECTIVES: Understand volcanism of near-ridge and ridge-transform transition

METHODS: INAA, XRF, microprobe, isotopes

FINDINGS: New project.

PLANS: Further sampling: Explorer Ridge/Dellwood Knolls Region.

CONTRIBUTIONS (1987-1988): Allan, J.F. et al., 1988.

(ii) R.L. Chase (Dept. of Geological Sciences, U.B.C., Vancouver, B.C., V6T 2B4; [604] 228-3086).

PROJECT: ONGOING

Explorer Ridge, Northeast Pacific: Relations of Seafloor Sulphides to Host Basalts.

OBJECTIVES: Relations of ridge volcanism to tectonics and sulfide deposition.

METHODS: Dredge, camera tows, geochemistry, ROV.

FINDINGS: Compositional gradients along Explorer Ridge.

PLANS: Data analysis and 1989 cruise.

CONTRIBUTIONS FOR (1987 -1988): Michael, P.J. & Chase, R.L. 1987.

(iii) P. Michael (Dept. of Geological Sciences, UBC, Vancouver, B.C., V6T 2B4; [604] 228-3914).

PROJECT: COMPLETING

Trace element behaviour in high-silica rhyolites and granites.

OBJECTIVES: Partitioning behaviour and accessory phase compositions for contrasting granites and rhyolites.

METHODS: microprobe mostly - INAA and XRF also

FINDINGS: REE partition coefficients are not as high as previously thought; accessory phases and inclusions in major phases are very important.

PLANS: Study of a dissected, caldera - subvolcanic system.

CONTRIBUTIONS FOR (1987 -1988): Michael, P., 1988.

(iv) P. Michael and R.L. Chase (as above; [604] 228-3914).

PROJECT: 1-COMPLETE, 2-ONGOING, 3-NEW

1. Crystallization of MORBS
2. H_2O in mantle
3. Chlorine and Sulfur in mantle

OBJECTIVES:
1. Determine controls on basalt crystallization - (MORBS)
2. Concentration, behaviour and storage of H_2O in MORB-mantle and ARC-mantle.
3. Determine behaviour of Cl + S in mantle and melts.

METHODS: Microprobe, gas chromatography, XRF, INAA, geochemical modelling.

FINDINGS: For MORBS, liquid line of descent is affected by primary magma composition and H_2O content but not by spreading rate.

PLANS: Study of back arc basin basalts. Study of Mid Atlantic Basalts and comparison with Pacific

CONTRIBUTIONS FOR (1987 -1988): Michael, P. and Chase, R.L., 1987 and 1988.

(v) J.K. Russell (Dept. of Geological Sciences, UBC, Vancouver, B.C., V6T 2B4; [604] 228-2703).

PROJECT: ONGOING

Crystallization and vesiculation of basaltic magmas.

OBJECTIVES: Produce a thermodynamic basis for modelling magmatic processes.

METHODS: Computer simulation and measurement of natural rock and mineral compositions.

FINDINGS: Results have been applied to the 1984 eruption of Mauna Loa, Hawaii.

PLANS: Couple thermodynamic model to equations describing physics of heat transfer and fluid flow.

CONTRIBUTIONS FOR (1987 -1988): Russell, J.K. and Nicholls, J., 1988.; Russell, J.K. et al., 1987.; Russell, J.K., 1987.; Pearce et al., 1987b.

(c) University of Saskatchewan

(i) M. Stauffer and L. Coleman (Geology, University of Saskatchewan, Saskatoon, Saskatchewan, S7N 0W0; [306] 966-5708).

PROJECT: Volcanology of the Amisk Group, Flin Flon, Manitoba

OBJECTIVES: Plate tectonic setting and evolution of the region.

METHODS: Mapping, trace elements, isotopic analyses

FINDINGS: Subduction zone with no prior continental crust.

PLANS: Continue slowly.

CONTRIBUTIONS FOR (1987 -1988): None.

(d) Guelph University

(i) M.E. Brookfield (Land Resource Sci., Guelph University, Guelph, Ontario, N1G 2W1; [519] 824-4120).

PROJECT: ONGOING

Radiometric dating of Himalayan magmatism.

OBJECTIVES: Determine times of magmatic activity.

METHODS: $^{40}Ar/^{39}Ar$, Fission track, Rb/Sr.

FINDINGS: Separation of Ladakl and Karnkorum as distinct phases.

PLANS: Extend to North Karnkorum and Lower China.

CONTRIBUTIONS FOR (1987 -1988): None.

(e) University of Western Ontario

(i) H.C. Palmer (Dept. of Geophysics, University of Western Ontario, London, Ontario, N6A 5B7; [519] 679-2111 Ext. 6749).

PROJECT: COMPLETING

Reconstruction of Mid-Tertiary volcanic centres in NE Nevada.

OBJECTIVES: From fabric data in Mid-Tertiary felsic tuffs to reconstruct the probable locations of volcanic centres (calderas)

METHODS: Field fabric elements, anisotropy of magnetic susceptibility and paleomagnetic data.

FINDINGS: Abstract submitted to AGU for Spring Meeting, 1988.

PLANS: Continuing

CONTRIBUTIONS FOR (1987 -1988): Palmer, H.C. et al., 1988.

(ii) P.W. Stewart (University of Western Ontario, London, Ontario, N6A 5B7; [519] 661-3187).

PROJECT: ONGOING

Geology of the Hope Brook gold mine, Nfld.

OBJECTIVES: Establish timing of gold mineralization within regional geologic context.

METHODS: Field mapping, petrography, lithogeochemistry, mineral chemistry (as required), geochronology.

FINDINGS: Gold mineralization associated with Cinq Cerf Shear Belt: a deformed and altered assemblage of volcaniclastics, felsic to mafic dykes and plutonics. Mineralization likely post volcanic.

PLANS: Complete Ph.D Thesis research on topic.

CONTRIBUTIONS FOR (1987 -1988): Stewart, P.W. and Stewart, J.W., 1988.

(f) McMaster University

(i) M.G. Truscott (McMaster University, Dept. of Geology, Hamilton, Ontario; [416] 525-9140 ext. 4194).

PROJECT: ONGOING

Lithoprobe - geochemical segregations in mafic gneisses (likely volcanic origin) under high-grade conditions.

OBJECTIVES: Estimating limitations on calculations for the composition and compositional variation.

METHODS: INAA, Prompt-Gamma NAA, AAS, XRF

FINDINGS: In early stages; some units show segregations which appear to be localized, with strong fractionations of REE's.

PLANS: Same study in other units of non-volcanological origin.

CONTRIBUTIONS FOR (1987 -1988): None.

(g) University of Toronto

(i) H.C. Halls and D.C. Palmer (Erindale College, Univ. of Toronto, and Dept. of Geophysics, University of Western Ontario, London, Ontario; [416] 828-5363).

PROJECT: ONGOING

A Paleomagnetic study of Precambrian dykes in the vicinity of Kapuskasing Structural Zone.

OBJECTIVES: Define post emplacement dyke deformation along KSZ.

METHODS: Paleomagnetism.

FINDINGS: Normal polarity Matachewan dykes are concentrated in vicinity of KSZ, whereas reversed dykes dominate outside.

PLANS: Analyze paleomagnetic and aeromagnetic data to understand polarity distribution of dykes.

CONTRIBUTIONS FOR (1987 -1988): Halls, H.C. and Palmer D.C., 1988.

(ii) S.D. Scott (Geology, University of Toronto, Toronto, Ontario, M5S 1A1; [416] 978-5424).

PROJECT: ONGOING

1. Volcanology of Explorer Ridge
2. Volcanology of Western Woodlark Basin, SW Pacific Ocean

OBJECTIVES: Map and interpret seafloor volcanic terrains

METHODS: Oceanographic survey vessels; deep-tow camera/video; bathymetry

FINDINGS:

1. Spatial distribution of basalt lava forms on Explorer Ridge;
2. Rhyolite, andesites, ferrobasalts and MORB in W. Woodlark Basin.

PLANS: 1. CUROSS II to Explorer Ridge, August, 1988; 2. PACLARK IV to Western Woodlark Basin, 1990

CONTRIBUTIONS FOR (1987 -1988): Scott, S.D. et al., 1988.

(h) Queen's University

(i) J.R. Drobe (Dept. of Geological Sciences, Queen's University, Kingston, Ontario, K7L 3N6; [613] 542-6174).

PROJECT: NEW

Petrology of the Ootsa Lake Volcanics, Whitesail Lake Area.

OBJECTIVES: Petrology and petrogenesis of this volcanic group

METHODS: Mapping, stratigraphy, laser interferometry, Nomarski contrast microscopy, electron microprobe analyses, whole rock chemistry.

FINDINGS: Determined fractionation assemblage from 24 analyses.

PLANS: Map and collect; analyze new samples.

CONTRIBUTIONS FOR (1987 -1988): None.

(ii) A.M. Kolisnik (Dept. of Geological Sciences, Queen's University, Kingston, Ontario, K7L 3N6; [613] 545-6174).

PROJECT: COMPLETING

Effects of magma mixing on phenocryst compositional zoning in lavas from Volcan Popocatepetl, Mexico.

OBJECTIVES: Petrogenesis of andesitic and dacitic lavas inferred from phenocryst zoning profiles, solution textures and disequilibrium assemblages.

METHODS: Laser interferometry, Nomarski interference contrast imaging, electron microprobe analyses, whole rock geochemical analysis.

FINDINGS: Phenocrysts of plagioclase, pyroxene, and olivine show a history of multiple mixing events prior to eruption.

CONTRIBUTIONS FOR (1987 -1988): Kolisnik, A.M. and Pearce, T.H., 1987; Kolisnik, A.M. et al., 1987; Kolisnik, A.M. et al., 1988; Pearce, T.H. et al., 1987a, b and c.

(iii) T.H. Pearce (Dept. of Geological Sciences, Queen's University, Kingston, Ontario, K7L 3N6; [613] 545-6174).

PROJECT: ONGOING

Laser applications in the earth sciences

OBJECTIVES: Major current objective: Igneous phenocryst growth and petrogenesis of basaltic, andesitic and dacitic rocks.

METHODS: Laser interferometry, Nomarski interference contrast imagery, electron probe.

FINDINGS: The theory of simple normal zoning has been developed.

PLANS: Phenocryst - liquid relationships in intra-plate, subduction and continental volcanism.

CONTRIBUTIONS FOR (1987 -1988): Pearce, T.H., 1987a and b.; Pearce, T.H. et al., 1987a,b,c,d and e.; Kolisnik, A.M. and Pearce, T.H., 1987.; Kolisnik, A.M. et al., 1987.; Kolisnik, A.M. et al., 1988.; Nixon, G.T. and Pearce, T.H., 1987.; Russell, J.K. et al., 1987.; Swinamer, T. and Pearce, T.H., 1987.

(iv) J.A. Stimac (Dept. of Geological Sciences, Queen's University, Kingston, Ontario, K7L 3N6; [613] 545-6174).

PROJECT: NEW

Evolution of the Clear Lake volcanics, California.

OBJECTIVES: Evaluate textural evidence for magma mixing and crustal assimilation at Clear Lake.

METHODS: Laser interferometry, Nomarksi imaging, petrography, and electron microprobe analysis.

FINDINGS: New study

PLANS: Thesis research on Clear Lake Volcanics.

CONTRIBUTIONS FOR (1987 -1988): Fryxell, J.E. et al., 1987.

(v) R.T. Swinamer (Dept. of Geological Sciences, Queen's University, Kingston, Ontario, K7L 3N6; [613] 549-8799).

PROJECT: ONGOING

The Geomorphology, Petrology, Geochemistry and Petrogenesis of the Volcanic Rocks in the Sierra del Chichinantzin.

OBJECTIVES: Petrogenesis of primitive high-Mg andesite and the derivation of the other more evolved rocks from this melt.

METHODS: Laser interferometry, Nomarski interference contrast, electron microprobe, XRF, Pearce diagrams, mass balance calculations.

FINDINGS: Using Pearce diagrams and mass balance calculations it can be shown that the andesites and dacites are derived from the primitive high-Mg andesite.

CONTRIBUTIONS FOR (1987 -1988): Swinamer, R.T. and Pearce, T.H., 1987.

(i) Carleton University

(i) J.M. Moore and L. Harnois (Dept. of Earth Sciences, Carleton University and Ottawa-Carleton Geoscience Centre, Ottawa, Ontario, K15 5B6; [613] 564-2630).

PROJECT: COMPLETING

Volcanic assemblages of the Central Metasedimentary Belt, Grenville Province, Ontario.

OBJECTIVES: Identify physical and chemical volcanic style, tectonic setting.

METHODS: Mapping, major (minor) trace chemical analysis, petrography.

FINDINGS: Both oceanic and ensialic signatures in close proximity; relate to arc evolution in mid-proterozoic (ca. 1300-1250 Ma).

PLANS: Integrate database.

CONTRIBUTIONS FOR (1987 -1988): Harnois, L. 1988.

(ii) J.M. Moore (as above; [613] 564-2630).

PROJECT: New

Nicola Volcanics (Triassic), south-central BC.

OBJECTIVES: Geology, petrochemistry and tectonic setting.

METHODS: Field relations and petrochemistry.

FINDINGS: New project

PLANS: as above.

CONTRIBUTIONS FOR (1987 -1988): None.

(iii) C.F. Roots and J.M. Moore (Dept. of Earth Sciences, Carleton University, Ottawa-Carleton Geoscience Centre, and GSC, 100 W.Pender St., Vancouver, B.C.; [604] 666-1129, [613] 564-2630).

PROJECT: COMPLETING

Regional tectonic setting and evolution of the Mount Harper volcanic complex, Ogilvie Mountains, Yukon.

OBJECTIVES: To understand physical evolution, petrochemistry and tectonic setting of MHVC and the age, structures and mechanism of rifting in the Late Proterozoic.

METHODS: Mapping, geochemistry and petrography; U/Pb dating.

FINDINGS: MHVC records growth of a basaltic seamount and transition to a more varied, subaerial/subaqueous activity at ca 750 Ma in an extensional setting near the W. Margin of N.America.

PLANS: Writing papers based on Roots Ph.D. thesis at Carleton. (Roots and Moore) Further field studies of regional relationships Study of associated sedimentary assemblage continuing at Carleton U. (P. Mustard).

CONTRIBUTIONS FOR (1987 -1988): Roots, C.F. - Ph.D. Thesis at Ottawa-Carleton; recipient 1987-1988 Gelinas Award.

(iv) D.J. Thorkelson (Dept. of Earth Sciences, Carleton University, Ottawa, Ontario, K1S 5B6; [613] 564-2630).

PROJECT: ONGOING

Volcanology of the Hazelton Group: Spatsizi Park, north central British Columbia.

OBJECTIVES: Petrogenesis/physical volcanology/tectonic affinity/age/correlations.

METHODS: Fieldwork/petrography/geochemistry

FINDINGS: Bimodal package; alkaline to tholeiitic; mostly subaerial; back-arc?

PLANS: Fieldwork continuing thesis study.

CONTRIBUTIONS FOR (1987 -1988): Thorkelson, D.J., 1988.

(j) McGill University

(i) A. Charland[1], D. Francis[1], J. Ludden[2] and J.G. Souther[3] ([1]Dept. of Geol. Sci., McGill Univ., 3450 University St., Montreal, P.Q.; [2]Univ.de Montréal, Montréal, P.Q., H3A 2A7 and [3]CD/CPGP, G.S.C., 100 W. Pender St., Vancouver, B.C., V6B 1R8; [514] 398-4885).

PROJECT: ONGOING

Geochemistry and petrogenesis of Tertiary alkaline volcanics in the Itcha Mountain Range, Central B.C.

OBJECTIVES: To investigate the petrogenesis of felsic and mafic alkaline magmas of the Itcha complex and their relation to the surrounding Anahim Belt volcanics.

METHODS: Field mapping, stratigraphy, petrochemistry

FINDINGS: Mantle derived undersaturated alkaline lavas.

PLANS: Complete Charland thesis and publications.

CONTRIBUTIONS FOR (1987 -1988): Charland, A. et al., 1988.

(ii) D. Francis (Dept. of Geol. Sci., McGill University, 3450 University St., Montreal, P.Q., H3A 2A7; [514] 398-4885).

PROJECT: COMPLETING

The nature of upper mantle volatiles beneath the northwestern margin of North America.

OBJECTIVES: Volatiles and their isotopic ratios in upper mantle xenoliths: implication for trace elements, C and ^{13}C in the upper mantle.

(iii) D. Francis and J. Ludden (Dept. of Geol. Sci., McGill University, 3450 University St., Montreal, P.Q., H3A 2A7, and Université de Montréal; [514] 398-4885).

PROJECT 1: ONGOING

Trace element constraints on primary magmas of the Baffin Bay picrites.

CONTRIBUTIONS FOR (1987 -1988): Francis, D. and Ludden, J., 1985 and 1986.

PROJECT 2: ONGOING

Continental alkaline volcanism at Fort Selkirk, Central Yukon.

OBJECTIVES: To investigate the genetic relationship between nephelinite, basanite, and alkaline olivine basalt lavas of the Fort Selkirk volcanic complex.

(iv) T. Skulski, D. Francis and J. Ludden (Dept. of Geol.Sci. McGill University, 3450 University St., Montreal, P.Q., H3A 2A7; [514] 398-4885).

PROJECT: ONGOING

Tertiary Magmatism in the Wrangell Volcanic Belt, SW Yukon.

OBJECTIVES: Setting and origin of transitional (sodic alkaline-calc alkaline) lavas found in the SE part of the Late Tertiary Wrangell Volcanic Belt.

METHODS: Regional petrochemistry, synthesis of geology and geochronology

FINDINGS: Wrangell to St. Elias, 60 Ma to 6 Ma, transitional (sub-alkaline) to over and undersaturated sodic alkaline lavas are related to leakage up Duke River and Denali Transform Faults. In contrast, 10 Ma to Recent calc alkaline lavas of the Wrangell Mountains constitute part of the Aleutian arc.

PLANS: Further publications based on Skulski Thesis.

CONTRIBUTIONS FOR (1987 -1988): Skulski, T. et al., 1987.

(v) J.S. Stevenson (Geological Sciences, McGill University, Montreal, Quebec, H3A 2A7).

PROJECT: COMPLETED

Origin of the Onaping Formation, Sudbury, Ontario

OBJECTIVES: Demonstrate volcanic origin of the Sudbury Basin.

METHODS: 30 years of field, petrographic and mineralogical work.

FINDINGS: Oral presentation at the International Workshop on "Cryptoexplosions and Catastrophes in the Geological Record" at Parys, South Africa, July, 1987.

PLANS: Dr. Stevenson died Sept. 7, 1987.

CONTRIBUTIONS FOR (1987 -1988): Stevenson, J.S., in press.

(k) Université Laval

(i) R. Laurent and R. Hebert (Département de Géologie, Université Laval, Cité Universitaire, St. Foy, Québec, G1K 7P4; [418] 656-2193).

PROJECT: ONGOING

Petrological study of volcanic associations of the Dunnage Zone, Quebec Appalachians.

OBJECTIVES: This project deals with a complex association of ocean crust (ophiolite) and island-arc volcanics of Ordovician age. The objective is to reconstruct the paleovolcanic environment from the front arc to the back and marginal basin.

METHODS: Geology and petrochemistry

CONTRIBUTIONS FOR (1987 -1988): Laurent, R. and Hebert, R., 1987.

(ii) R. Laurent, M. Berrhama and H. Rachdi (as above).

PROJECT: ONGOING

Petrology and geochemistry of the recent alkaline volcanism of Morocco.

OBJECTIVES: This project deals with 10 Ma and younger volcanic rocks from central and southern Morocco (Siroua massif): Characterization of this volcanism and comparison of its features with the nearby Canary Islands volcanoes.

METHODS: Field mapping supported by BRPM (Bureau de Recherches Petrolières et Minieres) of Morocco, Lab work by CRSNG grant.

FINDINGS: The work is done by two Moroccan Ph.D. students: M. Berrhama and H. Rachdi. Collaboration is provided by Swiss colleagues from the University of Geneva for geochronology and paleomagnetism.

PLANS: Proceed.

CONTRIBUTIONS FOR (1987 -1988): None.

(l) Université de Montréal

(i) J. Ludden (Dépt. de Géologie, Université de Montréal, Montréal, P.Q., H3C 3J7; [514] 343-7389).

PROJECT: ONGOING

Isotope Geochemistry of Mt. Edziza volcano, N. Central B.C.

OBJECTIVES: Magma evolution

METHODS: Isotopes, trace elements on J.G.Souther collection.

FINDINGS: Within plate continental basaltic volcanism with MORB-like characteristics.

CONTRIBUTIONS FOR (1987 -1988): Ludden, J. and Francis, D., 1987.

(m) Université du Québec à Chicoutimi

(i) L.P. Mueller[1], E.H. Chown[1], K.M.N. Sharma[2] and R. Potvin[1] (Université du Québec à Chicoutimi, 555 Boul. de l'Université, Chicoutimi, Quebec, G7H 2B1; [418] 545-5035).

PROJECT: ONGOING

Sedimentology, Volcanology, and Geochemistry of the southern part of the Chibougomau area.

OBJECTIVES: Paleogeographic reconstruction of NE corner of Abitibi belt.

METHODS: Mapping, facies analysis, petrography, geochemistry.

FINDINGS: Diachronous evaluation of thin volcano-sedimentary succession. Early emergent felsic volcanic centres built on 2-3 km precursor basalt.

PLANS: Systematic study of volcanic centres in northern Abitibi.

CONTRIBUTIONS FOR (1987 -1988): Mueller et al., 1988. and submitted.

(n) St. Mary's University

(i) J. Dostal (Dept. of Geology St. Mary's University, Halifax, N.S., B3H 3C3; [902] 420-5747).

PROJECT: ONGOING

Geochemistry of anorogenic volcanic rocks from the Canadian Shield, Appalachians and French Polynesia.

OBJECTIVES: This is a continuing study focusing on the geochemistry of continental tholeiites and oceanic island basalts. The aim of this study is to better understand the petrogenesis of these rocks and the composition of their upper mantle sources.

METHODS: INAA, XRF, petrography

FINDINGS: See references

PLANS: Continuing work on various suites.

CONTRIBUTIONS FOR (1987 -1988): Auchapt et al., 1987; Lebras et al., 1987; Dostal and Dupuy 1987; Dupuy et al., 1987.

(ii) G. Pe-Piper (Dept. of Geology, St. Mary's University, Halifax, N.S., B3H 3C3; [902] 420-5744).

PROJECT: ONGOING

Petrological studies of volcanic suites from:
1.) Atlantic margin and offshore
2.) Aegean back arc region

OBJECTIVES:
1.) Origin of sills, dykes, flows and volcaniclastics.
2.) Significance of Neogene to Recent volcanics of varied composition in back arc region.

METHODS: Volcanology, geochemistry and regional geophysics.

FINDINGS:

1.) Propagating reactivation of fractures controlling 120 Ma - 95 Ma magmatism: Baltimore Canyon - Grand Banks - Scotian Shelf.
2.) Relationship noted between alkaline and evolved back arc magmas and aseismic zone.

PLANS:

1.) Continue work on regional and geochemical evolution
2.) Conduct more sampling and analyses (1988 - 1989)

CONTRIBUTIONS FOR (1987 -1988): Jansa, L.F. and Pe-Piper, G., 1988.; and Pe-Piper, G. and Piper, D. 1988., Lambert, R.St.J. et al. 1988.

(o) Acadia University

(i) N.A. Van Wagoner (Dept. of Geology, Acadia University, Wolfville, NS, BOP 1XO; [902] 542-2201 ext. 590).

PROJECT 1: ONGOING

Physical volcanology and geochemistry of the Devonian volcanic sequence of SW New Brunswick

OBJECTIVES: Determining the paleogeography and tectonic setting of this area.

METHODS: Detailed mapping, measuring sections, petrography, whole rock major and trace element geochemistry.

FINDINGS: Sequence is bimodal and subalkaline, probably continental rift related. Many eruptive styles are present.

PLANS: Acquire data on the entire belt.

CONTRIBUTIONS FOR (1987 -1988): Van Wagoner, N. and Fay, V.K., 1988.

PROJECT 2: ONGOING

The volcanism and geochemistry of the Endeavour Ridge: Juan de Fuca Ridge system.

OBJECTIVES: Determine volcanic processes, compare magma systems at fracture zones, seamounts and axial valley floor.

METHODS: Dredging, petrography, detailed mineral and whole rock chemistry.

FINDINGS: Although seamounts and rift valley samples are chemically similar, eruptive systems are distinct.

PLANS: More detailed sampling and bottom photography during 1988.

CONTRIBUTIONS FOR (1987 -1988): Leybourne, M.I. and Van Wagoner, N.A., 1988.

PROJECT 3: ONGOING

Physical volcanology and geochemistry of the Proterozoic Amisk Lake volcano, Flin Flon - Snow Lake Greenstone Belt.

OBJECTIVES: Determine eruptive style, depositional process, volcanic stratigraphy and geochemistry.

METHODS: Measure stratigraphic sections, field description, petrography, geochemical analyses by ICP-MS.

FINDINGS: The area is a volcanic island characterized by several emergent and submergent episodes. Volcanics seem to have arc affinities.

PLANS: To publish data.

CONTRIBUTIONS FOR (1987 -1988): None.

(p) Dalhousie University

(i) P. T. Robinson and R. Hebert (Centre for Marine Geology, Dalhousie University, Halifax, NS, B3H 3G5, and Département de Géologie, Université Laval, Cité Universitaire, St. Foy, Québec, G1K 7P4; [902] 424-2361).

PROJECT: ONGOING

Oceanic Crustal Drilling: Atlantis II Fracture Zone - SW Indian Ridge.

OBJECTIVES: Investigate oceanic volcanic/magmatic processes in a lower crustal - upper mantle section from a fracture zone related to a slow spreading ridge.

METHODS: Oceanic hardrock drilling, petrological and geophysical techniques.

FINDINGS: Leg 118 of the Ocean Drilling Program successfully sampled 500 m of mafic rock from oceanic crustal layer-3 including magnesian troctolite, evolved ferrogabbro and trondjhemite. Insights were gained into the workings of oceanic volcanism and magma chambers beneath slow spreading ridges.

PLANS: Further analyses of core samples and regional data, re-entry drilling to penetrate layer-3/moho boundary.

CONTRIBUTIONS FOR (1987 -1988): Robinson, P.T. et al., 1988; Robinson, P.T. and Hebert, R., 1988.

(ii) M. Zentilli, P.H. Reynolds, V. Maksaev and T. Mulja and J.A. Walker (NIU, De Kalb, Illinois, USA) (Dept. of Geology, Dalhousie University, Halifax, Nova Scotia, B3H 3J5; [902] 424-3873).

PROJECT: ONGOING

Temporal evolution of central Andean volcanoes and ore formation.

OBJECTIVES: To document and better understand the relationships between tectonics, chemistry, volcanic styles (e.g. caldera evolution) and ore deposits during the Cenozoic development of the central Andes.

METHODS: Field mapping (+ satellite imagery), fission-track and $^{40}Ar/^{39}Ar$ dating, geochemical analyses, including isotopes.

FINDINGS: The timing of explosive and effusive volcanism, intrusion, unroofing and ore formation has been constrained for important volcanic complexes of N. Chile and their Cu, Au and Fe deposits.

PLANS: Field work planned for 1988; continuing fission-track and $^{40}Ar/^{39}Ar$ dating of ignimbrite cooling units and lavas, geochemical analyses. Graduate thesis to be initiated. Three papers submitted to Proceedings, V Geological Congress, August 88, Santiago, Chile.

CONTRIBUTIONS FOR (1987 -1988): Mulja, T. and Zentilli, M., 1987 and 1988.

(q) Mount Allison University

(i) J. Greenough (Geology Dept., Mount Allison University, Sackville, N.B., EOA 3CO; [506] 364-2217).

PROJECT: ONGOING

Mesozoic volcanism in Atlantic Canada.

OBJECTIVES: Evaluate geochemistry, petrogenesis and emplacement of Mesozoic volcanics of Eastern Canada.

METHODS: Geochemistry, petrofabric analysis.

FINDINGS: Magma may be injected horizontally through dyke systems. Little contamination at upper crustal levels.

PLANS: Further evaluation of emplacement mechanisms and geochemistry.

CONTRIBUTIONS FOR (1987 -1988): Greenough, J.D. and Papezik, V.S., 1987a and b.; McHone, J.G. et al., 1987.; Krogh, T.E. et al., 1987; and Greenough et al. (in press).

(r) Memorial University of Newfoundland

(i) D.F. Strong and M. Coyle (Dept. of Earth Sciences and Centre for Earth Resources Research, Memorial University of Newfoundland, St. John's, Nfld., A1B 3X5).

PROJECT: ONGOING

Regional study of diverse Silurian magmatic activity in western Newfoundland and Scotland.

OBJECTIVES: Relationships and genesis of enriched magmas.

METHODS: Geology, geochemistry, mineralogy.

FINDINGS: Related Silurian enriched magmatic suites from Great Glen, Scotland and Cabot Fault Zone, NFLD. Genetic link involving permitted magmatism along deep fractures and carbonate rich fluid phase.

CONTRIBUTIONS FOR (1987 -1988): Strong, D.F. and Coyle, M., 1988.

6. Private Enterprise

(i) L.A. Landefeld (Barranca Resources, 1418 Pike St., Golden, CO, U.S.A. 80401; [303] 278-1292).

PROJECT: ONGOING

Volcanology and Petrology of Mesozoic volcanic sequences in the Central Sierra Nevada Foothills Metamorphic Belt.

OBJECTIVES: To understand the deposition (in the Mother Lode region) of tectonic setting of those rocks.

METHODS: Mapping, measured sections, whole rock geochemistry, microprobe of relict minerals.

FINDINGS: 80% complete; The pyroxene phyric flows and volcaniclastic rocks are not ankaramites as claimed by some workers. The volcanic sequences were deposited in a forearc volcaniclastic apron of an immature J-Tr volcanic arc; facies range from proximal to distal.

PLANS: Compare these findings with similar volcanic sequences in the Circum-Pacific, complete thesis at the University of Western Ontario (London, Ontario) and related publications.

CONTRIBUTIONS FOR (1987 -1988): None.

(ii) J.G. Payne (877 Lillouet Rd., North Vancouver, B.C., V7J 2H6; [604] 986-2928).

PROJECT: ONGOING

Contract petrographic studies on referred rock suites

OBJECTIVES: Provide petrographic reports on volcanic rocks and altered/mineralized volcanic rocks for mining exploration companies and government agencies.

METHODS: Optical petrography, transmitted and reflected light.

FINDINGS: Petrographic databases for volcanic suites, contributions to the understanding of volcanic settings, volcanic assemblages and their hydrothermal alteration.

PLANS: Further work on referred samples.

CONTRIBUTIONS FOR (1987 -1988): private reports.

(iii) K. St-Seymour, R.P. Wares and A. Kiddie (Mineral Exploration Research Inst., P.O.Box 6079, Stn. A, Montreal, PQ, H3C 3A7).

PROJECT: ONGOING

Aphebian volcanics of the northern Labrador Trough, Quebec.

OBJECTIVES: Determine petrogenesis of tholeiitic suites.

METHODS: Field relations, petrography, major and trace element geochemistry.

FINDINGS: Polybaric fractionation of tholeiitic basaltic magmas accompanying eruption and emplacement of basinal marine Aphebian supracrustal facies of Labrador Trough.

CONTRIBUTIONS FOR (1987 -1988): St-Seymour, K. et al., 1988.

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V ISOTOPE STUDIES AND GEOCHRONOLOGY

Compiled by: J.C. Roddick

1. University of Alberta

(a) Radiogenic Isotope Studies; Dept. of Geology (H. Baadsgaard and collaborators)

(i) The geochronology of a major new lithological unit in the Late Archean of west Greenland, the Ikkattoq gneiss, has been started and will be extended in the coming year. Also in west Greenland, the detailed isotope geology of the type Nuk gneisses is being studied by M.J.M. Duke. Preliminary dating of the Kaminak Lake alkali intrusion has been completed and a field expedition is being mounted to thoroughly sample the intrusion.

(ii) Further samples of the Devonian potash salts have been collected in the Lanigan mine with a view toward establishing the latest time of salt recrystallisation. First results from K-Ca and Rb-Sr analyses on coexisting carnallite and sylvite have shown a complex pattern of diagenetic recrystallisation; most pronounced in the Cretaceous. Time scale dating of an Albian tuff near Hudson's Hope, B.C. and three locations containing bentonite horizons at or close to the Cretaceous-Tertiary boundary has been completed. Another bentonite, essentially at the close of the Campanian, has been sampled and analysed.

(iii) A comprehensive preliminary investigation of the Sr isotope variation in a well core yielding a vertical section from the Upper Cretaceous to the Cambrian has shown some formations to possess very homogeneous Sr isotope ratios while other horizons show great variability in the Sr isotope ratios. Work is now in progress for one of the formations to separate pure diagenetic products for Sr isotopic determination.

(iv) The isotope geochemistry of ultramafic inclusions in the Kettle River volcanics is almost completed, and significant differences in the Sr and Nd isotopic ratios between clinopyroxene, olivine and the whole rock sample have been found.

(v) U-Pb analyses of Late Archean pegmatitic monazite and euxenite have given a precise age of crystallisation at 2658 Ma. These samples are now being analysed by Prof. A. Masudas' group at the University of Tokyo for La-Ce and La-Ba in order to attempt a more precise determination of the half-life of 138La.

(b) Radiogenic Isotope Studies; Dept. of Geology (R. St. J. Lambert and collaborators)

(i) Instrumental development. The program supplied for the measurement of Sr and Nd isotope ratios on the Isomass 354 were extensively restructured to (a) provide exact isotopic interference corrections for 87Rb and 144Sm, (b) provide contemporaneous collection of data by simultaneous and sequential procedures, (c) make data collection more efficient by a factor of x4 for Sr and x2 for Nd and (d) test the use of 145Nd for normalizing purposes. Programs for measuring Sr, Sm and Nd by isotope dilution were created. Instrument control programs for automatic operation were extensively modified and pyrometer control of Sr and Nd analysis introduced by J. MacKinnon.

(ii) Lithoprobe-related studies (southern B.C.). With D.K. Ghosh, Pb, Sr and Nd studies of the Raft Batholith, Reade Lake syenite and Crowsnest Volcanics were completed. The analytical program for a variety of other Mesozoic plutons is in various stages of completion. Data are now available for the Whatshan batholith, Downie Creek stock, Galina Bay pluton, Horsethief Creek batholith, Seven Mile Dam granite and the Salmo stock. The data are being compared with data from the Ph.D. thesis of D.K. Ghosh (1986) on all metasediments from south-east B.C. and from the Nelson batholith and its satellites, and the Kuskanax and Bayonne batholiths. Plutons from the region north of the Tintina fault in the southern Yukon are being analysed for comparative purposes. In order to complete the data base for possible crustal contaminants in south-east B.C., samples of Archean and Proterozoic gneisses from the Malton gneiss complex have been analyzed, as well as possible Proterozoic gneisses from the 'core' complexes within the Shuswap complex.

(iii) Slave Province studies. V.E. Chamberlain analysed a suite of Dog Rib dykes in order to try to ascertain their age more exactly; J. McCorquodale analysed a suite of Yellowknife volcanic rocks to try to resolve geochronological problems raised by previous work on the Sr and Nd systematics of the Kam, Duck and Banting Formations by M. Cunningham. D.R. Pinckston commenced a Sr and Nd study of the peralkaline complex at Thor Lake.

(iv) Collaborative projects. M. Sun continued his Ph.D. work on various Archean and Proterozoic suites in north-east and central China in collaboration with analytical programs run by faculty in Beijing and Tianjin. Prof. G.G. Goles analysed suites of rocks from around Kangerdlugssuak, Greenland, and from Newberry Crater, Oregon, and undertook a project on human paleo diet via analyses for Sr isotopic compositions of bone. M. Hirschmann (U. of Washington) studied the Sr and Nd isotopic systematics of the Skaergaard intrusion. A. Brandon (U. of Oregon) worked on the Sr and Nd chemistry of the Bear Creek basalts of Oregon, while S. Atkinson, in conjunction with Prof. P.R. Hooper (Washington State U.) commenced a detailed study of the isotopic characteristics of the Roza dyke and flow (Columbia River basalts). V.E. Chamberlain and J.G. Holland (Univ. of Durham) commenced a study of the age of the Highland Series of Sri Lanka, while V.E. Chamberlain undertook analyses of Kaapvaal craton suites supplied by K.C. Condie (University of New Mexico).

(c) Stable Isotope Studies; Dept. of Geology (K. Muehlenbachs and collaborators)

(i) Oxygen diffusion coefficients have been measured in a variety of silicate minerals. These rate data have been used to elucidate aspects of the thermal history of meteorites (Connolly & Muehlenbachs).

(ii) Studies, with Bruce Nesbitt, on the regional isotopic variations of oxygen and hydrogen in gold deposits of the Canadian Cordillera have shown that Cordilleran mesothermal gold deposits formed from meteoric water and not metamorphic water as has been assumed. The data further suggest, analogously that the Archean load Au deposits also are derived from meteoric ore fluids (Murochick et al., 1986).

(iii) Isotopic measurements on carbon have been used to quantify the efficacy of upgrading schemes that produce transportation grade fuel from Alberta's largest energy resource; coal and bitumen. These feedstocks differ in ^{13}C sufficiently that monitoring the isotopic composition of the synthetic fuel helps set design parameters for the reactors (Ohouchi et al., 1987).

(iv) Long standing investigations continue of seafloor/ocean water interaction and tectonic control, on the isotopic composition of sea water over geologic time (MAC/GAC Short Course 1987).

(d) Radiogenic Isotope Studies; Dept. of Physics (G.L. Cumming, J. Gray, A. Changkakoti, D. Kristic, J.S. MacKinnon, L. Tober, P. Wagner, A. Birkeland (Visiting Graduate Student).

(i) Athabasca Basin, Saskatchewan. Pb isotopes in fluorapatite cements in sandstones of the Athabasca basin have yielded results very similar to data previously obtained in the Thelon basin, except that the new ratios are not so favorably distributed as are the Thelon basin data and there are some indications of later resetting. The ages indicated however, are clearly much older than the conventional ages ascribed to the formation of the Athabasca sediments and yield a compressed time interval between the end of the Hudsonian orogeny and the beginning of basin infilling.

(ii) Nanew Lake Ni deposit. A detailed study of Pb isotope systematics in a nickel deposit in Manitoba, close to Flin Flon provided some interesting results. The U/Pb system in the ores was last disturbed at 1944 ± 8 Ma, whereas the gneisses surrounding the mafic intrusive which hosts the ore were last disturbed at 1869 ± 5 Ma. This peculiar inverse relationship, where the host rock is apparently younger than the ore itself, suggests that metamorphic updating has occurred at different times in closely associated rocks. Further studies including U/Pb dating of zircons is in progress.

(iii) Norwegian Caledonides. As a result of various cooperative studies with colleagues in Norway and Sweden, Ms. Birkeland has been visiting our laboratory to carry out analyses and learn isotope techniques as part of her Ph.D. program at Oslo. She is studying the genesis of ore deposits associated with the Bindalen granitoid batholith of north central Norway and is applying a range of isotope dating techniques to the host rocks and associated ores in an attempt to characterize the different possible sources for the ore minerals.

(iv) Half-lives of ^{130}Te and ^{82}Se. A rare occurrence of the mineral kitkaite, NiTeSe, in close association with uraninite has provided an opportunity to simultaneously determine the noble gas decay products of Te, Se and U, thus placing close limits on the true age and the gas retention ages of these minerals. The project was undertaken by O.K. Manuel and W.J. Lin at the University of Missouri at Rolla, and we provided precise U/Pb dates on the uraninite and also some Pb isotope ratios on various associated minerals. The indicated half-lives are 1.2×10^{20} yr. for ^{82}Se and 7.5×10^{20} yr for ^{130}Te with errors in the 5-10% range, a substantial improvement in precision compared to previous measurements.

(v) Determination of radiogenic isotopes (Rb/Sr, Sm/Nd and Pb/Pb) in fluid inclusion waters. J. Gray in collaboration with R. Morton, Department of Geology. Preliminary results were presented at the conference on American Current Research on Fluid Inclusions at Socorro, New Mexico. Rb, Sr, Pb, Nd and Sm isotopes were determined in fluid inclusion waters extracted from quartz samples of the Bluebell Pb-Zn deposit in British Columbia. The results demonstrate that radiogenic isotopes in fluid inclusion waters can constitute geochronological and genetic tools when applied in conjunction with geological, geochemical and other geochronological studies.

Rb/Sr isotopes of fluid inclusion waters and of mineralized marbles hosting the deposit indicate a Tertiary mineralization age of 19.2 ± 5.9 Ma, and an initial 87Sr/86Sr ratio of 0.7143. This Rb/Sr date is in general agreement with a Cenozoic age suggested by geological field relations. Pb isotope data suggest two isotopically distinct fluids, one less radiogenic and similar to values measured on galenas and the other more radiogenic. Nd and Sm isotope studies also suggest mixing of fluids. Both Pb/Pb and Nd/Sm data suggest very old lower and upper crustal materials as a possible source of the metals.

(vi) Oxygen isotope ratios from tree rings containing compression wood. J. Gray in collaboration with B.H. Luckman, University of Western Ontario. Oxygen isotope determinations on the α-cellulose of tree rings cut from two leaning Picea engelmannii revealed significant differences between results from normal and compression wood radii. Nine samples (10 year periods) from the normal wood radii (1721-1953) showed good agreement with proxy climate information and maximum differences of 1.8% between the "warmest" and "coolest" decades sampled. Differences of equivalent magnitude were found between samples from the same decade from normal and compression wood radii. These differences are strongly related to the proportion and/or density of compression wood present and suggest that sampling for paleoclimatic work should be restricted to complacent, erect trees without compression wood rings.

2. University of British Columbia, Geochronology Laboratory (R.L. Armstrong)

(a) Insular Belt

A. Andrew, supported by LITHOPROBE funds is doing Sm-Nd analyses of Vancouver Island magmatic suites for which we already have abundant rock Pb and Sr data (and many O isotopic analyses thanks to K. Muehlenbachs). A suite of Flores Volcanics was analysed for Rb-Sr to extend our coverage of the near-trench Eocene magmatic episode.

(b) Coast-Cascade Belt

By February of 1988 Peter van der Heyden will have finished U-Pb and K-Ar dating of Coast Plutonic Rocks in the Banks Island-Douglass Channel-Whitesail Lakes transect. Triassic(?), Jurassic, Cretaceous, and Eocene plutons occur there, in partly overlapping belts. D. Brown defended his thesis on the geologic setting of the Silback-Premier Mine (Brown, 1987).

(c) Intermontane Belt

A manuscript on the Tatla Lake metamorphic core complex by R. Friedman and R.L. Armstrong has been accepted for publication in Tectonics. R. Friedman has finished labwork on structure and metamorphic aspects of the area and is near completion of the writing of his Ph.D. thesis.

C. Greig has finished geochronometry analyses on the Eagle Plutonic Complex and related rocks near the Coquihalla River. All major phases of the Eagle have Late Jurassic U-Pb ages but all Rb-Sr and K-Ar dates are Early Cretaceous. He is now analysing strain in the complex which is at least partly related to the Pasayten fault, and trying to explain the large discordance between dating techniques.

(d) Omineca Belt

D. Murphy has joined us as a postdoctoral staff scientist to do U-Pb dating. Part of his responsibility will be dating projects for the Geological Division of the B.C. Ministry of Energy, Mines, and Petroleum Resources, but he will pursue his own projects as well. First will be dating granitic sills and dikes to determine the ages of structural phases in the Cariboo region.

(e) Foreland Belt

Rb-Sr dates ranging from Silurian to Mississippian have been obtained for carbonatite and lamprophyre in the Rocky and Mackenzie Mountains regions on samples provided by J. Pell, U. Mäuder, C. Godwin, and M. Cecile.

(f) Other Work

Ten Rb-Sr mineral isochrons for Athabasca Basin diabase dikes give concordant dates averaging 1230 Ma for this part of the Mackenzie dike swarm (collaborative project with D. Quirt and J. Hoeve of the Saskatchewan Research Council). This means that magmatism was coincident with hydrothermal alteration and U mineralization in the Athabasca region.

Rb-Sr work on the Chaiwaukum Schist in the Cascade Mountains of Washington (and its metamorphism and associated plutons) by J. Magloughlin (U. of Washington, now U. of Minnesota) has provided isotopic confirmation of its correlation with the Settler Schist in Canada, over 100 km to the north on the opposite side of the Straight Creek fault. His dating has also bracketed several phases of deformation.

P. Ward (U.S.G.S., Menlo Park) and R.L. Armstrong have used U.S.G.S. and U.B.C. geochronometry data files to prepare a series of maps showing Cordilleran magmatic patterns over the last 225 Ma. The first of two papers incorporating the Mesozoic to Early Cenozoic maps was completed for the Western Interior Basin Symposium in Saskatoon in May. The second will focus on Cenozoic patterns and their relationship to metamorphic core complexes.

S. Abercrombie (U.B.C. M.Sc. student) has studied Sr and Pb isotopes in crust-contaminated Cretaceous granitic rocks of the Syenite Range, Yukon.

3. University of Calgary, Department of Physics (H.R. Krouse, C.J. Bland, C. Yonge), Geology and Geophysics (F.A. Campbell, I. Hutcheon, A. Oldershaw, A.A. Levinson, R. Spencer, J. Nicholls), Geography (S. Harris), Chemistry (T. Swaddle), Chemical Engineering (G. Moore), Medicine (H. Parsons), Archaeology (A. Katzenberg), Kananaskis Centre for Environmental Research (A. Legge), Visiting Scientists (H.K. Herbert, Geology and Mineralogy, University of Queensland; Y. Kiyosu, Earth Sciences, Nagoya University; L. Grinenko, Geochemistry, Moscow State University; G. Mamchur, Institute of Fossil Fuel Research, Lvov, Ukraine).

(a) Instrumental

(i) Microprocessor based temperature programmer developed for pyrolysis - stable isotope mass spectrometry unit.

(ii) Nupro valve modified for use with capillaries for sample - unknown sample switching. Need for waste line eliminated.

(iii) Manuscript on "The effect of sulphur isotope composition of zinc and lead sulphides on the EMF of electrochemical cells" accepted in Applied Physics Communications (J. Lusk and B. Batts, Macquarie Univ., New South Wales).

(b) Ore Deposits

(i) Sullivan, B.C. Detailed chemical and sulphur isotope study completed on over 200, one-mm slices from four hand specimens.

(ii) Pucara Basin, Peru. Continuing study on "zebra dolomite" and sulphide mineralization (I. Lange, University of Montana).

(iii) Yasov, Ukrainian S.S.R. Elemental Sulphur Deposit. C and O isotope analyses of calcite; S isotope analyses of S° and $BaSO_4$; O-isotope analyses of BaSO4 (G. Mamchur).

(iv) Akpatakpa Lobe Pb-Zn Deposits, Abakaliki District, Nigeria. Joint project with University of Alberta; Manuscript prepared.

(v) Shamrock Gold Mine, Kilkivan, Queensland (H.K. Herbert).

(vi) Mount Isa, Queensland (K.W. Hannan, Graduate Student, Univ. of Queensland; H.K. Herbert).

(c) Trace Sulphur in Minerals

(i) L. Grinenko compared an oxidation technique with the in vacuo Kiba reduction technique of Ueda and Sakai. Measurements have started on a number of host rocks and waste bands associated with Canadian ore deposits to see how the trace sulphide is related to the ore.

(ii) Studies continued with carbonates to ascertain sulphur isotope excursions in seawater sulphate over geological time.

(d) Sedimentary Rocks

(i) Harmon Member, Peace River Fm., western Canada. C and O isotope analyses of carbonate, S isotope analyses of pyrite, pyrolysis of shale (J. Bloch, Graduate Student, Geology).

(ii) Trona Beds, Green River, Wyoming. C and O isotope composition of calcite, dolomite, and trona (H.K. Herbert; W.G. Fischer, F.M.C. Wyoming Corp.).

(iii) Concretions, Antrim Shale, Michigan. C and O isotope composition of carbonate; S isotope composition of pyrites and trace S (G.S. Giles, Michigan State Univ.).

(iv) Worm Tube Mounds, Arctic. These mounds are believed to be Cretaceous analogues of modern ocean vent environments. Large depletions in ^{13}C have been found (B. Beauchamp, I.S.P.G., G.S.C.).

(v) Evaporites, Western Canada: S and O isotopes. H isotope composition of fluid inclusions.

(e) Origin of Sour Gas

(i) Paper in press in Nature provides evidence that light hydrocarbons reduced evaporites to produce high H_2S concentrations in the Wabamum Fm. of western Canada (joint project with C. Viau and L. Eliuk, Shell Canada).

(ii) Y. Kiyosu investigated sulphate reduction by hydrocarbons in the laboratory. Large carbon isotope fractionations were found during oxidation of light hydrocarbons.

(f) Pyrolysis - Stable Isotope Mass Spectrometry

Studies on the isotope compositions of light gases evolved during linear temperature increment pyrolysis of fossil fuels and biological materials. Emphasis was placed on the S isotope composition of H_2S. Projects included bitumen from the Pine Point Pb-Zn deposits (R. Macqueen, I.S.P.G.); a selection of heavy and light oils from the USSR (G. Mamchur); and shale from the Harmon Member.

(g) Hydrology, Glaciology

(i) Survey of the isotopic composition of precipitation along a transect from the west coast to Calgary; manuscript prepared.

(ii) Studies continued on cores from Mt. Logan and vicinity. Manuscripts prepared (G. Holdsworth, Environment Canada).

(iii) Manuscripts published and submitted on studies of Ward Hunt Ice Shelf, Sea Ice, Arctic precipitation (M. Jeffries, University of Alaska).

(h) Carbon and Hydrogen Isotope Analyses of Separated Light Hydrocarbons

(i) East Coast, Canada. Analyses continued on gases associated with oils and condensates (Collaboration with Petro Canada).

(ii) Devonian, Alberta. Comparison of H_2S - rich and sweet gases continued (Collaboration with Shell Canada).

(iii) Three investigations of gas leakage into basements which seem related to fermentation of old hydrocarbon spills.

(i) Oil

(i) C, N, and S isotope analyses of a selection of light and heavy oils from the Soviet Union (G. Mamchur).

(j) Bacterial oxidation of sulphides and elemental sulphur

(i) Experimental study using waters with different ^{18}O enrichments (R.G.L. McCready, D. Gould, Biotechnology, EMR, Ottawa).

(ii) Field studies of acid mine drainage and springs (R.O. van Everdingen).

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

(a) $^{40}Ar/^{39}Ar$ Geochronology

Argon analyses are carried out in a modified MS10 mass spectrometer. Three extraction furnaces are in use: (i) an external (quartz-tube) furnace of the Lindberg type, (ii) an internal (tantalum) furnace of the double-vacuum type, and (iii) a 'laserprobe' system built around a Quantronix 117 Nd-YAG laser.

Major projects include:

(i) Application to P-T-t histories of igneous and metamorphic rocks in Cape Breton Island (with R.A. Jamieson, graduate student H. Plint, S. Barr (Acadia University) and R. Raeside (Acadia)). It has been shown that metamorphic rocks in western Cape Breton Island underwent rapid cooling and uplift in response to tectonic exhumation in Early Devonian times. A broader study of the Cape Breton Highlands has documented belts with distinctly different cooling histories. These data can be used in regional correlation, and to constrain models of the accretion history of the eastern Appalachians.

(ii) Granite and mineralization ages in the Meguma Zone, Nova Scotia (with D.B. Clarke and M. MacDonald (N.S. Department of Mines and Energy) and F.J. Longstaffe (University of Western Ontario)). Argon dating has played an important role in unravelling the sequence of events in the Meguma terrane. Work now in progress concerns the timing of the important mineral deposit-related leucogranites in the intrusive sequence. Preliminary results suggest that they are considerably older than their contained mineral deposits and, consequently, may not be genetically related to the latter.

(b) Low Temperature Thermochronometry

This technique employs fission track dating of apatites and zircons, and $^{40}Ar/^{39}Ar$ dating of K-feldspars. A fission track dating facility is now in full operation at Dalhousie under the direction of M. Zentilli and NSERC postdoctoral fellow, C. Ravenhurst. Zeta calibration baselines for apatite and zircon have been established. The lab has recently been upgraded with the acquisition of a track length measuring system.

Major projects include:

(i) The Nova Scotia Continental Margin (with M. Zentilli). The subsidences and thermal history of this margin has been modelled by C. Beaumont (Dalhousie Oceanography) and co-workers, and a number of aromatization-isomerization (A-I) measurements have been made. A study presently underway will form the major part of the M.Sc. research of graduate student, A. Grist. Eight wells have now been sampled; preliminary results from the two dating labs suggest an amount of annealing (of fission tracks) and loss of argon (from K-feldspars) of the order expected from the Beaumont models. We look to the argon laserprobe and the fission track length measuring system to extend our interpretation. The overall aim of this research (in conjunction with the modelling studies of Beaumont) is to more fully understand the evolution of Canada's rifted continental margins; the latter are considered prime targets for frontier petroleum exploration.

(ii) The Alberta Foreland Basin (with C. Ravenhurst and M. Zentilli). Subsidence of this basin resulted from the flexural downwarping of the lithosphere due to loading imposed by overthrusting in the adjacent Cordillera. According to models developed by C. Beaumont, deepest burial (and highest temperatures) occurred at the peak of the Laramide Orogeny (~40 Ma ago) prior to uplift (and cooling) due to erosion of the overthrusted load. We wish to see if absolute age chronometers can detect this heating event and go on to estimate its duration and the apparent temperatures reached. Preliminary age data are in general agreement with model predictions; some apparently anomalous data may result from

the circulation of hot fluids in the basin.

(iii) Metallogenic and geological evolution of the Chilean Andes between 21° and 26°S (with M. Zentilli and graduate student, V. Maksaev). The apparent correlation between the formation of porphyry coppers and discrete episodes of Andean tectonism stresses the importance of dating Andean uplift, specifically, the uplift of the Cordillera de Domeyko block. Samples now being dated were collected from transverse profiles at the latitudes of the Chuquicamata and La Escondida porphyry copper deposits.

5. Geological Survey of Canada

(a) Geochronology (O. van Breemen, J.C. Roddick, R.R. Parrish, J.K. Mortensen, W.D. Loveridge, R.W. Sullivan, P.A. Hunt, M.L. Bevier, F. O.Dudàs, Geochronology Section, Lithosphere and Canadian Shield Division)

Further improvements in U/Pb zircon analysis have increased the production such that over 950 zircon fractions were analyzed in the year. Single grain analysis, though not routine, is extensively employed. The established common Pb procedure is being fine-tuned to cut separation time by 25% by using different size resin in the ion exchange columns. Techniques are being developed for the in situ measurement of Pb and S isotope compositions of galena and other sulfide minerals using a Cameca IMS-4F ion microprobe installed at CANMET (Ottawa). Work continues on the application of high pressure liquid chromatography to REE separations. F.O. Dudàs (PDF) joined the laboratory to assist in the development of the technique and is using it in Sm-Nd isotopic tracer studies. The ^{40}Ar-^{39}Ar step-heating system was commissioned and the first irradiation of samples took place in November. A range of projects is in progress on samples from the Cretaceous to the Archean. A GSC Paper (87-2) entitled "Radiogenic Age and Isotopic Studies: Report 1" was published. It represents the first of an annual series, and contains 20 short articles and a compilation of K-Ar ages generated by the Geochronology Section. Individual articles in 87-2 have not been listed in the p esent bibliography - only the report under 'Geochronology Section'.

J.C. Roddick spent six weeks at the Research School of Earth Sciences, Australian National University, using and assessing the application of the SHRIMP ion microprobe to U/Pb dating. Samples were selected from a number of projects currently in progress at the G.S.C. The ion probe analyses were particularly enlightening on the complexity of growth in zircon, and some difficult problems of multiple zircon growth were resolved which could not have been determined by single zircon analysis.

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

(i) Thelon Tectonic Zone, Taltson Magmatic Zone (O. van Breemen, W.D. Loveridge, J.C. Roddick, J.B. Henderson, P.H. Thompson and H.H.Bostock). Further work on the Thelon Tectonic Zone along the southeastern Slave Province has revealed a very sharp break between rocks of the Archean craton and granulites and migmatites with little evidence for an Archean memory. The pattern has also been confirmed by ion probe analyses which show early Proterozoic rather than Archean memory in cores, besides evidence for a major ca. 1.9 Ga tectonometamorphic event.

(ii) Slave Craton (O.van Breemen, J.E. King). Geochronology has started in support of a major west to east mapping traverse across the Slave craton starting west of Contwoyto Lake.

(iii) Southwestern Grenville Province (O.van Breemen, A. Davidson). U-Pb analyses of baddeleyite cores and zircon rims in coronites yield ages of ca. 1170 Ma and 1045 Ma respectively. The zircon ages clearly indicate that the coronitic fabrics were formed during granulite facies metamorphism of Grenville age, not during deuteric processes at depth. The older baddeleyite ages are related to igneous crystallization, younger than that of the Sudbury dyke swarm in the stable foreland.

(iv) Keewatin District, NWT (J.C. Roddick and A.N. LeCheminant). Geochronology of the magmatic events in the northwest Churchill province continues. A new U/Pb zircon analysis of a mildly foliated granodiorite - part of the granitoid basement complex northwest of Tulemalu fault yielded an age of 3.35 Ga, significantly older than other basement granites. Ion probe analyses of the grains confirmed this age and also determined the presence of younger zircon at 2.7 Ga and 1.8 Ga. While unexpected, the younger ages are consistent with regional events.

(v) Abitibi and Pontiac Subprovince (J.K.Mortensen). Continuing U-Pb geochronological studies of supracrustal and plutonic rocks and "basement" gneiss complexes within Abitibi and Pontiac Subprovinces, as well as adjacent portions of the Grenville Province, are helping to refine tectonic models for the evolution of this area. Sufficiently precise age data has now been obtained to permit stratigraphic correlation across most of the Abitibi Belt, and to place tight constraints on the timing of various deformation events. Most "basement" complexes dated thus far yield syn-volcanic to syn-Kenoran crystallization ages, and therefore do not represent depositional basement for the supracrustal sequences.

(vi) Ashuanipi Complex and Minto Block (J.K.Mortensen, J.Percival, J.C.Roddick). Ongoing U-Pb dating (together with regional mapping) of these large granulite massifs in northern Quebec, both by conventional mass spectrometry and SHRIMP ion probe, have provided preliminary ages for protoliths and for the high-grade metamorphism and subsequent retrogression that has affected the areas. Paragneisses from the Ashuanipi complex contain detrital zircons as old as 3.4 Ga. Pre-metamorphic felsic plutonism occurred between about 2750 and 2690 Ma. Granulite facies metamorphism occurred at 2670 Ma, and was apparently unrelated to the Kenoran Orogeny farther south.

(vii) Wawa Gneiss Terrane (J.K.Mortensen, D.Moser). U-Pb dating of various phases of metaplutonic rocks immediately west of the Kapuskasing Structural Zone is in progress. This data, together with detailed structural studies, will provide information on the nature and timing of deformation occurring at mid-crustal levels beneath Archean greenstone belts.

(viii) Slave Province (J.K.Mortensen, R.I.Thorpe, J.E.King, W.Padgham). Dating of the major felsic volcanic centers in the Slave Province is in progress as a first phase of a chronostratigraphic study of supracrustal sequences in the area.

(ix) Yukon-Tanana Terrane Evolution, Yukon and East-Central Alaska (J.K.Mortensen). U-Pb, K-Ar and Rb-Sr geochronology and regional mapping studies are being used to examine the composition, age and tectonic evolution of this complex terrane. Three main periods of magmatic activity are now recognized, in Late Devonian-Early Mississippian, mid-Permian, and Late Triassic-Early Jurassic time. Ductile deformation and medium grade metamorphism occurred between mid-Permian and Late Triassic time, and was followed by regional scale thrust imbrication and widespread mid-Cretaceous to Early Tertiary plutonism and volcanism.

(x) Late Mesozoic Peraluminous Magmatism, Central and Eastern Yukon (J.K.Mortensen, S.P.Gordey, R.G.Anderson). The field relationships, geochemistry, and U-Pb, Rb-Sr and K-Ar geochronology of widespread peraluminous plutons and related eruptive rocks in east-central Yukon are being studied. The aim of the isotopic component of this work is the determine the age and duration of this major magmatic event, and to address problems of severe zircon inheritance in young igneous rocks and U-Pb monazite systematics.

(xii) Gold-Quartz Veins in Western Yukon (J.K.Mortensen, B.E.Nesbit). The genesis of several types of gold vein mineralization in the Klondike and Sixtymile Districts of western Yukon is being studied using U-Pb (rutile) and K-Ar dating, Pb and stable isotope systematics of vein minerals and country rocks, and fluid inclusion data.

(xiii) Ion Microprobe Isotopic Studies of Sulfides (J.K.Mortensen, J.Jackman). A Cameca IMS-4F ion microprobe installed at CANMET (Ottawa) is being applied to Pb isotopic ratio measurements in micro- inclusions of galena in sulfide segregations in the Bushveld Complex and Muskox intrusion, and isotopic studies of zoned galena crystals from veins in the Atlin gold camp in northern British Columbia.

(xiv) New Brunswick granitoids (M.L. Bevier). U-Pb and common Pb studies are being employed to define the age of Paleozoic granites and the evolution of crustal terranes in New Brunswick. U-Pb ages of 9 granites from Miramichi terrane are Middle to Late Ordovician and all show a strong inherited component. SHRIMP ion microprobe ages on two of the granites show that crystallization ages of the plutons are in good agreement with the lower intercept ages derived from conventional U-Pb dating. Both these plutons contain inherited zircons of a variety of ages ranging from ca.600- ca.1800 Ma, thus indicating complex recycling of crust in the basement. Common Pb isotopic determinations for granites from five terranes in New Brunswick show four distinct groupings. Different basement can be characterized for 3 and possibly 4 of the terranes. Additional U-Pb zircon, sphene, and monazite ages as well as Pb isotopic determinations are in progress.

(xv) Stikine volcanic belt, British Columbia (M.L. Bevier). Pb and Sr isotopic ratios of Late Cenozoic volcanic rocks from the Stikine volcanic belt indicate that depleted mantle similar to the source for Juan de Fuca plate seamounts is widespread beneath all accreted terranes in northern British Columbia. Preliminary Pb isotopic determinations allude to a more radiogenic component in young basalts erupted near the edge of the North American craton. Further work (in progress) is needed to distinguish between old enriched sub-continental mantle and Precambrian upper crust as the source of this radiogenic component.

(xvi) Tombstone plutonic suite, Yukon Territory (M.L. Bevier, R.G. Anderson, R.J. Theriault). Whole-rock Rb-Sr isochrons are not useful for dating the Tombstone plutons due to initial isotopic heterogeneity within plutons. Initial Sr isotopic ratios are high but variable both within and between different plutons and indicate assimilation of radiogenic upper crust. Whole rock-biotite pairs from phases within plutons give ages of 91 Ma for the Tombstone, Deadman, and Antimony Range plutons. U-Pb (zircon, sphene), K-Ar (hornblende, biotite), and additional Rb-Sr dating of the suite will further constrain the age and duration of magmatic activity in the Tombstone Range. Additional Pb and Sr isotopic ratios will help further characterize the plutons and their source.

(xvii) Patton-Cowie seamounts (M.L. Bevier, J.C. Roddick, B. Blaise) K-Ar dating is in progress on several samples of basalt from Patton and Cowie seamounts, Gulf of Alaska, which were dredged in 1987 by G.S.C. staff at the Pacific Geoscience Centre. Pb, Sr, and Nd isotopic ratios determined from these will be compared to existing data for other seamounts in the northeastern Pacific Ocean.

(xviii) Purtuniq ophiolite, Cape Smith belt, Quebec (M.L. Bevier, E. Hegner, R.R Parrish, M. St Onge). A zircon dating and Pb and Nd isotopic study of mafic and ultramafic rocks of the 1900 Ma Purtuniq ophiolite is planned. The isotopic data will be compared to Pb and Nd isotopic data from Archean continental crust to the north to see whether or not the ophiolitic rocks were derived solely from the mantle or whether they contain a continental crustal component. Felsic plutons from the Cape Smith belt will also be examined.

(xix) Abitibi/Pontiac Subprovince Alkaline Magmatism (M.L. Bevier, J.K. Mortensen). The Pb isotopic signature of post-tectonic alkaline plutons in the Pontiac subprovince and southern Abitibi subprovince is being investigated. These bodies are Late Archean in age (2674-2686 Ma) and may be genetically related to crustal-scale wrench faults. The main goal of this study is to evaluate crustal versus mantle derivation for these bodies.

(xx) Tracer studies of Southern Slave Province (F.O. Dudàs, O. van Breemen and J. B. Henderson). Nd isotopic analyses of granitoids from the southern Slave province have yielded a range of model ages which suggest initial stabilization of the crust prior to 3.1 Ga, and subsequent mixing of crustal and mantle materials between 2.6 and 2.8 Ga. Work in progress aims to evaluate the relative contributions of crustal and juvenile components.

(xxi) Tracer studies of the Proterozoic from the Baker Lake area, District of Keewatin (F.O. Dudàs, A.N. Lecheminant). Nd analyses of Proterozoic samples from the Baker Lake area indicate no addition of mantle material during igneous activity at 1.7-1.8 Ga. Depleted mantle model Nd ages range from 2.6 to 2.9 Ga for all samples.

(xxii) Himalayan Leucogranites, Pakistan and Tibet. Studies are in progress on zircon and monazite geochronology of a number of leucogranites from Pakistan and Tibet (R.R. Parrish with M. Searle and T. Rex, U. of Leicester and Burchfiel, Royden, and Hodges of MIT and T.M. Harrison and P. Copeland of SUNY Albany).

(xxiii) Monazite systematics (R.R. Parrish). This involves documentation of a) monazite inheritance, b) diffusive Pb loss in monazite in granites and gneiss, and c) the closure temperature of monazite, approximately 700°C.

(xxiv) Dating of Basement beneath Alberta (R.R. Parrish, with colleagues G. Ross and M. Villeneuve). In an attempt to define the age domains beneath the Interior sedimentary basin, 45 basement cores have been dated using zircon and monazite. Correlation of the ages with major magnetic and gravity anomalies is also in progress.

(xxv) Dating of Kimberlitic Diatremes (R.R. Parrish, with I. Reichenbach) Single xenocrystic zircons within kimberlitic diatremes of Arctic Canada, the Mackenzie Mountains, and the southern Canadian Rocky Mountains have been analysed. The ages reflect the major age domains of the western Canadian Shield.

(xxvi) Continuing studies of geochronology and tectonics in British Columbia with University and government colleagues (R.R. Parrish with J. Monger, B. Struik, H. Gabrielse, R. Anderson, G. Woodsworth, S. Carr, L. Currie, S. Gareau, J. M. Journeay, and M. McDonough).

(xxvii) Continuing coordinated studies of geology, geochronology and seismic reflection interpretation of the southern Cordilleran LITHOPROBE transect. (R.R. Parrish)

(b) Stable Isotope Research (B.E. Taylor, Mineral Resources Division)

Dr. Taylor supervises the OCCG/GSC joint stable isotope laboratory housed in the Department of Geology, University of Ottawa which serves the needs of scientists at Ottawa and Carleton universities and in the G.S.C. for the isotopic analysis of O-C-S in waters, carbonates, and sulphur-bearing samples. At present a research laboratory is under construction at the G.S.C. for more specialized analytical work involving O-C-H-S, including oxygen and hydrogen isotopic analysis of silicate minerals, and micro-scale sampling and analysis.

Research in earth processes using stable isotope geochemistry principally includes the general thematic areas of: (1) crustal fluids, (2) magma genesis and magmatic volatiles, (3) hydrothermal ore deposits, and (4) environmental and life processes. Active projects include: under (1) fluid evolution in collisional plate margins and overthrust belts (including gold deposits in the Mother Lode, California; Cariboo District, British Columbia); under (2) volatile histories in magmatogenesis in the Taupo Volcanic Zone, N.Z., and submarine lavas on Galapagos rise, and other localities; under (3) comparison of Proterozoic (Great Bear Lake, N.W.T.) and Paleozoic (Mt. Pleasant, N.B.) caldera-hydrothermal systems.

(c) ICP Mass Spectrometry (D.C. Gregoire, Mineral Resources Division)

Methods have been developed for the determination of boron isotope ratios in geological materials using Inductively Coupled Plasma Mass Spectrometry with a recently installed Sciex Elan Model 250. Crushed rock samples are fused with sodium carbonate, dissolved in water and boron is concentrated with cation exchange resins. Boron isotope ratios can be determined with a precision of 0.7% in materials containing as little as 0.5 ppm boron. Shifts in boron isotope ratios ($^{11}B/^{10}B$) have been shown to be useful as an indicator of water-rock interaction in hydrothermal basalt alteration processes. In a second application, boron isotope ratios of tourmalines, in conjunction with other chemical parameters, are being studied as an indicator of gold mineralization. Methods for the determination of osmium isotopes in geological materials are now being developed for application to Re/Os dating.

6. University of Manitoba, Department of Geological Sciences (G.S. Clark)

The Rb-Sr isotopic studies recently completed and in progress in Manitoba include projects in the northern Superior province (Cross Lake area), Churchill-Superior boundary and Churchill province.

(a) Cross Lake Area

Samples of pseudotachylite and hornfels adjacent to the Molson Dykes have been analysed. The pseudotachylite shows the affects of open system behavior and gives an unrealistically low initial ratio. The regression of six samples of hornfels gives an age of 1970 Ma (i=0.703), in reasonable agreement with the ca. 1884 Ma U-Pb zircon age (unpubl.) for the main Molson Dyke at Cross Lake. The protolith is pelitic to semi-pelitic metasedimentary rocks giving a Rb-Sr age of ca. 2600 Ma. The method shows promise as a means to date mafic dykes in Archean terranes. Further work on pseudotachylites is being planned.

(b) Churchill-Superior Boundary

Work is continuing on the Fox Lake granite and basement gneiss in the Split Lake block. To date, the scatter of isotopic data for both units precludes determining ages. Work also includes major and trace element determinations (N.M. Halden) as part of the petrogenetic study. The Fox Lake granite shows extreme depletion in alkali elements.

(c) Churchill Province

Rb-Sr isotopic and geochemical investigations on the Chipewyan batholith and spatially associated batholiths are continuing. An initial study of the southern part of the batholithic complex has been completed and submitted for publication (with N.M. Halden, U. of Manitoba and D. Schledewitz, T. Corkery and P. Lenton, Manitoba Department of Energy and Mines).

Work is in progress on early granitoids intrusive into paragneisses of the adjacent Southern Indian domain. These plutons give consistently older Rb-Sr ages than both Rb-Sr and U- Pb zircon ages (for example, Van Schmus and Schledewitz, 1986) for phases of the Chipewyan batholith.

Now that our ARL 8420 X-ray fluorescence spectrometer is fully operational (N.M. Halden), more detailed geochemical studies will be integrated with the isotopic investigations of mid-Proterozic batholiths in the Churchill province.

7. McMaster University

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

(i) Oxygen isotopes in granulites, Kapuskasing Structural Zone. This work in progress is a part of a contribution to the Lithoprobe Project funded by NSERC. Preliminary measurements have been made of $\delta^{18}O$ of whole rocks collected in the 1987 field season. Granulitic meta-igneous rocks display somewhat lower values than equivalent lower grade rocks elsewhere in the Archean crust, including some very low values suggestive of meteoric water interaction (with D.M. Shaw and F. Ghazban).

(ii) Stable isotopes in acid rain. We are completing a project under a Strategic Grant to survey oxygen and sulfur isotopes in sulfate from rain over eastern North America. Distinct regional trends in both variables are found in individual storm events, that are roughly paralleled by successive events. Coastal rain in Nova Scotia, sampled through a year, shows the influence of sea-spray/terrigenous mixing but does not show a recognizable contribution from marine dimethysulfide (with J.R. Kramer, M. Wadleigh).

(iii) Stable isotopes in trophic chains. Studies continue of estuarine molluscs, comparing the organic matrix of the shells, the tissues, plankton, and sediment. Mixing trends between terrigenous and marine sources are evident but the proportions of land/sea constituents show different gradients depending on which index is traced (with M. Risk, C. Leblanc).

(iv) Paleodiet in archaeology. Mixtures of dietary foods can be recognized in residues attached to the inner surfaces of pot-shards from paleo-indian sites in Ontario. We have compared these with our earlier analyses of bone collagen from inhabitants of these sites. Much less maize (^{13}C-enriched) is recognizable in the food remains than was found in the bones, contrary to expectation. Also, beans (depleted in ^{15}N) do not appear to be important foods at any time; fish is an important protein source at all times (with J. Morton).

(v) Sulfur isotopes in gold ores. In cooperation with scientists from Queen's University, we are looking again at ^{34}S distributions in pyrite from the Timmins camp. At Hollinger/McIntyre there is a distinct difference between the distribution of isotopes in barren and in ore-grade pyrites (with R. Mason and L. Melnik, Queen's University).

(vi) Seasonality at archaeological sites. It is possible to recognize the seasonality of occupation of coastal sites where molluscs were used as foods, by analyses of $\delta^{18}O$ of the rim of the shell to test in what season the shell was collected. This is being applied to samples from coastal sites in Italy (with M. Stiner, U. of New Mexico).

(b) U-series Dating (H.P. Schwarcz, Department of Geology)

(i) Mass spectrometric analysis of U and Th. Following the lead of L. Edwards et al., at Cal Tech, we are using the VG 354 mass spectrometer to measure the $^{230}Th/^{234}U$ ratio in carbonates and other materials. This will permit us to achieve much better precision than was available with alpha spectrometry: about 1% vs 5 to 10% formerly. There will be a comparable improvement on age measurement of carbonates. It will also be possible to use the $^{234}U/^{238}U$ ratio for dating where the initial ratio has remained constant, as in certain spring deposits (A. Dickin, R.H. McNutt, W.-X. Li, Joyce Lundgren and D.C. Ford).

(ii) Rad-waste Deposits. Using the mass spectrometric method, we are testing for variation in the $^{234}U/^{238}U$ ratio in altered and fresh granites in the Underground Research Laboratory (URL) at Pinawa, Manitoba, to test for mobility of U through the rock in recent times. Further work on $^{230}Th/^{234}U$ ratios will be continued soon, using a ^{229}Th spike.

(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 $\delta^{34}S$ and $\delta^{13}C_{CO2}$ 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.

(d) Radiogenic isotopic research (R.H. McNutt, Department of Geology)

(i) The ICP/MS technique is now being used in the following projects:

(a) the isotopic composition of the stable isotopes of Ca, Fe, Zn and Se (medical application).

(b) isotope dilution determinations of Rb, Sr and the REE elements.

(c) the measurement of the Os isotopic composition for tracer studies and for geochronology.

(d) the simultaneous measurement by ICP/MS and ICP/AES using the same plasma torch. (R.H McNutt, A.P. Dickin and R.G. Jonasson)

(e) A correlation of iridium distribution with shocked minerals of terrestrial origin at Gubbio, Italy (J.H. Crocket and C.B. Officer, Earth Sciences Department, Dartmouth College, New Hampshire).

The distribution of iridium in two stratigraphic sections (Bottaccione and Contessa) near Gubbio, Italy was found to be anomalous from approximately 2 m above to 2 m below the Cretaceous-Tertiary boundary shale. Maxima in iridium and shocked mineral, (mainly feldspar and quartz) abundances are coincident. These minerals are texturally similar to shocked minerals recently discovered in ejecta from terrestrial explosive volcanism, including the Mt. St. Helens eruption. The data indicates that intense volcanic activity was coincident with the generation of anomalous iridium concentrations about the K/T boundary at Gubbio. These observations are best explained by models involving terrestrial phenomena rather than those incorporating a single-event, asteroidal impact. While the episodic distribution of iridium is more compatible with a comentary shower impact model, neither the iridium content nor the potential of cometary impact to produce shocked minerals is known.

(ii) The study of Sr, Nd, and Pb isotopes of brines on the Canadian Shield and the Michigan Basin continues, with the emphasis shifting from Sr to Nd and Pb and to the study of fracture mineral phases and diagenetic minerals (R.H. McNutt with S. Frape at U. Waterloo).

(iii) A Sr - O isotopic study of the siderite and calcite cements in the Cardium sandstone, Alberta, is being applied to the problem of marine vs. non-marine origin for certain stratigraphic horizons of the Cardium. (R.H. McNutt, H.P. Schwarcz, S. Zymela with R.G. Walker)

(iv) Geochronological studies include:

(a) the Rb/Sr and Sm/Nd ages of the White Bear Arm Pluton, Labrador, a 1600 Ma coronite gabbro. (R.H.McNutt, S .Prevec with C. Gower, Nfld. Dept. of Mines).

(b) the Rb/Sr and Sm/Nd age study of the granulite grade orthogneisses of the Melville Peninsula, NWT. (R.H. McNutt with M. Schau, G.S.C.).

(c) Nd model age dating of Grenville Province paragneisses and plutons to characterize structurally recognized domains. (A.P. Dickin , R.H. McNutt and F. Marcantonio).

(d) U/Pb dating of Grenville Province granites in the Westport area. (F. Marcantonio with L. Heaman, R.O.M.).

(e) Rb/Sr, Sm/Nd, Pb/Pb and U/Pb ages on the Islay-Inistrahull gneiss terrain.(A.P. Dickin, F. Marcantonio and R.H. McNutt).

(v) Igneous Geochemistry:

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

(b) Nd isotope analysis of tertiary igneous rocks from Arran, Scotland to determine the age of the basement of the Midland Valley (A.P. Dickin and R.H. McNutt).

(c) Pb, Sr and Nd isotope analysis of basic igneous rocks from the Blackstone complex, W. Scotland, to study intense crustal contamination processes. (A.P. Dickin, F. Marcantonio and R.H. McNutt).

8. Memorial University (B.J. Fryer, H.P. Longerich, G.A. Jenner, J. Wilton)

The Department's VG-MM30 has undergone some hardware upgrading over the last year, with installation of computer controlled focussing and beam control. In addition, a PC-clone has been interfaced to the HP controlling the mass spectrometer, so that data handling can be on the PC. This work has been facilitated by the use of LOTUS Measure and data reduction is now done on LOTUS 1-2-3.

Isotopic research on volcanic samples with low Sm-Nd concentrations (studies by Jenner and Swinden) has been facilitated by use of the mass spectrometry facilities at the Geological Survey of Canada (Ottawa). We are indebted to J.C. Roddick and O. van Breemen for access to the G.S.C. labs.

Projects in progress:

(a) Fryer: Sr and Nd isotopic studies of Archean Lode Gold Deposits; Sr, Nd and O isotope studies on Archean pegmatites N.E. Manitoba (with P. Cerny, U. of Manitoba and F.J. Longstaffe, U. of Western Ontario); Rb-Sr geochronology, Sr and Nd isotopic tracer studies on Newfoundland granites.

(b) Pb-Pb on Labrador uranium deposits (Fryer and Wilton).

(c) Sr and Nd isotopic studies on the Trans-Labrador batholith (A. Kerr).

(d) Sr isotopic composition of St. Lawrence fluorspar deposits (C. Collins).

(e) Age of alteration and associated Au mineralization using Rb-Sr geochronology (T. Al).

(f) Age of granitic intrusions, Labrador using Rb-Sr geochronology (Wilton, L. McKenzie, C. MacDougall).

(g) A study of Archean granitoid rocks in the central Slave province, N.W.T., using isotopic (Sr and Nd) and geochemical data will constain the petrogenesis of the granites and in particular determine crustal residence times (B. Davis).

(h) Nd isotopic studies on mafic volcanic rocks from Wild Bight Group, Central Newfoundland (S. Swindon with C. Roddick, G.S.C., Ottawa).

(i) Nd isotopic studies on island arc, oceanic island and ophiolite suites from the Tally Pond, Victoria Lake, Roberts Arm, and Pipestone Pond ophiolite, Central Newfoundland (S. Swindon and G. Jenner).

(j) Sm-Nd isotopic studies of boninitic volcanism in Cambrian-Ordovician sequences from Newfoundland (Betts Cove Ophiolite, Lushs Bight Group, Pacquet Harbour Group) and Tasmania (G. Jenner with T. Brown, Geological Survey of Tasmania).

(k) Sm-Nd isotopic studies on the Catchers Pond, Western Arm and Cutwell Groups, Central Newfoundland (G. Jenner and A. Szybinski).

9. Université du Montréal (C.E. Brooks, Department of Geology)

New Pb and O isotopic determinations were carried out on Mesozoic to Cenozoic calc-alkaline volcanic and plutonic rocks emplaced in the Precambrian basement of southern Peru. Since the Pb and O isotopic composition of the basement is extremely distinctive to that of mantle derived magmas (i.e. $^{206}Pb/^{204}Pb < 17.03$ and $^{18}O/^{16}O > +10$), we expect to better constrain a crustal contamination model previously developed to explain the chemical evolution of calc-alkaline magmas produced in the continental arc of southern Peru by a combined process of assimilation and fractional crystallization (i.e. AFC).

A new study has been initiated which combines Sr, Nd, Pb and O isotopes with trace elements on the youngest ignimbrites, andesites and granitoids (Miocene to Pliocene) emplaced in the Cordillera Oriental of northwestern Bolivia. This project will investigate the origin and magmatic history of a young volcano-plutonic belt formed over a thick continental crust ad located 500 km east of the Peru-Chile oceanic trench.

10. University of Ottawa (K. Hattori, J. Veizer, I. Al-Aasm, Department of Geology)

(a) K. Hattori is continuing a geochemical study of Archean gold mineralization and the study of the evolution of oxidation conditions in the Earth's near surface environments. In the past two years, work has focussed on the origin of sulfate in Archean time using S and Sr isotopes.

(b) J. Veizer is conducting a study of chemical and isotopic evolution of seawater through geologic history. He supervises the following students and their projects:

M. Mirota is studying the isotopic evolution of seawater in Early Proterozoic time through the study of the Albanel System.

D. Bottomley carries out an isotopic and geochemical study of fracture filling minerals in Precambrian crystalline rocks.

S. Hall (Diagenetic and secular variations of trace elements (Sr, Mn, Fe, Na, Al), stable isotopes (O, C, S) and $^{87}Sr/^{86}Sr$ in carbonates of the Proterozoic Belt Supergroup, Montana and Idaho, U.S.A.). Post-depositional alteration of carbonates are charted by trace element and isotopic variations with the result that regional and mineralogical influences can be distinguished and secular variations in the geochemistry of Proterozoic seawater can be characterized.

M. Savard has just started her Ph.D. project, classification of carbonate cements in the upper Paleozoic Sverdrup basin using stable isotopes and trace elements.

J. Morrison is studying the geochemical paleoecology of the Cretaceous seaway.

N. Evans is carrying out noble metal geochemistry and stable isotope geochemistry of the Cretaceous-Tertiary boundary clays to examine the mass extinction event.

M. Wadleigh recently started P.D.F. work on geochemistry and stable C and O isotopes of lower Paleozoic articulate brachiopods to define secular trends in ocean water composition.

(c) I. Al-Aasm is conducting stable isotope studies of diagenetic evolution of sedimentary rocks and paleo-oceanographic reconstruction of Quaternary and Pre-Quaternary oceans.

11. Université du Québec à Montréal, Centre de Recherche en Géochimie isotopique et en Géochronologie - GEOTOP : Département des Sciences de la Terre (C. Gariépy, C. Hillaire-Marcel, P. Pagé, U. Scharer), Department of Geological Sciences - McGill (R. Doig), GEOTOP (C. Causse, O. Carro, C. Guilmette)

(a) Instrumentation

Four mass spectrometers are in routine operation: (i) a SIRA-12, (ii) a Micromass 602C, (iii) a modified Micromass 602D interfaced to a computer and (iv) a VG Sector. A second VG Sector, equipped with an electrostatic analyzer and a pulse counting Daly system, will be installed in April 88. Four β-counters (^{14}C) and eight α-counters (Th/U dating) with on-line computer are in routine operation.

(b) Stable isotope studies

The principal ongoing programs are generally multidisciplinary and involve the participation of researchers from several universities. These programs concern: (i) the last climatic cycle in eastern Canada with studies of cores from ODP Leg-105, the Labrador Sea, the Davis Strait and Lake Bras D'Or; (ii) the paleohydrology of intertropical Africa (project GEORIFT) during the Pleistocene and the Holocene with studies of lacustrine basins from Ethiopia, Kenya, Tanzania, Cameroon and Burundi; (iii) the limnology of lakes from Arctic Canada; (iv) the geochemical evolution of recent sediments from the Laurentian Channel; (v) the present-day isotopic hydrology of Altiplano lakes in Bolivia, of SE Niger and of E Uruguay and (vi) punctual studies in isotopic biochemistry (absorption of pollutants associated with acid precipitations, isotopic control of food quality and isotopic tracing of human metabolism during physical efforts).

(c) Radiocarbon and Th/U dating

Both laboratories participate actively in the above mentioned programs. In addition, chronological studies based on the use of the Th/U disequilibrium method are being carried out on fossil woods found in the permafrost terranes of northern Canada, shells from marine terraces of south Spain, molluscs from Algeria and Tunisia (project PALHYDAF) and stromatolites from east Africa. Amino-acid measurements, which may

provide a relative chronology of some Quaternary fossils, are being completed in parallel with the Th/U studies of shell fossils. Finally, the behaviour of the U and Th isotopic families in a continental sabkha is being investigated in the Al Mouh basin of central Syria.

(d) Studies of deposits

The following research projects are underway: (i) Pb-isotopic composition of galenas from sulphide ores of the SE Quebec Appalachains; (ii) Pb/Pb dating of sulphide deposits from the Abitibi greenstone belt; (iii) C, O, S and Sr isotopic composition of post-Ordovician veins from the Frontenac axis and the Charlevoix astrobleme and (iv) C and O isotopic co-position of gangue minerals from Au-prospects of the SW Grenville province.

(e) Radiogenic isotope studies

(i) Geochronology. The following geological materials are being investigated:

- Shocked rocks and minerals from the Haughton impact, Arctic Canada (U/Pb)
- Granitoids from the Himalayas (U/Pb)
- Granitoids from the Eastern Townships (Rb/Sr and U/Pb)
- Volcanic series from the SE Quebec Appalachians (U/Pb)
- Detrital zircons from the Lower Tetagouche Group, New Brunswick (U/Pb)
- Sedimentary fluorapatites from the Quebec Appalachians (Pb/Pb)
- Granulites of the Grenville Front zone south of Val D'Or (Pb/Pb)
- Metamorphic history of the Grenville province south of Val D'Or and Chibougamau (Rb/Sr, Sm/Nd and U/Pb)
- Proterozoic and Archaean terranes in N Labrador and Ungava (U/Pb)

(ii) Isotopic tracing in petrology. The following materials are being investigated:

- Granitoid K-feldspars from the Eastern Townships, the McGerrigle Complex (Gaspé) and the Topsails igneous terrane (NewFoundland) (Pb/Pb)
- Proterozoic and Archaean terranes in N Labrador and Ungava (Rb/Sr and Sm/Nd)

12. Queen's University (E. Farrar, J.A. Hanes, D.A. Archibald, S. Clark, R. Langridge, S. Heinrich, P. Chaursiri, M. Gerasimoff, M. Queen and L. Wong, Department of Geological Sciences)

An argon extraction system employing a turret furnace or Lindberg furnace with a modified A.E.I. MS-10 mass spectrometer is used for high-resolution $^{40}Ar/^{39}Ar$ total fusion and step-heating experiments. A fission track dating facility is also operative. Several geochronological investigations are currently underway.

(a) South American Studies

(i) Investigations are continuing into the tectonic, magmatic and metallogenic evolution of the Cordillera Carabaya, S.E. Peru (E.F.). These investigations 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) A detailed study of the intrusive and mineralization history of the Palca Once deposit of the Cordillera de Carabaya, S.E. Peru, has begun (E.F.).

(iii) A paleomagnetic investigation (R.L.) in southern Peru is underway. The aim of this study is to compare the remnant magnetizations of rocks of known age (R.L., E.F.) 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.H., E.F.) to examine the tectonic and thermal history of the Zongo-San Gaban zone in the Cordillera Oriental of Bolivia and Peru. Total fusion and step-heating $^{40}Ar/^{39}Ar$ dating and fission track dating are being used. A comparable study in an adjacent, more southerly transect is being initiated (E.F.).

(b) Canadian Cordillera

(i) Kootenay Arc and neighbouring regions. A study of the geology and geochronology of the southern Kootenay Arc and Purcell Anticlinorium, B.C. (D.A.A., E.F.) continues. The study comprises conventional K-Ar dating as well as $^{40}Ar/^{39}Ar$, U-Pb (with T. Krogh, R.O.M.) zircon dating 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 $^{40}Ar/^{39}Ar$ study of dykes in the Irene Volcanics (Windermere Supergroup near 49°N) complements this work and supports the idea of an early Cambrian thermal event possibly related to the collapse of the miogeocline.

More recently, a paleomagnetic study of the mid-Cretaceous plutons (with E. Irving, P.G.C.) has been completed. The data for the Bayonne batholith east of Kootenay Lake yield the expected, mid-Cretaceous paleopole for cratonic North America. $^{40}Ar/^{39}Ar$ step-heating of biotite from some of the sites implies that the batholith was essentially unaffected by Eocene thermal activity.

(c) Other studies in the Canadian Cordillera

(i) A $^{40}Ar/^{39}Ar$ study (D.A.A.) of the west flank of Frenchman's Cap dome from the core zone to the Anstey pluton. Biotite and muscovite yield concordant or nearly concordant K-Ar dates between 45 and 55 Ma. In contrast, hornblende yielded mid- to late-Cretaceous K-Ar dates (117 to 88 Ma). $^{40}Ar/^{39}Ar$ step-heating results for hornblende reveal a component of excess argon as well as complex age spectra with two plateau segments (~185 and ~110 Ma). These results highlight the problems associated with interpreting conventional K-Ar hornblende dates for high-grade metamorphic rocks.

(ii) A $^{40}Ar/^{39}Ar$ and U-Pb zircon study (M.G., E.F. and T. Krogh, R.O.M.) of plutonic and metamorphic rocks on the N.E. margin of the Shuswap Metamorphic Complex, Wells Gray Provincial Park, B.C.

(iii) A K-Ar and $^{40}Ar/^{39}Ar$ study (D.A.A., with E. Mountjoy, McGill) of metamorphic rocks near the Purcell thrust (Canoe River map-area).

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

(v) A $^{40}Ar/^{39}Ar$ study of plutonic and volcanic rocks in the Warner Pass - Noaxe map-areas of S.W. B.C. was initiated in 1987 (D.A.A. with J.K. Glover, BCDEMPR). This work complements the paleomagnetic study of the mid-Cretaceous igneous rocks being done by P.J. Wynne (P.G.C.). The aim of this study is to establish the timing of volcanism, mineralization and alteration related to small, shallow-level plutons in the area.

(d) Studies of ore deposits

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

(ii) A $^{40}Ar/^{39}Ar$ study of the Mt. Pleasant Sn deposit is in progress (D.A.A. with R. Taylor, Carleton and D. Sinclair, G.S.C.). 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) A K-Ar study (D.A.A., E.F., with A.H. Clark) of selected W mining districts in Korea is in progress. K-Ar dates (80 to 1700 Ma) and $^{40}Ar/^{39}Ar$ age spectra suggest a complex thermal history for these areas.

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

(e) Precambrian Studies

(i) An ongoing $^{40}Ar/^{39}Ar$ thermochronometric study (J.A.H., S.C.) of the Grenville Elzevir trondhjemite in southeastern Ontario has demonstrated the suitability of Grenville muscovite as a thermo-chronometer. 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 $^{40}Ar/^{30}Ar$ thermochronometric transect of the Grenville Front from Montreal to Val d'Or (with J. Martignole, U. of Montreal). Electron microprobe studies of the mineral phases dated will be related to the $^{40}Ar/^{39}Ar$ age and diffusion data.

(ii) In a study (J.A.H., L.W.) of the tectonothermal history of the Archean Abitibi greenstone belt, $^{40}Ar/^{39}Ar$ thermochronometry and U-Pb dating (with T. Krogh, R.O.M.) are being used to elucidate the timing of late stage plutonic activity and major gold mineralizing events in Sigma Mine in Val d'Or, Quebec (with F. Robert, G.S.C.)

(iii) $^{40}Ar/^{39}Ar$ geochronology (J.A.H., M.Q., D.A.A.) of diabase dyke swarms in the Wawa-Kapuskasing-Abitibi transect of the Canadian Shield is providing information on the long-term tectonothermal history of these regions.

(iv) A $^{40}Ar/^{39}Ar$ study (D.A.A., E.F., J.A.H. with J. Percival, G.S.C.) of a "transect" of the Kapuskasing Structural Zone (KSZ) is in progress. Initially, this research began with a study of sheared and unsheared granitic and amphibolitic rocks within and near the Ivanhoe Lake Cataclastic Zone to resolve the time of brittle deformation. More recently, the scope of the investigation was expanded to include the timing of regional post-metamorphic cooling and uplift history the KSZ as part of LITHOPROBE.

(v) A $^{40}Ar/^{39}Ar$ study of the Proterozoic Kamatiwi pegmatites of the Zambesi mobile belt in Zimbabwe has been initiated to assess whether they are related to the ca. 1000 Ma Kibaran thermal event.

13. University of Saskatchewan (T.K. Kyser, E.G. Nisbet and graduate students, Department of Geological Sciences)

(a) Instrumentation

Despite the lack of support from the VG representatives in Canada, upgrade of the software for the MM 602C isotope ratio machine was finally successful. This machine is used routinely for sulphur and oxygen isotope determinations. A new laser ablation system which feeds directly into the MAT 251 has been installed and is currently being tested.

(b) Radiogenic and stable isotope studies

(i) 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 1.6 Ga. Oxygen isotopic compositions of the coexisting plagioclase and pyroxenes indicate that the pyroxenes normally have values typical of the mantle (+5.5 per mil) whereas the plagioclases have been altered by later metamorphic fluids which also affected the Rb-Sr systematics. ε_{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.

Oxygen and hydrogen isotopic compositions of the Wathaman batholith of the LaRonge Domain and of metavolcanic rocks from the Flin Flon greenstone belt also record a young (<1.6 Ga) metamorphic event that partially overprinted their original 1.8-1.9 Ga emplacement and peak metamorphic event. The fluids associated with the younger event in these terranes are also of metamorphic origin and most likely reflect an event that has affected most of the Churchill Province of Saskatchewan and Manitoba.

(ii) 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. $\delta^{18}O$ 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 $^{18}O/^{16}O$ ratios are compatible with derivation of the komatiites from depleted mantle sources.

(iii) Gold deposits. Sr isotopic compositions of tourmaline from several lode-gold deposits in the Abitibi greenstone belt are highly variable and suggest derivation of auriferous fluids from very heterogeneous sources. These data are not compatible with previous models that invoke only the mantle, the Abitibi volcanic rocks or the batholiths as sources for the fluids.

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. Fluid inclusions reflect a very complex history for most of these deposits but, in conjunction with stable isotope and field data, indicate formation of barren veins from aqueous fluids and auriferous veins from fluids with CO_2 immiscibility at depths of about 6 km. 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 and pressures near 3 km. Although similar to the temperatures, pressures and chemical compositions (i.e. CO_2 immiscibility) of the fluids associated with Archean gold-lode deposits, the Proterozoic deposits are much smaller because they are related to less intense events.

Stable and radiogenic isotope compositions of syenite host rocks and alteration minerals such as illite, kaolinite and smectite in the low-grade gold deposits of the Little Rocky Mountains, Montana, indicate that gold mineralization originated in fractures in the syenite shortly after the pluton was emplaced at 63 Ma. The alteration minerals formed from meteoric waters at 200°C and have very high $^{87}Sr/^{86}Sr$ ratios that require a source for the Sr (and presumably the gold) from the Archean basement rocks. The source for the syenites appears to be mantle lithosphere and the heat for the hydrothermal convection flow is from an intrusion beneath that of the host.

(iv) Potassic magmatism. U-Pb isotope systematics on sphenes from three lamprophyres from the Abitibi greenstone belt indicate ages of 2674 Ma which are similar to the latest stage of Archean plutonism in this belt. These lamprophyres can serve as indicators of the composition of the Archean mantle and place constraints on genetic models for the formation of gold mineralization in Archean terranes.

(v) Unconformity-type uranium deposits. M. Wilson and T. Kotzer have used the chemical and isotopic composition of clay minerals associated with unconformity-type uranium deposits to trace the fluid history of the Proterozoic Athabasca Basin. The results suggest that the deposits originally formed at about 1200 Ma 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 which have interacted with and modified the deposits at about 800 and 400 Ma. The original basinal fluid in the Athabasca may be related to the event that produced the late metamorphic fluid recorded in many of the rocks in the shield of N. Saskatchewan.

(vi) Paleoclimate studies. Carbon and oxygen isotopic compositions of fossil molluscs 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 form 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. The isotopic composition of water in the seaway was continually altered by influxes of meteoric water and modified pore waters which often served as controls on extinction of selected biota.

(vii) Fluids in the Elk Point/Williston Basins. Fluid events that have affected the Williston and Elk Point Basins are recorded in the isotopic composition and trapping temperatures of fluid inclusions in halite from the Devonian Prairie Evaporite formation. Trapping temperatures of fluids on which the H and O oxygen isotopic compositions have been measured indicate that three major fluid events have affected the evaporites. The earliest event occurred in the Devonian and represents a total recrystallization of the salt from near-coastal meteoric water at 35°C. The second occurred in the Cretaceous at ca. 80-100°C from basinal brines when the formation was at its maximum burial. Later Tertiary events, most likely related to uplift of the basin and in response to glaciations, have partially affected the evaporites.

14. University of Toronto

(a) IsoTrace Laboratory: Physics (A.E. Litherland, R.P. Beukens, L.R. Kilius, W.E. Kieser); Geology (J.C. Rucklidge, R. Cresswell, G.C. Wilson, P. Peltonen, Qiao Yangjiang)

(i) Radiocarbon dating. In the calendar year 1, 987, 399 ^{14}C dates were measured for researchers in Canada and the U.S.A. Precisions approaching 0.5% were routinely obtained on samples less than 10 000 years old. In the course of measuring the 399 samples, over 1000 targets were analysed. The weight of the machine ready target averaged 1 mg, but targets with as little carbon as 50μg were analysed successfully, although with lower precision.

A programme of measuring the ^{14}C activity of meteorites has been started. In collaboration with the Japanese National Institute of Polar Research, we have extracted carbon from a number of meteorites recovered from the Antarctic Ice (Allan Hills and Yamato regions). The terrestrial ages of these meteorites can be estimated from their ^{14}C activities compared to that of modern falls of similar composition, such as Bruderheim. Ages ranged from 500 to over 30,000 years.

The ^{14}C activity of CO_2 extracted from zeolite minerals saturated in groundwaters is the subject of another research programme. The level of exchange of radionuclides into the lattices of these minerals has implications for groundwater monitoring, particularly in connection with the determination of contamination connected with radioactive waste disposal programmes.

With Professor S.D. Scott ^{14}C measurements are being made on materials recovered from the black smokers on the sea floor. Preliminary data indicating remarkably young ages for petroleum associated with these features have stimulated an intense follow-up study.

Isotopes of heavy elements are the subjects of other research programmes which are just beginning, following the acquisition of a large 90° bending magnet, courtesy of AECL Chalk River Laboratories. With this magnet our already demonstrated capability to measure ^{129}I at natural levels (i.e. $^{129}I/^{127}I < 10^{-12}$) will be greatly enhanced, as well as providing similar sensitivities in the range of actinide elements. Currently we are making determinations of ^{129}I in groundwaters from the Cigar Lake uranium deposit in Saskatchewan in collaboration with workers from AECL Pinawa. ^{129}I studies on other materials of geological importance are also being investigated.

(b) Uranium, thorium and lead isotopic studies (R.M. Farquhar, P.E. Smith, Department of Physics)

A study of the Pb isotope ratios in a suite of metavolcanic rocks from a sequence of intercalated basalts and sediments in eastern Norway, led to the realization that crust-mantle mixing processes had altered the normal MORB Pb isotope signatures of those extrusive rocks. Working in conjunction with J. Fox of the Mineral Exploration Research Institute, we have continued this investigation by examining the Pb isotope systematics in basalts from a tectonic area which is the modern equivalent of the Caledonide Norwegian system. Measurements have been completed on basalts from the Guaymas Basin in the Gulf of California, and the data show that MORB Pb and continentally derived Pb have been incorporated into the volcanics. This finding is consistent with the earlier work of Chen and Wasserburg indicating that hydrothermal fluids emanating from vents on ridges in the Guaymas Basin also carry Pb containing a continental component.

We have been involved in two other studies of ocean floor volcanism. The first is a cooperative investigation with H. Kurasawa and S. Scott of the Pb isotope ratios in metamorphic basalts, minerals, and sulphides from the East Pacific rise and from Cyprus. Sedimentation on the ocean floor is being studied using Pb isotope measurements in a nontronite sequence on the Galapagos Ridge. Preliminary data suggests that at least two source regions have contributed Pb to the sediments, one of which has an isotopic signature which is enigmatic, and quite different from any preserved in eastern Pacific oceanic island basalts.

As part of project LITHOPROBE, we have begun an isotopic study of material from the amphibolite-grade Wawa domal gneiss terrain and from Matachewan dykes, in the Kapuskasing Structural Zone (KSZ). Preliminary results yield Pb-Pb isochron ages which agree well with U-Pb ages on zircon. When U and Pb concentration data are available it will be possible to define initial Pb isotope ratios more accurately, and to make comparisons with results for low-grade rocks from the greenstone belts to the west of the KSZ.

15. University of Western Ontario (F.J. Longstaffe, Department of Geology)

Stable isotope research at the University of Western Ontario has taken a new direction in 1987-88, with a new focus of activity being studies of low temperature water/rock interaction (e.g., diagenesis, environmental geochemistry). Collaborative research activities involving igneous and metamorphic rocks, and metallic minerals deposits will continue. New facilities for the analysis of O, C, H and S in water, silicates, carbonates and sulphides are under construction.

Research projects in progress include: (1) origin and evolution of diagenetic cements in the Clearwater Formation, Alberta, (2) meteoric diagenesis of the Brazeau Formation, Alberta, (3) porewater evolution and mass transport in the western Canada sedimentary basin (with C. Connolly, H. Baadsgaard), (4) porewater evolution in the Alberta Deep Basin (with B. Tilley), (5) diagenesis of the Inmar Formation, southern Israel (with A. Ayalon), (6) the origin of dedolomite and caymanite (with B. Jones), (7) the origin and evolution of pedogenic carbonate (with G. Spiers), (8) isotopic and chemical models for porewater evolution in the Illinois basin (with H.W. Nesbitt), (9) isotopic signature of sedimentary sequence boundaries (with L. Wickert, G. Pemberton, G. Plint, G. Bird), (10) origin of epithermal Au-Ag deposits in the Northern Black Hills (with C. Paterson), (11) origin of the JC tin skarn, Yukon (with G. Layne), (12) origin of Ag-Pb-Zn mineralization in Keno Hill, Yukon (with G. Lynch, B. Nesbitt), (13) origin and evolution of pegmatites and pegmatitic granites in southwestern Manitoba (with P. Cerny, B. Meintzer), (14) origin and evolution of massive sulphides associated with the Karmoy ophiolite, Norway (J. Malpas), (15) metamorphic studies of the Mirage Island area, Yellowknife (with C. Relf, T. Rivers), and (16) the origin and evolution of leucogranites from the South Mountain batholith (with D.B. Clarke).

16. University of Windsor, Department of Geology (A. Turek et al.).

U-Pb zircon geochronology of the Wawa greenstone belt is an ongoing study. The previously reported age of ~2.9 Ga for a granite has now been supported by similar ages obtained for volcanics. Work has also started on the dating of the adjacent greenstone belt at Mishubishu Lake. In addition, age determinations are in progress for several alkalic complexes (syenite-carbonatite) from the Superior province in Ontario.

Geochronology studies for the Island Lake area in Manitoba are essentially completed. Work is still in progress on the Rice Lake area of southeastern Manitoba.

A study of Sr isotopic composition of micro-fossils of post glacial Lake Champlain in Ontario and Quebec has commenced. The purpose of this study is to try to identify marine transgressions.

17. 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)
Royal Ontario Museum (Mineralogy and Geology)
University of Western Ontario (Geophysics)
St. Francis Xavier University (Geology)

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VI METEOROLOGY AND ATMOSPHERIC SCIENCE

Compiled by: E.J. Truhlar

1. University of British Columbia, Department of Geography

(a) T.R. Oke

Observations of atmospheric turbulence and energy fluxes over the suburbs of Vancouver are being analysed to investigate the applicability of Monin-Obukhov similarity, the homogeneity of surface fluxes, evapotranspiration in all seasons and other aspects of the energy balance.

(b) D.G. Steyn

Research continues into mesoscale and boundary-layer meteorology with observational and modelling studies of wind in complex terrains. A major study of sea-breezes during ozone episodes in the Lower Fraser Valley is nearing completion, and one on strong outflow winds in coastal inlets is underway.

(c) G. Thomas

Studies deal with the sensitivity of climate to variations in the character of the land surface; global-scale land-surface data archives for climate modelling and climate monitoring applications; and the impact of climate change on regional-scale water resources.

The Government of British Columbia has now provided UBC with funds to establish an Atmospheric Science Programme, which is cosponsored by the Departments of Geography and Oceanography. Research areas will include climate processes and variability. Four new faculty members (G.A. McBean, W.S. Large, J. Fyfe and P. Austin) joined the Programme during 1988.

2. Simon Fraser University, Department of Geography

Research continues on the following:

- Field studies of the radiation and energy balances of alpine tundra, at a site on Scout Mountain in south-central British Columbia. Models of heat and mass transfer are being developed and refined.
- Climate resources for ginseng production in Asia and North America.

3. University of Alberta, Meteorology Division and Institute of Earth and Planetary Physics

(a) R.B. Charlton

Weather radar studies using Alberta Research Council archives are near completion, and include the detection of hail using recent theories on polarization diversity radars and the spatial variation of echoes during continuous rain compared with in-cloud microphysical measurements.

Eight hundred responses to a public survey on the Edmonton tornado are under analysis. Preliminary findings are published in the "Review of the Weather Warning System Associated With the Edmonton Tornado of July 31, 1987" by K.D. Hage.

(b) E.P. Lozowski

Atmospheric and marine icing are being simulated by experiment and computer modelling. A new, refrigerated marine icing wind tunnel, the only such facility in the world, is now in use. Shipboard measurements of spray and icing have been conducted during two winters. Aspects of ice accretion being investigated include vessel icing, wet snow accretion on transmission lines, and the construction of artificial ice platforms.

A study of local and interannual climate variability is underway, using cumulative temperature and precipitation anomalies. The cumulative temperature anomalies exhibit bounded, non-periodic oscillations with significant geographical phase coherence.

(c) J.D. Wilson

A perturbation analysis of flow through a porous windbreak has been completed, complementing earlier numerical studies. Field measurements of the micrometeorology of small square sheltered plots have been made. Simulations of particle dispersion by Lagrangian stochastic methods continue; a partial reflection rule has been formulated for implementation in simulations of dispersion of a species that reacts with the surface.

4. Western Research, Division of Bow Valley Resource Services Limited

A two-year observational study relating to the behaviour of acid-producing gases was completed. This study, which involved air quality and meteorological measurements at three sites, was part of Alberta's Acid Deposition Research Program (ADRP). Observational and theoretical studies were also undertaken into the behaviour of vertical and horizontal wind fluctuations under stable atmospheric conditions.

5. Saskatchewan Research Council

Continuing research activities included operation of the 25-year old benchmark station, wind erosion studies, long- or short-term monitoring of pesticides, gas and particulates in the atmosphere and testing of agricultural sprayers (see CGB 1985, 1986).

A multidisciplinary project was undertaken to study the impact of a changing climate on the forestry industry.

6. University of Windsor, Department of Physics

Research reported in CGB 1986 continued on the interactions of electrons and photons.

7. McMaster University, Department of Geography

(a) J.A. Davies

Radiation studies continued on Arctic haze, and on surface albedo using Nimbus-7 data (see CGB 1986); on the radiation code and the land surface albedo for the AES GCM, and on the validation of solar radiation models (see GCM 1985).

(b) W.R. Rouse

The energy balance of the coastal environments of James Bay and Hudson Bay is being modelled in terms of the stomatal and surface resistance of wetland plants, the aerodynamic resistance and the climatological resistance to evaporation. Evidence indicates that with a non-limiting water supply, surface and climatological resistances are as important as the radiational energy impact in determining the magnitude of evapotranspiration. Climatic change, which affects air temperature and vapour pressure deficit, will thus exert a powerful influence on the magnitude of the water vapour flux.

The nature and rate of change in the surface energy balance and the boundary-layer energetics is being studied with field experiments that utilize successive inland measurements during onshore airflow from a cold Hudson Bay to a relatively warm land surface.

8. York University - Physics Department

Research activities included

- Atmospheric correction methodology research for satellite (AVHRR and CZCS) and airborne (FLI and MEIS II) imagery
- Water colour interpretation model studies

9. University of Toronto, Department of Physics

(a) Cloud Physics (R. List)

The first complete study on the dependence of the supercooling of water skins on hailstones, growing while gyrating in an atmosphere of variable liquid water content and air pressures at temperatures according to hail-day soundings, allowed a parametrization of collection efficiencies, net collection efficiencies, ice content in the growing spongy deposits, and surface supercooling. At liquid water contents of 3-5 g/m^3 and temperatures between -5° and -15°C typical supercoolings are to -3°C. These studies also showed a great dependency of shape on gyrational velocities.

The project on "Arctic haze" has come to an end with the final publication of the results, which are based on the growth of haze particles of given character in given environments, and the effect such haze has on the radiation budget. The experiences of these studies have been built into GCMs in order to study the large-scale effects of haze.

The data from the "Warm Rain Experiment", carried out jointly with the Malaysian Meteorological Service, produced a wealth of data on warm and warm/cold rain. In steady tropical rain, maxima were detected at the locations of the peaks predicted for the equilibrium peaks in numerical models, which were based on 17 years of laboratory experiments. Streaky rain, arriving in packages with the large drops arriving first, also has larger drop concentrations at the diameters predicted by the equilibrium spectra results.

(b) Mesoscale Atmospheric Dynamics (H.-R. Cho)

Research progressed in a number of areas, including dynamics of mature fronts, formation of rainbands in extratropical cyclones, the problem of cyclogenesis in the polar air stream, and dynamics of cloud-mean flow interactions.

(c) Synoptic-Scale Frontal Zones (G.W.K. Moore)

Synoptic-scale frontal zones and the coherent structures embedded within them are being studied to understand the dynamics responsible for these coherent systems, in particular: the dynamics responsible for the generation of secondary instabilities along frontal zones; the interaction of frontal zones and topography; the effect of air-sea interactions on frontal zones and the dynamics responsible for tropopause folds.

(d) Radiative Transfer and Composition Measurements (J.R. Drummond)

A satellite instrument to measure carbon monoxide in the troposphere (MOPITT) has been proposed to NASA (and accepted for the definition phase) for inclusion on the Earth Observing System Polar Orbiting Platform. Using correlation spectroscopy it can produce global profiles of CO in the atmosphere. A new technique for correlation spectroscopy called a Length Modulated Radiometer, has been developed for this instrument and is used in conjunction with pressure modulation to enhance instrument performance and provide height selectivity for the various channels.

A joint project with the Ontario Laser and Lightwave Research Centre (OLLRC) deals with the spectroscopy of atmospheric constituents. A very high resolution spectroscopic facility is being assembled for measurements of absorption profiles in the infrared, to improve our knowledge of the spectra of atmospheric constituents, leading to more accurate measurements by remote sensing instruments.

(e) Theoretical Studies of Large-Scale Atmospheric Dynamics (T.G. Shepherd)

Activities concentrated on understanding the ways in which Liapunov (normed) non-linear stability theorems can be used to constrain the statistical dynamics of turbulence in inhomogeneous environments. Applications involve the development of diagnostic tools (e.g. wave-activity conservation laws) for analysing the atmospheric general circulation, and obtaining a better understanding of the non-linear dynamics of synoptic-scale baroclinic eddies, including their interaction with the planetary-scale flow.

(f) The Fluid Mechanics of Synoptic-Scale Systems (W.R. Peltier)

The non-linear life cycles of frontal baroclinic waves is being studied, including both the long wavelength Charney-Eady modes of classical theory and the new "cyclone" mode discovered in the frontal stability analyses of Moore and Peltier (1987). The horizontal wavelength of the latter is near 1000 km and apparently is responsible for much of the mid-latitude synoptic activity on this scale. The life-cycle analyses are being performed with the same non-hydrostatic anelastic Navier-Stokes solver that has been employed in previous and ongoing work on the problem of severe downslope windstorms. The intention is to extend these simulations to incorporate the full influence of moist physics on the cyclone-scale motions.

(g) Non-Linear Internal Waves and Internal Wave Breaking (W.R. Peltier)

Work continued on refining the previously developed "breaking-wave" theory for the development of chinook windstorms and on analyses of the dynamics of the turbulence transition in stably stratified parallel flows. In the former area we have detailed an explanation of the transient pulsations having a characteristic period near 10 min that have been observed to accompany the development of the lee windstorm. This appears to involve a spatial instability of the Kelvin-Helmholtz type. Studies also continued on understanding the sequence of transitions through which a stably stratified parallel flow may eventually become turbulent, and currently deal with the Holmboe mode that is fastest growing when the density inversion coincident with the shear layer is sufficiently thin. Supercomputer simulations of these processes are being recorded on video cassette film both as aids to physical understanding and to instruction.

(h) Geophysical Fluid Dynamics and Paleoclimatology (W.R. Peltier)

Ongoing analytical and modelling studies of glacial isostatic adjustment include very high resolution simulations of this process developed to fit ^{14}C data on relative sea-level change since the last glacial maximum at 18 ka BP. Using this model modern tide-gauge measurements of secular sea-level change have been decontaminated to reveal more clearly the signal that might be related to anthropogenically induced climate change. The filtered signal is found to be one of rather high spatial coherence and therefore plausibly due to such a cause. The basic viscoelastic field theory that forms the core of this model is also being employed as the basis for a rigorous inverse theory for inferring the depth dependence of mantle viscosity, and for a new climate model of the glaciation-deglaciation process itself. The latter model appears capable of explaining the manner in which small variations of effective solar insulation are capable of inducing large amplitude fluctuations in continental ice volume. Other work continued on constructing detailed models of the mantle convection process responsible for continental drift - these models depend upon the mantle viscosity structures inferred from postglacial rebound analyses.

10. McGill University

(a) Department of Meteorology

The characteristics of persistent circulation anomalies have been studied both in atmospheric data and in a 20-year integration of the Canadian atmospheric general circulation model. These anomalies include, but are not restricted to, blocking highs. Other research included studies on the dynamics of the stationary stratospheric waves using a hemispheric numerical model; and on multiple equilibria in a beta-plane model and in a hemispheric model.

A high vertical resolution model of the instability of topographic planetary waves was used to examine modes corresponding to low-frequency variability and localized cyclogenesis. Low-order models of baroclinic adjustment and heat flux by synoptic-scale waves were examined, and the potential vorticity distribution in data from the Canadian Climate Centre general circulation model was analysed diagnostically.

A non-linear 2-dimensional model of mesoscale circulations forced by the melting of snow was formulated. Melting effects were shown to be potentially significant in various organized mesoscale systems, such as rain/snow boundaries, and deep 0°C isothermal layers.

Detailed observations of a rare case of explosive land cyclogenesis have been related to plausible physical mechanisms for the more common explosive oceanic cyclone. The physical processes required to forecast weak and heavy precipitation events are being explored.

The role of clouds in the transport and deposition of pollutants is being studied by means of a 3-dimensional dynamic cloud chemistry model.

As part of the polar cloud project of the International Satellite Cloud Climatology Project, algorithms have been developed that employ multi-channel AVHRR data to identify clouds at high latitudes. The cloud analysis resulting from the application of these algorithms to a pilot data set will be compared with analyses of the same data set performed by others working on the same problem.

The performance of a 6-channel passive microwave radiometer that operated in Halifax during the Canadian Atlantic Storms Program (CASP) was assessed by comparing radiometer-determined temperature profiles and integrated liquid water and water vapour with data from more than 100 radiosonde ascents. New methods are being developed to measure the complete horizontal wind field with a single Doppler radar.

A study on the effects of radiation boundary conditions in numerical convection modelling was completed. A new technique was devised that yielded superior results compared with existing methods.

The outbreak of severe convection in Alberta is being studied using data from the LIMAX experiment and mesoscale models. An explosive cyclone event observed duing CASP was analysed. Numerical modelling of rapidly intensifying cyclones is underway.

(b) Macdonald College, Department of Renewable Resources

Research activities continued on

- Laboratory simulations of in-canopy turbulent transfer processes of heat and mass, with applications to pesticide revolatilization and pollutant transfer. Radioisotope labelling is used for studies on dry deposition of pollutants and to assess water status in foliage.
- Field studies on acid deposition, and ammonia volatilization from manure.
- Collaborative flux measurements of sensible heat, latent heat and CO_2 from aircraft (with Agriculture Canada and the NRC National Aeronautical Establishment).
- Crop yield modelling studies carried out in conjunction with the Land Resources Research Centre of Agriculture Canada.

11. Atmospheric Environment Service

(a) Meteorological Services Research Branch (MSRB)

(i) Forest Research. Marine: Several models were being developed: a state-of-the-art spectral wave model for the North Atlantic, incorporating a coarse grid with third-generation terms for the North Atlantic, and a fine-mesh grid with up-to-date shallow water physics for the Scotian shelf and Labrador coast; lake wave models emphasizing the growth and dissipation of waves in shallow waters; and an oil spill motion model for ice-infested waters. Two models have been completed: a personal computer version of the real-time oil spill trajectory forecast model; and an empirical model for estimating the life expectancies of icebergs in the Grand Banks and Labrador Sea areas. Other studies included the influence of melting on the short-term drift of icebergs and verification of the Nova Scotian storm surge model.

Statistical: A graphics display station was developed for the 1988 Calgary Olympics to display mesoscale and synoptic-scale statistically generated weather forecasts, and weather prediction fields. Other work involved the development and testing of Classical REEP (Regression Estimation of Event Probability), and perfect mesoscale snowfall prediction using climatological station data. The statistical procedures now in use have proved inaccurate and unreliable for handling rare events, and some modifications have been made. A classification and regression tree procedure was selected as an alternative and is being tested.

Computer Assistance: Work using Artificial Intelligence continued (see CGB 1986) on a procedure to forecast severe thunderstorms for the Canadian Prairies and a Forecast Production Assistant for entering weather depiction charts in graphical format and for producing worded (bilingual) text.

(ii) Numerical Weather Prediction (NWP) Research. Data Assimilation: Data selection inside the analysis program has been improved by an algorithm to form "superobservations" for aircraft and surface reports and by a better data search procedure, and has produced better analyses, especially above 100 mb.

Tests are underway to evaluate the impact on the analyses of a new algorithm for calculating and periodically updating the correlation function parameters and other statistics required by the objective analysis.

The analysis program has been modified to run from a more complete observational data base, using data from the Southern Hemisphere and significant-level data from outside of North America. These additional data will permit a global, higher vertical resolution data assimilation scheme to be implemented.

Work is being carried out to retrieve satellite-derived surface air temperatures and humidities via a scheme based on pattern recognition of cloud classes that are associated with significant temperature or humidity anomalies.

The Integrated Environmental Simulation System (IESS). A new 3-D version of IESS was used to simulate the dispersion of radionuclides from Chernobyl over a period of one month. The model results were verified against measurements from a network covering the Northern Hemisphere and indicate substantial improvement when compared with the results from simple models used immediately after the Chernobyl accident.

The test against "Chernobyl data" should be very useful for intercomparing the different models used in atmospheric tracer studies. Current IESS work deals with incorporating complex chemistry into the hemispheric version and testing the global version.

The original 3-D version of IESS is used as an operational Emergency Response System to deal with a wide variety of Nuclear Accidents. This operational version is very flexible and can be executed either in the diagnostic mode using objectively analysed meteorological fields or in a predictive mode. The predictive version will use the output from the fine-resolution Finite Element Regional Model for the runs on the mesoscale grid or the hemispheric spectral model for the simulation of the very long-range dispersion (similar to Chernobyl).

Experience with the research and operational versions of IESS shows a beneficial link between NWP and environmental models. Physical parametrizations developed for the NWP models could be used directly in the environmental models assuring that all the components of the atmospheric environment are simulated using a consistent approach. Similarly, the state-of-the-art numerical algorithms developed for NWP could be used with very minor modifications for assimilating tropospheric and stratospheric tracers.

Sub-grid scale parametrizations: Studies to improve the physical processes in the operational regional finite-element model have indicated a sensitivity of the forecasts to the specification of soil parameters and to the presence of a snow cover. The use of more realistic soil parameters helped to reduce a problem of temperatures occasionally too warm in the boundary layer, and produced better locations for the warm sectors of depressions and for freezing rain events. Examination of the schemes for surface processes and vertical diffusion showed numerical stability problems occurred in particular situations; more stable schemes (à la Kalnay-Kanamitsu) were found to be beneficial.

Vertical-resolution experiments in the operational spectral model revealed a noise problem in the vertical diffusion. A revised scheme was developed in which stability is guaranteed at the expense of accuracy when t/z^2 exceeds a locally calculated limit.

Development of Numerical Methods: Further steps have been taken to use three-time-level semi-Lagrangian time discretizations in combination with a variety of spatial discretizations. Medium-range integrations in a spectral model of the shallow water equations reveal the presence of an unconditional instability related to the semi-Lagrangian treatment of the metric term near the poles of a spherical coordinate system. In order to avoid an explicit treatment of the metric term, the vector form of the horizontal momentum equation has been integrated in tangential Cartesian coordinates. Medium-range tests have shown that both interpolating and non-interpolating semi-Lagrangian treatments are accurate and stable using time steps that far exceed the CFL limit for the corresponding Eulerian model. Work has started to extend these schemes to a multilevel spectral primitive equations model. The three-time-level interpolating semi-Lagrangian scheme used in the barotropic finite-element regional model has been extended to the baroclinic finite-element regional model.

Work has also continued on the two-time-level version of the semi-Lagrangian scheme. In its application to the shallow water equations (both in the spectral model and the finite-element regional model), a Lagrange multiplier approach has been used to avoid an explicit treatment of the metric terms. Tests with the spectral model have shown that the two-time-level approach introduces an additional factor of two in efficiency compared with the three-time-level semi-Lagrangian approach, without decreasing the accuracy of the forecasts. A formulation has been proposed to test the extension of this approach to the baroclinic finite-element regional model.

A new two-dimensional nesting strategy, that was previously applied in one-dimensional models, was tested. Integrations were performed using a global spectral model of the shallow water equations with high- and low-resolution data in the Northern and Southern hemispheres, respectively. The strategy was used to blend the data in the equatorial region. Comparisons made using a high-resolution integration in both hemispheres showed that accurate medium-range forecasts for Canada can be produced using the low-resolution data in the Southern Hemisphere. Experiments using a high-resolution grid-point shallow water equations model, driven by a low-resolution global spectral model, have produced very accurate 24-hour forecasts in the area of interest.

A barotropic spectral model was run to compare the implicit normal mode initialization with conventional normal mode initialization. Since the implicit scheme is equivalent to the conventional one based on a perturbed set of normal modes, the "implicit" and the "true" normal modes were also compared. Implicit and conventional schemes on the sphere give essentially the same results except at the very longest scales.

(iii) Aerospace Meteorology. Continuing activities include operations in the Satellite Data Laboratory, research on microwave scatterometer data, and studies connected with the Askervein Hill Project (see CGB 1986).

Research was completed on using weather radar data to ground truth satellite data from geostationary satellites (RADARSAT) for the production of rain analysis and forecasts. Favourable evaluations of the real-time RAINSAT products have come from assessment of the system for forecast operations at the Quebec Weather Centre. A feasibility study is underway to determine the best approach to incorporate the system in other regional offices.

(b) Atmospheric Processes Research Branch (APRB)

(i) Cloud Physics Research Division. The Chemistry of High Elevation Fog (CHEF) program operated two sites in the province of Quebec in 1987: Mont Tremblant (45°12'50"N; 74°33'20"W); and Roundtop Mountain (45°04'51"N; 72°32'46"W). Measurements were made throughout the year at several altitudes (up to 970 m) of fog water and precipitation chemistry, ozone concentrations, wind speed, wind direction, temperature, relative humidity, pressure, solar radiation and precipitation amount. Several universities and the Canadian Forestry Service are also studying terrestrial effects at the sites.

A conceptual model of East Coast storms was developed as part of CASP. The physical processes incorporated into the model were shown to control the onset and ending of explosive storm deepening. The associated studies of precipitation-type formation have verified earlier hypotheses of the evolution within storms. Heavy snow and rain studies in the Toronto area, and cloud model development, have also progessed well.

Real-time automatic detection and reporting techniques for severe weather (mesocyclones, gust fronts, microbursts, hail, wind and heavy rain) are under development using an operational Doppler/conventional weather radar at King City. Recent studies at the radar station have shown that reflectivity structures of severe storms are similar to those elsewhere, whereas the wind fields of severe storms that produce tornadoes appear to be much weaker than those in the Midwest United States. Also, the Doppler radar has allowed the kinematics of mesoscale convective complexes to be examined; this has revealed three-dimensional wind fields not reported before. Development of radar interface hardware and the installation of two new computers are underway, which will permit the real-time processing of the complete Doppler data set and the generation and transmission of more sophisticated radar products to the forecast office.

The cloud chemistry group conducted a field study at St-Hubert, Quebec, during February, 1987 to continue development of new instrumentation for airborne measurements, and to collect airborne data for comparison with the data from the CHEF monitoring sites. Analysis of data from previous studies continued. One outcome of this analysis is the realization that scavenging during wintertime may account for a large fraction of the wet deposition of HNO_3. A model was developed detailing the interaction between trace gases, aerosols and cloud droplets during the condensational growth of cloud droplets.

(ii) Experimental Studies Division. The second phase of the Canadian ozone experiment (CANOZE 2), designed to study the effect of the Arctic polar vortex on the ozone layer, took place in February and March, 1987 at Saskatoon. Two STRATOPROBE balloon flights, February 27 and March 19, were coordinated to determine the distribution of nitric acid, dinitrogen pentoxide, nitrogen dioxide, water vapour, methane, chlorine nitrate, as well as ozone. Brewer spectrophotometers were used to measure the altitude profiles of ozone and nitrogen dioxide from the ground. An interferometer was set up at the RAGS site near Saskatoon to obtain the overburden of hydrochloric acid, methane, water vapour and nitric oxide.

Preparations for CANOZE 3 are underway to extend the observations made by CANOZE 2, but also include measurements at Alert. During the balloon flights a new light-weight mini-radiometer and infrared spectrometer will be tested.

To study long-period trends in chlorofluorocarbons, nitric acid, nitrogen dioxide, dinitrogen pentoxide and chlorine nitrate, and to develop new instruments for monitoring these gases, two STRATOPROBE balloon payloads were launched from the new site at Vanscoy near Saskatoon on August 15 and 22, 1987. Ground-based Brewer measurements of ozone and nitrogen dioxide were also made.

As part of the balloon campaigns, ozonesondes have provided ozone, temperature and pressure profiles. Ozone data obtained by processing TOMS imagery have been used to supplement ground-based measurements.

To improve spatial coverage in the Canadian ozone network, a Brewer instrument was installed at Alert (82.5°N). By observing the moon during the polar night and the sun in the spring, total ozone measurements are being obtained near the polar vortex.

(c) Air Quality and Inter-Environmental Research Branch (AQRB)

(i) LRTAP. The Acidified Deposition and Oxidants Model (ADOM) has been preliminarily evaluated using limited air quality observations from the OSCAR period of April 10-29, 1981 and the PEPE/NEROS period of August 7-12, 1980. In the evaluation, ADOM has been integrated for seven specially selected PERD episodes of high acidic deposition, which range in length from 4 to 11 days, and also for the first 47 days of the ANATEX experiment of 1987.

Data continued to be collected for the second full year at Camp Borden in the Dry Deposition Project so that the turbulent transfer processes associated with forest atmosphere exchanges may be parametrized.

Another major project is the Western Atlantic Ocean Experiment (WATOX), a collaborative undertaking with other countries, which has the objective of investigating the atmospheric chemical cycles of sulphur and nitrogen species over the North American continent and the North Atlantic Ocean. The scavenging of the primary pollutants, SO_2 and NO_x, appears to be much more efficient within the first few hundred kilometres off the coast than previously thought. Atmospheric budget calculations over the western North Atlantic show that less than 20% of North American sulphur and nitrogen, respectively, are transported beyond 66°W longitude.

(ii) Toxic Chemicals. The spatial and temporal resolutions of the LRTOX (Long Range Transport of Toxics) model were increased, and their effects on the modelling of the deposition of nutrients and toxic chemicals to the Great Lakes are being evaluated.

The Spray Mapping Project, using the rapid acquisition lidar system (ARAL) continued in order to provide regulators with better information on the atmospheric regimes that minimize off-target drift (see CGB 1986).

In the Regional Aerosol Composition Studies program, two studies were completed: the Canadian and American automobile lead emissions on the basis of their 206/207 isotopic ratios; and the detailed aerosol and precipitation chemistry at Dorset, Ontario.

(iii) Climate Change. The monitoring at Alert (see CGB 1986) of background air pollution includes sampling of CO_2, CH_4, O_3, and PAN, and weekly flask sampling. The occurrence of high levels of PAN during the Arctic haze season has been confirmed and PAN has been shown to be a major oxide of nitrogen at this remote site.

Aerosol black carbon (BC), which normally results from incomplete combustion of carbonaceous fuels, has been associated with the phenomenon of Arctic haze. Measurements of BC are useful in evaluating whether or not an air mass has anthropogenic input from high-temperature combustion sources, e.g. high CO_2/CH_4.

Aerosol samples collected at Alert were analysed for their isotopic composition of lead to determine the origin of this constituent. Arctic aerosol lead was shown not to come from the eastern United States.

Time series analysis was conducted of CO_2 flask data from Alert, Sable Island and Cape St. James. The data values obtained during the AGASP II experiment showed that the CH_4 values tended to track the high-frequency pattern of the CO_2 values. The time series of CO_2 and CH_4 values correlated very well with those of other anthropogenic species.

(iv) Core Research. A method for calculating surface fluxes and wind speed profiles over the sea was developed for flow over complex terrain.

The Pickering Nuclear Project has been undertaken in collaboration with the Atomic Energy Control Board to collect 12 months of data for safety analysis purposes.

An analytical model was developed to calculate the maximum concentration of a denser-than-air gas cloud released instantaneously.

(v) Air Quality Services. In support of the Air Quality Strategic Plan initiative to increase regional integrated research monitoring facilities, CARE was established at Egbert, Ontario as a multi-disciplinary centre for AES atmospheric research programs, including those in cooperation with the province, universities and industry.

(d) Canadian Climate Centre

(i) Hydrometeorology and Marine. A major ongoing activity was the development and validation of algorithms and techniques for the application of remotely sensed data to hydrometeorological problems. Algorithms for determining snow cover properties (extent, water equivalent, depth, wetness) were tested using NIMBUS-7 SMMR and DMSP SSM/I data. Coincident field and airborne surveys during 1986-87 and 1987-88 were used for validation over the Canadian Prairie target areas. Results confirm the feasibility of measuring snow cover properties by means of satellite passive microwave data.

Objective analysis schemes were evaluated using grids of data created from radar estimates of daily rainfall accumulations. The statistical optimal interpolation procedure had generally lower RMS errors than other techniques tested and, after optimization, required no more computer time. The same data sets were used to assess climate station network errors. Relationships between interpolation error for daily rain and network density were developed.

The ongoing application of micro-electronics to improve hydrometeorological data collection methods included evaluation of a particular potentiometer/data logger retrofit for the long-duration recording precipitation gauge design. The measurement of rainfall, using an electronic sensor interfaced with a commercial calculator and installed in the AES type B rain gauge, has proven feasible. However, changes in conductivity of the rain causes some erratic operation, but ways to prevent this are being considered.

Other continuing projects include developing techniques to estimate evapotranspiration from satellite remotely sensed data; operational mapping of surface water temperatures for the Great Lakes and East Coast regions; producing national maps and tabulations of water budget parameters and drought indices (see CGB 1986).

Development of the ultrasonic snow depth sensor was completed; field tests confirmed measurements within ± 2.5 cm compared with independent standard ruler measurements. The sensor was licensed for commercial manufacture by Campbell Scientific Canada.

Five test sites were operated as part of the WMO Solid Precipitation Measurement Intercomparison (see CGB 1986).

Work in marine icing and winds continued (see CGB 1986). A joint icing rig modelling program was initiated with Norway. A comprehensive study of wind gusts over ocean areas was completed.

A major hindcast of wind and wave extremes off the East Coast of Canada was initiated to produce wind and wave information for the 30 most severe wave-producing storms in each of the Grand Banks, Scotian Shelf and Georges Bank. Wind and wave hindcast and forecast models were implemented on a micro-computer in the Canadian Climate Centre.

Several other studies were completed on a revised statistical package to analyse extreme snowmelt events; assessment was made of the applicability of existing meteorological and oceanographic data bases and analysis techniques to methods for combined loads on structures from winds, waves, currents, sea ice and icebergs. This latter work is a first step in a process to incorporate the effects of combinations of environmental loads into the new offshore design code being developed by the Canadian Standards Association.

(ii) Hydrometeorological Research. Main research thrusts include hydroclimatology, remote sensing and hydrometeorological processes.

Hydroclimatology has been directed at documenting and understanding drought on the Canadian Prairies. One study has been undertaken to evaluate the frequency of occurrence of meteorological drought events in the Saskatchewan portion of the South Saskatchewan River Basin.

Other activities were started to identify and assess various methods used in drought forecasting; to analyse the mid-tropospheric flow patterns associated with very dry and very wet months on the Prairies and in British Columbia; to apply climatic impacts methodology to climatic change scenarios in the Saskatchewan River Basin; and to overview any research initiatives involving the impacts of climate variability and change on water resources on the Canadian Prairies.

The uses of satellite and conventional ground-based meteorological and hydrological data in hydrometeorology are being explored with a distributed hydrological model, developed by INRS-Eau at the University of Quebec. It is being applied to the Souris and Kootenay River basins to investigate the utility of using satellite data in a hydrological model in different physiographic and climatic areas and to use the model as a test-bed for different physically based components.

New work in hydrometeorological processes initially dealt with evaporation models and measurements. One study reviewed the potential climatic impacts of major water transfers.

Ongoing activities include the implementation of a radar upgrade at Elbow, Saskatchewan, and the use of outputs from this radar in the development of an irrigation scheduling information system for the Saskatchewan Water Corporation.

(iii) Climate Applications and Impacts. Several publications were issued including: a comprehensive climatology of the Yukon; a climatological atlas of the Beaufort Sea; climate handbooks for Montreal and Calgary; and an analysis of the homogeneity of long-term temperature records from selected Canadian climatological stations.

Two projects completed were revision of ground snow-load values required for building design, and analysis of summer weather along the east coast of Hudson Bay during the last century.

Two new systems were implemented: CRISP, for sea-ice information, and SPASM for analysis of surface high and low pressure systems.

(iv) Monitoring and Prediction. Monthly experimental forecasts of temperature have been carried out using an objective method of interpolating points on a hemispheric 50-kPa monthly height anomaly field (see CGB, 1986). Two-class temperature forecasts will be distributed to the public beginning May 15, 1988. Development of monthly precipitation forecasts is continuing, using linear regressions to relate precipitation anomalies to 50-kPa height anomalies.

(v) Numerical Modelling. The new version of the General Circulation Modelling (GCM) for studying doubled CO_2 (see CGB 1986) has been completed. Major changes to the vertical discretization were begun in order to implement a hybrid coordinate version (sigma in the low levels and pressure at the high levels), which will be used to test a new cumulus parametrization scheme.

Studies of the regional forcing due to anthropogenic aerosols at high latitudes has been started.

A Dynamical Extended Range Forecasting (DERF) experiment has begun with sets of six 30-day forecasts produced with the GCM for each of the three winter months, December, January and February for the eight years 1979 to 1986, and for the corresponding Julys. The results from these forecasts are being analysed, and the model "systematic error" or "climate drift" is being investigated.

Participation in the Radiative-Photochemical Climate Modelling study (ICRCCM) continued (see CGB 1985). Revised long- and short-wave calculations under clear and cloudy sky conditions have been submitted for discussion at the 1988 ICRCCM Workshop in Paris.

Experiments with a 1-D radiative-convective-photochemical model continued (see CGB 1986).

Experiments with a 2-D radiative-photochemical-dynamical model to simulate the anomalous spring variations of ozone, temperature and other minor constituents in the southern polar regions showed that transports and heterogeneous chemical mechanisms are both necessary to explain the observed rapid ozone decline in these regions during spring.

A study of the effects of gravity-wave drag and horizontal resolution on simulated climate has been carried out in preparation for the increased resolution of the new version of the GCM. Statistically significant differences in simulated climate were found to occur when the resolution is varied and when the gravity-wave drag parametrization is removed. Nevertheless, with this parametrization, the differences in simulated climate are rather less than those seen previously in tests of increased resolution and, in particular, the "zonalization" of the simulated flow is not a problem.

The angular momentum budget simulated by the GCM has many features that agree with those seen for the real atmosphere, for which the variation of the angular momentum is very well related to variations in the rate of rotation of the earth (i.e., to the length of day). However, it is difficult to deduce the dominant coupling mechanism between atmosphere and earth from the data. This is possible in a GCM, however, and it is found that both the mountain and stress torques contribute equally to short-period changes in (simulated) atmospheric angular momentum, although they themselves are uncorrelated.

A 40-year monthly climatology has been computed for the climate simulated by the CCC Atmospheric GCM using two extended simulations that were run back-to-back on the Cray XMP 2/4 located at the University of Toronto and the Cray XMP 2/8 located at the Canadian Meteorological Centre in Dorval.

Statistical techniques for analysing variability simulated by coupled oceanic and atmospheric GCMs were developed in collaboration with the Max Planck Institute for Meteorology (MPI). The techniques were applied to a 10-year coupled Tropical Ocean Global Atmosphere simulation conducted at MPI with ECMWF T21 climate model and a tropical Ocean General Circulation Model developed at MPI. The simulated tropical ocean cooled quickly during the first year of the simulation and continued to cool slowly during the remainder of the 10-year run. The response of the simulated atmosphere to the gradually changing boundary conditions was revealed by trends that were clearly apparent in variables such as the 300-mb streamfunction and the velocity potential.

A study of the growth and decay of atmospheric energy showed the importance of non-linear terms in explaining changes in APE and KE.

(e) Central Services Directorate

Ice Branch. Ice reconnaissance, data handling and ice forecasting continued as reported in the CGB 1982; iceberg surveillance and the system for producing an iceberg information service were developed, but only functioned at a low level. The HF radio-facsimile continued to improve the acquisition and dissemination of information. The Dash-7 was integrated into ice reconnaissance operations, and the new Side Looking Airborne Radar (SLAR) has been brought up to operational standards.

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VII OCEANOGRAPHY

Compiled by F.M. Boyce

1. Memorial University, Newfoundland Institute for Cold Ocean Science (NICOS)

Together with other University and Provincial groups, NICOS participated in the development of a proposal to build a Northern Oceans Research Ship (NORS Project) for the support of cold ocean research programs here and throughout the country. NICOS and the Department of Physics at Memorial University hosted the 21st Annual Congress of the Canadian Meteorological and Oceanographic Society. The Congress' theme was "Predictability in the Atmosphere and the Ocean". Members of the Institute specializing in earth sciences are developing a program in paleo-oceanography and paleo-climate. A new progam in acoustical oceanography is under development. The Cold Ocean Productivity Experiment (COPE) is being carried out by a team of biological and physical oceanogrphers (D. Deibel). The longterm integrated studies (physics, biology, chemistry) of large coastal embayments have been continued. Numerical models of circulations on the Labrador shelf and in the Labrador Sea have been developed for the VAX cluster. In support of the Seabird Program, D. Schneider is undertaking a study to examine the scale dependence of biological and physical processes in the ocean, focussing on both seabirds and capelin.

2. Dalhousie University Department of Oceanography

In May and June, 1987, the Department (A.J. Bowen) participated in a joint experiment at Bluewater Beach on Georgian Bay with the Department of Geography and Geology of the University of Toronto (B. Greenwood) to study sediment resuspension and movement in response to severe wave conditions, bottom roughness, and sedimentary structure. Other participants were the University of Southern California, the Atmospheric Environment Service, and the Marine Environmental Data Service. In the autumn of 1987, Queensland Beach on St. Margarets Bay, Nova Scotia, provided an approximately two-dimensional environment to study wave dynamics and wave-sediment interaction. Among the techniques employed to measure sediment concentration were acoustic backscattering, optical backscattering, and direct video observations. It was apparent that sediment movement depended strongly on the group structure of the incident waves. Collaborators in this experiment were the University of Toronto (B. Greenwood), Memorial University (A. Hay), Oregon State University (R. Holman), University of East Anglia (C. Vincent), and the Univeristy of Miami (D. Hanes). The two data sets, together with the previous observations will indicate the range of behaviour of the nearshore zone as a function of wave and geographical conditions.

Work has continued on the flow through the Strait of Gibraltar. M. Bormans has modelled the effects of rotation, friction, non-rectangular cross-section and barotropic fluctuations; we persist in our view that the exchange is not always, and maybe not often, maximal, a view that has important implications for long-term monitoring. C. Garrett, K, Thompson and J. Akerly have examined MEDAPLEX sea level data for the Strait, finding significant low-frequency variability that can be related to the models. Bormans has also conducted laboratory studies (rotating table) of the nature of the gyre in the Alboran Sea in relation to the Gibraltar inflow.

D. Gilbert and C. Garrett are calculating the rate of vertical mixing in the deep ocean due to internal wave-breaking at a sloping bottom.

Y. Andrade, B. Topliss (BIO), B. Petrie (BIO), and C. Garrett are analysing infrared stellite imagery, in the hopes that the spatial variability in several IR channels will help to discriminate between the sea surface and fog banks at night.

P. Galbraith and D. LeFaivre (DFO, Mont Joli) are conducting a field study on the relation of the internal tide to vertical mixing in the St. Lawrence estuary.

In October, 1984, a lens of Mediterranean water (Meddy) drifting in the Atlantic was tagged with neutrally buoyant droques and its size and

In October, 1984, a lens of Mediterranean water (Meddy) drifting in the Atlantic was tagged with neutrally buoyant droques and its size and structure were monitored over the next two years, during which time it lost most of its salt, heat, and energy through a variety of mixing processes. These processes have been studied by D. Hebert (B. Ruddick) using the data from four hydrographic surveys of the Meddy. A more detailed study of the most important mixing mechanism, that of lateral intrusion, is underway, both in the data and through the elaboration of the theory of such intrusions. The possibility that Meddies may be pulled apart by the background shear or strain of the ocean eddy field, in addtion to the slow decay through mixing has been studied theoretically (Ruddick) and experimentally (Brickman).

J. Hamilton suggests that small scale mixing rates in the presence of salt fingers may be several times greater than those inferred from microstructure observations using the usual parameterizations. The flux of nutrients into the ologotrophic surface layers of the oceans, the sinking of carbon, and the uptake of carbon dioxide from the atmoshpere may be several times larger than previously thought. The driving force for the efficient salt finger mixing is evaporation at the sea surface. In considering the unsteady esponse of an ocean forced by surface evaporation and heating, Zhang Ling-Qi finds that a non linear limit cycle may result, and it further appears that salt finger mixing may prevent such oscillations.

Satellite images of the Grand Banks are bein employed to study meanders of the Labrador Current and to quantify the mixing of water onto the Banks (A. Isenor).

In Victoria, B.C., B. Ruddick is working on an experiment in which internal waves are driven to the breaking point and cause turbulent mixing of salt and heat. The purpose of the experiment is to determine whether the mixing rates of salt and heat are equal as is usually, but possibly incorrectly, assumed.

In July, 1987, a line of pressure gauges was laid across the Labrador Current in a joint BIO/Dalhousie program to monitor transport variablliy in this western boundary current (Lazier, Wright, and Thompson). The moorings will be recovered in July, 1988. A numerical model of the North Atlantic circulation is under development at Memorial University (Greatbatch) and will be used to integrate sea level observations (from tide gauges and satellite altimetry) and to interpret the bottom pressure fluctuations in terms of the changes in ocean circulation. Models have been developed to study the approach of time-dependent, wind-driven shelf circulation to the "arrested topographic wave" solution of Csanady. F. Schwing is studying subtidal circulation on the Scotian shelf and has interpreted current and bottom pressure observation (made during the Canadian Atlantic Storms Program) in terms of a local wind-forced response and "free" shelf waves that propagate through the study region. J. Haines and K. Thompson have developed a method for fitting dynamical modes to observations and have applied it to data from the Australian Coastal Experiment.

J. Umoh is constructing a model that comprises a mixed layer overlying a diffusive interior in order to explain the extended persistence of sea surface temperature anomalies in the northwest Atlantic. Seasonal variations in water temperature on the Scotian Shelf have been used to estimate diffusivities as a function of depth and time of year; they will be parameterized in terms of U^3 and N.

S. Ranasinghe and K. Thompson are extending the method of Middleton and Thompson (1986) to predict the return period of extreme currents using short data records.

Page and Thompson have examined the spatial scale of fish recruitment variability in the northwest Atlantic. They have shown that synchrony occurs over distances of the order of 1000 km for stocks of the same species (cod and haddock), but the interspecies correlations are weak. This work is being extended to include data from the eastern North Atlantic.

3. Fisheries and Oceans, Scotia-Fundy Region.

(a) Ocean Circulation Division

Physical oceanographic field programs were carried out in the Newfoundland Basin, South East Shoal, Hamilton Bank and the Labrador Sea, Baffin Bay, and Davis Strait. These field programs both on the shelf and in the deep sea make use of the Region's abilities to set and recover current meter moorings having endurances of up to 18 months, to carry out high-quality CTD surveys with concurrent tracer measurements in cooperation with the Chemical Oceanography Division, and to map frontal structures quickly with a profiling CTD (BATFISH) combined with a ship-mounted acoustic Doppler current profiler (J.R.N. Loder). These field studies were carried out to investigate specific aspects of the circulation of water in the Northwest Atlantic within the climate research, energy research and development, and the living resources programs of the Branch.

The third year of a program to study the dynamics and thermodynamics of the Labrador Ice Pack used ice drifters and satellite imagery to trace the drift of ice along the Labrador Shelf (S. Prinsenberg). Additional work features iceberg drift models (S. Smith), generation of internal wave solitons at the edge of the shelf (H. Sandstrom), humidity fluxes as functions of the atmospheric boundary layer (S. Smith), and sea surface parameters and air-sea fluxs from climatological data (F. Dobson).

Scientists within the Circulation Division also carried out analytical and numerical modelling studies concerning the generation of shelf circulations, the improvement of techniques for numerical modelling of tidal circulations (D. Greenberg), models of the Labrador Ice Pack (M. Ikeda), and of various processes determining the ice edge, and other dynamical problems (D. Wright). Studies were also carried out using a regional general circulation model on a Gulf Stream data set collected by the Division over past years (R. Hendry).

Instrument testing and development included improvements in microstructrure profilers designed to measure temperature and velocity microstructure both in the oceanic surface layer and at greater depths (N. Oakey), testing of a wave buoy designed to measure the energy and momentum transfer from the atmospheric pressure field directly to the surface wave field (F. Dobson), and testing of a buoy designed to measure and report ice and snow thickness of a sea ice floe (S. Prinsenberg). Preliminary design work was carried out on a technique to tow in situ instrumentation such as the BATFISH in the presence of ice, and on improvements to our deep sea rosette system (R. Clarke).

(b) Coastal Oceanography.

The analysis of data from the Canadian Atlantic Storm Program (CASP) in order to determine the oceanic response to a storm continues to be a major focus of endeavour (C. Anderson, P. Smith). In cooperation with The Atmospheric Environment Service, an extensive set of meteorological observations is being correlated with the set of oceanographic variables; these last include current meter data, CTD observations, bottom pressure measurements, wave rider data (F. Dobson, W. Perrie, B. Toulaney), CODAR (HF radar) measurements of surface currents (D. Lawrence), and trajectories of satellite-tracked drifters (D. Lawrence).

Several studies relate to fisheries. A study of the circulation and dispersion around Brown's Bank contributes to the Fisheries Ecology Program (P. Smith). The temperature and chlorophyll on the Scotian Shelf is being examined using image analysis techniques on satellite data (B. Topliss). The effects of warm core rings on transport are being studied for their possible effects on fish stock recruitment (R. Trites, K. Drinkwater). The physical oceanography of the Gulf Stream is being related to squid populations (R. Trites).

Several computer model studies are in progress. A third-generation wave model is being developed and wave-wave interactions are being calculated using Boltzman integrals (W. Perrie). Barotropic circulation models contribute to studies of the mean currents over the Newfoundland Shelf and of the influence of storms over Hudson Bay on water motion on the Labrador Shelf (B. Petrie). A barotropic model with an embedded profile model is being used in the CASP studies and also as a means of interpreting the motion of drifters (K. Greenberg). An idealized two-layer model examines the mechanisms important in maintaining the Labrador Current (B. Petrie).

Expertise in Coastal Oceanography has been contributed to several applied problems such as, the suitability of different drifting buoys as simulators of oil spills (D. Lawrence), the mapping of cooling water outflow from the Point Lepreau nuclear reactor into the Bay of Fundy (G. Bugden), and the review of physical oceanography implications of the proposed "fixed link" crossing to Prince Edward Island (G. Bugden).

Site-specific studies include investigations in the Newfoundland offshore of the sea surface temperature signature of the boundary between the North Atlantic Current and Labrador water (B. Petrie), the motion of the sea at the edge of the marginal ice zone (C. Tang), and studies of the wind driven inertial currents over Grand Bank (D. Wright). In the Gulf of St. Lawrence, there is research into (1) the influence of the inflow through the Straits of Belle Isle (B. Petrie), (2) the forecasting of Gulf winter ice conditions (G. Bugden), (3) the low frequency motions in the Laurentian Channel (B. Petrie), (4) chemical tracing of the Gulf's source waters (K. Drinkwater), and (5), the wind forcing of St. Georges Bay. In the waters around Nova Scotia, the wind driven coastal upwelling indicated in satellite imagery has been confirmed by theoretical models (B. Petrie), and algorithms have been developed to determine the suspended sediment concentration from satellite observations (B. Topliss). Nova Scotia waters, the Mackenzie Delta, and San Francisco Bay are the settings for studies of the behaviour of suspended particles (K. Krank).

(c) Marine Chemistry.

On April 1st, 1987, the Chemical Oceanography Divsion was renamed the Marine Chemistry Divsion, assimilated resources from other ecological programs, and had its responsibilities broadened to include the conduct of marine contaminant and toxiclogy research, and to focus effort on applied environmental and fisheries problems involving chemicals. The conduct of the Point Lepreau Environmental Montioring Program and research on natural and contaminant geochronology in the Saguenay Fjord using radionucleides are being maintained (J. Smith). Recent work has included attention to the movement of weapons-derived plutonium pilled at Thule, Greenland, and to the movement of water-borne radio nucleides in the North Atlantic circulation (J. Smith). Investigation of the geochemistry of trace metals during estuarine mixing is continuing through a combination of field and laboratory mixing studies in collaboration with the Skidaway Institute of Oceanography and other agencies (P. Yeats). An evaluation of trace metal distributions in Canadian East-Coast waters has been completed and investigations of the oxidation chemistry of manganese in deep ocean water masses has commenced (P. Yeats). The features controlling trace metal partitioning and phase exchange in the St. Lawrence estuary have also been investigated (P. Yeats). Analysis of data obtained from Joint Canada-FRG studies of the partitioning of trace metals in inter-tidal zones has been undertaken during 1987 and assistance has been provbided to Danish evaluations of the effects of mine waste dicharges to Greenland coastal areas (D. Loring). Studies of the growth rates of sea scallops and the mobilization of organic matter in major world rivers using stable isotopes have continued (F. Tan). The potential application of oxygen isotopes to physical oceanographic processes of water mass mixing south of the Grand Banks has been evaluated (F. Tan). An investigation of the ventilation of the Arctic Ocean has been completed and a new Artic Ocean study commenced during 1987 through participation in an international expedition to the Nansen Basin (P. Jones). Further development and refinement of a sea-going method for the measurement of chlorofluormethanes in support of physical oceanographic investigaions has continued (P. Yeats). This work will permit the inclusion of freon measurements in a major study of the Greenland Sea, planned for 1989. A monograph on

the chemical oceanography of the Gulf of St. Lawwrence is being prepared for publication in 1988/89 (M. Strain).

Studies of the effects of acid rain on salmon in two contrasting Nova Scotian rivers has been carried out with major attention being given to liming and other mitigation procedures (J. Uthe). A new program on the deposition of organic contaminants and trace metals from the atmosphere into eastern Canadian waters has been started (R. Addison). The analysis of long-term data on the incidence of contaminants in fish and shell-fish for the purposes of trend detection has been continued as part of the activities associated with the International Council for the Exploration of the Sea (ICES) (J. Uthe). An evaluation of possible links between organochlorine residues and diseases in marine mammals has been completed as part of a review for the United Nations Environment Program, the Intergovernmental Oceanographic Commission, and the ICES (R. Addison). Techniques for the measurement of sub-lethal stress on marine biota have continued in both the Division's laboratories at BIO, where emphasis is placed upon the mixed function oxygenase method, and at the St. Andrews Biological Station (R. Addison). The effects of pesticides, emulsifiers, and other organic compounds used in agriculture and forestry on aquatic biota continues to be studied (R. Addison). Various investigations have been sponsored by the Panel on Energy Research and Development on the natural degradation of oil in the sea, tainting and other effects on marine organisms due to releases from offshore oil rigs, and effects of polycyclic aromatic hydrocarbons in Muggah Creek, Sydney, N.S. (J. Vandermeulen). A major new project aimed at assessing the distribution of oil seepage from subsedimentary deposits, and its importance to the sustenance of benthic marine communities has been started with initial field studies being conducted in Scott Inlet, Baffin Island, and Georges Bank (E. Levy). Studies of the physical and biological processes controlling nutrient distributions in the upper Bay of Fundy have been completed (P. Keizer). Development of a generic model for continental shelf ecosystems in order to facilitate assessments of the effects of contaminants on ecsosystems has commenced (P. Keizer). Assistance continues to be given to the analysis of the effect of sea dumping of radioactive waste in the context of a review of the scientific, legal, and economic and social aspects of this practice within the London Dumping Convention (J. Bewers). In addition to the above, a considerable number of applied fisheries and habitat problems associated with chemicals have had to be dealt with during the year. Much of the toxicology and organic chemical effort of the Division was diverted during the last 2 months of 1987 to deal with a shellfish toxin problem arising in eastern Prince Edward Island (R. Pocklington).

(d) Biological Oceanography (E.P.W. Horne)

(i) Open Ocean Production A month long observational program was undertaken in the Sargasso Sea to determine if isolated high biomass regions (50 to 100 km diameter) which showed up in a composite CZCZ image for the North Atlantic in May, 1979 were associated with seamounts. CTD, microstructure, nutrient, cell count and production data were collected in transects across the seamounts. Preliminary analysis shows that there is doming of isopycnals over seamounts and increased levels of turbulence and concentrations of small phytoplankton cells. However, the effects on the biomass extended for hundreds of kilometres downstream from the seamount.

(ii) Georges Bank Analysis is continuing of the current meter, CTD and turbulence data from an experiment on Georges Bank conducted in 1985. The nitrate flux onto the bank was found to be consistent with biological demand. The depth-integrated dissipation in the mixed layer was found to vary by several orders of magnitude over a tidal cycle.

(iii) Instrumentation A small scale fluorometer is being developed to mount on the microstructure probe EPSONDE to measure fluorescence on the same scale as the turbulence. A prototype was successfully tested this year, but the sensor proved to be too delicate. A more robust unit is being assembled.

(e) Ocean Technology

The Laboratory continues an active program in the development of sensors and related platforms (A. Bennett, J.-G. Dessureault), survey and positioning systems (N. Cochrane, D. McKeown) and sampling methods (G. Fowler).

4. Université du Québec à Rimouski, Département d'Océanographie

(a) Hydrodynamics of Estuaries and Coastal Zones

Satellite infrared images and current measurements were used to discuss the occurrence and evolution of a remarkable autumn episode of current instability occurring in the Gaspé Current. Differing considerably from summer events, the fall episode occurs downstream from the Gaspé Current's separation from the coast. The event is apparently initiated after about one week's acceleration under favourable winds. Satellite thermal images from three different years revealed that unstable disturbances are characteristic of the estuarine jet in the lower St. Lawrence. An update of previous work, together with modelling studies, shows that the Gaspé Current is both barotropically and baroclinically unstable (M.I. El-Sabh).

Current meter data taken at the mouth of the lower St Lawrence Estuary (LSLE) during two field programs (1962 and 1979) were examined, using spectral and bulk correlation analyses, to show that wind-driven motions apparently control the variability of the exchange between Gulf and estuarine waters. Meteorologically forced motions are shown to be most prominent in the 10- to 15-day period range (corresponding to the typical interval between passage of weather systems). The wind-induced current field is shown to produce a counter flow at depth in the LSLE (M.I. El-Sabh).

The lateral stratification and momentum balance in the lower St. Lawrence Estuary were investigated over a period of six days from current, temperature and salinity measurements taken in 1979 at the Matane transect. The spatial variability of hydrodynamic parameters at that cross-section was shown to be more pronounced than their temporal or tidal variability. Estimates of various acceleration terms in the lateral dynamic balance equation showed that, when averaged over many tidal cycles, the motion can be considered as quasigeostrophic to a first approximation, with contributions of the same order of magnitude from the baroclinic and the barotropic pressure gradients. Convection accelerations were found to be important only near the north shore, where strong cross-channel currents were recorded, while local and centrifugal accelerations were found to be of secondary importance (Koutionsky, Chanut, El-Sabh).

A two-dimensional numerical linear model was elaborated to simulate a tsunami resulting from a hypothetical earthquake in the Charlevoix area of the St. Lawrence estuary. We are currently developing a non-linear numerical model, using an irregular triangular grid to better represent the highly variable depth pattern in the estuary (El-Sabh, Murty, Dumais).

Using hourly observed and predicted sea level variation for a period of eleven years (1956 - 1975), statistical analyses were made to examine the extreme values, the return periods for negative surges of various amplitudes, the influence of an ice layer and the interaction between tides and surges on the eastern Canadian water bodies (El Sabh, Murty).

Measurements of currents during a 4-month period taken at three stations off Ste-Marthe-de-Gaspe in the Gulf of St. Lawrence were subjected to statistical time series analyses. The study suggested that, in addition to the tides, meteorological phenomena are contributing to the dynamics and variability of the Gaspé Current (Chanut, El-Sabh).

Daily mean water level records of St. Lawrence River at Trois-Rivières from February, 1925 to January, 1976 are analysed both in time and frequency domains. In addition to seasonal variation, a periodic component of approximately 25 years was identified in the series and is attributed to climate changes (Chanut, El-Sabh).

The results obtained from a major interdisciplinary field measurement program carried out in the Magdalen Shallows were used to study the space-time variability of mesoscale features and their consequences on the biological productivity of the area. These measurements include current meter data, satellite imagery, salinity, temperature, nutrient and chlorophyll concentration, seston concentrations and size analyses, sampling for particulate carbon, nitrogen and catches of zooplankton. Surface salinity and density distributions, together with satellite images taken in early summer, show the presence of a front separating offshore saltier , higher density and vertically mixed waters from coastal stratified waters. The corresponding changes in surface chlorophyll, silicate concentration changes, and zooplankton biomass show higher values within the coastal waters. Sharp changes in the species composition of zooplankton and fish larvae were also found to be unevenly distributed across the front. The data also show enormous variation in the physical characteristics (salinity, temperature, currents) occurring on relatively small time and space scales (hours, km). Our results clearly demonstrate that wave-like eddies and meanders associated with instability incidents of the Gaspé Current, the arrival of spring runoff from several rivers, tides, and storms are the major contributors to the physical characteristics of the Magdalen Shallows, and that the formation of fronts and eddies may result in increased aggregation of food organisms and larvae (M.I. El-Sabh, B. Cote).

5. Pêches et Océans, Institut Maurice Lamontagne

(a) Chemical Oceanography

C. Gobeil and G.H. Tremblay have completed a study of recent diagenesis of cadmium in the Laurentian Channel. Research on the postdepositional reactivity of lead in marine sediments is nearing completion. Other work in progress indicates that the sediments of the Laurentian trough act as an effective trap for mercury, accurately reflecting the changing inputs of mercury to the environment. An investigation of the vertical flux of phosphorus in the water column and the sediments of the St. Lawrence Estuary has been undertaken. The concentration of several metals (As, Al, Cu, Pb) dissolved in the waters of the Saguenay Fjord have been measured. A study of the distribution of dissolved mercury in the St. Lawrence estuary has been completed (C. Gobeil, G. Tremblay).

In organic chemistry (J. Gearing), a baseline survey of St. Lawrence sediments is in progress, focussing on selected lipid markers. The depth variations of specific hydrocarbons and fatty acids are being compared with spatial differences in various hydrologic regimes. The origin of particular marker compounds (alkenes and PAHs) in the plankton is being investigated as well as their temporal variability. Together with Biological Oceanography we are investigating the extent and mechanisms by which primary and secondary production affects the stable isotope ratios of carbon and nitrogen in the St. Lawrence ecosystem.

A major project focusing on interaction at the sediment-water interface (B. Sundby) has just begun. This will be an inter-disciplinary study (chemistry, microbiology, physics) involving both field work and microcosm studies.

(b) Océanographie Physique.

Grâce à un modèle numerique à trois dimensions du courant de marées au sud-ouest de la Nouvelle Ecosse, nous avons trouvé que l'amplitude du courant residuel induit par la marée est proportionnel au carré de l'amplitude du courant de marée et non pas simplement proportioniel à celle-ci. C'est la première fois que cette relation a été demontré parce que c'est la première fois que les résultats d'un modèle numérique réaliste ont été comparés à des mesures par courantomètres dans cette bande de fréquence.

Le projet COHJAC (Étude de la circulation, l'océanographie, et l'hydrographie du détroit de Jacques Cartier). Au cours des quatres missions en mer dans le détroit de Jacques Cartier, des mesures de courant , de niveau d'eau, de température et de salinité ont été effectuées en une douzaine d'endroits par une trentaine d'instruments simultanément pendant une période d'un an. L'analyse des données de la première période soit de l'été 1986 a été effectué. Le premier résultat est que la circulation dans le détroit de Jacques Cartier s'effectue essentiellement en deux couches: une couche de surface qui subit l'influence direct des vents, et une couche sous-jacente dont les éléments réagissent en phase jusqu'au fond.

L'objectif d'une étude hydrodynamique à la tête de l'estuaire est de quantifier l'influence de la marée, des ondes internes, du vent, et de la pression atmosphérique sur le mélange et la remontée des eaux. Sous la direction conjoint du Dr. C. Garrett (Departement d'Océanographie de l'Université Dalhousie) et du Dr. D. Lefaivre, M. Galbraith a analysé les données recueillies précédement. L'analyse a demontré la necessité d'obtenir de nouvelles mesures à plus grand résolution. Une mission en mer a été effectué avec succès. Les remontées d'eau le long de la rive nord dues au vent ont été quantifiées. Le mélange dû aux ondes internes est en voie d'être elucidé grâce aux nouvelles mesures.

Un modéle à boîte à deux couches pour simuler la circulation de l'estuaire moyen du Saint-Laurent en relation avec la concentration de bactéries a été mis au point. En collaboration avec M. Jean Painchaud et du Dr. J.C. Therriault de la Division d'Océanographie biologique de l'IML. Ce projet a pu être mené à bien pour la raison suivante: Les données de bactéries dans l'esturaire moyen sont difficilement interpretables si on ne tient pas compte de la circulation estuarienne dans cette région. Le Dr. D. Lefaivre a testé divers modèles pour touver celui que representait adéquatement la circulation. Un model à deux couches s'est avéré adéquat. Le modèle a alors permis d'identifier les zones de production et de perte de bacteries et de formuler des hypothèses de taux de croissance en fonction des régions.

Une expérience préliminaire a été entreprise dans la lagune de la Grande Entrée aux Iles-de-la-Madeleine, où se trouve un site majeur d'aquaculture de moules. L'étude a montré que les courants a l'intérieur de la lagune sont faibles et sont en gros induits par le vent. Les processus verticaux sont dominés par des cellules de la circulation de Langmuir (D. Booth).

Work on the under-ice dynamics of freshwater plumes in Hudson Bay and James Bay was completed with the publication of two articles (P. Larouche). Data analysis continues on the 1985-86 experiments focusing on the large scale circulation in Southeastern Hudson Bay (P. Larouche).

6. Groupe Interuniversitaire de recherches océanographiques du Québec: Université Laval, Ste. Foy, Québec; McGill University, Montreal, Quebec.

Studies of the energy partitioning of ocean swells and their effect on small harbours and offshore structures were continued in 1987. This work was applied to the St. Lawrence estuary and to the Gulf of St. Lawrence, with an emphasis on sand tranport (Y. Ouellet, Laval). Further work was done to develop a three-dimensional finite element model for simulation of natural flows and statistical studies were undertaken to determine the higher high water levels in the St. Lawrence estuary (Y. Ouellet, Laval).

A study has been initiated of sedimentological processes and of the late and post-glacial stratigraphy of Holocene sediments under the present Great Whale River plume (Hudson Bay), with 8 piston cores and 60 km of reflection seismic lines being obtained from CSS Hudson in August. These data are being processed and interpreted in terms of the established land-based stratigraphy of Quaternary deposits (N. Gonthier). Observations on the offshore dispersal and sedimentation of the present river suspended load, both under ice-covered and ice-free conditions, are also made for comparison with, and interpretation of, the Holocene record (d'Anglejean, Biskam).

In the St. Lawrence area, research has been completed on the geochemistry of phosphorus in the upper estuary, including measurements of partitioning between the particulate and the dissolved phases and within various fractions of the particulate phase, experimental work on P adsorption on particulate matter, and the establishment of a first-order P budget for the estuary (M. Lucotte, B. d'Anglejean).

In the same region, measurements of the particulate matter cross-channel fluxes and exchanges on the Kamouraska inshore platform have been obtained under high and low river discharge conditions. Geotechnical and stratigraphic observations on surface deposits of the platform have also been made (S. Lorrain).

Detailed compositional and diagenetic studies on the submerged Champlain Sea Clay outcrops in the estuary are being carried out (R. Ramesh).

A large scale survey of sea surface temperature and salinity was made aboard CSS HUDSON in August, 1987 over transects from NW to SE Hudson Bay and Kuujjuarapik (Great Whale) to Churchill. NOAA satellite data were archived for the same period for later analysis of the surface temperature field. A small scale study of the Great Whale River Plume was also completed (Lepage, Ingram).

Analysis of large data sets collected near the Great Whale River during spring and summer 1986 is still in progress. In addition to studies of the under-ice plume dynamics, processes occurring during ice breakup and dispersion were also observed (Lepage, Ingram). Boundary layer characteristics at the ice-water interface were also investigated (Shirasawa, Ingram).

A study of the propagation of coastal trapped waves under the landfast ice of southeast Hudson Bay was begun. The forcing mechanism is thought to be the large scale atmospheric pressure gradient across the Bay (Ingram, Larouche (DFO), Reynaud).

The oceanographic field data taken in Rupert Bay in 1976 is being rexamined with the aim of understanding the importance of lateral gradients on the dynamics, frontogenesis and island wake formation (Ingram, Veilleux, Chu).

A global ocean circulation model for coupling to the Canadian Climate Centre atmospheric general circulation model for climate studies is being developed and implemented. The coinvestigators are Drs. L.A. Mysak and G.J. Boer. The ocean model is a 2-layer global upper-ocean primitive equation model, with wind and buoyancy-driven entrainment between the layers. Experiments have been carried out with a box version of the model as well as with the global model. The results with the latter model show that realistic sea surface temperatures and mixed layer seasonal cycle are obtained with climatological wind stress and heat flux forcing at the surface. Further parameter sensitivity studies and resolution experiments will be carried out (C. Lin).

The role of diffusion parellel to isopycnal surfaces (isopycnal diffusion) in ocean-climate interaction is being investigated (C. Lin). Box diffusion model studies have been carried out comparing the results of lateral and isopycnal diffusion. The results show that both the steady and transient responses are qualitatively modified by isopycnal diffusion. Further studies with the box advection-diffusion model and the box version of the multi-level Cox-Bryan model are being carried out (C. Lin).

Concerning midlatitude Pacific atmosphere/ocean interactions, a theoretical study has been completed of both the steady-state and the time-dependent responses of a two-level atmosphere to oceanic heat fluxes (A.J. Weaver, L.A. Mysak). The results help to explain the large-scale statistical correlations found by McBean and Zhao between the SLP and the 700 mb height fields in the North Pacific.

A limited-area, quasi-geostrophic circulation model of the Northeast Pacific Ocean with mesoscale resolution has been developed to study the circulation in the Gulf of Alaska. A long-term integration has been performed with climatological wind stress forcing. Several statistical properties of the solution have been determined and compare favourably with in situ and satellite observation (L. Mysak).

Ice extent and anomalies in the Arctic Ocean, as well as in seven subregions (Bering Sea, Beaufort Sea, Hudson Bay, Baffin Bay, Labrador Sea, Greenland Sea, Barents Sea and East Siberian Sea), were studied using 32 years of monthly Arctic sea-ice concentration data on a 1 by 1 degree grid (L. Mysak, D. Manak). Of particular interest is the discovery of a large positive ice anomaly in the Greenland Sea for the 1962 - 72 period which appears to travel southward into the Labrador Sea at a speed of about 2.7 cm/s. It is also of interest to note that this travel speed is roughly the same as the average current speed of the subpolar gyral circulation and the advection speed of the "Great Salinity Anomaly" in the northern North Atlantic.

A simple, coupled, steady-state Arctic ice-ocean model has been constructed (L. Mysak, A.J. Willmott) comprising a thermodynamic reduced-gravity ocean model forced by the wind stress and air temperature. The model has been used to determine the ice-edge position, ice thickness, ocean circulation and ocean temperature in a high latitude meridional channel. The model has been applied to the Greenland and Norwegian Seas, and successfully predicts the climatological position of the ice-edge boundary recently presented in the ice atlas of Manak and Mysak (1987).

7. Physical and Chemical Sciences Directorate, Fisheries and Oceans, Ottawa.

(a) Oceanography and Contaminants Branch (G.L. Holland, Director)

(i) National Ocean Science. The Oceanography and Contaminants Branch coordinates national and international policies , programs and priorities for the physical and chemical oceanography and aquatic contaminants research programs of the Department of Fisheries and Oceans. In 1987, 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, IRAP, the Unsolicited Proposal Program, and the Environmental Studies Research Fund. Contracted R&D activities under these programs provide the mechanism for technology transfer from departmental laboratories to Canadian industry. The Branch administered the DFO Science Subvention Fund that supports university research in the marine sciences and th Ocean Dumping Control Act Research Fund that supports R&D for problems related to the disposal of wastes and dredged spoils at sea. Perhaps the most urgent responsibility for the year was the Branch's participation in the formulation of a DFO science response to the East Coast toxic mollusc crisis.

Included in the Federal Oceans Strategy, announced in September, 1987, was a committment to address the problem of plastic pollution in the aquatic environment. Branch staff began working on the preparation of an action plan, a prerequisite to a program to be initiated in 1988. As an ongoing responsibility, the Branch continued to provide advice to regulatory agencies concerning the disposition of wastes from offshore exploration and development activities. In addition, work was initiated on strategy papers for ocean climate research and toxicology/contaminants science.

(ii) Remote Sensing As part of its remote sensing coordination role, the Branch undertook the review of regional departmental remote sensing application and analysis system support requirements. The recommendations for developing regional data bases and enhanced image analysis facilities are now being implemented to assure effective use of data. In addition, the Branch took the lead in preparing a plan for the Canadian development of the imaging spectrometer technology based on the prototype. The Fluorescence Line Imager System is currently on loan to industry.

(iii) Intergovernmental Ocean Science Affairs. 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 services. The Branch continued to be the focal point for DFO participation in five bilateral Science and Technology agreements, and for 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.

(b) Marine Environmental Data Service (Dr. J.R. Wislon, Director)

(i) Ocean Information and Systems Division. The Ocean Information and Systems Division is responsible for the maintenance and devlopment of software systems at MEDS in order to support data aquisition, quality control, archiving and retrieval. In 1987, a substantial effort was expended in upgrading software for the handling of wave data received in real-time. The other major developmental activity was the redesign of the system handling drifting buoy data received on the Global Telecommunications System of the World Meteorological Organization.

The Division also made a number of contributions in support of international data management. For example, MEDS is the data centre for the Northwest Atlantic Fisheries Organization. MEDS also worked with the Radar Data Development of the Canada Centre for Remote Sensing to conduct a survey of ocean data products, information and services required by present and potential clients for in-situ and remotely sensed oceanographic variables.

(ii) MEDS Wave Climate Study Program. In 1987, the wave climate study installed and operated 18 wave stations. Four that reported in real-time were maintained in the Great Lakes in support of AES flood warning forecasting program and the Queen Charlotte Wave Program continued with 5 stations used for real-time AES wave forecasting purposes on the West Coast. Measurements continue at Tofino, B.C., Shearwater, N.S. and at Hibernia using satellite Waveriders, and a version of the Datawell WAVEC buoy modified for satellite transmission of data was field-tested.

Other wave climate work included a wave-ice interaction experiment conducted as part of the LIMEX/LEWEX experiment off Newfoundland in March, 1987, and a project under the DSS Unsolicited Proposal Fund to carry out a continuous hindcast of directional wave properties on the East Cost of Canada for a three year period.

(iii) Data Management and User Services Divsion. In 1987, MEDS received records from the Canadian Hydrographic Survey network of 113 permanent water level gauges. These hourly observations of height were digitized, analysed and stored as water height elevations. The stations are located on the East Coast (18 stations), the West coast (16), the Great Lakes (36), the St. Lawrence (42) and Hudson Bay (1). Real-time water level data are available for 32 of these 113 gauges.

MEDS also prepared tidal predictions, 43 tidal height stations, and 21 tidal current stations for the Canadian Tide and Current Tables. Under an international agreement, advance predictions were exchanged with the United States, the United Kingdom, Germany, Denmark and Japan.

MEDS is the responsible agency for the management and the archiving of oceanographic and related data collected by Canadian and foreign research and survey agencies in the area of Canadian interest. Data files contain oceanographic data measured mainly by Conductivity-Temperature-Depth probes, expendable bathythermograph probes and Nansen water bottle samplers. A wide variety of technical inventories, products and services is offered, including data aquisition, computer processing, archiving, computerized retrieval and display, data publishing, national data inventories and referral services for data not held in MEDS. MEDS is also the responsible agency for oceanographic data exchange with the World Data Centre System.

The Centre is the archiving agency for oceanographic data collected at oil drilling platforms. Copies of the data are available on computer magnetic tape once the confidentiality period has expired.

8. Canada Centre for Inland Waters

(a) Environment Canada, National Water Research Institute.

(i) Lake St. Clair. Physical studies in the shallow and turbulent Lake St. Clair have been undertaken in order to estimate the residence times of toxic contaminants both dissolved in the water and adsorbed on fine sediments. New or modified instrumentation has been assembled to meet the difficult conditions imposed by this lake. At various times we have deployed shallow water tide gauges, vector averaging current meters and wind sensors, near bottom current profiler based on electromagnetic curent sensors, sediment traps, a rapidly (2 Hz) sampled array of acoustic current meters and optical transmissometers. The acoustic current meters incorporate microprocessors that compute the sum of squares and cross products of current components as well as the number of reversals of a current component in the course of an averaging period. With this information, it is possible to estimate the average characteristics of surface waves, direction, period and height. These instruments are being evaluated (P. Hamblin, F. Boyce).

Persistent horizontal flow in Lake St. Clair due to the St. Clair/Detroit River system (residence time of the basin is 9 days) means that the horizontal flux of suspended sediments must be accounted for in the study of local resuspension of bottom sediments. A two-week long time series of the divergence of suspended sediment flux shows pronounced deposition preceding and following tow local resuspension events. Work continues on estimating the bottom stress during these events in order to determine the critical bed shear stress required for resuspension (P.F. Hamblin, F.M. Boyce).

(ii) Thermodynamic Modelling of Lakes and Reservoirs. In a review of vertical mixing processes in lakes and reservoirs, two semi-empirical forms of vertical diffusion were compared against temperature observations in a lake. Compressibility effects on the convective readjustment mixing algorithm were shown to be important during the cooling phase in a deep lake. A two-dimensional non-hyrodstatic model showed that the thermobaric term in the equation of state for fresh water could account for the temperature maximum in deep lakes in winter. The bulk heat transfer coefficient between lake ice and water was inferred from various observations in ice-covered lakes and should improve modelling capability for these situations (P.F. Hamblin).

(iii) Niagara River. From detailed observations, a conceptual model of the dynamics of the Niagara River plume in Lake Ontario was developed. The mixing of the plume is controlled by a complex interaction of small scale turbulence and large scale circulation features in the lake. In the initial stage the river inflow momentum dominates and the river plume is well-mixed vertically over the Niagara Sand Bar. In the intermediate stage the interaction of the well-mixed, buoyant river plume with colder water from the deeper parts of the lake generates a sharp thermal front. In the final stage, the river plume responds to the prevailing winds and the general circulation of the lake. The correlation between these observed plume characteristics and the distribution of toxic contaminants such as mercury and mirex in the sediments of Lake Ontario attributed to the Niagara River outflow are illustrated (C.R. Murthy).

The compartmental distribution and transport of toxic chemicals in the vicinity of the Niagara River plume were simulated using a simple partition hypothesis. The distribution of the dissolved and adsorbed forms of the contaminants depends mainly on the interactions of water and suspended sediments, including advection, diffusion, net settling, adsorption and desorption. This hypothesis was tested with the observed physical and chemical data collected simultaneously in the vicinity of the river mouth in Lake Ontario. It was found that the key factors controlling deposition and transport of contaminants were the sediment water partitioning coefficient and the suspended sediment concentration. When the suspended sediment concentration is high, most of the adsorbed contaminants are deposited in the Niagara Bar area. Otherwise, a significant proportion of the contaminants are carried in the dissolved form with the river plume and into the Lake. This modelling approach is useful in the short-term analysis of the pathway and transport of contaminants in coastal areas (C.R. Murthy).

(iv) Evaluation of Sediment Traps. In relatively calm environments, cylindrical settling tubes of depth equal or greater than 10 diameters, are shown to be reliable integrators of the gross settling flux of suspended material. Their performance in wave-dominated shallow waters, such as those of Lake St. Clair, has not until now been tested. A trap designed by B. Kenney, consisting of a vertical cylinder that communicates with the surrounding fluid via an array of horizontal ports drilled into the walls at the top of the cylinder, offers attractive possiblities such as reduced vertical encumbrance compared with the standard settling tubes, and a simplified version can be improvised by drilling ports into the sides of the one-litre water sample bottle. Tests of the Kenney design as well as the standard settling tube were conducted in Lake St. Clair (1985, 1986), Hamilton Harbour and western Lake Ontario (1987). Catch rates measured with the Kenney traps in the actively resuspended bottom layer are repeatable but are strongly dependent on the square of the rms current speed, surely an awkward characteristic, while the catch rates inferred from the settling tubes are highly erratic. An understanding of this behaviour is a prerequisite to the quantitative interpretation of sediment trap measurements (F. Boyce).

(v) Lake Erie Synthesis. A special issue of the Journal of Great Lakes Research (Vol. 13, No. 4) reviewed recent progress in the understanding of the biochemical consequences of the physical behaviour of Lake Erie and is the culmination of a binational experiment undertaken in 1979 - 80 (F. Boyce).

(vi) Coastal Engineering. Steady-state wave prediction equations (SMB, JONSWAP, Donelan Similarity Equation) were evaluated together with the application procedures outlined by the US Army Corps of Engineers in their Shore Protection Manual. The predictions were compared against wave data from Lake Ontario, among other sources. The SMB and the Donelan Similarity Equations provided the best results. The revised procedures outlined in the Shore Protection Manual consistently overpredict both wave height and period (C. Bishop, M.A. Donelan). Also under

evaluation is a one-dimensional wave climate model (PHEW) a model employed by Public Works Canada and by the Hydraulics Research Group, Wallingford, U.K. (M. Skafel, C. Bishop).

A literature review on Great Lakes Water levels was completed and provides Public Works Canada with background information for design water levels and harbour structures. A growing interest in the effects of climate change has made this review timely (Bishop).

Field experiments to map the joint probability distribution of wave heights and periods in shoaling waves were completed in Lake Ontario (Donelan, Bishop).

The third and final phase of the joint Woods Hole/ NWRI WAVES (Water Air Vertical Exchange Studies) field study on the dynamics and effects of deep water wave breaking was completed. Among the practical results of this study of wave-induced turbulence in the upper ocean will be improved predictions of the dispersion of pollutants spilled into lakes and oceans. In the course of post field calibrations, good agreement was found between the NWRI and Woods Hole measurements, despite different instrumentation (Donelan).

NWRI's array of wave gauges was shown to yield high resolution and very accuarate wave directional spectra. Preliminary results indicate new findings. For example, the downwind spectral densities are quasi-saturated, but the spreading increases linearly with frequency away from the spectral peak, causing the frequency spectra to obey a f^{-4} law (Donelan).

In collaboration with the US Naval Research Laboratory, radar measurements of surface waves were made from the NWRI tower during the WAVES experiment. The radars were operated in a scanning mode, yielding continuous azimuthal information. The radar data, together with the simultaneous boundary flux data, will be useful for relating high altitude microwave radar data to surface winds (Donelan).

A new recirculating wind tunnel for gas transfer studies is nearing completion. The wind tunnel portion will excite waves (a hydraulic wave maker is also provided) and enhance gas transfer in a 32 m flume, the latter being equipped with a closed circulation mechanism for the water. Maximum design velocities for air and water are 22 m/s and 50 cm/s respectively. An initial series of experiments will study the air/water transfer of the common pesticide, Lindane (Donelan).

(vii) Instrumentation. A hydraulic powered, servo-controlled Wave-Follower system was developed to support the 1987 Waves and Air-Water Interaction experiment. The system was installed on the NWRI Lake Ontario Research Tower located 1 km offshore of the southwest corner of L. Ontario. Capable of remote operation from shore, its prime purpose was to measure static and dynamic air pressures at distances of 10, 20 or 30 cm above the water surface in wave regimes of up to 1 m crest to trough. This system was also used to measure water motions immediately below the surface in similar wave regimes (Valdmanis, Madsen).

Videocassette recorders have the potential to record large quantities of digital data because of their spinning head, helical scan approach. A data logger was built in which two 8mm VCR's were used in a stereo audio-only mode. Digital signal streams from four acoustic current meters (.5 sec sampling) were frequency shift keyed (1200 baud) and recorded along with a real-time clock signal (110 baud) (J. Valdmanis).

A multi-optical measurement system was assembled and deployed from a highway bridge in order to develop techniques for the remote monitoring of water quality parameters in flowing rivers. The system consists of four microprocessor controlled radiance sensors and one irradiance sensor which measure downwelling and upwelling radiance from the river as well as downwelling irradiance. Data are logged on digital recording tape cassettes. Provision has been made in the design for logging to solid state memory and for down-loading data via a serial line (R. Desrosiers, J. Jerome).

A peripheral kit is being developed for use in combination with an existing fluorescence microscope to provide a low cost flow cytometer (Desrosiers).

A Water Quality Profiler System has been developed comprising a profiling sonde, a winch, a microcomputer and a calibration bath. This System has the potential to replace the labour-intensive bottle-cast techniques currently used as standard methods for the Great Lakes Water Quality Surveillance activities involved in the measurement of temperature, dissolved oxygen, light transmission, pH and conductivity with depth (J. Ford, M. Charlton).

(b) Fisheries and Oceans, Canadian Hydrographic Service

The ARSS (Airborne Resistivity Sounding System), formerly called TIBS, was demonstrated in Pelly Bay in April, 1987. Despite some problems with the system, in three operational days, 700 km of line soundings over a 75 km^2 area were completed, demonstrating the potential of ARSS. Where gound truth data was sufficient, the results were very good. Recent upgrades to the system allow incorporation of a digital receiver as well as more efficient means of data transfer. Improvements are ongoing. A further evaluation of the repeatability and the accuracy of the upgraded ARSS is sheduled for late summer, 1988 and again in early spring, 1989.

9. Environment Canada, National Hydrology Research Institute

Research is being conducted on physical, chemical and biological processes in lakes on the prairies and in the north. Work is continuing on the quantification of mixed layer entrainment and sediment resuspension in prairie lakes and on the nutrient dynamics in a chain of lakes in the Qu'Appelle Valley of Saskatchewan. New research projects include the development of engineering design parameters for suspended particle profiling in rivers, the effect of supercritical flow and turbulence on the growth of benthic algae, and a contribution to the theory of spurious relations in science and engineering (B. Kenney).

10. University of British Columbia, Department of Oceanography

(a) Physical Oceanography

B.C. coastal waters have continued to be our main area of interest. S. Pond (with P.H. LeBlond and M. Stacey) has concluded a major observational study of low frequency currents in the central Strait of Georgia. The data have been used to examine the dynamics of current fluctuations in a coastal basin. Another project under the direction of S. Pond involves detailed flow observations in Knight and Burrard Inlets in order to provide the background for modelling studies aiming at predicting the seasonal variability of fjord properties.

LeBlond and post-doctoral fellow, D. Griffin have been examining the role of wind and tides in carrying the Fraser River outflow out of Juan de Fuca Strait onto the continental shelf. The buoyancy flux associated with the freshwater outflow has been investigated, in collaboration with R.E. Thomson of the Institute of Ocean Sciences, as a driving force for the Vancouver Island Coastal Current. A. Weaver and W. Hsieh have performed a theoretical study of the outflow from a channel into an unbounded ocean which is pertinent to that situation.

A. van der Baaren, a student of Pond, has been examining the balance of forces in Knight Inlet as well as the local characteristics of the fine temperature and salinity structures. R. Dewey (supervised by LeBlond and W.R. Crawford (IOS)) has completed a Ph.D. thesis on direct dissipation measurments on the Vancouver Island Shelf.

Studies of the North Pacific Ocean have included the Northeast Pacific Current Study initiated by W.J. Emery (now at the University of Colorado) in collaboration with LeBlond and Thomson, in which three sets of deep-drogued drifters have been launched and two deep moorings set to study the flow around the Gulf of Alaska. Hsieh and P. Cummins have pursued numerical studies of the response of the Gulf of Alaska to meteorological forcing. Other aspects of the numerical studies under Hsieh's supervision include the development of a semi-Lagrangian finite element model by Rodolfo Bermejo and a study of the interaction of eddies with bottom topography by J. Zou.

Smaller scale work has included acoustic studies performed jointly by Pond and D. Farmer (IOS): Ph.D. Student, S. Hill is examining the use of a bottom mounted acoustic array to measure surface wave directional spectra. Y. Xie is investigating acoustic signals associated with ice breaking, and L. Zedel is studying acoustic signals obtained during the STROMS experiment.

Research on physical mechanisms has included D. Masson's recently completed Ph.D. thesis on wind wave generation in the marginal ice zone and B. van Hardenberg's MSc. work on flows down an inclined bottom induced by haline convection.

(b) Marine Geochemistry

S. Calvert is continuing a survey of the major and minor element compostion of ferromanganese nodules and crusts from the Pacific, using samples obtained from a number of institutions. The geochemistry of sapropels in the Black Sea is also being examined and the results applied to the paleo-oceanography of the Black Sea.

A major study of the geochemistry of the sediments of the B.C. inlets is underway. R. Francois has completed a Ph.D. thesis on the geochemistry of sulfur and iodine in humic substances in nearshore sediments. He also examined the distribution of trace elements in Saanich Inlet. R. Powys completed a M.Sc. Thesis on a study of the chemical composition and assemblages of diatom shells in the annual varves in anoxic Saanich Inlet. C. Jones is studying the trace metal geochemistry of oxic and anoxic sediments from several B.C. fjords.

Time series of sediment trap collections in Saanich and Jervis Inlets have been continued of another year.

T. Pedersen has also been considering geochemical questions in B.C. coastal waters and elsewhere. Students K. Drysdale and K. Perry, respectively, have been studying the diagenesis of buried marine mine tailings (the Britannia Mine) and the geochemistry of meromictic lakes (Powell Lake). The occurrence of high Cd concentrations in Ucluelet Inlet is being studied in collaboration with R. MacDonald (IOS).

Pedersen spent two months in the autumn aboard the Sedco/BP 471 as a pore water specialist during Leg 117 of the Ocean Drilling Program. A number of targets were drilled on the Oman Margin, Owen Ridge and the Indus Fan in an effort to study the history of the monsoon in the Late Cenozoic.

Pedersen's work on the paleogeochemistry of the eastern equatorial Pacific Ocean has continued, along with similar studies of the northeast Pacific, recently initiated in collaboration with B. Bornhold of IOS.

A new high-precision VG Prism isotope ratio mass spectrometer was delivered to the Department in May and is now operational. The installation can make measurements of ^{13}C ^{18}O and ^{15}N in a wide range of materials and will support paleo-oceanographic, geochemical, archaeological, and plant science research.

Geochemical modelling studies by R. Boudreau have included modelling pH levels in anoxic pore water, the growth of discoidal manganese nodules and diagenetic concentration fields in the sediments beneath nodules.

(c) Marine Geology

During a cruise (CUROSS 1) to the northeast Pacific spreading centres, R.L. Chase sampled basalts from the Tuzo Wilson Seamounts, the southern Explorer Ridge, and the western valley of the northern Juan de Fuca Ridge. Suggestions of hydrothermal activity were seen on videos of the southern part of the latter area. A new self-recording deep-towed video system was used to survey the seafloor for sulfide deposits during CUROSS 1, and was subsequently modified for use in the Woodlark Basin in the southwest Pacific.

Research Associates, P. Michael and R.L. Chase showed that basalts from the Woodlark Basin have arc affinities.

G.T. Shea defended his M.Sc. on the basalts of Magic Mountain area, Explorer Ridge, finding evidence for several distinct magma sources for the basalts.

11. Fisheries and Oceans, Institute of Ocean Sciences

(a) Ocean Physics

(i) Fjords and Channels. The year-long field measurement program in Neroutsos Inlet, completed in the fall of 1987, was part of the oceanographic study intended to identify the dominant physical processes affecting the upper layers of this polluted (severely depressed dissolved oxygen content) fjord. Analysis of these data has identified local winds as the primary forcing for the currents in the upper 25 m. These currents are relevant to the pollution problem in this fjord because they are believed to play the dominant role in replenishing the dissolved oxygen content of the fjord and in dispersing the pulp mill effluent. A dissolved oxygen budget analysis of the upper 25 m of the fjord is underway with the objectives of determining the major sources and sinks of dissolved oxygen, their time scale of fluctuations, and the problems involved in their estimation (D. Stucchi).

Using the CTD data gathered by the Institute of Ocean Sciences in B.C. fjords over the past decade, vertical eddy diffusivities, $K_v(z)$, were computed for the deep waters of five fjords using the budget method as outlined by Gargett (1984). Eddy diffusivities were computed for both heat (temperature) and salt (salinity), and the results fitted to a model of the form

$$K_v(z) = a_o N(z)^{-q}$$

where N(z) is the Brunt-Valasala frequency and a_o and q are parameters of the fit. The above model was applicable in three of the five fjords with $1.3 \leq q \leq 1.8$, while values of a_o varied by an order of magnitude. In the two fjords in which the above model was not applicable, double diffusive conditions were present. Vertical eddy diffusivities varied widely but were smallest in Saanich Inlet and largest in Knight and Observatory Inlet. The eddy diffusivity for heat was not found to be significantly higher than that for salt (D. Stucchi).

Analysis of an extensive set of data from two cruises to the Strait of Gibraltar was completed. The observations include current measurements from a moored array, Doppler current profiles from a ship, together with XBT deployments and high frequency echo-soundings. The analysis has demonstrated that over the course of our measurements the exchange flow was maximally controlled in the hydraulic sense. Two layer hydraulic theory has been shown to provide a consistent basis for interpreting the results, and accounts for several features of the exchange flow, including the periodic tidal flooding of the sill control at Camarimal, the release of an internal bore and the presence of a supercritical jet in the eastern part of the Strait (D. Farmer).

(ii) Continental Shelf. In April and May, 1987 an array of current meter moorings was installed in a triangular pattern in 20 m water depth off Cape Bathurst. Each mooring contained seven meters with the object of measuring the response of the water columns to forcing events under conditions where the under-ice and benthic boundary layers merge. One such event was recorded during the six-week deployment period (D.R. Topham).

An extensive series of laboratory experiments has been performed to measure the drag of models of ice keels when towed in two-layer stratified water conditions. The entire Froude number range, from subcritical through to supercritical, has been investigated for a keel depth to upper layer depth ratio of 0.5. Force measurements and detailed flow patterns have been obtained throughout this range (D.R. Topham, H.D. Pite).

A regional CTD and water-chemistry survey of the Beaufort Sea was carried out in late March, the fourth year of a planned five-year sequence. This year shelf-water salinity was high, as in 1981, but not in intervening years, despite below-normal ice growth. The water-chemistry data suggest that strong upwelling in the fall of 1987 was responsible for a significant portion of the seasonal salinity increase. Cold shelf waters of enhanced salinity ventilate the upper portions of the Arctic in some winters, and thereby isolate the ice cover from warmer underlying waters of Atlantic origin (H. Melling and R.M. Moore).

A study of the mesoscale (5-50 km) flow structure over the Mackenzie shelf was conducted in August and September. Eleven drifters were used, all equipped to measure SST, and four equipped to measure temperature profiles down to 20 m. The drifters were drogued at 2.5 m and 17.5 m. The shallower drogue depth corresponded to that of oceanic water freshened by melt and river inflow. This layer most strongly affects the drift of sea ice. The deeper depth corresponded to that of the layer whose motions are simulated by the barotropic circulation model under consideration for the simulation of ice drift. Thus the different trajectories observed at the two depths provide a measure of the suitability of the barotropic-ocean-model predictions for ice-drift prediction in this area (H. Melling).

An intercomparison of computed and observed sea levels and currents was undertaken for the Minuk storm of September, 1985 in the Beaufort Sea. It was found that the computed values were generally in good agreement with sea levels and depth-averaged currents observed during the PERD observational study of 1985/86. Following the passage of a storm, however, the relaxation of the sea-level and circulation fields was accomplished through the radiation of energy by shelf waves, and through scattering into high mode components. These are unlikely to be predictable by deterministic means (W.P. Budgell).

Numerical simulations of remotely forced coastally trapped waves in the Beaufort Sea suggest that the Canadian portion of the Beaufort shelf is decoupled from the Alaskan portion. Incident shelf waves propagate further east. In this series of simulations no scattering of shelf waves into smaller scales was observed. This, and preliminary comparison with observations, suggest that for circulation modelling attention can be restricted to the Canadian shelf (W.P. Budgell).

New modelling work concerned with the representation of the structure of current, temperature and salinity in a vertical "slice" across the shelf has been initiated. The Mellor circulation model, using a second-moment turbulence closure scheme, is being applied to represent property advection, mixing and dissipation in the ice-capped water column. Results obtained indicate that the strongest interaction between the shelf sea and the ice cover occurs near the ice edge. It has been found that the vorticity introduced into the water column by the strong gradient in surface stress across the ice edge, is sufficient to drive an eastward counter-current along the continental slope, as is observed (W.P. Budgell).

An analysis of the vorticity budget in a localized region of the B.C. continental shelf was completed. Results show that the dominant terms in the dynamical balance are the two non-linear terms. These, though large, almost perfectly correlate so that the sum (the Jacobian of vorticity with stream function) is small. This implies that a linear model of the large Rossby number flows on the continental shelf may have surprisingly good validity. The analysis also demonstrated that the Tully Eddy (a large cyclonic circulation off the north of the Juan de Fuca Strait) is driven by upwelling from the head of a small canyon (H.J. Freeland).

A statistical dynamical theory was developed to show how eddies on the continental margin, interacting with longshore variations in bottom topography, produce a systematic force which drives coastal undercurrents. The effect also extends to driving a systematic upwelling tendency, bearing upon the nutrient burden and productivity of the shelf region. The theoretical model was examined and compared with numerical simulation results (G. Holloway).

A CTD survey was conducted from the Canadian Ice Island off the coast of Axel Heiberg Island (approx. 81°N). The line of stations over the 400 m deep continental shelf indicated the existence of an unexpectedly strong geostrophic shear at the shelf break where the depths increase sharply to 3000 m. This feature was coincident with a frontal zone separating offshore water and shelf water which is somewhat modified by vertical mixing. Surface salinities on the shelf were significantly higher than offshelf, and also higher than they were in previous years in spite of very intense summer melting - 1 m of ice was lost from the surface of the ice island. Further studies from the ice island are planned to provide direct measurement of current in order to verify the conclusions drawn from CTD data (R. Perkin).

Research was conducted on a wide variety of problems involving mesoscale oceanic variability off the B.C. coast. Analysis of field observations consisting of current meter measurements, water property data, satellite tracked drifter records and satellite thermal imagery, were combined with numerical simulation models to verify that the quasi-permanent 50 km scale eddy off the southwest tip of Moresby Island arises from rectification of the regional tidal currents. Available current and water property data were further used to provide a detailed description of the seasonal

circulation patterns off the west coast of Vancouver Island with particular emphasis on the poleward-flowing, buoyancy-driven Vancouver Island Coastal Current. An attempt was made to link the flow structure to fish distribution and recruitment along the southwest coast. Data collected in 1984 during the joint US-Canada Vancouver Island Coastal Current Experiment was used to investigate possible non-linear interactions between high frequency internal waves and mean currents over the continental shelf. The long-term fishery-oceanography monitoring programs, entitled the La Perouse and Marine Survival of Salmon (MASS) projects, were continued over the southwest shelf region. In addition to maintaining the three moorings, a total of 14 oceanographic surveys were conducted in the region in support of fisheries research. Work began on the dynamics of the Spring and Fall transitions along the coasts of Vancouver Island and the Queen Charlotte Islands (R.E. Thomson).

(iii) Deep Sea. Two moorings were deployed in deep water in the Alaska gyre system. One of the moorings released prematurely, but one is apparently still in place and should supply our first deep ocean current measurements in FY 1988/89 from this part of the North Pacific Ocean (H.J. Freeland and R.E. Thomson).

A novel suggestion was developed that fluctuations of sea level, obtained from satellite altimetry, may be combined with global ocean atlas data to estimate eddy transports of heat and freshwater. At first this was done for the North Pacific, and then for the entire Southern Hemisphere. In the Southern Hemisphere, the calculation showed how oceanic heat is transported toward Antarctica before escaping to the atmosphere. Further applications are being explored in cooperation with scientists at the NASA Jet Propulsion Lab (G. Holloway).

Three ocean-climate monitoring cruises were made during 1987 to Ocean Station PAPA (50°N, 145°W) and associated lines. The main task involved the collection of temperature-salinity-oxygen data. Two cruises were made to support the Ocean Storms project.

In September, an RD Instruments Acoustic Doppler Current Meter was used for the first time to measure the backscatter intensity and three-dimensional current structure associated with a mid-ocean ridge hydrothermal plume. Observations conducted at this time also marked the end of the three-year field program with Oregon State University to investigate the physical and chemical oceanic properties in the vicinity of the Endeavour Segment of Juan de Fuca Ridge (R.E. Thomson).

In June and October, a total of 24 deep-drogued satellite-tracked drifters were deployed in the northeast Pacific Ocean as part of a joint research program with the Universities of Alaska and British Columbia to monitor the structure and variability of the Gulf of Alaska circulation at depths of 100 to 150 m. The study also includes the deployment of two deep-sea current meter moorings to monitor the long-term changes in absolute flow structure over the two-year duration of the experiment (R.E. Thomson).

The sensitivity of large-scale ocean models to different representations of small-scale mixing has been examined in context of the Geophysical Fluid Dynamics Lab ocean model (G. Holloway, P. Cummins).

An analysis of linear trends in steric sea level obtained from the 27-year hydrographic record from Station PAPA (50°N, 145°W) indicates that sea levels in the northeast Pacific are rising at approximately 1 mm/year relative to the 1000 m reference level, and that 67% of this change is due to thermal expansion at depths below the 100 m deep surface layer. Dilution of the surface layer is also contributing to the trend. The results are consistent with possible climate-induced sea level rise due to increased concentrations of "greenhouse" gases in the atmosphere. At present the trend is of marginal statistical significance. Another decade of observations may be required before we can have complete confidence in the observed trend (R.E. Thomson, S. Tabata).

(iv) Forecasting. A major review paper, summarizing all the numerical models developed by the Institute of Ocean Sciences for the system consisting of the Strait of Georgia, Juan de Fuca Strait and the Puget Sound, has been accepted by the journal "Oceanography and Marine Biology: An Annual Review". T.S. Murty and J.A. Stronach (Pacific Ocean Sciences Ltd.) visited Dr. J. Backhaus at Hamburg to initiate discussions on Phase II of Canada-Germany collaboration on developing advanced three-dimensional models, for the Straits of Georgia and Juan de Fuca (T.S. Murty).

The contract with SeaConsult Marine Ltd., of Vancouver on the evaluation of potential tsunami levels for the Pacific coast of Canada was completed. The final report is expected to be submitted soon. Collaboration with the U.S. on evaluating tsunami threat to the Pacific northwest region of North America is continuing (T.S. Murty).

The development of a finite element barotropic tidal model of the southwest coast of Vancouver Island for the Marine Survival of Salmon Project was undertaken and its results were compared with both observations and other numerical models. In conjunction with Andrew Bennett at Oregon State University, work was also begun on the development of a 3-D thermocline model of the North Pacific Ocean (M. Foreman).

As part of a joint program with DOE and MOT, two large meteorological buoys were installed at the outer limit of the Canadian Exclusive Economic Zone, and a network of coastal wave buoys was maintained. A study of the significance of interactions between waves and tidal currents was completed by Pacific Ocean Sciences, Ltd., which showed that this effect is important for many areas on the B.C. Coast. A test of the feasibility of running wave models locally, under the control of the operational meteorological forecaster, was begun (J. Garrett).

(v) Processes. A series of laboratory grid-stirring experiments, with two-layer systems stably stratified by both heat and salt, showed that heat and salt are not necessarily transferred at the same rate, with implications for turbulent transfers in the ocean (A. Gargett).

A new "large-eddy" approach has been suggested for remote sensing of turbulence kinetic energy and its dissipation rate (E), using acoustic Doppler profiling techniques. A preliminary comparison of E values determined by this technique and by standard microscale velocity measurements is encouraging (A. Gargett).

Research continues on the parametric representation of sub-gridscale processes for large-scale ocean models aimed at climate research. Both statistical dynamical theory and detailed numerical modelling are used. One of the more unusual results is a demonstration of how internal gravity wave "breaking" can sustain a mean counter-gradient buoyancy flux. A larger scale eddy representation, called "anticipated vorticity", has been re-examined to find that the numerical implementation of this method can be made more than 1000% more efficient than is presently used.

A new numerical hydrodynamical technique was developed so that fluid flow past irregularly shaped boundaries can be treated with the accuracy and efficiency of spectral transform methods, compared with more traditional finite difference or element methods. Applications have begun with respect to internal gravity waves encountering seafloor topography (G. Holloway).

(vi) Observational Techniques. A fibre optic, fluorescence-based dissolved oxygen sensor, developed in conjunction with Seastar Instruments, was deployed at a depth of 100 m for a period of six days in Saanich Inlet. The instrument has a rapid response of less than 10 seconds and is capable of resolving variations of less than 0.1 mg/litre. Results provided the first time series measurements of high frequency oxygen variability from a moored oceanographic site. The observations proved the long-term stability and accuracy of the instrument in the moored mode and will assist in the development of a commercial sensor for general oceanic application (R.E. Thomson, T.A. Curran).

Sea-I Industries was contracted to produce a modified version of its Manata-II Remotely Operated Vehicle for oceanic applications at depths up to 2500 m. Requirements are for the development of a stable, rapidly towable (5 knots) oceanographic platform for use in deep-sea surveys in the northeast Pacific. Specific applications include synoptic surveys of hydrothermal vent regions and deep-sea turbulence measurements (R.E. Thomson, T.A. Curran).

A study of ice-cracking and break-up was begun using new acoustic methods of observations. Ambient sound was recorded in Amundsen Gulf at six frequency bands between 50 and 14,500 Hz, over the period April to August. This work was supplemented in 1987 with a broad-band (20 Hz to 22 kHz) recording from a three-dimensional array of hydrophones beneath the ice. The purpose of these observations was to elucidate the stages of ice cracking and eventual break-up, and to determine the acoustic signature of various cracking events. The broad-band measurements have been interpreted in terms of a theoretical model of cracking that is related to models of earthquake mechanics (D. Farmer).

An experiment was carried out in the Ocean Storms program to study turbulence in the upper ocean boundary layer. Using a novel deployment system in which an instrument package was suspended in the relatively quiet environment at 30-35 m depth, observations of surface waves and bubble clouds could be used to trace coherent features of the turbulence in the water above. Sidescan images showed the organization of bubble clouds into long horizontal columns aligned approximately with the wind. Multiple frequency echo-sounder and Doppler measurements allow delineation of bubble size distribution and vertical velocities. Clear indication of Langmuir Circulation was obtained and the results will be used to test various generation models for this type of circulation. On a similar front, ambient sound measurements from several locations have been used to probe the breaking of the surface waves. It has been learned that, with appropriate signal analysis, we can determine the wave period, group structure, mean density of breakers and the acoustic strength of the breaking events. Subtle influences of the bubble clouds on the acoustic signature have been identified and analytical techniques developed to use the structure of ambient sound to probe their distribution and behaviour (D. Farmer).

In addition to ambient sound studies and active sonar measurements of ocean surface processes discussed elsewhere, techniques are being developed for the study of flow structure and turbulence, using the method of acoustic scintillation. Sound travelling through an inhomogeneous medium accumulates variability from the structure of the flow through which it passes; the art of scintillation analysis concerns the extraction of useful information from the resulting signal. Two-dimensional arrays deployed in Cordova Channel have been used to acquire data that allows analysis of the turbulent structure of the flow; spatial aperture filtering has been successfully applied to profile properties along the acoustic path (D. Farmer).

The FLI (Fluorescence Line Imager) was flown over Barkley Sound as part of the MASS operation. The imagery showed the distribution of solar induced fluorescence from near surface chlorophyll. Observed fluorescence correlated well with simultaneous surface measurements of chlorophyll concentrations.

To test the correlation between solar-induced fluorescence that can be measured remotely with the FLI, and phytoplankton productivity, water-leaving radiance spectra were collected during a two-week cruise of the PARIZEAU off the west coast of Vancouver Island. Further work is planned on this problem as part of a cooperative research program with the Federal Republic of Germany.

Imagery of Barkley Sound was also produced from thermal and visible data provided by the Thematic Mapper on the Landsat satellites, and by an airborne Daedalus scanner. These showed thermal patterns, but lacked the sensitivity and spectral resolution to map phytoplankton.

GEOSAT altimetry data was evaluated for its potential to monitor mesoscale ocean dynamics in the north-east Pacific. Software was written to reduce satellite tracking errors by minimizing cross-over differences. This will be used to produce monthly composites of sea surface height anomalies (J. Gower).

(vii) Tidal and Current Surveys. A network of 21 permanent tide gauges and four temporary tide gauges was maintained in the Western Arctic and on the Pacific Coast. Data from these gauges were carefully processed and archived on a monthly schedule. The information is used for studies of mean sea level (e.g., IGOSS Sea Level Pilot Project), crustal movements and storm surges, as well as hydrographic surveys, oceanographic studies and the Tide and Current Tables.

In addition, two tsunami warning stations were maintained on the Pacific Coast. A prototype station using Meteor Burst mode for data transmission was operated at Queen Charlotte, telemetering data to Victoria once an hour or whenever a rapid rise or fall in water level was detected. Two additional Meteor Burst mode stations will be built on the outer coast in 1988. These stations will improve the reliability and speed of the Canadian Tsunami Warning Network (F.E. Stephenson).

The narrow passes project is proceeding on schedule. Current surveys of passes in the Stuart Island area (Whirlpool, Greene, and Arran Rapids) were carried out, as well as surveys in Sulphur Passage and Seymour Narrows. The current was measured during a complete spring and neap tidal cycle. A short current survey of Hayden Passage was carried out with the PENDER hydrographic field party, whereby a prototype digital current meter developed at the Institute of Ocean Sciences for hydrographic field parties was tested. It performed well in this first field application.

All CODE data obtained in the years 1979-81 have now been published and are available to the public. On two cruises on the PARIZEAU, Loran C drifting buoys were deployed to measure surface current rates and direction, for navigational information and to support various projects by fisheries scientists at Nanaimo, such as the study of crab larvae distribution (M.J. Woodward).

Explosive storms develop in the N.E. Pacific so quickly that forecasters must be alert to predict their growth. Before these storms can be modelled successfully, the rate of transfer of heat between the ocean surface, the deep ocean and the atmosphere must be understood. The Ocean Storms program in the autumn of 1987 in the N.E. Pacific combined the expertise of 30 Canadian and American scientists to examine this heat transfer, by observing the atmosphere and ocean for several months with airplanes, moored instruments, ships and ocean drifters. The intensive field program ended in November, 1987 and the last moorings were recovered in June, 1988. The results of this work are still being processed and over the next few years the predictive models will include the new physics of these storms (W.R. Crawford, S. Tabata, D. Farmer).

What happens to the water along the west coast of Vancouver Island? Our previous studies with moored current meters showed a northward Vancouver Island Coastal Current near the coast, and in summer a southward flowing current near the shelf break. Over the past few years we have seeded these waters with Loran C drifters for a month or so in the summer to see how well the near-surface water is "trapped" on the continental shelf. We have found that the Tully Eddy off the mouth of Juan de Fuca Strait does indeed "hold water", but not as well as expected. More surprising, we found that the flow on La Perouse Fishing Bank is much slower than found in surrounding waters, and the Vancouver Island Coastal Current sometimes squirts away from the coast just south of La Perouse Bank. These drifter studies will continue, as part of the MASS program, to determine if other preferred sites of these offshore flows exist along the island (W.R. Crawford, G. Jamieson).

A computer model was developed to study the effect of a proposed training wall in the Annacis Channel of the Fraser River upon the stability of this waterway (part of the trifurcation below New Westminster). Both model and field observations to verify the results were completed in December, 1987.

Time series analyses in the Fraser River were continued in the seaward reaches to measure currents near the interface of an advancing salinity wedge.

A computer-graphic film was produced to simulate the movement of a pollutant in the Fraser Estuary, as affected by the interaction between tides and river discharges.

An earlier technique to track oil spills from the air during periods of poor visibility was modified. This technique makes use of floating transmitters; the modification consisted of replacing the previous Inertial Navigation System by a portable Loran C inside the aircraft. The new navigation system was successfully tested and subsequently applied to inspect an off-shore dumping site of gypsum, at the request of Environment Canada (A.B. Ages).

Revised "100 - year" flood levels at Tuktoyaktuk were estimated on the basis of observed driftwood levels and numerical model studies. An interactive irregular grid generation and editing package was developed for use with finite element tide and storm surge numerical models (R.F. Henry).

(b) Ocean Chemistry

(i) Beaufort Sea Oceanography: NOGAP Project. The project, started in 1986, is being carried out to measure (1) the natural hydrocarbon sources and sinks for the continental shelf in southern Beaufort Sea and (2) the magnitude and controls for the regional primary productivity in Arctic waters. A successful sampling program was carried out to collect time-series data of water geochemistry, physics and biology on a transect across the centre of the Beaufort Shelf, starting from late winter of 1986 and following the processes through spring breakup, with field work done in ice and throughout the summer from the CSS Tully. Four large sequential sediment trap moorings were recovered in the summer cruise after deployment under the ice in 1986. Supporting studies have been carried out on (1) inputs of materials from the Mackenzie River, including water flow, hydrocarbons, particulates and other oceanographic properties, (2) bottom resuspension in response to storms, (3) the effect of storms on microbial populations and their ability to degrade hydrocarbons, (4) the geochemistry of hydrocarbons by tangential cross-flow filtration techniques, (5) satellite data on sea-ice distribution and Mackenzie River plume structure. A unique, comprehensive and complete data set extended from March to September, 1987 was collected for interpretation of the arctic processes in the Beaufort Sea shelf area. A model describing the production and transport of natural hydrocarbons on the Beaufort Sea shelf is being constructed (R.W. Macdonald, W.J. Cretney, M. Yunker, K. Iseki)

(ii) BIOS. Ocean Chemistry participation in the BIOS (Baffin Island Oil Spill) project culminated in the publication of a special issue of the Journal ARCTIC on various aspects of the study: biodegradation; fate of chemically dispersed oil; effects on sediment on the biogeochemistry of oil degradation; description of the experiment (W.J. Cretney).

(iii) Contaminant Chemistry. The program studies the levels, effects and pathways of chlorinated hydrocarbons, metals and hydrocarbons in the waters of the B.C. coast and rivers. The project on chlorinated hydrocarbons is being conducted within the Fraser River system to examine the body burdens of toxic chemicals in fish. Chlorophenols, DDTs, and PCBs were measured in starry flounders collected near a large municipal sewer outfall at the mouth of the North Arm of the Fraser River. Muscle tissue contained maximum chlorophenol levels about half of the Canadian limit and one tenth of the limit for PCB's in edible fish. Comparison of matched tissue samples from the polluted zone and an adjacent reference area showed statistically significant higher levels of all target compounds in muscle tissue samples from the outfall areas, except for DDD which was greater in the reference area. Bone and liver tissues were enriched in PCBs and DDTs (I.H. Rogers). Another project studies the juvenile chinook salmon overwintering in the upper Fraser River between Prince George and Quesnel. The fish survive exposure to treated pulp mill wastes and muicipal sewage in water at 0.5° C under shore ice, and they typically reside in areas of cobble. Comparison of body burdens of chlorophenols and chloroguaicols in fish taken in November, 1986, with fish sampled in March, 1987, showed statistically higher levels for five out of six target compounds after the winter exposure. The compounds, 3,4,5-trichloroguaiacol and tetrachloroquaiacol (residues of pulp bleaching) were most concentrated in the river water and in the fish (I.H. Rogers).

A four-year study of arsenic in interstitial waters from the sediments of two B.C. coastal fjords was completed in 1987. The study centred around the hypothesis that arsenic contained in mine tailings discharge to the inlets may result in an increase in the availability of the element through conversion to organic derivatives. For the first time quantifiable amounts of three organoarsenic moieties were found in the pore waters of marine sediments of both natural and anthropogenic origin. In Rupert Inlet, arsenic exchange sediment and water was insignificant. In Alice Arm, arsenic flux was negative from the deposited tailings. Other trace metals in pore waters of mine tailings deposited on inlet floors were studied using a new analytical method having improved recovery (J.A.J. Thompson).

An international symposium on Marine Ecosystem Enclosure Experiments was held in Beijing in May, 1987 to mark the completion of a 3-year cooperative project between Canada and China on the application of the enclosure techniques to study the pathways and fate of pollutants in the marine environment. These experiments were conducted in both Xiamen, China and at Patricia Bay, B.C. Forty-four papers were included in the abstract volume of the Symposium, with participants from Canada, China, U.S.A., Federal Republic of Germany, Netherlands, Norway, U.K. and Hong Kong. A symposium proceedings will be published by IDRC, the funding agency (C.S. Wong).

(iv) Centre for Ocean Climate Chemistry. The Centre for Ocean Climate Chemistry, as a focus of DFO activities in this area, was established as one of the DFO centres of disciplinary expertise. A unique manometric system for fundamental calibration of CO_2 standards, based on PVT measurements, was set up as a Canadian National Facility. The system is capable of measuring pressure to 0.005 mm Hg. Intercalibration with other standards under the WMO BAPMON system is being conducted (C.S. Wong).

An oceanic program for CO_2 using container carrier ships is being conducted regularly between Vancouver, B.C. and Brisbane, Australia six times a year to measure partial pressure of CO_2, nutrients and other chemical and physical oceanographic properties. During the weak El Nino in 1986, a sudden drop in nutrients to zero was observed in the December, 1986 transect across the Pacific. The partial pressure difference in CO_2 between atmosphere and ocean again decreased to about one-third its usual peak of about 100 ppm at the equator. The oceanwide decrease in nutrient and CO_2 in surface equatorial ocean was far more extensive than previously thought and has implications for CO_2 modelling (C.S. Wong).

An ocean biogeochemical flux program involved the deployment of free-floating sediment traps in the upper ocean (0 - 1000 m), and automated sequential sediment traps moored at 3800 m at Ocean Station P (50° N, 145° W) and 500 m depth for a coastal station at La Perouse (48° 32'N, 126° 24'W) off the west coast of Vancouver Island. Time series data since 1982 for the deep ocean station indicate very marked interannual and seasonal variabilities for the flux of materials, including organic carbon, nitrogen, carbonate and opal, raining into the deep ocean environment. The mercury flux was found to be almost equal to the atmospheric mercury flux input into the ocean. Data from the coastal station indicate peak flux during the winter months, possibly from terrestrial input rather than biogenic input, with seasonal peaks in spring and summer. The program will be part of the Pacific JGOFS (Joint Global Ocean Flux Study) now being formed for the North Pacific countries (C.S. Wong).

12. Gore and Storrie Limited, Water Resources Division

(a) Numerical modelling

The RAND 2-dimensional water circulation and estuary model has been generalized for various boundary conditions no longer requiring modifications to the code for each situation. The model was used in studies of Yellowknife Bay, Ashbridge and Humber Bays (Toronto) and Britannia Beach (Ottawa).

A laterally-averaged reservoir model (LARM), originally written by Edinger (1979), has been modified to allow a moving upstream boundary. Formerly the upstream boundary was fixed which could not reproduce the seasonal water level changes. The model was applied to thermal modelling of the Oldman River reservoir.

A stochastic model was developed for nutrients in rivers. This was an extension of the development of a stochastic dissolved oxygen model for rivers. The model was applied to the North Saskatchewan River in Alberta.

(b) Field Studies

Dye dispersion studies and drogue tracking were carried out in Gravenhurst, Yellowknife, Ashbridge Bay and Humber Bay, and in the North Saskatchewan River in the City of Edmonton.

13. OceanChem Group, Dartmouth, Nova Scotia

(a) Ocean Dumping Control Act Permits

In support of applications by Public Works Canada for open-water disposal permits under the Ocean Dumping Control Act, samples were collected and analyzed from 55 harbours throughout the Atlantic region. The samples were analyzed for mercury, cadmium, lead, zinc, copper, PCB, DDT, particle size, total carbon and oil and grease. Most of the harbours contained contaminants at levels less than those set in guidelines of the Act and the sediments could be jettisoned in the ocean.

(b) Fourth ODCARF - Atlantic Workshop (February, 1987)

Under contract from Environment Canada, the firm facilitated the biennial workshop on research and projects related to the Ocean Dumping Control Act. Presentations were made covering eleven projects and there was a discussion on research needs within the region relating to ocean disposal. The proceedings were edited by S. MacKnight (Environment Canada, 1987).

(c) Seventh International Ocean Disposal Symposium

This symposium, convened by S. MacKnight of Oceanchem, attracted over 100 participants from a total of 20 countries. Topics focussed on the environmental consequences of contaminants entering or residing in the system. Proceedings were edited by S. Macknight.

(d) Neguac Sewer Outfall Impact Study.

An outfall for treated sewage was proposed for the village of Neguac on the Gulf of St. Lawrence shore of New Brunswick. The outfall would be discharged into Neguac Bay, a small embayment mostly enclosed by sand barrier islands. The study showed that circulation would have directed the discharge towards a large aquaculture facility. Recommendations were made for a different outfall location.

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15. Addresses of Reporting Groups

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VIII HYDROLOGY

Compiled by: E.M. Nicholson

1. Introduction

The International Association of Hydrological Sciences (IAHS) is the oldest and foremost of the international nongovernmental organizations dealing with hydrology and water resources, including glaciology. It was established in 1922, incorporating the International Commission of Glaciers which had been set up in 1894, to bring together individual hydrologists to promote the science that involves them. It is one of the more active of the seven associations which together form the International Union of Geodesy and Geophysics (IUGG). [The IUGG associations and their Canadian representatives are given on pages viii-ix, ed.].

The aims of IAHS include the promotion of the study of hydrology, the provision of means for discussion, comparison and publication of results of research, and the initiation and coordination of research that requires international cooperation. To fulfil these aims the Association organizes general assemblies, symposia and workshops in various parts of the world, publishes the proceedings of these meetings and special monographs, publishes a quarterly scientific journal, contributes to a wide range of international initiatives and generally fosters activities and collaboration in hydrology and water resources.

At present, Dr. V. Klemes, National Hydrology Research Institute, Environment Canada is the President of IAHS.

There are six scientific commissions within the Association, each dealing with a specific area in hydrology including glaciology, and in addition one specialist committee. These are:

International Commission on Surface Water (ICSW)
International Commission on Groundwater (ICGW)
International Commission on Continental Erosion (ICCE)
International Commission on Snow and Ice (ICSI)
International Commission on Water Quality (ICWQ)
International Commission on Water Resources Systems (ICWRS)
International Committee on Remote Sensing and Data Transmission (ICRSDT)

Most, but not all countries which are members of IUGG, have a national committee for IAHS, which is usually a subcommittee of the national committee for IUGG and appointed by the national academy of science or equivalent body. In Canada, the Associate Committee for Hydrology (National Research Council of Canada) is the national committee for IAHS.

The following National Correspondents provide Canadian contributions to IAHS:

ICSW, Dr. W.E. Watt, Dept. of Civil Engineering, Queens University

ICGW, Dr. R.E. Jackson, National Water Research Institute, Environment Canada

ICCE, Dr. E.D. Ongley, National Water Research Institute, Environment Canada

ICSI, C.S.L. Ommanney, National Hydrology Research Institute, Environment Canada

ICWQ, Dr. B.J. Adams, Dept. of Civil Engineering, University of Toronto

ICWRS, K. Adamowski, Dept. of Civil Engineering, University of Ottawa

ICRSDT, J. Whiting, Saskatchewan Research Council
Dr. B.E. Goodison, Atmospheric Environment Service, Environment Canada

National Representative for IAHS: Dr. Carolyn Miller, Executive Secretary, NRCC Associate Committee for Hydrology.

The Association has had individual members since 1983. The membership consists of hydrologists named by National Committees of the member countries from amongst those hydrologists with established reputations who have played, or who are playing, a substantial part in IAHS activities. Consequently, individual hydrologists seeking membership of the Association should approach their National Committees to have their names registered as candidates for membership. There is no membership fee. The Secretary General will publish a list of members of the Association from the names forwarded to him by National Committees.

Whereas in previous editions of the Canadian Geophysical Bulletin, a report on glacier studies has constituted a separate chapter, the Associate Committee on Hydrology has decided that this report will now form part of this chapter on Hydrology [ed.].

2. Surface Water Hydrology (E. Watt, International Commission on Surface Water, Department of Civil Engineering, Queen's University at Kingston).

(a) British Columbia

C.H. Coulson, Hydrology Section, Ministry of the Environment, directed projects on the regionalization of peak flows. In 1987, five regions (out of 8) had procedures in place for estimating peak flows from ungauged streams. His nine-chapter manual of operational hydrology for B.C. is nearing completion. It will be used by technical and professional staff in regional offices and in head office.

W.G. Bailey, Department of Geography, Simon Fraser University, studied energy and water balances of alpine environments. In 1987, research was conducted on Scout Mountain in south-central British Columbia. Measurements of radiation, energy and water balance components were made during winter, spring and summer conditions. Physically-based models of heat and mass transfer are being developed.

(b) Alberta

D. Andres, H. Hudson, G. Van Der Vinne and L. Wojtiw, Alberta Research Council, through the Alberta Co-operative Program in Surface Water Engineering, conducted research to enhance the management of water resources in Alberta. Areas of activity included the evaluation of ice forces on bridge piers, ice jam studies, river mechanics (bed and bank scour), surface water hydrology, forest hydrology and the study of sediment yield, transport and deposition. The focus in 1987 was primarily on forest hydrology. As assessment of the impact of logging on the hydrologic regime of the Tri Creeks watershed was completed. Also, 20 years of scour measurements on the sand bed rivers were assembled for analysis. Work is continuing to define the hydrologic characteristics of small basins within the basin of the North Saskatchewan and Battle Rivers. The program to document freeze-up on the North Saskatchewan River and breakup on the Athabasca River was also continued. A technique has been developed to relate the response (vibration) of a bridge pier to the force of a moving ice floe. This should simplify and reduce the costs of the measurements of ice forces on bridge piers.

(c) Saskatchewan

In 1970, the Hydrology Division of PFRA initiated a study to determine gross and effective drainage areas tributary to active and discontinued hydrometric gauging stations in the prairie provinces. In 1975, PFRA accepted responsibility, on a continuing basis, for delineating gross and effective drainage areas in consultation with the Provinces of Alberta, Saskatchewan and Manitoba and Water Survey of Canada. In 1987, a third addendum to PFRA Hydrology Report #104 entitled "The Determination of Gross and Effective Drainage Areas in the Prairie Provinces" (1983), was prepared; it will be distributed in 1988.

Since 1972, the Hydrology Division of PFRA has been updating potential gross evaporation estimates for 14 key stations in the Prairies using methodology based on the Meyer Formula. Recently, concern has been expressed regarding the validity of gross evaporation estimates in light of the apparent significant trend of increasing gross evaporation. In 1987, the basic data and the methodology were revised to correct the apparent inadequacies. Gross evaporation for the 14 key stations in the Prairies has been recalculated for the entire 1911-86 historic period using the revised methodology and data.

The Hydrology Division of PFRA initiated a Spring Runoff Monitoring Program in 1974 to provide information on snowmelt runoff from small prairie watersheds by monitoring the response of selected reservoirs. The program provides valuable data on runoff characteristics (i.e. hydrograph shapes, volumes, peaks, etc.) for small prairie watersheds. PFRA Hydrology Report #112 was prepared in August, 1987 to document information collected at 17 sites in Saskatchewan and at 7 sites in Alberta during the 1987 snowmelt (spring) runoff period and to summarize pertinent information obtained during the program's operation from 1974 to 1987.

B. Kallenback and A.B. Banga, Saskatchewan Water Corporation, undertook a project to determine depression storage and artificially drained areas using satellite imagery. The project was completed in 1987. Depression storage parameters were determined (using satellite imagery) but the data could not be readily transformed into a usable format. Artificially drained land could not be determined to an acceptable level of accuracy using satellite imagery.

M. Aaston, A. Banga and E. Light, Saskatchewan Water Corporation, completed a report on Calculation of Magnitude and Frequency of Peak Flows in Saskatchewan. The province was divided into what were considered to be 12 hydrologically homogeneous areas. Prospects of the study included peak flow and flow volume frequency analysis for over 300 hydrometric station locations and a median unit runoff map for the province.

(d) Manitoba

V.M. Austford and colleagues in the Water Resources Branch, Manitoba Natural Resources, continued work on three major projects. A detailed report for Phase 2 of the Canada-Manitoba Agreement Respecting Flood Forecasting reached the final draft stage. This report describes the application of the HSPF hydrologic model to three smaller watersheds in southwestern Manitoba: Willow Creek, Gopher Creek and Elgin Creek, and investigations of stream channel routing methodologies and unique adaptations of the HSPF model to the prairie environment. Application continued of the Environment Canada 1-Dimensional Dynamic channel routing model to the Red River from Emerson to Winnipeg. This work is primarily being done by Environment Canada in Ottawa, with data and advice provided by the Manitoba Water Resources Branch. It is anticipated that this project will be completed in 1988. A number of projects to modify discharge from artesian aquifers into agricultural drainage systems have been completed in recent years. Methods are being investigated to overcome severe icing problems associated with low flow conditions in agricultural drains during the winter.

(e) Ontario

L. Wong, A. McCorquodale and M. Sanderson, Great Lakes Institute, University of Windsor, conducted research into climatic change and Great Lakes levels. A hydrologic response model (Great Lakes) was developed and applied using various climate change scenarios and consumptive use and diversion scenarios. A final report was prepared.

V. Chris Lakhan and P.D. Lavalle, Department of Geography, University of Windsor, undertook two projects dealing with a) the testing, development and implementation of hydrological and sedimentological models to simulate erosion from flat (<2% slope); and b) the design, and construction of sediment traps to measure suspended sediment concentrations in the near and offshore areas of Point Pelee. In 1987, nine erosion and sediment yield models were reviewed and tested and modifications made to GAMES and EPIC under (a). Sediment trap designs were evaluated and materials acquired to build three sediment traps under b).

A.A. Kostaschuk, Department of Geography, University of Guelph, with J. Laternauer, Geological Survey of Canada, examined patterns and mechanisms of sedimentation in the Fraser River estuary, B.C. These included large-scale processes in channel, resuspension of bed-material, bedforms and bed-load, hysteresis effects in suspended sediment, salt-wedge sedimentary processes, and river mouth processes. In 1987 field work focused on salt-wedge sedimentary processes by examining circulation patterns and associated suspended sediment transport. Two papers were accepted for publication: Bedforms (Geo-Marine Letters), and Sediment Resuspension (J. of Coastal Research.)

G.J. Young and K. Hewitt, Department of Geography, Wilfred Laurier University, carried out a snow and ice hydrology project; a cooperative Canada/Pakistan research and operational hydrology project in snow and ice resources conducted in the Karakoram Himalaya; in cooperation with University of Waterloo, U.B.C., U. of Manchester and U. of New Hampshire. 1987 saw the third full summer field season in Pakistan; 3 MA theses were completed; and 2 Pakistani research fellows studied at WLU. A fourth field season is planned for 1988.

J.R. Pitblado, Department of Geography, Laurentian University, examined the associations between selected lake (surface) water quality parameters and reflectance data derived from airborne and satellite remote sensors. Emphasis was placed on the discrimination of acidic and non-acidic lakes (300) in the Sudbury and Algoma areas of northeastern Ontario. The following results were obtained in 1987. Certain parameters (particularly Secchi depth and dissolved organic carbon) may be predicted with confidence using sensor responses with regression models; image processing techniques provide reasonable discrimination. Separation of these lake classes is enhanced when the spectral/spatial resolution of the sensor data increases. Procedures are to be refined/reviewed in 1988.

S.Beltaos, B.G. Krishnappan, Y.L. Lau, J. Marsalek, H. NG., G. Tsang and J. Wong, Rivers Research Branch, National Water Research Institute, conducted field, laboratory and theoretical studies to develop knowledge and build predictive models for runoff processes and contaminant transport through the land-water interface; riverine transport, dispersion and interaction of sediments and pollutants; river ice formation, evolution and effects with emphasis on frazil ice, anchor ice and ice jams. In 1987, the group contributed extensively to a UNESCO Manual on Urban Drainage; quantified and showed importance of non-point sources of pollution in the Upper Great Lakes connecting channels; initiated work on riverine transport and flocculation of fine sediments; supervised development of a 2-D transient dispersion model by a doctoral student; and completed development of a material suitable for room-temperature, laboratory study of river ice breakup.

T. Roulet and A. Hill, Department of Geography, York University, continued ongoing research which includes studies of the interaction between groundwater and surface runoff systems in headwater wetlands and the evaporative flux of water from northern wetlands. This work is being undertaken to assess the hydrological significance of wetlands in relation to adjacent terrestrial and aquatic environments. Research is concentrating on the flux of water and materials associated with the flux of water. In 1987, work was completed on a small southern Ontario headwater wetland. New field sites have been established in the subarctic-boreal forest region and this work will continue for the next few years. In addition, sites are being established to assess the potential significance of climate change of natural wetland environments.

J.M. Buttle, Department of Geography, Trent University, carried out two projects. The first (project a) dealt with groundwater-streamflow interactions in a forested catchment during snowmelt - an investigation of the role of groundwater upon runoff generation during snowmelt based on hydrometric and environmental isotope techniques. The second project (b) dealt with field monitoring of metolachlor concentrations in surface runoff, tile drainage and streamflow in order to assess the hydrologic pathways of herbicide transport and the influence of application technique upon herbicide losses in streamflow. Progress on project (a) in 1987 included determination of hourly inputs of meltwater to the soil surface. Moisture contents and fluxes down an instrumented hillslope were assessed using soil coring and a tensionmetric system. Deuterium contents of snowmelt, soil moisture, groundwater and streamflow have been employed to determine the groundwater contributions to runoff. On project (b) metolachlor loadings to streamflow were compared for two application techniques (pre-emergence surface broadcast and pre-plant incorporated) using runoff plots, weirs and streamflow sampling. A comparison with 1986 results highlighted the importance of saturation overland flow as a mechanism for flushing metolachlor into receiving water bodies.

W.E. Watt, Department of Civil Engineering, Queen's University, carried out research in three areas: real-time flood forecasting, flood frequency analysis using an expert system, and modelling quantity and quality of agricultural drainage. In 1987, a CJCE paper describing the development of a transfer function-noise real-time forecasting model for the Boyne River was published. Work continued on development of similar models for basins in Ontario and New York. In addition, a physically-based continuous model for agricultural areas was developed; it was reported in two conference papers: CSCE (Montreal) and MOE (Toronto).

D. Farley, Inland Waters Directorate, Environment Canada and S. Beltaos, Rivers Research Branch, National Water Research Institute, began work on the development of a non-proprietary comprehensive numerical river ice model. The main in-house participants will furnish field data and provide numerical modelling and river ice expertise related to their particular experiences. Collaborators include the following agencies: IWD, B.C. Hydro, Manitoba Hydro, Ontario Hydro, New York Power Authority, Hydro Québec, Alberta Environment, Ministère de l'Environnement du Québec, Ontario Ministry of Natural Resources, N.B. Dept. of Municipal Affairs and Environment, Dept. of Fisheries and Oceans, and US Cold Regions Research and Engineering Laboratory.

M. Sydor and G. Brown, Inland Waters Directorate, Environment Canada, are undertaking development and testing on a generalized expert systems model (REGUSE) for flow regulation of reservoir/channel networks. The model employs the out-of-kilter network flows algorithm as part of the inference engine. New features in this model include channel routing, backwater routines, and a variable number of unit time periods within the time horizon for which a simultaneous solution is required. In 1987, the model was tested with Qu'Appelle Basin (Saskatchewan) and Winnipeg River (Ontario) data.

K. Wiebe and D. Harvey, Inland Waters Directorate, Environment Canada, began development of a distributed, modular hydrologic model which can make effective use of remotely-sensed data inputs.

K. Adamowski, Department of Civil Engineering, University of Ottawa, carried out three projects, dealing with (a) space-time autoregressive-moving average (STARMA) modelling of regional precipitation, (b) Kalman Filter and modelling of space-time rainfall using radar rain gauge observations, and (c) nonparametric flood frequency analysis with historic information and hydroclimatically defined mixed distributions. Progress in 1987 included (a) development of an aggregate regional forecasting STARMA model for a watershed in Southern Ontario, (b) development of a model which integrates a square grid mean aerial rainfall utilizing raingauge measurements with a state-space model based on Z-R relationship which uses radar measurements and incorporates a discrete Kalman filter to provide real-time parameter estimation, and (c) development of the nonparametric kernel probability density estimation methodology and application to real and synthetic data. The nonparametric approach is particularly useful for mixed distributions (i.e. snowmelt vs rainfall). Inclusion of historic information increases the accuracy of flood estimation.

(f) Quebec

V.D. Hoang and R. Poulin, Ministère de l'Environnement, developed a mathematical model of streamflow simulation for a complex hydraulic system and implemented a real line system in order to forecast the level of lake Saint-Pierre during the free-water period between May 15 and October 31.

(g) New Brunswick

N. El-jabi, School of Engineering, Université de Moncton, carried out three projects.

Evaluation hydroéconomique des projets hydrauliques à buts multiples : Ce projet a pour but de construire un modèle théorique et un logiciel d'aide à la conception qui permet l'optimisation des interventions à buts multiples en milieu hydrique.

Modélisation statistique et régionalisations des crues au Canada : Le but de ce projet est d'obtenir une meilleure caractérisation régionale des crues. Cette connaissance permettra une conception plus économique et une gestion plus rationelle des ouvrages de retenue.

Etude hydrodynamique des embâcles de glacè et leur caractéristiques au Nouveau-Brunswick : L'objectif de cette étude est de formuler la relation qui caractérise les embâcles de glace sur les rivières. Cette relation doit permettre une gestion efficace des crues d'hiver dues à ces formations glacières.

(h) Nova Scotia

R.J. Pakczynski, School of Engineering, Acadia University, initiated a new project. The relatively heavy load of suspended sediments is observed in the Minas Basin when tides in excess of 12 m cause intensive vertical mixing and high turbidity of the water column. Laboratory experiments have been conducted to study the inter-relationship between the Minas Basin sediments and crude oil spilled onto water. Measurements of oil and the suspended particulate matter interaction, using a particle counter and an electron microscope, show that a relatively large fraction of oil is removed from the slick and is carried into the water column by suspended estuarine particles.

3. A Survey of Hydrogeological Research in Canada (R.E. Jackson, International Commission on Groundwater, National Water Research Institute, Burlington).

At present it is estimated by the Institute for Groundwater Research of the University of Waterloo that there are about 400 hydrogeologists and ground water engineers in Canada. This relatively small number of Canadian hydrogeologists is partly due to the small size of the research and regulatory agencies in the federal and provincial governments and partly to the relatively low Canadian use of ground water as a component of total water use (25% vs. 50+% in the USA).

Hydrogeology and/or ground-water hydrology is taught today at about a dozen Canadian universities. The largest program is that at the University of Waterloo. Since its inception in 1971, the hydrogeology program at Waterloo has produced 140 graduates, including 16 Ph.D.'s. There are active, but smaller, graduate programs at the Universities of British Columbia, Alberta, Windsor, Toronto, Carleton, McGill, Laval, New Brunswick, Memorial and the Technical University of Nova Scotia. At present there are approximately 150 graduate students enrolled in these programs.

Writing 20 years ago, one of the founders of Canadian hydrogeology, Peter Meyboom (1966), observed that there existed two trends in hydrogeology. He referred to the first of these as the "inward look ... directed at the very fundamentals of flow in porous media", to which Meyboom himself had contributed through his studies of flow systems on the prairies. He felt that ultimately these microscopic and macroscopic approaches would converge. This now seems to have occurred in contaminant hydrogeology with the development of the numerous small-scale test sites spread across Canada, but concentrated in Ontario, which are dedicated to the study of hydrogeological phenomena in well characterized bodies of granular sediments or fractured sediments or rocks. That is, the test sites have become sufficiently well defined to allow field-scale experiments to be undertaken; in some cases, these field experiments have induced further laboratory experimentation.

The first two sections of this report are concerned with work in contaminant hydrogeology in granular and fractured media, the third with progress in mathematical modeling and the fourth with work on the analysis of regional aquifer systems.

(a) Contaminant Hydrogeology in Granular Media

Field-scale testing in contaminant hydrogeology grew rapidly in the late 1970s with test sites being developed at the Chalk River Nuclear Labs of Atomic Energy of Canada Ltd. (AECL), northwest of Ottawa, and at the Canadian Forces Base, Borden, north of Toronto. Pickens and colleagues undertook several field tests at Chalk River using nonreactive and reactive tracers with the objective of determining the origin of the scale effect -- the large difference between laboratory column and field scale dispersivities first identified by Theis (1963). Pickens and Grisak (1981), then with the National Hydrology Research Institute (NHRI), ascribed this effect in the stratified outwash at Chalk River to aquifer heterogeneities and to the diluting effect produced by sampling from monitoring systems with large dead volumes. Pickens and colleagues (1981) also developed an injection-withdrawal test for determining the in-situ adsorption of a nonreactive tracer ^{85}Sr; the results of this test correlated well with the long-term behaviour of ^{90}Sr elsewhere in the same aquifer. More recently, hydrogeologists with AECL (Killey and Moltanyer, Water Resources Research, in submission) have conducted extraordinarily detailed tracer tests in another area at Chalk River using vertical continuous profiles of tracer concentration (radioiodine) versus depth, using 80 monitors and generating about 750,000 data points.

While the Chalk River tests have been analysed assuming that the tracer spreading was due to advection and dispersion, the Waterloo group have used an advection-diffusion model to explain the observed tracer distribution in a similarly layered aquifer at Borden (e.g. Gillham and Cherry, 1982; Sudicky et al., 1983). In this model lateral advection causes the rapid migration of the tracer through the more permeable layers with transverse molecular diffusion causing interlayer tracer transport; the net effect is non-Fickian transport behaviour (Gillham et al., 1984). These field observations were experimentally tested in a Plexiglass box containing a layer of sand sandwiched between two silt layers (Sudicky et al., 1985). They demonstrated that, in such media, the advection-diffusion model yields results that closely mimic the observed breakthrough curves. However, in experiments with a reactive tracer there was increasing divergence between simulated and observed results as the transport velocity was decreased (Starr et al., 1985).

Borden has also been the site of two natural-gradient tracer tests studying the transport and transformation of organic contaminants. The first test was conducted jointly by Stanford University and the University of Waterloo and involved the injection of bromide, chloride and five halogenated organic compounds into the Borden aquifer. In subsequent monitoring over a period of two years Sudicky (1986) examined the spatial variability of hydraulic conductivity in the test section of the aquifer, and showed that current stochastic theories of transport yield meaningful descriptions of the observed macrodispersion. The second test was concerned with aromatic contaminants derived from refined petroleum -- benzene, xylene and toluene. For these compounds Patrick and Barker (1986) of the University of Waterloo determined retardation factors ranging from 1.1 (benzene) to 1.6 (m-xylene).

Retardation factors have also been determined by NHRI hydrogeologists (Patterson et al., 1985) for six organic compounds migrating in outwash materials at the Gloucester, Ontario landfill. At this site Whiffin and Bahr (1984) of GTC/Intera (Ottawa, Ontario) conducted a purge well test to determine the efficacy of decontaminating the aquifer by pumping. The rest yielded both retardation factors and an estimate of the number of pore volumes to be purged to attain a specified level of decontamination (Jackson et al., 1985). Similar ground-water velocities were measured at the site by both a borehole dilution technique (Belanger, Ground Water, in submission) and the distribution of tritium in the aquifer (Michel et al., 1984).

Other studies concerning the migration and fate of organic contaminants are being undertaken at landfills throughout Canada. Barker of Waterloo and Reinhard of Stanford (Barker et al., 1986; Reinhard et al., 1984) have provided a particularly detailed account of the identity, quantitation and spatial distribution of organic contaminants migrating from the North Bay, Ontario landfill. Probably the largest plume of contaminated ground water in Canada is being purged from an outwash aquifer overlying fractured dolomite at Ville Mercier, south of Montreal; both units are contaminated with oil, PCBs and organic solvents (Poulin et al., 1985). This plume is now the subject of an intensive study by Locat and his colleagues at Laval University.

Complementing these studies of organic contaminant behaviour are several concerned with the ground-water geochemistry of radionuclides. Johnston and Gillham (1984) were concerned with the effect of stable Sr concentrations on the measured distribution coefficient for radiostrontium. Others have measured the partitioning of ^{90}Sr in aquifer materials at waste disposal sites (Jackson and Inch, 1983; Lyon and Patterson, 1984; Johnston et al., 1985). Dubrovsky et al. (1984) investigated the acidification of a uranium tailings deposit at Elliot Lake, Ontario and accounted for the geochemical evolution of the tailings water. Killey et al. (1984) and Champ et al. (1984) studied the speciation of radionuclides in ground waters at Chalk River.

Finally, electromagnetic methods have become commonplace in the identification of polluted ground water, due to the work of Greenhouse at Waterloo (Greenhouse and Monier-Williams, 1985) and the Geological Survey of Canada (Stephens and Graham, 1985).

(b) Contaminant Hydrogeology in Fractured Media

Field testing of the hydraulic and transport properties of fractured media began in Canada in the mid-1970s with the work of Gale and others on bedrock in the Maritime Provinces and Cherry and others on tills in the Prairie Provinces. This led to the identification by Grisak and Pickens (1980) of matrix diffusion from fractures as a major sink for solutes in transport. (Its conceptual similarity to Waterloo's advection-diffusion concept in layered porous media reflects the role that Cherry and Grisak's work on Prairie tills have played in Canadian thinking.)

Recent work has concentrated on the statistical characterization of the fractured medium, the development of methods for measuring its hydraulic transport and geochemical properties and the simulation of flow and transport, all of which have been prompted by the possibility that hazardous and radioactive waste disposal will take place in fractured rock.

Rouleau and Gale (1985) statistically characterized a fractured rock mass by detailed mapping of this fracture geometry, frequency and dimensions. Francis et al. (1985) identified the high permeability zones in a sandstone aquifer by hydraulic interference testing, geophysical logging and core inspection to establish hydraulic conductivity, anisotropy and fracture inter-connectivity. Bottomley et al. (1984) developed a borehole methodology to determine the geochemical properties of ground water in situ. Raven et al. (1985) instrumented a 200 m by 150 m by 50 m deep flow system in gneiss at CRNL and developed a fracture orientation- aperture model to describe flow and transport. Recent work by Gale et al. (1985) has shown that the cubic law, describing laminar flow in discrete fractures, may be invalid.

Novakowski et al. (1985) undertook an injection-withdrawal tracer test in similar rock nearby to determine dispersion within a single fracture. Feenstra et al. (1984) investigated the injection of wastes into a fractured sandstone. Hitchon et al. (1985) have simulated flow and aquifer response in a deep sandstone in the Western Canada sedimentary basin to determine its suitability for liquid waste injection.

(c) Mathematical Modeling and Systems Analysis

The development of mathematical (i.e. numerical or analytical) and systems models of hydrogeological systems is undertaken at four universities in Canada: U.B.C., Alberta, Waterloo and Québec.

Les Smith at U.B.C., together with his students, has investigated a number of processes, all of which have a hydrogeological basis. The first involved the simulation of the thermal, hydrologic and mechanical response of a fault zone during an earthquake event (Mase and Smith, 1987). The second concerned the hydrogeologic and thermal regimes of mountainous terrain (Forster and Smith, in press), which has shed light on how the advective transfer of heat by ground water effects the thermal regime of mountain systems. Finally, Smith and others (1987) have developed a three-dimensional stochastic model of solute transport in fractured rock masses and applied this to hydraulic and tracer testing.

Al Freeze, also at U.B.C., has developed a risk-based method for the engineering design of waste management facilities and has applied it to the investigation of the relationship between engineering design and regulatory policy (Massmann and Freeze, 1987).

At the University of Alberta, Frank Schwartz and his students have addressed a broad range of problems including the impact of coal strip mining on ground water levels (Schwartz and Crowe, 1987), saline soil genesis due to irrigation (Schwartz et al., 1987) and the development of an expert system to simulate organic contaminant transport (Schwartz et al., 1985). Also at Alberta, Allan Crowe and Fred Longstaffe have developed a coupled transport and geochemical code (based on PHREEQE) to simulate the transport of ionic species in brine solutions (Crowe, 1987).

Frind and Matanga (1985) of the University of Waterloo have adopted the stream function approach for the simulation of contaminant transport in order to achieve greater accuracy in the definition of the velocity field. Also at Waterloo, MacQuarrie employed Frind's principal direction, Galerkin finite element technique to simulate the transport of organic contaminants subject to biodegradation in a shallow aquifer where dissolved oxygen is the sole electron acceptor (MacQuarrie, 1988).

At INRS-Eau, a constituent research centre of the Université du Québec outside Quebec City, J.-P. Villeneuve and his coworkers have developed a stochastic model of pesticide movement in the unsaturated zone called VULPEST.

(d) Regional Aquifer Systems Analysis

Hydrogeological studies of aquifers continue to provide essential information on the groundwater supplies which are used by one quarter of all Canadians for drinking water.

Mark Trudell at the Alberta Research Council has been involved in studying the hydrologic effects of surface coal mining on the Alberta Plains and was responsible for all hydrogeologic aspects of assessing those flow systems containing coal beds, and for evaluating ground water recharge to the flow systems.

Garth van der Kamp and Harm Maathuis at the Saskatchewan Research Council are continuing SRC's tradition of maintaining an extensive observation well network and have recently undertaken detailed studies of the hydrogeologic properties of glacial tills and a detailed evaluation of the ground water resources of the Regina aquifer.

In Ontario, Mike Sklash of the University of Windsor has continued his studies of surface water/ground water relationships by measuring the flux of ground water entering the St. Clair River off Sarnia using seepage meters and minipiezometers. The streambed ground water was of complex isotopic origin (Sklash et al., 1986).

Within the consulting industry, much work on developing new ground water supplies is going on. For example, Derek Smith and Roger Woeller of Water and Earth Science Associates of Carp, Ontario, have found that buried glaciofluvial sand and gravel aquifers are the best targets for the development of communal water supplies in Eastern Ontario, i.e. > 100 gpm. In a few cases, however, they have been able to develop high volume supplies in the fractured carbonate bedrock aquifers.

At Waterloo, Bob Farvolden and his students are continuing to undertake studies of the hydrogeology of two of the major regional aquifer systems of Ontario - the Oak Ridges Moraine and the Waterloo tills. Several papers on the latter system will appear in the Canadian Geotechnical Journal.

Kent Novakowski of Environment Canada's National Water Research Institute has conducted a detailed assessment of the hydraulic properties of the bedrock flow system along the Niagara frontier. This study showed the existence of some very high heads in shales which are thought to be of ancient origin (Novakowski, in press).

In the Maritimes, hydrogeologists from Environment Canada and the Government of Prince Edward Island have been studying ground water discharge to the Winter River, in which basin are sited both of Charlottetown's well fields (Cruikshank et al., 1988). At the University of New Brunswick, Dale Bray and Gil Violette are developing a three- dimensional model of the main Fredericton well field which is hydraulically connected to the Saint John River.

(e) Concluding Remarks

Over 400 Canadian ground water hydrologists are actively involved in all aspects of ground water science and engineering. However, the work is unevenly spread across the nation. While Ontario, the Prairie Provinces and British Columbia all have active ground water research groups and those in Quebec and Newfoundland are developing rapidly, the Maritime Provinces have a weak research base despite being the region of highest per capita ground water use and one with numerous pollution problems.

4. Canadian Studies of Erosion and Sedimentation (E.D. Ongley, V/P International Commission on Continental Erosion, National Water Research Institute, Burlington, Ontario).

Table I characterizes the types of sedimentation and erosion studies underway in Canada as of February, 1988. The list is inevitably incomplete; however, its east to west organization mirrors the nature and geographical distribution of sediment studies in Canada. Sediment issues, nationally, tend to be increasingly focussed on the role of sediment in water quality. In prairie, alpine and northern terrains of Canada more traditional physical sedimentation issues remain important due to climatic controls (prairies) and ecological implications (e.g. Mackenzie River delta). An important development since the last review period is the detailed examination of long-term sediment records of Environment Canada.

Generally, Canadian work falls into four categories: (I) evaluation of regional and station data sets, (2) sediment-contaminant research (3) process studies, and (4) equipment evaluation.

(a) Evaluation of Regional and Station Data Sets

Much of the Canadian effort in data evaluation is part of Environment Canada's program to assess its sediment network data with a view to (I) rationalizing data collection activities and (2) generating knowledge of sediment behaviour in selected Canadian environments. This work has been undertaken in prairie, northern and alpine regions of Canada. Of particular interest is the observation in two such studies that sediment yield increases as basin area increases. This is contrary to most published data and opens up a number of intriguing questions about sediment provenance, transport and storage, and basin/channel characteristics. A significant by-product of this evaluation will be a time base against which to assess record shifts which may arise from climate change over the next several decades. Such data will, in hindsight, be very important in coping with changing hydrologic regimes.

(b) Sediment-Contaminant Research

Three types of environmental issues are represented in this research - - long range transport of airborne pollutants (LRTAP), nonpoint source phosphorus management, and contaminant pathways research. LRTAP has been principally an eastern Canadian issue (e.g. INRS-Eau), phosphorus management has long been a concern at the University of Guelph. The National Water Research Institute (NWRI) has a large national and international program focusing on sediment-contaminant pathways together with chemical, microbiological and physical studies of particle-to-particle and particle-boundary interactions for cohesive and non-cohesive sediment. Sediment toxicity assessment is a continuing research concern.

(c) Process Studies

Process studies involving rainfall-runoff, sedimentation and channel hydraulics are carried out in a variety of locations. A number of universities and NWRI carry out hydraulic studies of non-cohesive sediment transport. Research into cohesive sediment (wash load) transport is largely centered at NWRI in Burlington where two large circular flumes are being constructed for federal, university and private sector studies. Model development for phosphorus transport is being carried out at the University of Guelph. Other model development is located at several universities (mainly civil engineering and physical geography) and at NWRI. The National Hydrology Research Institute (NHRI) in Saskatoon examines soil erosion processes as part of its focus on physical hydrology. Other "pure" research questions, such as Holocene and glacier-lake sedimentation, are focused on alpine systems of the western cordillera. Dryland erosion continues to be of interest in prairie Canada.

(d) Equipment and Method Evaluation

Part of Environment Canada's assessment activities include evaluation of traditional sediment sampling techniques. Although not reported here, other non-standard techniques such as continuous-flow centrifugation, are being used across Canada for sediment-contaminant studies because of the large sample size required for organic contaminant analysis.

Erosion and sedimentation studies are at a critical juncture in Canada. Traditional sedimentation concerns are giving way to sediment in water quality issues. These, together with budget restraint by federal and provincial governments, are forcing a re-evaluation of the role of sediment data networks, of sampling technologies, and of physics and particle/biological/chemical interactions of the silt-clay fraction. Conventional models of sediment transport exclude or poorly characterize cohesive sediment. Because of environmental concerns over chemical pathways it is likely there will be major advances in cohesive sediment science in the next five years. Similarly, the traditional focus on nonpoint sources of sediment-associated phosphorus is being replaced by nonpoint source sediment-toxics (e.g. pesticides) issues.

TABLE 1: Erosion and Sedimentation Studies in Canada

Acadia University
R.J. Palczynski

(i) The interrelationship between the Minas Basin sediments and crude oil spilled onto water
Issue: Hydrocarbon contamination
- when tides in excess of 12 m cause intensive vertical mixing and high turbidity of the water column a relatively large traction of oil is removed from the slick and carried into the water column by suspended estuarine particles.

INRS-Eau
Université du Québec
H.G. Jones
M.H. Ouellet

(i) Surficial Sediments of Lake Saint-Jean, P.Q.
Issue: Deforestation and lake regulation on lake sediments.

(ii) Surficial Sediments of the Upper Saguenay River
Issue: Sediment-contaminants
- contaminated sediments from industrial pollution.

(iii) Palaeolimnological Evidence for Air-Borne Pollutants
Issue: Acid and Toxic Rain
- increased Hg, Pb, Zn, Cu, since 1940.
- data from remote Quebec lakes.

Univ of Guelph
W.T. Dickinson
G.T. Wall
R.P. Rudra

(i) Guelph Rainfall Simulator
Issue: Instrumentation
- overcome traditional limitations by measuring velocity, size-distribution, momentum and kinetic energy.

(ii) Discrimination of Soil Erosion Areas and Fluvial Sediment Sources
Issue: Sediment provenance
- provenance can be discriminated using physical and land use data.

(iii) Phosphorus Transport Model for Small Agricultural Watersheds
Issue: Phosphorus dynamics
- predicts seasonal phosphorus loadings.

National Water Research Institute
Burlington, Ontario, Environment Canada

(i) Sediment-Contaminant Pathways in River
Issue: Toxics pathways and suspended sediment
- hydrocarbon and PAH transport in contrasting discharge regimes in Mackenzie River
- metals and organic contamination pathways in North Saskatchewan River.

(ii) Hydraulic Studies of Cohesive and Non-Cohesive Sediment
Issue: Fluid mechanics of particles
- applications to channel stability under human interventions
- 2- and 3-dimensional model development.

(iii) Flocculation
Issue: Cohesive particle transport
- field program to measure flocculent conditions under seasonal changes of chemistry and microbiology

(iv) Measurement of Sediment Toxicity
Issue: Environmental contamination.
- microbiological methods to assess lethal and sublethal effects of contaminated sediments

(v) Vertical and Lateral Distribution of Fine-grained Sediment in Rivers
Issue: Sampling protocols for water quality.
- representative Canadian data are evaluated.

Water Resources Branch
Inland Waters Directorate
Environment Canada
P. Ashmore (U. Sask.)
M. Church-UBC

(i) Data Collection for suspended sediment
Issue: National and regional priorities
- navigation, reservoir sedimentation environmental impacts, water quality.

(ii) Analysis of regional data sets
Issue: Large scale monitoring
- specific sediment yield increases with basin area contrary to conventional wisdom.

(iii) Sampling Technology
Issus: Apparatus
- field precision of suspended samplers
- comparison of non-filterable residue with suspended sediment data.

P. Ashmore (U. Sask.)
M. Church & D. McLean (Vancouver)
R. Kellahals (Victoria)
C.P. Lewis (Victoria)
C.R. Neil (Edmonton)

(iv) Sedimentation Research
Issue: Regional issue
- Mackenzie River Delta (NWT)
- Churchill River Diversion (Man)
- Saskatchewan River Basin
- Fraser River

Univ. Toronto
J.R. Desloges

(i) Sedimentation in Glacier - Fed Lakes
- relationships amongst glacier fluctuations, sediment and water discharge, and climate.

Univ. Saskatchewan

(i) Evaluation of Bed Load Samplers
Issue: Apparatus
- scoop-type, drag bucket, 3MH-53 and 54

(ii) Sediment Transport in Saskatchewan R. Basin
Issue: Record analysis for regional interpretation
- spatial and temporal variability of load and concentration
- extreme events
- regime modification

Univ. of Calgary
G.R.E. Beckstead

Suspended Sediment Records
Issue: Station analyses
- Red Deer River, Pembina River
- existing records adequately characterize long term sediment transport and yield
- extreme event data may be inadequate

Alberta Research Council
R. Howitt

(i) Quantification of Soil Erosion in East-Central Alberta
Issue: Agricultural erosion
- measure and model water erosion and deposition
- 5 year project

Agriculture Canada (Br. Columbia)
J.C.W. King

(ii) Agriculture Watershed Hydrology
Issue: Agriculture practices.
- South coastal B.C.
- predict runoff and erosion potential for improved farming practices.

Simon Fraser Univ.
G. Brierley
G. Brooks
E.J. Hicklin

(i) Sediment Budget of B.C. Coast Mountains Rivers
- contemporary and Holocene sediment yields from Squamish River Basin (B.C.)
- test concept of "paraglacial sedimentation"

5. Snow and Ice Research in Canada (C.S.L. Ommanney, International Commission on Snow & Ice, National Hydrology Research Institute, Saskatoon).

The International Commission on Snow and Ice (ICSI) is interested in all aspects of glaciology, or the science of snow and ice, including ice in the atmosphere, glaciers, floating ice on lakes and rivers, sea ice, snow, permafrost and ice in the ground. Although ICSI now is part of IAHS, its interests and activities extend well beyond the traditional bounds of hydrology. Thus a report limited to hydrology will omit many ICSI activities, may deal inadequately with others and will likely overlap with reports from some related Commissions. In 1987, the Subcommittee on Glaciers was instructed by ACH to include their annual report with that of the ICSI Correspondent. Thus the long tradition of a separate report on glaciers in the Canadian Geophysical Bulletín has regrettably been broken.

This report includes material which would have been published in the glacier research chapter. In addition, it covers floating lake and river ice, snow and permafrost to the extent that they may relate directly or indirectly to hydrology. It is based largely on recent publications and events; by next year an appropriate reporting structure should be in place.

A recent highlight for many Canadian glaciologists was the hosting of the IUGG in Vancouver with its special symposia. Symposia on the Physical Basis of Ice Sheet Modelling, Modelling Snowmelt-Induced Processes, Large-Scale Effects of Seasonal Snow Cover and the Influence of Climate Change and Variability on the Hydrologic Regime and Water Resources featured many Canadian contributions. 1987 was also the year the International Glaciological Society (IGS) celebrated its Anniversary by hosting a one-day session on the history of glaciology and a symposium on remote sensing in glaciology. Canadians have always played a very active role in this society and Clarke, currently Vice-President, and Gold, a past President, both presented review papers. These, and other reviews, make frequent reference to work by Canadians. The National Student Conference on Northern Studies, held in November, 1986 in Ottawa, reported activities that will likely be indicative of some research directions for the future.

(a) Glaciers

Another very significant glaciological meeting, held in Whistler Village, B.C., in May, 1986, was that on fast glacier flow. Organized by Clarke of UBC as an American Geophysical Union Chapman Conference, it brought to the forefront the question of the nature of the glacier bed itself and its influence on flow. The published proceedings include Clarke's paper on subglacial till.

(i) Arctic Current glacier research will be discussed in a geographical context. Much work is now being done on Ellesmere Island. The ice-core project on Agassiz Ice Cap, recently transferred from the Polar Continental Shelf Project to the Geological Survey of Canada, continues to contribute interesting results. Theoretical problems associated with the interpretation of cores from this area include the effects of wind pumping, by Clarke et al., and improved flow models by Reeh et al. Borgeois has investigated the pollen record. Fisher and Koerner have assessed the rheological properties of ancient ice laden with microparticles. The latter heads a team that is establishing a climate history for the High Arctic using the ice-core records from the Agassiz, Devon and Meighen Ice Caps. The mass and energy balance of two small ice caps near St. Patrick Bay was studied by Bradley and Serreze, University of Massachusetts. Along the north coast, Jeffries, now with the University of Alaska, is continuing work started at the University of Calgary on ice islands, ice shelves and associated glaciers. Holdsworth, with the National Hydrology Research Institute (NHRI), has contributed further to an understanding of their development. Stewart and Bednarski studied structures in Dagger Glacier; Brochu those associated with the surface of Gilman Glacier; and Fisher and Evans, University of Alberta, debris-entrainment and ice falls in the vicinity of Phillips Inlet.

Results continue to be published on work undertaken by scientists from ETH, ZU^rich, on Axel Heiberg Island. Blatter found an interesting thermal regime in White Glacier and a stagnant ice body at its bed. Data from this glacier were used in a Soviet study by Kaser on the role of evaporation in mass balance.

Koerner continued to monitor mass balance at a number of High Arctic sites and proposed a technique for using glaciers as "climatometers". A resurvey of Meighen Ice Cap by Haythornthwaite shows a slight thickening in the centre when compared to the 1960 levels.

On Baffin Island, the Barnes Ice Cap work has now drawn to a close. Hooke et al. (University of Minnesota), Hanson and Dickinson, and Stolle and Killeavy have reported the latest mass balance data and the results of some theoretical studies. Dowdeswell, from Cambridge University, completed a study of tidewater-glacier sediments in Frobisher Bay using an outlet from the Grinnell Ice Cap.

(ii) Yukon Territory Another major palaeo-glaciological investigation is being carried out by Holdsworth using ice cores from the top of Mount Logan (YT). Reports have been published on some trace acid results and those relating to links with atmospheric nuclear testing. Recent analysis revealed a striking correlation between the precipitation record here and for parts of the Soviet Union, which is being investigated further. Johnson and University of Ottawa students are studying debris-covered and rock glaciers in the Dalton Range. He and Kasper looked at the drainage characteristics of a lake dammed by Kaskawulsh Glacier. To the north, Liverman has been studying sedimentation in ice-dammed Hazard Lake. Trapridge Glacier has been the primary focus of much of Clarke's work and one of his UBC students, Maxwell, has recently completed an assessment of the use of isotopes for studying subglacial processes.

Considerable public interest and comment was occasioned by the advance of Hubbard Glacier into Russell Fiord, its subsequent damming and the trapping of marine aquatic life. The glacier is one of many that rises in Canada and drains into Alaska. It appears to be undergoing a normal advance and will likely dam the fiord again.

(iii) Coast Mountains Studies in the Coast Mountains are now limited to Sentinel, Helm and Place Glaciers where Mokievsky-Zubok and Fogarasi (NHRI) have reported on recent mass balance results and an analysis of discharge data from Sentinel, and, to Wedgemount Glacier where Ricker, a consultant, and Tupper, BCIT, have continued mass balance and photogrammetric surveys. Pelto, U.S. Geological Survey (USGS), has recently been using remote sensing techniques to establish mass balance values for southeastern Alaska and northwest British Columbia; an area identified by Meier as being crucial in the assessment of the role of melting glaciers in the recent rise of sea level.

(iv) Interior Ranges In the Interior Ranges, Luckman and colleagues from the University of Western Ontario, including H.M. Watson, have reported glacier advances in the Premier Range. Luckman and McCarthy have done extensive field work in the area of Glacier National Park and in the Rockies around the Columbia Icefield and Mount Robson. Osborn, University of Calgary, has documented the Neoglacial history of Bugaboo Glacier.

(v) Rockies In the Rockies, NHRI continues mass balance observations at Peyto Glacier. Letreguilly analysed the record in relation to data from two neighbouring weather stations. Munro, University of Toronto, has initiated an energy balance study there. Leonard has been investigating sedimentary sequences in some of the neighbouring lakes. Around the Columbia Icefield, Gardner and Jones, University of Waterloo, have looked at debris transport and erosion at Boundary Glacier while Sloan, Trent University, has been investigating some of the melt processes. Trombley (USGS) completed a radio echo-sounding survey of the Athabasca Glacier and Smart (Western Ontario) reported on his karst hydrology study in the Castleguard area.

(vi) General The length of glacier mass-balance data records from a number of Canadian glaciers in the Cordillera and Arctic has resulted in their use in a variety of studies by international scientists. Recent ones include those by Konovalov, Kotlyakov and Shamin, Makarevich and Rotatayeva, Xie and Zhang, Ohmura et al., and Valdeyev. Ananicheva has reported on data reduction methodologies used for the World Atlas of Snow and Ice Resources.

Results of glacier mass balance in the Torngat Mountains, Labrador, some with rather unusual regimes, have now been published by Rogerson et al.

A long-standing analysis by Shoemaker, Simon Fraser Uni
versity, is now coming to a close with the publication of a number of theoretical papers on glacier-flow problems. An airborne UHF radar system, developed by Clarke at UBC, was used to measure ice depth and stratigraphy in the caldera of Mount Wrangell, Alaska.

(vii) Glacier Hazards The sudden drainage of a number of ice-dammed lakes in B.C., particularly Ape Lake, and some other glacier-related hazards led to studies by Clague, Evans, Gilbert and Desloges, Ricker and Ricker, and Jackson. Clarke recently paid tribute to the work of Mathews in this area.

(viii) Exploitation One interesting new development has been the exploitation of glaciers as a source of pure water. According to media reports, a company was formed in Alberta to mine glacier ice in the Front Ranges for sale in supermarkets. A similar proposal in British Columbia ran into difficulties when officials could not issue a licence because glacier ice was deemed to be neither a mineral nor a water resource. Other ventures in B.C. plan to export glacier melt water.

(b) Floating Ice on Rivers and Lakes

Most recent reports on lake and river ice are in the proceedings of the 4th Workshop on the Hydraulics of River Ice held in June, 1986 in Montreal and the 8th International IAHR Symposium on Ice, held in Iowa City the same month. Some appear in the proceedings of the Symposium on Cold Regions Hydrology, which took place a month later in Fairbanks, and those of the Eastern Snow Conference. Other have appeared in the scientific literature and as internal reports. Economic costs of lake and river ice problems, particularly those related to ice-jam flooding, can be assessed from newspapers. Gold, in his IGS anniversary review paper also alluded to some of these aspects.

(i) Quebec A major recent focus has been the St. Lawrence River in the vicinity of Montreal, lac St-Louis and the Lachine Rapids, particularly in connection with Projet Archipel and the development and testing of the RHIVER model. Much of the work has been done by Laval University under the direction of Michel and by the LaSalle Laboratories. Individuals involved have included Desroches, Fau, Fonseca, Hausser, Ho, Holder, Leclerc, LeVan, Parkinson, Petryk, Rivard, Saucet and Silver. Robert, Brochu and Robitaille have considered the problem of ice management at Beauharnois and Larouche, Tanguy and Tremblay have discussed ice jam flooding on the rivière du Nord and freeze-up and break-up on a number of northern Quebec rivers. Upstream from Montreal, Garrity et al. have been carrying out microwave experiments on the river ice over the past three winters.

(ii) Ontario In Ontario, much of the work also relates to flooding and operational problems. Beltaos and Wong (NWRI) have investigated ice jams and freeze-up and break-up processes on the Upper Grand River. Ice conditions on the Niagara River were studied by Churchill, and the International Niagara River Working Committee continues to observe the operation of its ice boom. Cumming-Cockburn and Associates were contracted by the Inland Waters Directorate (IWD) and the Government of Ontario to report on ice jams in the Credit River valley. Elsewhere, Burrell et al. have looked at break-up on the Meduxnekeag River. Jams in the St. Clair River influence Great Lakes' levels and this aspect is under investigation by Derecki and Quinn. Tsang (NWRI) is in the process of developing a frazil ice model. Unfortunately Hanley, another frazil-ice researcher, based at the University of Regina, passed away recently. An historical study of Red River flooding has recently been published by Bumstead.

(iii) Western Canada Alberta also has significant ice-jam flood problems, particularly in the vicinity of Fort McMurray on the Athabasca River. Research here is under the direction of the University of Alberta (U of A) and the Alberta Research Council and includes Andres, Flato, Gerard and Rickert. Loch, Kirchner and Simpson (U of A) are studying the potential of a thermosyphon system for influencing ice growth in the Peace River. Mercifully, B.C. seems fairly free of lake and river ice problems so there is little research on this being done there.

(iv) Territories In the Territories there are significant problems and interesting research possibilities. Alford (IWD) is investigating the ice cover and streamflow of the Yukon River, Whitfield and McNaughton the levels of oxygen under the ice, and Campbell, University of Manitoba, channel icings and their geomorphological effects. Along the Liard and Mackenzie Rivers, Prowse and Marsh (NHRI) have carried out a series of experiments on heat fluxes, break-up, ice jamming, the decay of ice jams and discharge measurements during break-up. S.A. Watson, Trent University, has assessed the use of aerial photographs for obtaining ice-jam measurements. The problems of break-up on small Subarctic rivers have been addressed by Woo and Heron at McMaster University.

(v) Atlantic Provinces River ice problems also exist in the Atlantic Provinces and those in New Brunswick, at Simonds, have been tackled by the provincial government while Davar and Hendrickson have looked at flow resistance in ice-covered channels using the Naskwaak River as an example.

(vi) Lake Ice Recent research on lake ice has taken a variety of directions. Adams and his colleagues from Trent University have been developing measuring techniques using a lake much as a snow pillow. Other studies have been on the chemical composition of the ice and water and the problem of acid shock. Students such as Allan and Doran have pursued this line of research on Colour Lake (Axel Heiberg Island), Knob Lake (Newfoundland) and Plastic Lake (Ontario). Anderson and Skinner (AES) and Barry and Maslanik, University of Colorado, have compiled information on freeze-up and break-up dates on lakes as indicators of climate change. In the Mackenzie Delta, Bigras (NHRI) has been assessing the influence of different river levels on a variety of Delta lakes. Operational considerations on the Great Lakes have led to studies of Lake Erie by the IWD in Canada and NOAA in the United States. Foulds has reported on the nature of the research problems, Agiroff and Weigum on matters pertaining to the extension of navigation on the Great Lakes and Greene and Campbell on lake ice dynamics.

(c) Permafrost

Although many universities, the Geological Survey of Canada and the NRCC Institute for Research in Construction have active permafrost research programs, much is geotechnical or geothermal rather than hydrological in orientation. French, Bennett and Hayley from Ottawa University have continued working on Banks and Melville Islands. Lewkowicz completed an investigation of ablation, slumping and thermokarst development, and Pollard one on frost mounds. At Carleton University, Smith and Michel, studying permafrost development in the Territories, are also looking at implications of climate change. Burn's work on aggradational ice was finished and Williams reissued his book on pipelines and permafrost. McGill University published an index of permafrost data in the Schefferville area where Granberg, Wright, Moore, Desrochers and Kingsbury have reported

on active layer development, thermal regimes and other studies. Largely through the Centre d'Etudes Nordiques, Université Laval has been involved in the Nouveau-Québec and Hudson Bay areas through the work of Allard, Seguin, Levesque and Pelletier. The interest at McMaster University has been in effects on karst (Ford), active layer development (Halliwell) and hydrology (Roulet and Woo). Mackay at UBC continues his work on pingos and the investigations at Illisarvik. High-altitude permafrost and climate change in Yukon is the subject of research by Harris, University of Calgary, who has just published a book on permafrost. Young (Waterloo) is studying the distribution and thickness of permafrost, Leclerc (Sherbrooke) permafrost found in Mayo, Marsh (NHRI) run-off from it in the Mackenzie Valley and Obradovic (Windsor) the role of permafrost run-off in the Apex River, Baffin Island. Finally, Van Everdingen with the Arctic Institute of North America is looking at broad aspects of the hydrological regime of permafrost and Allan et al. (Trent) the influence of solifluction on chemistry.

(d) Snow

Broad, regional studies of the snow cover of Canada by Dewey, Goodison et al. (AES), Morinaga and Yasunari, Walsh and Wiesnet are included in the proceedings of the IAHS Symposium on Large Scale Effects of Seasonal Snow Cover. These consider snow cover/atmosphere interactions and the impact of the seasonal snow cover. Much more comprehensive coverage at this scale is provided in Snow Watch '85 through the reports of Baldwin, Barry, Chang, Dewey and Heim, Goodison, Matson, Robinson, Roback and Scialdone, and Ropelewski. These reports generally deal with satellite-derived snow-cover data. Goodison, Goodison et al. and Kind continued the national perspective with their papers on snow surveying and drifting in the recently-published proceedings of the Snow Property Measurement Workshop. The IAHS Symposium on Modelling Snowmelt-Induced Processes included an initial report on the WMO intercomparison of snow-melt run-off models, which used the UBC and CEQUEAU models from Canada, and the final report should now be available. Cavadias and Morin have also commented on this work. A major meeting on Snow Management for Agriculture will be discussed below in the context of Prairie studies. AES continues to collect and publish snow data. These, together with other sources, were used by Ivanovskaya and Kravchenko in a study of the North American snow cover. Harvey, University of Toronto, developed explicit snow balances for his three-level energy balance climate model. Goodison and Louie have continued their discussion about the correction of Canadian snow data.

(i) Atlantic Provinces In the Maritimes, Daugharty and Dickinson of the University of New Brunswick continue their research in the Naskwaak River basin (N.B.) on the effects of the forest cover. The Saint John River basin, the target of a number of remote-sensing experiments over the years, was studied by Haas (NHRI) using ground and airborne snow surveys, and its headwaters by Merry and Miller, Cold Regions Engineering and Research Laboratory, using Landsat digital data. Snow data for the basin are provided by the province through a cooperative snow survey project. In Kejimkujik National Park, Roussel and Clair (IWD) have investigated the chemical and physical characteristics of the snow cover.

(ii) Quebec Research on snow in the Province of Quebec is led by McGill University and INRS-Eau of the Université du Québec à Québec. At the latter, H.G. Jones and his colleagues including Bédard, Deblois, Sochanska, Stein, Roberge, Plamondon and Charette, some from Université Laval, have worked on the chemistry of snow in the lac Laflamme basin. Jones organized a recent NATO Advanced Studies Institute on the physics, chemistry and hydrology of the seasonal snowcover. McGill's research area is Schefferville where Granberg and Moore, together with Desrochers, Wener, Kingsbury, Kulkarni and Nadeau have investigated the energy balance and stratification of snow.

(iii) Ontario In Ontario, pollution of snow by acids and road salt is being investigated by scientists from a variety of institutions, including AES and McMaster and Guelph Universities. They include Goodison, Louie, Metcalfe, Drake, Vermette, Landsberger, Simsons, Whiteley, Pakala, Schroeter, Hendershot, Dufresne, Lalande, Corchesne, Pilon, Howard, Thompson, Blackwood and Davies. The matter of winter storm tracks is being addressed by Stewart and McFarquhar (AES) in their studies of the rain/snow boundary. The energy balance of urban and forest snow covers has been measured by Adams, Lafleur, Xu and Buttle from Trent University and Woo and Steer (McMaster) have also considered the latter. Bottomley, Craig and Johnston (NHRI) used isotopes to monitor snowmelt run-off. Spatial distribution of snowmelt run-off for a number of basins is the object of research at McMaster by Irvine and Drake and for the Great Lakes basin by Hartmann and Croley.

(iv) Prairies The subject of snow research in the Prairies benefitted greatly from the recent meeting on Snow Management for Agriculture. The proceedings, edited by Steppuhn (Agriculture Canada) and Nicholaichuk (NHRI), catalogue a variety of swathing, tilling, cropping and other agricultural management practices designed to enhance soil moisture through efficient trapping and utilization of the snow cover. Researchers were drawn from Agriculture Canada, various Prairies universities, other government laboratories including NHRI and from the farming community. Another symposium, held to commemorate the opening of the National Hydrology Research Institute in Saskatoon, identified techniques for more efficient use of the available snow cover as an appropriate focus for some of the research programs. The same theme has been repeated by Gray, Granger, Landine, Pomeroy and others from the University of Saskatchewan in a variety of recent papers and again by Nicholaichuk and Steppuhn. The large flat expanses of the Prairies are ideal for remote sensing. Microwave radiometry experiments by Goodison et al. were reported in Vancouver, as was the integration of digital terrain models with snow and runoff measurements by Whiting and Kiss of the Saskatchewan Research Council. Problems of precipitation and its measurement have been considered by K.H. Jones (AES) and techniques for augmenting it through cloud seeding by Robitaille, Barlow and Reineck of the Alberta Research Council (ARC) and U of A.

(v) Cordillera In the Cordillera, snow problems are slightly different. The relationship between timber-harvesting techniques and snow melt run-off has been the object of a long-standing research project in Marmot Creek, Alberta. Golding (UBC), Bernier, Nip and Swanson (Alberta Forest Service) have reported some results from here, Toews and Guns for parts of southeastern B.C., and Beaudry and Golding from Jamieson Creek (B.C.). Remote sensing has been applied to the assessment of the snow cover in some areas of the Cordillera: Sargent, Gardner and Howarth (Waterloo) in the eastern Rockies, and Sutherland and Ferner (Alberta Environment) in the headwaters of the Bow River. Thyer (U of C), Barlow and Robitaille have analysed winter precipitation, snow cover and atmospheric conditions in the southern Rockies. Provincial and federal agencies continued to monitor the snow cover in this area and to publish the results of the snow surveys. Coles et al. (Alberta Environment) have discussed their experience in operating snow pillows in the mountains of Alberta. In central B.C., the Illecillewaet River was the object of tests by Quick and Pipes (UBC) designed to improve their model. With Calgary hosting the Winter Olympics, there were a number of contracted studies reporting on past and expected snow and weather conditions at the various event venues. Some controversy was raised over the proposed use of bacteria in the snow making machines, and this received fairly extensive coverage in the newspapers despite assurances from officials that the bacteria was harmless.

(vi) Northwest Territories: In the Northwest Territories, a regional study on the July residual snow cover in the Arctic was completed by Lauriol et al. (Ottawa). Barry (University of Colorado), at a conference on the impact of climate change on the Arctic, considered the impact of a climate warming on snow and ice in the area. Marsh (NHRI), Woo and Heron (McMaster) have been investigating grain growth, heat flux and discharge in a basin on Cornwallis Island. Isotope variations in snow along the north coast of Ellesmere Island were measured by Jeffries and Krouse (University of Calgary) and those in the small Apex River watershed on Baffin island by Obradovic and Sklash (Windsor). The Department of Indian and Northern Affairs publishes the results of snow surveys.

(e) Snow Properties

Comparatively little work is being done on some of the fundamental properties of snow which may be critical for the proper evaluation of remotely-sensed signals. The leading Canadian researcher in this area is Perla (NHRI) who, with colleagues from the United States, has developed a dilution method for measuring liquid water in snow, techniques for the preparation of serial sections of dry snow specimens and for the study of microstructure using stereology, and has reported on the metamorphism, morphology, and microstructure of snow as well as its permeability. The problems of snow drifting have been addressed by Pomeroy, Brown and Male (U. Sask.) who have measured blowing snow properties with optical attenuation devices, modelled it for agricultural production and assessed the wind transport of seasonal snowcovers in the Prairies. The remaining investigations into physical properties of the snow cover have been sponsored by the military. Granberg (McGill) has developed a computerized snow information system for military field operations. Fukue and Yong (McGill) studied the mechanical and physical properties of snow and completed an energy analysis of its confined compression and shear behaviour. Hutt and Shirkey (DND) have verified certain snow transmittance predictions and Irwin (DND) has investigated index measurements in studies of snow under vertical loading. These latter studies relate more to questions of traffic-ability than to hydrology.

(f) Concluding Remarks

Although this review might seem to indicate that glaciological research is flourishing in Canada, most of those involved would not agree. If one considers that Canada is snow-bound for almost six months of the year, that the country has more glaciers than any other in the world (excluding Geeenland and Antarctica) and is probably second only to the Soviet Union in the extent and size of its ice-covered lakes and rivers, then our present research effort has to be considered an absolute minimum. Ice and snow will be among the elements most immediately affected by any warming in climate. Glaciers in the Front Ranges may disappear completely and eliminate much of the late-summer streamflow that helps sustain agriculture in the Prairies. Degradation of permafrost may result in significant and widespread changes in the hydrological regime of the north, due to a deeper, and possibly more mobile, active layer. Reduced sea-ice cover in the Arctic could compound any climatic change. We may be able to reasonably assume such consequences, but our knowledge of the fundamental processes, required for accurately modelling such changes, is still inadequate.

6. Water Quality

Research Needs for Canadian Water Quality Guidelines
(Extracted from February 1987 report "Research Needs for Canadian Water Quality Guidelines" prepared by the CCREM Task Force on Water Quality Guidelines)

The first edition of the "Canadian Water Quality Guidelines" was presented to the Canadian Council of Resource and Environment Ministers by its Task Force on Water Quality Guidelines in October, 1986 and was approved for publication (CCREM 1986). An ancillary project of the Task Force was to make recommendations on research priorities required to address deficiencies identified during the preparation of the report.

Water quality guidelines provide scientific information about the effects of water quality parameters on water uses. Guidelines are used to assess water quality issues and to establish water quality objectives for specific sites. Water quality issues, however, are difficult to assess for a number of reasons, the primary being a lack of appreciation of the dynamic complexity of the aquatic environment itself, including the interactions among physical, chemical and biological components. Superimposed upon this complexity are the social and economic constraints confronting the effective management of water quality. Although water quality guidelines, per se, are not always able to address these complex issues completely, they do, nevertheless, contribute to the judicious use of water resources. They provide an essential component in the water quality assessment process. As such, they are used to formulate site-specific water quality objectives which are, in turn, used to provide a basis for protecting water uses, to determine effluent limits and other regulations on activities affecting water quality, and to identify water quality problems. Scientific criteria that are based on research that quantifies cause and effect relationships provide the essential foundation for the development of water quality guidelines and, in turn, the effectiveness of water quality management programs. Hence, it is critical that research provides scientific data appropriate to the development and use of sound water quality guidelines. During the development of the first edition of the Canadian Water Quality Guidelines a number of deficiencies were identified. These deficiencies focused primarily on scientific data gaps which prevented the recommendation of a guideline, or only allowed for the proposal of a tentative guideline. It must be recognized that the identification of and action on scientific data gaps for guideline development is only one need among various research, data, management, and socio-economic needs requiring consideration in the overall assessment of water quality issues.

The Task Force on Water Quality Guidelines considers that the following specific research is of high priority for the further development of Canadian Water Quality guidelines.

(i) Raw Water for Drinking Water Supply Improved methodologies are needed for the identification of organic chemicals that are found in drinking water sources and are a health concern. The possible formation of toxic substances during water treatment and the removal efficiency of various water treatment practices require investigation.

(ii) Recreational Water Quality and Aesthetics There is a high priority for research on new microbial indicators and studies relating these to disease incidence during recreational activities. Epidemiological studies should be conducted so that health risks can be quantified.

(iii) Freshwater Aquatic Life The use of aquatic organisms relevant to Canadian conditions in the development of appropriate water quality guidelines is of high priority, not only on a national but also on a regional scale. Studies on the bioavailability of toxic substances to aquatic organisms, as well as studies on the persistence of toxic contaminants, should be encouraged. The ecological significance of residues of persistent substances in the aquatic environment warrants further attention. Information about water quality and resident biota in the northern aquatic environment must be obtained so that appropriate water quality guidelines for northern regions can be developed. Many water quality guidelines are based on extrapolations of data obtained from acute toxicity tests in order to estimate safe levels. The use of application factors in aquatic toxicology, however, remains controversial, and increased efforts are required to identify alternative, cost-effective methods for estimating hazards to aquatic biota. The first edition of the Canadian Water Quality Guidelines does not contain recommendations for phosphorus; the scientific data base for phosphorus in aquatic systems, particularly in riverine systems, should be reviewed to determine whether sufficient information is available to recommend appropriate guidelines for waters other than the Great Lakes. Research on the fate and effects of pesticides in modern agricultural usage is required so that relevant water quality guidelines can be developed where needed. The Task Force on Water Quality Guidelines considers that high priority should be assigned to the specific studies for the following water quality parameters: chlorine, copper, zinc, cadmium, dissolved oxygen, aluminum, mercury, chlorophenoxy compounds, polychlorinated biphenyls, polynuclear aromatic hydrocarbons, chlorinated phenols, and phthalate esters.

(iv) Agricultural Uses Research on the fate and effects of toxic substances associated with Canadian agricultural practices has a high priority. The biological availability of these substances in irrigation water and livestock drinking water requires attention. In addition, the impact upon other water uses of irrigation return-flow waters warrants study. Needs for research on specific water quality parameters in agricultural waters include studies on pathogens in irrigation and livestock drinking water, aluminum in irrigation water, herbicides in irrigation water, and pesticides in livestock drinking water.

7. Remote Sensing and Data Transmission (J. Whiting, International Committee on Remote Sensing and Data Transmission, Saskatchewan Research Council).

(a) Remote Sensing

Environment Canada's, Inland Waters Directorate received two reports from A.J. Robinson & Associates on the Study of Methodologies of Streamflow Forecasting Incorporating Remotely Sensed Data. The first was a literature review. The second focussed on the implementation of operational remote sensing techniques in a streamflow forecasting model (the SSARR model). The techniques interfaced were snow cover extent

using density sliding and digital techniques, snowpack water equivalent combining airborne gamma-ray flight surveys with snow course data, and land cover using a pseudo-digital technique. The study area was a tributary of the Saint John Basin.

Alberta Environment continued their demonstration study assessing the utility of computer processed NOAA imagery for snow cover mapping and streamflow simulation using the SSARR model. Lack of resources could limit operational implementation.

The Hydrometeorology and Marine Division of Environment Canada's, Atmospheric Environment Service (AES) has been carrying out a study to evaluate the ability of three satellite rainfall estimation techniques to derive daily, weekly and monthly precipitation estimates under Canadian conditions. The study includes investigation of the applicability of various objective analysis schemes for interpolating precipitation data to a regular grid. The Division also conducted research on the determination of snow cover water equivalent using passive microwave radiometry. Contract support to the private sector allowed for steady progress in the development and testing of algorithms for determining snow cover properties from passive microwave satellite data.

Dr. N. Kowwen of the University of Waterloo has developed a micro-computer-based, distributed rainfall-runoff model which can incorporate ground-based radar precipitation data and other remotely-sensed input. The model has excellent potential for flash flood forecasting purposes.

(b) New Initiatives

The Hydrometeorology and Marine Division (AES) contracted with PhD Associates for the development of a turn-key micro-based passive microwave image analysis system. The interactive system will use NIMBUS-7 SMMR or DMSP SSM/I data formatted on floppy disk.

Saskatchewan Research Council initiated a joint study with AES (Saskatoon, National Hydrology Research Institute (NHRC)) on "The design of a western Canadian real-time system for integrated forecasting of basin specific floods and low flows". The study includes an examination of the use of remote sensing in integrated forecasting.

An interagency working group involving members of the Canadian Advisory Committee on Remote Sensing (CACRS) Water Resources Working Group developed plans for the Prairie snow cover passive, microwave validation experiment. The DMSP SSM/I was launched in 1987. A mini-program of ground and airborne snow data collection was collected in the winter of 1987 in preparation for the main 1988 experiment.

The Canada Centre for Remote Sensing (CCRS), in cooperation with Environment Canada, contracted with the University of Quebec (INRS-Eau) to produce, in 1988, a prototype of a micro-computer-based, distributed hydrologic model designed to make direct use of remotely-sensed data. The various modules comprising the model have been under development by INRS-Eau over the past several years.

(c) Data Transmission

Canada currently operates 678 Data Collection Platforms (DCP's) on the U.S.A. NOAA GOES satellite. The exact number operating on the French ARGOS system is not currently available but is estimated to be about 60 stations (the majority are floating buoys). The largest user is the Water Survey of Canada with 334 active sites with another 45 about to be installed. Of these, 53 are read by multiple users. Table 2 is provided to give an indication of the diversity of users and the types of station operated.

The majority of stations in Canada are used for flow and flood forecasting with some used for water quality, reservoir operation, and river navigation. Most stations are now frequency-agile to allow for station movement across Canada.

There is an effort to move the entire system to an operational mode from the present historic data collection and research environment. As part of this shift many stations are being fitted with meteorological and water quality sensors to fulfill a dual role for other agencies.

Research is currently being carried out by Water Survey on providing information on ice conditions, break-up and jamming using DCP's.

TABLE 2: Canadian Users of Data Collection Platforms (DCP's)

	ST	I	INT'L	RR	ACT
Alberta Environment	45				39
Alberta Forest Service	5				4
Atmospheric Environment Service	58				53
British Columbia Hydro Authority	81				72
British Columbia, Ministry of Transportation	2				1
British Columbia, Min. of Water Mgmt	6				6
Bristol Aerospace	1			1	1
Canadian Institute of Ocean Sciences		1			
anadian Marine Environmental Data Services	9				4
Canadian "ASAP" Program (NWCASP)			4		3
ESSO Resources Ltd	2				
Ministère de l'Environnement, Québec	148				132
Ontario Hydro	20				19
Ontario Ministry of Natural Resources	13				8
Petro Canada Exploration Inc	6				
Saskatchewan Research Council	2				1
University of Calgary	1			1	1
Water Survey of Canada	389			3	334
Total Canada	788	1	4	5	678

Note: St-Self Times; I-Interrogated; Int'l-International; RR-Random Reporting; ACT-Active.

8. Report from the Associate Committee on Hydrology

The National Research Council's Associate Committee on Hydrology (ACH) brings together hydrology researchers and managers from federal and provincial governments, universities and professional societies to advise on research priorities and on the application of hydrologic knowledge to Canadian water management. The Committee has three administrative subcommittees; International Affairs, Research Priorities and Dissemination of Knowledge and two technical subcommittees; Glaciers and Hydraulics of Ice Covered Rivers.

The 1987 National Lecture Tour co-sponsored by CWRA was conducted by Dr. R.H. Swanson, Canadian Forestry Service, who gave the audience a choice of three topics - (1) Measuring Transpiration of Trees, (2) WRENSS - A Model-Based Procedure for Estimating the Annual Water Yield from Forested and Partially Forested Catchments and (3) Canadian Research Basins. A video of the lecture was made and this procedure will be recommended for future tours.

In August, 1987 the ACH, as Canadian National Committee for the International Association of Hydrological Sciences, was responsible for organizing five symposia and eight workshops for the IAHS/IUGG General Assembly in Vancouver. The proceedings of the five symposia were pre-published and are available from IAHS offices. Proceedings of some of the workshops will be published either as separate volumes or in the Hydrological Sciences Journal. During the Assembly Canada was honoured to have five Canadians elected as officers to IAHS and its Commissions for the period 1987-1991. Dr. V. Klemes of Environment Canada's National Hydrology Research Institute is the new President of IAHS.

As the Canadian National Committee for the Unesco IHP, ACH is preparing an evaluation of the existing IHP III (1984-1989) and the proposed IHP IV (1990-1995) programs. For IHP IV, entitled "Water Resources for Sustainable Development in a Changing Environment", Canada is proposing to take a lead role in four of the 39 projects. ACH has proposed Canada as the representative for Western Europe and North America on the IHP Bureau. Elections will take place in June, 1988. Canada is already a member of the Intergovernmental Council.

Publications and Papers: (for copies or further information call D. Greene ((819) 953-1507)

- "Hydrologist"; a career brochure
- "International Organizations with Water Resource Interests".
- "1985 Bibliography on Hydrology".
- "Hydrology of Floods in Canada" (available in 1988).
- "The Status of Water Resource Education in Canadian Universities"; a paper to be presented at the ACH sponsored Education and Training Session of the 6th IWRA Congress, Ottawa, May, 1988.
- State-of-the-art review papers produced by the ACH Subcommittee on Research Priorities include; Dryland Salinity; Organic Contaminants; Water Demand Management; Glacier Mass Balance; Hydrology Aspects of Drought.

9. Report from Environment Canada

(a) Federal Water Policy

The major initiative in 1987, a response to the numerous recommendations of the 1984-85 Inquiry on Federal Water Policy, was the tabling in Parliament on November 5 of the new Federal Water Policy. The policy statement consists of two goals and five strategies, with water quality protection and realistic pricing and valuation of water as the dominant themes. The policy is applied to 25 areas of concern, including drinking water protection, diversion and export, interjurisdictional issues, climate change and research needs. The range of concerns is not intended to be exhaustive, and the policies will evolve in response to changing conditions. The report on Federal Water Policy is available free from Environment Canada in Ottawa.

The involvement of the provinces in the consultative process during the development of the Federal Water Policy and discussion through the Water Advisory Committee of the Canadian Council of Resource and Environment Members has prompted several provinces to examine their legislative base and policy frameworks in relation to water management. It is expected that joint federal/provincial policy statements in specific water areas will emerge in the not-too-distant future. The development of a Canadian Water Policy is probably still a few years away.

The Federal Government is proceeding with two initiatives to update its water and environmental management capabilities in support of the new Federal Water Policy.

The Canadian Environmental Protection Act has been mentioned in the above report for Environment Canada and is expected to be passed in 1988.

The Federal Government is also reviewing existing legislation with a view to improving its response to international and interprovincial water issues. Specific attention is being directed to water export, both to prohibit large-scale diversions of water into the United States and to regulate small containerized shipments in collaboration with provinces; also to the current vacuum in Canadian legislation for resolving conflicts between provinces/territories on interprovincial rivers. One possible vehicle for consolidating federal approaches to such issues would be an amended Canada Water Act.

(b) Federal/Provincial Agreements

During the 1987-88 fiscal year two new federal-provincial water management agreements were concluded by the Minister of the Environment. The first of these was a Canada-Prince Edward Island Work-Sharing Arrangement which will identify future development potential in the province's water resource bases–groundwater, surface water, and estuaries (each party contributes up to $500,000 over three years). The other was a Canada-British Columbia Floodplain Mapping Agreement (each party contributes up to $2,500,000 over five years). Policies under the agreement

extend until 1998.

(c) Streamflow and extreme events in Canada in 1987

Streamflows in Canada throughout 1987 were, in general, in the below normal to normal range.

Winter flows on the east coast were below normal at 30 to 50 percent of median flow while the rest of Canada generally had flows in the normal range.

Spring flows were generally normal throughout central Canada. Parts of eastern Canada and western Canada experienced above normal flows. In eastern Canada, areas that had below normal flows at 20 to 50 percent of median in late winter had above normal flows and flooding in the early spring. For instance, in Central Newfoundland, the Gander River at Big Chute, (drainage area 4400 km^2) recorded a monthly mean discharge of 522 m^3/s at 261 percent of median flow that was the highest on record for April since 1949.

Heavy rains beginning March 30 and falling on a higher-than-normal snow pack caused flooding in the Perth-Andover, New Brunswick area and in the Beauce area of Quebec. Some 2000 people fled their homes along the St. John River as ice jams sent the water through the streets and into basements. The flooding caused millions of dollars in damage, including the collapse of a railway bridge and damage to a hospital. At the same time, in the Beauce region south of Quebec City, Quebec, hundreds of people were evacuated and thousands of homes were cut off from electricity. Damage, estimated at more than ten million dollars, was caused by rivers swollen by rain and spring runoff combined with ice jams on the rivers. At Ste-Anne-de-la-Perade, between Trois Rivières and Quebec City, a large railway bridge was swept away by huge blocks of ice carried down the flooding St. Anne River. In the region of Charlevoix stretching 200 kilometres from Quebec City east to La Malbaie, an estimated two million dollars in damages, mainly to roads, and to several homes, was caused by landslides brought on by the heavy rain.

The areas that had below normal winter flows in eastern Canada continued to experience, with the exception of spring runoff, below normal flows from spring to early fall. With almost drought-like conditions being experienced throughout this period, there were shortages of water for agriculture and municipal purposes. In rural areas, wells dried up, forest fires were difficult to bring under control and streams were extremely low. For instance, in western Newfoundland, the Upper Humber River near Reidville (drainage area 2110 km^2) recorded in August a mean monthly flow of 4.07 m^3/s that was 9 percent of the long term median flow.

Across Canada from New Brunswick to British Columbia, hot dry weather in April and May set the conditions for below normal runoff and the occurrence of numerous forest fires. More than 100,000 hectares of forest were burned and millions of dollars of private property and prime timber destroyed.

Throughout the summer in central and western Canada, unsettled weather conditions resulted in the development of severe storm systems and local heavy precipitation causing local heavy flooding. On July 14, severe thunderstorms lashed the Montreal area of Quebec for two hours and resulted in flooded streets and homes, uprooted trees, left two men dead and caused an estimated one hundred million dollars in property damage. The storm dumped 57 millimetres of rain in two and one-half hours.

On July 31 a tornado ripped through the Edmonton, Alberta area and left a 40 kilometre path of destruction as much as one kilometre wide. The tornado, with winds of up to 330 kilometres per hour, killed 27 people, left 100 families homeless and caused over 250 million dollars in property damage.

A major storm struck southwestern Manitoba and the city of Winnipeg on August 14. Rainfall amounts of up to 200 mm occurred. Flood and crop damages were high. Five traffic deaths in southern Manitoba were attributed to rain drenched roads.

In northwestern Alberta, between 12:00 hours July 30 and 06:00 hours August 2, 293 mm of rain fell in the headwaters of the Simotte River and 228 mm in the Keg River area. Extensive flood damage, estimated at six to ten million dollars, was caused to bridges, roads, crops and campsites.

The fall to early winter period across Canada had variable flows. The east coast had generally normal flows with pockets of below normal and above normal flows. No records were set. Central Canada had normal flows. The west coast had variable flow conditions. Southern British

Columbia had below normal flows at 50 to 80 percent of median which began in June and continued to December. The Fraser River at Hope (drainage area 217,000 km^2) recorded in October a daily mean flow of 744 m^3/s that was the lowest since records began in 1912. The central interior of B.C. experienced very dry fall conditions with many new low records established. Concerns for a good recovery for the 1988 irrigation season were expressed. Meanwhile northern British Columbia had above normal flows; however no records were set.

10. Bibliography

The 1985 Bibliography of hydrology produced by WATDOC from the AQUAREF database was published as special edition volume 12, number 2 of the Associate Committee on Hydrology's newsletter Hydrological Events. (For a free copy contact G.A.D. Greene, 819-953-1507).

The 1986-87 edition is scheduled for publication in 1988. The AQUAREF database is searchable online through the CAN/OLE system of the Canada Institute for Scientific and Technical Information (CISTI) of NRC.

For more information on WATDOC or AQUAREF, contact:

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IX MINING GEOPHYSICS

Compiled by: Stephen W. Reford and D. James Misener

1. Introduction

Fifteen organizations reported research in mining geophysics in 1987. A further five organizations reported no research in mining geophysics in 1987. A total of twenty responses were received from eighty-eight organizations contacted. As in previous years, the apparent level of effort is distorted by a lack of submitted information in the private, university and government sectors. Total research and development expenditure reported by the fifteen organizations for 1987 was 550 person-months and $3.25 million, comprising 356 person-months and $2.15 million from industry, 52 person-months and $0.93 million from government and 142 person-months and $0.17 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 in fact, a factor of two or three higher than is indicated.

The reported level of expenditure in industry has increased by 42% over the level reported in 1986. This can be attributed in part to the significant recovery in exploration activity over the past year.

The dollar amounts reported by the government have dropped significantly over 1986, although this sector is very much under reported. The university amounts are also understated; however the level of expenditure, as reported, indicated a decrease to 41% of the 1986 level (and to 27% of the 1985 level). This is indicative of the underfunding problems suffered by our universities at present.

A highlight of 1987 was the Exploration '87 conference held in September in Toronto, focusing on mineral and groundwater exploration. Some 77 papers and 111 poster papers were presented. All of the speakers were invited by the organizing committee as recognized experts in their particular field. A volume of refereed papers resulting from the conference will be published in late 1988.

Research is underway in all areas of instrumentation, survey methods and interpretation. Of particular interest in 1987 were the development of methods for imaging geophysical data and the utilization of satellite images for exploration purposes.

INDUSTRY

2. A-Cubed Incorporated, Mississauga, Ontario (A. P. Annan, J. L. Davis)

The company continued with the installation and testing of the new wideband PROSPECT airborne elecromagnetic system, with particular focus on real-time system development, transducer testing and post-survey data processing.

Development of the pulse EKKO III ground penetrating radar system continued. The work included field evaluation of the system, improvement of system performance and data acquisition components, and enhancements to data processing and interpretation.

The level of effort expanded on these projects in 1987 was sixty person-months and $500,000.

3. Geosoft Incorporated, Toronto, Ontario (I. MacLeod, D. Gresham, E. Lycklama, B. Thacker)

The company has continued development of commercially available geophysical software for the routine and enhanced display and interpretation of geophysical data. Significant effort has been placed on improving the utility of micro- computers, especially for map-making purposes and more ergonomic and intuitive use of inverse modelling methods. Highlights have been the development of efficient high- resolution colour plotting and imaging with low-price equipment, and the development of fully interactive potential field inversion systems for the micro-computer. Significant effort has also been expended on developing UNIX software systems in support of UNIX-based graphics workstations.

The level of effort expended on these projects in 1987 was twenty-four person-months and $150,000.

4. Paterson, Grant & Watson Limited, Toronto, Ontario (N. R. Paterson, D. J. Misener, I. N. MacLeod, S. W. Reford, E. Baranyi, R. B. Hearst, D. Hatch)

The company has continued its efforts to improve methods for the modelling, processing, enhancement and presentation of geophysical data. This work has included the imaging of two-dimensional datasets in colour and grey scales for screen and hard copy modes on a variety of devices. Regional studies have required the development of techniques for the coherent levelling and linking of disparate aeromagnetic datasets (thirty or more in some cases). This work is now done on a routine basis.

The method for SVD inversion of airborne frequency- domain EM data to a layered earth has been extended to the time-domain (INPUT) and has been successfully implemented on two datasets.

A two-dimensional equivalent source inversion technique for modelling the geometry of sources from gravity data has been developed. It can work with grids of gravity, density and surface data and may also be applied to such problems as terrain correction and gravity stripping.

A study of airborne geophysical datasets (magnetic, EM) originally acquired for mineral exploration purposes has shown their applicability to groundwater exploration in shield areas.

The level of effort expended on these projects in 1987 was eight person-months and $50,000.

5. Picodas Group Incorporated, Richmond Hill, Ontario (B. Pavlik, J. McClure)

An IBM based data acquisition system has been developed for a high resolution airborne magnetic gradiometer. This allows the acquisition of data from up to four magnetometers with accurate synchronization. Sample rates of 10 Hz with a resolution of 0.001 nT, 1 pT, and bandwidth of 2.5 Hz have been achieved. A horizontal two sensor installation has been flown. Compensated results have shown repeatable transversal magnetic gradients of approximately 5 pT/m for a wide bandwidth of signals. Plots showing the horizontal magnetic vector pinpoint the positions of sharp interline anomalies.

A spectrometer calibrator has been developed. This automatically calibrates, monitors and adjusts the gains of up to fourteen crystals. This enables high resolution to be maintained for large volume crystal arrays. This can replace existing summing amplifiers and improve data quality.

The level of effort expended on these projects in 1987 was twenty-four person-months and $250,000.

6. Sagax Geophysics Incorporated, Montreal, Quebec (R. Bazinet, J. Roy, J. Legault, D. Paiement, D. Bérubé)

The development of a lightweight 300W automated induced polarization (IP) transmitter began. A PC-based program for three-dimensional IP modelling has been developed. A program for integrated IP and resistivity modelling is under development.

The company's scalar audio-magnetotelluric instrumentation has been improved, particularly the data processing software. The interpretation method for this technique has also been improved. The level of effort expended on these projects in 1987 was twenty-four person- months and $200,000.

7. Scintrex Limited, Concord, Ontario (H. O. Siegel)

The software and hardware development of the S-2 Echo 12/24 Channel Portable Seismograph was essentially completed. This is a lightweight, low-cost, high resolution seismic receiver with enhanced software-based filtering and signal processing. The device is controlled by a lap-top microcomputer mounted on the upper surface of the console. The computer also facilitates data viewing and storage and signal processing. Microcomputer-based applications software for reflection and refraction surveys has also been developed.

Development of the CG-3 Autograv mechanical/electronic gravimeter was essentially completed. The quartz-element gravimeter uses electronic displacement sensing and electrostatic nulling of the proof mass. Features of the instrument include the use of electronic levels to provide corrections for off-level conditions, signal stacking for reduction of noise due to seismicity or unstable ground, and software corrections in real time for long-term creep and tidal variations.

A study of cesium vapour magnetometer sensors and their related electronics was undertaken, with the objective of improving the mean time between failure, ease of manufacture and alignment, sensitivity and orientation errors. Considerable improvements in all these factors have been effected and will be incorporated in future production designs.

The level of effort expended on these projects in 1987 was 216 person-months and $1,000,000.

GOVERNMENT

8. Aeromagnetic Surveys Section, Geophysics Division, Geological Survey of Canada, Energy, Mines and Resources, Canada, Ottawa, Ontario (E. E. Ready, W. A. Knappers, P. E. Stone, D. J. Teskey, R. A. Gibb, S. D. Dods, P. J. Hood)

During the year four detailed total field/ gradiometer/VLF- EM surveys, and three regional total field surveys were flown for a total of 203,365 km. In addition four total field/gradiometer/VLF surveys and one regional survey initiated in 1986/87 were completed in 1987/88 for an additional 110,628 km. The survey parameters are given in Table 1, while the areas are shown in Figure 1.

The areas in southeastern and southwestern British Columbia were flown as part of the ongoing mapping program of the Geological Survey of Canada and will complement the recent Lithoprobe transects of Vancouver Island and the southern mainland. The central B.C. area while extending the regional coverage will also assist and stimulate mineral exploration.

The Lake Superior survey was flown with the GSC's Queenair aircraft as part of the Great Lakes Multidisciplinary International Program on Crustal Evolution (GLIMPCE). These data, along with the deep seismic profiles recorded in 1986 will help to unravel the complex geology of this area. Navigation and flight path recovery for this survey, as with the previous Great Lakes surveys flown by the Queenair, were by Loran-'C' which, when tied to known land points, has proved to be highly reliable. The Grand Banks survey, funded under the Frontier Geoscience Program was flown as part of a detailed mapping program of the Grand Banks to complement the 1985 Laurentian Channel and Orphan Knoll surveys to the west and north-east respectively. This survey area has significant economic potential and was the site of deep seismic reflection profiles in 1985. Navigation for this survey was by an integrated onboard Global Positioning System (GPS) and Loran-'C' system provided by Nortech Ltd., which resulted in both accurate flight path recovery and real-time guidance to the pilots, essential for a high resolution survey in this area.

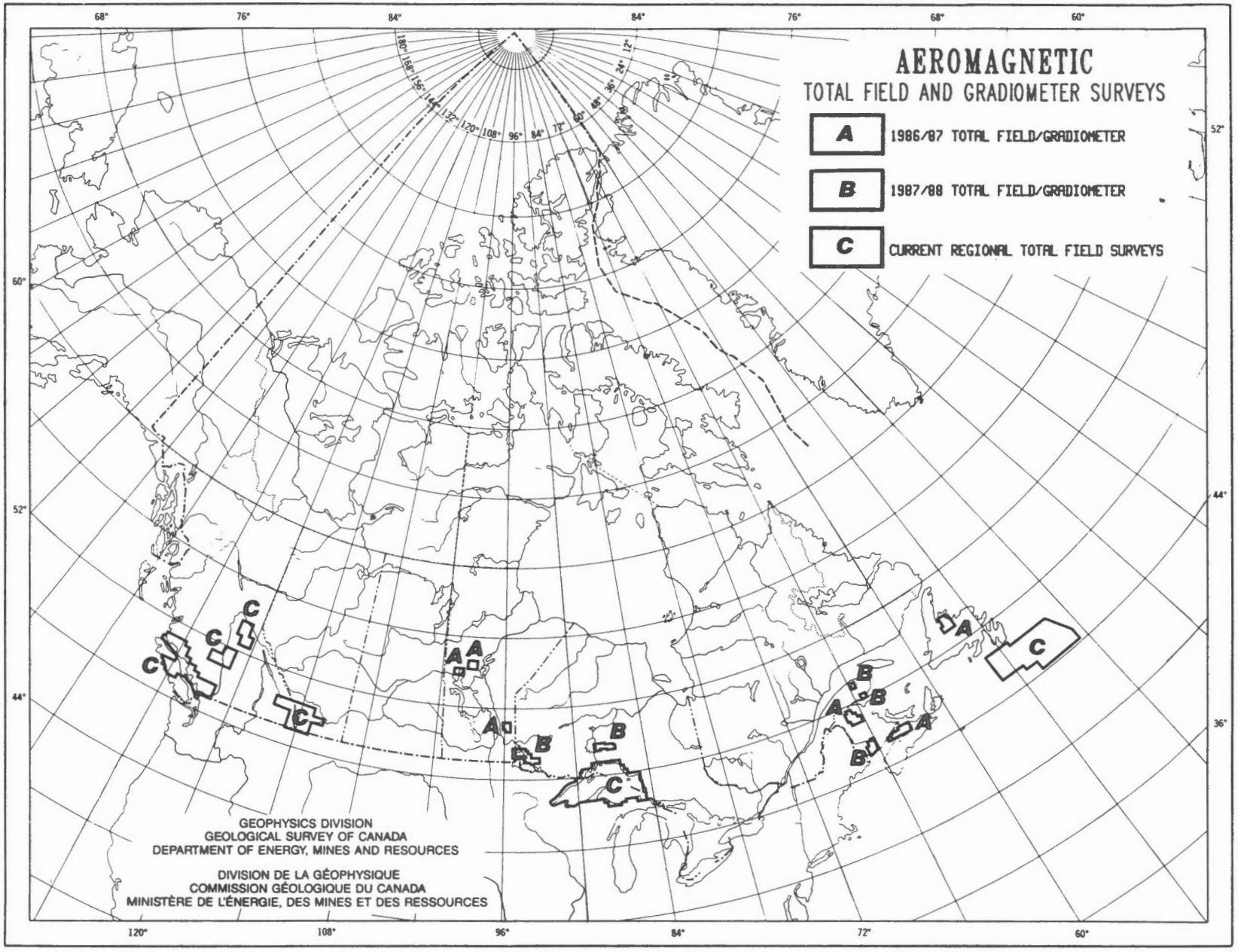
AEROMAGNETIC
TOTAL FIELD AND GRADIOMETER SURVEYS
A 1986/87 TOTAL FIELD/GRADIOMETER
B 1987/88 TOTAL FIELD/GRADIOMETER
C CURRENT REGIONAL TOTAL FIELD SURVEYS
GEOPHYSICS DIVISION
GEOLOGICAL SURVEY OF CANADA
DEPARTMENT OF ENERGY, MINES AND RESOURCES
DIVISION DE LA GÉOPHYSIQUE
COMMISSION GÉOLOGIQUE DU CANADA
MINISTÈRE DE L'ÉNERGIE, DES MINES ET DES RESSOURCES

Table 1. Aeromagnetic Surveys - 1987

Survey	Type	Km	Line Spacing	Altitude (m)
Newfoundland (1986-87)	Aeromagnetic Total Field Gradiometer VLF	18,686	300 m	150 Radar
Nova Scotia (1986-87)	Aeromagnetic Total Field Gradiometer VLF	17,150	300 m	150 Radar
New Brunswick (1986-87)	Aeromagnetic Total Field Gradiometer VLF	17,985	300 m	150 Radar
New Brunswick (1987-88)	Aeromagnetic Total Field Gradiometer VLF	13,524	300 m	150 Radar
Gaspé (1987-88)	Aeromagnetic Total Field Gradiometer EM	4,060	Murdochville (North) 100 m Port Daniel (South) 200 m	150 Radar
Ontario (Kenora-Ft. Francis) (1987-88)	Aeromagnetic Total Field Gradiometer VLF	21,288	300 m	150 Radar
Ontario (Geraldton-Beardmore) (1987-88)	Aeromagnetic Total Field Gradiometer VLF	16,725	200 m	150 Radar
Manitoba (1986-87)	Aeromagnetic Total Field Gradiometer VLF	19,129	300 m	150 Radar
Grand Banks (1987-88)	Regional Aeromagnetics	37,304	4 km	400 Radar
S.E. B.C./Alberta (1987-88)	Regional Aeromagnetics	53,548	Williams Lake 1 km Lethbridge 1.5 km	Variable Altitudes Depending on Topography (by blocks)
Lake Superior (1987-88)	Regional Aeromagnetics	56,916	1.9 km	300 Radar
Vancouver Island (1986-87)	Regional Aeromagnetics	37,678	1.5 km	Variable Altitudes Depending on Topography (by blocks)

The detailed total field/gradiometer/VLF surveys, except that in Quebec, were funded under Mineral Development Agreements with the provinces, as was the central B.C. regional survey. These areas were selected by the relevant provincial agencies in co-operation with the Geological Survey of Canada to stimulate, guide and improve the effectiveness of mineral exploration in these areas. The Gaspé survey which combines total field/gradiometer and active EM was funded under the Canada Initiatives-Gaspé and Lower St. Lawrence program.

Contractors involved in the current program are: Aerodat Ltd., Toronto, Geoterrex Ltd., Ottawa, Kenting Earth Sciences, Ottawa, Les Relevés Géophysiques, Quebec City, Questor Ltd., Toronto, and Sander Geophysics, Ottawa. Nortech Ltd. of Calgary provided the integrated GPS-Loran-'C- system for the Grand Banks survey as a subcontractor to Geoterrex.

The final version of the Decade of North American Geology Magnetic Anomaly Map of North America was compiled by the Aeromagnetic Data Processing Section, Geological Survey of Canada, Ottawa, from the following forms of data: original shiptrack data, flight-line data, gridded data, and compiled region maps.

This map has been compiled using a nucleus of data from the conterminous United States, Canada, and Alaska. Each of the three data sets forming the nucleus was prepared individually using the new Definitive Geomagnetic Reference Field (DGRF), and the original join between them was remarkably free of major discrepancies. Adjustments to this nucleus were necessary, however, in the northeast corner of the United States, where the United States data were tilted 70 nanoteslas to match New Brunswick data and newly acquired Canadian offshore data, and in the panhandle area of Alaska, where the data were lowered approximately 150 nanoteslas.

The extensive shiptrack data provided by the U.S. National Geophysical Data Center (NGDC) were also corrected using the DGRF. Even though they were not extensively edited or leveled, except for obvious erroneous tracks, the data merged very well with the nucleus; however, discrepancies still remain at some track intersections. These shiptrack data and the nucleus then served as a basis for making necessary adjustments to other data sets.

Control lines flown by the Geological Survey of Canada for the purpose of providing data for this map were used to resolve leveling problems in the area south of James Bay and to verify data levels in the Caribbean region.

All data were transformed to map coordinates using the North American transverse mercator projection with a central meridian of long. 100° west and a scale factor of 0.926, and were gridded at 2 km intervals using the minimum curvature method. The gridded data are available on magnetic tape from NGDC in Boulder, Colorado.

Colour separates were produced from the final gridded data by the Geological Survey of Canada using a wide format laser plotter and were forwarded to the U.S. Geological Survey for final cartographic preparation and printing. The map is available from G.S.A. Publication Sales, Boulder, CO, 80301, U.S.A., P.O. Box 9140.

The fifth edition of the Magnetic Anomaly Map of Canada, the first all digital version of the map, was published in 1987. The major land portion was compiled from data collected under the ongoing regional aeromagnetic program of the Geological Survey of Canada. More than 10 million kilometres of data have now been flown mostly in co-operative programs with the provinces. In recent years this program has included large offshore areas on the east coast and in the Beaufort Sea. In addition to the GSC's aeromagnetic data, significant data sources included the GSC's offshore shipborne programs conducted by the Atlantic Geoscience Centre and the Pacific Geoscience Centre, private data, particularly in the Great Plains Region, and Arctic Islands and airborne data flown by the U.S. Naval Research Laboratory and the Naval Oceanographic and Atmospheric Agency over the Arctic Ocean.

The map is available from the Publications Office, GSC, 601 Booth St., Ottawa, K1A 0E8.

9. Mineral Resources Division, Exploration Geophysics Subdivision, Geological Survey of Canada, Department of Energy, Mines and Resoures
(K.A. Richardson, Q. Bristow, R.L. Grasty, P.G. Killeen, G.J. Palacky)

In exploration geophysics, the Division proceeded with the development of technology and new applications of geophysical techniques.

Instrumentation developments included the implementation of an automatic background monitoring system for the Skyvan gamma-ray spectrometer and the design, fabrication and testing of an inductive borehole conductivity and magnetic susceptibility probe.

The Skyvan system with its new upward-looking background detectors was tested by conducting airborne gamma-ray/VLF/magnetometer surveys in several areas: west of Ottawa; at Gander, Newfoundland; and in southern Nova Scotia and New Brunswick. A contract gamma-ray/VLF/magnetometer survey was flown (under the Newfoundland MDA) in the Great Northern Peninsula of Newfoundland. During the year, radiometric surveys from previous years were complied and published for approximately 75 1:50,000 scale map sheets in Newfoundland, Nova Scotia, and New Brunswick.

The GSC Skyvan was used in the summer of 1987 for flight testing of a new Scintrex airborne gamma-ray spectrometer system which was being delivered to the People's Republic of China. Test flights with this system were carried out over Maniwaki, Quebec, as part of a GSC/DSS-supported Unsolicited Proposal to investigate the relationship between airborne gamma-ray spectrometric measurements and the level of radon in houses.

In borehole investigations, field work in British Columbia in cooperation with the Terrain Sciences Division demonstrated geotechnical applications of natural gamma-ray logging combined with the new technique of magnetic susceptibility logging, for interpretation of stratigraphy in the sediments of the Fraser delta. Continuing development of the spectral gamma-gamma (SGG) logging technique showed that SGG measurements in boreholes at the Yava Mine in Nova Scotia and lead analyses on drill core samples gave a correlation coefficient of 0.88, indicating good potential for achieving a borehole heavy metal assay capability.

Geophysical studies of Quaternary sediments continued under the Ontario Mineral Development Agreement. An experimental helicopter electromagnetic survey was carried out along selected roads in the Kapusakasing-Timmins area, Ontario (total 840 line-km). The contractor, Aerodat Ltd., used a 4-frequency HEM system in the survey, which was flown in February, 1987. The data were compiled as composite profiles and colour-bar maps of apparent conductivity, depth-to-bedrock, and VLF amplitude. Selected features were investigated on the ground using the APEX MaxMin I horizontal-loop EM equipment. Of the 73 targets investigated, 26 were drilled in 1987. The results have shown that ground EM techniques can be effectively used in mapping Quaternary geology. Each Quaternary sediment type (sand, silt, till, clay) has a unique signature which permits its identification on EM data. Inversion of ground EM data leads to bedrock topography profiles whose accuracy has been confirmed by drilling. Electrical properties of glacial sediments have been studied in the laboratory. Generally, a good agreement has been obtained between resistivities determined in the laboratory and interpreted from ground EM data. Field work at the Val Gagné test site, Ontario, was completed in August, 1987. A variety of ground EM methods has been used to investigate this site in great detail.

Numerical modelling of the VLF-EM response of sheet-like conductors in a host rock of finite resistivity has been carried out to devise a simple method of ground VLF interpretation using characteristic diagrams. The diagrams produced for vertical and inclined two-dimensional sheet-like conductors of finite conductance, depth and depth extent will aid interpretation of ground VLF data in the field.

Analysis of EM-37 transient EM sounding data over several long profiles in southern Ontario was completed with a view to demonstrate the feasibility of using deep EM sounding techniques for stratigraphical mapping to a depth of 600 m. The interpreted data from EM soundings agree well with information from boreholes.

International activities in geophysics included the participation of staff-members:- (i) as borehole logging scientist for Leg 114 of the Ocean Drilling Program from Falkland Islands to Mauritius, (ii) as advisor to CIDA for helicopter EM surveys conducted by Canadian contractors for the Thailand Department of Mineral resources, (iii) as consultant to the International Atomic Energy (IAEA) for radiometric surveys and calibration in Turkey and Jordan, (iv) as organizer and host for IAEA technical consultants meeting on nuclear techniques in exploration and borehole logging, which was attended by delegates from 12 countries including China, Russia, Australia, U.K. and U.S.A.

10. 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, R. M. Johnstone)

The Night Hawk geophysical test range near Timmins, Ontario was utilized for testing, research and construction purposes by industry, universities and government. Field work was conducted using the new, scaled down Maxiprobe EM system (manufactured by Geoprobe Limited, Toronto).

Research continues to investigate the potential for detecting and tracing conductive strata in basement Precambrian rocks, overlain by thick Huronian stratigraphy. The study area lies west of Cobalt in the Moose Lake sub-basin. Field work included analysis of the EM noise conditions in the vicinity of Cobalt and ground transient EM surveys in Coleman and Firstbrook Townships. Computer modelling was undertaken for the purpose of improving existing interpretation techniques.

A gravity survey in the Iroquois Falls-Lake Abitibi area (7200 km^2) established 2000 new gravity stations. The survey will aid in the regional subsurface geological interpretation of a complex stratigraphic succession of komatiitic, tholeiitic and calc-alkalic rock groups.

11. Service de la Géochimie et de la Géophysique, Ministère de l'Energie et des Ressources, Québec, Québec (D.-J. Dion, D. L. Lefebvre, R. Boivin)

Un levé gravimétrique a été effectué à l'échelle régionale dans la région de Chibougamau, soit une station à tous les 500 mètres le long des voies carrossables et des cours d'eau. La production de la carte des anomalies de Bouguer et la carte du gradient vertical gravimétrique est en cours.

Un levé magnétique et électromagnétique héliporté de type REXHEM IV a été attribué pour couvrir les régions de Ste-Sabine et Amy-Corners (Beauceville). L'objectif était de fournir des cibles d'exploration minière dans une région des Appalaches, jugée propice aux minéralizations aurifères et qui est caractérisée par l'association entre cette minéralisation et les schistes graphitiques.

A l'aide des plus récents développments en télédétection (images SPOT avec vue stéréoscopique), une étude comparative intégrée des différentes facettes de l'information géoscientifique recueillee dans la région (géologie, géochimie, INPUT EM, etc.) a été réalisée à l'ouest de Kuujjuak. L'objectif était de présenter une vision synthétique de la géologie et du potentiel économique de la région.

Un levé sismiques refractions (trois coupes) avec prise de mesure aux 30 mètres, totalisant 60 kilomètres, a été effectué dans la région de Casa-Berardi et Normétal (Amos-Joutel), afin de vérifier la présence de grandes structures cassantes.

Un relevé visuel (sans ordinateur) et une interprétation géologique des linéaments à partir d'images de télédétection (LANDSAT) à l'échelle 1:250 000 sur un territoire de 70 000 km^2, situé dans la province géologique du Grenville, ont été realisés. L'objectif est de montrer sur le fond géologique des cartes de gîtes minéraux des linéaments principaux et secondaires, leur âge relatif et leur interprétation géologique en comparaison avec la carte exacte: failles, diaclases, contacts lithologiques, plis, etc. en utilisant un symbolisme correspondant à leur degré de certitude.

Une étude des données électromagnétiques héliportées dans une région cible des dépôts meubles de l'Estrie/Beauce (Appalaches) a été réalisé. La relation exacte qui existe entre les cartes de la résistivité apparente, déduites des données électromagnétiques, et les épaisseurs des dépôts meubles, a été verifiée par moyen géophysique au sol.

Les données magnétométriques corrigées pour des levés INPUT réalisés dans le Nord-Ouest québécois ont été obtenues et des cartes couleur 1:50,000 du champ magnétique total et du gradient magnétique vertical calculé ont été produits.

Une banque de données géophysiques digitales (électromagnétique et magnétique), bien structurées et classées, facilement manipulables et accessibles aux utilisateurs du service et de l'industrie, a été crée, par la reformatage des données, la création des disquettes, logiciels de contrôle et le développement de logiciels de consultation interactive et d'exploitation des données. La banque de données géophysique constituera la base de tout traitement éventuel de données géophysiques pour déboucher sur de nouvelles cibles d'exploration minière et des évaluations systématiques de potentiel minéral de la province.

Une interprétation intégrée dans la région de Joutel (Abitibi) est en progrès. Cette région est présentement intensivement prospectée pour l'or par de nombreuses compagnies d'exploration minières. La synthèse réalisée devra permettre d'avoir des cartes de potentiel minier basé sur le recoupement d'indices et d'anomalies propres à chaque type d'information. Cette étude nous permettra de voir dans quelle mesure la technique utilisée est valable pour d'autres régions. L'étude va bénéficier du Programme d'Utilisation des Images SPOT (PUIS) au Québec dans le cadre de la Coopération scientifique et technique franco-québécoise en télédétection. Présentement, toutes les informations géoscientifiques accessibles ne sont pas intégrées. Les données de télédétection ont permis avec le temps de développer des méthodes de traitement, de corrélation et d'intégration avec d'autres données; ces méthodes sont informatiques et permettent le traitement de grande quantité de données disparates. Chaque type de données sera traité et analysé individuellement avant de l'être de façon combinée. Les résultats seront présentés sous forme thématique à l'échelle 1:100 000 et 1:50 000.

Une interprétation de données géophysiques de la région ouest de Rouyn-Noranda, à l'échelle 1:50,000, est en progrès. L'étude utilise les données du levé magnétique-électromagnétique aéroporté de Noranda et du levé gravimétriques, ainsi que toutes les informations géologiques et géophysiques complémentaires. Premièrement, une interprétation qualitative sera produite à partir des cartes géophysiques. La deuxième étape consistera en une interprétation quantitative, en utilisant la simulation numérique à deux et trois dimensions, effectuée sur les structures géologiques détectées les plus intéressantes (failles, contacts, etc.) pour obtenir des informations sur la géométrie en profondeur.

En tout, quarante personne-mois et $850,000 était employés pour ces projets en 1987.

12. Newfoundland Department of Mines, St. John's, Newfoundland (G. J. Kilfoil)

Geophysical projects, designed to assist 1:50,000 scale geological mapping projects undertaken by the Department's project geologists in areas of insular Newfoundland and Labrador, consist of: 1) compilation, enhancement and interpretation of existing geophysical survey data in assessment files; 2) ground geophysical follow-up targeted for areas showing interesting geophysical character but presenting problems for geological mapping due to extensive surficial and/or vegetative cover.

Three areas in Central Newfoundland were surveyed by the magnetic and VLF-EM methods from June to August, 1987. Data compilation is complete; internal maps and reports are in preparation. In addition, developmental work is ongoing on image enhancement of large airborne geophysical datasets in aid of interpretation.

The level of effort expended on these projects in 1987 was twelve person-months and $85,000.

UNIVERSITIES

13. Department of Geology and Geophysics, University of Calgary, Calgary, Alberta (K. Duckworth, D. O'Neill, H. T. Culvert)

Physical model tests have been conducted of the behaviours of fixed loop electromagnetic systems for both resistive and conductive environments using frequency domain methods. Single and multiple conductor cases have been treated and results have been compiled in the form of secondary field component profiles, as well as in the field strength ratio and phase difference format employed by Turam surveys. Emphasis has been placed in a new mode of operation called the Tx-parallel mode.

Surveys have been conducted over a heavy oil field using a long grounded line transmitter operating in the frequency range 1 Hz-20 Hz. Traverses were laid parallel to the transmitter and the fields were detected by means of a SQUID magnetometer. The results indicate that the brine conductor underlying the oil was detected at a depth of 780 m.

Complex resistivity spectra have been recorded for a wide range of sulphide mineral samples taken from Canadian mines. These results were obtained over a range of temperatures ranging from +20|C to -20|C. The Cole-Cole impedance model was employed throughout these tests and the behaviour of the mineral specimens has been simulated by means of a number of two-dimensional models.

The level of effort expended on these projects in 1987 was six person-months and $43,500.

14. Department of Geological Sciences, University of Manitoba, Winnipeg, Manitoba (W. M. Moon, T. Salvail, G. S. K. Rao, M. Serzu, E. Kublick)

A study of seismic anisotropy in high resolution seismic tomography applied to a Precambrian environment (greenstone belts, etc.) is underway. The objectives of this project are to understand seismic anisotropy in such environments, experimentally measure anisotropy in hard lithology and to evaluate the effect of the seismic wave (P and S) anisotropy in the conventional and VSP type seismic tomography. The first phase of this research includes synthetic seismograph modelling of various geological settings related to mineral deposits.

Two years ago, a high resolution seismic reflection survey was conducted to test the effectiveness of this method for the exploration of deep-seated metallic ore bodies. Processing of the 1200% data is now almost complete. Detailed processing methods, including pre-stack migration (DMO), developed at the university have proved to be very effective. Currently, a new seismic stratigraphic interpretation technique is being developed for Precambrian and other hard rock environments. The preliminary results indicate that for the first time in the Precambrian Shield, the seismic reflection method can, in practice, be used for direct mapping of massive ore bodies.

Research to study integrated geophysical imaging in a Precambrian Shield environment is underway. The objectives of this work include development of mathematical methodology for integrating various geophysical data, processing and geocoding of available remote sensing data and final integration of the processed data sets for the selected target areas. Currently, a target area in northern Manitoba has been chosen. Ground geophysical data, airborne magnetic (including gradient) data and satellite remote sensing data are being collected and/or processed.

The level of effort expended on these projects in 1987 was sixty person-months and $62,000.

15. Department of Geophysics, University of Western Ontario, London, Ontario (L. Mansinha, J. King)

The mise-à-la-masse method of electrical exploration involves the direct charging of a conducting body with an implanted cement electrode. If there is another neighbouring ore body, which may or may not be in electrical contact, the question of detecting and resolving the latter from the former arises. This problem has been investigated for tabular bodies with a series of model tank experiments. A parallel investigation involving a pair of parallel dipping, conducting veins has been carried out in a drill hole near Bancroft, Ontario.

The level of effort expended on this project in 1987 was twenty person-months and $15,000.

16. Geophysics Laboratory, Department of Physics, University of Toronto, Toronto, Ontario (R. C. Bailey, R. W. Groom, S. W. Reford)

A major obstacle to successful magnetotelluric sounding in exploration is the distorting action of local conductivity in homogeneities. Techniques like EMAP (TM) try to deal with this by multiple and extended electrode arrays. We present an analytic approach which applies the physics of Bahr to removing these effects when the underlying regional structure is at most two-dimensional.

Utilization of a minimum mean absolute density gradient norm allows the automatic computer fitting of gravity data with density models that can accommodate continuously variable density yet are simple. A two-dimensional computer implementation of this method has been produced. It has demonstrated its successful operation on synthetic data and is currently being applied to gravity profiles in the Timmins-Kirkland Lake area.

The level of effort expended on these projects in 1987 was thirty-six person-months and $22,000.

17. Geophysics Laboratory, McGill University, Montreal, Quebec (O. G. Jensen, M. Gregotski, J. O. Barongo, P. Keating, D. Crossley)

Work is underway to develop a statistical approach to the deconvolution of potential field data in one and two dimensions to produce a geologic mapping technique. This requires the implementation of stochastic data models to describe the geophysical measurements. The stochastic processes which were chosen to excite the geophysical system are self-scaling or fractal. From this class of processes, flicker noise is the fundamental random element that is incorporated in the modelling. This technique is being tested on synthetic data while in the development stage, and in the future it will be used with real data.

Chemical weathering of geology in tropical terrains causes problems in conventional geological mapping and geophysical mineral prospecting. In order to obtain useful information from the bedrock geology, airborne electromagnetic and ground resistivity methods as tools for geological mapping in these environments are examined. Algorithms for the automated inversion of conductivity and thickness of the weathered layer are being developed and applied to practical data. Preliminary results from one such environment show that the fairly conductive layer is sandwiched between two resistive layers of what is commonly seen to be a three layer model.

Present interpretational techniques for airborne time- domain EM data are mostly based on the use of nomograms. For high accuracy interpretation however it is better to use an inversion technique which can make full use of the available data. A method has been developed using a modified form of the PLATE program (Annan, Dyck) in an SVD inversion procedure to automatically fit INPUT data. The algorithm has been run successfully on IBM-PC's and has been modified for simultaneous EM-magnetics interpretation as well as inversion using only the late time channels (to allow for a surface conductivity layer, to some extent).

The level of effort expended on these projects in 1987 was twenty person-months and $25,000. Funding was provided by EMR, NSERC, the University of Nairobi and the Government of Kenya (via CIDA).

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X ENGINEERING GEOPHYSICS

Compiled by: K. Howells

1. Université Laval (M. K. Séguin)

The contribution to Engineering Geophysics by le Département de géologie and Centre d'études nordiques, Université Laval may be divided into two parts: Geophysical studies related to permafrost in northern Quebec (a) and geophysical investigations related to environmental studies in southern Quebec (b). These are described in more detail as follows:

(a) Geophysical Studies Related to Permafrost in Northern Quebec

These studies were conducted at four localities in northern Quebec: Kangiqsualujjuaq; Sugluk and Kangirsuk; Manitounuk Strait.

At Kangiqsualujjuaq, electrical resistivity, induced polarization, self potential, gravimetric and geothermal surveys were conducted both at the surface and in hole. The objectives of these surveys were to: outline the lateral and vertical distribution of permafrost (active layer and permafrost base) in shoreline and terrestrial environments; to study the long term thermal regime of specific permafrost mounds; to determine the temperature and ice content of discontinuous permafrost.

At Sugluk and Kangirsuk (Ungava Bay), electrical resistivity, induced polarization, geothermal and georadar surveys were conducted to outline the depth of the thaw front or of the active layer in continuous permafrost, to determine the depth to the bedrock and to obtain an approximate estimate of the ice content. These surveys are conducted on projected airport sites and the investigations are the results of a joint project: Transport Canada-Ministére des Transports du Québec - Geological Survey of Canada - Centre d'etudes nordiques.

At Manitounuk Strait (Hudson Bay), electrical resistivity and geothermal surveys were carried out to: outline the shape of discontinuous permafrost in cryogenic mounds; obtain an estimate of the temperature distribution in discontinuous permafrost; monitor the thermal evolution of permafrost morphologies potentially in degradation.

(b) Geophysical Investigations Related to Environmental Studies in Southern Quebec

These studies were carried out at two localities in southern Quebec: Havre Saint Pierre and Sept-Iles.

At Havre Saint-Pierre, both electrical resistivity and gravimetric surveys were used to determine the nature and extent of sink hole sand underground dissolution tunnels in indurated sand layers. The geophysical surveys were used as complimentary tools to locate the position of the highway on the north shore of the St. Lawrence River which extends to the east of Havre Saint-Pierre. The field work executed by Januz Frydecki was done in collaboration with the Ministére des Transports du Québec.

At Sept-Iles, electrical resistivity surveys were conducted to obtain data related to the susceptibility to corrosion of a series of fuel reservoirs (old and new) which are potentially leaking. The electrical resistivity data were instrumental for the estimation of the lifespan of specific reservoirs. Recommendations related to their maintenance were made accordingly. This investigation was carried out by a group of scientists from Transport Canada, Roche et Associés and André Galibois et Associés.

2. Nova Scotia Research Foundation Corporation (A. G. McKay)

The Geophysics Section of the Nova Scotia Research Foundation Corporation continued geophysical work in Chedabucto Bay and St. Georges Bay at the eastern extreme of mainland Nova Scotia. A six day cruise on board CSS Dawson provided bathymetry, sidescan sonar and

seismic profiling data along 165 km and 190 km of track in Chedabucto Bay and St. Georges Bay, respectively. The seismic profiling systems consisted of the NSRFC Deep Tow Sparker System and the NSRFC Surface Tow Sparker System. The geophysical equipment was operated by NSRFC personnel with assistance from Dalhousie University personnel.

Positioning utilized Loran C, Ship's radar and the Atlantic Geoscience Centre mini-ranger electronic positioning system. Positioning data acquisition and processing was carried out by the AGC min-nav system operated by AGC personnel with assistance from personnel of the College of Geographical Sciences, Lawrencetown.

Data analysis is underway with results showing improved resolution of sediment distribution, buried drainage channels and bedrock structures.

A magnetometer survey was carried out to locate buried metallic waste in southern Nova Scotia, and inshore seismic profiling surveys were carried out for dredging and harbour construction investigations.

3. Gartner Lee Limited (D. D. Slaine)

Geophysical surveys and research programs for a number of hydrogeological studies were carried out by Gartner Lee Limited. These included a seismic refraction survey to define bedrock topography in southeastern Ontario and a seismic reflection survey to map buried valleys for ground water supply investigations near Aurora and Newmarket, Ontario. In addition, electromagnetic surveys were carried out to map buried metallic waste and define fill boundaries on a property development project in the northeastern United States, to map buried industrial wastes in southeastern Ontario and to map buried paint solvents and industrial waste in southern Ontario. A borehole electromagnetic survey mapped the extent of leachate plume emanating from a municipal landfill in south central Ontario.

Other projects are described in the two publications listed in the Bibliography.

4. Paterson, Grant and Watson Limited (S. W. Redford)

(a) High-Resolution Reflection Seismics (N.M. Soonawala (A.E.C.L), A. Sartorelli and J. Henderson (Geophysicon))

The objective of the high-resolution seismic reflection surveys was to map fracture zones in granitic rocks to a depth of about 1 km. Modelling was initially done, based on density and acoustic data. Both the shot and geophone spacings were 17 m. Shots were placed in holes drilled 3 m into bedrock. A 0.25 ms sampling rate was used. Coherent reflections were obtained, and at one test area the correlation with known geological structure is good. Further data processing is proposed.

(b) Crosshole Seismics (J. G. Hayles)

The crosshole seismic activity is centered around two separate systems. The longer-range system is capable of transmitting energy between boreholes up to 500 m apart, and will be used principally to image fracture zones between pairs of boreholes. The smaller of the two systems transmits high-frequency seismic energy over distances of only a few meters, and is used to measure p- and s-wave velocities, and the effects of regional stress snd mechanical and thermal loading on these parameters. Both these systems are in the final stages of development and have not been fully deployed for field work as yet.

(c) Radar Surveys (A.L. Holloway)

Surface and borehole radar surveys are used to map fractures in granitic rocks. Frequencies of between 60 and 500 MHz are used. Fractures have been mapped to depths of 30 m in granitic outcrop, and the results have been verified by drilling. Radar logging was done in the single-hole reflection, crosshole and vertical profiling modes. The radar methods are fully operational, and good-quality field results have been obtained.

(d) Geophysical Logging (D. K. Tomsons)

Electrical, nuclear, sonic and caliper logging is being carried out to map fracture zones, lithology and groundwater salinity in granitic rocks. A Mount Sopris Series 3 system is used. Excellent results have been obtained over the course of the year, and the system is fully operational

(e) EM and Magnetic Surveys (N. M. Soonawala)

Electromagnetic and magnetic surveys are being carried out to map near-surface fractures in granitic rock. The VLF-EM, magnetic and horizontal-loop EM systems were used along cut-line grids over a number of areas. Magnetic modelling was done to determine the geometry of the fracture zones believed to be responsible for the EM and magnetic anomalies. These methods are applied on a routine basis for initial reconnaissance.

5. Ontario Hydro (R. J. Heystee)

Hydrogeologic investigations of sedimentary sequences were carried out by Ontario Hydro. Two deep holes (76 mm diameter; 243 and 390 m long) were drilled at two widely-spaced locations along the northshore of Lake Ontario. They intersected a thick sequence of sedimentary rock (shale and/or limestone) and penetrated the Precambrian basement rock. The sedimentary rock generally has a low measured hydraulic conductivity (less than 10^{-11} m/s). These low hydraulic conductivity values are corroborated by: observations of no visible ground water flow to two 9 m diameter tunnels that are located close to one deep borehole; the presence of saline groundwaters at the Paleozoic/Precambrian contract; and the measurement of anomalously high fluid pressures at depth in the sedimentary sequence.

Future work in this study will include the collection and analysis of ground water samples from these deep borings. The detailed chemical and isotopic data will hopefully shed some light on the ground water flow patterns in the vicinity of these two deep borings.

6. Geological Survey of Canada: Terrain Geophysics Section (J. A. Hunter)

The Terrain Geophysics Section of the Terrain Sciences Division, Geological Survey of Canada, was actively engaged during 1987 in several projects in engineering ground water, terrain mapping and mining exploration geophysics.

A high resolution seismic reflection program has been completed in the Fraser River delta in British Columbia. Approximately 50 line-kilometres have been surveyed in an attempt to map the structure of the southern portion of the delta. This data forms part of a larger program to map the Fraser delta and to evaluate the earthquake risk.

Approximately 5 line-kilometres of high resolution reflection data were shot in the Ft. Frances area of Ontario to evaluate the technique for stratigraphic mapping of overburden materials. This program is being conducted in co-operation with the Ontario Geological Survey. Further testing is planned for 1988.

A two-year program of high resolution reflection shooting in Val Gagne, Ontario, was completed this year. The work was conducted to provide overburden thickness and stratigraphy as part of ground truthing of experimental airborne EM surveys. Fifteen line-kilometres were shot over the Val Gagne test strip. This work was done as part of the Ontario Mineral Development Agreement.

A program of high resolution DCP reflection shooting was completed this year in the Cumberland Basin area, Nova Scotia. The survey was conducted to map the structure of coal-bearing strata in the area. Over 90 line-kilometres of data were acquired and are currently being processed. This work was supported by the Nova Scotia Mineral Development Agreement.

Geophysical surveys were conducted at the shoreline of Richards Island, MacKenzie Delta, N.W.T., to map the presence of configuration of ice-bearing permafrost in an area where oil pipeline landfalls are planned. Borehole logging, temperature logging, surface EM and refraction surveys were carried out.

A test of a deep-towed marine seismic refraction system was carried out in the Beaufort Sea shelf area offshore MacKenzie Delta. The technique has been designed to map ice-bearing permafrost at depths up to 20 metres below seabottom as an aid to pipeline route selection and for site surveys for bottom founded structures.

7. 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 the nature of morphological features on the continental margins of eastern and arctic Canada. These regional programs provide a framework for the interpretation of studies undertaken to solve site-specific engineering and scientific problems.

Projects are also underway to provide a better understanding of the relationship between the physical and acoustic properties of marine sediments through:

application of a computer-assisted system for on-line determination of near-surface seismic velocity using wide-angel reflection seismic techniques,

development of an IBM-PC based system for measurement of attenuation, compressional, and shear wave acoustic velocity of marine sediment (with Dalhousie University),

development of a portable system for calibrating the output pulse of high resolution subbottom profilers,

use of a directional hydrophone to improve the resolution of seismic records obtained in shallow water,

compilation of the Tertiary seismostratigraphy of the Grand Banks of Newfoundland and integration of available borehole and well-log data,

development of Labrador Shelf geotechnical zonation maps based on seismostratigraphy and detailed core analysis,

testing of a fluid-filled boomer seismic source for deep water deployment,

laboratory testing to determine the correlation between physical and acoustic properties of sands (with Centre for Cold Ocean Resources Engineering of the Memorial University of Newfoundland).

Geophysical surveys for engineering properties evaluation have been performed in the following locations:

Scotian Slope and Flemish Pass: to evaluate sediment instability, (Huntec Deep Towed Seismic subbottom profiler data were collected in 4000 m water depth on the Scotian Slope survey),

Sable Island Bank and Banquereau: to study sediment transport,

Hudson Bay: continuation of mapping program to study the distribution and genesis of surficial sediment and bedrock geology,

Arctic Islands: continuation of programs for regional geological and geotechnical data for assessment of sediment stability, and for engineering and other constraints,

Beaufort Sea coastal zone: determination of seabed geology and physical properties,

Emerald Basin, Flemish Pass, and Tail of the Banks: data collection for correlation between acoustic and physical properties,

Grand Banks: geotechnical boreholes for determination of physical properties and ground truthing interpretations for surficial geology made on the basis of geophysical surveys,

Cape Breton Island nearshore: surficial geology mapping for resource inventory purposes.

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