Energy Mines and Resources Canada
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Earth Physics Branch
Direction de la physique du globe

CANADIAN GEOPHYSICAL BULLETIN

BULLETIN CANADIEN DE GÉOPHYSIQUE

Volume 37

Editor/Rédacteur en chef R.A. Gibb

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

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INTRODUCTION

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

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

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

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R.A. Gibb
Editor

INTRODUCTION

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

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

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

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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.

R.A. Gibb
Rédacteur en chef

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I (A) GEODESY

Compiled by: R.B. Langley

1. Summary

Geodesy continues to be a healthy discipline in Canada. Developments are reported by 19 organizations including federal and provincial agencies, universities, and private industry. Interest in the Global Positioning System (GPS) has accelerated. GPS is being used for a variety of surveying tasks on land, in the air, and at sea. Research is being carried out to improve the accuracy of absolute and relative positions from GPS observations. Work continues in preparation for NAD83 and NAVD88 at both the federal and provincial levels. Publication of the first NAD83 values is expected to begin in 1987. The first long baseline interferometry (LBI) observations under the auspices of the Crustal Dynamics Project (CDP) of the U.S. National Aeronautics and Space Administration (NASA) were carried out in 1984. Other LBI activity includes the continued development of the Canadian Geophysical Long Baseline Interferometry system. Reports of theoretical work include studies of earth rotation phenomena, sea-surface topography, and the geoid. Studies of various time dependent phenomena affecting geodetic measurements are under way. Work is also reported in the applications of inertial surveying systems (ISS), Loran-C, and electronic distance measurement (EDM) instruments. Much of the university research reported here is supported by the Natural Sciences and Engineering Research Council and by Energy, Mines and Resources Canada.

2. Geodetic Survey of Canada

Preparation for NAD83, the redefinition of the North American horizontal datum, continued. A training course in the use of program GHOST was attended by representatives of federal and provincial agencies participating in the redefinition. Their Helmert blocks of secondary data will be added to the framework blocks of Doppler and triangulation data using program GHOST. Preparation of federal secondary blocks of conventional surveys is nearly complete and preparation of inertial survey blocks has begun. Publication of 400 000 NAD83 values is expected to begin in early 1987 in both Canada and the United States.

Nearly 50% of the data for the North American vertical datum redefinition (NAVD88) has been automated and verified. Software exchanges with the U.S. National Geodetic Survey have begun. One-way relevelling in Nova Scotia was completed with encouraging results. A

preliminary analysis of loop closures in the basic 55 000 km framework was completed. A study of collimation error effects was carried out as well as an investigation of other systematic errors such as refraction using the data from a special test net established near Sherbrooke, Quebec. A digitizing system for capturing bench mark positions from topographic maps was developed and tested. All previously obtained positions in the historical file will be verified using the digitizing system prior to finalizing NAVD88.

A system for uniquely naming files to be included in the observation data bank, with cross-references to the National Geodetic Data Base, was developed. User needs for such a data bank were reviewed.

Extensive satellite Doppler work was undertaken mainly in the Yukon and Northwest Territories. This included 122 first-order points for densification of the primary horizontal control network, 68 points for mapping control and additional points at local settlements and along highways, to serve as survey control.

A special high-accuracy trilateration network on Vancouver Island was measured for framework strengthening and to assist crustal movement study. Other high-precision measurements were made relating to LBI sites at Penticton and Algonquin Park.

Astronomic deflection measurements were made at 38 stations in Newfoundland, Nova Scotia, Ontario, Yukon, and the Northwest Territories.

In 1984, 1875 km of first-order or special-order new levelling and 2150 km of relevelling was completed, and 1562 new bench marks were installed. Contract work accounted for most of the new levelling. Progress also continued on the installation and testing of a calibration facility for precise levelling rods.

Extensive inertial surveys were completed in 1984 partly because of the acquisition of a new LASS II system. The result was 18 000 km of ISS traversing (1070 points), established for mapping and multipurpose use, and a further 5400 km (445 points) for a special gravity network. Other supplementary control surveys included flood plain map verification in Manitoba, vertical control by a combination of levelling and a motorized ground elevation meter, and aerial photo station identifications for the National Mapping Program.

Research and development progress was made in eight general areas: application of GPS, planning for the implementation of mobile LBI, ISS, geoid estimation, systematic errors in levelling, geodetic network adjustment models and analyses, satellite Doppler (Transit) positioning, and EDM.

Considerable progress was made, both in house and under contracts, in theoretical and software development for the application of GPS in Canada. Work continued toward recovery of gravity and deflection of the vertical differences from ISS measurements. Adjustment models for ISS surveys were investigated further. The development of methodology and computer programs continued, under contract, for the computation of topographic corrections for gravity data (using a Fast Fourier Transform approach), and for the representation of the Canadian geoid by an analytical (polynomial) surface.

The magnetic effect on automatic compensator levels was investigated further, and plans were made for setting up an in-house calibration system for this effect. Work continued, under contract and in house, on the modelling of various other systematic errors in levelling. The development of a precise trigonometric levelling system continued under contract.

The development of methods and software for interactive design and analysis of two- and three-dimensional geodetic networks, using strain and error analysis techniques, continued under contract.

Methodology for the integration of geodetic networks was developed further. Study began on the application of "integrated geodesy", i.e., models for the integration of various types, geometrical and physical, of measurements in network adjustments, to geodetic networks in Canada.

GEODOP software was installed on the HP 9816 microcomputer for field processing of Doppler (Transit) data.

Study began on the implications of new technology (GPS, LBI, computers) for geodetic surveying, and positioning in general, in Canada.

A detailed study of the application of Helmert blocking to the NAD83 project was completed.

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

Precise monitoring of the earth's rotational dynamics by optical astronomical (PZT) and satellite Doppler (TRANET) techniques continued from observatories near Ottawa and Calgary. The results are transmitted weekly to the Bureau international de l'heure in Paris, the International Polar Motion Service in Mizusawa, Japan, and daily to the DMAHTC Polar Monitoring Service in Washington, D.C., for evaluation of global parameters. Project MERIT standards have been implemented for routine reduction of PZT observations in 1984. Satellite data for 1983 have been reprocessed and systematic variations of the satellite-derived positions for the Ottawa and Calgary stations have been analyzed over the 1979-83 period.

Development of the TRANET II compatible station has been completed and operational testing is under way at the Shirley's Bay observatory. Software has been developed to facilitate real-time satellite orbit prediction, computer aided tracking, data validation, and communication.

Research and development of astronomical and satellite interferometric techniques continued in cooperation with York University, University of Toronto, and Boojum Research Ltd. of Toronto. The prototype correlator board for the Canadian Geophysical Long Baseline Interferometry (CGLBI) system has been assembled and the playback control software developed. Integration of the GPS Pseudo-Range Surveying System hardware is in progress and prototype testing is planned for 1985.

The first annual long-baseline measurements for the study of crustal dynamics were made in Canada in 1984. The measurements were made by NASA mobile LBI equipment in conjunction with Algonquin Radio Observatory. Initial measurements were made at Whitehorse to stations in Alaska to determine the relative velocities between the Pacific and North American plates and the rate of strain accumulation near the plate boundary. Baselines connecting Yellowknife, Penticton, and Algonquin Radio Observatory in Ontario with Fairbanks, Alaska; Westford, Massachusetts; and Fort Davis, Texas, were measured to determine the stability of the North American Plate. This experiment is a joint effort by NASA, EPB, GSC, Pacific Geoscience Centre, York University, and the University of New Brunswick (UNB).

4. National Research Council, Division of Physics

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

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

5. Canadian Hydrographic Service

The Canadian Geodesy Section, located at CHS headquarters, Ottawa, carried out several moderately large adjustments of horizontal control surveys established by the regional offices of CHS. Areas adjusted were: part of the Labrador coast, Magdalen Islands, Belcher Islands, St. Mary's River, and Queen Charlotte Islands.

Loran-C calibration data were collected in Hecate Strait, Lake Superior, Cheticamp to Percé, and the south, east, and northwest coasts of Newfoundland. These data will be converted into Additional Secondary Factor chartlets published in Radio Aids to Marine Navigation and into lattices for the marine navigation charts. Twenty-nine charts were published with Loran-C lattices during the period from 1 December 1983 to 1 December 1984.

A network of water level gauging stations is operated along the shores of Canada's coastal and inland navigable waters by the Tides, Currents and Water Levels sections of the various regions of CHS. The accumulation of long and continuous time series of water level data at these stations contributes to studies of sea level variations and vertical coastal movements, as well as to the establishment and control of vertical datums for levelling networks. Of particular interest at the present time is water level gauging for use in re-evaluation of the International Great Lakes Datum.

Water level gauging of a more temporary nature is also carried out to provide mean sea level estimates for specific applications such as the GSC level lines which terminate along the Arctic coastline. Temporary gauges are presently being operated at four sites in the Arctic Islands to determine mean sea level variations. This information will in turn be used to estimate variations in water mass transport through the islands.

Offshore tidal information is being gathered by moored deep-sea pressure gauges. The CHS continues to operate the International Hydrographic Organization Tidal Constituent Bank through the facilities of the Marine Environmental Data Service.

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

GPS differential tests were made over baselines of 300 km (Halifax - Sydney), 600 km (Halifax - Quebec), and 900 km (Halifax - St. John's). Initial analysis showed good correlation in range bias right out to 900 km. GPS was used at sea for a total of 12 weeks under evaluation, for Loran calibration, and in surveys. It consistently gave four hours of coverage per day, using known geoid height in the correlation, though there were occasional minor problems due to the advertised fact that the system is still under development by the U.S. Department of Defense. All this work was done under contract by Nortech Surveys, Calgary. In addition, Nortech have been contracted to identify potential problems in using GPS in the Arctic.

A wide sampling of Loran calibration observations has been made, particularly around Newfoundland, to verify overland phase lag predictions based on a conductivity model and Millington path-reversal method. The results will be used to lattice about 75 large-scale charts (up to 1:60 000). This chart scale, where one-tenth of a microsecond can be one mm on the chart, is a severe test of the model, which is not proving out well. As in previous experience, the phase recovery observed within a few wavelengths of the land-sea boundary tends to be 50% greater than predicted. In addition, at ranges of 1000 km, time-variable reading errors of around 0.5 microsecond because of skywave are showing up.

Work on evaluating the effect of the "electronic chart" on the hydrographic data base of the future is starting in earnest, with the development of a test-bed version. This will be used at sea and in the lab to assess the number and type of data bases required, and also to investigate the updating problem, to establish minimum standards, etc. The work is being done under contract by Universal Systems Ltd., Fredericton, who have considerable experience in computer cartography, including work on computer-assisted cartography for CHS.

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

In 1984, Service de la géodésie du Québec made the following additions to the geodetic networks: horizontal points - 16 first order, 139 second order, and 226 third order; level

lines - 393 km first order, 51 km second order, and 224 km third order. All first- and second-order levellings were aided by electronic notekeeping by HP-41CX calculator. Two thousand existing points were inspected and action taken where necessary (protection, targetting, replacement). Adjustments were completed for 1090 horizontal and 924 vertical points and new software was developed to aid processing in spirit and trigonometric levelling. Geodetic data base "GEODEQ" activities were pursued: 18 000 point descriptions and coordinates (files) were added; 100 000 files were printed and distributed. Network compilation maps were copied and distributed (2100 copies); 397 such maps were either prepared or updated. New maps at scale 1:2 000 000 were made available, showing horizontal and vertical networks. In the standardization/classification/microgeodesy sector: 2500 horizontal and 440 vertical points were integrated and classified; supervision was exercised in urban densification (700 horizontal and 130 vertical points); program CAVALE was developed for preliminary network processing; tests were made on 7 electronic tacheometers; a new calibration base was established at Trois-Rivières and another is planned for the Quebec area; the following Quebec-produced data were transferred to GSC in view of redefinitions: for NAD83, 15 new primary points and observations relevant to 62 Quebec-U.S.A. boundary points; for NAVD88, 216 points (210 km of first-order levelling). Various activities were reported by Rousseau et al. (1984).

Geodetic research activities completed by early 1984 were summarized by Moreau (1984). The results of an experiment using helicopter inertial/laser profiling, conducted in late 1983, were analyzed in 1984. This technique permits sampling of true ground elevations between foliage obstructions. The results, after comparison with spirit-levelling on 750 points, indicate that accuracy by inertial/laser profiling is much better (0.6 metre r.m.s.) than can be obtained by photogrammetry (1/3 height of trees). The principal research activity in geodesy was the GPS Macrometer™ experiment in Ste-Foy and subsequent analyses of results with contributions from the Universities of Bern, Laval, and New Brunswick. The results indicate that for lines under 2 km, phase-difference observations yield better than 5 mm r.m.s. accuracy in each coordinate.

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

Forty-two satellite Doppler horizontal control stations were established in Ontario to support mapping and control densification.

Inertial surveying was used to provide 550 vertical control stations (benchmarks) in north-central Ontario to support mapping and vertical control densification.

Second- and third-order horizontal and third-order vertical municipal densification networks, established in 1983, were analyzed for 15 municipalities in various areas of Ontario. About 15 new contracts have been let for second- and third-order horizontal and vertical municipal control densification networks in 1984. These networks will support large-scale mapping and integrated surveys in these municipalities.

Positional and associated observational data for nearly 11 000 horizontal control stations have been stored in the Ontario horizontal control survey data bank COSINE in 1984. This gives a total of 36 000 stations complete with positional and observational data and an additional 14 000 stations with positional data only, currently residing in COSINE. COSINE is a control survey data base capable of storing positional, observational, and textual data associated with horizontal control stations, i.e., ellipsoidal and geoidal parameters, station names, positional values, directions, angles, azimuths, distances, accuracy estimates, error ellipses, and informational data such as station descriptions.

Area readjustments were completed for two large blocks of the province - the northern and western portion of southwestern Ontario. The northern Ontario block consisted of 5605 horizontal control stations, involving 29 444 observations. The southwest Ontario block consisted of 3925 stations, involving 18 025 observations. The horizontal control in these areas of Ontario is now ready for readjustment onto NAD83.

On 26 July 1984 the Ontario Ministry of Natural Resources was given the mandate to collect, store, analyze, validate and adjust, update, maintain, publish, and distribute vertical control data; develop and publish standards, specifications, and guidelines; secure field data as may be required to locate errors and upgrade vertical networks; and act as the

provincial representative on matters of provincial concern respecting vertical control.

Precise calibration baselines for EDM equipment were constructed at two locations: Lindsay and Conestogo, Ontario.

A bibliography of geodetic-related articles appearing in The Canadian Surveyor, from Vol. 3, 1928 to Vol. 38, 1984, complete with their associated abstracts, has been prepared.

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

Under a cooperative inertial survey program with GSC designed to establish a control survey station at or near every township corner in southern Manitoba, coordinate values were published for 114 stations in southwestern Manitoba and for 89 stations in the interlake region. As well, inertial field measurements were completed for the eastern half of another network located adjacent to and west of Lake Manitoba comprised of 220 stations. Finally under this program, sites were selected and prepared for approximately half of a 211 station network due for field measurements by ISS in June 1985.

Control survey networks were established in the communities of Virden and The Pas and in two separate areas of the City of Winnipeg.

Six stations were established by GPS as part of an experimental project to assess various surveying methods including a photogrammetric approach for the development of a geographical reference framework for the province.

The Dominion Land Survey system and geodetic framework were integrated at 30 locations.

Efforts continued to produce a VAX 11 version of the Helmert block adjustment software GHOST, which was developed by GSC. This software will be used for the production of reduced normal equations for the junction points of provincial blocks of the secondary horizontal networks with respect to NAD83, and for the subsequent secondary integration process.

A continuing program of data preparation and validation associated with secondary integration is in place.

10. Alberta Bureau of Surveying and Mapping

Limited in-house evaluation of a municipal control fabric installed in the Crowsnest Pass area of Alberta by GPS technology was undertaken.

Stations were positioned using the Macrometer™ system in a network design with 84 degrees of freedom using a 3-D adjustment. This network was densified with conventional observations and an evaluation of the consistency between the two data sets was performed.

Investigations into EDM calibration on baselines of known length were carried out. Observing procedure optimization is suggested, and data processing techniques are under review. The data processing techniques include statistical testing of the linear regression solution to validate the reliability. These investigations are ongoing and the inclusion of a cyclic error model in the software is expected in the near future (Kassam, 1984).

The effect of using diagonal, estimated, or sparse covariance information in a weighted station adjustment approach as opposed to a fully populated covariance matrix input was investigated. The subsequent effect on evaluating integration blocks and marker stability was investigated. These investigations were done in support of exploring the possibilities pertaining to covariance information generation and maintenance (Voon, 1984).

Upgrades to the existing CANDSN package were implemented by the University of Calgary under contract. These upgrades included improved design capabilities, weighted stations capabilities, and data evaluation tools such as multiple variance factor testing, Type II errors, sensitized global test, and advanced data snooping.

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

A calibration baseline for EDM instruments was built in West Vancouver. The elevations have been determined by differential levelling and preliminary distances have been measured by HP 3808A.

Branch survey activities are primarily directed in support of mapping at 1:20 000 and 1:5000 scales and in support of the integrated survey areas in urban areas. Mapping control surveys are used to densify the existing permanently marked survey networks. A data bank of survey station information is maintained and searches are made upon request.

Program MANOR was installed this year and is now being used for horizontal least-squares adjustments.

12. Memorial University of Newfoundland, Department of Earth Sciences

Recent compilations of the angular momentum of the atmosphere have revealed that nearly all of the short-term (less than 1 year) irregular fluctuations in the length of day are caused by the exchange of angular momentum with the atmosphere. It has been demonstrated that the removal of the wind-induced signal from UT results in a less noisy signal, which permits better estimates of tidal terms in the length of day to be made. These new measurements can, in turn, be used to constrain models of mantle anelasticity.

Work continues on transverse surface stresses. J. Merriam has shown that the strain from transverse surface stresses can be described by a new toroidal Love number that augments the existing set of spheroidal Love numbers. The degree 1 toroidal Love numbers have the special significance that they measure the strain from a surface stress which exerts a net torque on the earth. The apparent UT signal from the elastic displacement of the surface (which is indistinguishable from a rigid rotation) is proportional to the toroidal Love number of degree 1 and may amount to a millisecond under some circumstances.

13. University of New Brunswick, Department of Surveying Engineering

Research in the area of geoid determination has continued with the result that algorithms for atmospheric gravitational effect, indirect effect, and topographic effect of free-air gravity anomaly have been reformulated. Work has continued on combined solutions for the geoid in Canada. The first phase of investigations related to the inverse gravimetric problem has been completed.

An investigation has begun into the use of satellite-altimetry-determined sea surface for the determination of gravity anomalies. Results from this study will also impact on an investigation of the effect of ocean current variability on the length of day. The use of sea level records collected by means of tide gauges for vertical crustal movement determination has been reviewed. The development of a navigation algorithm based on motion in a probability space was successfully finalized.

The UNB earth tide station (2 tiltmeters and one gravimeter) is being refurbished to allow automated data collection. Further analysis of existing data has been performed. Formulation of schemes and algorithms for statistically rigorous densification of horizontal geodetic networks has been successfully accomplished. The book Geodesy: The Concepts has been substantially rewritten and a manuscript prepared for the publisher.

The GEOAIM program for processing LBI data has been further developed. It has been made interactive and installed on an HP 1000 minicomputer. Participation in NASA's Crustal Dynamics Project continues.

Studies continued into applications of GPS to geodetic positioning. General purpose software for processing data from a variety of receiver types (Santerre et al., 1984) and dedicated software for processing data from Macrometer™ receivers (Beutler, 1984) has been developed. Data from Macrometer™ receivers on networks in the Ottawa area (Abdullah, 1984; Beutler et al., 1984; Langley et al., 1984) and Ste-Foy, Quebec, have been processed. Dedicated software has also been developed for differential positioning with Texas Instruments TI 4100 GPS carrier phase observations. Results for the Ottawa network

agree with the previously obtained Macrometer™ results on the ppm level.

Work continues on the development of a generalized method for the analysis of deformation surveys (Secord, 1984). A study on efficient numerical processing of horizontal control data was concluded (Steeves, 1984).

A project on tidal boundary delimitation entailing an assessment of the legal, scientific, and technical criteria is continuing (Nichols and McLaughlin, 1984).

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

Dans le domaine de la métrologie, les travaux reliés à l'automatisation des opérations de nivellement géométrique se sont poursuivis (Jobin et Plante, 1984; Plante, 1984). La mise au point du système interférométrique de calibrage des mires invar s'est poursuivie. Une comparaison entre le calibrage en position verticale et horizontale a été effectuée. Un système de calibrage pour des rubans d'invar de 200 mètres de longueur a été développé et une étude sur le comportement des fils de Kevlar a été effectuée pour le CRDV. Un projet est en cours pour l'évaluation de 10 instruments du type "station totale". Finalement, différents protocoles de communication entre les calculatrices HP-41, HP-71 et différents micro-ordinateurs (Sharp PC-5000 et PC/IBM) ont été mis au point.

Dans le domaine de la géodésie spatiale, une étude sur les variations des résiduelles Doppler a été publiée (Gélinas et al., 1984). Une étude sur l'application de la compensation généralisée à l'analyse des observations Doppler se poursuit (Arancibia, 1984). Dans le cadre d'une participation au projet ADOS (African Doppler Survey), une campagne d'observation Doppler a été effectuée au Maroc et un projet a été amorcé en vue de faire l'analyse du réseau géodésique primaire marocain à partir de l'intégration des données Doppler. Une étude préliminaire sur l'utilisation du récepteur Macrometer avec GPS a été complétée (Leclerc, 1984). L'étude se poursuit en utilisant les données d'un réseau test établi à Sainte-Foy, Québec. Une étude a été amorcée par L. Jeudy sur l'analyse, le traitement et l'utilisation des données LTS (Laser-Terre-Satellite).

Dans le domaine du nivellement, une étude sur les effets de la réfraction atmosphérique a été complétée sous la direction de J.-G. Leclerc (Santerre, 1984). Une étude sur l'évaluation d'une différence de potentiel par nivellement trigonométrique a également été complétée sous la même direction (Faucher, 1984). Le programme de mesure de nivellement de précision à l'observatoire géophysique de Saint-Hilarion, Charlevoix s'est poursuivi. Une analyse des données de 1978 à 1984 a été complétée (Gagnon et al., 1984; Sanchez et al., 1984).

Dans le domaine de l'astronomie, une méthode a été développée par R.N. Sanchez en vue d'accélérer les opérations de mesures astronomiques sur le terrain. Utilisant les résultats d'une recherche effectuée en 1981, L. Jeudy a amorcé un projet en vue de développer une méthode d'acquisition et de traitement des données gyroscopiques visant à obtenir une précision accrue de la détermination de l'azimut astronomique. R.N. Sanchez a complété une étude d'une solution unifiée des deux problèmes géodésiques pour les lignes de longueur illimitée sur l'ellipsoïde ainsi qu'une étude sur la solution des problèmes de la projection de transverse de Mercator en appliquant le deuxième développement de Gauss pour la représentation sphérique conforme de l'ellipsoïde.

15. York University, Department of Earth and Atmospheric Science

Work is continuing on the development of a 3 baseline LBI correlator and data processor for applications to geodesy and geodynamics. This correlator will accept data in the Canadian Geophysical Long Baseline Interferometry (CGLBI) format at 12 megabits per second (Mbs^{-1}) on two simultaneously recorded side bands for an overall data rate of 24 Mbs^{-1}. The development of the CGLBI system is a joint project of York University, University of Toronto, and Earth Physics Branch.

Researchers are participating along with workers at UNB, EPB Pacific Geoscience Centre and GSC in the NASA Crustal Dynamics Project using fixed and mobile LBI antennas to study the stability of the North American plate. York University was responsible for the overall

operation of the 46 m radio telescope at Lake Traverse in Algonquin Park, Ontario, in August 1984, during the first of four annually repeated measurements.

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

A computer program was produced for the determination of azimuth from observations on the sun and Polaris (Craymer and Gunn, 1984). Studies in levelling and the monitoring of ground movements were published (Carrera, 1984; Carrera et al., 1984; Craymer, 1984b; Vanicek and Craymer, 1983, 1984; Carrera and Vanicek, 1984). Work on the computation of horizontal networks in the Ontario coordinate system (Martin, 1984) and an earlier study on strength analysis of networks (Dare, 1983) were also published.

Work was pursued on systematic effects in first-order levelling, sea-surface topography, nonlinear least squares, network analysis and maintenance, and automated space resection and intersection using cameras containing linear arrays of infrared sensors.

Comprehensive studies in the methodology of analysis and evaluation of levelling errors continued along the lines indicated in the terms of reference of the International Association of Geodesy Special Study Group 1-74.

Limitations of terrestrial and space techniques for monitoring crustal movements were assessed (Wassef, 1983), and a strategy for crustal movement studies in Africa was presented and approved at the Second International Symposium on Recent Crustal Movements in Africa.

A plan of action to increase the efficiency of the contribution of the International Union of Geodesy and Geophysics (IUGG) to the promotion of geodesy and geophysics in the developing countries was charted by the IUGG Committee for Developing Countries, chaired by A.M. Wassef. The plan is being implemented.

17. University of Manitoba, Department of Earth Sciences

The coupling processes at the air-sea interface and the ocean-solid earth boundary layer (ocean bottom) have been investigated using a numerical solution method of the hydrodynamic equations. The results are interactively correlated with the SEASAT-ALT data, and the optimum coupling coefficients (quadratic and linear) are computed for the Hudson Bay area of Canada and the East China Sea. The tests indicate that the algorithm developed also can be easily used for the transient correction of satellite data over water-covered areas (Moon and Tang, 1984).

18. University of Calgary, Division of Surveying Engineering

Research continued on the use of inertial and satellite technology for precise positioning and navigation. In stationary positioning, software is under development that will use GPS phase-difference data from multiple stations to simultaneously improve GPS orbits and station coordinates. The first phase of this research, giving the orbital model and the adjustment approach, has been described by Nakiboglu et al. (1984). In inertial positioning, a detailed comparison of optimal and empirical smoothing methods shows that differences between the methods are small for the standard surveying cases (Gonthier, 1984). A new approach to process unfiltered inertial data has decisive advantages in the post-mission analysis of inertial data (Vassiliou, 1984). A comprehensive comparison of adjustment and smoothing methods for inertial networks is given in Schwarz et al. (1984a). In dynamic positioning, research on the integration of satellite and inertial techniques using GPS pseudo-ranges was brought to a conclusion. Results of offshore tests have been reported (Wong et al., 1983; Wong, 1984; and Schwarz et al., 1984c). Integration methods are presently extended to include GPS difference data and interesting applications in photogrammetry are envisaged (Schwarz et al., 1984b).

Considerable progress has been made in applying Fast Fourier Transform methods to geodetic problems. A tutorial discussion of the method with reference to geodetic problems has been given by Schwarz (1984). The accuracy of geoidal height difference computation has been analyzed in order to find out whether it is comparable to that achieved by GPS interferometry.

The CANDSN program (Mepham and Krakiwsky, 1984) has been upgraded to include the computation of redundancy numbers, external reliability, and multiple variance factors. Work is continuing on the computation of internal reliability and the inclusion of a free network option.

Work on a research agreement with EPB to develop and implement a method to determine three-dimensional movements in a local survey network has been completed. The method utilizes the usual three-dimensional network observations as well as ordinary EDM distances or scaled EDM distances (Gruendig and Teskey, 1984), ordinary constraints or free network constraints, data snooping, a single variance factor or variance component analysis, and S-transformations for the localization of single point movements or group movements (Teskey and English, 1984; Gruendig and Bahndorf, 1984).

The third epoch of low-level aerial photography was flown over the summit of Turtle Mountain where the Frank Slide took place in 1903. Using a high-precision photogrammetric deformation monitoring system, the relative movements of some 23 permanently affixed targets are being observed. Results of the third epoch of photogrammetry indicate some minor point deformations are taking place. A geotechnical study is currently under way to determine whether these point movements are significant.

Research in vertical crustal motion and global sea level changes has continued. An important finding, based on the uplift of the Late Pleistocene Lake Bonneville, is that the upper mantle viscosity has to be less than 10^{21} poise and that the earth's seismic crust in the region behaves elastically under surface loading of 10^4 year period (Nakiboglu and Lambeck, 1983). This can be compared with the longer term response of the lithosphere, under larger stresses (Lambeck et al., 1984) to improve our understanding of lithospheric rheology.

The photogrammetric and auxiliary data corresponding to the 1983 aerial coverage of the Kananaskis Test Network area are currently being analyzed using the extended version of SPACE-M (Blais, 1984a; Blais and Chapman, 1984a,b). The investigation in the use of Givens transformations in least-squares estimation has been continued in filtering and smoothing applications (Blais, 1984b). Kriging and related estimation methods have also been studied in terms of the generalized covariance functions (Blais, 1984c).

19. Nortech Surveys (Canada) Inc.

Research and development related to the use of GPS for marine, air, and land positioning was pursued using TI 4100 GPS receivers. Airborne and marine single point navigation accuracies of 15-20 m and differential navigation accuracies of 5 m have been achieved (Lachapelle et al., 1984a,c). GPS differential static positioning using phase data was carried out with accuracies better than 10 cm (Beck et al., 1984). Integrated GPS-INS navigation development was pursued (Schwarz et al., 1984b). The local gravity field in the Rogers Pass was studied in connection with the construction of a 14.5 km CP railway tunnel (Lachapelle et al., 1984b).

20. The McElhanney Group Ltd., Marine and Geodetic Services Division

Integrated laser, inertial airborne positioning was used to provide terrain profiles for route designs. Software was developed for full editing and automated computer plotting.

Inertial surveys were undertaken using vehicle and airborne methods for mapping projects in Ontario and Quebec and photo control survey for transmission line routes.

A special application for the inertial system was employed for obtaining 'as built' survey information along the Canadian National railway tracks from Jasper to Prince Rupert, British Columbia. The system was installed in a high rail vehicle and automatically recorded horizontal and vertical position to centimetre accuracy every 20 m along the track.

Major monitoring and deformation analysis projects were completed on dam sites in British Columbia and Alberta.

Satellite Doppler observations were made for mapping projects in northern British

Columbia and along the Mackenzie River in the Northwest Territories for a proposed hydrographic survey.

Field gravity surveys were undertaken and evaluation completed for two areas in northern Ontario for Earth Physics Branch.

The company has acquired two Magnavox T-Set GPS receivers and is testing and evaluating them for on-land and offshore positioning.

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I (B) GRAVITY

Compiled by: M.D. Thomas

1. Summary

The Canadian national gravity mapping program continued with sizable surveys in Yukon Territory (~1200 stations), on the frozen sea-ice of Prince Regent Inlet (1050 stations) and in the region of St. Pierre bank (~12 000 line kilometres); national coverage was extended by underwater surveys (277 stations) in nearshore regions off Newfoundland. Also added to the national database were 1.2 million observations acquired from the Atlantic Geoscience Centre; these data were obtained in the Labrador Sea, Baffin Bay and Davis Strait.

Surveys by Earth Physics Branch and other institutions which also contribute to national coverage, but which were directed at specific scientific targets included: Lithoprobe-related surveys across Vancouver Island and the Kapuskasing structural zone; surveys of granitic plutons (and associated greenstones where present) in the Superior Province and Appalachians - the objectives are diverse, for example one of these studies is related to geothermal investigations, another to the Canadian Nuclear Fuel Waste Management Program; surveys to investigate structure in the La Malbaie region, Grenville Province and in the Labrador Trough; site specific marine surveys in the Labrador Sea to support the Advanced Ocean Drilling Program (AODP); surveys of economic targets such as coal basins and potash deposits.

Subject areas for gravity interpretation studies, apart from those associated with the aforementioned surveys, included the Wopmay Orogen of the Bear Province, the Appalachians, the Arctic, coastal Newfoundland, western Quebec and the Pacific margin - Cordillera.

In the field of microgravity, the semi-annual surveys of the Charlevoix network have been discontinued after eight years of monitoring - this program will be replaced by a long term monitoring program involving surveys at intervals of three years. At LaGrande-2 reservoir in Quebec, modelling of microgravimeter data is being undertaken to determine the mechanism responsible for an anomalous uplift near the shore of the reservoir.

Theoretical investigations of gravity data have included: examination of the relationship between change in gravity on the surface of observation and ground displacements; source-oriented representation of surface data; development of a new method for computing a radial gravity profile for a body with circular symmetry; development of packages for spherical harmonic expansion of gravity data and fast Fourier transforms for application programming for upward and downward continuation and derivative computation; optimization of terrain correction computations - an integral part of which has been the evaluation of fast Fourier transform techniques in assisting such computations.

2. Earth Physics Branch (EPB)

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

In response to requests from the International Gravity Commission (IGC) and the Commission for Geodesy in Africa (CGA) a new first-order gravity reference network was designed for the African continent. A draft proposal outlining training requirements, methodology, and cost of the project was prepared in collaboration with the Gravity Network Committee of the CGA and circulated to African agencies for comment. Further discussions of the proposal were held between IGC and CGA officials during the recent Crustal Movements Symposium held in Cairo late in November 1984 and a decision was reached to hold a workshop in Paris in May 1985, to work out detailed plans for the project.

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

The Gravity Data Centre processed 140 external requests for information involving digital gravity and terrain data, manuscript maps, open file maps, gravity network control station descriptions, software routines, and earth tide values.

Approximately 1.2 million one minute observations in the Labrador Sea, Baffin Bay, and Davis Strait were acquired from the Atlantic Geoscience Centre, adjusted by least squares and added to the National Gravity Data Base. The data base has been redesigned to accommodate this increase in volume and to facilitate the storage and retrieval of offshore magnetic data. This new system should be in full production by March 1985.

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

Two new open file gravity maps covering areas of the eastern seaboard have been released. These are map 84-30 (Scotian Shelf/Sable Island) and map 84-31 (Banquereau/Whale Deep); the scale of the maps is 1:1 000 000. Work continues on the compilation of a polar gravity map (north of latitude 64°N) at a scale of 1:6 000 000; it will be published as a colour APPLICON map. A prototype National Earth Sciences Series map for the Sudbury region, maps of the Arctic, North and South America and a gravity station distribution map of Canada have been produced.

(d) Gravity Software (J.F. Halpenny)

Several software conversions to the new VAX and Orca 3000 computers were completed.

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

(i) Cordillera

In the Yukon Territory approximately 620 new gravity observations were made, mainly at intervals varying from 5 to 10 km. A regional gravity survey was conducted within a 100 km wide corridor centred on the Dempster Highway between Dawson City and Fort McPherson in the Yukon. Regional gravity profiles were also acquired across the Eagle Plains Basin from the Dempster Highway to Old Crow, and along the Canol Road from Norman Wells to MacMillan Pass. Detailed gravity transects with stations spaced about 1 km apart were made across the Tintina Fault at Ross River and at Dawson City, and across the Richardson Mountains at approximately 67°N.

Preliminary results from the 1984 surveys show large Bouguer anomaly lows of 15 to 20 mGal over the Tintina Fault system and a large Bouguer anomaly high of 35 to 50 mGal present along the spine of the Richardson Mountains.

Another large gravity survey in the Yukon Territory was conducted, under contract, along roads feeding off the Alaska Highway near the towns of Atlin, Mayo, Ross River, Tungsten and Whitehorse. Approximately 600 gravity stations were occupied at bench marks.

On Vancouver Island roughly 150 gravity observations were made along the Island Highway and along the Lithoprobe transect.

(ii) Arctic Archipelago

In Prince Regent Inlet 1050 gravity stations, distributed on a 6 km grid, were observed on the sea-ice between latitudes 71°N and 73°N. The project was carried out jointly with the Canadian Hydrographic Service and was supported by the Polar Continental Shelf Project.

(iii) Superior Province

As part of the Lithoprobe Project to investigate the Kapuskasing Structure, 209 gravity observations were made in the region between Chapleau and Foleyet, Ontario.

Near Atikokan, Ontario 200 gravity stations spaced an average distance of 3 km apart were surveyed to define the regional gravity field surrounding the granitic Eye-Dashwa Lakes pluton. This work was a contribution to the Canadian Nuclear Fuel Waste Management Program.

(iv) Appalachians (New Brunswick)

Three detailed north-south gravity profiles were established across the St. George Batholith in southern New Brunswick; 156 stations, generally spaced 1 to 3 km apart, were occupied. The surveys were conducted as a follow-up to earlier geothermal logging carried out in the eastern part of the batholith with the objective of assessing the geothermal potential of the intrusion. The gravity investigations were designed to learn more about the deep structure of the batholith and to determine whether there are any large-scale changes in density within the batholith that might be related to different compositional phases.

(v) Newfoundland Offshore

Underwater gravity measurements were made in Placentia Bay (155 stations) and St. George's Bay (122 stations) at a spacing of 6 km. The surveys were conducted from the CSS Dawson as part of a multi-disciplinary cruise by Memorial University.

Shipborne dynamic gravity data were collected over St. Pierre Bank in the Laurentian Channel, an area extending from the south coast of Newfoundland to the margin of the continental shelf and limited to the west by Cape Breton. A total of 12 000 km of gravity data was obtained with two systems, one from Earth Physics Branch (SL1) and the other from Atlantic Geoscience Centre (KSS-30). This work was completed during a hydrographic cruise of the Canadian Hydrographic Service (Dartmouth) on CSS Baffin.

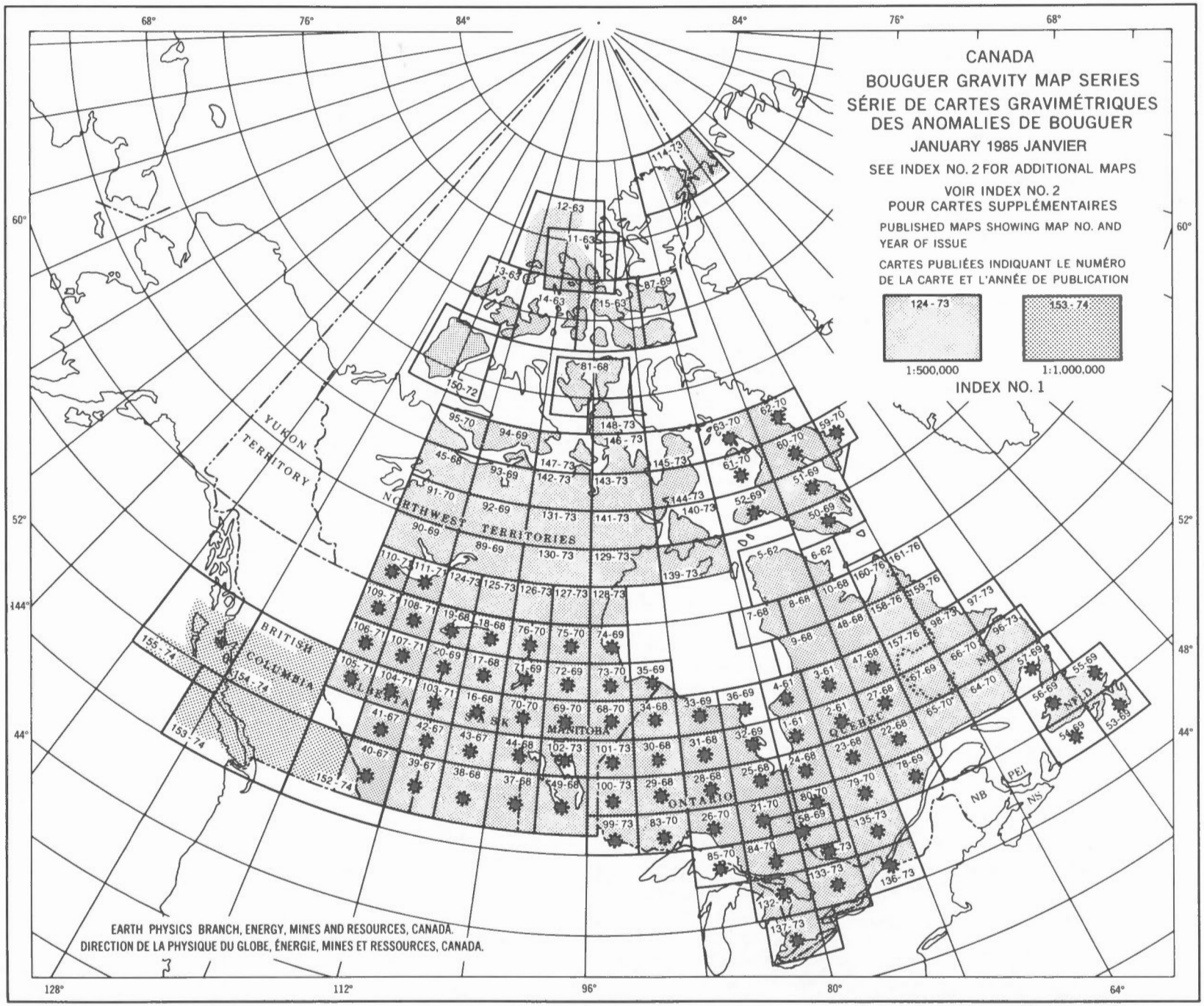
(vi) Gravity Meter Calibration (P.J. Winter)

Two calibration trips were made in 1984 along the Canadian long-range calibration line (Calgary to Inuvik); 8 gravimeters were calibrated. Additional connections were made to strengthen the termination point (Manning Park) of the recently established British Columbia calibration line that runs between Manning Park and Fort St. John. This calibration line was established mainly for calibrating dynamic gravimeters used in shipborne surveys.

(f) Microgravimetry (A. Lambert)

Semi-annual surveys of the Charlevoix microgravity network were discontinued after eight years of monitoring. A survey of both north and south shore (St. Lawrence River) networks, including helicopter crossings of the river, was carried out in preparation for long-term monitoring of crustal deformation at approximately three year intervals.

Analysis of the data from the International D-meter Calibration Campaign was completed. Calibration functions and accuracy estimates were calculated for 13 LaCoste and Romberg model D gravimeters.



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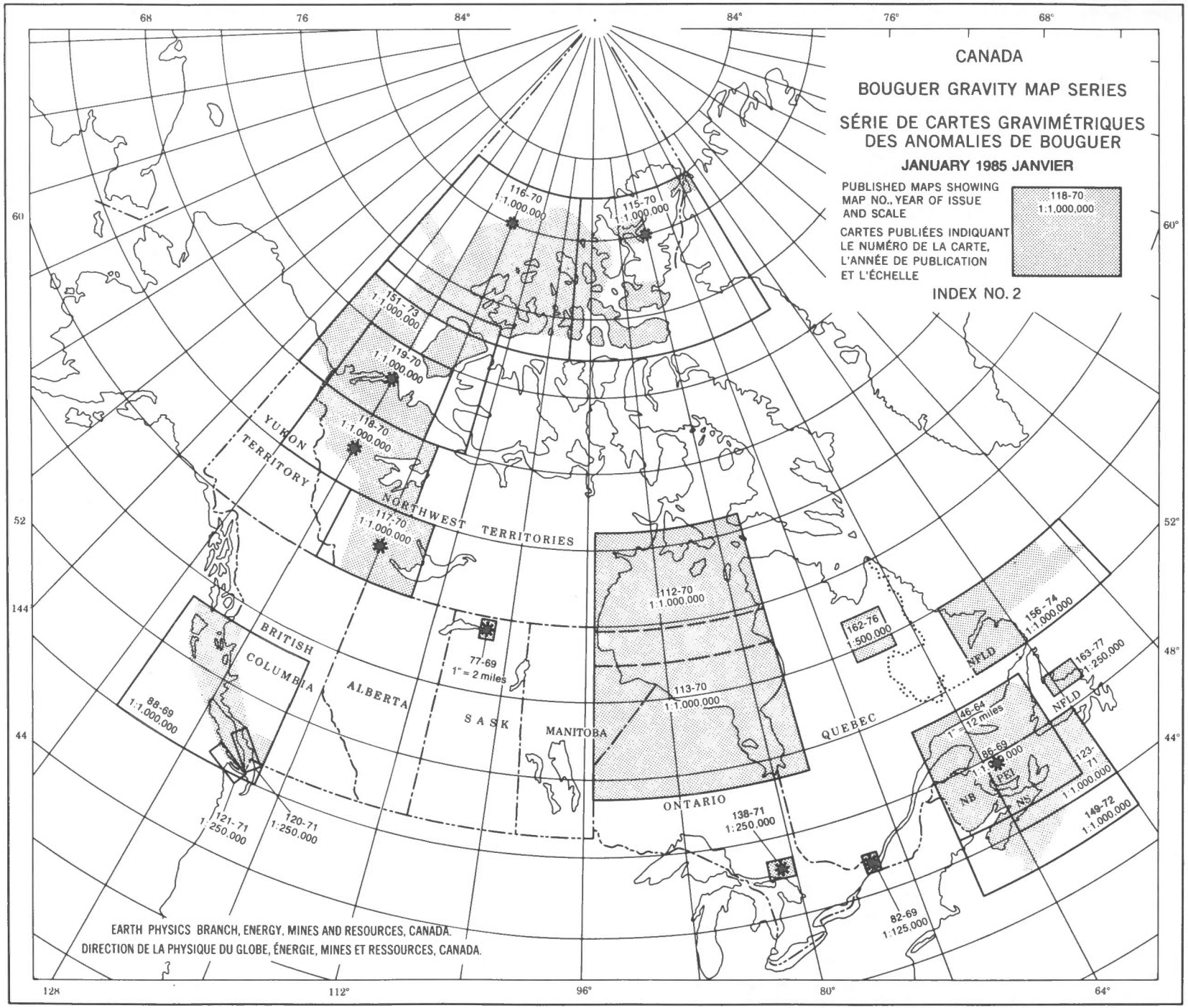

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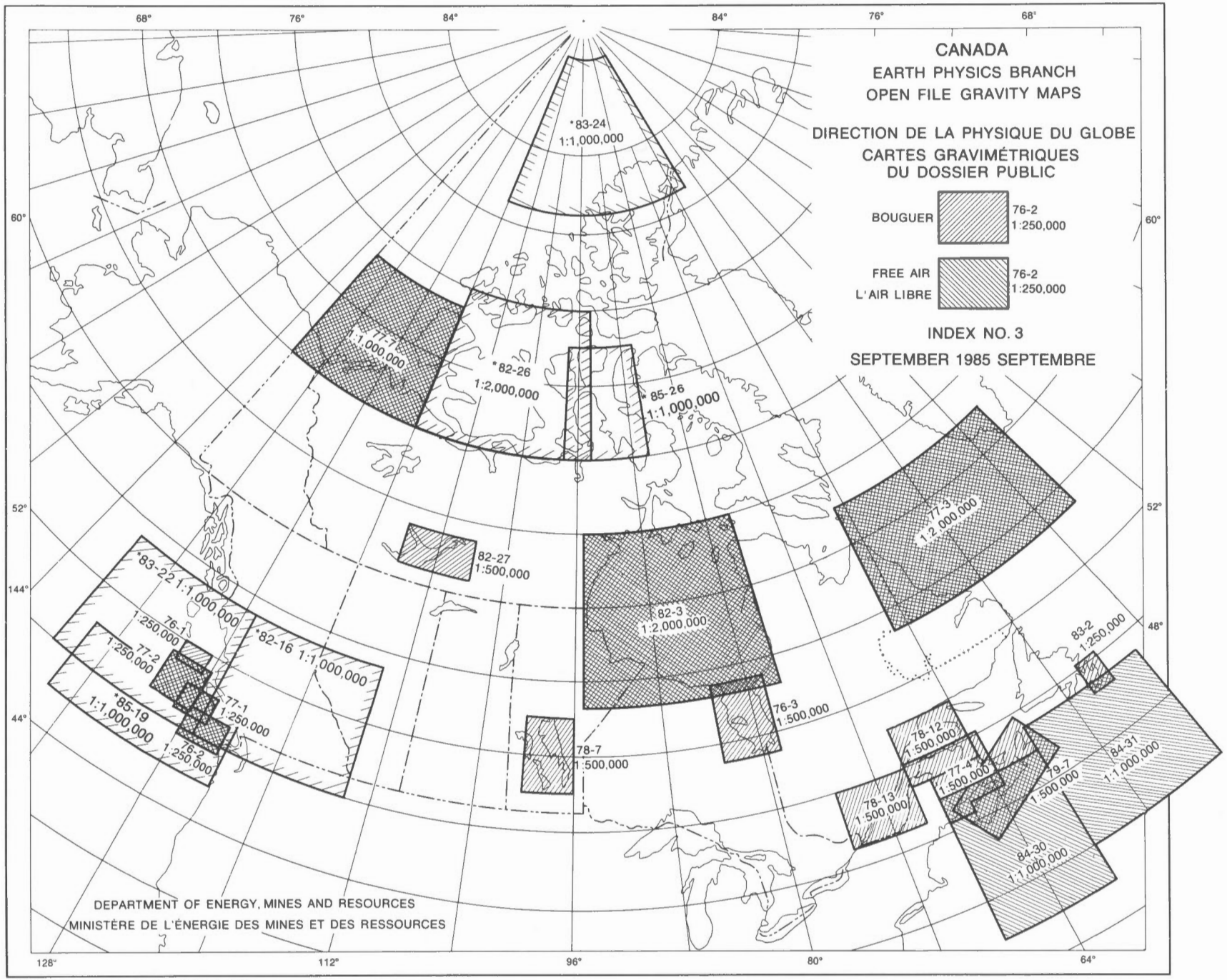

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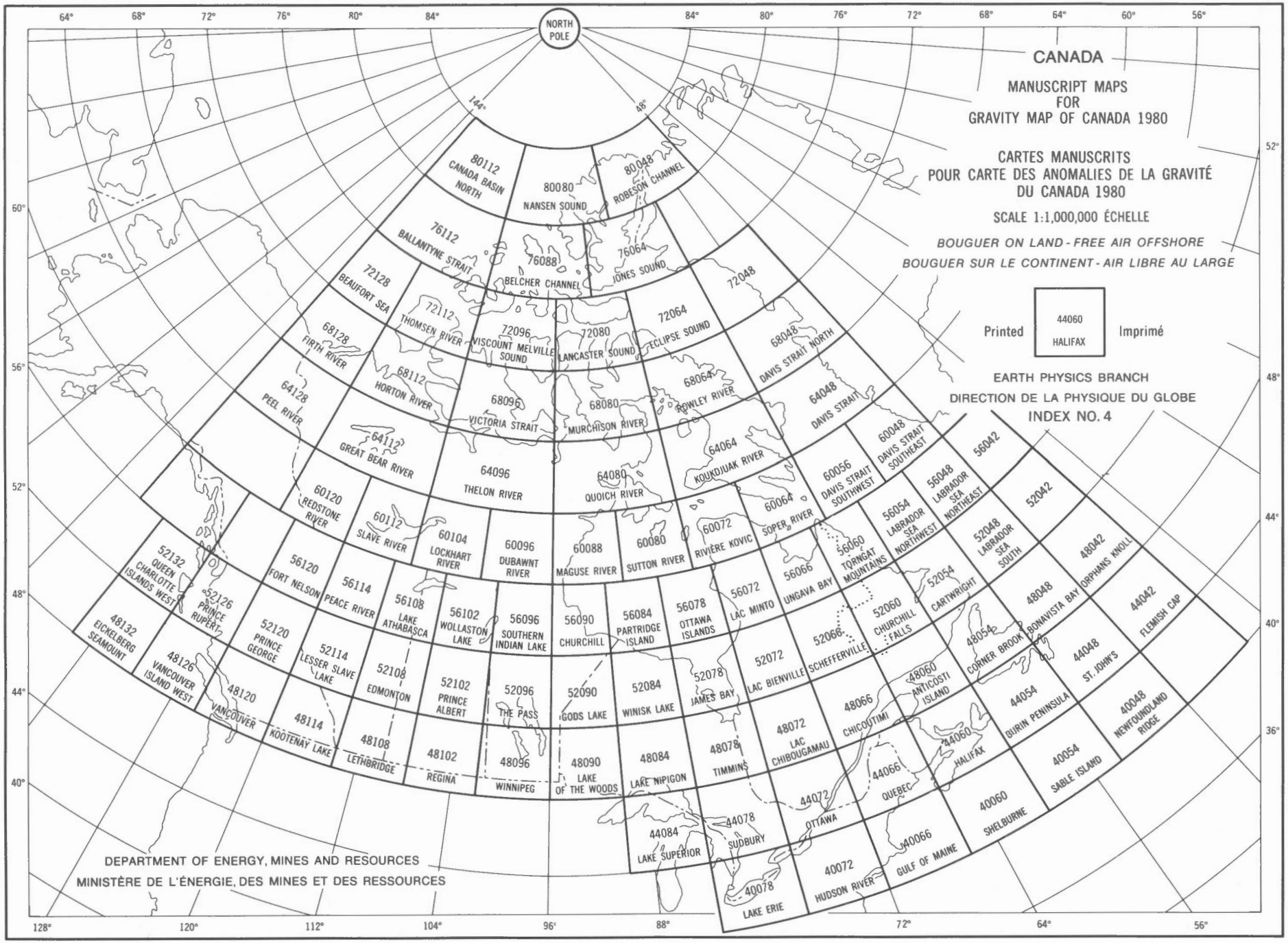
CANADA
MANUSCRIPT MAPS
FOR
GRAVITY MAP OF CANADA 1980
CARTES MANUSCRITS
POUR CARTE DES ANOMALIES DE LA GRAVITÉ
DU CANADA 1980
SCALE 1:1,000,000 ÉCHELLE
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DIRECTION DE LA PHYSIQUE DU GLOBE
INDEX NO. 4
DEPARTMENT OF ENERGY, MINES AND RESOURCES
MINISTÈRE DE L'ÉNERGIE, DES MINES ET DES RESSOURCES
NORTH POLE
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64° 68° 72° 76° 80° 84°
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60° 56° 52° 48° 44° 40°
52° 48° 44° 40° 36°
128° 120° 112° 104° 96° 88°
72° 64° 56°

Levelling and precise gravity observations made before and after the filling of the LaGrande-2 reservoir in Quebec in 1979 indicate the occurrence of an anomalous uplift just beyond the shore of the reservoir, coupled with a subsurface movement of mass into the uplifted area. Models involving the expansion of cracks under increased pore pressure or warping caused by the high ambient horizontal deviatoric stress are being considered.

(g) Gravity Interpretation (R.P. Riddihough, L.W. Sobczak, J.F. Sweeney, M.D. Thomas, J.R. Weber)

(i) Pacific Ocean - Cordillera

Gravity profiles and explanatory texts are being compiled for DNAG Transects B1 (The Queen Charlotte Islands Continental Margin) and B2 (Juan de Fuca Plate to Alberta Plains).

Gravity data have been compiled and analysed in the regions of a major gravitational and crustal discontinuity in Central Oregon. This forms the southeastern margin of the Columbia embayment and possibly represents a Cretaceous ocean-continent boundary.

(ii) Arctic Islands and Ocean

Four manuscripts and two large display sheets dealing with the morphology of the central Arctic Basin, the age of the Canada Basin, and the history and structure of the polar continental margin in Canada have been completed.

A paper describing a crustal section to a depth of 48 km across the polar continent-ocean transition (Somerset Island to the Canada Basin) is being prepared. Results indicate that the continental Precambrian crystalline crust thins from 48 km to 8 km and may have been stretched from 540 to 825 km (a stretch factor of 1.5).

A paper and gravity map relating to the Innuitian and surrounding regions, and a paper describing a polar gravity map north of 64°N latitude (1:6 000 000) are being prepared.

(iii) Canadian Shield

Results of gravity studies of the Wopmay Orogen indicate that (i) a positive gravity anomaly associated with the Hepburn metamorphic-plutonic belt is related to westward thickening, above Slave basement, of a metasedimentary wedge that attains a thickness of 7.5 km near the centre of the belt; (ii) a thrust-block of high grade metamorphic sedimentary-volcanic rocks immediately east of Wopmay fault has a maximum thickness of about 0.5 km at its western margin, which apparently is a vertical discontinuity that penetrates to at least 7.5 km depth and truncates the Hepburn metasedimentary wedge - this discontinuity is located 7 km east of the Wopmay fault; (iii) 'granitic' rocks of the Hepburn Batholith have a tabular geometry and a general thickness of around 2 km; (iv) at the eastern edge of the metamorphic-plutonic belt near Coppermine River, the eastern thrust boundary of another thrust-block dips steeply westward (55°), and may be related to a dramatic westward thickening (4-5 km) of the metasedimentary wedge across a step in the basement.

(iv) Appalachians

Studies were initiated to examine the enigmatic nature of the origin of the Appalachian paired gravity anomaly. While there is a general consensus that the negative component is related to crustal thickening, the origin of the positive component is controversial. Apparently, such drastically different geological phenomena as continental rift sequences, continental slope-rise prisms, passive margin basement slices, subduction-island arc complexes, continental-oceanic crust transitions and upthrust lower crust on overriding plates all offer a reasonable explanation of the observed gravity pattern.

(v) Numerical Methods (D. Nagy, M.K. Paul)

Mathematical investigations on the relationship between the change in gravity on the surface of observation due to subsurface tectonic deformation and ground displacements have been completed. Some techniques for source-oriented representation of surface gravity data have been worked out and a computer program has been developed to test both model and practical data. A manuscript on a new method of computing a radial gravity profile for a body with circular symmetry has been submitted for publication.

A software package to carry out spherical harmonic expansion of gravity data has been implemented on the VAX/VMS system. Sample runs to order and degree = 180 were carried out using 1° x 1° block averages over Canada.

A fast Fourier transform package has been implemented on the CYBER. Application programming to carry out upward and downward continuation, derivative computation of gravity has been completed. Evaluation of this technique using three dimensional model data is being carried out.

3. ATLANTIC GEOSCIENCE CENTRE (AGC) (J. Woodside)

(a) Gravity and Magnetic Surveys

There has been a temporary shift in emphasis away from systematic multiparameter surveys towards the re-organization of all AGC data within the national data base at Earth Physics Branch (EPB) (see below), the release of data, the interpretation of key data within the Frontier Geoscience Programme, and the use of aeromagnetic surveys to improve coverage and assist levelling of the marine surveys in specific areas. An evaluation of quality and coverage of data will follow, prior to designation of areas requiring future gravity surveys. As a consequence, only one major multiparameter survey was carried out this year in collaboration with the Canadian Hydrographic Service and EPB. One other set of surveys was completed as part of a series of site surveys undertaken in support of proposed drilling by the Advanced Ocean Drilling Program (AODP).

(i) Newfoundland Shelf

Regional potential field coverage south of Newfoundland was completed with a combined hydrographic-geophysical survey of the Laurentian Channel, St. Pierre Bank, and the western Grand Banks. Bathymetric, gravimetric, and magnetic data were collected over 12 000 km of track at an average spacing of 18.5 km, to map an area covering some 117 000 km^2.

(ii) Labrador Sea

Three detailed surveys were conducted as site surveys for AODP. They were located roughly in the vicinity of 53°23'N-45°16'W (Site 9), 58°4'N-48°23'W (Site 5), and 58°28'N-57°50'W (Site 2). Gravity and magnetometer lines were run east from the Strait of Belle Isle to Site 9, north to Site 5 (with a number of eastward zig-zags just to the north of Site 9), west to Site 2 (again, with a number of zig-zags over the Northwest Atlantic Mid-Ocean Channel or NAMOC), and a long dog-leg track from Site 2 to Nain Bank, east to the centre of the Labrador Sea and south to St. John's. Accuracy of the detailed surveys ranged from 0.2 mGal where navigation was good (Site 9), to 2-3 mGal where navigation was poor. A Barringer proton precession magnetometer system was used with digital output recorded on a newly developed data logger.

(b) Data Handling

Progress continued on the development of a national data base containing all gravity data collected within Energy, Mines and Resources, along with magnetic data collected at sea from AGC and PGC. The existing EPB National Gravity Data Base is being modified to accommodate magnetic data. During the year, the structure of the data base was designed and prototypes tested. The new data base will be completed in 1985.

In preparation for entry of AGC data in the new data base, all data were reviewed, edited, and assigned quality flags. The data were then sent to EPB in Ottawa where further

editing for quality control was carried out. All the data were prepared for adjustment by the EPB least-squares program for network adjustments. Final adjustment and entry of the data in the data base are scheduled for early 1985.

(c) Data Interpretation

Results of a gravity survey in Mahone Bay (reported in Vol. 36 of the Canadian Geophysical Bulletin) were presented along with a geological interpretation at the annual meeting of the Canadian Geophysical Union in May. The high precision of the gravity measurements permitted delimitation of the westward projection of the Goldenville quartzites across the southern part of the Central Basin (causing an anomaly of only 2 or 3 mGal). The contact between Halifax slates and Devonian granites to the north creates the largest anomaly measured (over 10 mGal). The purpose of the study was to show that useful gravity measurements could be made in protected inshore water from a small ship if good navigation is available. In this case, navigational accuracy was better than 5 m (using SYLEDIS) and the RMS accuracy of the survey was about 1.5 mGal (using the BSW KSS-30 sea gravity meter system).

(d) Instrumentation

The KSS-30 sea gravimeter was employed on two expeditions in 1984: the CSS HUDSON was used for on site surveys for ODP in Labrador and the CSS BAFFIN was used for a survey of Laurentian Channel and St. Pierre Bank. On the latter expedition, Earth Physics Branch operated a LaCoste SL1 Linear Meter so that a comparison between the two meters could be made. The agreement between the two meters under a variety of operational conditions was remarkable, though mean crossover discrepancy was significantly smaller for SL1.

Progress was made with new on-line analysis and logging equipment (CIGAL). This system will replace the principal geophysical logger BIODAL which has been in continuous operation since 1965.

4. Geological Survey of Canada (P.H. McGrath)

Density measurements have been made on drill core obtained from two areas of the Canadian Shield. Approximately 40 drill cores from holes near Kapuskasing, Ontario have been measured as part of a gravity study of the northern part of the north-northeast trending Kapuskasing structure.

In the Artillery Lake area, N.W.T., core from about 40 holes has been measured to provide control on the interpretation of gravity anomalies near the Slave-Churchill boundary.

5. Ontario Ministry of Natural Resources (V.K. Gupta, D.R. Wadge)

A gravity surveying program has been initiated by the Ontario Geological Survey to map the deeper geological characteristics of the Abitibi greenstone belt for the purpose of arriving at a better understanding of its evolution and its associated mineral deposits. During the 1984 field season approximately 2000 gravity stations were established in an area in excess of 8000 km^2. Over 850 density measurements were made on fresh rock samples collected from outcrops at or near gravity station sites.

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

In 1984 gravity surveys were conducted on land using Lacoste and Romberg G meters and at sea using underwater meters; all gravimeters were supplied by the Earth Physics Branch. One survey was conducted in Placentia Bay and on the adjoining peninsula to the east. Here, a total of 155 underwater and 222 land stations were occupied; the mean spacing between stations was 6 km at sea and 2.5 km along roads on land. A second survey was carried out in the region of St. George's Bay and consisted of 122 underwater stations and 275 land stations. The spacing between underwater stations was 5.5 km, whereas land stations were generally spaced at intervals of 2.5 km (151 stations) along roads and 6 km (103 stations) along helicopter traverses.

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

Gravity activities included additional gravity measurements in the Point Aconi - Boularderie Island area on the western margin of the Sydney coal basin, Cape Breton Island; the sale of gravity data to an oil company; and a gravity survey over a potash deposit in southern New Brunswick with accompanying interpretation of the results.

8. Université Laval (M.K.-Séguin)

M.K.-Séguin et deux étudiants ont effectué un levé gravimétrique détaillé dans la région de Baie-Saint-Paul - Sainte-Anne-de-Beaupré, Québec. Quelque 350 stations gravimétriques ont été observées au cours de l'été 1984. Ces levés constituent la continuation de travaux entrepris en 1982 et 1983 dans la région de La Malbaie. Toute la zone séismiquement active de Saint-Siméon à Cap-Tourmente est maintenant couverte par le levé gravimétrique détaillé. Le but de ces levés est l'obtention d'une carte de Bouguer qui soit suffisamment précise pour pouvoir en arriver à l'élaboration de modèles géologiques et structuraux assez complets pour interpréter la nature de la séismicité de cette région en rapport avec les événements géologiques régionaux, p. ex. rift du Saint-Laurent, impact météoritique, surcharge causée par l'allochtone appalachien, soulèvement vertical causé par la déglaciation à l'Holocène, etc. De façon à améliorer la carte de Bouguer, nous effectuons les corrections topographiques étant donné le relief accidenté de la région investiguée.

Le relevé gravimétrique et pétrophysique effectué par un étudiant gradué, D. Lapointe, dans le cadre d'une maîtrise ès Sciences sur l'intrusif Dévonien des monts Sainte-Cécile et Saint-Sébastien sous la direction de M.K.-Séguin est maintenant complété. Il comporte quelque 400 points d'observation couvrant l'intrusif granitique lui-même, les cornéennes à son pourtour ainsi qu'une fraction des sédiments de Compton encaissants.

La carte de Bouguer est complétée et afin d'améliorer la justesse de cette carte, nous avons effectué les corrections topographiques dans les régions accidentées. Un modèle 2-D et 2-D1/2 de la masse intrusive a été élaboré et quelques modifications légères sont encore en cours.

9. Ministère de l'Énergie et des Ressources, Québec (D.L. Lefebvre)

Quelque 3 697 mesures gravimétriques ont été effectuées dans la Fosse du Labrador (région de Schefferville) du 24 janvier au 13 avril 1984. Ce levé héliporté était combiné à un levé de sédiments de fond de lac. Deux gravimètres Lacoste et Romberg, modèle G, amortis, ont été utilisés. Le pas d'échantillonnage était d'environ une station à tous les 1,5 km. L'anomalie de Bouguer et le gradient vertical ont été calculés. Les résultats sont contenus dans la publication DP 84-46 du ministère de l'Énergie et des Ressources.

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

The optimization of terrain correction computations for gravity measurements has been completed in its first phase (Blais and Ferland, 1984; Ferland, 1984). Research has also been done on the use of Fast Fourier Transform techniques in these computations (Sideris, 1984). In addition to the remarkable economic advantages of these techniques, a wealth of spectral information can be extracted from the results.

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

S.J. Balch completed a B.Sc. Honours thesis under the supervision of H.H. Schloessin on 'A Mathematical Model for the Gravity Surface in Western Quebec'. This is the third in a series of gravity studies of Western Quebec which includes the Gatineau River seismic region fringing the 'marble-line', the Central Metasedimentary Belt and the Ottawa Graben. The features of the Bouguer Anomaly surface were described by means of curve analysis using integral properties and the topology of analytical surfaces in spherical polar coordinates. The results from the curve analysis based on 6900 data points were compared with those resolved by direct polynomial fitting of the gravity surface up to n=21 during a follow-up summer study carried out by G.W. Thompson, S.J. Balch and H.H. Schloessin. Curve analysis defines the topological properties of the gravity surface with specifiable precision of

continuity and strength of singularity which takes into account variable station density. Residuals obtained from the numerical values of the polynomial coefficients in the approximations and the associated Legendre polynomial coefficients allow one to relate the short-range anomaly features to the broader global but localized features of the geoid given by terrestrial or satellite data.

12. University of Windsor (D.T.A. Symons and P.S. Newman)

P.S. Newman has completed an analysis of gravity data gathered under the auspices of the Ontario Geological Survey for the eastern flank of the Round Lake Batholith near Englehardt, Ontario. The analysis indicates that the batholith is quasi-funnel-shaped and extends to a depth of about 10 km. The adjacent major gravity high appears to be caused by near-vertical mafic to intermediate volcanics of the Paucaud-Wabewana- Catherine-Skead sequence extending to depths of about 8 km adjacent to the contact and decreasing to about 4 km away from the contact.

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II SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR

Compiled by: E.R. Kanasewich

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

Provisional data for more than 600 earthquakes in or bordering Canada in 1984 have been collected. Out of this total there are at least 26 events with magnitude greater than 4.0 and two with magnitude greater than 5.0 but less than 6.0. The larger events occurred in the following sequence:

January 23	M4.7	Brock Island, N.W.T.
January 24	M4.6	Brock Island, N.W.T.
February 11	M4.7	B.C. - Alberta Border
March 14	M4.8	Baffin Bay
March 27	M4.5	Off Vancouver Island
June 24	M5.8	South of Queen Charlotte Islands
August 30	M5.2	North of Queen Charlotte Islands

The pattern of activity has, in general, been similar to that of previous years, but some unusual features have been noted. Extensive earthquake swarms have occurred on Brock Island, N.W.T., starting with the large events in January, and at Pelly Bay, N.W.T. during April, May and June. The earthquake of February 11 (noted above) along the British Columbia - Alberta border in the Crowsnest Pass region was one of the largest that is known to have occurred in that region. Preliminary data on these earthquakes are available from the Earth Physics Branch in Ottawa.

Another unusual feature of the seismic activity in 1984 was the occurrence of a large number of rockbursts in mines in eastern Canada. The seismograph network in eastern Canada detected more than 40 shocks that have subsequently been confirmed as rockbursts. However, many smaller rockbursts were not detected by the seismic network. The larger rockbursts occurred in the following sequence:

March 13	M3.1	Macassa Mines, Kirkland Lake, Ontario
June 20	M3.4, 3.5 & 3.6	Falconbridge Mine, Sudbury, Ontario
July 6	M4.0	Creighton Mine, Sudbury, Ontario
September 7	M3.0	Quirke Mine, Elliot Lake, Ontario
December 9	M3.5	Brunswick Mines, Bathurst, N.B.
December 17	M3.4	Quirke Mine, Elliot Lake, Ontario

Four mine fatalities were caused by the sequence of events on June 20 in the Falconbridge Mine. Rockbursts at the IMC potash mine in Esterhazy, Saskatchewan on September 27 were also recorded. Induced seismicity continued under the La Grande 3 (LG3), Quebec, reservoirs during the early part of 1984. Of the 13 events located, the largest was

the M3.0 on March 29. Induced seismicity also occurred at the Strachan natural gas field in Alberta, where an M4.1 occurred on September 4 and an M4.0 on November 19. Induced seismic events, with M<3.0, also occurred at Fort St. John, British Columbia, on November 9.

At least 37 tremors were reported felt in Canada in 1984, of which 17 were in eastern Canada and 19 in western Canada. No damage was caused by any of these events. The most widely felt event was the one along the B.C. - Alberta border on February 11, which was felt with maximum intensity V close to the epicentre and with less intensity to distances of 300 km in B.C., Alberta, Montana, Idaho and Washington State. A detailed isoseismal map has been prepared for this event. Other earthquakes that were felt strongly but in limited areas were:

January 14	M3.0 & M2.7	Meager Mt., B.C.
February 11	M3.9	Sioux Lookout, Ontario
August 30	M5.2	Queen Charlotte Islands
September 3	M4.1	Strachan, Alberta
September 23	M3.7	Moncton, New Brunswick
September 27	M3.5	Esterhazy, Saskatchewan

The operation of the Charlevoix array continued during 1984 and a further 95 hypocentres with magnitudes from 0.7 to 3.0 were located in the active zone. As observed in past years, the aseismic zones still exist, and the 1984 events occur randomly amongst the previously located hypocentres.

The Canadian (National) seismograph network is made up of 16 standard stations, 41 regional stations, 21 eastern Canada telemetered (into Ottawa) stations and 18 western Canada telemetered (into Victoria) stations. Special networks include the Yellowknife Array, strong motion networks in eastern and western Canada, the Charlevoix Array and a digital station telemetered into Sudbury.

Details of these stations are described in Canadian Seismograph Operations, which is published annually as part of the Seismological Series of the Earth Physics Branch.

R.J. Wetmiller has completed an analysis of the activity recorded by the 1980 microearthquake survey near Rocky Mountain House, Alberta. The study identifies a confined source of earthquake activity in and/or below the Strachan D3A natural gas reservoir. The earthquakes are thrust events, occurring at a depth of 4.0 km, possibly on the Precambrian - Paleozoic contact, and possibly induced by stress adjustments accompanying the depletion of the reservoir. Studies of the exact relationship between the gas production and the earthquake activity are continuing.

R.J. Wetmiller is completing analysis of the data collected in the July, 1983, microearthquake survey of the Miramichi, New Brunswick aftershock zone. The survey found the activity manifesting the same V-shaped configuration observed in 1982, but also detected changes in the distribution of activity, which suggest continuing long term migration in the post-main shock stress field. Renewed activity occurred on the west side of the aftershock zone, which had become aseismic by mid-1982, and persistent activity occurred in clusters outside the original aftershock zone, in areas where aftershocks had not been detected previously. Another microearthquake survey of the aftershock zone is being contemplated for the 1985 field season.

2. Atlantic Geoscience Centre

Deep marine multichannel seismic reflection studies were carried out by C. Keen, I. Reid and B. Nichols. The first of the Lithoprobe East reflection lines was shot by Geophysical Services Incorporated under contract to EMR and with our participation. A complete section across the northern Appalachian orogeny was obtained, together with one across the Mesozoic rift structures and the ocean-continent boundary. Deep reflections were obtained by the use of a 120-channel streamer, a 6300 cu-in airgun source, and recording to 15 sec. Testing is currently (January, 1985) underway to determine the optimum combination of processing and display parameters.

The Grand Banks transform fault has been a study area of I. Reid, C. Keen, B. Nichols and W. Kay. We concluded the seismic study of the deep structure of the margin begun in 1983. The principal technique used was refraction with explosive and airgun sources to arrays of ocean-bottom seismometers deployed across the margin. Reflection work was also carried out. The data have not yet been processed due to the commissioning of, and backlog of data on, the new processing system.

3. Earth Physics Branch

R. Haddon has further developed the method of leaking modes for the computation of complete synthetic seismograms in layered media. The theory is also applicable to the computation of synthetic seismograms in axially symmetric boreholes. Work in this general area is continuing.

G. Buchbinder and R. Haddon have analysed particle motion for events at teleseismic distances using S.R.O. data. The results show that azimuthal deviations in excess of 6° occur for about one third of the data analysed.

A. Green, Z. Hajnal and W. Weber have completed a multidisciplinary study of the Precambrian basement beneath the Williston basin. One paper on this work has been accepted for publication and another paper has been submitted.

A. Green, M. Berry, C. Spencer, E. Kanasewich, S. Chin, R. Clowes, C. Yorath, D. Stewart, J. Ungar and W. Poole have completed a review of recent seismic reflection studies in Canada for publication in the forthcoming Geodynamic Series volume of the American Geophysical Union entitled Deep Structure of the Continental Crust: Results from Reflection Seismology. D. Stewart, W. Poole, J. Ungar, J. Phillips, R. Goldsmith, C. Spencer, A. Green, M. Loiselle, P. St. Julien have been interpreting seismic reflection data collected from the Northern Appalachians in Quebec and Maine. A preliminary paper on this work has been submitted to the same volume.

As part of Lithoprobe phase I, R. Clowes, A. Green, C. Spencer, E. Kanasewich and C. Yorath have, through a contract to industry, collected and processed 200 km of high quality seismic reflection data from Vancouver Island. Outstanding images of the mid-crustal section and of the actively subducting oceanic plate beneath the island were obtained. Several papers have either been written and submitted or are in an advanced stage of preparation.

M. Huang and C. Spencer have developed and implemented a method for inverting travel times of refracted and reflected crustal phases to obtain laterally inhomogeneous velocity models. The procedure allows models that fit observed data to be constructed quickly and the uncertainty in these models to be quantified. The method is being applied to the 1982 Ottawa Valley Cocrust data.

C. Spencer, P. Morel, D. Forsyth, C. Michaud, I. Asudeh et M. Gervais ainsi que R. Meldrum de l'Université de Colombie Britannique ont participé à l'expérience de sismique-réfraction de Québec - Maine qui s'est déroulée du 21 septembre au 5 octobre 1984. Cette opération a été menée en collaboration avec le USGS et faisait suite à la sismique-réflexion effectuée l'année dernière. P. Morel et A. Green poursuivent l'interprétation des données recueillies lors des expériences COCRUST de 1977, 1979 et 1981. L'interprétation des arrivées premières est terminée et le modelage des amplitudes est en bonne voie.

D.A. Forsyth, H.S. Hasegawa and R.J. Wetmiller have submitted a manuscript on Seismicity and Focal Mechanisms of the Canadian Arctic for publication in a volume on the Decade of North American Geology. The work summarizes the available epicentre data, nodal plane studies and stress field information to 1983 and highlights relationships between the geophysical and geological anomalies.

D.A. Forsyth, R.J. Wetmiller and D. Weichert completed a description of the epicentre distribution and the relationship between the earthquakes and features of the continental margin for the Science Atlas of the Beaufort Sea to be available in late 1985.

H.S. Hasegawa and D. Forsyth collaborated in producing a paper on Seismotectonics in Northern Canada for the Seismological Society of America meeting, Anchorage, Alaska in May.

D.A. Forsyth, A. Green, P. Morel, C. Michaud, I. Asudeh, H. Huang, J. Clark, R. Schieman, R. Haddon and G. Buchbinder participated in the planning, execution and data reduction phases of the lithoprobe crustal refraction program across the Kapuskasing structure during June and July.

I. Asudeh, D. Forsyth and A. Green are continuing the interpretation of the CESAR refraction program. Data from the line along the strike of the northern ridge of the Alpha Cordillera indicate a crustal thickness of 35-40 km and a velocity depth profile with oceanic crust similarities. Lateral changes in the velocity gradient may reflect an evolutionary intrusive mode of development. Data from the basin area 180 km to the north indicate a crustal thickness near 23 km.

A.M. Jessop and the Earth Physics Branch geothermal group have assembled and published a catalog of completed heat-flow data in Canada. The distribution of heat flow shows peaks in the Cordillera and on the eastern continental shelf and broad trends in the central plains and the shield. This catalog will be kept current at the Earth Physics Branch.

In the Atlantic region M.J. Drury has completed a diamond-drill hole in the Wedgeport granite batholith, in order to test temperature gradient in an area of apparent high heat generation. This batholith shows evidence of being one of the most promising sites for geothermal exploration for hot dry rock in eastern Canada. This hole and previous holes under the Geothermal Energy Programme will permit a review of the heat-flow distribution in the Canadian Appalachian area.

M.J. Drury and A.M. Jessop are continuing to examine the question of hydrological influence on crustal temperature. Measurement anomalies in boreholes resulting from different types of water movement have been documented and the thermal effects of large-scale slow water migration in sedimentary aquifers have been examined, both in-house and by contracted work at the Universities of Alberta and Regina. It seems probable that the distribution of surface heat flow in sedimentary basins is governed by a combination of conductive supply from the basement and hydrological redistribution in the permeable sediments.

A.E. Taylor and A.S. Judge have continued to collect temperature data from Arctic wells although the emphasis has switched to completion of the logging programme and analysis of the resulting body of data from 130 wells. Papers were presented at the Canadian Geophysical Union on an analysis of the Holocene paleoclimatic events in the Sverdrup Basin and on the geothermics of the Beaufort Sea region of the western Arctic.

Using the geothermal well-logs as an interpretive tool to calibrate conventional logs, A.S. Judge and I. Jones of R.M. Hardy and Associates have determined the permafrost distribution at 500 well-sites across northern Canada. Observations of the distribution of gas hydrate made at the same time indicate the widespread nature of hydrate in the Sverdrup Basin in contrast to Beaufort Sea results.

The final stage of a contracted study of industrially - acquired thermal data from wells north of 60°N was completed by A. Matiisen of Geotechnical Resources Ltd. in Calgary. Results have been open-filed for the Mackenzie Valley and Yukon and show a strong contrast in geothermal gradient associated with the mountain belts. They define in greater detail the anomalously high temperatures in the region between Fort Liard and Hay River.

J. Pilon and M. Burgess have commenced a programme of shallow temperature studies along the 800 km oil pipeline from Norman Wells to Northern Alberta. The study will include monthly ground termperature observations at 60 drillholes to depths of 20 m located in disturbed and natural settings, providing a profile from discontinuous to non-permafrost areas.

M. Burgess and A. Judge have continued investigations of freezing and thawing processes through joint operation of the Calgary Test Loop with D. Fielder and J. Woolmer of

Foothills Pipeline Ltd. and through the joint Canada-France simulations at Caen with P. Williams of Carleton University. Highlights have included a contracted report by L. Carlson of LEC Engineering analysing the operating history of the Calgary Test Loop and a very successful seminar on frost heave processes at Caen.

J. Adams and A. Stevens are investigating the historical earthquake record of the Atlantic Provinces through contracts to systematically search old newspaper records: Newfoundland (c. 1755-1964) has been completed, northern New Brunswick (1867-1943) is in progress, and Nova Scotia and southern New Brunswick are planned for 1985. Results will be issued as a series of EPB Open Files in 1985-86.

J. Adams led a collaborative project among EPB, the Atomic Energy Control Board, Ontario Hydro, New Brunswick Power, N.B. Dept. of Natural Resources, and Weston Geophysical to remove till cover from a 1.5 km strip across the projected outcrop of the 1982 Miramichi fault plane. While recent cracking of the bedrock was found, there was no firm reason to consider it represented a primary fault rupture.

H.S. Hasegawa has completed a study of the attenuation of Lg waves in eastern Canada, using (digital) ECTN records. The anelastic attenuation coefficient has been determined over the frequency range 0.6 Hz to 20 Hz, which is a much broader range than has been reported for other regions of eastern North America. Also a technique has been devised to calculate, directly, response spectra (related to Lg waves); intensity data of two of the largest earthquakes in the selected data set are "quantified" by comparison with corresponding response spectra.

P.W. Basham and R.G. North represented Canada at the meetings of the Ad Hoc Group of Scientific Experts of the Committee on Disarmament, and took part in the planning of an international data exchange experiment which was conducted from October to December of 1984. Canada, represented by the Earth Physics Branch, was one of 29 countries taking part in this test of data exchange and analysis procedures. C.W. Duff and R.G. North collected, prepared and sent data from stations GAC, MBC and YKA on a daily basis, as well as analysing incoming data from other participating countries. C. Wong added special features to the waveform display program SAM to measure the particular parameters required for the experiment. M.D. Andrew established the communications links needed to send and receive messages; these included one to the Global Telecommunications System of the World Meterological Organisation, as well as DATAPAC and direct computer Telex connection.

R. Hayman has participated in a number of planning sessions under the aegis of the U.S. Incorporated Research Institute in Seismology (IRIS), tracking developments related to the proposed new digital Global Seismic Network and the PASSCAL committee. Regarding the Canadian Lithoprobe project, he has consulted with representatives from several universities to draw up specifications for a very portable seismic event recorder. A prototype is now under development, with F. Andersen and J. Parmelee taking the lead in the hardware and software aspects, respectively.

J.A. Lyons has continued to maintain and develop the ECTN and WCTN operating and application software systems. He installed new WCTN software and the Seismic Analysis Monitor (SAM) interactive graphics package at the Pacific Geoscience Centre in September and implemented a backup WCTN system on a PDP 11/24 computer. Planning has begun for a 32-channel ECTN system using state-of-the-art computer hardware.

C. Wong and a contracted programmer/analyst completed the conversion of the SAM package for operation on the VAX computer. Many new features were added to SAM to support the two-month international data exchange experiment, including automatic phase, amplitude and period determination, Butterworth filtering, and colour graphics support.

M.D. Andrew undertook several experiments in seismic waveform exchange with Norway. With assistance from A. Vesa, he installed the Sudbury Local Telemetered Network (SLTN) system at the Science North centre in Sudbury. Triggered event files are being transferred daily to Ottawa at 9600 bps over a dial-up telephone link.

W.E. Shannon has continued to be involved with the digital data processing in the Ottawa Datalab and the Eastern Canada Telemetered Network (ECTN) operations. Several changes were made to the configurations of both the ECTN and the Western Canada Telemetered Network (WCTN) at Sidney, B.C. The ECTN station at Eldee, Ontario came on-line on March 8 1984. The ECTN station at the LaGrande-4 resevoir was closed on March 12 1984 and moved to LaGrande-3 on April 1 1984.

4. Pacific Geoscience Centre

D. Weichert and staff continued the Beaufort Sea special seismicity study. Dome Petroleum did not extend their participation in the co-operative project and the four Beaufort Sea shore stations were closed in July. Alternate funding allowed re-opening of the station at Komukak Beach which is telemetred to Inuvik. The Sachs Harbour regional seismic station has been refurbished, and a new regional station for this project was installed in Dawson in September.

WCTN has expanded as a result of the installation of a station in Strathcona Park. A total of 18 stations covering Vancouver Island and the Lower Mainland are now telemetered into PGC; included in this total are three stations operated by UBC. One regional station has been added to the Queen Charlotte area network at Langara Island. Another regional station was installed near Wells Gray Park for the purpose of testing the Anahim hotspot hypothesis by studying teleseismic residuals.

D. Weichert presented a review of the growth and current status of the Canadian strong motion networks at the IASPEI meeting in Hyderabad. The Miramichi earthquake series has provided an impetus toward upgrading these networks. In the east, the former NRC network is now serviced and directed by EPB staff. In the Queen Charlotte area, five SMA-1 accelerographs are now deployed, and the Vancouver-Vancouver Island networks are being upgraded.

D. Weichert completed the analysis of the Miramichi strong motion records. Accelerations were up to several tens of percent of gravity, but their high frequencies appear to reduce their relevance for intensity and damage potential. Lower frequency ground motion (1-4 Hz) was found to attenuate considerably faster than previously believed.

G. C. Rogers has completed an isoseismal map of the 1949 magnitude 8.1 Queen Charlotte Islands earthquake. The data are sparse but clearly show this event to be much larger than the 1906 San Francisco earthquake.

G. C. Rogers continues to investigate the seismotectonics of the Juan de Fuca subduction zone and has demonstrated the effect of the change in margin orientation on the tectonic environment.

G. C. Rogers has been investigating the microearthquakes recorded on the Queen Charlotte Islands since the first seismograph was installed in 1970. There is very little activity east of the Queen Charlotte fault.

T. Lewis and W. Bentkowski have acquired geothermal data along the Lithoprobe profile on Vancouver Island as well as in holes drilled for EPB and for mineral exploration in areas near Clearwater, Banks Island and Anyox. Samples for heat generation measurements were collected from intrusive bodies in southeastern B.C. Using the equivalent uranium concentrations determined by gamma-ray spectroscopy on cores near the shelf they have found that, to the present time, deposition depends on the half-life of Ra-226 rather than Th-230. H. Villinger is testing a pulsed needle technique in the lab for rapid measurements of the thermal conductivity of chip samples.

T. Lewis and W. Bentkowski have analyzed heat flux in southwestern B.C. and their results show that the Intermontane and Omenica Crystalline Belts form a single heat flow province with a high reduced heat flow, similar to areas of the Basin and Range province to the south. Low heat flux under the Insular Belt and the Coast Plutonic Complex is the result of subduction. An abrupt change in heat flux over a distance of 20 km along Jervis Inlet is thought to reflect a thermal boundary above the zone where the hot asthenosphere

flows at first towards and then down with the subducted oceanic crust and entrapped sediments start to significantly heat the subducted material. A data file containing all of the results of heat generation measurements up to 1984 was published.

E. Davis, R. Currie, and B. Sawyer are continuing co-operative, detailed Seabeam mapping efforts with S. Hammond, NOAA, with the production of several new 1:50 000 detailed map sheets and 1:250 000 regional compilations over the Juan de Fuca ridge system.

E. Davis is continuing the investigation of the tectonic and volcanic history of the northern Juan de Fuca ridge system with a Seamarc I acoustic imagery study on C.F.A.V. Endeavour. The study involves scientists from Lamont-Doherty Geological Observatory (W. Ryan) and others from Pacific Geoscience Centre (N. Massey). A clear idea about the recency of many of the tectonic and volcanic events related to the sea floor spreading process is emerging.

E. Davis and H. Villinger have been involved with the collection, analysis, and interpretation of heat flow data from the Jurassic sea floor of the Western Pacific. This is part of a continuing study of the thermal history of old oceanic lithosphere with C. Lister (U. Washington) and J. Sclater (U. Texas). The heat flow is generally higher than that which can be explained by any simple cooling history. A widespread reheating event in the Cretaceous may be the cause of the anomalously high heat flow.

E. Davis and H. Villinger have conducted a heat-flow study over a well-sedimented axial valley of the northern Juan de Fuca ridge. A number of active hydrothermal features have been identified, and basement (hence probably groundwater) temperatures beneath the sediment all have been established to be in excess of 300° C.

5. Lithoprobe

Lithoprobe is a Canadian geoscientific research project which involves a collaborative effort by geophysicists, geologists and geochemists in a study of continental crustal structure in all three dimensions. Scientists from universities, government and industry are involved. A major portion of the effort is in seismic reflection recording using a Vibroseis source on land and airgun arrays in offshore surveys. Another aspect involves refraction studies with in-line and broadside profiles.

Three major transects were begun in 1984. The first transect crossed Vancouver Island where 205 km of seismic reflection data were acquired using a Vibroseis source. Reflection data on all four lines showed energy at 8 to 10 seconds from the top of the subducting Juan de Fuca plate. Another band of reflection at 4 to 6 seconds may represent the top of underplated oceanic crust associated with an earlier phase of subduction. Excellent imaging was obtained for the Leech River fault in the southern part of Vancouver Island. At Kapuskasing, Ontario, a large scale refraction survey was carried out over the Ivanhoe Lake cataclastic zone which appears to mark a major fault. The Ivanhoe Lake cataclastic zone may be a reverse or listric fault that cuts through the entire crust and brings to the surface, middle and lower crustal levels of greenstone and gneissic belts. In addition to reflection work, 10 km of exploratory seismic reflection data were obtained using a large truck-mounted airgun. The third transect comprised a major seismic marine reflection survey to the east of Newfoundland. This project, called Lithoprobe East, is reported under Section 2 of this report.

6. University of Alberta

Lithoprobe studies on the Vancouver Island project are being carried out by E.R. Kanasewich, S. Chiu and S. Phadke. Spurious high energy noise was removed from all the channels as recorded from a Vibroseis source. This improved the display sections substantially. Further studies are being carried out with respect to migration of the data and three-dimensional imaging.

Least squares inversion of spatial seismic refraction data has been completed by E.R. Kanasewich and S. Chiu. This is a tomographic technique to obtain three-dimensional structure and velocity using seismic wide-angle, seismic reflection and refraction data

(Kanasewich and Chiu, 1985). A damped least-squares inversion method gives rapid convergence even in the case of complex faulted models using noisy data. Spatial seismic refraction recording has been applied in a suboptimal experiment over the Williston Basin in southern Saskatchewan. Several normally faulted blocks appear in an area notable for its thick crust, local seismicity and a linear conductive anomaly.

J. Zahradnik of the Institute of Geophysics, Charles University (Prague, Czechoslovakia), and F. Hron have been investigating seismic waves in two-dimensional sedimentary basins. Extensive numerical experiments were performed to study the effects of the basin geometry and velocity-depth distribution inside the basin, as well as the effect of absorption. The experiments were based on the finite-difference method, solving a hyperbolic equation of motion for a heterogeneous medium and SH waves directly in the time domain, by means of so-called 'homogeneous' difference schemes developed in the 60's in the U.S.S.R.

P.F. Daley and F. Hron have also concluded development of programs based on the ray-reflectivity method for the P-SV waves formulated by them earlier. The new computer package is suitable for the computation of synthetic seismograms for layered media composed of stacks of very thin (less than one predominant wavelength) layers.

R. Chan and F. Hron concluded their investigation of various high frequency techniques which can be used for numerical modelling of seismic waves diffracted by surface irregularities. Theoretically, one may use the Fresnel-Kirchoff theory method of transverse diffusion, which is equivalent to the parabolic approximation of the transport equation characterizing the energy dissipation along the wavefront, or the Klem-Musatov iterative method which represents a diffracted field by an infinite sum of generalized waves.

L. Pascoe and F. Hron have completed an adaptation of a series of computer programs based on the Alekseev-Mikhailenko method for the numerical simulation of seismograms produced by the so called Vertical Seismic Profiling (VSP) technique.

Bao-Shan Zheng and F. Hron have continued their studies leading to the development of an entire package for the computation of ray synthetic seismograms for generally inhomogeneous models. They will be using the latest theoretical developments in the field such as Dynamic Ray Tracing systems and the Gaussian beam approach, to design an efficient computer package which would meet current needs in the oil industry.

C. Macrides is working under the direction of E.R. Kanasewich on the Cold Lake seismicity project. At present, research is focussing on the following two problems: to attempt a statistical correlation between the steam injection history of the area and its microseismicity, and to analyse well-to-well seismic data, taken before and after steam injection, in order to delineate the steam invaded zone. Analysis of an initial tomography experiment seems promising and a new experiment with increased resolution and better design is under preparation.

A total of 66 microseismic tremors were recorded in 1984 in the Cold Lake area by an array operated by Alberta Environment with data analysed by E.R. Kanasewich and his associates. All of the events were in the magnitude range -1 to +1. A total of 50 microtremors occurred in 1983 and are reported in Cold Lake Seismicity Project Report No. 4 (Kanasewich, 1985).

S. Phadke and E.R. Kanasewich are analysing deep crustal reflection data obtained by P.J. Savage and W.L. Kelsch of Pan Canadian Petroleum. The 32 km profile was obtained near Vulcan, Alberta with a Vibroseis source. Data were recorded to 20 seconds across the southern Alberta Precambrian rift valley.

F.W. Jones and J.S. Rogers of the Low Temperature-Solid State Group in the Department of Physics have been employing short baselength mercury-level tiltmeters to monitor Earth tides and local tilts at four locations in western Canada: Leduc, Alberta; Regina, Saskatchewan; Penticton, B.C. and Victoria, B.C.

T.J.T. Spanos, V. de la Cruz and J. Hube are carrying out an analysis which applies volume averaging to pore scale dynamics. The standard theory of wave propagation in porous media as constructed by Biot can be shown through this theory to require significant modifications. Also, an extremely interesting result, which is predicted by this theory and is not present in Biot's theory, is the propagation of two S waves for certain values of the physical parameters.

E. Nyland and his group continue to investigate applications of seismic emissions to the nature of in-situ heavy oil recovery techniques. In addition they continue studies of finite element models of geodynamic processes.

E. Nyland and A. Litav have implemented the Wicat GPIB hardware with a C language driver and GPIB communication is now possible to any GPIB storage device in the system. Soon this will include a 24 Megabyte disk. The Wicat now does automatic arrival time picking and simple location calculations. It displays in graphic form all events detected by the system while the system is working. The system now provides the full power of the UNIX based operating system to 12 channels of the DFS5 sampled at 500 samples per second.

E. Nyland and Li Qing are developing a finite element model of the geodynamics of the Vancouver Island Lithoprobe transect. Wu Xuan-zhi is a visiting scholar from the People's Republic of China. He began his sojourn here by working with Li Qing and is now exploring the application of expert systems to the joint interpretation of disparate geophysical and geological data sets. This work is related to some early work of E. Nyland in the development of the Hedgehog method of inversion with investigators from the Soviet Union. The capabilities of both Artificial Intelligence and computers have advanced sufficiently that this problem seems worth a return visit. The Southern Mexican geodetic networks will be reobserved in December of 1984. At A. Uribe's urging, the Comision Federal de Electricidad has become involved.

F.W. Jones, M. Ertman and M. Rahman are using a numerical method to study heat flow through regions with lateral thermal conductivity contrasts. The heat flow associated with both two-dimensional and three-dimensional thermal conductivity contrasts is being studied. A model which includes thermal anisotropy has been developed and is being used to investigate whether or not thermal anisotropy may have contributed to metamorphism in a zone in the southwest Scottish Highlands.

F.W. Jones, J.A. Majorowicz, H.-L. Lam, M. Rahman, A. Linville, C. Nguyen, R. Beach and A.M. Jessop are studying variations in thermal gradients and heat flow in the Alberta part of the western Canadian sedimentary basin on the basis of 55 244 bottom-hole temperature values from 28 260 petroleum exploration wells. Both regional heat flow variations and variations with depth exist.

F.W. Jones, H.-L. Lam, J.A. Majorowicz, A. Linville and C. Nguyen are carrying out an investigation of the geothermal energy resources of the western Canadian sedimentary basin. From analysis of data from the bottom-hole temperature file, the temperature distribution in Alberta is well known.

F.W. Jones, B. Peters, I. Vinokurov and A. Linville have constructed a divided bar thermal conductivity measuring apparatus and measurements on sedimentary rocks from Canadian sedimentary basins are underway. The apparatus has four divided bars, and the measurements are controlled by a Hewlett-Packard 9826A minicomputer. Measurements on solid core plugs and of rock chips by the 'cell' method are being carried out. Some measurements of rocks from the Pennsylvanian of New Brunswick are being done.

7. University of British Columbia

G.D. Spence, with R.M. Ellis and R.M. Clowes, has completed analysis of the 350 km VISP (Vancouver Island Seismic Project) onshore-offshore refraction profile recorded by COCRUST in 1980. The velocity structure section shows the oceanic Juan de Fuca plate subducting beneath the continental America plate; in the overlying crust above the downgoing slab, a segment of high velocity material (7.7 km/s) in the depth range of 20 to 25 km may represent a remnant of subducted lithosphere, perhaps detached during an earlier phase of subduction, when the locus jumped westward to its present position. W.R.H. White of

Centennial College, Toronto and R.M. Clowes are interpreting the offshore refraction profile recorded perpendicular to the onshore-offshore line during the VISP project.

E. Gens-Lanartowicz and R.M. Clowes have completed interpretation of a sonobuoy study in southern Queen Charlotte Basin. The Tertiary Masset volcanics are pervasive throughout the area. On three of four profiles a low velocity layer, of thickness from about 1 km to nil interpreted as Mesozoic sediments, was found to lie beneath the volcanics. E. Gens-Lenartowicz and R.M. Clowes are continuing with a more thorough interpretation of the southern part of the Fennolora (Scandinavia) profile, a 550 km segment extending from the European Paleozoic platform across the Baltic Sea to the shield of southern Sweden.

E. Davis of the Pacific Geoscience Centre and R.M. Clowes have completed a study involving unusual seismic properties of Pleistocene turbidites in Winona Basin, a young deep water basin along the base of the continental slope off central British Columbia.

R.M. Clowes has completed his contribution to Continent-Ocean Transect B2 from the Juan de Fuca plate to the Alberta plains. Based on existing seismic refraction and reflection interpretations from the published literature, a seismic model for the crust and upper mantle along the transect corridor was compiled. Transect leader J.W.H. Monger of the G.S.C., with all contributors, compiled a tectonic interpretation, based on the integrated data set along the transect.

D. Mackie, S. Dehler, C. Pike, R.M. Clowes and R.M. Ellis have begun interpretation of data acquired during a 1983 COCRUST offshore-onshore refraction program. The objective of the study is to determine crust/lithosphere structure of the Queen Charlotte transform fault zone, and below the Queen Charlotte Islands and Hecate Strait, in particular to test tectonic models which indicate oblique subduction across the fault zone.

J. Berube, R.M. Ellis and G.C. Rogers of the Pacific Geoscience Centre are continuing their analysis of data acquired during a nine-week seismicity experiment in the Queen Charlotte Islands in 1983. Of the 95 earthquakes recorded at four or more stations, 81 are associated with the Queen Charlotte Fault; the 14 events on the islands appear to be the result of normal faulting.

R.M. Ellis and R.D. Meldrum participated in two of the Lithoprobe Kapuskasing seismic experiments using the 12 UBC digital seismographs: the major refraction experiment and a feasibility study to determine whether standard refraction equipment can record crustal seismic arrivals from a land airgun source. Interpretation of part of the refraction data set will be carried out with C. Zelt. R.D. Meldrum with the 12 UBC seismographs participated in the Quebec-Maine refraction experiment organized by the USGS, EPB and Maine Geological Survey.

R.M. Clowes as principal investigator and A. von Breymann as project manager are continuing their work on a geophysical reconnaissance study of the Caribbean continental margin of Costa Rica for the purpose of petroleum exploration under the terms of a contract with Recope, the national oil company of Costa Rica. Recent work has concentrated on an analysis of the 14 airgun/sonobuoy reflection/refraction profiles and an interpretation of CSP lines and multichannel CDP profiles made available by Recope.

R.M. Ellis spent April-June 1984 in Canberra at the Bureau of Mineral Resources and Australian National University completing two cooperative studies with D. Denham which were initiated during a 1982-83 sabbatical year. In the first program fundamental and first higher modes of the Rayleigh and Love wave group velocities along seven paths in Australia were jointly inverted by a controlled Monte Carlo procedure to obtain regional shear wave velocity structures of the crust and upper mantle. The data support results which show an S-wave low velocity zone centred near 110 km in eastern Australia. In the second study surface waves from two medium sized (M 5.5) earthquakes in southeast Australia were examined to determine the focal mechanisms. This interpretation and that of the 1982 Wonnangatta earthquake are indicative of a northwest-southeast compressive stress region in this area.

T. Bostwick, working with R.M. Ellis and G.C. Rogers, has completed a re-examination of

the 1949 Queen Charlotte earthquake (M_S=8.1). The aftershock zone was found to extend from 300 km north of the epicenter to 190 km south of the epicenter. This aftershock zone implies that a previously suggested gap to the north of the M_S=8.1 earthquake does not exist.

L. Fisk, working with R.M. Ellis and G.C. Rogers, has undertaken a program to assess the accuracy and improve present earthquake epicentres offshore from Vancouver Island and Washington State. Using large teleseismically located earthquakes as calibrating events, travel time corrections for a local crustal model have been determined and with these all earthquakes of M 3 and greater are being relocated.

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

M.J. Yedlin is developing a spectral balancing filter to improve the quality of first break picks in refraction data. The major premise is that the spectral differences between wavelets at the first arrival are due to variations in local geology. For each trace an autoregressive filter is calculated. An average of these filters is then used to balance the spectrum of each trace. The spectral balancing operator is applied to a window centred about the expected location of the first break. M.J. Yedlin is working on a new formulation for steep dip migration operators. Most finite difference migration methods rely on a one way factorization of the wave equation using Muir's recursion formula as a basis. Currently, an algorithm is being investigated which uses an exact factorization method due to Friedlander (1946). This method is expected to accommodate dips up to 90°. Presently, the technique is limited to constant velocity media. M.J. Yedlin is developing a median stack procedure to obviate the difficulty with conventional stacking procedures in areas where recorded seismic data have a very low S/N ratio. After NMO correction of a CDP gather, the median of all traces at a particular time bin is computed. This process is repeated at all times to obtain a median trace. Using the quick sort procedure, the sort time for a list of N values can be reduced from N^2 operations to N log N operations.

B.B. Narod, M.J. Yedlin, R. Sorley and R. Kowalski are developing a physical modelling apparatus similar to that used at the Seismic Acoustic Laboratory in Houston. The basic apparatus is currently recording reflections. The apparatus will also be used to study half-plane diffractions, and the results will be compared with an existing computer code developed by M.J. Yedlin.

T.J. Ulrych is on leave of absence at the Universidade Federal de Bahia in Bahia, Brazil for 1984-85. There, his research with Brazilian graduate students is centering on well-log analysis, particularly methods of correlating density and sonic logs. His approach is to analyse the statistics of logs to understand them better.

M. Lane and T.J. Ulrych are investigating the application of statistical and information-theory techniques to geophysical problems. Classic examples include maximum entropy spectral analysis and the related predictive deconvolution. Maximum entropy is a special case of minimum relative entropy (M.R.E.). They are examining the use of the more general M.R.E. in spectral analysis and inverse problems. Examples include subsurface density and seismic wave velocity.

T. Matsuoka and T. Ulrych have developed a procedure for seismic amplitude recovery based on measures of information. The gain curve is modelled as an all-positive exponential polynomial which is fitted to the envelope of the seismic time series using the maximum likelihood method. The order of the polynomial is selected by means of Akaike's information criterion.

C. Walker, T. Matsuoka and T. Ulrych are applying a frequency domain minimum entropy algorithm to seismic reflection data. A frequency domain filter is determined in the seismic pass-band which produces an output that has the minimum entropy property in the

time domain. The procedure also generates an estimate of the seismic wavelet and reflector phase shift information.

T. Ulrych and C. Walker have developed a package for subsurface acoustic impedance estimation using an autoregressive gap-filling technique applied in the frequency domain to band-limited seismic reflection data. Other information, such as interval velocity determined from RMS velocity inversion, may be incorporated into the solution using linear constraints in the time domain.

T. Ulrych and T. Matsuoka are applying a new theory for predictive deconvolution with optimum selection of gap distance and noise level to seismic data for the elimination of short period multiples. T. Matsuoka and T. Ulrych have completed the investigation of the Bispectrum. The application of this method to the phase estimation of seismic wavelets has been compared with other techniques. T. Matsuoka and T. Ulrych have investigated the ill-posedness of integral equations which arise from geophysical inverse problems using a statistical model identification technique.

W. Nickerson, T. Matsuoka and T. Ulrych are working on a geometrical interpretation of minimum entropy deconvolution using vector space methods.

S. Leaney and T. Ulrych are working on the prediction of sonic logs based on existing logs for velocity constraints in the inversion of seismograms.

I.F. Jones, with S. Levy, T. Ulrych, D. Oldenburg, R. Clowes and R. Ellis, is investigating applications of the Karhunen-Loeve transformation (KLT) in reflection seismology. Some of the applications are: separation of diffractions from stacked seismic data; seismic anomaly reconstruction using a misfit reconstruction method based on KLT; seismic trace cluster analyses, designed to identify the locations of changes in the character of the seismic waveform within a stacked seismic section with the objective of localizing stratigraphic character changes; suppression of multiples in CDP and common source gathers; and iterative inversion of Q structure using Futterman's third relation and the KL eigenvalue ratio similarity criterion.

J.J. Cabrera, S. Levy and D.W. Oldenburg are continuing their studies of plane-wave decomposition and spherical-wave reconstruction. Applications include trace interpolation and separation of converted S modes. Work is also in progress to invert Common Source gathers in the plane wave domain to recover a two-dimensional velocity structure.

D.W. Oldenburg, S. Levy and K. Stinson are continuing their efforts to invert normal incident reflection seismograms to recover the acoustic impedance. Stacking velocity and well-log information can now be included. S. Levy and K. Stinson have developed a fast linear programming deconvolution algorithm which greatly reduces the computation time when adjacent seismic traces are fairly coherent. They have also developed a new procedure for scaling seismic data. S. Levy and D.W. Oldenburg have developed a procedure, based upon the Varimax norm, to estimate the residual phase of the wavelet in CDP stacked sections.

8. University of Calgary

Source parameters for earthquakes are being studied by R.J. Brown and G.C. Rogers (PGC). Discrepancies in angular distances on the Earth due to ellipticity may be removed by use of so-called equidistant latitudes. These also make ellipticity corrections to body-wave travel times unnecessary for shorter distances (< 15°, say). The next phase of this work is to encompass dynamic parameters as well and consider the seismic moment tensor method of determining such source parameters as focal mechanism and location. It is intended to apply this method to certain Canadian earthquakes.

A seismic modelling tank has been developed by D. Lawton and S. Cheadle for experiments in seismic data acquisition over physical models. Scaled 3-D models are placed in a 4m x 3m x 2m water-filled tank and reflection seismic surveys are undertaken using piezoelectric transducers as source and receiver. The received signal is digitized at a rate of 5 MHz and processed as conventional seismic data on the Department's Perkin-Elmer computer. Current studies involve modelling permafrost structures and testing source and receiver array design.

High resolution reflection studies are being carried out by D. Lawton and D. Poley. This research involves the study of reflection seismic data from permafrost-affected areas of the Canadian Beaufort Sea. The objective is to find improved methods for imaging shallow reflectors in the depth range 0 to 1000 m sub-seabottom. Ray-tracing (2-D and 3-D) programs are being developed and used to create synthetic multichannel shot records for improving recording geometry. Wavelet attributes show dramatic changes with receiver offset where shallow velocity inversions occur.

F.A. Cook and P. Grennell are applying seismic reflection profiling to the crystalline terranes of the Rocky Mountains in an effort to delineate the crustal structure. To date we have recorded two profiles of 10-15 km length. The first was obtained in the Purcell Anticlinorium west of the Rocky Mountain Trench, with the results about to be published. The second was recorded in the Porcupine Creek Anticlinorium, with the results now being analysed.

F.A. Cook and D. Dufresne completed a 10 km seismic reflection pilot survey at Kapuskasing, Ontario in July 1984 in an effort to preview the potential results and potential logistical problems of a large-scale (200-300 km) Lithoprobe survey to be run in 1985 or 1986. The results are extremely encouraging with reflections from at least 16-18 km depth recorded.

E.S. Krebes continued his theoretical study of the reflection and transmission of 2-D and 3-D viscoelastic waves and showed how the elastic 'radiation condition' must be modified. D.J. Hearn and E.S. Krebes are investigating possible improvements to the theory of viscoelastic ray tracing and ray amplitude calculations. K. Coflin and E.S. Krebes are studying the effects of absorption and dispersion on vibrator-generated signals and possible improvements to vibrator data processing.

9. University of Manitoba

C. Dilliston and W. Moon are currently inverting surface wave data to image the crust-upper mantle velocity structure across the Prairie region of Canada.

W. Moon and A. Carswell carried out a high resolution VSP seismic survey at the URL site, Pinawa, Manitoba. The multi-offset VSP data sets are being interpreted using the Radon transform wavefield separation technique (Carswell et al., 1984). The theoretical VSP synthetic seismogram algorithm has also been written and tested for both WKBJ and reflectivity methods (Owusu and Moon, 1984).

Research by W. Moon, R. Tang and B.H. Choi on the solid earth-ocean tide coupling mechanism is continuing. The linear and quadratic coupling coefficients are estimated for the Hudson Bay area of Canada and East China Sea (Moon and Tang, 1984a, 1984b).

Global tidal energy dissipation processes are being investigated by W. Moon and Seongho Na throughout geological time and the result is being correlated with the acceptable thermal history models.

A theoretical modelling (ART) study of seismic structural mapping of the Sudbury Structure (North Range) has been completed (Messfin and Moon, 1984) and the actual field test is being planned for the next two years.

10. McGill University

A. Vafidis and O.G. Jensen have obtained algorithms for the deconvolution of non-Gaussian seismic and general geophysical data. These methods presume a stochastic excitation function (or reflectivity sequence in the case of the seismic reflection problem) which is uncorrelated to 4th order moments but which is essentially non-Gaussian. The solutions employ extreme skewness or maximum kurtosis as criteria in the optimal deconvolutions.

Work has continued by D. Crossley, C. Parker and R. del Valle on the interpretation of refraction data obtained from the Abitibi Greenstone Belt during 1982. Initial models, which showed a low velocity layer at about 10-15 km depth beneath the central portion of

the belt and also a fairly flat Moho interface at about 35 km north-south across the belt, are being modified slightly to allow improved agreement between theory and data. We are also testing the possibility of a faulted block within the Abitibi Belt as a cause of a pronounced offset in the profile data (north-south). The fan shot data suggest there may be a depression in the Moho in the eastern portion of the belt towards the Grenville Front. Refraction modelling is currently being extended to consider Monte-Carlo and generalized inverse methods (together with two-dimensional synthetic seismogram programs) as alternatives to the layer/block approach to crustal structure.

During the 1984 Kapuskasing refraction experiment (Lithoprobe Phase I), a one-day experiment was undertaken by D. Crossley, O. Jensen and C. Samson to record shots from a land-based airgun (used during the pilot reflection experiment) on refraction equipment. With small arrays at 1, 2, 5, 20 and 50 km, it was hoped to stack 25-30 single shots as a feasibility experiment to enhance the reflection survey. Although processing is still at a very early stage, clear arrivals have been identified at the three nearer arrays but none so far at 20 or 50 km (stacking has not yet been attempted).

Work is now being completed by D. Crossley and J. Todoeschuck on an investigation of whether non-linear, e.g. amplitude dependency damping mechanisms, are present in normal-mode (free oscillation) data. Results suggest a negative result and therefore that the current trend towards patching, existing in solid-state theories to yield a more linear damping mechanism, is probably correct. Nevertheless the studies provide quantitative evidence on the difference between linear and non-linear damping mechanisms that could be of general interest.

11. Memorial University

Marine heat flow measurements on the continental shelves of Canada's east coast are being continued by J.A. Wright. The primary objectives of the research are twofold: thermal characterization of the Mesozoic margin in order to assist geodynamic modelling of the subsidence and thermal history of the sedimentary section; and a measurement of heat flow across the tectonic zones of the Appalachian orogen in order to assist in defining suitable models for the evolution of the orogen. In the course of the work, a new microprocessor-based heat flow probe has been developed and tested. It provides the capability for real-time heat flow measurement. Results from the Labrador Sea indicate that valid measurements can be made on the shelf. These were reported at the 1984 Fall AGU meeting in San Francisco.

High-resolution, reflection seismic studies by J.A. Wright, H.G. Miller, T.E. Laidley and J. Read of the Carboniferous basins of western Newfoundland are continuing. The primary objective of this research is to study, in conjunction with geological investigations, the tectonic development of these pull-apart basins. These basins have been proposed as on-land analogues to those Mesozoic structures containing oil offshore Newfoundland. The studies in 1984 included 15 km of 48 channel (24 fold) coverage in the Bay St. George region. The source used was a Betsy seis gun with recording digitally (at 2 ms) on a microcomputer system assembled at Memorial. Good reflections indicating structure within the basin were received from several hundreds of metres depth, with power quality results from 2-3 km depth. Work is progressing at improving the signal-to-noise ratio for these deeper reflections. Memorial was awarded an NSERC/Petro-Canada Senior Industrial Fellowship in seismology that included approximately $1.2 M for a marine seismic system. It is expected that a marine system will be in place late in 1985 to continue this work offshore as well for use in other projects.

12. University of Saskatchewan

Induced seismicity studies are being carried out by D. Gendzwill and A. Prugger. Earthquakes with magnitudes ranging as high as 3.6 have been induced by underground potash mines in Saskatchewan. Four of the ten mines have a record of seismicity. Microearthquakes have been recorded from underground and from surface monitoring equipment. Rapid computer techniques for source location using non-linear inversion techniques for layered earth have been developed. Improved detection equipment is being designed.

The seismicity of southern Saskatchewan is being studied by D. Gendzwill, R.B. Horner and M. Stauffer, continuing studies of low level seismic activity in southern Saskatchewan by means of regional seismic stations, microseismic studies of specific areas, and geological investigations of lineations, joints and structures.

The 1981 COCRUST refraction data are being analysed by Z. Hajnal. Four reversed and three broadside refraction profiles were interpreted from south-western Saskatchewan. The analysis included modelling of all the data with Chapman's WKBJ integral approximation. This preliminary interpretation shows that the crust is anomalously thick under the Williston Basin portion of the investigated area. The upper mantle velocity reaches values 8.1-8.25 km/sec in the central portion of the basin.

An eleven km long, high resolution reflection survey was conducted by Z. Hajnal and D. Scott over the western flanks of the Haughton impact structure on Devon Island in the High Arctic. A 48 channel TI-DFS-V system formed the core of the recording system. The energy souce was 1 kg 60% Geogel which was placed in 0.3 to 1.0 m depth of the active layer. Digital data processing of the records is in progress.

Velocity spectral analysis of crustal reflections is being carried out by Z. Hajnal and D. Wilkinson. Applying the principles of common offset and velocity filtering, a statistical process was developed which establishes optimal coherence values for computation of stacking velocities from deep crustal reflection data.

Delay times in a broadside refraction program are being studied by Z. Hajnal and D. Wilkinson. The multiplicity of crossing three-dimensional broadside refraction shots permits the establishment of a set of constrained linear equations. These sets of equations were applied to the 1981 COCRUST broadside data set, in an attempt to obtain reliable velocity and depth values.

The reflectivity methods of modelling are being studied by B. Pandit and Z. Hajnal. The principles of reflectivity are being implemented for the computation of multitrace reflection records to study the influence of near surface and sedimentary rock-crystalline basement contacts in the Athabasca Basin of northern Saskatchewan.

13. University of Toronto

A large-scale refraction survey under the direction of G.F. West has been carried out in 1984 in the Kapuskasing region under Lithoprobe. This is a cooperative study with recording equipment and personnel from the Earth Physics Branch and the Universities of British Columbia, Alberta, Toronto and Western Ontario. Twenty shots were fired into a recording array of 58 seismographs.

14. University of Western Ontario

R.F. Mereu is studying induced seismicity with the operation of a three station seismic array around London, Ontario, and a four station network over the Gobles oilfield. More than 460 small earth tremors have been detected over a four-year period from the oilfield. The evidence to date indicates that the activity is being induced by secondary recovery operations. Also being studied is seismicity located at about 100 km NE of Quebec City. The Charlevoix region has been the site of continuous microseismic activity. This activity is constrained to the Precambrian basement under the St. Lawrence River. In this study the hypocentres of earthquakes are relocated using a revised earth model which incorporates a wedge of sedimentary rock on top of the Precambrian. Attempts are also made to classify the events according to their fault plane patterns.

The analysis of past COCRUST experiments was continued by R.F. Mereu, D. Wang, O. Kuhn, J. Baerg and T. Cox during the past year with emphasis on solutions based on synthetic seismogram analysis which allows both vertical and horizontal velocity gradients within two-dimensional models. The most significant result of the 1982 experiment across the Ottawa Valley graben experiment was the disrupted nature of the Moho along the graben. The 1982 experimental analysis has been submitted for publication as a multi-author paper by the participants.

During the summer of 1984 the University of Western Ontario participated with the University of Toronto and other research groups in a survey across the Kapuskasing structure. Seismic data recorded over various geological structures such as pinnacle reefs were obtained from the Cangeo Company in Oil Springs, Ontario. In this project a number of data processing methods are being tested by R.F. Mereu, J. Behr, G. Miller, S. Pamidi and D. Kennedy in an effort to resolve some of the interpretational problems which have arisen in the past for data shot in southwestern Ontario.

The partition of incident P wave energy at a solid-solid interface is a function of the angle of incidence, among other factors. Intuitively one expects some change in the reflected P wave amplitude at the P critical refraction and the S critical refraction. L. Mansinha and A. Sultan have conducted field experiments in a region near London, Ontario with a horizontal interface at a depth of about 70 m. Reflected P amplitude versus source-receiver distance plots show two identifiable peaks. We hope to be able to infer the P and S velocities of the medium below the reflecting interface from the amplitude study.

Sub-bottom temperature perturbations due to temperature variations at the boundary of inhomogeneous lake and oceanic sediments have been studied by A.E. Beck, K. Wang and P.Y. Shen. Using various surface thermal histories we compare results from models assuming constant diffusivity, a linear increase of diffusivity with depth and an exponential increase of diffusivity with depth, the latter two situations being realistic in the Gyttja layer at the sediment/water interface where conductivity may change by a factor of two over two or three metres. In some situations, errors as large as several hundred percent may occur but in such cases it should be possible to deduce from the data that something has occurred to make the data unreliable; more realistically, situations may arise where a temperature depth plot linear within normally acceptable limits of accuracy and within the range of expectations may be 100% in error.

Temperature distribution in flowing liquid wells has been studied by A.E. Beck and P.Y. Shen. The temperature distribution in flowing liquid wells is usually calculated from a simple equation, advanced by Boldizsar (1958) and Ramey (1962) under the assumption that the vertical temperature gradient is negligibly disturbed by the fluid flow. The crucial parameter in this equation is a time function derived by considering the heat conduction in a region bounded internally by a circular cylinder. The present results, obtained by the alternating direction implicit finite difference method, confirm the validity of this equation for elapsed time of intermediate range from days to months. For very large times (>1 year), the assumption of negligible net heat transfer in the vertical direction, upon which the equation is based, ceases to hold. This leads to the introduction of systematic errors which reach 10% after about 11 years, when the equation is used to estimate the formation temperature gradient and/or thermal conductivity.

The luminescence properties of insulating and semiconducting diamond are being studied by H.H. Schloessin. These depend on stress-sensitive impurity, and defect levels in the forbidden gap are determined against known phase transitions and can thus be utilized as pressure indicators.

High pressure fluid encapsulation experiments have been conducted by Y.L. Ling, Zhao You-xiang and H.H. Schloessin. High pressure experimental devices are sealed into stainless steel cylinders, filled with fluid, and then compressed inside solid medium high pressure cubes. Pressures up to 60 Kb and temperatures up to 620°C have been obtained. This technique is most suitable for observing phase transformations (e.g.λ-transitions, FE$\rightarrow$PE, FM$\rightarrow$PM) under hydrostatic conditions.

Thermal conductivity measurements were made by M. Osako, R. Govindarajan and H.H. Schloessin on natural single crystals of almandine and spessartine at pressures up to 56 Kb and temperatures up to 950°C. X-ray topography confirmed that the origin of specular phonon scattering has to be sought in oriented impurity distributions.

Perturbations of the fair-weather electric field by seismographic sources have been investigated by H.H. Schloessin. Seismic faults originating as inhomogeneous (ellipsoidal) elastic and dielectric inclusions inside the earth's surface layers undergo several long

and short-term stages of evolution involving deformation leading to shape changes and eventually fracture. These affect, both globally and in close proximity, the potential field and 'leakage currents' in the spherical air-earth capacitor.

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III (A) GEOMAGNETISM

Compiled by: G.W. Pearce

1. Summary

During the past year considerable work was done on magnetic surveying by federal government institutions, with highlights including progress in establishing the national data bank at Earth Physics Branch (EPB), the determination of the present position of the north magnetic dip pole by EPB and the first aeromagnetic gradiometer surveys contracted by the Geological Survey of Canada (GSC). Surveying was again concentrated in the north and the east coasts but a wide range of localities were examined.

Five institutions were engaged in electromagnetic induction studies during the year. Included among their activities were several cooperative studies: EMSLAB, an international project to study the Juan de Fuca plate at depth, has both University of Alberta and Queen's University personnel involved in the planning; MOSES (magnetometric off-shore electrical sounding) is a joint project of the Pacific Geoscience Centre (PGC) and the University of Toronto to measure seafloor resistivity. In more conventional surveys the University of Alberta concentrated on western surveys and continued its cooperation with China; EPB did surveys in many parts of the country. The University of Victoria continued a variety of analogue model studies.

Paleomagnetic studies continue to attract a large number of groups. Workers from EPB, Laval, University of Toronto, University of Western Ontario and University of Windsor were engaged in Precambrian projects in all parts of the country and on the Baltic shield (Laval). Notable among these is the study by University of Toronto on the use of the paleomagnetism of dyke swarms to determine tectonic rotations in the region. PGC and University of Windsor have been active in the Cordillera and PGC have evidence for a major displacement of the western Cordillera southward in Mid-Cretaceous. EPB, Laval and Memorial are currently running projects in Eastern Canada with the EPB's synthesis being potentially the most exciting event. The findings of the Memorial-GSC group of the late magnetization of the Alabama redbeds is interesting as it suggests that hematite remanence may sometimes be implanted only after burial dewatering. The University of Alberta and University of Windsor did work during the year on Cenozoic samples. A University of Alberta study found oven tiles in a Mediterranean archeomagnetic study with complex remanences suggesting reuse

in ovens over a considerable period of time. EPB and University of Toronto both had projects on rock magnetism. EPB was interested in demagnetization techniques finding, for example, that tumbling improves AF demagnetization results. University of Toronto did much work on basic magnetic properties of minerals and on magnetization processes.

2. Geomagnetic Surveys and Interpretations

(a) Atlantic Geoscience Centre (R. Nacnab)

(i) Magnetic Surveys.

See Chapter 1(B), Section 3(a).

(ii) Data Handling.

Progress continued on the development of a national data base containing all gravity data collected within Energy, Mines and Resources, along with magnetic data collected at sea from AGC and PGC. The existing EPB National Gravity Data Base is being modified to accommodate the magnetic data. During the year, the structure of the data base was designed and prototypes tested. The new data base will be completed in 1985.

Geomagnetic data in the data base will have been edited for spikes and obviously bad data (generally collected during magnetically noisy periods); however, most of the data are uncorrected for diurnal variations. Where possible, diurnal variations will be stored in the data base with the observed magnetic values. Experiments are underway to determine ways of levelling bad data (e.g., using aeromagnetic grids in the same areas) or flagging data collected when geomagnetic conditions were poor (e.g., using geomagnetic indices from stations at appropriate geomagnetic latitudes and proximity to the survey area).

(iii) Instrumentation.

Progress was made with a new on-line analysis and logging equipment (CIGAL). This system will replace the principal geophysical logger BIODAL which has been in continuous operation since 1965.

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

As part of a continuing study of geomagnetic secular variation, 11 repeat stations were occupied, primarily in western Canada. Six of these were done by contract. The routine occupation and observations are similar to those outlined in CGB Vol. 32, p. 60. This year, for the first time, the reduction of digital repeat station data has been integrated into the magnetic observatory editing system.

In May of 1984 a local survey was conducted to redetermine the position of the North Magnetic Dip Pole. A three-component recording magnetometer was installed on King Christian Island for the duration of the survey, and absolute observations of declination, inclination and total force were taken at seven sites around the estimated pole position. After the elimination of transient variations from the data, a mean pole position for 1983.9 of 77.0°N, 102.3°W was determined. Its average motion is 11.6 km/yr to the north-west.

An interactive magnetic information retrieval program has been developed which allows the determination of magnetic field values using the CGRF 1985 inside Canada, and the IGRF 1980 outside Canada. At present this system is directly accessible by users of the EMR computer.

A new technique, the method of spherical cap harmonic analysis, has enabled the construction of an analytical model of vertical-field anomalies above 40°N from magsat data. With this technique, proper consideration can be taken of altitude variation, and maps can be produced at any altitude.

The new technique was also used to construct a model of secular variation over Canada, valid from 1960 to 1983. The model is continuous in time as well as spatially, and by nature of the technique satisfies the zero curl and divergence constraints.

Charts of D, H, Z, I, and F have been produced for epoch 1985.0, again using the method of spherical cap harmonic analysis to model the main field from aeromagnetic data updated to 1985 by means of the above secular variation model.

(c) Geological Survey of Canada (P.J. Hood)

A total of 73 aeromagnetic maps was published by the Geological Survey of Canada (GSC) during 1984, of these 30 were 1:50 000, and five were 1:250 000 scale total field line contour aeromagnetic maps. Eighteen 1:1 000 000 coloured magnetic anomaly maps in the new National Earth Science Series and the fourth edition of the 1:5 000 000 Magnetic Anomaly Map of Canada were issued. In addition five coloured 1:25 000 total field, five coloured 1:25 000 and nine coloured 1:50 000 vertical gradient maps were published.

Sixteen of the above maps resulted from a 5400 line km total field and vertical gradient survey of the Lunenberg-Chester area of Nova Scotia carried out by Kenting Earth Sciences Ltd. of Ottawa in 1983. The company used their Navaho aircraft CF-FRY which is equipped with an inboard cesium-vapour gradiometer system. This was the first commercial aeromagnetic gradiometer survey contracted by the GSC.

The first helicopter gradiometer survey amounting to 10 386 line km was awarded by the GSC to Les Relèves Géophysiques (Geophysical Surveys Inc.) of Quebec City to survey a mountainous area in the Gaspé Peninsula, Quebec. In the gradiometer system, two cesium-vapour magnetometers separated by a distance of three metres are vertically mounted on a hook towed by the helicopter.

A medium sensitivity aeromagnetic survey contract to assist Pb-Zn exploration in NW Baffin Island was issued in April 1984 to Geoterrex Ltd. of Ottawa. The total line distance for the survey was 64 000 line km and 90% of the flying was completed by September 8 1984 when bad weather and serious damage to one aircraft caused the suspension of data collection until the spring of 1985. The aircraft in question, a vintage Learstar, has now been donated to a museum in Winnipeg.

Total field aeromagnetic surveys amounting to 38 240 line kilometres were carried out by the GSC Queenair aircraft in the Lake of the Woods area, Minnesota and Lakes Ontario and Erie to fill in unsurveyed areas for the Magnetic Anomaly Map of North America, and in central Vancouver Island in support of the Lithoprobe project.

In April 1984, the NAE Convair 580 aircraft flew a number of low-level lines across Judge Daly Promontory in northern Ellesmere Island adjacent to Nares Strait. Results obtained show a 200 km dyke anomaly extending from the Arctic Ocean along and parallel to the Nares Strait. It is inferred that the dyke has been injected into an existing fault system. This appears to be the first direct geophysical evidence that there has been movement along the Nares Strait as Wegener postulated in 1912.

In addition a tie line was flown from Denmark Strait between Iceland and eastern Greenland to the southern tip of Greenland to join surveys previously flown for the Magnetic Anomaly Map of North America. Additional lines were also flown across southern Greenland at the request of and with financial support from the Greenland Geological Survey.

3. Magnetic Observatories and Instruments

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

The Geomagnetic Observatory unit of the Division of Seismology and Geomagnetism continued its management of the Canadian Magnetic Observatory Network (CMON) consisting of the following ten digital magnetic observatories: Resolute Bay, Cambridge Bay, Baker Lake, and Yellowknife in the Northwest Territories; Fort Churchill, Manitoba; Great Whale River,

Quebec; Meanook, Alberta; St. John's, Newfoundland; Ottawa, Ontario; and Victoria, British Columbia. The observatories at Alert, N.W.T. and Mould Bay, N.W.T. have changed their primary recorder from a photographic/analogue system to a one-minute spot value digital system. Glenlea, Manitoba was operated in cooperation with the University of Manitoba in Winnipeg. The observatory in Great Whale River, Quebec was moved from its first location near the NRC complex north of the village to a suitable site approximately three kilometres south and closer to the village. The move began in August 1984 and was completed in mid-September 1984. The observatory has changed its name from Great Whale River to Poste-de-la-Baleine in order to indicate the change. The variation station in Igloolik, N.W.T. has been closed. The 10 second digital data acquired from 1979-84 are available on request. Full descriptions of the network are contained in the various annual reports for magnetic observatories. The latest published report is for 1983.

The final 1983 digital magnetic observatory data which include one-minute values and hourly means and hourly ranges were deposited in the World Data Centre in Boulder, Colorado in June 1984. Copies of magnetograms and digital data are available at cost plus 100% handling charge from: Division of Seismology and Geomagnetism, Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, Ontario, K1A 0Y3. Telephone: (613) 995-5474. Details of other services are listed in the Catalogue of Services for the Geomagnetic Service of Canada.

Reconstituted magnetograms from 10 second spot data have replaced analogue records as the principal data source for the measurement of the Meanook, Victoria, and Ottawa K-indices. The indices are scaled in Ottawa in the middle and at the end of each month.

To provide timely data on the state of the AMOS network, a computer file containing summary information of the magnetic variations and the operation of the AMOS MKIII is updated each day.

An uninterruptible power supply for AMOS systems was evaluated at Ottawa magnetic observatory. It has improved the data integrity at that site and similar supplies have been purchased for all AMOS sites. These will be installed during 1985. A full AMOS station will be installed at Alert in February and at Mould Bay in the summer of 1985.

Investigations into ring-core fluxgate technology culminated in the installation of a ring-core sensor in a spinner magnetometer for paleomagnetic measurements. Sensitivity of the instrument improved by an order of magnitude compared with the former linear sensor. A three-component ring-core variometer is under development, with characterization to be completed in early 1985.

The Geomagnetic Service issues 27 day forecasts of geomagnetic activity every three weeks to users on a mailing list. Short-term 72 hour forecasts are available on a telephone answering service (613-992-1299). The present 27 day one-zone forecast will be replaced in 1985 by a three-zone forecast which will reflect magnetic conditions in sub-auroral, auroral and polar cap regions. Research into improved methods of forecasting is in progress.

4. Electromagnetic Induction in the Earth

(a) Earth Physics Branch, Ottawa (E.R. Niblett, R.D. Kurtz, A.G. Jones, J.A. Ostrowski, J.C. Gupta, C.C.M. Michaud)

Magnetotelluric data continue to be recorded at a reduced set of two stations in the seismically active area near La Malbaie, Quebec, as part of the on-going program of the Earth Physics Branch to detect changes in earth resistivities. The stations are located near the southwest and northeast ends of the active zone where the large magnitude earthquakes are thought to have occurred in the past. The remarkable correlation between time variation of electrical impedance and seismic P-wave travel time residuals continues at the southwest station.

The interpretation of the data from 11 scalar audio magnetotelluric and 8 tensor magnetotelluric stations from the gabbro-anorthosite intrusion at East Bull Lake, Ontario is nearly complete. The scalar results suggest the major shear zone, the Folson Lake

Fault, has nearly vertical dip and extends to depths of at least one kilometre. Interpretation of the tensor data indicates the presence of an anisotropic layer at 800 m with the axis of minimum resistivity parallel to the general geological trends in the area (northwest-southeast). This may have important implications to the flow of groundwater in the region. An increase in conductivity is observed at a depth of 18 km in agreement with reports from other Shield areas. Also the phase and apparent resistivity data support an increase in conductivity at upper mantle depths below 100 km.

A magnetotelluric survey was conducted, jointly with Pacific Geoscience Centre, along the main Lithoprobe transect across Vancouver Island in May and June 1984. A total of 18 stations (seven with complete remote reference) recorded tensor data in the frequency range from 384 to .00055 Hz. As well scalar audio magnetotelluric data were obtained at each site to extend the frequency range to 5000 Hz. Three stations capable of recording electromagnetic variations with periods as long as eight hours were operated for three months to obtain data to better resolve structure in the deep crust and upper mantle. Preliminary interpretations suggest a well defined conducting zone coinciding with a strong seismic reflector beginning at a depth of 15 km on the southwest side of the Island and dipping to more than 20 km to the northeast. Two dimensional interpretations of the magnetic transfer functions and the magnetotelluric responses are in progress.

Scalar audio-MT measurements were made at 24 sites in the Mackenzie Delta to study upper crustal structure in the region and to test the feasibility of the method for estimating permafrost depths. Twelve of the stations were located on and near the floor of a recently drained lake (Illisarvik). The remainder of the measurements were made at three well sites where geothermal logs and geological data are available. Good AMT data were obtained at these locations and are now being analysed.

A scalar audio-MT survey was completed in August on the Eye-Dashwa Lakes pluton near Atikokan, Ontario by École Polytechnique de Montréal (R. Bazinet, J. Legault) under contract to Atomic Energy of Canada Limited. Observations were made at frequencies between 8Hz and 5000 Hz at about 140 stations on a cut-line grid immediately to the east of the area surveyed in 1983. The objective was to identify and map conducting faults and fractures beneath the overburden, and to investigate variations of electrical conductivity with depth in the upper crust.

Results from a single tensor magnetotelluric station on the Wopmay Orogen (near Great Bear Lake) indicate the presence of an extremely resistive upper crust 12 km thick, overlying a conductive lower crust. A lithospheric thickness of the order of 100 km is estimated for the region. Interpretation of scalar audio magnetotelluric data across the Wopmay Fault zone suggests that the zone is about 4 km wide and nearly vertical. The structure is conductive at shallow depths on both sides of the fault scarp. The 3-component GDS data from eight stations indicate a minor conductivity anomaly at periods less than 500 s associated with graphite pelites (slope-rise sediments) mapped by P. Hoffman and colleagues at the eastern edge of the Hepburn metamorphic-plutonic belt. The absence of a major conductivity anomaly leads to the conclusion that most of the oceanic material has been consumed during the various subductions proposed by Hoffman.

A detailed magnetotelluric survey of 11 sites was undertaken around Summerside on Prince Edward Island, to map further the contact between the volcanic zone and sediments occurring at 2.5 km depth, discovered by the 1983 reconnaissance MT survey. The present interpretation of the observed two-dimensional responses is that they are indicative of anisotropy in horizontal electrical conductivity in the volcanic zone. Another implication from the observations is that the lower crust beneath PEI is only moderately resistive, i.e., of the order of 250 ohm m - a result which is in complete accord with all other em experiments carried out in Eastern Canada.

A 13 site magnetotelluric survey was undertaken across a sedimentary basin close to Fredericton, New Brunswick. The responses have yet to be interpreted.

A profiling-telluric (PTMT) survey was undertaken across the well-known Gloucester Fault which bisects Ottawa and has been mapped through Quebec as far as northern U.S.A. In this relatively novel experiment, the two horizontal components of the telluric field were recorded at eight locations 50 m apart straddling the fault, and the three components of

the magnetic field were recorded at the two end locations. It is hoped that this investigatory survey will indicate that sufficient recording of the telluric field will resolve the problem of near-surface distortion.

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

An innovative method to measure the electrical resistivity of the seafloor was developed in association with R.N. Edwards of the University of Toronto. The Magnetometric Off-Shore Electrical Sounding method (MOSES) determined the resistivity and thickness of the sedimentary section beneath Bute Inlet. The MOSES method was also used, at ocean depths of approximately 2200 metres, for two locations within Middle Valley near the Juan de Fuca ridge. The centre of the valley had a sediment thickness of 1800 metres with a resistivity of 0.8 ohm-metres. The resistivity of the underlying fractured basalt layer was 9.0 ohm-metres.

A controlled source sounding of a young basalt flow in the axial valley of the Juan de Fuca ridge was carried out using the United States deep submersible ALVIN to position the seafloor instrumentation.

The monitoring of changes in apparent resistivity related to the increase in tectonic strain in central Vancouver Island continued at two sites in the area.

(c) University of Alberta

(i) Magnetometer Array and Magnetotelluric Studies. (D.I. Gough, D.McA. McKirdy, Chen Guangming, Wang Xishuo, V.R.S. Hutton (University of Edinburgh), G. Dawes and D.K. Bingham (Department of the Environment, Government of Alberta), M.R. Ingham (Victoria University of Wellington, New Zealand), K. Wilson, G.S. Hoye, M. Connors, S.Kapotas.)

Colleagues from other institutes whose names are listed above have worked in this institute with us, and continue to collaborate in various ways at their present addresses. The study of conductive structures in the crust and upper mantle of western Canada continues. A large magnetometer array, 1980A, covered southwestern Canada south of the Edmonton-Prince Rupert highway at low resolution and located anomalies studied later by smaller arrays whose closer station spacing gave higher resolution. We have now acquired magnetotelluric equipment and have begun to use this to determine depths to conductive structures mapped by the arrays.

The 1981A Array Study. This array was centred at Tête Jaune Cache in the Rocky Mountain Trench west of Jasper. It spanned the Rocky, Cariboo and Monashee Mountains and if the Trench marks the pre-Mesozoic edge of North America, the northeastern half of the array was on the old continent and the other half on accreted terrains. It is well known from earlier work, and confirmed in this, that a good conductor in the lower crust or upper mantle lies beneath the half of the array southwest of the Trench (and under the terrains). One principal result of the 1981A study was to show that there is a large increase in conductance near the edge of the conductive region; this can be visualised as a thickening of the conductive layer, or as an increase in conductivity at constant thickness. With this reservation, we think of it as a conductive ridge. The second notable result of the study is that this conductive ridge lies under the Main Ranges of the Rockies rather than the Trench. In last year's report we described the details of the magneto-variation anomalies, and their interpretation. These are not repeated here. A paper on the interpretation of this array study is in press. The tectonic significance of the conductive structures will be discussed in a paper now in preparation. Previous geophysical and geological work in the region provides much evidence of high temperatures, and partial melt and hot saline water are high on the list of possible causes of the high conductivity.

Southern Alberta and Southeastern British Columbia. Two arrays of good resolution for large crustal structures have been used in this area. Array 1981B covered southern and east-central Alberta and the southeastern corner of British Columbia. It was placed to investigate a large, elongated conductive body striking northeast-southwest which was detected by the 1980A array. This we call the Southern Alberta anomaly. It strikes

across the Rockies and may be associated with the lower crustal rift reported 15 years ago by E.R. Kanasewich and his colleagues.

The second array study was made in 1983. This array was placed to give coverage along the Rocky Mountains up to the Thompson Highway, and to extend coverage over eastern British Columbia to stations west of the Kootenay Arc. The primary aim of this study was to find out whether the massive conductor which lies beneath the Rocky Mountains Main Ranges and Trench west of Jasper, between latitudes 52° and 54°N, continued along the Rockies to the United States border. Carner, Dragert and others found the eastern limit of the conductive layer under southern B.C. to be at the Trench north of about 52°, but near Kootenay Lake between 49° and 52°. In southeastern British Columbia it would be easy to confuse the edge of the B.C. conductive layer with the Southern Alberta anomaly.

A year ago we had material for a paper on the Southern Alberta conductive structure. We also had data from the 1983 array at an early stage of the long process of preparation for interpretation. As results from the second array have emerged, it has become clear that the results from the two arrays should be studied and eventually published together. This has delayed publication of the Southern Alberta structure, but will result in a more comprehensive treatment of the whole region about a year from now. To combine the two arrays, which recorded different events in different years, we have determined single-station transfer functions, at a range of frequencies, from horizontal to vertical components. This enables one to apply any desired artificial horizontal field to all stations of both arrays, in the computer, to obtain the vertical component of the field of currents induced by that artificial field. First results confirm the edge of the conductive layer under B.C. to be near the Kootenay Arc; improve the precision of our maps of the Southern Alberta structure transverse to the Rockies; but show no sign of any conductive structure along the Rocky Mountains and Trench south of 52°.

Magnetotellurics. We have purchased a short-period automatic magnetotelluric system (SPAM Mark II) designed by G. Dawes, from the University of Edinburgh. Magnetic sensor coils for this system have been given to us by J. Booker, on long-term loan from the University of Washington. Other coils will be added. This year the system has been tested in Scotland, where D.I. Gough is on study leave, by D. McKirdy; the coils have been calibrated in Alberta by McKirdy and Kapotas; and the complete system has been used in trial soundings in the Holmes River valley in the Rocky Mountains east of McBride in the Rocky Mountain Trench. The frequency range is 0.03-30 hertz. In 1985, we expect to use it in that general area and in that of the conductive structure mapped in the 1981A array study, provided this can be added to EMSLAB within our resources of time and personpower. The interpretation of the magnetotelluric data from the Rocky Mountains and Trench, secured in the summer of 1982 by V. Hutton and G. Dawes working with the Edinburgh system, is now being completed by Hutton, Gough and McKirdy. Various conductive structures have now been mapped with some precision by means of magnetometer arrays. The next step is to measure their depths by means of magnetotelluric soundings located with the aid of the array maps. The only array study planned for the next few years is our share of EMSLAB. High priority will be given to magnetotellurics.

Collaboration with Chinese Institutes. Mr. Chen has now been registered as a student for the M.Sc. and Mr. Wang has been admitted to the Ph.D. program. In Beijing the construction of a set of Gough-Reitzel type magnetometers is in progress, but we do not know how close they are to completion.

The EMSLAB Experiment. The United States consortium has been funded by the U.S. National Science Foundation for preparatory work this year, and calibration runs for magnetotellurics have been carried out. Final funding of the main field operation, planned for 1985, is contingent on the response of the N.S.F. to a second draft of the proposal by the U.S. consortium. As soon as a positive response is received from the N.S.F., D. Woods (Queen's University) and D.I. Gough will apply to NSERC for funds to cover the field work of the large land magnetometer array, planned to cover the States of Oregon and Washington and southernmost British Columbia. Assuming the project is funded, the seafloor array of magnetometers and telluric stations will be deployed from a Canadian ship directed by L.K. Law and recovered from a United States ship directed by J.H. Filloux. The plan is to secure simultaneous magnetovariation data from about 25 ocean-bottom magnetometers covering the Juan de Fuca Ridge and Plate, and 63 land magnetometers covering the volcanic belt

above the subduction. The field season planned is July-September 1985.

(ii) Magnetotelluric Studies. (D. Rankin, E. Pascal, R. Singh)

D. Rankin, though officially retired, is carrying on his research using a large field data base acquired over the past several years. Refined interpretational techniques including the inversion method of Rankin and Pascal (1982) have produced consistent and repeatable results on the data processed to date. Reports on these results are currently being prepared.

(iii) Numerical Modelling Studies. (F.W. Jones, H.-L. Lam, M. Ertman)

The perturbation of uniform and nonuniform electromagnetic fields by two-dimensional and three-dimensional electrical conductivity anomalies is being investigated by a numerical method. The three-dimensional numerical program has been adapted to the FPS164 array processor and the grid size has been increased to 37x37x37=50 653 points so that more detailed models can be constructed. Work on local anomalies is underway, and both electric and magnetic fields as well as perturbation and induction arrows are being calculated. The electromagnetic response of a subducting slab, in which the electrical conductivity is derived from the thermal regime obtained from the heat flow modelling work is being studied.

(d) Queen's University (D.V. Woods, M. Allard, H. Geiger, R. Renaud)

(i) A set of 30 Gough-Reitzel magnetic variometers was repaired and modified with the addition of achromatic lenses for improved optical precision, and more accurate digital timing boards. The instruments were field tested during a three week period in May at the Blackburn Geomagnetic Laboratory of the Earth Physics Branch. The instruments were fine tuned, random malfunctions were corrected, and operational procedures were perfected. Data recorded during the test will be compared against the observatory records and the precision level of the instruments will be documented.

(ii) A magnetometer array study was carried out during the summer field season over the Kapuskasing Structural Zone (KSZ). Instruments were installed in June in an array of five lines of six stations each, crossing the KSZ at right angles. Distance between lines was approximately 50 km and stations were spaced on average 25 km apart. The instruments recorded in two sessions for a total of eight weeks in July and August and were retrieved in September. Recording efficiency was high with only one instrument malfunction during the first recording session. Record losses were greater during the second recording session due to operational mistakes. Preliminary analysis of the wealth of data recorded by the array indicate a relatively uniform response across the array area except for isolated anomalies immediately adjacent to the Ivanhoe Lake Cataclastic Zone and a larger anomalous response at stations near the buried Trans-Canada gas pipeline along Highway 11. These anomalies are noted only at the highest recorded frequencies of geomagnetic fluctuation (1-2 min) when the horizontal source fields are polarized perpendiciular to the two-dimensional structures.

(iii) Magnetometer array data from the 1974 auroral electrojet array of Bannister and Gough in northern Alberta and the Northwest Territories is being analysed by the horizontal spatial gradient technique to determine the one-dimensional conductivity structure beneath this region of the North American craton. The results will be compared with a previous analysis of the 1969 mid-west U.S. magnetometer array of Porath and Dziewonski, which indicated an abrupt increase in conductivity at a depth of approximately 400 km, and the apparent absence of a high conductivity layer in the asthenosphere at 100 to 200 km depth. Horizontal spatial gradient analysis may also be carried out with the 1984 Kapuskasing magnetometer array data.

(iv) A major, international electromagnetic induction study of the lithosphere and asthenosphere beneath the Juan de Fuca plate (project EMSLAB) is planned for the 1985 field season. The Queen's University geomagnetic induction group will be taking part in the project by deploying their set 30 Gough-Reitzel magnetic variometers, along with the 33 instruments from the University of Alberta group, in a large array covering Washington, Oregon and surrounding regions. Other collaborators from United States, Canada,Japan and

the U.S.S.R. will deploy magnetic variometers and magnetotelluric instruments on land and the seafloor off the Oregon/Washington coast.

(e) University of Victoria (H.W. Dosso, W. Nienaber, R. Charters, W.B. Hu, J.T. Weaver)

Measurements of induced electromagnetic fields in a laboratory analogue model of the Hainan Island region of the South China Sea have been completed for both E- and H-polarizations of a uniform horizontal source field. The responses of the shallow Gulf of Tonkin, the narrow Hainan Strait, Hainan Island, and a large seamount in the deep ocean have been studied for a simulated period range 5 min - 500 min.

An analogue model of the Tasmania region was constructed and model electric and magnetic field measurements completed. Induction in the oceans surrounding Tasmania has a considerable influence on magnetic variations in Tasmania. Analogue model studies were carried out so that this effect could be allowed for in the interpretation of field station measurements. A technique is being studied that subtracts the model induction arrows from the field site induction arrows in order to remove the coast effect. This work is carried out in collaboration with W.D. Parkinson, University of Tasmania.

An analogue model of the west coast region, including Vancouver Island, is under construction. The model will include a simulation of the tectonic structure of the region and will be used to examine the effects of the subducting Juan de Fuca plate. This study is in part funded by Phase I of the Lithoprobe project.

J.T. Weaver spent a six month study leave at the Observatoire Cantonal in Neuchâtel, Switzerland where in collaboration with G. Fischer and B.V. LeQuang he has developed a "control model" for testing two-dimensional numerical modelling programs in electromagnetic induction. The control model can be solved analytically in the B-polarization mode and by a "quasi-analytical" method in the E-polarization mode. Further collaborative modelling and field work was completed on an investigation of a buried fault in the Jura limestones using natural and controlled source AMT.

In Collaboration with D. McA. McKirdy, now working at the University of Alberta, a further development of the thin sheet program for modelling three-dimensional structures has been completed. It includes a resistive thin sheet beneath the surface conductive sheet and a layered substructure.

5. Paleomagnetism and Rock Magnetism

(a) Earth Physics Branch, Ottawa (J. Roy, J. Park, P. Lapointe, E. Tanczyk, and B. Chomyn)

(i) Precambrian Program.

Two papers on the Tsezotene Formation and Katherine Group of the Upper Proterozoic Mackenzie Mountains supergroup of northwest Canada have been submitted for publication. Results from the units support the existence of a unique polar wander segment for North America, which lies to the west of the Grenville Loop but joins it at its younger end. Another Precambrian unit under current co-investigation with the Geological Survey of Canada is the 1400 Ma Michael gabbro of Labrador. During August of 1984 eleven sites were collected from the early Paleozoic Old Crow batholith and auxilliary granite plutons of the northern Yukon. We hope to test whether northern Yukon and northern Alaska have rotated from the Canada Basin or have been transported from farther south in the Cordillera.

(ii) Appalachian Program.

A synthesis of paleomagnetic results from the Appalachians is nearing completion. It consists of a locality map and a set of accompanying notes on each individual result. Similar publications for the trans-Atlantic equivalents of the entire orogen are also in preparation.

Studies in Nova Scotia are aimed at unravelling the tectonic history of the Meguma Block during the Paleozoic. Sampling of a number of basic bodies in the Yarmouth and Mavilette areas was carried out this summer. A paleomagnetic feasibility study at the

East Kemptville tin deposit is planned.

A study of the Permian redbeds of the Cap-aux-Meules Formation (upper and lower members) of the Iles-de-la-Madeleine has revealed so far remanences that are very stable under all forms of treatment (thermal, chemical, and alternating field). A reliable pole has been isolated, and is in agreement with other Permo-Carboniferous results of cratonic North America as mentioned below.

(iii) St. Lawrence Platform Program.

Since it has now been accepted that our results from the Carboniferous Basin are representative of the reference path for cratonic North America, efforts are being intensified to obtain results from pre-Carboniferous units from the St. Lawrence Platform. The goal of this program is to define the craton. This is necessary if we are to interpret properly the results from the Appalachian foldbelt. A study of the Cambrian anorthosite body at Sept Iles is now completed and should be published shortly. A preliminary study of the Cambrian Potsdam Formation shows the presence of a thermally stable direction yielding another intermediate to high latitude pole. Further experimental work is in progress in order to establish the significance of this result.

(iv) Arctic Program.

The investigation of Mid-Paleozoic redbeds from the Boothia Uplift area is currently in progress.

(v) Technical and Analytical Program.

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

A magnetometer for measuring at high or low temperatures is in the advanced phases of development at the Geomagnetic Laboratory of the Earth Physics Branch. The replacement of a linear core fluxgate sensor with a ring-core sensor has increased the magnetometer's sensitivity to 0.001 A/m. The instrument now operates in the heating mode from room temperature to 650°C.

The first results obtained from natural rock samples demonstrating that the tumbling of samples is more effective than non-tumbling for removing magnetization during alternating field treatment have now been published.

(vi) Nuclear Fuel Waste Management Program.

The ground magnetic properties of the East Bull Lake gabbro have been published in EPB Open-File 84-20. These surveys clearly show the use of rock magnetic properties in mapping lithological changes and the extent of fracture/alteration zones on the surface and at depth. The Atikokan research area was mapped using susceptibility, total field, and gradiometer surveys in order to produce a map of the extent of fractures or alteration zones, and their depth estimates.

Two articles have been published on the use of susceptibility in detection of fractures and their alteration extent in granitic plutons. These papers present also the different oxide assemblages associated with each characteristic susceptibility signature, and relate them to the geohydrologic conditions which have affected the plutons.

(b) Pacific Geoscience Centre, Sidney, B.C. (E. Irving and P.J. Wynne)

Further collections of Cretaceous and Permian rocks were made in Axel Heiberg in 1984 in collaboration with ISPG, Calgary, and of Cretaceous and Tertiary rocks in the Cordillera in collaboration with GSC, Vancouver. Notable results are from a Cretaceous intrusion near Prince Rupert (Smith Island gabbro) which yields a multiplicity of reversed and normal magnetizations commonly present in the same specimen. Work by a student from Carleton University yields a secondary magnetization of probable mid-Cretaceous age in Triassic rocks of the Quesnel Terrane. All these Cordilleran mid-Cretaceous data indicate a displacement of the western Cordillera by 2000 km to the south at that time.

(c) University of Alberta

(i) Archeomagnetism. (M.E. Evans, M. Mareschal, G.S. Hoye, W.I. Gough, V. Frnoch)

As a result of a very active field season, the archaeomagnetic collection previously reported on has now been extended from Italy to Greece and North Africa in an attempt to sample as fully as possible the Mediterranean Basin during antiquity. Well over 1000 separately oriented samples, representing sites ranging in longitude from 6°W to 26°E, are now in hand. Complete processing of this large collection will take some time but high-quality results are already emerging, for example, a pottery kiln at Pompeii yields D=358.0, I=59.1, k=952 (9 samples) and another at Metapontum in southern Italy yields D=62.0, k=252 (12 samples). A third, very interesting, baked feature currently being analysed is a Fifth Century A.D. domestic oven, located in a villa being excavated by the University of Alberta Classics Department. The floor of this oven consists of large fragments of planar tiles which should retain two distinct episodes of heating, the first being the initial firing to make the tile and the second (possibly multiple) relating to subsequent use in the oven. This is borne out by the preliminary thermal demagnetization conducted to date which strongly suggests that an estimate of the later magnetization will be obtainable from an analysis of the demagnetization trajectories. It may also prove possible to deduce something about the magnetization acquired during the original firing - since good "end-points" are obtained in some cases - and about the temperatures associated with the two phases of heating.

The laboratory phase of the paleointensity work mentioned in last year's report is now complete and the results are very encouraging. The specimens yield very high-quality data with correlation coefficients between NRM and TRM and between ARM1 and ARM2 mostly above 0.99. Furthermore, as a test of the method four specimens from a disused modern kiln were studied. These yield a field value of 44.2 μT which is in excellent agreement with the known field (44.7 μT) at the site at the time the kiln was last fired (1960).

(ii) Paleosecular Variation. (M.E. Evans, M. Mareschal, W.I. Gough)

During the field work involved in the archaeomagnetic work described above the opportunity arose to make a preliminary collection of sediments from a dried-out lake in southern Italy, now exposed in road cuts. The immediate objective was to test the viability of paleomagnetism as part of a larger project involving the thick sequence of undisturbed Recent lacustrine sediments available. A total of 43 samples was collected (one per horizon) spanning 1.87 m of section. Despite a generally weak remanence, these samples yield well-grouped remanence directions. After 15 mT alternating field demagnetization the following values were obtained: D=008.5, I=54.0, k=164, α_{95}=1.7°. These values imply a pole position which is both right-handed and far-sided, in accord with modern ideas concerning the second-order asymmetries in the time-averaged geomagnetic field. Furthermore, the results exhibit a high degree of serial correlation which presumably reflects real declination and inclination swings caused by secular variation.

(iii) Cretaceous Magnetostratigraphy. (M.E. Evans; J.F. Lerbekmo and K.C. Coulter (deceased) both of Geology Department, University of Alberta)

The magnetostratigraphy of late Cretaceous to early Tertiary sections in the Red Deer Valley, the Cypress Hills of southwestern Saskatchewan, and the Missouri Valley of central North Dakota has allowed precise correlation of these sections near the

Cretaceous-Tertiary Boundary, as well as correlation to a "type" marine section at Gubbio, Italy. This work has been presented in a series of three papers. A fourth paper, to be submitted for publication before the end of the year, deals with a magnetostratigraphic comparison of sections within the Red Deer Valley. This work has permitted detailed correlation of coal seams in the upper part of the Edmonton Group not before attainable.

Samples for paleomagnetic analysis have been collected from another Cretaceous-Tertiary boundary section east of the Cypress Hills in Saskatchewan and from one of the marine type sections in northern Denmark.

(iv) Quaternary Magnetostratigraphy. (M.E. Evans; N.W. Rutter and P.M. Waters both of Geology Department, University of Alberta)

A sequence of lacustrine silts exposed in the Old Crow region of northern Yukon was sampled for paleomagnetic work in the summer of 1980, as part of a major multi-disciplinary project aimed at elucidating the Quaternary history of the non-glaciated part of the Yukon Territory. Eighty-five horizons spanning 8.5 m of section were sampled (two specimens per horizon), and blanket alternating-field demagnetization at fields of 5 and 10 mT was carried out. In many cases there is considerable disagreement between two specimens from the same horizon and more detailed laboratory work is required. However, those horizons showing good internal agreement (R>1.95) yield a well-grouped population of vectors, all of which are reversed, with a mean of D=173.6°, I=-78.5°, α95=4.0° in very good agreement with the expected reversed dipole direction. The polarity information has obvious implications for the age of sedimentation, and the actual directions and their associated dispersion will have implications for the symmetry and temporal variation of the geomagnetic field.

(d) Université Laval (M.K. Séguin)

(i) Quebec.

Extensive paleomagnetic studies of Archean and Proterozoic rock units (lavas, gabbros, tuffs, peridotites, tonalites, granites, granodiorites and diabases) from the Frotet-Evans greenstone belt, Quebec have been undertaken by M.K. Séguin and E. Gahe in collaboration with A. Simard from the Quebec Department of Energy and Natural Resources (QDENR), Marina B. Vega-Carreno from the Academy of Sciences of Cuba, Havana and D.T.A. Symons from the University of Windsor.

A paleomagnetic study of gabbro sills in the northern sector of the Labrador Trough by M.K. Séguin in collaboration with T. Clark from the Quebec Department of Energy and Natural Resources is at the final write-up stage.

A paleomagnetic study of the alkaline suite of Mount Megantic, Quebec and surrounding rock units by M.K. Séguin in collaboration with B. St-Hilaire of Petro-Canada, Calgary has been completed and accepted for publication.

In Anticosti and Mingan islands, Gulf of St. Lawrence, M.K. Séguin and A.A. Petryk of QDNER have continued a second, detailed paleomagnetic investigation of type-sections (Ordovician-Silurian). The preliminary results will be presented at the 1984 CGU meeting in Calgary.

M.K. Séguin in collaboration with G. De Brouker, E. Gahe and J. Desbiens (students) has undertaken a large paleomagnetic study of Ordovician and Devonian sediments and of Upper Paleozoic diabase dykes from the eastern Gaspé Peninsula. The preliminary results will be presented at the 1985 GAC meeting in Fredericton.

(ii) New Brunswick.

The paleomagnetic studies of Lower Carboniferous lavas and redbeds from central New Brunswick and of Devonian volcanics and basic dykes from northern and central New Brunswick have been completed by M.K. Séguin and students (A. Singh and E. Gahe) in collaboration with L. Fyffe, New Brunswick Department of Natural Resources.

(iii) Nova Scotia.

The paleomagnetic research done by M.K. Séguin and K.V. Rao in collaboration with E.R. Deutsch (Memorial) is continuing. A paper on the Morrisson River Formation was submitted for publication and is under revision; we are concentrating our effort on the Torbrook-Nictaux Falls diabase and sediments in the Meguma zone.

(iv) Newfoundland.

The Cambrian Brigus Shale formation was investigated paleomagnetically by K.V. Rao and M.K. Séguin. A paper has been written and will be submitted for publication shortly. Paleomagnetic studies of the Finn Hill Sequence and porphyrite intrusives from the Harbour Main-Colliers area have been completed. A paper on the Finn Hill Sequence has been accepted for publication.

(v) Baltic Shield (Norway, Sweden and Baltic Islands).

A joint project between Université Laval (M.K. Séguin) and the University of Lund, Sweden (G. Bylund) with the collaboration of P. Nystueen (Norway) was started in 1981 and is now continuing. A paleomagnetic study of the tillites of Vendian age and of the whole Cambrian sequence has been completed. The Ordovician sequence and a part of the Silurian units is now the subject of an exhaustive investigation. The specimens with weak magnetization were measured with the cryogenic magnetometer of the USGS in Flagstaff, Arizona and at the University of Copenhagen in Denmark.

(vi) South America - The Andes.

An important paleomagnetic study (over 50 sampling sites) was undertaken in the summer of 1983 by M.K. Séguin in collaboration with T. Feininger of EPB. This investigation is aimed at a better understanding of the formation of the Andean mountain chain. In Ecuador, the sampling was carried out in different metamorphic and unmetamorphosed terranes from the Sierra, Oriente and Costa regions. In Peru, the sampling was carried out in sedimentary, volcanic and granitic rocks of Cretaceous and Tertiary age. The paleomagnetic measurements of Peruvian samples have been completed and those from Ecuador are underway.

(e) Memorial University of Newfoundland (E.R. Deutsch, J.P. Hodych, G.S. Murthy, R.R. Pätzold, S. Gower, J.N. Prasad, M. Tubrett)

Paleomagnetic studies of rock units from Labrador are continuing (G. Murthy, M. Tubrett, R. Pätzold). In cooperation with the Newfoundland Department of Mines and Energy, a major collection of dike swarms from the Cartwright area of Labrador was made. The material sampled includes N-S trending Eocambrian dikes, an E-W trending younger (Mesozoic?) dike swarm, and older suites of gabbro (Michael gabbro equivalent?) also from the same area. The laboratory work, presently in progress, suggests a NW and upward directed characteristic magnetization for the E-W dikes. The other collected material is not yet processed.

A major paleomagnetic study of the constituents of the Carboniferous Bay St. George sub-basin of western Newfoundland was completed (G. Murthy, S. Gower). The magnetostratigraphic horizon marker in the Carboniferous (Roy and Morris, EPSL 65, 1983), is suggested at the base of the Searston Formation of the Barachois Group (Namurian). Pole positions were obtained for various constituents ranging in age from the Tournaisian to Visean with a Kiaman overprint. The results are interpreted as not supportive of the major transcurrent motions suggested earlier by other workers for the northern Appalachians during Carboniferous times.

J. Prasad (doctoral student), with E. Deutsch and M. Tubrett, collected Early Paleozoic limestones and dolomites from three widely separated areas of the Humber Zone in western Newfoundland, continuing a major paleomagnetic study of Cambro-Ordovician rocks in this part of the North American craton. Measurements so far have concentrated on Early to mid-Ordovician samples with magnetite as the chief remanence carrier. Consistent remanence directions with low inclinations and NW-SE or N-S declinations have

been isolated at many sites. Work is continuing to establish whether, at different sites, the age of magnetization is primary or perhaps was acquired during early to late diagenesis. The collection includes limestones from the allochthonous Cow Head Group where fold and conglomerate tests, still in progress, may offer magnetic stability clues. The mostly very weak magnetizations of these carbonates are being measured with the prototype unit of the CTF cryogenic magnetometer at Memorial University.

The Early Cambrian Morrison River/MacCodrum red beds on Cape Breton Island were studied as part of a continuing joint project by E. Deutsch with Laval University (M.K. Séguin) on Paleozoic paleomagnetism in the Avalon Zone. The results require a minimum 20° angular displacement of the Avalonian sites relative to the craton, and they indicate that in the Paleozoic the Avalon Zone drifted as a distinct block relative to the other Atlantic borderlands. A paper by K.V. Rao, M.K. Séguin and E. Deutsch has been submitted for publication.

Hodych, Pätzold and Buchan (1984) found that the oolitic hematite ores of Alabama carry a single-component remanence acquired some 130 Ma after Silurian deposition but before Permian folding. This long delay in remanence acquisition may be due to the ore having originated as goethite which was not heated enough to dehydrate to hematite and magnetize until deeply buried by a Pennsylvanian clastic wedge. This mechanism of remanence acquisition by deep-burial diagenesis could be common in fine-grained red beds since their hematite may have a goethite precursor. This could be a reason for some of the late Carboniferous directions so common in Appalachian red beds. Certainly paleomagnetic results from red beds should be carefully interpreted; even a positive fold test may not prove that the remanence was acquired close to the time of deposition.

A new analysis of British Isles Ordovician data (Deutsch, 1984) has broadly confirmed earlier estimates of a Proto-Atlantic (Iapetus) ocean of about the present Atlantic width for mid-Ordovician Ireland, using a quantitative approach (Deutsch, J., Geomag. Geoelec., 32, SIII 77, 1980) whereby paleomagnetic results from across the proposed collision suture were applied to Phillips' (J. Geol. Soc. London, Spec. Publ. 9, 267, 1981) updated British Caledonides model. The analysis also indicates a $\geq 15°$ angular Proto-Atlantic width relative to Britain and requires a 30° anticlockwise rotation of the British Isles relative to the geomagnetic field during the Ordovician.

(f) University of Toronto (D.J. Dunlop, H.C. Halls, G.W. Pearce, O. Ozdemir, K.C. Jackson, H. Hyodo, F. Heider, K.S. Argyle, R.J. Enkin, V. Constanzo, E. Shaw)

(i) Chemical Remanent Magnetization (CRM) during τ-Fe_2O_3 to τ-Fe_2O_3 Transformation. (O. Ozdemir, D.J. Dunlop)

The effect of the transformation of maghemite to hematite on the intensity and the direction of the remanent magnetization is being investigated. The CRM will be studied in synthetic SD maghemites of different shapes. After the samples are characterized (by X-ray and DTA or DTG), an anhysteretic magnetization (ARM) will be induced in fields ranging from 0.5 to 10 Oe. Then the samples will be oxidized by heating in air at the inversion temperature. During inversion of maghemite, fields ranging from 0.5 to 10.0 Oe will be applied perpendicular to the initial ARM. The purpose of the present project is to observe changes in the intensity, stability and direction of ARM/CRM of the inversion product of maghemite. The second objective is to compare single-domain theories of CRM in fine-grained material with the experimental results.

(ii) Hysteresis Properties of Submicron and Micron-Sized Magnetites. (D.J. Dunlop, K.S. Argyle)

Saturation hysteresis properties (coercive force, remanent coercive force), initial reversible and irreversible susceptibilities, static remanence (induction) curves and AF demagnetization of saturation remanence have been measured for two sets of magnetite samples. One set of four samples contains perfect cubic crystals with mean sizes from 0.04 μm to 0.22 μm. These particles are mainly single-domained (SD) or two-domained (2D). Their TRM properties have been well studied in previous work. The second set of three

samples are less perfect, somewhat rounded crystals produced by reducing hematites, as described in last year's report. The nominal grain sizes range from 0.75 μm to 5 μm but scanning electron microscopy is showing that the true, unflocculated mean particle sizes range from about 0.3 μm to about 1 μm. The data are presently being compared with theories of SD, 2D, 3D and large multidomain (MD) grains, and written up for publication.

(iii) Micromagnetic Theory of Domain Structure. (R.J. Enkin)

A micromagnetic model of continuous magnetic structure in pseudo-single domain (PSD) size particles has been developed. Stable configurations are determined by iteratively minimizing the magnetic energy (exchange + anisotropic + magnetostatic). Equilibrium structures, energies and moments are being compared as a function of particle size and shape, temperature and external field. The energy barrier between local energy minima can also be found. The results will be applied to theories of thermoremanent and viscous remanent magnetization.

(iv) Viscous Remanent Magnetization (VRM) in MD Magnetites. (F. Heider, D.J.Dunlop)

A new study is being initiated to grow magnetite grains of distinct size ranges in a hydrothermal pressure cell. This technique allows us to obtain stress-free single crystals of MD size > 5μm). The magnetic properties (hysteresis, TRM) will be measured. The VRM acquisition and decay curves and their temperature dependence will be examined and compared with the VRM properties of natural MD grains in different size ranges. The question of whether or not diffusion after-effect contributes to VRM processes will also be investigated.

(v) VRM and Viscous Induced Magnetization in Submicron PSD Magnetites.
(R.J. Enkin, D.J. Dunlop, D. Walton, McMaster University)

The viscous acquisition and decay of magnetic moment in four sized magnetite powders has been measured at a number of external fields and temperatures, using a SQUID 2nd order magnetometer at Cambridge University. The data have been digitized for computer analysis. Magnetization usually increased faster than log(time), possibly implying interactions between particles. Acquisition and decay rates generally increased with field and temperature, but not systematically, reflecting some memory effects between runs.

(vi) Paleotemperature Determination by Paleomagnetism and $^{86}Ar^{87}Ar$ Method.
(H. Hyodo, D.J. Dunlop and D. York)

The heating effect of an igneous intrusion can reset, either partially or totally, the magnetization and Ar isotopes in adjacent country rocks. Since these two systems (magnetic and isotopic) can carry information on the secondary heating events, paleotemperature of the country rocks at the time of intrusion can be estimated. However, there is no direct experimental way to justify the paleotemperature obtained in either method separately because laboratory unblocking temperatures are systematically higher than the temperatures experienced in nature, the difference depending on the thermal history of the rocks (slow or fast cooling). In this study, direct comparison between these two physical systems will be made, and the effect of short-term heating will be investigated. Presently, AF cleaning results of an Abitibi dike (2100 Ma or 1100 Ma?) and Nipissing diabase host rocks near Gowganda, Ontario give two distinctively different directions of magnetization. Direct dating of these rocks may provide a solution for the problem of two Nipissing "primary" paleomagnetic directions.

(vii) Kapuskasing Zone Paleomagnetism (Project Lithoprobe). (V. Constanzo, D.J. Dunlop)

A paleomagnetic study using multicomponent analysis has been initiated in an attempt to work out the structure and timing of the Kapuskasing structural zone (KSZ) uplift, which is considered to be an oblique cross section through the upper two-thirds of the Superior Province crust. Preliminary results have isolated three directional groupings

of remanence in highly metamorphosed Archean anorthosites and gneissic tonalites sampled in across-strike traverses at the southern end of the KSZ (Chapleau-Foleyet area). Group A has NNE intermediate downward directions, group B has steep upward easterly directions and group C has shallow easterly directions. Groups A and B have been already reported in previous works. The former is interpreted as a metamorphic component (2.5Ga) by D.T.A. Symons and T.A. Vandall (1985, paper in press), but it also could be a younger metamorphic component or a present earth's field viscous overprint. The second is interpreted by Symons and Vandall as an Archaean (2.8Ga) metamorphic component but as a younger overprint (approximately the age of the Abitibi dykes) by H.C. Halls and R. Ernst (1985, CJES). Group C has not been previously reported. It could represent either a third paleomagnetic component of unknown age or the unresolved resultant of B and A components. Paleopoles for these three potential paleomagnetic components fit fairly well on the Precambrian apparent polar wandering path of North America.

(viii) Structural and Paleomagnetic Data from Dyke Swarms in the Eastern Lake Superior Region. (E.G. Shaw, H.C. Halls)

Patches of lakeward-dipping Keweenawan volcanics and sediments show that the shield along the coast of Lake Superior has been tilted in response to subsidence of the Lake Superior Basin about 1.1 Ga ago. These Keweenawan rocks are only rarely found along the eastern shore and thus are insufficient to define the full extent of shield deformation associated with basin development. However Precambrian dyke swarms ranging in age from 2.6 to 1.1 Ga are common in the shield, and through combined study of their attitude and primary paleomagnetic direction, offer an alternate means to assess the extent of crustal tilting.

Thirty-nine paleomagnetic sites were sampled. A total of 300 samples was collected from northwest-trending diabase dykes along two traverses roughly normal to the eastern shoreline of Lake Superior and oblique to the trend of the dykes. The northern traverse, about 45 km long, follows the Montreal River to the coast. Since it was important to know the structure and paleomagnetism of dykes in a relatively stable area, a southern traverse - remote from the Lake Superior Basin - was chosen as a control. This traverse is located 5 to 10 km south of the northern traverse, 35 km from the coast, and extends eastward for a distance of 70 km. Twenty-three dykes in the southern traverse and sixteen dykes in the northern traverse were sampled.

Based on paleomagnetic direction, there appear to be at least four ages of dyke intrusion in the interior corresponding to Keweenawan, Sudbury, Matachewan and an undated dyke set that has similar lithology and paleomagnetic direction to 2.1 Ga-old Preissac dykes. All sampled interior dykes trend NW to N, and beyond about 2 km from the shoreline, dip less than 5 to 10 degrees from the vertical. Dykes within about two km of the shoreline tend to have a more westerly trend and all dip NE at angles ranging from 45 to 70 degrees. These dykes, in comparison with those of the interior, are more altered and sheared, especially at the margins.

An easterly rotation of approximately 40 degrees about a NNW axis returns both the attitude and paleomagnetic direction of the coastal dykes to those of the control group. This is in agreement with the rotation needed to return the Keweenawan rocks in the south to the horizontal. The combination of rotated attitudes and paleomagnetic poles, and also the large degree of shearing, indicates that the present anomalous dips and strikes of the coastal dykes are due to tectonic rotation and not to a geographic change in the ambient stress field during dyke emplacement. In addition, the study shows that, at least locally, a rim of shield no more than 2 km wide has been tilted in response to subsidence in the Lake Superior Basin.

(ix) Paleomagnetism, Structure and Longitudinal Correlation of Middle Precambrian Dykes from Northwestern Ontario and Minnesota. (H.C. Halls)

A primary magnetization about 2.1 Ga old is well-preserved in the Kenora-Kabetogama dyke swarm in Minnesota and Ontario. Its direction, the mean for twelve dykes, incorporating results from 30 paleomagnetic sites, is 115.9/-55.6 yielding a paleomagnetic pole position of Lat 42.7°S, Long 4.2°E (dm=7.3°, dp=5.2°).

The primary nature of the magnetization can be demonstrated using geochemistry to correlate individual dykes over distances that can exceed 300 km. While the remanence direction varies between dykes it remains constant along a dyke, sufficient proof that it was formed during initial cooling of the dyke.

A weak longitudinal increase in hydrous alteration, MgO content and degree of magnetic overprinting is observed as the swarm is followed to the south and may reflect increasing proximity to a Precambrian continental margin that underwent rifting, sedimentation and deformation during the time interval 2.2 to 1.8 Ga bp. While the cause of the longitudinal changes in terms of margin evolution can only be surmised, the results illustrate the potential of dyke swarms as sensitive indicators of how shield terrains may respond to events occurring around their margins.

(x) The Age of the North Mokka Anticline, Axel Heiberg Island, Canadian Arctic Archipelago: an Application of the Paleomagnetic Fold-Test. (K.C. Jackson, H.C. Halls)

A paleomagnetic fold-test of sills in the North Mokka Anticline shows that the deformation both pre- and post-dates the intrusion of diabase. The anticline is one of several in the eastern part of the Sverdrup Basin that are associated with evaporite diapirs. This Late Paleozoic-Early Tertiary sedimentary basin was deformed by the Late Cretaceous to Tertiary Eurekan Orogeny, but the extent to which the orogeny initiated and formed the diapirs has been debated. The paleomagnetic direction obtained from the anticline (285°, +73°) is the same as that from a nearby Cretaceous lava flow. The corresponding paleopole, 180°N 62°E, is also in agreement with a Cretaceous age of intrusion. These results support the suggestion that the diapirism in the Sverdrup Basin is older than, and independent of, the Eurekan Orogeny. The asymmetric distribution of sills on the anticline may reflect a local stress-environment created by the diapir.

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

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

A paper describing the paleomagnetic results from this Early Keweenawan unit has been submitted to the Journal of Geophysical Research.

(ii) Diabase dikes in the Kapuskasing Structural Zone. (H.C. Palmer; H.C. Halls, University of Toronto).

Diabase dikes exposed in the Chapleau-Foleyet area of northern Ontario were sampled at an additional 25 sites. The sampling of these dikes was concentrated in the chilled margins as this material has proved to have high magnetic stability. Most sites possess Matachewan type magnetic directions with both normal and reverse polarities being represented.

(iii) Aston and Hunting Formations, Somerset and Prince of Wales Islands, N.W.T. (H.C. Palmer, W.A. Morris, G.M. Young).

The dominant magnetic component isolated in arkoses and brown mudstones from the Aston and Hunting Formations (275°, 20°) is post-folding in age. Although other components of magnetization can be isolated in some sites, none can be demonstrated as primary.

(iv) Lamprophyres near McKellar Harbour (Lake Superior), Ontario. (A. Valentini, H.C. Palmer).

Lamprophyres exposed near McKellar Harbour, Ontario have a moderately stable remanent magnetization which yields a pole at 39°N, 190°E. Samples from three of these dikes have concordant K-Ar ages of 1165 Ma.

(h) University of Windsor (C.P. Gravenor, D.T.A. Symons)

(i) Instrumentation.

A CTF cryogenic magnetometer has been made operational with complete on-line computer control, data analysis and plotting. Also, a Sapphire Instruments AMS meter with on-line computer control, data analysis and plotting has been added to the facilities.

(ii) Western Canadian Cordillera.

Paleomagnetic studies have been: (a) completed and published on the Topley intrusions of Stikinia and the Copper Mountain intrusions of Quesnellia in Terrane I; (b) completed (Geodynamics, in press) on the Nicola volcanics of Quesnellia in Terrane I, and the Westcoast Complex and Island Intrusions of Wrangellia in Terrane II; and, (c) completed on the Mayie Sills and Aldridge Formation of the Purcell Anticlinorium. These studies place age and magnitude restraints on the geotectonic motions of the various subterranes in the Cordillera.

(iii) Western Canadian Basin.

R. Deklerk (M.Sc. thesis) is currently conducting a paleomagnetic study of the Devonian potash deposits of Saskatchewan looking particularly at the age of carnallitization.

(iv) Canadian Shield.

D. Dunsmore (M.Sc. thesis) is beginning a study to differentiate between mineralized and non-mineralized gabbroic intrusives in the Lynn Lake area of Manitoba. A. Timmins (M.A.Sc. thesis) is completing a study of the Bird River chromite sill with additional U-Pb-zircon data. T. Vandall (M.Sc. thesis) is studying the paleomagnetism of four intrusive and extrusive units with well-defined U-Pb zircon ages in the Wawa Belt as part of the KSZ-Lithoprobe project.

(v) Glacial Sediments.

The use of plastic "push-in" specimen holders for soft glacial sediments has been shown to produce systematic errors in remanence and AMS results. A study examining magnetic and pebble fabrics from three sites in glaciomarine sediments from the Champlain Sea, Ontario, has been completed and shows evidence for post-depositional deformation. Another study of the magnetic fabrics in the clay and silt fractions of varved clays indicates that the winter clay layers were deposited from bottom currents and not primarily from suspension as is generally thought (D. Coyle, M.Sc. Thesis).

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III (B) AERONOMY AND SPACE PHYSICS

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2. University of Calgary, Space Science Group
3. Communications Research Centre (CRC), Radio Propagation Laboratory
4. Earth Physics Branch, Department of Energy, Mines and Resources
5. Herzberg Institute of Astrophysics, National Research Council
6. University of Lethbridge, Department of Physics
7. University of Saskatchewan, Institute of Space and Atmospheric Studies
8. University of Victoria, Department of Physics
9. University of Western Ontario, Centre for Radio Science
10. York University, Centre for Research in Experimental Space Science

1. University of Alberta

Magnetospheric Physics

Four major themes were pursued in magnetospheric studies: (i) the suggestion that Kelvin-Helmholtz (K-H) instability in the velocity shear zone separating the low latitude boundary layer and the central plasma sheet causes quasi-periodic geomagnetic activity (from Pc 4, 5 ULF pulsations to substorm surge and Ps 6 (omega band)); (ii) the possibility that reconnection is a time-dependent phenomenon whose rate during steady state conditions is overshadowed by a viscous-like interaction along the magnetopause which provides, through mass and momentum transfer into the low latitude boundary layer, all the energy needed to power conventional auroral oval activity; (iii) transient reflection of shear Alfven waves from the auroral ionosphere and the convection of these mechanisms with the onset of substorm expansive phase; (iv) evaluation of superposed epoch analyses commonly used to find predictable structures in time series of magnetospheric and solar wind phenomena. On the basis of past studies of Ps 6 phenomena (related to auroral omega bands in the dawn sector), G. Rajaram, G. Rostoker and J.C. Samson are exploring these structure characteristics across a broad azimuthal range (analyses of large scale evolution with data from Alaska, Alberta, Churchill and E-W line of IMS magnetometer arrays and of smaller scale evolution with Alberta E-W line data from Ft. Providence to Uranium City). Using Samson-Young techniques, Rajaram is estimating both group and phase velocities to provide a better physical explanation for the observed eastward propagation of Ps 6s and exploring the Rostoker-Samson contention that Ps 6 and westward travelling surge phenomena are due to sunward propagating waves associated with magnetotail K-H instabilities at the central plasma sheet - low latitude boundary layer interface.

For many years two mechanisms were cited for interplanetary medium-magnetosphere energy transfer; (i) magnetic reconnection (Dungey, 1961) and (ii) viscous interaction (Axford and Hines, 1961). Recently (ii) has been given physical meaning in terms of anomalous mass transport through the action of K-H instability on the magnetopause. G. Rostoker is now exploring the explanation of conventional auroral oval activity in the context of anomalous transport (modulated by IMF orientation). His study of polar cap responses to sudden changes in IMF orientation and substorm expansive phase onsets suggests that the magnetospheric cross polar cap potential associated with reconnection has an impulse response time much like that found for auroral electrojet currents (McPherson, UCLA). Observations of anomalous Z-component field strength at very high latitude in the morning sector studied by G. Rostoker and M. Yeremy, suggest that magnetic reconnection is a time-dependent phenomenon, with no steady state counterpart; this points to a magnetospheric model in which all auroral processes associated with the conventional oval take place on closed field lines. G. Rostoker and Tai Duc Phan, from a study of decay of the driven system electrojets after sudden northward IMF turnings, found the decay time depends on the prior level of auroral electrojet activity (1/e decay time being shorter for weaker magnetic levels). Treating the relevant 3-D current systems in terms of an equivalent LCR electric circuit, they showed consistent behavior with the closed field line region of the tail, becoming largér with increasing activity levels. They also studied the

growth of the driven system after sudden southward IMF turnings and found the growth times roughly the same as decay times for northward turnings. C. Hedlin will study the response of auroral currents in the Harang discontinuity, just prior to onset of the substorm expansive phase, to seek possible signatures of precursor activity to substorm expansive phases in terms of electrojet distortion. J.C. Samson and B.G. Harrold have nearly completed their studies of polarizations, group and phase velocities of transient Pi 2 magnetic fields accompanying the onset of substorm expansive phase. These Pi 2s are related to reflection of shear Alfven waves associated with a brightening auroral arc at substorm onset. At mid-latitudes, the Pi 2 phase velocities are predominantly westward, indicating that the dominant arc brightening spreads westward in association with enhanced field-aligned current. At auroral latitudes westward propagation prevails to the west of the onset, and eastward propagation prevails to the east of the onset. These indicate a somewhat weaker eastward propagation of the field-aligned current and arc-brightening. In all cases, azimuthal phase velocities are very high (50-150 km/s). Samson and M.G. Connors constructed numerical models of the transient reflection of field-aligned current from the auroral ionosphere; this predicts most of the observed features of Pi 2 magnetic fields at ground. Samson and Young have found that estimators similar to those used in factor analysis give far more objective results than those based on a simple averaging of the time series (based on superposed epoch analyses). Most of the revised estimators use an eigenvector decomposition of the covariance matrices.

The Space Physics Group hosted an International Workshop (August, 1984) related to magnetotail processes which are associated with substorm expansive phase initiation. Two teams presented detailed studies of substorm events supporting two different frameworks in which substorm-related tail observations were placed; one involved development of a near-earth neutral point leading to a clipping off of the plasma sheet and ejection down the tail as a plasmoid; the other held that substorm-associated plasma and field perturbations could be accounted for by thinnings and thickenings of the plasma sheet, observed effects are detected when the observing satellite finds itself in the plasma sheet boundary layer. Several papers will be presented at the AGU meeting in Fall, 1985.

2. University of Calgary, Space Science Group

(a) Collaborations and Special Projects

D. Venkatesan's collaborative study of multispacecraft observations of cosmic ray intensity variations in the heliosphere with S.M. Krimigis and R.B. Decker, JHU/APL and J.A. Van Allen, Iowa, using data from Pioneers 10 and 11, Voyagers 1 and 2 and IMP 7 and 8, continues. Venkatesan visited S.P. Agarwal at the Vikram Space Physics Centre, A.P.S. University, Rewa, India. In a new collaboration with L.J. Lanzerotti and A. Wolfe, Bell Labs, N.J., an observatory will be set up at Frobisher Bay, the conjugate station to the South Pole, Antarctica, where Bell Labs already has a magnetometer and riometer. Routine observations will begin in the early summer of 1985. The collaborative study of the frost-free season in Canada with the Department of Geography, Calgary (Nkemdirim) is continuing.

(b) X-ray Astronomy Balloon Program

A balloon payload of 21 million cubic feet (X-ray Astronomy) was launched from Gimli, during August 1983 (by D. Venkatesan, R. Lieu, D. Leahy and H. Graumann of Calgary in collaboration with J.J. Quenby, A.R. Engel, K. Beurle and N. Spooner of Imperial College, London). The engineering flight was a success. The sudden cancellation of the balloon and rocket program by the new government leaves this project in jeopardy. A balloon observation from Hyderabad, India (1983) of QSO 3C 273 in the 20-120 keV range was presented at the American Astronomical Union Meeting, Tucson, January 1984. A balloon-borne payload launched from Hyderabad, India on 18 December 1984, obtained 10 hours of data (D. Venkatesan and D.A. Leahy, Calgary in collaboration with S. Naranan, S.V. Damle and P.K. Kunte, Tata Institute of Fundamental Research, Bombay). Several X-ray sources were observed. The guest observer program at the Einstein Observatory, to study SNR HB3 has been completed, (D. Venkatesan, C.M.F. Galas and D.A. Leahy, Calgary in collaboration with K.S. Long, Space Telescope Institute, Baltimore and S. Naranan, TIFR, Bombay). The collaboration of D. Venkatesan and R. Lieu, Calgary with Mitani, Institute of Space and Astronautical Science, Japan, relating to Cen X-3 observations by the Japanese satellite,

Hakucho has been completed.

(c) Government Honours Research Station

The federal government honoured the Sulphur Mountain Cosmic Ray Laboratory, for its role in advancing the understanding of cosmic rays. A commemorative historic plaque recognizes the significant contributions made to space studies for almost 20 years of operation since the International Geophysical Year, 1957. The Historic Sites and Monuments Boards of Canada Plaque was unveiled at the Nickle Arts Museum on 1 November 1984 (to be later mounted permanently on the Campus). A similar plaque will be mounted next year at the Sulphur Mountain site.

(d) Miscellaneous Studies

The analysis of HEAO-1 LED soft X-ray spectra of extended supernova remnants continues (with Garmire, Pennsylvania State University); detector calibration is in progress. A theoretical study of pulsar magnetospheres is continuing with numerical computations recently started. Numerical calculations and experimental work are also in progress for the design and development of a phoswich-type hard X-ray balloon astronomy.

During August 24 to November 14, under the Canada-Japan Scientific Exchange Program, collaboration was continued with the Institute for Space and Astronautical Science, Tokyo, to study Tenma X-ray satellite data on the X-ray Binary GX301-2; analysis of spectral data is nearing completion.

(e) Galileo

Activities are underway for the launch (1986) and arrival at Jupiter (1988) of the Galileo orbiter and probe spacecraft. Detailed planning of observing sequences is going on; during a two hour period in the Jovian shadow, the CCD camera system will take time exposures of lightning and auroral emissions. Bright moonlight from the moons, Io and Europa and detector noise induced by Jovian radiation belts are problems to contend with; however, detection of aurora and lightning is still anticipated. Later and more distant 'sun occultations' with a more favourable alignment of the inner moons and less of a problem from radiation is also anticipated. However, moonlight will enable the study of cloud patterns at the site where the probe descends through the Jovian atmosphere.

(f) Viking

Many problems with the Viking UV Imager flight hardware have been uncovered and are being solved. Noise and gain problems have been of particular concern along with serious flaws in the intensifier assemblies. These are being addressed. The launch is planned for fall 1985. Preparations are underway for the UV Imager ground station to be installed in Kiruna, Sweden during the summer of 1985. Members of the UVI Science team will take turns in participating at Kiruna in the planning and execution of "campaigns" aimed at various scientific objectives during the active life of the spacecraft. Scientific planning for the mission was advanced at the Viking Science team meeting (Copenhagen, fall 1984).

(g) Infrared Group: Infrared Solar Physics and Aeronomy

(i) Balloon-borne Solar Observations

The nearly completed analysis of far IR (20-90 wave-numbers) solar spectra measured in 1982 includes radiometrically calibrated solar brightness temperature values from depths near T-minimum in the solar atmosphere, line intensities from high-n H recombination lines of solar chromosphere origin, and, from the ubiquitous stratospheric absorption spectra, a measure of the HCl/HF ratio at stratospheric altitudes from several line pairs. The 1984 balloon flight series (two planned) was terminated; in the first flight the payload landed in Lake Manitoba, destroying the majority of its working parts. Measurements of the calibration source verified the correctness of filter choice and the operation of the Michelson interferometer. The sudden cancellation of the entire Rocket and Balloon program by the new government will terminate this important solar physics program just when proven instrumental design is producing new exciting results. The

one-year reprieve for 1985 will permit a search for more recombination lines in the sequence and provide an estimate of the relative strength of H versus the Mg,Al and Si lines seen in the intermediate IR.

(ii) Atomic Oxygen 63 Micron Emission Line from Ionospheric Altitudes

Analysis completed on this line (taken by D.A. Maylor with the ESA/University College of London balloon-borne telescope and Michelson interferometer) has demonstrated that the intensity of this fine structure line is independent of zenith angle when viewed from below, a fact of some significance when measuring this line from astronomical sources.

(iii) Airborne Annual Eclipse Expedition

The Lear-35 jet aircraft of Business Flights Ltd. of Calgary was again equipped with a LiF window, a NASA heliostat and a continuously-variable (2-12 micron) filter spectrophotometer to observe the extreme solar limb from above Mexico during the annual solar eclipse of 30 May, 1984; ferry flights permitted a search of a small part of the sun for 5-minute oscillations in solar CO bands and the continuum. Several passes were made across Kitt Peak National Observatory, Tucson, Arizona at different altitudes to verify the correctness of synthetic spectra for IR atmospheric extinction measurements of importance in IR astronomical photometry. Analysis is continuing on the data, albeit somewhat degraded by electronic and recording problems.

3. Communications Research Centre (CRC), Radio Propagation Laboratory

ELF spectrum of artificially modulated D-E region conductivity was computed. Artificial currents that flow when the conductivity is time modulated in the presence of the auroral dc electric field were evaluated with a collisional theory of ohmic heating and cooling. Long after the start of heating, the electron temperature fluctuation becomes a steady-state waveform. The corresponding waveform of conductivity perpendicular to the magnetic field was computed and Fourier analyzed as a function of altitude. This establishes the source spectrum of electrojet-driven currents which radiate ELF waves. The results show, in daytime, three different height regions with characteristic spectra. Source heights of waves observed on ISIS and the ground were deduced by comparing spectra with theory. Spectral ratios predicted with a daytime model for a fundamental frequency of 525 Hz and for heights around 81 km agree with spacecraft observations. A review of topside sounding observations of the cusp will appear in The Polar Cusp, edited by J.A. Holtet and A. England (D. Reidel Publishing Company). A paper Uniformly spaced field-aligned ionization ducts by S.H. Gross and D.B. Muldrew, (JGR, October, 85) points out a possible effect of gravity waves on the formation of ducts. A numerial study shows the electron density and electric field distribution near the reflection height of a powerful HF wave as a function of time following wave turnon.

(a) ISIS Operations

The Department of Communications closed its ISIS spacecraft operations in March 1984. At a ceremony on 13 March at Shirley's Bay attended by G. Davies and D. Boulding, the ISIS Experimenters' Group pointed out the historic place of Alouette and ISIS spacecraft in both world space science and in the development of Canada's space industry. Up to 1 April 1985, CRC will process some ISIS data, after that date, processing will be extremely curtailed. For information, contact D. Boulding, H.G. James or D.B. Muldrew.

The DOC has transferred the operation of the ISIS-1 and ISIS-II spacecraft to the Radio Research Laboratories (RRL) of Japan. RRL is recording several sounder and VLF passes per week at both Kashima and Syowa (Antarctica). Indications are that French CNES stations in the southern hemisphere assist RRL in acquiring ISIS data. The RRL will entertain reasonable recording requests at their two stations and supply telemetry tape copy for specific passes to CRC.

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

Design and development of the Canadian part of WISP hardware, HFSS, is nearly on schedule; a successful preliminary design review was held in February 1984. Engineering

model 1 of four or five independently mounted units for the Shuttle payload bay will be assembled by December 1984; unit tests will begin soon. Development by NASA of the US WISP instrumentation continues to have funding problems which cause it to lag behind the Canadian activities. Nevertheless, NASA is aiming at a 1989 first mission of the 'Space Plasma Lab', a dedicated mission at high orbital inclination with heights between 325 and 475 km. The two-pallet Spacelab payload would include an electron beam injector, a low-light level TV, a separate VLF transmitter using a large magnetic antenna and a subsatellite for particle and field detection.

4. Earth Physics Branch, Department of Energy, Mines and Resouces (J.K. Walker, J. Hruska, G. Jansen van Beek)

The undisturbed reference levels recently determined for the magnetic observatories for the separation of external and internal magnetic fields, were compared with those calculated from annual averages and the quiet day means. A rigorous statistical test used for comparison found the three reference levels statistically significantly different for most of the Canadian observatories. It was concluded that the new undisturbed reference levels could be used for most studies of external current systems, as they were physically more meaningful than the other levels which average in the disturbances. A new more objective method to determine the magnetic K indices is being investigated. It uses a data adaptive technique which reconstructs the regular daily variation from Fourier coefficients, which have been modified to be a composite of the regular component of the daily disturbance and of a quiet reference day. This regular variation is then subtracted before determining the K indices in the traditional manner. A multilinear correlative analysis of magnetic storms and atmospheric warmings found the latter depends on storm's duration and magnitude of the storm and also on the vortex strength. A study of the theory of vortices confirmed that they are a closely coupled system that can readily transfer energy and mass from one level (the upper mesosphere) to another (the stratosphere). Further, disruptions of the inflow region of the polar vortex in the upper mesosphere by magnetic storm-induced heating and winds could lead to a reduction in the outflow region in the polar troposphere and hence to changes in the high latitude winter weather.

Forecasts of geomagnetic activity issued regularly by the Earth Physics Branch include long term (27 days) on request, and short term (72 hours) on telephone answering service: (613) 992-2199. These are based on magnetic data from the Canadian Magnetic Network, EMR, and on the solar radio data from the Algonquin Radio Observatory, HIA, NRC and on other solar and interplanetary data from the SESC, NOAA, USA. The present one-zone, 27-day forecast will be replaced in 1985 by the 'Three-zone geomagnetic forecast'; this will reflect the special magnetic characteristics in the subauroral, auroral and polar cap zones. The study of improved methods in forecasting is in progress.

The Geomagnetic Observatory (Division of Seismology and Geomagnetism) continues to manage the Canadian Magnetic Observatory Network (C.M.O.N.) consisting of the following stations: Alert, Resolute, Mould Bay, Cambridge Bay, Baker Lake and Yellowknife all in N.W.T.; Churchill, Manitoba; St. John's, Newfoundland; Ottawa, Ontario; and Victoria, B.C. Glenlea, Manitoba is operated in cooperation with the University of Manitoba and has limited absolute control. With the proposed installation of the Earth Physics Branch's version of the AMOS MKIII in Alert (February 1985) and Mould Bay (July 1985), the C.M.O.N. will have the AMOS MKIII as the primary magnetic recorder at all of the geomagnetic observatories. A full description of the present network is given in the Annual Report for Magnetic Observatories - 1983. For copies of magnetograms and/or edited digital data, contact G. Jansen van Beek; (613) 995-5474. In response to demonstrated needs with regard to accessing geomagnetic information in near real time, the Unit is maintaining files of one day old summary information. Investigation into downloading magnetic variation data from the observatories at a frequency greater than the present once or twice a month is proceeding.

5. Herzberg Institute of Astrophysics, National Research Council

(a) Planetary Sciences

(i) Radio Aurora (A.G. McNamara)

Pulsed radar backscatter data from the August 1983 campaign have been processed and analysis is continuing. Comparison of simultaneous echoes on the pulse radar and the c.w. links of G. Sofko and J. Koehler were also studied. A preliminary report was presented at the MPI/Lindau meeting in September 1984. Several periods of unusual Doppler spectra behaviour have been selected for more intensive study. Minor modifications and improvements to the pulse radar data system are being made in preparation for further observations of the spectral and magnetic aspect characteristics of radio aurora.

(ii) Pulsation Theory (D.R. McDiarmid)

Glabmeier (Geophys. Res. Lett., 10, 678, 1983; J. Geophys., 54, 125, 1984) has recently suggested that the pulsation double-resonance described by Nielsen and Allan (J. Geophys. Res., 88, 5760, 1983) may have been the consequence of non-uniform ionospheric conductivity rather than radial structure of the cold plasma mass density as suggested by Nielsen and Allan. This has been examined and it was concluded that although spatial conductivity variation may have contributed to the double-resonance structure, it was unlikely to have been the sole cause.

(iii) STARE/SABRE (D.R. McDiarmid)

The response of the dusk magnetosphere to the SSC of 4 February 1983 has been examined using STARE/SABRE data. The SSC polarization pattern observed by the radars was more complicated than those previously published using magnetic data. There are several possible reasons for this difference. The radar systems have greater resolution than magnetometers. In this event, a significant portion of the observed ionosphere was under the plasmasphere. Also, the SSC was large. It was clear that the preliminary reverse impulse of the SSC was the result of a preliminary anti-convection flow. Within two minutes, however, the flow was entirely in the convection direction throughout the fields of the two systems. About 15 minutes after the SSC, a complicated pulsation was observed by the two radars. In the STARE field, the polarization was elliptical. More equatorward, the pulsation appeared to be monochromatic but not with the usual phase characteristics.

(iv) BARS (A.G. McNamara, D.R. McDiarmid, B.A. McIntosh)

Construction of the bistatic auroral radar system (BARS) by Canadian Astronautics Limited has progressed well but the original target date for completion has passed. Site work at Nipawin and Red Lake will not be completed until February 1985, and radar and signal processing electronics should be ready by then. Field installation and testing is due in March, and full operation of the system possibly by April. Computer programs are being developed for the VAX 11/780 of DAN which will handle the continuous stream of observations from the two auroral radars. These will monitor the radar systems and align and format the data streams for merging. Merging operations programs have been developed by G. Sofko and J. Koehler (University of Saskatchewan).

(v) Space Science Program

Members of the Planetary Sciences Section have been active in the planning and development of projects CANOPUS, VIKING, WAMDII, WINDII, WISP/HF, HILAT, and DAN.

(vi) Plasma Probes (A.G. McNamara, J.M.-Chaker)

Studies of Langmuir probe behaviour in the ionospheric plasma have continued, resulting in the publication of a paper on the roles of hyperthermal electrons, geomagnetic fields, collisions, and vehicle velocity on the determination of electron temperature and density. Work was also done on the ionosphere disturbances induced by an injected electron beam on a rocket. Papers are being written on the ionization, electron density, and plasma waves generated by the beam. Good plasma data were obtained on both ARIES rocket flights.

Preliminary results were reported at the first ARIES workshop and analyses are proceeding on several aspects of the data. Probe experiments have been prepared for the flights of MARIE, Waterhole IV, and COBRA scheduled for early 1985.

(vii) Photometry of the Aurora and Airglow (F. Creutzberg, R. Gattinger, F. Harris, A. Vallance Jones)

A number of good data sets were obtained during the ARIES campaign. The three new 1° meridian scanning photometers were operated at Churchill, Lee Lake, and Bird throughout the period; final calibrations have been performed, and the analysis is progressing. Topics under consideration include multiwavelength height profiles of aurora aimed at further clarification of electron excitation of atmospheric species, morphological studies structured to investigate auroral energization processes, and correlated rocket and ground-based observations to measure directly the relationships between particles and optical emissions. Photometers instrumented to measure the O_2 Atm. (0,0) and (0,1) bands and the $N_2$1PG (4,2) band flown on both ARIES rockets resulted in good data. A failure occurred in the B instrument before apogee. Data analysis is underway to separate the auroral and airglow profiles, to determine the brightness ratio for the O_2 Atm. (0,0) and (0,1) bands and to obtain a measure of the albedo at 864.5 nm. Echelle spectra were obtained in the 7000-8500 Å region (resolution of ~4 Å). These will be used to further extend the auroral atlas, but more directly they will be helpful in analysing the photometer data collected in this region. Instrument modifications are now in progress to permit echelle observations in March 1985 in this spectral region at a resolution of ~ 1 Å. Considerable software has been developed to aid in the analysis of the echelle data on an interactive image processing facility. The PHOTONS (Photometric Thermospheric Oxygen Nightglow Study) experiment is scheduled for Shuttle STS1-51D, March 1985. The objectives are to understand the roles played by 0 and O_2 in airglow excitation and to provide additional information on the Shuttle ram-glow. The observables include the O_2 Herzberg I bonds, the O_2 Atmospheric bands, $O(^1S)$ and $O(^1D)$. Good data were obtained from the coordinated radar and photometer observations in Sondre Stromfjord. A study using the observational data and the theoretical auroral model is leading to some interesting conclusions on electron acceleration processes. Good airglow and auroral data were obtained in November 1983, and January and February 1984. The 0.5 m Ebert spectrometer is being operated at the University of Michigan Airglow Observatory at Sondrestrom under the control of the observatory computer. The observing program includes studies of auroral and visible nightglow features with automatic switching between scan programs on the basis of local time and monitor intensity. Observations to monitor the H_2O^+ twilight emission are planned for this winter. A number of tasks were performed in the preparation of the Shuttle OGLOW experiment. Now that the data are in hand, assistance is being provided in the images analysis. The major objective was to measure the Shuttle Glow at the WAMDII wavelengths; the results are very encouraging. Selected photometric IMS substorm data sets were studied to search for indicators of electron energy. Use of zenith ratio measurements involving 4278 Å, 5577 Å, and 6300 Å, reveal striking relationships between energy and auroral brightness in some cases. It appears that use of such observations can determine thermospheric composition under certain conditions.

(viii) Meteor Radar (B.A. McIntosh)

The meteor radars (Springhill Meteor Observatory) operated a few days during each major meteor shower; such data gathered over more than 20 years determine the cross-section of a meteor stream and particle distribution around it. Differences in these distributions as a function of the meteoroids enable assessment of past and continuing evolution of meteor showers. In collaboration with M. Simek, Ondrejov Observatory, Czechoslovakia, analysis was continued on the long series of radar observations of the Perseid meteor shower from Ottawa and from Ondrejov. This shower is unusual in that, although it is one of the most spectacular visual meteor showers, it stands out above the background of radar meteor echoes only in long-duration echoes. This is partly because of the size distribution of particles in the stream and partly because of the high velocity with which they enter the atmosphere. Plans are made for international collaboration in observation of the Halley Comet meteor streams; the Eta-Aquarids in May, and the Orionids specialists of the International Halley Watch.

(ix) Topological Nomenclature for Planets and Satellites (P.M. Millman)

The 10th Meeting of the International Astronomical Union (IAU) Working Group for Planetary System Nomenclature (WGPSN), was held on 3-7 April 1984 in Mzkheta, the capital of Georgia, USSR. It was hosted by the Academy of Sciences of the Georgian SSR and highlighted by views of the high-resolution (about 1.25 km) records of Venera 15 and 16 spacecraft. The WGPSN recommended the adoption of additional Latin terms for use with new types of topographic features, not previously observed on planets or satellites. It was decided to delay the publication of the Gazetteer of Planets and Satellites, authorized by the XVI General Assembly and IAU in Grenoble, 1976 for 1-2 years to include accurate coordinate positions, particularly desirable for recently photographed features on the surfaces of the Jovian and Saturnian satellites. The production of the Gazetteer is a joint effort of all members of WGPSN. Millman summarized a plan for the arrangement of the material for inclusion. A Preliminary Working Check-list of Topographic Names on Planetary Bodies was circulated from Ottawa in February 1982, and a revised check-list will be issued early in 1985. Also, at Flagstaff, Arizona, H. Masursky produced a computer-compiled listing (370 pages) entitled 'Planetary Nomenclature' containing details of all features whose names have been officially approved by the IAU. The 2nd Preliminary Edition of this list was circulated in June 1984. These two informal publications will assist the various cooperating scientists in producing Gazetteer of Planets and Satellites, for public use.

(x) Meteorite Research (I. Halliday, A.T. Blackwell)

Eight fireball events observed by the MORP camera network late in 1983 and in 1984 are believed to have produced meteorites on the ground (size from 100 g to >10 kg). For five events field investigations were conducted and local residents were encouraged to continue a search for possible meteorites. Probably the most spectacular fireball recorded in recent years in Canada was on 22 February 1984, with a 500 km path length and lasting 30 s. Good photographic coverage was secured for a large portion of the trajectory but the final stages were beyond network range near the city of Grande Prairie, Alberta. Some fragments appear to have landed and HIA staff participated in recovery attempts along with several scientists from Alberta. A total of 244 MORP fireball orbits has now been reduced and reductions continue, including estimates of luminosity of each event. A major study of the frequency of meteorite falls on the earth, based on nine years of MORP data has been published.

(xi) Comet Research (A.F. Cook, I. Halliday, B.A. McIntosh)

Observations of several faint comets were obtained with the 3.6 metre Canada-France-Hawaii telescope in December 1984. The project is intended to study the physics of cometary nuclei including the production of streams of meteoric particles. Good images were obtained with the CCD detector in white light and with a series of special comet filters for Halley's Comet, 1983TB (the unusual parent object of the Geminid meteor stream which resembles an asteroid), three other short-period comets and one long-period comet. The project is a cooperative one with astronomers from JPL, Pasadena, DAO, and the University of Victoria.

(xii) Image Processing (R.L. Gattinger, B.A. McIntosh)

A small image processing system is being established in the Planetary Sciences Section. It consists of a Data General MV 4000 with appropriate software (GKS) and GDC 1000 high-resolution graphics hardware. Further software is being developed.

(b) Space Physics

(i) Plasmas and Fields in the Ionosphere

Data from charged particle sensors of Space Physics/HIA on ARIES (Auroral Modelling Campaign) rockets launched in February and March 1984 were analysed; comparisons being made with other in-situ and ground-based optical data gathered at the same time. Comparisons will be made between the measured altitude profiles of the precipitating energetic electrons and optical emissions, to test various aeronomic models. Two particular sensor packages built and tested are ready for rockets Waterhole IV (last in

series) and MARIE (ionospheric ion acceleration investigation) to be launched early in 1985.

(ii) Magnetospheric Studies

Magnetospheric current systems studies with MAGSAT vector magnetometer data continue. Developed software will facilitate the quantitative study of perturbations transverse to current systems. MAGSAT data reveal that transverse magnetic field vectors undergo rapid direction reversal when traversing the poleward boundary of auroral oval (shear reversal) or more gradual direction change (rotation). Statistical analysis of this feature is underway to determine the relationship between shear reversals/rotations and the interplanetary magnetic field (IMF). Quantitative modelling of the 3-D auroral current systems continues. Developed software will automatically model MAGSAT perturbations and produce current models whose associated magnetic fields fit the observed E-W and field-aligned components to a very high degree of accuracy. These procedures also separate the magnetic field due to external currents from the crustal field. The models so derived will permit analysis of the ratio E-W current to N-S current as a function of various indices and IMF parameters. Considerable developmental work was carried out for instrumentation and software for the MARIA component of CANOPUS, and the design of the DAN (Data Analysis Network) system. B. Lanchester and D. Wallis used MAGSAT data and Spitzbergen TV observations to precisely locate auroral arcs relative to field-aligned currents in the noon and dusk sectors. J.R. Burrows, M.D. Wilson, D. Wallis and T.J. Hughes were honored with a NASA Group Achievement Award for their outstanding contribution to human knowledge (analysis of MAGSAT data). A Space Physics Section mass spectrometer to measure the thermal and superthermal ion composition has been accepted as part of the Japanese EXOS-D spacecraft instrument complement (launch 1989).

(iii) Cosmic Ray Studies

Operation of the neutron monitors at Alert, Inuvik, Goose Bay and Deep River, and transmittal of data, continues routinely (supervisor M. Bercovitch). The correlation of cosmic ray sidereal diurnal variation (SDV) in the median primary rigidity range 100-1000 GV with the reversal of the solar magnetic polarity was investigated using the Ottawa Horizontal Muon Telescope Array data. The 1979-80 magnetic reversal produced no detectable change in the SDV: this disagrees with results of particle trajectory calculations in a model heliosphere which predicts significant and easily observable effects. After a year's storage on completion of initial qualification tests (late 1983) the International Solar Polar Mission spacecraft is undergoing an extensive recertification program prior to transportation to Kennedy Space Flight Center for pre-launch operations. A novel cosmic ray experiment has been proposed for installation at the Creighton mine of the International Nickel Company near Sudbury, Ontario, viz., a large area (150 m^2) muon detector situated underground (depth, 700m), to operate in coincidence with a large extensive shower array deployed on the surface; the primary objective is to determine the average atomic weight of cosmic ray primaries in the energy range 10^{14}-10^{16} eV.

6. University of Lethbridge, Department of Physics

Development of a high resolution mid infrared Fourier transform spectrometer for infrared astronomical studies is nearly completed; it involves a beam-folding technique resulting in a simple, compact and versatile instrument usable at the Cassegrain foci of different telescopes (CFHT, IRTF, etc.) and at the new infrared telescope facility under development at the University of Calgary's Rothney Astrophysical Observatory.

Analysis of stratosphere far infrared emission spectra obtained with the European Space Agency - University College London, balloon borne telescope spectrometer system continues to yield valuable results. The collaboration includes ESA-UCL Rutherford Laboratory, UK, the University of Calgary (Clark) and Lethbridge (Naylor). The first measurements of the downward 63 micron emission from the fine structure ($^3P1$ - $^3P2$) transition of OI from balloon altitudes shows that emission line intensity is independent of viewing angle and significantly greater than theoretical prediction (Nature, in press). Current aeronomy activities include detailed analysis of high resolution far infrared stratosphere emission spectrum in a search for minor constituents and their concentrations. The European Space Agency has approved the ISO mission (launch 1992), an observatory-type infrared astronomical satellite. D.A. Naylor

(previously with Infrared Astronomy Group at ESA now with Infrared Space Observatory) was a member of the ISO instrument study team. The first instrument selection for ISO will be made shortly; Naylor hopes to join the team for this mission.

7. University of Saskatchewan, Institute of Space and Atmospheric Studies

(a) VHF Doppler Radar Group

This group used 1984 for analysis of data from four successive summer campaigns (1980-1983) in conjunction with A. McNamara and D. McDiarmid, HIA/NRC. The following provides a summary.

(i) The 1981 Aspect Sensitivity Campaign

The campaign (August 1981) obtained scatter at four different magnetic angles from a common volume of aurora over Southend, Saskatchewan with transmitters at Swan River and Minot, and receivers at Saskatoon and Havre. The Minot-Southend-Havre path acted as a reference path of best mean magnetic aspect angle. On that path, the angle between the magnetic field and the bisector (i.e. the bisector of the angle subtended at Southend between the transmitter and the receiver beams) was only 1.5-1.75° from perpendicularity. On the worst path, the Swan River-Southend-Saskatoon path, the angle varied from perpendicularity by about 4.5 - 6.5°. The Minot-Southend-Saskatoon and Swan
River-Southend-Minot paths provided intermediate values of aspect angle. A statistical study of the data was undertaken, in which two minutes of data per hour was Fourier-analyzed for each of the four paths, over an 11-day period. Results revealed no consistent influence of the magnetic aspect angle either on spectral power, mean Doppler velocity, or spectral width.

(ii) Meteor Scatter and Neutral Winds

The Perseid meteor shower occurs about August 12; at 50 MHz there is a strongly scattered signal from many of the meteor trails. Prikryl studied the 1981 data for Doppler shifts associated with the trails. Analysis of ~400 days of data, involving 1800 meteor trails showed that the meridional wind over Southend can reach southward values of 90 $\pm$ 50 m/s during geomagnetically disturbed periods. Comparison with neutral wind measurements by A. Manson at Saskatchewan indicates that the Southend measurements appear to have a southward shift of 25-50 m/s compared to Saskatchewan during some geomagnetically disturbed periods. This additional southward neutral wind at auroral latitudes might possibly be the result of a high pressure ridge near the auroral H-zone-polar cap transition boundary.

(iii) 1982 Summer Polar Cap Campaign

In the Northwest Territories a July 1982 campaign was run with transmitters at Inuvik and Cambridge Bay and receiver at Fort Franklin. All antenna beams pointed at a common ionospheric region over Sachs Harbour. A magnetic storm (the largest in the past decade) occurred during this time. M. McKibben is analyzing data on day 197, when scatter was received right through the magnetic local noon period. The results clearly show an antisunward electron flow from the throat region, which was to the south of Sachs Harbour during this period. The frequency of the scatter at these high latitudes, despite the presence of very bad magnetic aspect sensitivity, suggests plasma waves with a ratio of K_1/K_{11} of 5.1 or less; these are components perpendicular and parallel to the magnetic field. Some extremely deep fading echoes with a period of ~2 Hz and a quite large peak amplitude, unlike any seen in the auroral zone, were found; these alternated in time between Inuvik and Cambridge Bay paths, as if an oscillating specular-like reflecting region occurred over Sachs Harbour, with its normal being first along the Inuvik-Sachs Harbour-Fort Franklin bisector, then later along the Cambridge Bay-Sachs Harbour-Fort Franklin bisector.

(iv) 1983 Summer Auroral Measurement Campaign (D. McEwan)

In 1983, 50 MHz transmitters were installed at Hay River and Gainsborough, and

a receiver at Camrose, all beams again directed toward Southend. With this geometry auroral scatter along the magnetic E-W and N-S directions could be examined simultaneously. In addition, A. McNamara operated his pulsed radar at Saskatoon, along the bisector of the Gainsborough-Southend-Camrose path of the CW radar. Spectral data analysis is concentrated on five main areas. (i) The Eastward Electrojet - during the eastjet, echoes are received only along the magnetic N-S direction (the Gainsborough circuit) and not at all along the E-W (Hay River circuit) direction. (ii) The Harang Discontinuity - on several occasions, the Harang discontinuity passed through Southend, and a variety of spectral types incurred, including ion acoustic spectra, narrow sub-ion-acoustic spectra (Type III), and sharp zero-shifted spectra. Strong electron flow toward the Harang discontinuity is a feature of the Doppler shifts. (iii) Substorm Onsets - there are rather rapid and spectacular spectral changes at time of breakup, with extremely broad spectra observed along the magnetic N-S direction, and much narrower ones in the magnetic E-W direction. (iv) Type III Echoes - a large number of relatively narrow spectra with peaks in the 30-80 Hz region have been observed; the mechanism producing them is being investigated. D. McEwan's good quality Southend scanning photometer and all-sky camera data, are aiding this project. (v) Comparison of CW and Pulsed Radar Spectra) - the NRC 48 MHz pulsed radar measured the spatial distribution of echoes over the region around Southend, and so provided the spatial resolution lacking in the CW radar system. Preliminary analysis shows good general agreement between appearance times of both the pulsed radar echoes over Southend and the CW echoes, and between the spectra obtained by both radars.

D. Haldoupis (Univ. of Crete) is to visit ISAS January to August 1985. He will examine Type III spectra, and work with B. Sofko on interpreting subauroral striated scatter echoes from the STARE radar. D. Haldoupis will also collaborate with A. McNamara and D.R. McDiarmid on a comparison of the 1983 pulsed radar and CW radar spectra.

(v) STARE Related Research (G.J. Sofko and J.A. Koehler)

The STARE flow patterns and the GEOS-2 particle and magnetometer data of the morning of 28 August 1978 were compared. The geo-stationary GEOS-2 was in the magnetosheath for 3.75 hours, so the magnetopause was just earthward of 6.6 R_E during that period (actually the magnetopause crossed the satellite several times). The particle pitch angle distributions indicate that field-line merging occurred just south of the satellite, on several successive magnetopause crossings. This suggests that continuous, rather than patchy merging dominates in this sector. The ionospheric electron flows seen by STARE show sunward-moving ULF waves just prior to and during the first magnetopause crossings. This suggests that the inner edge of the boundary layer is subjected to a Kelvin-Helmholtz instability driven more by the magnetospheric sunward-directed flows than by boundary-layer antisunward-directed flows. Analysis of this event is done with magnetometer data from the IMS Scandinavian Magnetometer array. The data show strong upward field-aligned-currents (FAC) in the polar cap region just northward of the auroral zone - polar cap interface. Work with D. Haldoupis deals with an unusual weak class of STARE echoes called subauroral striated scatter; this occurs in the region south of the auroral electrojet. The magnetospheric implication appears to be that auroral electrons have become detached from the inner edge of the plasma sheet, possibly due to the electric fields associated with Pc5 waves. These detached groups in the trough then appear to almost co-rotate with the earth, spreading out longitudinally due to differential drift. Eventually, some of these trough particles precipitate, likely due to wave-particle interactions, leading to the observed scatter.

(vi) Middle Atmosphere Dynamics (60-110 km) (A.H. Manson)

Activities deal with the use of Medium Frequency Radar (2.2 MHz) at Saskatoon; members of the Atmospheric Dynamics Group are A.H. Manson, C.E. Meek, and T.M. Reid. Continuous real-time observations of the wind field in the 60-110 km level provide a set of mean wind and tidal parameters over 1978-84. This has enabled global comparisons with radar observatories in New Zealand (1978-79), France (1979-80), and Germany (1982-84). We are very active in projects of MAP (1982-85), and plan continued work within MAC (1986-88). Mean winds measured during winter of 1983-84 are now part of the data base for WINE (of MAP). Several collaborative papers have been written with German colleagues using radar and Nimbus V, VI radiance data and derived geostrophic winds (DYNAMICS). The evident

ageostrophic nature of the wind field at 80 km confirms the strong frictional drag provided by gravity wave momentum deposition. Mean winds from the global radar network have been combined to form seasonal-latitudinal cross-sections (60/80 - 110 km) for the new COSPAR Reference Atmosphere - this set far exceeds anything available in 1972.

Several tidal campaigns (April, June, September 1984) were successfully run as part of ATMAP, so that four solstitial and two equinoctial intervals now exist since 1981. These were considered at the Kyoto MAP Symposium (November/December 1984) and global results were compared with theory. It was concluded that both tidal data and models had considerable uncertainty, but that models do not have a sufficient contribution from anti-symmetric modes. More long term observations were called for.

Gravity wave data from our expanded GRAVNET radar (multiple bi-static) include the first Doppler-shifted measurements of wavelengths, phase velocities and periods. These are essential for comparisons with theory. Also, seasonal height-time spectral cross-sections of waves (τ; 10-60 min; 1-8h) have been compared with mean winds and tides, and provide the first evidence for interaction between these on a seasonal basis. Global comparisons are planned.

(b) Aeronomy (E.J. Llewellyn, I.C. McDade)

We participated in the ARIES campaign (1983) and in a truthing experiment for the Solar Mesospheric Explorer spacecraft (SMERF), a joint experiment with W. Evans, AES. For the ARIES campaign, we supplied green line and N_2^+ (e914A) photometers together with an oxygen resonance lamp experiment designed to measure (O) in the auroral thermosphere. For ARIES-B we added a TOI photometer to measure the 1.27 oxygen emission while for ARIES-A R.G.H. Greer and D.P. Murtagh from Queen's University, Belfast joined us. Preliminary data analysis reveals that for ARIES-A the measured green line profile is not inconsistent with an excitation mechanism involving transfer from an excited O_2 intermediate. There is some support for such a conclusion from the oxygen atmospheric band measurements made on the same flight. The ARIES-B data analysis is progressing slowly; large roll-rate has meant that overflows in the photon counts need care. Overflows also occurred on ARIES-A suggesting that the rocket-measured intensity was much larger than ground-based measurements indicate.

For the SMERF experiment, launched within an hour of an SME overpass at Churchill (10 May), we included two TOI photometers each designed to measure the oxygen emission at 1.27 μ and obtained profiles in good agreement from the two photometers. In each case the profiles have been converted to ozone concentrations; these differ by less than 10% in absolute values at all altitudes and show a highly structured ozone profile.

We have also developed extensive analysis routines for determination of (O) and have shown that there remains some difficulty with a reduced concentration in the aurora. We have been able to check many of these ideas against the MSIS-83 model run on a personal (Apple) computer. The code for this MSIS-83 model is available on request.

We are also involved with the OGLOW experiment flown on the STS-41G mission. Only preliminary results are available; these clearly indicate that much further work is necessary before the processes responsible for the Shuttle glow are clearly understood.

8. University of Victoria, Department of Physics

Plasma Waves

Horita (on sabbatical) at the Danish Space Research Institute analyzed data from satellites GEOS 1 and 2, ISEE 1 and 2, etc. Counter-streaming hydrogen and oxygen ions observed on the ISEE 1 satellite were investigated; over 60 ion events were analyzed.

Further results from a co-operative project, with T. Watanabe, UBC and R.M. Shier, B.C. Hydro were obtained; a draft paper on geomagnetically induced currents in the B.C. Hydro 500 kV power line was completed in Denmark with S. Lundby (Geophysical Institute, University of Copenhagen).

9. University of Western Ontario, Centre for Radio Science

(a) HILAT Program

The Churchill station operated all year with few interruptions and produced good data. The transportable station (at U.W.O.) was essentially completed for operation at Inuvik but installation delayed due to late deliveries and faults in the associated computer. Equipment huts, signal cables and power lines were installed on site; the equipment is expected to operate at Inuvik early in 1985. Canadian Hilat Archive is in business; computer system will soon allow flexibility in handling the data tapes. Summary tapes from Sondre Stromfjord, Tromso, the U.S. 'Rover' station, and both raw data and summary tapes from Churchill, are available. For information and assistance call D. Turnbull 519-679-2746.

(b) Ionospheric Physics (P.A. Forsyth, J.A. Fulford, G.F. Lyon and J.W. MacDougall)

An optical-radio correlation study is underway. A scanning photometer recording the intensity of two auroral emission lines is under construction (designed to follow an orbiting satellite). It operated twice briefly at Churchill in conjunction with the Hilat station giving simultaneous intensity, electron content, and scintillation observations along ray path to satellite. J.W. MacDougall operated the rocket total-electron-content receivers and 'Long-line' experiment at the Lac Lee Guild site in conjunction with the Aries campaign. The latter experiment provided particularly good quasi-continuous ionospheric convection measurements throughout the campaign. Data both 'raw' and analysed by a 'real-time' analysis system were recorded; the two will be compared to determine the effectiveness of real-time data analysis for the long-line measurements.

10. York University, Centre for Research in Experimental Space Science

(a) Optical Doppler Imaging

The Spacelab WAMDII (Wide Angle Michelson Doppler Imaging Interferometer) operated at the University of Saskatchewan Park Site in February 1984 (with SED Systems and the University of Saskatchewan coinvestigators); the performance was excellent and good 5577 Å auroral data were obtained. Small scale velocity wave structures first reported are now shown to be waves of change in auroral intensity. Data processing is continuing (K.V. Paulson and P. Kosteniuk at the University of Saskatchewan, with R.H. Wiens and C.O. Hines involved in the interpretation). Discussions are in progress with NASA for a pre-Spacelab flight of WAMDII, but would occur on a pointing system, late in 1988. Field measurements planned again for February/March 1985.

NRC, CNES (France) and NASA have agreed that a modified WAMDII instrument will replace the French WINTERS instrument on the Upper Atmosphere Research Satellite (launch, October 1989). The new instrument, called WINDII (WIND Imaging Interferometer), will be managed by CCSS and designed and built in Canada, assisted by France (Canadian coinvestigators are G. Shepherd (PI) and R. Link, York University; L. Cogger, University of Calgary; T. Llewellyn, University of Saskatchewan; R. Lowe, University of Western Ontario; W. Evans, Atmospheric Environment Service; and D. Gattinger, Herzberg Institute of Astrophysics). Data from WINDII, and all the UARS instruments are stored in an on-line data base at GSFC, and accessed from the PI and coinvestigator sites. Data are essentially composition, temperature and dynamics of the atmosphere (10 to 110 km) for the 18 month mission.

(b) ARIES and OASIS Campaigns

W. Ward and R. Wiens operated a WAMI for wind measurements, and PRESTO (Programmable Etalon Spectrometer for Twilight Observations) at Bird during the campaign. W. Ward is analysing data for his thesis. R. Wiens is concentrating on measurements of O and O^+ in the aurora and twilight. PRESTO operation is planned on York campus;
F. Hamade, will again study twilight emissions. R. Van flew successfully his OI 6300 Å, NI 5200 Å and OII 7320 Å photometers on Aries A. B. Solheim was successful in interpreting CCD photometer data flown on OASIS. This interference filter

instrument, with CCD detector, organizes light from the O_2 atmospheric band into 32 spectral bins, enabling measurement of rotational temperature as a function of altitude.

(c) Laboratory and Other News

J. Lee joined W. Gault and R. Koehler on the scanning wide-angle interferometer project. L.-C. Liang will assist with development of special computer interface and control systems.

R. Koehlerk visited Ottawa frequently for CANOPUS Science, Optical and DAN team meetings. His microcomputer-based data transfer and system tests (Toronto-Saskatoon and Toronto-Ottawa) ran successfully.

(d) Theoretical Modelling

R. Link continued to develop auroral and airglow excitation models. Analysis of satellite USAF STP 78-1 EUV spectral measurements in the dayglow, sunlit cleft and polar cap arc aurora is in progress (in collaboration with S. Chakrabarti, University of California, Berkeley; G.R. Gladstone, University of Colorado; and J.C. McConnell, York University). Models are also used in the analysis of (visible and UV) optical and electron spectrometer data from the CENTAUR, ARIES and E.S.A. Energy Budget rocket campaigns. L. Davidson is developing an N2 LBH band excitation model based on recent laboratory measurements of non-Franck-Condon vibrational populations resulting from electron impact; this will be applied to the analysis of Viking Auroral imager data.

IV VOLCANOLOGY

Compiled by: Raymond Goldie

1. Introduction

Thirty-five reports have been submitted from fifteen institutions: two federal government agencies, three provincial government agencies and ten universities. The reports mostly concern field studies which are supplemented by laboratory work. Of the thirty-four studies which concern rocks of a particular age, fifteen are of Cenozoic rocks, five are of Mesozoic rocks, five are of Paleozoic rocks and nine are of Precambrian rocks.

2. Geological Survey of Canada

(a) Volcanism in the Circum-Superior Belt of Eastern Hudson Bay (W. R. Baragar and others)

This is a continuing study. Our objectives are to investigate the petrochemistry, stratigraphy, physical volcanology, and tectonic setting of the komatiitic-tholeiitic volcanic filling of the Circum-Superior Belt. We are examining two sequences: tholeiitic (older) and komatiitic (younger). These sequences are distinct from one another, both chemically and physically. Both sequences show considerable ranges in composition. The komatiitic suite includes komatiitic basalts, pyroxenites and basalts, the latter markedly depleted in incompatible elements such as Ti. The mechanism of flow involved the formation of a pillowed base by tube advance, and then a massive top which resulted from doming of the base and overriding by the flow behind. We plan further study of the tectonic setting of the belt by mapping the forelands and hinterlands where both are exposed in the Cape Smith Belt.

(b) Mesozoic to Tertiary Calc-Alkaline to Alkali Olivine Basalt Suites, Iskut River - Telegraph Creek Map Areas; 120-250 km northwest of Stewart, B.C. (R. G. Anderson.)

This is a new study. I am mapping this area at a scale of 1:250 000, but little of my work so far has been devoted to volcanic stratigraphy. Future work will include mapping, isotopic dating and geochemistry of Late Triassic and Jurassic volcanic rocks.

(c) The Sheeted Dyke Zone of the Late Cretaceous Troodos Ophiolite, Cyprus (W. R. Baragar, M. B. Lambert, N. Baglow, and I. Gibson)

This continuing study is a phase of the Cyprus Project of the International Crustal Research Drilling Group (I.C.R.D.G.). Our objectives are to examine the petrochemistry of the sheeted dykes in relationship to the pillow lavas and the plutonic complex, and their

history of intrusion. The compositional variation of the sheeted dykes, like that of the lavas, ranges from basalt to dacite and generally follows a similar differentiation trend. However, there is no break corresponding to the division between compositions traditionally associated with upper (high Mg-high Si) and lower (andesite-dacite) pillow lavas. Furthermore, we have used chilling relationships to establish age relationships among the dykes. These relationships show no systematic correspondence to the stratigraphic relationships within the lavas. Our future plans are to supplement the present data base, which is derived mainly from mapped sections, with data from the drill hole CY-4 and possibly from an additional future hole.

3. Indian and Northern Affairs Canada, Geology Division, Northern Affairs Program, Yellowknife, N.W.T.

Precambrian (Archean) Geology of Hepburn Island area (NTS 76M/11), Slave Province, N.W.T. (V.A. Jackson and others)

This is a continuing study. Our objectives are to complete regional maps of the Hepburn Island area and to resolve problems delineated in previous mapping projects within the Anialik River greenstone belt. The Anialik River granite-gneiss complex is locally bordered by younger granitoid and porphyritic rocks which are transitional into the volcanic rocks of the greenstone belt. Elsewhere, relationships between the gneiss complex and the greenstone belt are uncertain. In an area previously reported to be underlain by schistose granitoids of the gneiss complex, we have found both volcanic rocks and possible arkosic sandstones as well as granitoid rocks. Within the greenstone belt, we examined the nature and distribution of granitoid clasts within a previously defined conglomeratic unit and studied the structural disposition of this unit. Our laboratory research plans include detailed petrography of samples from the Anialik River greenstone belt and, possibly, geochemical analysis of volcanic rocks from the entire Hepburn Island map sheet. Continued mapping in the eastern Hepburn Island map sheet will concentrate on the southern extension of the mineralized High Lake greenstone belt and provide a complete regional scale map of the granite-greenstone terranes in this area.

4. Ministry of Energy, Mines and Petroleum Resources, British Columbia

"Salmon River Project" - Late Triassic to Middle Jurassic Rocks in the Stewart Area, British Columbia (Lat. 55°55' N, Long. 130°00' W, NTS 104B/1) (D.J. Alldrick)

I finished the field work for this project in 1984. The objectives of the project are to document the structural and stratigraphic relationships of a sequence of volcanic rocks which hosts epithermal precious-metal mineralizations, and to use petrographic and geochemical studies in order to determine the evolution and depositional environment of the volcanic system. My field work has shown that the volcanic rocks comprise an Early Jurassic sequence of subaerial, andesitic to rhyolitic (or rhyodacitic) rocks, predominantly tuffs, with about 5% to 10% flows. Future plans include whole rock analyses for major, minor and trace elements; micropaleontology; macropaleontology; and geochronology.

5. Ontario Geological Survey

(a) Geological Mapping of Goldie and Horne Townships - Thunder Bay District (M.W. Carter)

This is a new project. This map-area is underlain by metavolcanic and metasedimentary rocks intruded by gabbroic and granitic plutons and lamprophyre and diabase dykes. The volcanic rocks comprise one complete mafic to felsic cycle and the ultramafic base of an incomplete second cycle.

(b) Hawaii Field Trip Guidebook (R. M. Easton)

This is a new project related to the anniversary of the Hawaiian Volcanoes Observatory in 1987.

(c) Stratigraphy of the Hemlo Deposit Area, Ontario (T. L. Muir)

This is a continuing study. My objectives are to produce a map of the area surrounding and including the Hemlo gold deposit. The main emphasis is on lithology (including the effects of alteration and metamorphism) and structure. I have begun mapping at a scale of 1:5000 and have identified lithological units appropriate to this map scale and to the fact that deformation is intense. Further research will include petrography, geochemistry and structural interpretation.

(d) Lakehead-Atikokan Compilation Sheet (P. C. Thurston)

This is a new mapping project. I intend to study the physical volcanology of Timiskaming-type volcanic rocks in this area.

(e) Archean Andesites (P. C. Thurston)

This is a new project. I plan to study the petrography and geochemistry of Archean andesites.

6. New Brunswick Geological Surveys Branch

Stratigraphy, Chemistry and Mineralization of the Mississippian Mount Pleasant Caldera, Southwestern New Brunswick (S. R. McCutcheon)

This is a continuing study. My objectives are to determine the geologic history of the Caldera and the nature of the fossil hydrothermal system that was responsible for the mineralization at Mount Pleasant. Geologic mapping of the Caldera is complete and the stratigraphic section established. Whole-rock and trace-element chemistry on the major rock units is underway in conjunction with a petrographic study. I plan oxygen isotope studies on altered and mineralized zones, microprobe studies on phenocryst phases, and a $^{40}Ar/^{39}Ar$ dating program to establish the longevity of the igneous activity.

7. University of British Columbia

(a) K-Ar Dating of Cenozoic Igneous Rocks of the Cordillera (R. L. Armstrong and J. E. Harakal)

This is a continuing study. In 1983-84, our work was concentrated on the Level Mountain, Igachuz Range and Mount Cayley areas. We plan further work on the Clearwater area, on South Fork Volcanic Rocks, and on the west end of the Anahim Belt near Bella Bella.

(b) Rare Earth Elements in Cenozoic Volcanic Rocks from Differing Tectonic Environments, B.C. (L. Erdman)

This is a continuing study. My objectives are to determine the validity of discrimination diagrams for volcanic rocks in B.C., based on major, trace and rare earth element contents. I have finished analytical work and writing computer programs for plotting data, and have started writing my thesis. I have also collected data for Sicker, Metchosin and Karmutsen volcanic rocks on Vancouver Island as well as metamorphosed volcanic rocks and intrusions from the West Coast Complex of Vancouver Island. I would like to see if discriminant diagram analyses can be used for determining the environment in which these older rocks were erupted.

(c) "Plateau Basalts", Southern Interior of B.C. (W.H. Mathews)

This is a continuing study. My objectives are to identify domains distinguishable by K-Ar dating of this complex succession of Tertiary lavas and sediments. So far, I have found ages from 26 Ma to 0.72 Ma. Some units of different ages are indistinguishable by field characteristics or chemistry.

8. University of Alberta

(a) Isotopic Geology and Major and Trace Element Geochemistry of Mesozoic Volcanic Suites in Southeastern B.C. (D. Ghosh and R. St. J. Lambert)

This is a continuing study. Our objectives are to relate volcanic types to their tectonic setting. We have analyzed samples of Rossland volcanic rocks, the Kaslo volcanic rocks and the Irene volcanic rocks for Sr, Nd and Pb isotopes. The results confirm the conclusion of Beddoe-Stephens and Lamberts that the Rossland volcanic rocks do not contain a continental component. The Kaslo and Irene rocks also appear to be dominantly mantle-derived. Our future plans are to acquire and analyze more material from Kaslo and Irene.

(b) Tectonic, Geochemical, Petrogenetic and Isotopic Studies of Miocene and Pliocene Columbia River Basalts, Oregon and Washington (R. St. J. Lambert and V.E. Chamberlain)

This is a new study. Our objectives are to study details of isotope geology and petrogenesis, and to relate them to tectonics. Seventy-five samples have been analyzed for major and trace elements, 40 for Pb and some other isotopes, and 16 for REE and related elements (by INAA). First results were reported at the Pacific Northwest A.G.U. meeting in September 1984. A further 50 or so samples are being analyzed this winter and the project is to be extended to related basaltic sequences in central Oregon.

(c) Sr and Nd Isotope Studies of Southern Intermontane Belt Volcanics, B.C. (A. Smith and R. St. J. Lambert)

This is a continuing study. Our objectives are to better understand both the petrogenesis of basalts and the nature of the upper mantle beneath the Intermontane Belt. We have analyzed Sr and Nd isotopes in about 200 samples, including some xenoliths, from Quaternary, Tertiary and a few older sequences near Clearwater and Kamloops. Most samples have been analyzed by XRF for major and trace elements and a few by INAA for REE etc. First results were reported at the GAC/MAC meeting in London, Ontario in 1984. We plan to extend the program to include Pb isotopes.

9. University of Windsor

(a) The Geochemistry of the Metavolcanic Rocks of the Hastings Lowlands of the Greville Province (T. E. Smith)

This is a continuing study. My objectives are to establish the rock associations present in the area and to use this information to place constraints on its tectonic evolution.

(b) The Geochemistry of the Ordovician Rocks of the Llandrindod Wells - Builth Wells Inlier of the Welsh Borderland, U.K (T.E. Smith).

This is a new study. My objectives are to identify the nature of the magma association and to use it to place constraints on the tectonic evolution of Wales during Ordovician time.

(c) The Geochemistry of the Ordovician Rocks of the Shelve Inlier of the Welsh Borderland, U.K. (T. E. Smith).

This is a new study. My objectives are to identify the nature of the magma association and to use it to place constraints on the tectonic evolution of Wales during Ordovician time.

(d) The Petrogenesis of the Volcanic Rocks of Cerro Azul, Vulcan Wulf, and Sierra Negra Volcanoes, Galapagos Islands, Ecuador (T. E. Smith).

This is a new study. My objectives are to identify the similarities and differences between these volcanoes and to determine the nature of their source materials. I will also examine t..eir relationships to the rocks of the East Pacific Rise.

10. University of Toronto

Quaternary Tephrochronology of Alaska and the Yukon. (J. Westgate)

This is a continuing study. My objectives are to use tephra layers in order to date and correlate Quaternary events in Alaska and Yukon. So far, I have defined the first widespread Pleistocene tephra layer in Alaska and Yukon. This unit, which I named the 'Old Crow tephra' is about 100 000 years old. The source was probably in the eastern Aleutian arc. My plans are to map and sample tephra sequences in the Wrangell Mts. and in the eastern Aleutian arc. These are the two main source areas for distal tephras across central Alaska and the Yukon. I wish to see if there are significant differences between the geochemical and isotopic signatures for these two regions.

11. University of Montreal

(a) Primary Structures and Sequences in Pyroclastic Deposits of Mt. Pelée, Martinique (J. Lajoie and A. Charland)

This is a continuing study of the deposits formed by the flows of 1902. Our objective is to compare these deposits with other sedimentary mass-flow deposits. We have mapped in detail four deposits resulting from turbulent suspension. Primary structures, sequences and textural variations are similar, if not identical to those in turbidite sequences. We plan to study lateral variations in these deposits. We hope that this will lead to facies descriptions which we could use in interpreting ancient deposits.

(b) Cenozoic Volcanism in the Southern Yukon and in North-Central B.C.: Isotope and Trace Element Studies (J.N. Ludden and D. Francis)

This is a continuing study. Our objectives are to study the petrogenesis of lavas and the evolution of the mantle in the Canadian Cordillera. We have completed two field seasons, and have initiated M.Sc. students in the project. Analyses are underway.

12. McGill University

Origin of the Proterozoic Onaping Formation, Sudbury, Ontario (J.S. Stevenson)

This is a continuing study. My objectives are to gather field and laboratory evidence related to the meteoritic or volcanogenic origin of the formation. I am presently assessing new chemical and petrologic data.

13. Laval University

Volcanism of Chaleurs Bay Area, Gaspé Peninsula, Quebec Appalachians (R. Laurent).

This is a continuing project. We have finished mapping and a petrological study. Detailed geochemistry is underway. We plan to extend this study to cover all of the Gaspé Peninsula and to include the volcanic rocks of Devonian age.

14. Dalhousie University

(a) Iceland Research Drilling Project (J. M. Hall)

This is a continuing study of rocks 7-12 Ma old, concentrating on hydrothermal alteration and variations in magnetic properties.

(b) Cyprus Crustal Study Project (J. M. Hall)

This is a continuing study, concentrating on hydrothermal alteration and variations in magnetic properties.

(c) Age, Petrology and Metamophism of Volcanic Rocks in Western Cape Breton Island, Nova Scotia (R. A. Jamieson)

This is a continuing study. My objectives are to map, date, analyze and interpret the volcanic and subsequent tectonic history of Late Precambrian to Early Carboniferous volcanic rocks in Cape Breton. There appear to be at least two ages of volcanism in western Cape Breton - one late Precambrian, the other Devono-Carboniferous. The status of postulated Ordovician-Silurian volcanism remains uncertain. The volcanic rocks have been traced through most of western Cape Breton. Studies in geochemistry, petrology, and metamorphism of older volanic rocks are still in progress. I plan further mapping, structural, and petrological and geochronological studies.

(d) Miocene Dyke Swarm in Reydarfjordur, Eastern Iceland (M. Zentilli and J. Helgason)

This study is terminating. Our objectives have been to understand the formation of a laterally emplaced swarm of dykes. Field characteristics and geochronology indicate that exhumed part of the Breidalur dyke swarm in Reydarfjordur, E. Iceland, is younger than the strata it intrudes and could not have been their feeder. These dykes appear to have been intruded laterally from the south. Our future plans are to carry out geochemical analyses.

(e) Volcanic Evolution of the Central Andes at 27°S: Miocene to Recent (M. Zentilli and J. Walker)

This is a new study. Our objectives are to understand the complex evolution of volcanism at a boundary between a steep and a shallow-dipping subduction zone. We have completed one month of field work, mapping the Copiapo Volcanic Complex (Miocene) and related ignimbrites. Chemical analyses and K-Ar geochronology are in progress. Our research plans are to determine the chronology of evolution, emphasizing the following events; ignimbrite eruptions, caldera collapse, hydrothermal activity and quiescence. We will also consider the petrogenesis of the magma and the distribution of precious metals.

15. Saint Mary's University

(a) Geochemistry and Petrology of Non-Orogenic Volcanic Rocks (J. Dostal)

This is a continuing study, which focusses on the identification of the role of various processes such as fractional crystallization, crustal contamination and partial melting which were involved in the genesis and evolution of volcanic suites from the Maritimes, Marquesas Archipelago, Zaire and Liberia. The geochemical data are used to characterize both the nature of the parental magmas of individual volcanic successions, and the composition of their upper mantle source.

(b) Mesozoic Volcanism Offshore Southeastern Canada (G. Pe-Piper and L. F. Jansa. (Atlantic Geoscience Centre, Geological Survey of Canada))

This is a continuing study of volcanic rocks, possibly of Early Cretaceous age, from the eastern continental margin of North America. Our objectives are to establish and characterize the stratigraphy, geochemistry and petrology of these rocks, and to use this information to draw tectonic conclusions. So far, we have found that rocks from Georges Bank, Baltimore Canyon and the New England seamounts are alkali basalts derived from plume(?)-enriched mantle. Those of the Scotian Shelf and Grand Banks have trace elements suggestive of normal mantle derivation. Unusual labradorite bearing felsites in the Montagnais well, offshore southern Nova Scotia, have trace element and REE contents identical to Meguma basement. These felsites contain shock metamorphic features which are interpreted as probably derived from a meteoritic impact 55.8 $\pm$ 0.9 Ma ago. Olivine tholeiites occurring in the Northumberland Strait well (F-25) have been dated as mid-Triassic (239 $\pm$ 10 Ma), and may represent the earliest phase of opening of the North Atlantic. Our future plans are to use stable isotopes to interpret geochemical evolution.

(c) Hadrynian Volcanic Rocks of the Jeffers Brook Formation, Western Cobequid Highlands, N.S. (G. Pe-Piper)

This is a continuing study. My objectives are to establish the character of the

volcanism and of the subsequent metamorphism. The Jeffers Brook Formation of volcanic, pyroclastic and deep-water siliciclastic rocks has recumbent folds and a horizontal penetrative cleavage. The folds and the cleavage were formed prior to the intrusion of the Late Hadrynian Jeffers Diorite. Hornblende gabbro intrusions east of the Jeffers Diorite thermally metamorphosed part of the Jeffers Brook Formation prior to the main deformation. The oldest rocks in the area are marbles, shales and quartzites, possibly correlative with the Green Head Group. These rocks were also thermally metamorphosed prior to acquiring the horizontal penetrative cleavage. The margin of the Jeffers Diorite and parts of the Jeffers Brook Formation are cut by large complex dykes and sills of basalt and pink porphyritic rhyolite. These intrusions do not cut nearby Silurian rocks. My future plans include detailed geochemical investigation and further mapping where necessary.

16. Western State College of Colorado

Rare Earth Element Analyses of Miocene Chilcotin Group Basalts and Miocene Rainbow Range Alkaline-Peralkaline Volcanic Rocks, B.C. (M.L. Bevier)

This is a continuing study. My objectives are to use REE data to further quantify partial melting and fractional crystallization models for these two rock suites. I have begun to analyse and interpret 25 REE analyses done by INAA in G. Goles' laboratory at the University of Oregon in Eugene, Oregon.

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V ISOTOPE STUDIES AND GEOCHRONOLOGY

Compiled by: A. Hayatsu

1. University of Alberta Department of Physics (G.L. Cumming, J. Gray, D. Kristic, H. McCullough); Department of Geology (L. Tober, P. Wagner)

(a) Instrumentation

The most significant development was the award of an NSERC major installation grant to H. Baadsgaard and R. St. J. Lambert of the Geology Department and G.L. Cumming of the Physics Department. We have ordered an MM354 mass spectrometer with automatic control of all functions including multi-collector. We expect delivery by the end of the year and acceptance tests by March 1985.

(b) Radiogenic Isotope Studies

(i) Buchans, Newfoundland. Galenas and other sulfides from the Buchans mines and several nearby prospects within the Central Volcanic Belt of Newfoundland, define a pair of linear arrays which intersect the standard growth curve of Stacey and Kramers, at about 3200 Ma at the lower end. The upper intersections are both far too young to be consistent with the age of the ore deposits and imply a complex history for the ores. The simplest model which could account for the data would be a three-stage evolutionary model with a short period addition of Pb from a source with relatively high U/Pb ratio.

(ii) Thelon Basin. A suite of fluorapatite concentrates from the Thelon Formation and veins below the Thelon unconformity have been analysed for U and Pb. The data indicate three ages of apatite formation, from 1720 to 1650 Ma, probably the age of sedimentation and two later resetting events. Galena in veins below the unconformity have isotopic compositions of much greater apparent age, but consistent with the inferred common Pb in the phosphates.

(iii) Pueblo Viejo gold deposit, Dominican Republic. A paper has been submitted comparing ore Pb to rock Pb isotopic composition in the early Cretaceous Los Ranchos Formation, which is the host rock for this large gold deposit. Ore and rock Pb form a short linear array on a Pb/Pb diagram, of slope appropriate to the age of the rocks. Comparison with previously reported results from other parts of the Greater Antilles where the data suggest a very steep array of data points, indicated that the early Caribbean magmas were derived from sources with significant crustal and mantle components, and that the contribution of continental material to the magmas increased toward the western part of the Greater Antilles island arc.

(iv) Other work in progress. Cooperative studies with other workers in many parts of the world are in progress. These include examination of Pb isotopic composition of ore minerals in gold deposits in Nicaragua, in base metal deposits in Peru, rock Pb studies of the Molson dyke swarm of northern Manitoba, ore and rock Pb in the western craton of northern Saskatchewan and the Northwest Territories, and a reexamination of the Pb in gold and base metal deposits of Zimbabwe. The major emphasis of the work is to attempt to gain

a clearer understanding of the systematics of Pb isotope variation in different geologic environments.

(c) Stable Isotope Studies

Tree ring isotope ratio work is continuing albeit at a reduced pace. Results of an extended study of the relationship between D/H and $^{18}O/^{16}O$ and climate variables have now been published in two papers. A third paper describing the mathematical modelling of this system has been submitted for publication. It is now proposed that the production of a 500 year record of Canadian climate be undertaken which will involve the sampling of trees from approximately twenty sites. D/H and $^{18}O/^{16}O$ sampling of five year groups of rings from these samples will be obtained so that a 500 year record of variation in climate will be obtained at 20 selected sites across Canada. This should enable the production of temporal and spatial patterns of climate behaviour which will be invaluable in the development of circulation patterns across Canada and may ultimately lead to prediction of future climate trends.

A collaborative project with A.B. Cormie of H.P. Schwarz's group at McMaster is now underway to study the potential use of D/H ratios of bone collagen for paleoclimate and paleodietary research. Results so far show clear differences in D/H content of bones from different regions of North America which appear to correlate with isotopic precipitation patterns for these areas.

Isotope studies of fluid inclusions are continuing and a number of systems are being studied.

Subglacial precipitates from carbonate and granodiorite terrains are being investigated. Since all glaciers in the Canadian Rockies are presently in retreat, a wealth of calcite deposits formed at the previous ice-bedrock interface have been exposed. Since there is good temperature control on the formation ($\approx 0°C$), stable isotope studies of calcite oxygen and carbon yield information about the ice from which they were precipitated. Thus a record of past precipitation is indirectly gained from successive layers of calcite.

A problem occurs however in modelling the water-ice-calcite oxygen fractionation and hence deriving paleoclimatic significance to the calcites whose isotopic composition is close to that of the carbonate bedrock from which they are derived. We have collected calcite samples from a granodiorite terrain (Bugaboo Mountains) which have a very distinctive isotopic composition (close to atmospheric CO_2) and which are rich in fluid inclusions. It is hoped that by using stable isotope measurements of the mineral fluid, rigorous control on the ice-water-calcite fractionation model can be obtained.

2. University of British Columbia, Department of Geological Sciences

(a) Insular Belt

C. Isachsen finished a thesis (M.Sc.) on the Westcoast Crystalline Complex near Tofino. His U-Pb work was continued as a contribution to the LITHOPROBE project. New dating objectives included several Early to Mid Jurassic Island Intrusions and two Early Cretaceous plutons of the Coast Plutonic Complex, which extends just to the northeast edge of Vancouver Island. Additional work on Westcoast and Wark-Colquitz Complex rocks produced late Paleozoic and Triassic to Early Jurassic U-Pb dates, and Pb-Pb dates (200-300 Ma) invariably older than those of the Island Intrusions. The U-Pb and Rb-Sr evidence now suggests an episode of regional metamorphism and major Pb loss in Late Triassic time and Pb loss again in Jurassic time as well as more recently. Zircon dates for Sicker complex rocks near Buttle Lake are in progress (as part of S. Juras' Ph.D. thesis on Western Mines).

(b) Coast Plutonic Complex

P. van der Heyden began, as a Ph.D. thesis, a regional U-Pb geochronometry study in the Coast Mountains near Prince Rupert, ran additional zircon dates from several areas along the eastern side of the Coast Plutonic Complex in the Whitesail Lake Map Area, and started U-Pb dating of zircon separates from the Bella Bella-Bella Coola area originally

prepared for fission-track work by R. Parrish.

(c) Intermontane Belt

Several undated or little dated major plutons between 50° 30' and 53°N have been collected for multiple method dating and Sr isotopic mapping. R. Friedman has started mapping and geochron work on orthogneiss and paragneiss of regional extent in the Tatla Lake area.

(d) Omineca Belt

D. Parkinson has finished mapping the Eocene low-angle fault along the west side of the Shuswap Complex near Oliver, B.C. and is in the process of U-Pb dating several plutons (Jurassic to Eocene) critical to bracketing multiple structural events there. P. van der Heyden and J.K. Mortensen have obtained nearly identical Devonian U-Pb dates for two Quesnel Lake Gneiss samples collected by J. Getsinger and J. Montgomery, respectively.

(e) Mantle and Oceanic Crust

Sun Min has improved our Sr analysis procedures in order to analyse whole-rock and mineral separates of ultramafic nodules from several localities in eastern B.C. Most appear to come from a depleted mantle lithosphere.

P. van der Heyden and J.K. Mortensen are working with GSC geologists to collect and date Cordilleran ophiolites (via plagiogranites).

(f) Foreign Collaborations

E. Agyei of the Physics Department, University of Ghana, a CIDA fellow, has been dating basement rocks of western Africa by Ar and Sr and is setting up Sm-Nd dating chemistry for us.

Ronggui Sun from the Geology Department, University of Beijing, China, is undertaking a Rb-Sr study of Archean gneisses in northern China.

3. University of Calgary Physics (H.R. Krouse, C.J. Bland, J. Case, A. Ueda, C. Yonge); Geology (F.A. Campbell, I. Hutcheon, A. Levinson, A. Oldershaw); Geography (S. Harris); Biology (E. Laishley); Chemistry (R. Roche, G. Ritchie); Kananaskis Centre for Environmental Research (A. Legge); Alberta Research Council (A. Shakur)

(a) Instrumental, Analytical

Projects include: data accumulation and mass spectrometer control are being standardized with Apple II microcomputers; an extraction line has been built by A. Ueda for trace sulphur compounds in silicates and carbonates; combination gas chromatograph-combustion line - MS facility for C and H isotope analyses of individual light hydrocarbons has been upgraded by installation of HP6890 GC; a linear temperature programmed pyrolysis unit has been constructed for determining concentrations and isotope compositions of different sulphur structures in fossil fuels or extracts.

(b) Projects

(i) Fossil fuels. C and H isotope compositions of separated gas and oil fractions from wells in Alberta and Eastern Offshore; sulphur isotope composition of H_2S in gas wells of Alberta; H, C, and S isotope composition of coal; C isotope monitoring of light gases in oil sand in situ recovery operations.

(ii) Secular time variations in isotope composition of the ocean (C. Viau, B. Beauchamp). S and O isotope studies of evaporites and barites in western Canada, Montana, and the Arctic; S isotope variations in trace sulphate and sulphide in marine carbonates; C and O isotope studies of marines carbonates.

(iii) Hydrology. H and O isotope variations in ice cores of the Ward Hunt Ice Shelf

(M. Jeffries); H, C, O, S, ^{14}C, and tritium ion stratified Arctic lakes (M. Jeffries); glacial tills of Alberta (in collaboration with Alberta Research Council); springs in Western Canada; see (iv) also.

(iv) Environmental. Sulphur isotope analyses of atmosphere, surface waters, groundwater, lake sediments, soil cores, vegetation, animal hair, and bees to assess uptake of industrial sulphur emissions by the environment - various locations in Alberta, New York, California.

(v) Biogeochemical isotope selectivity. Sulphur isotope fraction by reducing and oxidizing bacteria; sulphur isotope variations in thermal spring algae; C and S isotope composition of kidney stones; carbon isotope fractionation during photosynthesis by plants in salt stressed environments (R. Guy); S isotope composition in food chains.

(vi) Uranium series disequilibrium. ^{210}Pb: $^{234}U/^{230}Th$ ratios obtained from surface deposits in southern B.C. imply ages between 1000-20,000 years. These results are being compared with carbon-14 data on organic matter in these deposits which yields similar ages. As part of the programme for certifying Canadian reference ores, a series of measurements of ^{210}Pb activity was carried out.

4. Dalhousie University, Departments of Physics and Geology (P.H. Reynolds)

Two mass spectrometer systems are in routine operation, a modified MS10 now interfaced to an Apple computer, and a Micromass 602D which is equipped with an on-line carbonate extraction system.

(a) K-Ar and $^{40}Ar/^{39}Ar$ Geochronology

Graduate student P. Elias has continued his study of the metamorphic and intrusive rocks of southwest Nova Scotia. A number of detailed $^{40}Ar/^{39}Ar$ age spectra on micas suggest that the post-metamorphic cooling history has been protracted (from about 400 Ma ago to ~340 Ma ago) and is apparently quite variable over the region. Age spectra from some areas are severely discordant; these are perhaps a reflection of a Hercynian thermotectonic (and metallogenic) event. The latter has been dated by M. Zentilli and P.H. Reynolds at ~300 Ma (on the basis of a study of muscovites from greisens associated with economic tin mineralization at East Kemptville). Elias plans to study the later stages of cooling by looking at argon in feldspars and fission tracks in apatites.

Recently completed but not yet published is a study (P.H. Reynolds with E.R. Deutsch, Memorial University) of a suite of Mesozoic lamprophyre dykes from north-central Newfoundland.

P.H. Reynolds in collaboration with M.E. Brookfield (Guelph University) continues to work on the Indus Suture Zone. A report on this work (with M.E. Brookfield and R.H. McNutt, McMaster University) was published in Geologische Rundschau; additional $^{40}Ar/^{39}Ar$ analyses are now being carried out on a more recently acquired sample collection.

(b) Stable Isotope Studies

D. Scott, V. Baki, P.J. Mudie and G. Vilks are doing carbon and oxygen isotope studies on a wide range of marine material from the Atlantic margin and mid-Atlantic Ridge. We have done some of the first stable isotope work on continental shelf cores. Although these oxygen isotope curves cannot be compared directly with standard deep-sea curves they can be used to correlate with events detected by other means (e.g. benthonic foraminifera). We have also done the first analysis from the same core of both right and left coiling planktonic species N. pachyderma. The significance of this is that the two forms occupy different water masses (one cold, one warm) and the analysis of both from the same time-interval gives the seasonal range of temperatures at that site. We have shown contrary to what CLIMAP has indicated, that seasonal deviations now are much greater than that occurring just after deglaciation. These results were presented at the 1984 GSA in Reno by Scott and others. We are continuing work on ODP sites 612 and 613, Arctic Ocean cores (Ice Station CESAR) and Labrador Sea cores.

Graduate student C. Ravenhurst (along with P.H. Reynolds and M. Zentilli) is continuing the work of former student S. Akande on oxygen/carbon isotopes of carbonates spatially associated with the mineralization at Gays River, Nova Scotia; specifically, Akande's work is being expanded to an area within a 3 km radius of the mine, and will concentrate on postulated fault zones. Eventually, it is planned to cover the entire margin of the Shubenacadie Basin. The aim is to investigate the usefulness of oxygen/carbon isotopic measurements in mining exploration.

5. McMaster University, Department of Geology

(a) Rb/Sr Geochronology and Sr Isotope Studies (R.H. McNutt)

We have received two new mass spectrometers in 1984. The SCIEX, ICP Qadrupole mass spectrometer was installed in July, and has been undergoing tests and factory upgrading. It seems to work best for concentrations in the low ppm to ppb level (ng/ml). One application will be the low precision, stable isotopic ratio measurement of K and Ca^1 in medical applications, a joint study with H.P. Schwarcz, R. Whyte and C. Webber (Medical Faculty). It will be useful also as a trace-element analytical facility. The second machine is a VG 354 solid source machine with five collectors and a Daly detector. It will be operational in March/April 1985.

The research areas of interest continue to be: (i) comparison of Rb/Sr, zircon U/Pb and Sm/Nd geochronology in high grade metamorphic terrains, (ii) the isotopic geochemistry of ground waters and brines in rocks in the Precambrian Shield, and (iii) $^{143}Nd/^{144}Nd$ measurements on Mesozoic and Cenozoic rocks of the Central Andes of South America.

(b) Isotope Studies of Hydrogen, Oxygen, Carbon and Sulphur (H.P. Schwarcz)

We continue our studies of the carbon and oxygen isotope ratios of carbonates associated with gold deposits of the Abitibi Belt of the Canadian Shield. We are now analyzing fluid inclusions in quartz, and relating the carbon isotope ratio of carbon dioxide and methane to the conditions of metamorphism and the source of carbon. Sulphur isotope studies of pyrite associated with gold have shown possible correlations between isotope ratios and gold tenor, and also between oxidation state and isotope ratio (with J.H. Crocket, A. Fyon).

Magnetite-bearing iron formations from Temagami and from Kirkland Lake show consistent relations between iron content and isotope ratio that can be interpreted in terms of temperatures of deposition of the primary iron-rich sediment. We are also learning about the scale of exchange of oxygen during low-grade and medium grade metamorphism (with N. Blum).

Research continues on the deuterium/hydrogen ratio of carbon-bound hydrogen of collagen. We have shown a correlation between this isotope ratio and the isotope ratio of local precipitation. We are also analysing the oxygen isotope ratio of the phosphate of bone apatite, which, for mammals, is linearly related to local environmental water. These two techniques should, collectively, allow us to reconstruct the hydrogen-oxygen isotope relationships for paleowaters, as well as provide paleoclimatic information (with A. Cormie and B. Luz, visiting from Hebrew University of Jerusalem).

Sulphur and oxygen isotope studies of sulphate in atmospheric precipitation are continuing, in order to trace the sources of this component of acid rain. Rain collected in maritime environments shows a characteristic S-isotope signal that is related to degree of sea-salt content. The role of dimethyl sulphide as a biological contributor to atmospheric sulphur is being studied both in natural samples and in the laboratory (with J. Kramer, M. Wadleigh, and F. Caron).

Sulphur, carbon and oxygen isotopes of sulphides and carbonates, respectively are being studied in the ores of the Nanisivik ore deposit, Baffin Island, in order to determine the source of the ore-forming fluid and the conditions of ore deposition. By careful drilling of samples from discrete growth layers recognized by cathodoluminescence, we hope to be able to trace the detailed variation in isotopic composition of the ore fluid.

(c) U-Series Dating of Carbonates (H.P. Schwarcz and D.C. Ford)

We have for some years been doing alpha-spectrometric analyses of disequilibrium between members of the uranium isotope decay chains. The aims of this research lately are: (i) dating of stalagmitic layers in archeological sites of the Old World, to establish the time of occupation of the sites by early man; (ii) dating of stalagmites and other calcite deposits from karstic caves, to calibrate paleoclimate data accumulated by isotope studies; (iii) study of disequilibrium between U and its daughters in granitic rocks, to determine the time scale of mobilization of these isotopes in potential nuclear fuel waste depositories (U-series studies serve as a model for the potential mobility of artificially introduced radioisotopes); (iv) dating of calcite deposits (stalagmites, etc.) which are being studied by natural remanent magnetization methods, to determine secular variation of the earth's field. The latter two topics are being carried out by A.F. Latham.

(d) ESR Dating (H.P. Schwarcz)

We are using electron spin resonance analysis of hydroxyapatite from tooth enamel to determine the time of burial of the teeth. Trapped, free electrons in the apatite lattice accumulate with time as a result of bombardment by environmental radiation. The age is determined by comparing the natural dose with an artificial dose of known magnitude and by measurement of the environmental dose rate (with S. Zymela).

6. University of Manitoba, Department of Earth Sciences

Rubidium - Strontium Geochronology (G.S. Cark)

Rb-Sr geochronology and Sr-isotope investigations in the major tectonic domains of the Churchill Province in northern Manitoba are continuing. The work includes the dating of orthogneisses and paragneisses, granitoid plutons, and volcanic rocks. The more recent work completed involves rock units from the Wathaman (Chipewyan) batholithic belt and the Southern Indian, Lynn Lake, and Kisseynew domains. Results obtained so far indicate that these are Hudsonian orogenic terrains.

In the northern Superior Province, we have started work on selected rock units from the Split Lake Block, which is marginal to the Churchill - Superior boundary. The isotopic work is being done in collaboration with N. Halden, who is doing a structural mapping and geochemical modelling study of the intrusive lithologies in this region. The purpose of this work is to establish: (i) whether the igneous activity is Archean; (ii) an absolute age stratigraphy for the Split Lake Block; and (iii) the source regions of the magmas.

A whole rock and mineral Rb-Sr age investigation is in progress for selected granites and pegmatitic granites from the Cross Lake area in the northwestern Superior Province. This work is related to an ongoing study of rare-element pegmatites in the area (with P. Cerny, R. Meintzer and A. Anderson).

We have obtained a new Rb-Sr whole-rock isochron age for the Skukum rhyolite of the Skukum volcanic complex in southwestern Yukon. The age is 53.3 ± 1.1 Ma, confirming an Eocene age for these rhyolite plugs (with M. Pride).

7. Queen's University, Department of Geological Sciences (E. Farrar, J.A. Hanes, D.A. Archibald, D.J. Kontak, L. France, S. Clark, R. Langridge, S. Heinrich)

The argon extraction system has been rebuilt and is used on-line (to a modified MS-10 mass spectrometer) for conventional K-Ar dating and with a Lindberg furnace for high-resolution $^{40}Ar/^{39}Ar$ step-heating experiments. Recently a fission track dating facility has been reactivated. Several geochronological investigations are currently underway.

(a) South American Studies

Investigations into the tectonic, magmatic and metallogenic evolution of the Cordillera Carabaya, S.E. Peru (D.J.K., E.F.) have revealed a close temporal and spatial relationship between Sn-W-base metal mineralization and specific magmatic and tectonic

events. The combination of K-Ar geochronology, $^{40}Ar/^{39}Ar$ step-heating experiments and Rb-Sr studies, petrology, geochemistry (120 whole rock analyses), and ore deposit studies has permitted the development of a tectonic model to explain the distribution of rock types and ore deposits with respect to the surrounding Andean system. In addition, a 500 km long zone of thermal overprinting of enigmatic origin (the Zongo-San Gaban zone) has been identified.

An isotopic (K-Ar) and petrologic study (L.F., E.F.) of neogene volcanic rocks from southern Peru is in progress. Twenty-five dates on biotite, plagioclase, hornblende and whole-rock samples define three periods of volcanism (22-19, 14-11 and 7-0.5 Ma).

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 (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.

A study is being initiated (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. Geomorphologic studies combined with K-Ar and fission track dating will be used.

(b) Kootenay Arc and Neighbouring Regions (D.A.A., E.F.)

A study of the geology and geochronology of the southern Kootenay Arc, B.C. 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.

Isotopic studies are being continued in selected areas in and bordering the southern and central Kootenay Arc. Samples have been collected from several mid-Cretaceous stocks and batholiths in the Purcell Anticlinorium for fission track dating and $^{40}Ar/^{39}Ar$ experiments on muscovite and K-feldspar. The Precambrian Hellroaring Creek stock and related amphibolite-facies metamorphic rocks have been sampled for a detailed isotopic study (U-Pb zircon, K-Ar, $^{40}Ar/^{39}Ar$ and fission track). It is anticipated that these studies will provide a complete tectonothermal history of the Purcell Anticlinorium from Precambrian to Eocene time. A $^{40}Ar/^{39}Ar$ study of dykes in the Irene Volcanics (Windermere Supergroup near 49°N) should complement this study.

(c) Additional Work in the Canadian Cordillera (D.A.A.)

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. is underway. A K-Ar and $^{40}Ar/^{39}Ar$ study of metamorphic rocks near the Purcell thrust (Canoe River map-area) is also in progress. In a $^{40}Ar/^{39}Ar$ study 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; one mica pair yielded a reverse discordance (Bi>Ms). In contrast, hornblende yielded mid- to late-Cretaceous K-Ar dates (117 to 88 Ma). $^{40}Ar/^{39}Ar$ step-heating results for one hornblende reveal a component of excess argon as well as a complex age spectrum with two plateau segments (~85 and ~110 Ma). These results highlight the problems associated with interpreting conventional K-Ar hornblende dates for high-grade metamorphic rocks.

(d) Lake George Antimony Deposit (D.A.A.)

An isotopic study of the Lake George antimony deposit in southern New Brunswick is underway. K-Ar mica dates for a variety of rocks suggest that mineralization is not younger than Late Silurian. A $^{40}Ar/^{39}Ar$ study of these samples has been initiated.

(e) Mining Districts in Korea (D.A.A., E.F.)

In cooperation with A.H. Clark, a K-Ar study of selected Sn and 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.

(f) Kapuskasing Structural Zone (D.A.A., E.F.)

A $^{40}Ar/^{39}Ar$ study (with J. Percival, G.S.C.) of the sheared eastern margin of the KSZ is in progress. Initially, this study of sheared and unsheared granitic and amphibolitic rocks was undertaken in an attempt to resolve the time of brittle deformation in the Ivanhoe Lake fault zone. This study has been incorporated into a regional $^{40}Ar/^{39}Ar$ study of the KSZ and neighbouring regions as part of a Lithoprobe transect.

(g) Elzevir Trondhjemite (J.A.C., S.C.)

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

(h) Abitibi Greenstone Belt (J.A.H.)

In a study on the tectonothermal history of the Archean Abitibi greenstone belt, $^{40}Ar/^{39}Ar$ thermochronometry is being used to elucidate the timing of late stage plutonic activity and major gold mineralizing events in the Sigma Mine, Val d'Or, Quebec (with F. Robert, G.S.C.). As well, further $^{40}Ar/^{39}Ar$ dating of Matachewan, Hearst and Kapuskasing diabase dykes will be conducted and related to their paleomagnetic signatures (with H. Halls, University of Toronto).

8. University of Toronto, Geophysics Laboratory

Lead and Hafnium Isotope Studies

Lead isotope analyses have been made (with S.J. Haynes) on small quantities of galena found in quartz veins of the Goldenville Cambro-Ordovician sedimentary rock formations of the Meguma terrane of eastern Nova Scotia. The least radiogenic of these leads lie close to the average terrestrial growth curve of Stacey and Kramers, and have an average model age of 550 Ma. The proximity of the data to the average growth curve suggests that the isotopic compositions of the galenas were determined by processes similar to those envisaged by Doe and Zartman in their 'plumbotectonics' model. Lead isotopic ratios in more radiogenic galenas are variable; this is interpreted to be the result of the extraction of lead from Meguma metasediments during remobilization. Whole rock leads are also more radiogenic than the least radiogenic galenas, indicating that there are local sources for the radiogenic additions.

Studies by P.E. Smith of lead isotope variations among volcanic and granitoid rocks of the Michipicoten and Gamitagama greenstone belts are continuing. Zircon U-Pb ages for several of the volcanic units and granitoids are in good agreement with Pb-Pb ages on the same rocks. There are indications of significant differences among the initial Pb isotopic ratios of the various volcanic and granitic units, but there is insufficient data to determine whether the variation is time-dependent. Hafnium isotopic measurements (with M. Tatsumoto) on zircons are being undertaken. Preliminary results suggest that the $^{176}Hf/^{177}Hf$ ratios in granitic rocks define a trend different from that for chondrites (i.e. for the whole-earth).

Lead isotope fingerprinting of sources of archaeological galenas has continued. Most galenas of the Late Archaic-Early Woodland periods (ca. 3000 - 2500 b.p.) in the Great Lakes area appear to have come from one vein in the Rossie, New York area, although one site contains galena from the Upper Mississippi Valley region. Galena at later sites in the southern United States also appears to have come from a very limited number of sources, most probably in the South East Missouri region.

9. University of Western Ontario, Department of Geophysics

Research continues on Triassic-Jurassic rocks in eastern North America by the K-Ar isochron method. The Holyoke Basalt in the Hartford Basin and the Palisade Sill in the Newark Basin yielded initial $^{40}Ar/^{36}Ar$ ratios around 200.

10. University of Windsor, Department of Geology (A. Turek)

Collaborative U-Pb zircon geochronological studies are in progress for: the Port Coldwell Complex, Ontario; the Michipicoten belt, Wawa, Ontario; the Island Lake greenstone belt, Manitoba; the Bird River Sill in Manitoba. Collecting for a new project in the Rice Lake area in Manitoba commenced in 1984.

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VI METEOROLOGY AND ATMOSPHERIC SCIENCE

Compiled by: E.J. Truhlar

1. Introduction

Canadian universities are vigorously pursuing a wide variety of basic research projects in meteorology and atmospheric science. Federal and provincial government departments and agencies have committed much of their resources to interdisciplinary air quality research that involves monitoring pollutants, modelling pollutant trajectories, and studying acid precipitation and deposition and the long-range transport of air pollutants. Two large field studies were carried out by the Atmospheric Environment Service (AES), NRC and the U.S. Brookhaven National Laboratory on pollutant transport and transformation by cloud: the Acid Snow Experiment near North Bay, Ontario, and the Smoking Gun Experiment (using sulphur hexafluoride as a tracer) in northwest New York State. The Ontario Ministry of the Environment completed an extensive field study to determine how Sarnia emissions affect ozone levels in southwestern Ontario. Canada's first astronaut participated in an AES experiment aboard the October space shuttle
flight of Challenger by using a sunphotometer during sunsets to help determine altitude profiles of atmospheric constituents including stratospheric aerosols.

2. University of British Columbia, Department of Geography (J.E. Hay, T.R. Oke, D.G. Steyn)

Studies of radiance distribution, short-wave irradiance for inclined surfaces, spatial variability of solar radiation, and satellite estimates of solar radiation at the Earth's surface were continued.

A wind field network was set up and operated during the summer for a continuing study of sea-breeze flows in the lower Fraser River valley. Concurrent tethersonde profiles provide a data set that will be used for validating mesoscale numerical models. Terrain height fluctuations are being studied by computing two-dimensional spectra.

Studies of the energy and water balances of cities also continued. Activities include observation of surface energy balances using eddy correlation techniques; field measurements at Vancouver and Mexico City; numerical simulation of urban-rural nocturnal cooling and the dynamics of the urban heat island.

3. University of Alberta, Meteorology Division and Institute of Earth and Planetary Physics (N. Aktary, K. Al-Jumily, R.B. Charlton, K. Finstad, R. Goodson, K.D. Hage, F. Hopper, P. Klivokiotis, E.P. Lozowski, A. Nowak, D. Phillips, E.R. Reinelt, J. Roesler, C. Sackiw, F. Safwat, G. Strong, D. Yiu)

Ice-accretion experiments were carried out to test and verify theoretical icing models. Results pointed out the critical importance of the precise measurement of droplet size, as well as the need for modelling the formation of spongy ice.

An airfoil icing model is being developed that includes a computationally-fast collision efficiency algorithm. The spatial distribution of ice density in accreted ice has been measured. Mechanical and X-ray absorption techniques have been used. Two marine-icing wind tunnels are under construction.

A study of the mesoscale and synoptic-scale weather of May 1979 is nearing completion. Mesoscale regions of vertical ascent have been identified that precede the onset of severe convective weather by several hours.

Studies continue of man-made snow, fog and cloud prevalent on very cold days in the petrochemical district of Edmonton. A finite-difference model of drainage airflow and particle dispersion has been used to generate vertical profiles of wind speed, air temperature and carbon monoxide concentrations for comparison with measurements obtained in the North Saskatchewan River valley in Edmonton. Recent models simulating the erosion of low-level inversion layers by entrainment have been combined with Brunt's radiative model for the nocturnal temperature profile.

The frequencies of reports of specific weather events in Alberta community histories for the period 1880-1960 have been used to identify weather extremes, such as dry years, wet years, severe winters, hailstorms, summer frosts, spring snowstorms, blizzards, duststorms and destructive winds. Information on the impact of these extremes was used to develop objective 'severe winter' and 'drought' indices for Edmonton, Calgary and Medicine Hat. Destructive-wind data from Alberta and Saskatchewan were classified by severity of damage. Even though the frequencies of tornadoes in the two provinces are similar, intense tornadoes are about twice as frequent in Saskatchewan. Surprisingly high frequencies of weak tornadoes are associated with small cumulonimbus clouds.

A linear, hydrostatic model has been developed for the flow of stably-stratified air over a mountain barrier with an elliptical base. Analytical expressions for the surface pressure perturbations were used to study the differences between two and three-dimensional flows. The horizontal divergence and lateral streamline deflection associated with the velocity component perpendicular to the mean flow were also considered.

A study of the use of satellite data in determining precipitation from convective clouds in Alberta and western Saskatchewan suggests that rain accumulation is inversely proportional to temperature, with enhanced rates of precipitation occurring when the clouds are colder, or when the temperature difference between cloud top and tropopause is large.

The cohesiveness of upper-air soundings in space and time, in pressure, temperature and wind is being examined using data sets obtained from serial releases of radiosondes.

Several years of satellite images have been examined for cloud configurations that do not fit readily into current cloud classification schemes, in order to identify causes and mechanisms of cloud development that are not associated with fronts and cyclonic systems. A related project is the transport mechanism and distribution of Arctic haze.

A climatology is being formulated of upper-air parameters relevant to the incidence and control of forest fires. Vertical wind and temperature profiles are being catalogued for specific sites within the boreal forest regions of west-central and northern Canada.

The determination of the onset of turbulence has been studied. An algorithm was devised for examining the solutions of the Navier-Stokes equation during transitional conditions, from stationary states to solutions periodic in time. The mechanism for the generation of turbulence assumes a sequence of three Hopf bifurcations on the N-S equations.

4. Alberta Environment

Alberta Environment continued to support research and monitoring activities related to air quality and meteorology. A review and synthesis of urban air quality research in Alberta was undertaken in the context of national and international research activities. This helped form the basis for an urban air quality/climatology research program to: (i) characterize urban air quality, and (ii) delineate and understand the consequences of urban air pollution, in order to optimize the use of climate information to examine probable effects on the environment.

An Energy Resources Conservation Board Inquiry into the 1982 Lodgepole Sour Gas Well Blowout addressed many scientific issues including health effects of hydrogen sulphide, monitoring methodologies and strategies, diffusion and deposition calculations, and effects on soil, vegetation, and animals. Other projects included: (i) updating the provincial inventories of SO_2 and NO_x emissions; (ii) developing new sources and emissions inventories for Edmonton and Calgary; and (iii) summarizing and analysing five years of precipitation chemistry data. Point source diffusion and deposition modelling continued with (i) regulatory models being made available on floppy disk for personal computers, and (ii) the EPA UNAMAP models being examined by a consultant for possible application in Alberta.

Research on acid deposition and liaison with various Federal/Provincial agencies and industry continued. The Alberta Government/Industry Acid Deposition Research Program initiated in 1983 deals with the biophysical effects of deposition, especially on agricultural ecosystems, on northern forested areas and on sensitive lakes in the Canadian Shield. The program also studies human health effects and provides information needed for sound environmental management and control of acid-forming substances.

5. Alberta Research Council

(a) Hailstorm Seeding Experiments

Controlled seeding experiments on hailstorms using silver iodide, dry ice or a placebo accompanied by in situ measurements using a research aircraft have verified the initial steps of the hail suppression hypothesis. Alternative hypotheses have also been developed. Analysis of time-resolved samples of hailstones collected at ground level have led to size distribution relationships that provide a method for predicting the numbers and sizes of hailstones for a storm. This technique will greatly enhance the ability to evaluate cloud seeding on a storm-by-storm basis. Experiments are continuing to determine if competition amongst growing hail embryos can occur. Operational cloud seeding was carried out in the southern part of the Alberta Hail Project area from June 20 to August 31, when 2180 occurrences of hail were reported on 34 days.

(b) Rain Experiments

Thirty-four non-precipitating towering cumulus clouds have been randomly treated with silver iodide, dry ice or a placebo to stimulate the precipitation process. In situ cloud physics measurements accompanying seeding experiments from the two dozen trials now analysed, show that a category of cumulus clouds exists where precipitation is not initiated naturally but can be initiated by cloud seeding. The amount of precipitation produced with various treatments and the statistical significance of the results is being studied.

(c) Snow

Limited cloud physics observations in winter clouds over the mountains indicate that precipitation mechanisms do not always remove all available cloud water, implying that some potential for snow augmentation exists. Case studies are being analysed. Climatological studies of winter precipitation frequencies and quantities have been initiated.

(d) Atmospheric Transport and Diffusion

In situ observations in and downstream of the tar sands processing plants in

northeastern Alberta have provided measurements of the conversion rates of sulphur dioxide and nitrous oxide gases in the atmosphere. A plume tracing study was conducted in southern Alberta in July using a ground-based cloud seeding device, to test its practicality for seeding.

(e) Radar Studies

A means of predicting damaging lightning flashes using radar information is being developed. Small-scale rainfall intensity-duration curves have been obtained using radar data; and polarization signatures of storm cells have been identified.

(f) Mesoscale Forecasting Studies

Investigations of the mesoscale reactions of the atmosphere to approaching synoptic weather systems has confirmed the existence of preferred regions for convective storm development induced by the larger-scale weather systems. Studies are continuing on ways to improve the convective weather forecasting.

6. Western Research, Division of Bow Valley Resource Services Limited

Western Research provided meteorological evaluation and consulting services to a wide variety of industries. Major research projects included: field study of acid gas flare combustion efficiency at a sour gas processing plant; field study of plume dispersion in flat terrain located about 50 km east of the Rocky Mountains; evaluation of air quality impacts and risks associated with sour gas well blowouts; and collection of data in the Athabasca oil sands area to study dry sulphur deposition. A study of winds and turbulence in the lower 500 m of the atmosphere based on Doppler acoustic radar measurements was completed.

7. Saskatchewan Research Council

As part of its continuing commitment to programs in climatology SRC has operated a benchmark climate station for over 20 years. Wind erosion studies have made significant progress. Major contributions have been made to the Environment Canada IIASA (International Institute for Applied Systems Analysis) programs.

Acid rain chemistry data from a regional event rain gauge network in northern Saskatchewan are being analysed and interpreted; the surface geostrophic air mass back trajectory at the ending of precipitation was used. Fires were shown to increase the acidity of the sample, primarily by increases in the nitrates; anthropogenic influences were also present.

As a service to Saskatchewan industries, mainly potash and uranium mines, SRC monitors the rates of emission of various gases and particulates to the atmosphere.

A long-term program to monitor the vapour flux of commonly used pesticides has shown that the atmosphere is a major return pathway for many commonly used pesticides in western Canada, and many of the newly created formulations can be detected in the air at virtually any time during the growing season.

Several major point-source emitters in Saskatchewan have been instrumented with ambient sulphation monitors and event rain chemistry networks. Results show that the air quality is significantly influenced by wind rose patterns, but if the wind rose is not structured in a "site specific" manner, then it does not represent the air quality data collected. The event rain chemistry network reveals that the precipitation is significantly different from that reported by the Environment Canada CANSAP network, particularly for southern Saskatchewan. Total deposition of sulphur is approximately a factor of four less than reported and the pH is very near 5.6, suggesting a carbon dioxode major control on acidity.

A detailed study of the strong acidity in precipitation on the Precambrian Shield areas of Saskatchewan, showed that although the precipitation is quite dilute, pH values ranged from 4.5 to 5.2 in most of the samples, both in summer and winter. A natural

organic acid may contribute in part to the acidity.

Several years of data on metal particulate deposition to the snow pack of the Flin Flon area are in place at the Saskatchewan Research Council. The observed patterns are being modelled using selections from the UNAMAP series of USEPA air quality models. A year-by-year direct comparison of results is quite encouraging.

8. University of Windsor

(a) Department of Geography and Great Lakes Institute

A major interdisciplinary study of toxic contaminants in the Essex Region is in its third year. It includes monitoring the fallout of Pb, Cd, PCBs and octachlorostyrene, observing the mesoscale wind field and stability conditions, and modelling the transport of pollutants from potential sources. A Great Lakes Institute study, under contract with AES, is concerned with possible socio-economic impacts on the Great Lakes Basin resulting from projected climatic changes caused by anthropogenic CO_2.

Research continues on Holocene paleoenvironments of southern Baffin Island. Palynological analysis of lake sediments and buried soils collected in the Frobisher Bay area has been completed and the resulting paleobotanical and paleoclimatic interpretations have been published. Field investigations in the Baffin Island interior are being carried out to elucidate past and present climate-vegetation relationships.

(b) Department of Physics

Continuing research includes measurements of electron-impact processes of interest to planetary atmospheres, and development of associated monitoring technology.

9. University of Toronto, Institute for Environmental Studies (B. Boville, I. Burton, A.P. Grima, F.K. Hare, H.M. Hutchon, R.E. Munn, H.A. Regier, P. Timmerman, A. Whyte).

The main objective of the Institute's interdisciplinary research is to improve the science of environmental management. Many of the areas covered involve atmospheric processes including air pollution, acidic deposition, climate impact assessment, sustainable development of the biosphere, nuclear winter, and management strategies for snow and ice control. Specific research studies dealt with trends in acidic deposition at Hubbard Brook (New Hampshire); methods of detecting trends; dispersion of oil in Arctic waters; economic costs of SO_2 abatement strategies; and the effect of water temperature on fish production.

10. Ontario Ministry of the Environment, Air Resources Branch, Air Quality and Meteorology Section

An Eulerian model for long-range transport and deposition of acidic pollutants has been developed and will be evaluated with observed data during 1985-86. Work continues on a Lagrangian trajectory model of sulphur oxides and a 3-D mesoscale wind field model (see CGB, 1983).

Routine monitoring of air chemistry and atmospheric deposition across Ontario continued. Much time was spent on analysing the impact of the Sudbury smelters on acid deposition in the province. Special studies were continued to establish the accuracy and precision of atmospheric deposition data from the APIOS network.

A large field study was carried out during June and July in the Sarnia area. It included airborne and ground-based sampling of ozone and its precursors to determine the impact of Sarnia emissions on ozone levels in southwestern Ontario. Data are being analysed.

11. Trent University, Department of Geography

(a) Ice Studies (W.P. Adams)

Studies of ice, including snow cover of lakes in northern Québec-Labrador and in Southern Ontario, continued and were focussed on biological as well as hydrological aspects. The land snowpack, radiation balance, work in northern Québec was completed.

A second field season, involving ice studies on Colour Lake and mass balance work on White Glacier, was completed on Axel Heiberg Island, N.W.T.

(b) Land Surface Climatology of the Canadian Climate Centre GCM (J.G. Cogley)

In collaboration with A. Henderson-Sellers' group at the University of Liverpool, initial studies of 10 years of model climate suggest that the model gives a good generalized representation of land-surface energy and water balances but several deficiencies have been identified. The goal is to upgrade and refine the model so that it may be applied to problems of climatic change resulting from changes in surface properties.

(c) Radiation Climate of the High Arctic (J.G. Cogley)

Weather-station records from Resolute and Alert were used in a continuing study of cloud-cryosphere interactions.

(d) Energy Balance Modelling of Snowmelt in a Suburban Environment (J.M. Buttle)

This new project concentrated on the comparison of point estimates of snowmelt using the energy balance approach with observed snowmelt runoff rates from urban and non-urban environments. It includes a study of spatial and temporal trends in net radiation in suburban areas during snowmelt. The goal is to develop a snowmelt model for urban areas that can be employed in conjunction with current hydrological forecasting techniques.

12. National Aeronautical Establishment, Flight Research Laboratory (FRL)

The FRL Twin Otter atmospheric research aircraft was flown about 230 hours in cooperation with the AES, mainly to obtain a better understanding of the physical and chemical processes by which atmospheric pollutants, especially those contributing to acidic precipitation, are removed from the atmosphere by cloud and precipitation and how they may inadvertently modify precipitation patterns.

In January and February the aircraft was based at CFB North Bay and flown in the Acid Snow Experiment, which was designed to investigate the winter-time chemistry and cloud interactions with airborne pollutants for comparison with the summer 1982 data. In the fall, it was operated for five weeks from Syracuse, N.Y., in the project known as "Smoking Gun", a cooperative program with the AES and the U.S. Brookhaven National Laboratory (see this Chapter, Section 18(b)(i)).

There is much discussion in the cloud physics research community about the effects of mounting location on results from airborne spectrometers used to measure cloud and precipitation particles. FRL is investigating this, e.g., by modelling the flow about the Twin Otter wing, calculating particle trajectories, and determining factors to correct measured particle images and concentrations based on aircraft lift coefficient and particle size.

At the request of Agriculture Canada, FRL has been conducting experiments to measure the vertical flux of CO_2 in the boundary layer above vegetation. Instrumentation and analytical techniques were developed to use aircraft to measure CO_2 exchange rates over wide areas and to infer vegetation growth rates. Forty-five flying hours were logged over various crops and forests in Manitoba and Ontario. Flights over a hail-damaged area suggest that this technique also offers promise in assessing damage due to drought, severe storms, insects, and forest fires.

13. McGill University

(a) Department of Meteorology

The main research areas are large-scale dynamic meteorology, numerical weather prediction, geophysical fluid dynamics, cloud and precipitation physics, mesoscale meteorology, and radar and satellite meteorology.

Models were used to study: the dynamics of atmospheric blocking using FGGE data; the interactions between forced stratospheric waves and that between a time-dependent zonal flow and the topographically forced planetary waves; and the stability of finite-amplitude wavy stationary flows by processing both topographic- and Rayleigh-type instabilities.

Numerical simulations carried out with the three-dimensional cloud chemistry model were used to study the interaction of pollutants with individual convective clouds. The simulations are being compared with the measured chemical composition of the cloud water in selected clouds. Algorithms are being developed to retrieve cloud parameters such as cloud top height and cloud amount from satellite data. Changes in the shape of the drop-size distributions below cloud base and the implication of these changes on radar reflectivity are being studied. Numerical simulations are being compared with a large number of measured drop-size distributions in order to increase the understanding of the role of drop interactions in shaping the drop-size distribution.

Diagnostic budget studies for a squall line in SESAME and a rapid deepening winter cyclone during FGGE were completed. A consistent set of equations governing explosive cyclones was obtained and included the dynamic and thermodynamic effects of clouds. A baroclinic instability analysis indicated that convective clouds can account for the major features in these cyclones.

The mixing process in cumulus congestus clouds was investigated by analysing aircraft observations using the Paluch method and numerical simulation in a high-resolution cloud model. The importance of cloud top mixing and penetrative downdrafts was clearly demonstrated.

Other research included work on the cloud dynamics/pollutant interactions in a rainband, the effects of lateral boundary conditions on cloud modelling, and the effect of topography on hailstorm genesis, using a mesoscale boundary-layer model.

(b) Macdonald College, Department of Agricultural Chemistry and Physics

Research continued in the following major areas: observations and mapping of fluxes of sensible heat, water vapour and CO_2 from aircraft (in collaboration with Agriculture Canada and the National Aeronautical Establishment); volatilization of ammonia and trace gases from fields and surface-applied manure; non-steady state heat and mass transfer processes from foliage to air; acid deposition processes related to fog; the use of beta-absorption to determine water stress in plants; the radioisotope tagging of agricultural pests; and selected aspects of agroclimatology.

14. Université du Québec à Montréal, Département de physique

Les projets de recherche se poursuivent (voir BCG, 1983): la mesure des dépôts secs des polluants gazeux; une étude sur l'évolution du champ de la divergence; une méthode d'analyse de la cinématique des orages; une étude d'évaluation théorique des performances des systèmes radar; et une étude des paramètres analysés et prévus du modèle opérationnel de prévisions.

15. Université de Sherbrooke

(a) Voir le BCG, 1983 pour les projets de recherche en cours.

(b) Laboratoire de climatologie

(i) Climatologie régionale des Cantons de l'Est: climatographie des Cantons de

l'Est (1941-1980); types de temps estivaux (1972-1981).

(ii) Paléoclimatologie des vents de la vallée du Saint-Laurent à partir des dunes.

16. Agriculture Canada, Agrometeorology Section, Ottawa

Research activities include: addition of routines to the wheat yield/ protein model to calculate conserved overwinter moisture for both the continuous crop and crop summerfallow rotation (model calculations compared favourably with yield data from summerfallow and stubble); measurements of CO_2 flux above a wheat field near Winnipeg, and instantaneous rates of growth of several crops; study of the potential of this flux technique for estimating the extent of damages due to a hailstorm near Winnipeg; development of a climatic criterion for estimating optimum planting date of winter wheat, used to prepare a zonation map for the Maritime Provinces (A. Bootsma); development of procedures for estimating corn leaf stage and leaf expansion from air temperature and soil temperature data; conversion of a wheat yield/protein quality predictive model to a crop productivity model by incorporating soil textural factors (D. Stewart); study of the effect of 30 years of actual daily weather data as opposed to climatic normal weather data, as input to soil water models; preparation of crop characteristics, including rooting depth and ground cover, for a soybean crop as input to the Hayhoe-de Jong soil moisture model; performing simulations for the growing season using new numerical schemes at the soil surface, which gave an improved fit of the simulated soil water near the surface boundary; development of an improved crop stress index for wheat, and of coefficients for each crop district related to five phenological stages; monitoring the winter and spring microenvironments including solar, diffuse and net radiation, soil heat flux and thermal gradients in the snow and soil; formulation of a numerical model of heat flow in the snow for specific snow depths and densities and integration of this model with a soil heat flow model; successful application of this model for comparison with frost depth estimating from the electrical frost probe; establishment of a network of soil moisture observations in three Quebec areas; monitoring the response of strawberries to irrigation scheduled according to three water potential criteria; carrying out a greenhouse experiment to monitor B-gauge response to water stress and comparing its response to that of other indicators of water stress; adaptation of the new frost probe for automatic recording with a CR5 data logger, and design and testing of a different electrode configuration; and monitoring of water movement and freeze of thaw processes with TDR and the neutron probe.

17. Canadian Forestry Service

(a) Newfoundland Forest Research Centre, St. John's

The dendrochronology study of red pine in relation to fire history continues (see CGB, 1982). A thesis on the tamarack as a biological indicator of winds has been completed by A. Robertson who is conducting a (United Kingdom, Iceland and Newfoundland) study of the impact of wind on forest stand dynamics and forest management strategies.

Under the ENFOR (Energy from the Forest) program, J. McCaughey of Queen's University has been developing an energy balance measuring system for climate studies in Salix energy plantations. A study relating cumulative degree-days and the peak occurrence of spruce budworm larvae was published.

(b) Maritimes Forest Research Centre, Fredericton

Climatic data used in a study to delineate climatic regions of New Brunswick and a paper describing the methods were published. A study associated with the Nashwaksis Watershed Project indicates the necessity of modelling the heating effects of streams following logging.

(c) Laurentian Forest Research Centre, Ste-Foy

See CGB, 1983 for activities.

(d) Petawawa National Forestry Institute, Chalk River

The FOSBERG, WHITE SANDS, and AES TAYLOR models amongst others are being examined, in a study of wind over rough terrain. Field test data sets are being obtained from seven towers distributed across a valley, measuring winds 6 m above the forest, which are compared with winds from an open field site at an automatic weather station reporting by satellite.

In cooperation with the McGill University Radar Weather Observatory, under the PRUF program, research is under way to establish the optimum strategy for the estimation of rain for remote forested regions. Studies have shown that the X-band wavelength (3 cm) does not penetrate to the back of storms as well as the longer wavelengths of the C-band (5 cm) and S-band (10 cm), however, the X-band is considerably less costly. Currently the X-band radar is being evaluated in conjunction with data from the GOES satellite. The LLP (lightning location) system and 18 automatic reporting rain-gauges are being added for ground truthing.

Temperature profiles at three locations in a red pine stand frost hollow are being measured (see CGB, 1983). Strip cuttings in the red pine stand are being followed to establish the microclimate conditions that will discourage pine weevil attacks. A description of a model of radiation received in a strip-cut has been published. The effect of solar radiation and precipitation on forest fuel moisture is being studied. The monitoring of forest fires in Alberta using NOAA satellites is being investigated at Colorado State University. Cloud-to-ground lightning near three LLP sensors located around Maniwaki, Quebec, is being recorded together with forest fuel moisture and fire occurrence.

(e) Forest Pest Management Institute, Sault Ste. Marie

See CGB, 1983.

(f) Great Lakes Forest Research Centre, Sault Ste. Marie

The Fire Research Unit maintains the fire weather network archive for Ontario based on about 100 AES and Ontario Ministry of Natural Resources stations. These are extensively used in case history studies of large fires. (See also CGB, 1983).

(g) Northern Forest Research Centre, Edmonton

A report is nearing completion on the forest fire environment of Puskaskwa National Park, Ontario, also a fire history atlas for Alberta. A two-year PRUF study is under way at the University of Alberta entitled 'Climatology of atmospheric conditions related to extreme fire behaviour in west-central and northern Canada'. Changes in the Fine Fuel Moisture Code (FFMC) and the Initial Spread Index (ISI) have been incorporated in the revised tables for the Canadian Forest Fire Weather Index. An interim user guide to the Canadian Forest Fire Behaviour Prediction System was prepared and includes ISI/head fire rate of spread relationships for 14 major Canadian fuel types as well as procedures for applying this information to potential or actual wildfire situations. A "blow-up fire" in east-central Alberta during the 1980 fire season was studied. Several reports were published: two ENFOR boreal forest studies - one on the impact of climatic variation on biomass accumulation, the other on the influence of climate on tree growth; in cooperation with Forintek Canada Corporation - (i) dendroclimatic reconstructions based on tree-rings from Duck Mountain, Manitoba, (ii) X-ray densitometric analysis of an old Douglas-fir stand (over 600 years old) from Banff, Alberta, (iii) biomass productivity of white spruce in Alberta and Manitoba, and (iv) dendroclimatological analysis of white spruce from five tree-ring sites in the Yukon Territory. Other reports are being prepared on the following: the winter climate, expecially snow conditions of the Marmot Basin (Mt. Allen), the Calgary 1988 Winter Olympics ski site; the passive microwave method for measuring snow accumulation; and the hydrologic effects of timber harvest on the Marmot Creek and Steeter Basins, Alberta.

Data are being measured at the James River microclimate study site to provide information needed to develop theoretical and/or empirical relations between microclimate parameters, transpiration and evapotranspiration for use in hydrologic land use models.

Snowpack ablation is also being followed there.

(h) Pacific Forest Research Centre, Victoria

A prototype UHF telemetry system for automatic weather stations gave satisfactory performance. Tree water stress, soil water potential precipitation interception, stemflow, and the usual climate elements are being studied to examine the effects of fertilization and thinning on growth; Forintek is analysing ring density and radial increment in relation to climate variables; soil temperature and moisture models will also be tested in relation to litter decomposition.

Climate data were gathered for the Inland Spruce Cone Rust and Bark Beetle Dispersal studies. A further paper on weather effects on the western spruce budworm was published. The procedure for adjusting spring starting drought codes for the Canadian Fire Weather Index was modified for use by certain B.C. and Yukon stations that receive little over-winter precipitation.

18. Atmospheric Environment Service

(a) Meteorological Services Research Branch (MSRB)

The general program of the Branch remains as described in the CGB, 1983.

An automated wind forecast system for Canadian airports was implemented on the Canadian Meteorological Centre (CMC) computer. The system applies the products of the national numerical weather prediction model to statistical regression equations derived for each airport requiring wind forecasts. Statistical regression equations are being developed to forecast other weather parameters: cloud, precipitation type and temperatures for 20 Canadian cities, and winds for many Canadian marine forecast areas.

Evaluation of the products of an ice modelling forecast system showed that the system had modest skill and some areas had to be improved. An iceberg deterioration model was developed and evaluated with selected iceberg data.

Evaluations in real-time of systems to forecast ocean waves and swell on the North Atlantic Ocean, waves on the Great Lakes and sea-spray icing, revealed that systems' models are reliable yielding products of good quality, and that a better method of specifying winds on the Great Lakes would be required to ensure operational viability of the system for forecasting lake waves. Work was initiated to make this modification. A wave forecast system for the North Pacific Ocean was adapted from the North Atlantic Ocean system and will be evaluated in the Pacific setting. An ocean spectral wave model (SOWM) was evaluated for potential application to Canadian waters but was judged not to have desirable accuracy. Another ocean spectral wave model (Resio) will be evaluated similarly.

Atmospheric Dynamics Corporation and the Institute of Ocean Sciences, Patricia Bay, applied the storm surge forecast model to the southern Beaufort Sea. The model treats the pack ice edge as a moving feature.

Application of artificial intelligence methods for preparing and wording weather forecasts was demonstrated to be feasible.

The prototype RAINSAT system (see CGB, 1983), which combines radar and GOES satellite data, was further evaluated.

The three-dimensional finite-element model (see CGB, 1983) is being tested at the CMC and will be implemented as a short-range regional model. Results so far are very encouraging (equal to or better than the actual operational model).

Work on the global medium-range forecast model, scheduled for delivery in 1986, is well advanced; testing with full physics was begun with global FGGE data.

A semi-Lagrangian and semi-implicit time scheme was successfully applied to a baroclinic primitive equations model. The time needed to integrate these models can be

reduced by a factor of four. This is recognized as a significant breakthrough by atmospheric scientists.

A physical retrieval inversion method was developed for the TOVS system to improve accuracy.

The Microwave sensor studies continued in cooperation with UCLA, JPL and NASA.

Full-scale and wind-tunnel measurements of boundary-layer flow over hills were compared.

(b) Atmospheric Processes Research Branch (APRB)

(i) Cloud Physics Research Division. Two major cloud chemistry field projects, designed to improve the understanding of pollutant transport and transformation by clouds, were organized. From 16 January to 24 February field experiments were conducted near North Bay, Ontario to study snow and pollutant interactions. A team of 25 scientists and technicians from AES, the U.S. Brookhaven National Laboratory (BNL), National Research Council (NRC), the Canada Centre for Remote Sensing, Ontario Hydro and the Ontario Ministry of Environment were involved. Aircraft measurements were supplemented by regular air quality monitoring stations as well as a sophisticated mobile chemistry laboratory. Many of the measurements form unique and "first of its kind" data sets.

From 15 October to 15 November, another project (with BNL and NRC) was conducted in the northwest region of New York state, mainly to obtain direct "smoking gun" evidence that SO_2 oxidation to $SO_4^=$ was occurring in cloud water. An SF_6 tracer was released from an aircraft to tag parcels of air entering cloud. This tracer technique has shown the potential of providing useful information to study chemical transformations inside cloud.

A new Doppler weather radar with a dual wavelength (5 and 3 cm) capability was put into operation near King City, Ontario, replacing the radar near Woodbridge. This radar has research and operational roles and will be used to test the utility of Doppler radar data in the Canadian climate.

Other activities included: developing a new technique to detect rain areas from GOES satellite data without simultaneous radar data; starting a Canadian High Elevation Fog (CHEF) study to determine the effect of acid fog upon forests at high elevations; and planning the Canadian Atlantic Storms Program (CASP) to study severe Atlantic winter storms, from 15 January to 15 March 1986 concurrently with a U.S. Genesis of Atlantic Lows Experiment (GALE).

(ii) Experimental Studies Division. The first Canadian astronaut conducted an experiment on the STS 41-G mission with a more sophisticated (dual channel, six-wavelength) version of the commercial sunphotometer that is used to measure acid haze in the Canadian air pollution network and to study volcanic haze in the stratosphere from aircraft.

A zero atmosphere calibration of the sunphotometer was determined from measurements of the sun through the side hatch window of the shuttle. These space calibrations will be compared with ground-based calibrations conducted using classical methods that require measurements from mountain tops.

Solar occultation measurements were made from the shuttle, by pointing the instrument at the sun during sunsets, and were used in determining altitude profiles of ozone, nitrogen dioxide, water vapour and stratospheric aerosol.

Scientific and political activities by the AES helped prepare the UNEP Framework Convention on the Protection of the Ozone Layer which was signed by over 20 nations including Canada, the United States and the Soviet Union. The signatory countries agree to conduct research and monitoring and to exchange technical information on the ozone layer. A control protocol is being developed.

The main stratospheric research with balloon-borne instruments was the analysis

of data obtained in the two international NASA Balloon Intercomparison Campaigns (BIC) in which AES participated. So far, altitude profiles of O_3, HNO_3, NO_2, HCl and CH_4 have been derived from the AES measurements.

Development of Brewer ozone spectrophotometers and maintenance of the international Brewer network continued. The ground-based Brewer standard reference has been established at AES, and comprises three independently calibrated instruments. A Brewer instrument was installed at Edmonton.

A three-year international program to improve solar irradiance measurement is being led by the National Atmospheric Radiation Centre. New highly characterized reference pyranometers are being operated at AES Downsview where 230 radiometers were calibrated including twenty reference instruments from seven countries.

(c) Air Quality and Inter-Environmental Research Branch (AQRB)

(i) LRTAP. The Eulerian 12-level model is approaching final assembly. Various component processes (mean and eddy transport, gas phase chemistry, chemistry in cloud, dry removal and scavenging by precipitation) and 4-level prototype model results have been compared with experimental results.

The trajectory and concentration/deposition components of the Lagrangian model are running on the CRAY computer. Evaluation of the trajectory model using CAPTEX-83 tracer data shows good correlation with tracer plume surface concentration data. A more sophisticated chemistry model incorporating sulphur and nitrogen chemistry is being tested and evaluated in a research mode.

The CAPMON was upgraded and four new sites were established, one in Québec and three in Ontario, giving a total of 22 operational sites. A comprehensive Quality Control and Quality Assurance Program was developed, resulting in changes in CAPMON operating procedures. A new data base management system was partially developed as a subsystem of the new Climate Data Base Management System. The 1983 CANSAP Data Summary was published with the 1983 CANSAP Annual Report.

Research to estimate the dry deposition loading to forests was initiated at CFB Borden. Development of the eddy-accumulator instrumentation for measuring the mass fluxes of trace constituents continued. Data from this system showed good agreement with direct eddy correlation measurements of evaporative flux.

Fog sampling on Kent Island continued. Comparison of 1983 and 1939 data showed no significant change in fog water $SO_4^=$ concentrations for flow from the Atlantic Ocean but did show increases of a factor of four for flow from the Maritime Provinces and the eastern United States.

(ii) Toxic Chemicals. In the study of canopy pesticide dispersion, a suitable pesticide spray drift assessment model was put in place for evaluating the fate of sprays applied by aircraft over forests. After surveying available spray models the U.S. Forestry Model was implemented on an IBM microcomputer. A parallel study used a research-grade model with explicit treatment of aircraft trailing vortices.

Air sampling at Mould Bay, NWT, found gas-phase chlordane in all samples, which clearly demonstrates the long-range transport into the Arctic from mid-latitudes.

The ASTRAP model, suitable for estimating the long-range transport of acidic material, has been modified for toxic chemicals and installed on the AS/6 computer. Work on estimating emissions inventories of toxic chemicals continues.

The continuing Niagara River toxic chemical survey indicates that many PCB isomers, phthalates and PAH compounds are gaseous rather than particulate in the atmosphere. The concentrations of gaseous compounds vary on a scale that is regional or synoptic rather than local. Certain PAH isomers, however, clearly show local input into the atmosphere.

(iii) Climate Change. Weekly 'grab flask sample' monitoring of CO_2 for the WMO BAPMON program continued at Alert and Sable Island. AES is preparing to upgrade its BAPMON station at Alert to monitor CO_2 continuously. A calibration laboratory has been established at Downsview and the first two continuous monitoring systems have been assembled. Two temporary stations monitoring aerosol and surface meteorology have been established near Alert to determine optimum siting for the permanent BAPMON stations and intensive field measurements were made in March.

The carbon budget was studied using data from Alert that had been interpreted in terms of the synoptic-scale atmospheric circulation. The spatial and seasonal distributions of CO_2 sources and sinks in the Arctic could be determined using a trajectory model.

Atmospheric turbidities, for Resolute from 1969 to 1980 have a slight increasing trend with a mean of 0.038; the seasonal variation (with a maximum in late winter or early spring and a minimum in late summer) is consistent with aerosol measurements in the Canadian Arctic.

(iv) Core Research. Construction started on a differential absorption lidar (DIAL) system to determine the vertical profiles of sulphur dioxide and ozone.

In July, the field phase of the international marginal ice zone experiment (MIZEX) was completed. Intensive boundary-layer studies were undertaken as a joint AES/BIO experiment to characterize the surface wind stress field associated with varying ice conditions and to measure the modification of the boundary-layer across the MIZ.

In support of the NOGAP, a project was initiated to obtain and disseminate relative baseline meteorological and dispersion data for air quality modelling for the Arctic. A 100 m tower at Inuvik was instrumented at six levels to obtain continuous measurements of dispersion parameters.

Continuing studies of wind-driven entrainment and enrichment at the air-sea interface included an experiment to measure the rate of change of oxygen levels in the upper few centimetres of Lake Ontario during wind mixing. Multi-channel imagery of the ocean off Nova Scotia was analysed to quantify the extent of the breaking wave field. A new instrument was developed in-house to increase the dwell time on the same area of the water surface in order to estimate the depth of mixing from the duration of the breaking waves.

As part of the AES support for the 1988 Winter Olympics, a study was initiated to establish the wind climatology of the ski-jump site at Canada Olympic Park in Calgary. Five 10 m towers were installed parallel to the 90 m jump to establish the frequencies at which the criteria for safe operation of the jump are exceeded.

(v) Air Quality Services. Work on air quality assessment models continued with the addition of a LNG model to estimate the liquid pool size and evaporation rate of LNG that is pouring into water from a ruptured container; the 21 EPA UNAMAP models that are operational on the AS/6; and a climatological model (PLUMELT) to calculate long-term average air concentration and ground deposition of dioxins emitted from incinerator stacks. Because of the lack of demand, the AIMS program was cancelled at the end of 1984. Several EIA reviews were undertaken, in particular, a technique for calculating minimum chimney height, and dispersion models used for EIAs in Canada and disposal of waste in the Arctic atmosphere. AQPAC was extended - the chemicals directory was expanded to 22 chemicals and six radionuclides, and a graphical display capability and a diffusion model for heavy gas application were added.

(d) Canadian Climate Centre

The Canadian Climate Centre issued 275 publications during the year including four issues of Snow Cover Data from 1979-1980 to 1982-1983; the Normals for the period 1951-1980 for Lake Evaporation, Soil Temperature and Days With ...; four issues of the new series Canadian Meteorological History; Series 1, Temperature and Degree Days of the Climatic Atlas of Canada; and 98 issues of the fairly new series Principal Data Summaries.

Programming for Climate Extremes was completed and information on microfiche will be issued for thirty major cities. About 385 000 weather documents were microfilmed, and 600 000 archived. Climate data were supplied in response to 12 000 requests. Another 500 requests were received for magnetic tape copy or special computer statistical analyses of digital data retained in the National Climatological Archive.

(i) Hydrometeorology. Short-duration rainfall intensity-duration-frequency tables and curves were prepared for 500 stations across Canada and a new atlas of these statistics was completed. Fifteen significant events were analysed and prepared for the series Storm Rainfall in Canada. Near real-time water budgets continued to be processed weekly for climate monitoring. Water budget normals for the period 1951-1980 were computed for the 286 operational water budget stations. Interactive computer procedures to assist climate network design were developed and documented.

A comparison of analyses was completed on Saint John River Basin snowcover prepared from satellite data using a digital image analysis system and a hybrid analogue-digital procedure. Comparison of satellite-derived estimates of precipitation with radar and gauge estimates over southern Ontario was initiated. Significant progress was made on the implementation of algorithms to properly map the data, estimate rainfall and derive comparative statistics.

Processing of airborne and satellite passive microwave data was completed for selected time periods and regions as part of the Prairie Snow Cover project. An initial algorithm for determining snow water equivalent from airborne passive microwave data (18 and 37 GHz) has been developed using data collected over the Canadian Prairies in February 1982. Development of an ultrasonic snow depth sensor continued with enhancements to improve sensor performance under varying ambient temperatures.

A model to generate acidic snowmelt shock potential scenarios was developed. Snowmelt and snowpack chemistry were measured for the second season at Dorset, Ontario.

Development of Marine Climate Information Systems continued with the CONAN (CONtour ANalysis) and DUST (DUration STatistics) software, which produces charts and graphical or tabular summaries of persistence and extreme value statistics of climatological data. Energy-related R&D studies resulted in 'Storm Catalogues' for the Atlantic and Pacific offshore areas detailing significant storm events in recent history. A marine climate atlas for the east coast was completed. A mesoscale model for hindcasting winds was evaluated for the Pacific coast and marine wind modelling techniques were investigated.

In the first phase of an impact assessment of climatic change on the Great Lakes, changes in the water budget and lake evaporation were estimated from four scenarios of CO_2 - induced climate change.

(ii) Climate Applications. Continuing research activities included: examination of 'typical' or reference meteorological years that could be used for solar energy applications; improvement of methods for estimating wind speeds at various heights for energy applications; study of historic climatic fluctuations and their impacts; examination of various climate change scenarios on the Saskatchewan agricultural community; and study of the climatology of drought on the Prairies.

Applications of climatology to the design and improvement of the quality of life in urban centres were promoted through the 'Livable Winter City Association', and through publications on the climate of Canadian cities.

Six volumes of Solar Radiation Data Analyses for Canada 1967-1976 were published.

A report on Climatological Ice Accretion Modelling with particular application to electrical transmission lines was completed. A new analysis of wind pressures in Canada for building design was commenced. The first phase of a forest climatology project for elucidating the relationships between forest fire and the coincident synoptic-scale weather has been completed. Another project for estimating changes in the severity of the Ontario

forest fire season induced by the proposed CO_2 climate change scenarios is under way. Applications of climatology to the management of forest seed orchards in Ontario included studies on irrigation scheduling, microclimate modification and climate-seed production relationships.

The impact of possible future climate change on the permafrost regime in Arctic Canada is being evaluated. Four stations will be instrumented to measure ground temperatures and several atmospheric elements concurrently, to test a model designed to predict permafrost response under various climatic conditions.

Climatic data are being collected at Adams Island at the southern edge of Lancaster Sound, to support a project for estimating environmental driving forces around an offshore structure.

(iii) Data Management. A new system to manage climatological data was set up to improve the timeliness of data capture, the productivity of the quality control process, and user access to data.

A system to archive GOES satellite data was set up and tested. Operational archiving will commence when GOES-E is re-established; until then, a partial archive of GOES-W data is being created.

(iv) Monitoring and Prediction. Research continues as reported in CGB, 1983. Near real-time monthly temperature anomaly forecasts are operational based on the autoregressive moving average extrapolation of time series.

(v) General Circulation Modelling. A simple ocean mixed layer and sea-ice model for interactive use in the GCM is being tested in the GCM in long (several annual cycles) climate simulations. Preliminary results are encouraging.

The parameterization of topographically generated gravity wave drag was modified to make use of information about mesoscale orographic height variability obtained from high-resolution orographic elevation data. The modification was tested extensively.

An explicit parameterization of the effects of deep cumulus convection has been partially completed and is being tested.

Tests of an interactive cloudiness scheme in long-range simulations showed reasonable results but revealed some problems, now being investigated, that are associated with the treatment of the energy balance at the surface.

(vi) Radiative-Convective-Photochemical Modelling. Using improved radiative transfer codes and revised atmospheric chemistry, experiments have been carried out with a 1-D coupled time-dependent radiative-convective and photochemical diffusion model to assess the possible effects of increased atmospheric CO_2, N_2O, CH_4, volcanic aerosols, nuclear smoke, and NO_x on atmospheric ozone and temperature structures and surface climate.

Experiments were also carried out with a 2-D stratospheric time-dependent radiative-photochemical transport model to assess the effects of volcanic aerosols from the El Chichón eruption on the seasonal and latitudinal variations of ozone, temperature and mean circulation in the stratosphere.

(vii) General Circulation Diagnostics. Programs for statistical analysis and manipulation of data in the archive were added to the diagnostics package.

The perpetual and annual cycle simulations for January were compared statistically. A study of the semi-diurnal thermal tide in the GCM shows that the amplitude of the simulated tide agrees well with observations but there is a phase differential which is under investigation. A statistical study of the estimates of the 'equivalent sample size' was completed.

Production of a five-year global climatology from NMC analyses is

continuing. Basic circulation statistics have been produced for all months, but January and July also have statistics in terms of zonal wavenumber.

Daily Northern Hemisphere sea-level pressure analyses for the period 1 January 1899 to 31 January 1983 and the GFDL FGGE III-b analyses for January and July 1979 were added to the data archive.

The standard set of general circulation statistics computed from the GFDL analyses and from the ECMWF FGGE III-b analyses are being compared.

A study was completed of the EKE of the Southern Hemisphere in terms of zonal wavenumber based on the ECMWF FGGE analyses and on five years of NMC analyses.

(e) Central Services Directorate

(i) Ice Branch. The use of scanning passive microwave radiometers was studied for acquiring data about ice characteristics and distribution as well as wind speed. Satellite and airborne sensors can be used to do this; operational systems will be in place only in the late eighties.

(ii) Instrument Branch. The Doppler radar being applied to the measurement of the fall velocity of atmospheric precipitants (reported in CGB, 1983) has been split into separate transmit and receive portions to remove the rain shield from the region of common sensitivity. The general sensor performance has improved but its threshold sensitivity in snow has been reduced. Further refinements continue.

A resistance-to-digital converter has been developed using standard digital techniques for the transmission of meteorological temperature and dew-point temperatures over moderate distances, for the range of -80 to +60°C to an accuracy of 0.2°C.

Microwave radiometers have been constructed for measuring upper-air parameters. Water vapour overburden measurements compare to within 10% of nearby radiosonde measurements. Estimates of vertical temperature profiles are promising but need further development.

(f) Field Services Directorate

Various studies, on-going programs and applications of atmospheric science and meteorology to agriculture, forestry, hydrology and environmental issues were undertaken at headquarters and in Regional Centres. Regional activities include: commenting on Environmental Assessment and Review Process (EARP) Guidelines and developing regional screening guidelines; reviewing Environmental Impact Assessments and other EARP documents such as Eldorado Nuclear Limited's "Systematic Modelling Tool for the Analysis of Chronic and Intrusion Exposures from Waste Disposal Sites"; conducting field observations and instrument siting for air quality programs such as the Canadian Air and Precipitation Monitoring Network (CAPMON) and an aerosol survey in Eastern Canada; performing local climatological dispersion studies; responding to environmental emergencies and to simulated exercises; and handling numerous requests from the general public, legal firms, students, and the media for information in applied meteorology, climatology and air quality.

Considerable effort was devoted to making the technologically advanced air quality package of models for environmental emergencies (called AQPAC) useful in AES Regional offices. Quebec Region assumed responsibility for preparing a weekly acid rain report for Eastern Canada. AES Regions undertook seven LRTAP projects, including dry deposition analysis, modelling in Western Canada, West Coast precipitation analysis, and testing of hydrometeorological collectors.

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VII OCEANOGRAPHY

Compiled by: F.M. Boyce

1. Memorial University

(a) Newfoundland Institute for Cold Ocean Science

The Newfoundland Institute for Cold Ocean Science coordinates and encourages the basic oceanographic research of 28 staff members. Research areas include physical oceanography, geophysics, biological oceanography, seabird ecology, biochemistry, chemistry of marine natural products, and regional geographic studies. Interdisciplinary and cooperative fundamental research is stressed.

(b) Physical Oceanography

A program of fjord studies focusses on the deep water exchange in Newfoundland's south coast fjords, particularly Fortune Bay. The objective of the program is to understand the coupling between the exchange process and circulation on the adjacent continental shelf. The data will be used to test a model of the inflow of the Labrador current into Fortune Bay. A numerical model of wind-driven circulation in Lake Melville has been developed.

The continental shelf and shelf break program seeks to understand the interaction of the Labrador current with changes in bottom topography and to understand the effects of topography on the exchange of water between the shelf and the deep ocean. A model emphasizing the interaction of storm-generated low-frequency wave motion with topography has been applied to the Labrador shelf. A numerical model has been modified to forecast ice movement on the Labrador shelf.

The acoustic remote sensing program includes experimental study of the buoyant plume from a submarine spring in Cambridge Fjord and of wind-induced relaxation processes in other Baffin Island fjords. A recently completed theoretical study of acoustic scattering from an elastic sphere that includes the effects of viscosity in a novel way will serve as the foundation of our remote acoustic studies of sediment transport processes.

2. Dalhousie University

Research interests at Dalhousie include nearshore and continental shelf processes (Bowen, Huntley, Chriss), the dynamics of flow through straits (Garrett, Thompson), mixing

and dispersion processes in the open ocean (Garrett, Ruddick), and large scale ocean circulation (Thompson).

(a) Nearshore, Continental Shelf Processes and Flow in Straits

Research on turbidity currents includes an interest in the fundamental mechanisms (Bowen). There is a shortage of data with which to validate models. A study of the Navy Fan, a small system off Southern California has led to some success in reconstructing the flow pattern of recent events. We are encouraged to look at larger systems, particularly the Laurentian Fan. D. Haines is studying basic mechanisms of sediment movement and, in particular, rapidly moving granular flow.

The Canadian Coastal Sediment Study (C2S2), spearheaded by the Hydraulics Research Laboratory of the National Research Council and sponsored by other Government Departments has been a primary focus for nearshore studies. A group from Dalhousie participated in the fall of 1983 at Pte. Sapin, N.B. deploying a bottom-mounted array of current meters, a transmissometer, and an optical backscatter sensor. The experiment was repeated in October, 1984 at Stanhope Beach on the north shore of P.E.I. The measurements were expanded by the addition of the NOAA acoustic sediment sampling system (operated by Haines and Vincent). Very extensive data sets of velocity, pressure and sediment concentrations were obtained in a wide variety of wave conditions. J. Haines has published a paper on the vertical structure of flow from the Pte. Sapin data and is extending his analysis to include the Stanhope Beach data. J. Doering is investigating the spatial distribution of moments computed from a wave-induced velocity field with a view to their application to sediment transport phenomena. Analysis of data from a local pocket beach (Queensland) showed convincing evidence that long period wave motions forced by wave groups is an important component of surf beat (Huntley and Kim, 1985). Kim continues to study the phenomenon in the more extensive Pte. Sapin data. An unexpected time lag between onshore and alongshore currents at incident wave frequencies was observed in both the Queensland and the Stanhope data. A cooperative study (Haines, Huntley, and Matthews) of the relationship between sediment suspension and wave velocity in and near the surf zone is underway using optical backscattering data from Pte. Sapin and data from the NOAA acoustic sediment sampler taken at Stanhope Beach.

An extension of the nearshore work is the study of water and sediment motion close to the seabed in the deeper water of the Continental Shelf. Supported by the NSERC Strategic Grant program, Huntley and Chriss have developed a tripod of current sensors, cameras, turbidity meters and other sensors to measure the physical characteristics of the flow within 1 m of the seabed. Field deployments have been made in water depths ranging from 10 m to 270 m. The instruments are described by Chriss et al. (1983). The data are being analyzed to yield the nature of seabed stress in the presence of waves and currents, the intermittent structure of turbulence, and the spectra of turbulence at different heights above the seabed.

S. Waddell is completing his study of tidal and subtidal flows through the Canadian Archipelago using a numerical network model. M. Mitchell, working at BIO is examining current meter data and CTD data in order to estimate the importance of intrusions on phytoplankton productivity of a fjord.

C. Garrett, J. Middleton, F. Majaess, and M. Hazen have used iceberg trajectory data from the Labrador shelf to determine tidal currents, the effect of wind on iceberg motion, the Lagrangian statics (and hence diffusivity) and Eulerian Statistics. A statistical prediction scheme for trajectories has been developed.

S. Todoroff is analyzing BIO bottom pressure data from the Labrador Shelf off Nain and Hopedale in an attempt to resolve the paradoxes that arose in the analysis by Garrett, Majaess, and Toulany of the historical data from Nain in terms of forcing by atmospheric pressure and wind.

L. Royer is developing a numerical model of the Labrador Shelf which should also help to resolve the response of the Shelf flows to atmospheric pressure, wind, and other forcing, and to elucidate the role of a complex bottom topography.

D. Brickman and F. Dobson (BIO) are studying mixed layer changes at weather ship Bravo in response to air-sea fluxes. Lung Ku (Ottawa), D. Greenberg (BIO), J. Garrett, and F. Dobson (BIO) are completing an analysis and interpretation of the 18.61 year modulation of the M2 tide in the Bay of Fundy.

B. Toulany has examined low-frequency flow fluctuations in the Strait of Belle Isle, finding increased reduction with depth at low frequencies. M. Bormans, J. Garrett, and K. Thompson are studying seasonal fluctuations in flow through the Strait of Gibraltar using historical data.

(b) Mixing and Dispersion in the Open Ocean

Work in the past two years has concentrated on two areas: analysis of the Batfish data from the Warm-core Ring project and theoretical and laboratory studies of oceanic mixing mechanisms. In the Batfish data, we successfully traced the progress of a tongue of cold shelf water as it intruded into the Ring. We observed frontal intrusions and found that, overall, the mixing was dominated by the exceptionally strong shear-driven turbulence.

Laboratory and theoretical work had the general aim of quantifying the effects of double-diffusive ocean mixing. The time scale, stability and density change in the run-down of an intrusive layer was studied. This has led to an experiment designed to measure heat and salt fluxes in the oceanic parameter range. A parameterization was proposed for the eddy viscosity in sheared salt fingering regimes which will be used in the lens spindown study in 1985 (Ruddick). Work was also completed on improving the transient response of laboratory conductivity probes.

Research aimed at quantifying mechanisms of ocean mixing in the next few years will take two complementary directions: a major collaborative field effort, and laboratory measurements of convective velocities on the microscale.

The fieldwork will take advantage of an experiment in which American researchers are presently tracking a large, rotating, subsurface lens of Mediterranean water. We plan to find the lens, survey it with fine structure and microstructure instrumentation, and estimate the rate of loss of energy, heat, salt, and angular momentum due to dissipative mechanisms. The unique situation of the lens being isolated from surface fluxes, having a coherent, identifiable core, and being tracked over a prolonged period, combined with our microstructure observations, will allow a complete budgeting of the large-scale quantities. This is a first for oceanography. The information gained will lead to an increased understanding of the mixing and friction involved in the poleward transport of heat and the slow vertical recycling of deep ocean water, both of which play a part in the ocean's contribution to control of global climate.

The velocity sensors used in the fieldwork will also play a major role in the laboratory, where we will measure microscale velocities and viscous dissipation in several types of turbulent convection. These measurements are needed to interpret the oceanic observations, and will test the predictions of theories of convection.

D. Hebert has been investigating mechanisms of friction which can act on the Gulf Stream. He is starting to analyze moored current meter array measurements from the Gulf Stream region (collected by R. Hendry, BIO). Hebert will look for internal wave stresses which act to dissipate the spatially concentrated energy of the Gulf Stream.

What sets the scale of the steps in a thermohaline staircase, and controls the heat and salt fluxes? Thick layers mean big temperature steps across the interfaces, and so allow large fluxes. D. Kelley is investigating this problem. He has already discovered a scaling relation that seems to work in the ocean, and is currently using numerical models of the process, looking for something in the basic physics which limits the layer thickness.

(c) Open Ocean Circulation

K. Thompson has examined the influence of Ekman pumping over the North Atlantic on the transport of the Labrador Current. Useful comparisons have been made between coastal sea level, observed monthly currents (courtesy of J. Lazier, BIO), and bottom-modified Sverdrup

transports, 1950-80. In a joint project between BIO and Dalhousie, the spatial scale of monthly sea surface temperatures from Cape Hatteras to Cape Farewell, and their relationship to climate and fish recruitment is being examined. On a completely different topic, a new method for estimating the occurrence of extreme sea levels and currents has been developed with J.F. Middleton.

3. Bedford Institute of Oceanography

(a) Ocean Circulation Division

A major two-year study of the eddy scale structure of the Gulf Stream near 60°W continues with the successful recovery and redeployment of an array of five-year long moorings. Principal investigator R. Hendry is collaborating with the Woods Hole Oceanographic Institution in a study of the meandering and eddy structure of the upper and deep portions of the flow. A hydrographic grid surrounding the mooring area is being occupied at six month intervals.

The study of the Labrador Sea continues with effort directed toward development of a diagnostic model to elucidate the dynamics of the mean flow. The analysis of the Polar Front data set collected in the southern Labrador Sea has concentrated on energetics and mixing across the front. J. Lazier is maintaining the long-term moorings on the Labrador Shelf near Hamilton Bank. Initial analysis of these data indicates significant interannual variability of the flow and water properties.

In preparation for a proposed major study of the circulation and mixing in Baffin Bay starting in 1988/89, four survey moorings were again set by C.K. Ross at selected sites around the Bay. Historical data, including the EAMES data set, are being edited and archived for background studies. This program may not continue past 1984/85 due to reduced funding.

A number of projects are aimed at examining processes on the east coast continental shelves. Work on tidal rectification over bathymetric features such as Georges Bank is nearing completion. Analyses by D. Wright, J. Loder and K. Tee revealing important sensitivities of the predictions to the variation of the friction coefficients (through stability, bottom roughness, etc.) and to the nonlinear terms have been published. Also, a model of the estuarine circulation within the Gulf of St. Lawrence by K. Tee has shown good agreement with measured cross-channel average properties; however, the observed flow was dominated by a strong seasonal circulation with large along-channel and cross-channel variations. Tidally-generated large amplitude internal waves were observed in the vicinity of Sable Island, and by SLAR imagery from aircraft overflights covering the Scotian Shelf and Grand Banks. Modelling of the generation process is underway by H. Sandstrom. These high amplitude waves are believed to represent a highly nonlinear, dissipation mechanism for the internal tide as it propagates shoreward over the shelf break.

A group headed by S. Smith participated in a successful pilot experiment for HEXOS, an international study of the humidity flux over the open sea. He and F. Dobson continued their evaluation of bulk formulae required for large scale budget calculations of the air/sea heat flux as proposed for the world climate program. A study of surface wave generation mechanisms by the direct measurement of the atmospheric input was advanced through additional field effort.

As part of the MIZEX field program, a large-scale (100 km) array of satellite-tracked ice beacons was deployed in the East Greenland ice field under the supervision of G. Symonds. Analysis of their mean motion and variance has been used in conjunction with historical data to develop a stochastic model for the prediction of iceberg movement. A similar field program is in preparation for the Labrador Coast including development of new instrumentation suitable for ice dynamics studies. Modelling the dynamics and thermodynamics of the Labrador ice sheet by G. Symonds and M. Ikeda has shown high correlation between interannual variability of ice and forcing parameters. The local dynamic modelling of iceberg drift by S. Smith was advanced by another field program near the Strait of Belle Isle.

Field trials by N. Oakey of a new microstructure profile, ESPONDE, showed the instrument to be capable of routine and continuous cycling to depths of nearly 600 m. This capability will be extended to 1000 m as required for a proposed field study to measure dissipation and mixing in a 'meddy'. In addition, newly-developed instrumentation will be used to study mean shear and turbulence simultaneously in mixed-layer dynamics experiments. N. Oakey, in collaboration with University of Washington scientists, also participated in the Tropic Heat field program in the equatorial Pacific where studies included measurements of energy dissipation and turbulent mixing above and within the equatorial undercurrent.

(b) Coastal Oceanography

Surface wave climate studies by H. Neu based on a time series of visual observations from the North Atlantic have revealed strong three- to seven-year fluctuations and a continuous increase in sea state over a 13-year period (1970-1982). In addition, a program to develop a state-of-the-art spectral wave model and test it against east coast measurements with pitch-and-roll buoys has been initiated by W. Perrie. Timely estimates of sea surface temperature in Canadian offshore waters, based on NOAA 'oceanographic analysis' charts, satellite data, and scattered in situ observations, are now being issued as part of a monthly 'state-of-the-ocean' message (contact P.C. Smith). Also, 2000 data days of bottom temperature measurements have been collected in support of the inshore fisheries temperature climate study (B.D. Petrie). D.A. Greenberg has developed numerical models of the Grand Banks and Scotian Shelf to study the mean, wind-driven and tidal circulations; MEP Ltd. of Toronto are utilizing one model under a PILP grant to improve their commercial oil spill trajectory model originally obtained from AES.

An investigation of Gulf Stream warm core rings by C.L. Tang has indicated the importance of interleaving at the boundary of subsurface thermohaline intrusions. In the Gulf of St. Lawrence, G. Bugden's study of heat, salt and ice budgets concluded that the dominant mode for freeze-up is gulfwide; however, during 'light' ice years, ice formation in Northumberland Strait and ice transport through Belle Isle Strait become significant. A continuing joint study of the Gaspé Current with the University of Quebec at Rimouski has revealed that the current is less stable during spring and summer than winter time. On the Grand Banks, B. Petrie's simple models of the circulation, exchange processes and iceberg drift have been used to provide an estimate of the seasonal distribution of icebergs which is in reasonable agreement with observations. This analysis, part of a joint BIO/Dalhousie/Industry venture, indicates that meandering and eddy formation by the Labrador Current is an important process for exchanging icebergs on and off the Banks. Also, K. Kranck has derived a general model of suspended sediment grain size distributions and applied it to data for fresh water and marine environments. Her sediment laboratory, with sponsorship from RODAC, has continued studies of Miramichi dredge spoils. Her work has shown that the dumped spoil initially behaves as a high density fluid and spreads well beyond the designated site, but in time it consolidates so that only the top few millimeters will resuspend. Circulation and dispersion studies on Browns Bank, by P.C. Smith, as part of a fisheries research program to study the ecology of haddock, have established a 15-day 'residence time' for the clockwise gyral circulation of the Bank in the absence of wind. In addition, results from his long-term moorings off Cape Sable have revealed important interannual variations associated with the timing and strength of the fresh water pulse from the Gulf of St. Lawrence.

(c) Chemical Oceanography

Trace metal geochemistry studies have involved the development of methods for the collection of deep-ocean suspended particulate matter for the examination of the extent of trace metal association with different types of host materials and investigations of the nature of particulate-dissolved metal interactions in the St. Lawrence estuary (P.A. Yeats and J.A. Dalziel). Work has also been carried out on the uptake of metals by deep-oceanic phytoplankton communities and the effects of iron on planktonic growth rates and abundances (P.A. Yeats).

Field experiments have been completed on the exchange of cadmium and lead between aqueous, particulate and biological phases in intertidal mud flats bordering the North Sea, using medium-scale artificial enclosures developed by the Institute of Marine Research,

Bremerhaven (D.H. Loring). The results show that both metals are rapidly taken up by particulate matter and transferred to the surficial sediments. Sessile organisms show a concomitant increase of the metals in their tissues with the sites of accumulation being the gill and respiratory organs rather than the alimentary canals. These experiments have confirmed that medium-scale enclosures, of the type developed in Germany, can reliably simulate conditions in the external, natural environment and provide a valuable means of determining the effects of contaminants in intertidal communities.

Other field experiments are being carried out to examine the rates and mechanisms of the biodegradation of Sable Island condensate under the conditions that prevail in a sandy beach environment (E.M. Levy and P.M. Strain). Changes in the chemical composition of the condensate have been found to occur much more slowly than work elsewhere on the degradation of light crude oils suggests, or than might have been expected on the basis of the physical-chemical properties of individuals components of the condensate. Further investigations are being carried out to determine the extent to which microbiological degradation may be enhanced by the provision of nutrients to oiled beach material under otherwise natural conditions of exposure.

Time-series measurements of the discharge, and stable isotopic composition of organic matter by the St. Lawrence River have been made since August 1981, as part of an international study of carbon in world rivers (R. Pocklington and F.C. Tan). This study was conducted in order to determine the relative contribution the St. Lawrence River discharge makes to organic carbon within the estuary and Gulf of St. Lawrence. Studies of the carbon isotope geochemistry of the Amazon, Orinoco and Yangtse Rivers have also been started in collaboration with the Massachusetts Institute of Technology (F.C. Tan). Further studies of sterols in the lipid fraction of particulate material have been carried out within Bedford Basin in an effort to determine the predominant terrigenous and anthropogenic sterols in a nearshore area and to examine seasonal variability in sterol concentrations in relation to biological activity (R. Pocklington and J.D. Leonard).

Studies of the incidence of sea-ice meltwater in various Arctic areas, including Hudson Strait and Fram Strait, and paleoclimatic studies of Lake Melville sediments are being continued (F.C. Tan). Investigations of the chemical and physical oceanography of Fram Strait, which is situated between Spitzbergen and Greenland, have been inititated in collaboration with institutions in the Federal Republic of Germany and Sweden using the new icebreaker FS Polarstern (E.P. Jones). Preliminary evaluations of the results of this cruise reveal the existence of an important return flow of Atlantic water along the east Greenland Slope. Water within the East Greenland Current was also identified as having chemical characteristics that suggest that it is derived from the nearsurface halocline in the Arctic Ocean which has been extensively studied at the CESAR Ice Camp.

An investigation of the distribution of radionuclides in the vicinity of Thule, Greenland, has been carried out in collaboration with Danish scientists. Attention has been paid in this study both to plutonium, released in 1968 following the crash of an aircraft carrying nuclear weapons, and to nuclides released from the Sellafield nuclear fuel reprocessing facility that can be detected and used as tracers in physical oceanographic investigations of the North Atlantic and Arctic Oceans (J.N. Smith and K.M. Ellis).

The results obtained from environmental monitoring of the Point Lepreau nuclear generating station, subsequent to the commissioning of the reactor, indicate that tritium is the only nuclide whose routine releases can be detected as being above background environmental levels. Studies of the thermal plume from the discharge of cooling water resulted in the identification of conditions of vertical containment of the plume under stratified spring conditions caused by high freshwater discharge from the Saint John River. The accumulated results of the Point Lepreau Monitoring Program have been widely used in the assessment of the environmental impact of the construction of a second CANDU reactor on the Point Lepreau site (J.N. Smith and K.M. Ellis).

(d) Ocean Technology

Anemometers and thermistor chains for long-term, unattended operation on drifting buoys are being developed (G. Fowler, J.-G. Dessureault). First generation thermistor

chains are going into routine use and a second generation system with salinity measuring capability is being considered. Fast CTD sensors and a dissolved oxygen sensor are being evaluated with a view to improving physical oceanographic parameter measurement (A.S. Bennett, M. Stepanczak). Substantial activity continues on biological sensor development (A.W. Herman) including: a second generation vertical profiling pumping system with a servo-controlled winch (A.W. Herman, M. Mitchell, J.-G. Dessureault) for constant depth sampling; an optical zooplankton sensor designed to measure a wide size range of species (A.W. Herman, M. Mitchell); and analysis of engineering data is being carried out to answer both biological and engineering questions.

Applications of acoustic techniques to the study of the water column are being carried out with emphasis on the acoustic signature of internal waves and biological targets (N.A. Cochrane). Methods of digitizing and logging high frequency acoustic data have been developed (A.S. Bennett, G. Youle) and data obtained during the investigation of a dying warm ring will be analyzed (N. Cochrane). Acoustic positioning methodology is being used to study the behavior of various oceanographic devices such as surface current Lagrangian drifters (D.L. McKeown). Equipment recently acquired is being evaluated to determine its applicability to applications such as mooring relocation, towed body positioning and sample site positioning. The use of acoustic doppler current profiles has become very prominent and engineering development is progressing rapidly (J. Whitman).

Development of improved oceanographic moorings continues (G. Fowler). During the 1983 field season losses were reduced to zero. Efforts are now being redirected toward creation of new mooring concepts (G. Fowler, J. Hamilton). The use of servo winch technology for heave compensation (J.-G. Dessureault) is being expanded beyond its application to CTDs and new, streamlined instrument packages (J.-G. Dessureault) are being designed to exploit this technology. One such device is a mini-rosette water sampler and another is an in situ particulate matter sampler (G. Fowler). The latter will permit the collection of up to 12 large volume filtered water samples from various depths collected under supervision from the surface.

4. Université du Québec à Rimouski, Département d'océanographie

(a) La Biochimie des milieux marins

L'estuaire du Saint-Laurent est un véritable laboratoire pour l'étude des phénomènes liés à la diagénèse primaire.

On mesure la distribution verticale des propriétés du sédiment sur des carottes subdivisées à des intervalles de l'ordre de quelques millimètres. Chaque sous-échantillon est soumis à une batterie d'analyse donnant entre autres la distribution granulométrique, le potentiel d'oxido-réduction, le pH, la porosité, ainsi que les teneurs en carbone organique, en nutriants, en sulfate, etc. La distribution de certains radionucléides, par exemple le thorium-234, nous permet d'obtenir une mesure du brassage biologique. Nous procédons aussi à la mesure directe des taux de sédimentation en utilisant des pièges à sédiments dérivants. En comparant les produits de solubilité ionique calculés à partir des concentrations mesurées dans les eaux de pore avec les valeurs théoriques, il nous est possible de prévoir quelle sera la phase solide contrôlant la solubilité. Par contre, les mesures de vitesse s'avèrent plus difficiles, d'autant plus que les réactions sont fortement influencées par les bactéries. Nous utilisons de plus en plus les techniques de la microbiologie pour identifier les différentes bactéries agissant sur une espèce chimique donnée et, en même temps, des simulations en laboratoire permettent de mesurer les facteurs responsables des vitesses des réactions. De plus, nous utilisons les résultats des diverses mesures effectuées sur les échantillons dans un modèle de diagénèse conduisant au calcul du bilan de masse pour chaque élément impliqué.

(b) Hydrodynamique des estuaires et des zones côtières

Les buts généraux de notre programme de recherche sont les suivants: étudier la dynamique de circulation et le processus de mélange estuarien dans l'estuaire maritime et le golfe du Saint-Laurent en utilisant une approche descriptive et théorique, et mettre ces processus en relation avec la distribution et la dynamique de la communauté planctonique,

ainsi que le transport de matières nutritives et polluantes entre l'estuaire et le golfe.

Notre analyse récente des observations courantométriques prises en 1979 a montré le caractère complexe et la grande variabilité spatiale et temporelle du courant résiduel de l'estuaire maritime. Le système de circulation résiduelle proche de la surface dans l'estuaire est associé avec des séries de tourbillons cycloniques et anticycloniques avec une échelle spatiale de 50 km.

Une analyse spectrale croisée a montré que le courant côtier, à une station localisée à proximité de la côte sud, était corrélé négativement avec le courant observé sur une station proche de la côte nord avec une cohérence élevée dans une gamme de périodes supérieures à sept jours. Une évidence a été trouvée quant à l'existence de courants transversaux à des stations situées au centre de l'estuaire maritime.

À partir d'un modèle numérique simplifié, nous avons étudié les ondes côtières piégées, à basse fréquence, dans un chenal à deux couches et de fond variable et nous avons appliqué les résultats à l'estuaire maritime du Saint-Laurent. On a trouvé que la caractéristique principale des tourbillons et des courants transversaux peut être expliquée par la superposition des ondes barocliniques de plateau à longue période voyageant dans des directions opposées et qui sont vraisemblablement générées par les variations de débit fluvial. En effet, les oscillations de basses fréquences sont responsables dans l'estuaire d'environ 50 % de l'énergie cinétique observée. La nature et les mécanismes générateurs de ces courants sont encore mal connus. Ces mouvements se caractérisent par de longues périodes, de petites échelles spatiales et par une intensification des courants de surface. Notre travail théorique actuel consiste à étudier l'influence du vent et du courant moyen sur ces ondes topographiques. Les résultats analytiques seront comparés aux observations recueillies dans l'estuaire et le golfe du Saint-Laurent.

(c) Analyse statistique des données océanographiques

Nous nous intéressons plus particulièrement à l'analyse conjointe de plusieurs tableaux de données du type 'échantillons x variables' indicées par le temps, encore appelées données à trois indices ou données cubiques. Différentes méthodes ont été proposées pour décrire de telles données et comparer les différents tableaux. Elles découlent d'une généralisation soit de l'analyse en facteurs communs et spécifiques, soit de l'analyse canonique, soit de l'analyse en composantes principales, soit de l'analyse factorielle des correspondances. L'introduction de l'opérateur d'Escoufier, associé à un tableau de mesures, et du produit scalaire entre opérateurs ont permis de définir une distance enclidienne entre les opérateurs, c'est-à-dire entre les tableaux, et ainsi de les comparer. Un programme informatisé, dénommé STATIS, assure l'exécution des calculs pour différents types de données (données de distance, de similitude, ultramétriques et de profil).

Différentes applications ont déjà été menées dans le cadre de l'évolution de polluants métalliques chez la moule bleue, de variations spatio-temporelles de l'activité des enzymes digestives du zooplancton marin et du transport de sédiments côtiers avec traceur radioactif. D'autres domaines d'application sont actuellement à l'étude.

Par ailleurs, nous nous préoccupons des méthodes d'échantillonnage aléatoires en mer. Le programme informatisé d'un plan optimal d'échantillonnage en milieu stratifié a été mis au point pour estimer une ou plusieurs caractéristiques du milieu. D'autres protocoles d'échantillonnage en mer seront également examinés.

5. Centre Champlain des sciences de la mer, Pêches et Océans, Québec

(a) Océanographie physique

Deux rapports portant sur des mesures océanographiques dans le panache de la Grande Rivière de la Baleine au sud-est de la baie d'Hudson ont été publiés. Les données de ces rapports ont été recueillies dans le cadre d'un projet multidisciplinaire visant à étudier à la fois les aspects physiques et biologiques du panache sous un couvert de glaces. L'échantillonnage a été effectué sous diverses conditions de débit afin de prédire l'impact de l'aménagement hydro-électrique de la rivière sur le régime de circulation et la

production de plancton de cette région côtière (P. Larouche, S. Peck).

Quelques campagnes océanographiques ont permis de compléter une série de mesures de courants et de vent dans le cadre d'une étude sur la circulation au large des Escoumins (D. Lefaivre).

On participe également au traitement des résultats d'un modèle à trois dimensions du courant résiduel induit par la marée au large du Sud-Ouest de la Nouvelle-Écosse (D. Lefaivre).

(b) Océanographie chimique

La publication de trois rapports complète l'étude entreprise sur la distribution et le comportement du mercure dans le fjord du Saguenay, milieu ayant été contaminé de 1946 à 1976 par des rejets industriels riches en mercure. Du point de vue de la salubrité des écosystèmes, les données recueillies permettent de conclure que seuls les organismes vivant en contact avec les sédiments contaminés et ceux qui y sont reliés par les réseaux trophiques continuent à être affectés par la contamination mercurielle. Les travaux sur le mercure se poursuivent cependant par l'étude sur la distribution de ce métal dans les eaux de l'estuaire maritime et du golfe du Saint-Laurent. Ces recherches, couplées aux travaux sur l'utilisation de la moule bleue comme espèce indicatrice de la pollution, devraient permettre une réévaluation de la contamination mercurielle du littoral maritime du Saint-Laurent (C. Gobeil, D. Cossa, J. Piuze).

On effectue aussi une étude sur le comportement de divers éléments (Al, Fe, Hg, Cd, F, I, Se) dans la zone de mélange eau douce/eau salée. Les résultats témoignent du comportement conservatif de l'iode, du fluor et du sélénium alors que le fer et l'aluminium dissous démontrent un enlèvement aux très basses salinités (C. Gobeil, K. Takayanagi, D. Cossa).

L'étude de l'apport en minéraux à l'estuaire par le fleuve Saint-Laurent se poursuit dans le cadre du programme SCOPE/UNEP (Carbon and Minerals Transport by Major World Rivers). Les résultats publiés ont montré les tendances à long terme et les variations saisonnières des éléments majeurs (Na, Cl, sulfates, etc.). Les éléments mineurs (Fe, Mn) et quelques éléments en trace, comme le cadmium, sont à l'étude (G. Tremblay, D. Cossa).

(c) Océanographie biologique

On a réalisé plusieurs projets de recherche visant à étudier les processus de production primaire et secondaire dans l'estuaire du Saint-Laurent. Les différentes études ont porté sur le contrôle de la répartition temporelle et spatiale de la production planctonique, l'influence des variations du mélange vertical sur la production et sur les facteurs contrôlant la distribution spatiale et temporelle de l'activité bactérienne (potentiel hétérotrophique) et la distribution de Protogonyaulax tamarensis, principale algue responsable de la toxicité chez les mollusques (J.C. Therriault, R. de Ladurantaye, M. Levasseur, J. Painchaud).

D'autres travaux ont porté sur l'écophysiologie du phytoplancton. Ces études ont nécessité l'utilisation d'enceintes fermées où les conditions environnementales sont contrôlées afin de détecter les facteurs responsables des variations physiologiques et des paramètres photosynthétiques. Une méthode simple pour étudier la photoadaptation en continu du phytoplancton en utilisant deux fluorimètres et une source de lumière brillante a également été developpée (S. Demers, J.C. Therriault).

Le rôle biologique du phytoplancton et de ses produits d'excrétion dans le déclenchement des pontes d'invertébrés dans l'écosystème marin a fait l'objet d'un projet particulier (M. Starr, J.C. Therriault).

Enfin, un projet sur la productivité de la flore épontique a été développé (S. Demers, J.C. Therriault).

6. GIROQ, Groupe interuniversitaire de recherches océanographiques du Québec

Le GIROQ regroupe des chercheurs des universités McGill, Laval et de Montréal. En 1984, les activités du GIROQ en sciences physiques se sont déroulées dans le cadre des études menées dans l'estuaire et golfe du Saint-Laurent et dans les baies James et d'Hudson.

Estuaire et golfe du Saint-Laurent: analyse de la variabilité à long terme des caractéristiques des masses d'eau et de la circulation dans l'estuaire maritime, principalement à la tête du Chenal laurentien, à proximité de l'embouchure du Saguenay (R.G. Ingram, McGill); étude de la dynamique des fronts à petite échelle (R.G. Ingram); étude de la variabilité à court terme causée par les vagues dans l'estuaire et golfe (A. Bah et Y. Ouellet, Laval); formes du phosphore dans la matière particulaire et les sédiments (M. Lucotte et B. d'Anglejan, McGill).

Baie James: étude des caractéristiques des masses d'eau et de la circulation dans l'Estuaire de la rivière Eastmain et à son embouchure dans la baie James et effets de la réduction des débits d'eau douce (R.G. Ingram, S. Lepage, McGill); étude du régime sédimentaire de l'Estuaire de la Rivière (B. d'Anglejan et J. Basmadjian, McGill); étude du mélange en baie James pendant l'hiver (R.G. Ingram, McGill)).

Baie d'Hudson: étude de la circulation et des caractéristiques des masses d'eau du détroit de Manitounuk et de l'embouchure de la Grande Rivière de la Baleine dans l'hiver (R.G. Ingram, J.C. Deguise, McGill).

7. McGill University

(a) Institute of Oceanography

Research focusses on the dynamics, sediment distribution and geochemistry of estuarine and coastal areas. Amongst the effects considered are the influence of an ice cover, changing freshwater input both from climatic variability and hydro-electric development and altered sources of suspended matter, nutrients and other properties. Study areas include Hudson Bay and James Bay as well as the St. Lawrence River.

(b) Hudson Bay

No new field work was done in 1984. Analysis of data collected in the winters of 1982 and 1983 showed a large interannual variability in the magnitude of the coastal circulation and the plume configuration of the Great Whale River. Both sea ice conditions and large scale atmospheric forcing (on the scale of Hudson Bay) are thought to account for a large part of the observed variability. Further work on entrainment and mixing across the strong pycnocline bounding the river plume was completed. A strong relationship between the generation of high frequency internal waves, upward nutrient transport and primary production under the ice was shown (Ingram, Legendre).

(c) James Bay

The focus of recent studies has been the response of the Eastmain River estuary to a permanent cut of over 90% in freshwater discharge. The observed response of the estuary included modification of the tidal and mean circulation as well as a major upstream salinity intrusion. A one dimensional model for the transition period was developed (Lepage).

A study of the winter current regime near the La Grande River outflow and adjacent waters was done. A sharp separation in the degree of vertical mixing in the surface layer was evident between landfast and pack ice (almost 95% cover) regions.

Previously reported studies of circulation in the St. Lawrence estuary and the Avalon Channel region were continued this past year. Emphasis was placed on analysis of existing data sets.

A study of the chemical partitioning of phosphorus between the organic and inorganic phases of the seston in the St. Lawrence upper estuary was completed. The monitoring of

sedimentological changes in the Eastmain estuary following river cut-off two years ago was continued.

8. Marine Sciences and Information Directorate, Fisheries and Oceans, Ottawa

The Ocean Science Affairs Branch provides a focus for the establishment of national and international policies, programs and priorities for the oceanography program of the Department of Fisheries and Oceans. In 1984, staff participated in Federal R&D Programs such as the Energy R&D program, the Canadian Climatic program, the Northern Oil and Gas Action Plan, Program for Industry Laboratory Projects, the Unsolicited Proposal and Source Development programs, the Environmental Studies Revolving Fund, etc. The branch provided national coordination for DFO environmental position statements on the Beaufort Sea Hydrocarbon Production Proposal, the Venture Development Project (Sable Island), the Bent Horn Production Project, Point Lepreau 2 Nuclear Power Generating Station, and Renewed Petroleum Exploration in Canada's West Coast Offshore. The Canadian input of real-time subsurface temperature and salinity data to the Integrated Global Ocean Services System (IGOSS) approached 800 messages in 1984. The aircraft-deployed Fluorescence Line Imager, which has been developed under contract to monitor chlorophyll a concentrations as a measure of phytoplankton distributions, is now undergoing evaluation trials, and plans are being made for applications in 1985-86. A contract continued for the Adams Island ice deformation study being carried out by the Division of Building Research (NRC) to determine Arctic sea-ice forces against fixed structures. Work was completed on James Bay river plumes and the Bay of Quinte Lake Ontario flow exchanges.

The Marine Environmental Data Service (MEDS) archives oceanographic data collected around Canada, including the northeast Pacific, Arctic, and northwest Atlantic oceans. The Canadian Marine Data Inventory continued to expand in 1984. In addition to its ongoing wave climate studies, MEDS carried out a major wave climate study on behalf of the Royal Commission on the Ocean Ranger Marine Disaster.

The Scientific Information and Publications Branch (SIPB) provides the national focus for fisheries and oceans scientific and technical information. It produced and distributed about 12,000 printed pages last year including the widely-read monthly Canadian Journal of Fisheries and Aquatic Sciences. SIPB is also the input centre for the Aquatic Sciences and Fisheries Information System sponsored by Food and Agriculture Organizations/Intergovernmental Oceanographic Commission.

9. National Water Research Institute, Burlington

Physical limnology research at the National Water Research Institute is carried out by two Divisions, the Aquatic Physics and Systems Division, and the Hydraulics Division. The former deals with the observations, theory and simulation of water movements in large lakes and the optical properties of lake waters. A program of environmental simulation links physical studies with biological and chemical research carried out at the Institute. The latter deals with riverine problems such as sediment transport and flow in ice-covered rivers, as well as air-water interaction, shore erosion, design of breakwaters, and scale model studies. An engineering component of the Hydraulic Research Division participates in instrument development.

(a) Physical Limnology

The study of the interaction of the Niagara River plume with Lake Ontario continued in 1984. Further experiments were made with satellite-tracked drifters (C.R. Murthy), and the results show the dominant effects of winds and large scale circulations on the path of the Niagara River outflow. The principal conclusions to date are summarized in the bibliography.

Analysis of the Lake Ontario circulation experiment under the leadership to T.J. Simons has continued. Principal findings are that currents along the north shore of Lake Ontario are strongly correlated with the wind, but topographic wave effects must be included to produce adequate simulations of observed currents. Along the south shore, a strong eastward flow persists throughout the year while the water transport in the deeper parts of the lake is generally to the west. It appears that non-linear effects must be

included if seasonal current patterns are to be reproduced by hydrodynamic models. The measured lake circulation helps to explain the observed distributions of contaminants in the sediments.

Analysis of the 1979 and 1980 Lake Erie experiments is nearing completion (F.M. Boyce). This year's study has focussed on the spatial structure of the dominant near-inertial current component in the summer months (F.M. Boyce, L. Royer, P. Hamblin). The initial response of the Central Basin to wind forcing can be described in terms of Ekman dynamics with a variable vertical eddy viscosity to which is added a surface slope term to account for the closed nature of the basin.

Studies of convection near a density extremum continued (P. Hamblin). In a laboratory experiment reported by Marmoosh et al. (1984) a remarkably simple expression was found for the penetration distance of a lighter fluid over a heavier layer before the density extremum arrests the horizontal intrusion by vertical sinking.

Simulation of long-term distributions of temperature, salinity, and other water quality variables in lakes and reservoirs has been reported by Patterson et al. (1984). The modelling approach is of geophysical interest as the physical processes responsible for the distribution of heat are represented in the model. For example, the effect on the mixing of shear associated with basin-scale internal waves is taken into account.

(b) Environmental Simulation

The interfacing of ground water and surface water contaminant transport models has been carried out using data collected near a nuclear waste dump site (G. Bobba and D. Lam, 1984). Watershed models for investigating acid rain problems have been applied to several sites in Ontario, Quebec, and the Atlantic regions (D. Lam, G. Bobba, M. Thompson, A. Fraser). A toxic substance model, TOXIFATE, has been verified in Lake Ontario with chlorinated benzene data (E. Halfon). Statistical procedures have been applied to discern toxic chemicals and their sources in the Niagara River (A. El-Shaarawi). Operational water quality models have been applied to 10 years of data for Lake Erie and 12 years of data for Lake Ontario (W. Schertzer and R. Stevens). Climatic model linkages on air-water heat transfer have been developed (W. Schertzer and T.J. Simons).

(c) Environmental Optics

The work of Environmental Optics Section is concerned with the experimental and theoretical description of the aquatic environment as depicted by the relationships among the optical properties of a natural water mass and its physical and biochemical behaviour. Direct measurements of the underwater light field are used in conjunction with spectral radiance measurements obtained remotely from optical sensors mounted on ships and satellites to assess the applications of spectro-optical data to water management problems. Reports (R.P. Bukata, J.H. Jerome and J.E. Bruton) have been recently generated relating the colour of lake water to sediment, chlorophyll, and dissolved organic loading; discussing and intercomparing the optical properties of the Great Lakes (exclusive of Lake Michigan); evaluating the use of transmissometry at NWRI; and presenting the dependency of irradiation and primary production upon solar zenith angle.

(d) Shore Processes

A composite divided scale model for radar backscatter from the ocean surface was constructed for the remote sensing of surface winds using microwave radar. The primary scattering mechanism was taken to be Bragg scattering and an equilibrium wavenumber spectrum was derived on the assumption that the short wave energy density reflects a balance between direct wind forcing and dissipation. The model was tested against aircraft data with very encouraging results. (M.A. Donelan).

A study was initiated on the south shore of Lake Ontario, at Stoney Creek, to examine the rates and processes of underwater erosion of exposed glacial sediment in the nearshore slope. This is the most common type of substrate in shallow water in the lower Great Lakes and its erosion has an effect on both the recession of the adjacent shore bluff and on the

supply of sediments to the Lake (N. Rukavina, J. Coakley and A. Zeman).

The freeboard requirements for caisson-retained artificial islands suitable for petroleum production in the Beaufort Sea were examined using physical models. The problem of modelling overtopping and spray on these structures was also addressed. This work was partially funded by the Panel on Energy Research and Development (M. Skafel, C. Bishop).

The CCIW Wave Direction Buoy was deployed off Stanhope, P.E.I. to collect wind and wave data in support of the Canadian Coastal Sediment Study in October 1984 (M. Skafel).

Work on design requirements for floating-tire breakwater continued and a workshop was held in November 1984, co-sponsored by the U.S. Army Corps of Engineers (C. Bishop).

A compilation of waste disposal sites in the coastal zone of the Great Lakes has started. Exposure of these sites by wave action could have significant effect on local or even regional water quality. Potential hazards are being evaluated, based on proximity to the shoreline, local recession rates, and subsurface hydrogeology (J. Coakley).

(e) Environmental Hydraulics

In support of Hydro-Québec (Archipel Project) G. Tsang studied the formation of frazil and anchor ice and their hydraulic effects in the Lachine Rapids of the St. Lawrence River near Montreal. Anchor ice lumps as thick as 2 m are not uncommon in this reach which has a depth of 10 m. The open water of the Lachine Rapids is a breeding ground for an abundance of frazil ice.

(f) Instrumentation

J. Ford and G. Dolanski produced a dissolved oxygen profiling system for limnological applications. The sonde has AC power and bi-directional microprocessor communication on a single circuit, allowing data to be displayed, stored, and printed during deployment. The system has provided profiles of oxygen distribution in detail not previously available.

A second-generation meteorological buoy has been developed by J. Valdmanis to provide a sensor complement of improved accuracy and reliability. Solar power, satellite monitoring, and increased data recording capacity have been added to extend mission life. Efforts are being made to promote the commercial development of a "BASIS" (buoy for Air/Sea Interface Sensing) that combines essential meteorological equipment with wave height and direction sensors on a low-cost toroidal buoy structure.

Ice-related work has prompted several developments. A frazil ice sensor and recorder that uses a calorimetric method is under development for deployment in small rivers. An under-ice video system has been assembled to examine the underside of river ice, and an under-ice drogue has been developed for the study of river-induced currents in Yukon lakes.

10. National Water Research Institute, Western and Northern Region, Winnipeg

Research is conducted on physical limnology of large shallow lakes in support of water management problems in the prairies. Currently, interest is focussed on hypereutrophic lakes and physical-biological interactions by resuspension of sediment and nutrients. Suspended sediment collected with a prototype sampler in Lake Manitoba had two distinct layers with large quantities of sand in the upper layer and a high silt load in the lower. A two layer regime was also found in the lake currents. Since the water column was not thermally stratified, the two layers may be produced dynamically by density stratification caused by the high silt load near bottom. The unusual particle size distribution, which was explained in terms of the origin of the resuspended sediment and subsequent transport by lake currents, suggest a decoupling of lake turbulence between the two layers during high winds (B.C. Kenney).

Work is continuing on simulation of nutrient levels in lakes using simple dynamic models. The simulation of time varying phosphorus concentrations for Lake Washington from 1962 to 1978 provided substantial insight into the effects of the 1972 and 1975 floods. The simulation of phosphorus concentrations in a chain of four lakes in the Qu'Appelle

Valley, Saskatchewan, required extension of the dynamics concept to account for high prairie evaporation, precipitation and variable lake levels. It was found that three time scales were necessary to dynamically describe this lake chain.

Changes in South Indian Lake, Manitoba, following impoundment for hydropower are being studied, using water and nutrient budgets from an adjoining bay, Long Bay. Vertical temperature profiles along the bay axis show horizontal gradients in the inverse stratification that suggest the presence of an under-ice circulation. Temperature fluctuations accompanying the two layer flow are intense and show large changes in the thermal structure over a short period of time. A low velocity current meter was designed to directly measure the flow in the narrow channel joining Long Bay to South Indian Lake. Currents in excess of 1 cm/s were found. Winter circulation could dominate the water renewal time in the bay with concomitant impact on the budget studies.

11. National Water Research Institute, Pacific and Yukon Region, West Vancouver

The Pacific and Yukon Regional Branch of NWRI, located in West Vancouver, B.C. conducts applied research related to regional water management problems. The goal is to predict the ecological sensitivity and response of lakes and rivers in the region to changes in environmental stresses such as nutrient loadings, industrial waste discharges, mining wastes, hydroelectric development, and water diversions.

The experiment to study the dynamic processes affecting intra-lake sediment transport in Lake Laberge and Kluane Lake has continued. A meteorological station and a thermistor array were maintained in Kluane Lake. The effect of the seasonal ice cycle on river-lake interaction was further studied; M. Alford modelled the upstream effect of lake ice on a river flow.

12. University of British Columbia, Department of Oceanography

(a) Physical Oceanography

A numerical simulation study of stratified circulations in Indian Arm is now almost completed. No attempt is being made at present to fine tune the model beyond its apparent general agreement with observed barotropic and internal tides and averaged density driven circulations and mixing. Solutions have been found for quasi-geostrophic flows along indented coastlines including capes and bays separated by more than one Rossby radius. Seiches in small bays of Jan de Fuca Strait have been successfully modelled and found to be related to wind-forced edge waves. Measurements of currents and water properties off the mouth of Juan de Fuca Strait have been carried out (with R.E. Thomson, IOS and R. Hickey, University of Washington) to study runoff-driven flows on the shelf. Deep-water replacement in the Strait of Georgia has been found to occur in pulses; the speed of travel is now being modelled. Long-distance correlations between wave groups have been found between sensors 1.5 km and more apart; their significance is under examination. Measurements of boundary-layer turbulence are underway (with W. Crawford, IOS) using a free-falling instrument (P.H. LeBlond).

The stability and modulation of modons (a pair of eddies with zero net vorticity) in the presence of bottom friction, variable topography and a mean shear flow are being investigated. A theory for the generation of trench waves by incident baroclinic Rossby waves has been developed and applied to the Izu Trench in the Western Pacific. A variational technique has been used to determine the topographic wave eigenmodes in an elliptical basin and applied to various lakes in Europe and North America. The generation of annual-period Rossby Waves by the observed winds has been investigated numerically using a reduced gravity model. A major review has been completed describing the observations and theories associated with El Nino-Souther Oscillation episodes and their impact on fisheries (abundance and migrations) in the Northeast Pacific. A three-year cooperative study (with C. Grooth, PBS) has begun on the interannual variability of the Northeast Pacific Ocean and its influence on sockeye salmon migration routes (L.A. Mysak).

Cyclesondes (internally-recording profiling current meter/CTD systems) continued to be used to explore the vertical structure of the velocity and density fields in B.C. waters. Two instruments were deployed in Indian Arm from November 1983 to March 1984. One to three

cyclesondes and four Aanderaa meters on additional moorings were deployed in Indian Arm from December 1984 to April 1985. Four cyclesondes were deployed in the central Strait of Georgia from June 1984 to October 1984. Two were replaced with current meter moorings, one in October and one in December. In July, five current meter moorings were added (in cooperation with D.M. Farmer, IOS). The nine mooring array was maintained until mid-January 1985 (S. Pond).

A study of drifting buoy tracks in the northeast Pacific from 1981-83 was completed. The relationship between atmospheric pressure patterns in this same region and the occurrence of El Nino episodes was examined. Two successful cruises were completed to collect in situ data to compare with satellite information off the southeast coast of Vancouver Island. A new project on the changes in ice patterns in the eastern Beaufort Sea using satellite imagery was started. The satellite receiving facility is undergoing major upgrading in collaboration with MacDonald-Dettwiler and Associates (W. Emery).

The relation between El Nino-Southern Oscillation events and warming episodes in the Northeast Pacific Ocean was investigated using very long time series of oceanographic and meteorological data. The results showed that the effects of tropical Los Nino are communicated to the midlatitude ocean largely via an atmospheric link (K. Hamilton).

(b) Chemical Oceanography

Studies of the geochemistry of the sediments of oxic and anoxic coastal inlets of B.C. are continuing (S. Calvert and T. Pedersen). Studies of the geochemistry of molybdenum mine tailings in Alice Arm, B.C. and of copper-molybdenum mine tailings in Rupert Inlet, B.C. have examined the post-depositional mobility of metals in the sediments, and are nearing completion. The work in Powell Lake, a meromictic former fjord lake containing permanently anoxic relict sea water, is continuing (with N.S. Shackleton, Cambridge). Investigation of the early diagenesis of the sediments of the Guatemala Basin and at 21°N on the East Pacific Rise have shown post-depositional enrichments of certain metals (T. Pedersen).

The geochemistry of ferromanganese nodules and their associated sediments from the northern equatorial Pacific is being examined in several projects (with D. Piper, USGS and D. Huntley, Simon Fraser). An improved method for the measurements of ^{230}Th and ^{231}Pa in sediments by x-scintillation counting has been developed. Studies of the geochemistry of Holocene sapropels in the Black and Mediterranean Seas have continued with a view to determining their environments of formation (S. Calvert).

Further cruises using surface vessels and Pisces (with V. Tunnicliffe, University of Victoria and S. Scott, Toronto) were made to the Juan de Fuca-Explorer Ridge system and new hydrothermal vents were discovered and sampled. The studies will continue in 1985 (R. Chase).

Studies of natural product chemistry of marine organisms are continuing (R. Andersen).

13. Institute of Ocean Sciences, Sidney, B.C.

(a) Fjords and Narrow Channels

Work during 1984 concentrated on stratified flow over sills and through constrictions mostly using data obtained in Observatory Inlet and Alice Arm but also using historical records from the Strait of Gibraltar. Analysis of data from Observatory Inlet demonstrated that variations in the energy loss detected through phase difference measurements across the sill can be explained largely in terms of the generation of progressive internal tides. A second study, in Knight Inlet, extended this work and examined the importance of rotation effects.

The influence of two-way flow through a horizontal constriction and over a sill was examined with reference to the exchange of Atlantic and Mediterranean water through the Strait of Gibraltar. Historical records were used to show that hydraulic control is governed by conditions at two locations with the outflowing Mediterranean water being

independently controlled at another sill.

A test of new techniques for measuring mixing processes was carried out in Haro Strait using the FLY microprofiler, the acoustic Doppler velocity profiler and Ross sounders. Results indicate the potential of the combined suite of instrumentation.

(b) Continental Margins

A major experiment, ACE (Australian Coastal Experiment), was mounted by an international group from Canada, the United States and Australia to examine the dynamics of coastally-trapped waves. Instruments were deployed and observations were made from September 1983 to March 1984 off the east coast of Australia - one of the most regular stretches of continental shelf in the world. The experiment focussed on the propagation of events in the weather band of frequencies, centred on periods of about ten days. The theoretical shapes and speeds of the first three coastally-trapped wave modes were computed and the data expanded in terms of these modes. The resulting amplitudes were examined individually for phase propagation in the alongshore direction at various frequencies, all subinertial. The best estimates of phase speed as a function of frequency were used to construct empirical dispersion relationships for comparison with theoretical predictions. These show that the theory of coastally-trapped waves is a reasonably good description of the alongshore propagation of fluctuations but that waves propagate alongshore systematically faster, by about 25%, than theory predicts; this difference may be accounted for by the background potential vorticity field producing a kind of shear mode. There is evidence that the propagating modes were affected by the presence of eddies shed from the East Australian Current. Validation of the theory in the simple geography of the East Australian shelf increases confidence that it can be applied eventually to the more complicated continental shelf of the North American west coast and lead to an ability to predict the propagation of disturbances, such as El Nino, from one area to another along the coast.

The CODE experiment, conducted along the continental shelf west of Vancouver Island during 1979-82, continues to yield results. Diurnal period currents in the area are dominated by a first mode baroclinic continental shelf wave and are seasonally modified by the mean flow which shifts the wave length by 20-30%. Since the tidal currents are primarily diurnal, this result will permit improvements in prediction. Verification was also provided for the idea of a baroclinic instability in the strong currents over the continental slope west of Vancouver Island, leading to the growth of meanders and the formation of eddies. The CODE data permitted the calculation of energy and energy flux terms for a 50 km diameter eddy that formed over the slope in September 1980. CODE data is being combined with historical information to investigate eddy variability and structure.

A mooring program off the west coast of the Queen Charlotte Islands and in Dixon Entrance was begun in May, 1983 to permit a comprehensive description of mean and monthly current patterns. Operations will continue through May 1985.

A study of the narrow (15 km) northward current found in all seasons along the west coast of Vancouver Island was begun in cooperation with the University of British Columbia and the University of Washington. It is suspected that this current may be driven by pressure gradients due to the presence of large quantities of relatively fresh water from river discharge. In a related activity, IOS cooperated in a study of the relationship of the drift of floating objects to currents as it might affect search and rescue activities.

A preliminary analysis of the mean monthly steric heights from Line P stations and the mean monthly sea levels recorded at Tofino and Victoria indicates that the annual amplitude of steric heights can account only for about 50% of the observed amplitude along the shore. It appears that the remainder can be accounted for by the changes of sea surface slopes associated with the annual shift in the coastal currents. Annual amplitude of the mean current in the upper 10 m over 890 km is about 13 cm/s.

The mixing and circulation induced when penetrative convection reaches the bottom of a region of non-uniform depth are being investigated in the laboratory in cooperation with the Department of Oceanography at the University of British Columbia.

To gather additional data capable of exposing the presence of any long period water height disturbances as part of the Arctic Continental Shelf program, gauges were installed at Isacksen, Audhilde Bay and at Fram Strait. Preliminary indications from these data show some low frequency peaks somewhat below the level of statistical significance. More work is necessary to remove the influence of long period tidal energy and to identify active portions of the record since the long period disturbances almost certainly do not have a stationary phase and amplitude.

A set of year-round moorings was deployed to measure currents and density field parameters in the shelf region of the Beaufort Sea. These measurements will address a number of problems (shelf drainage, shelf run-up, water mass modification) and the long period variations will be correlated with the water height measurements to define the character of the currents associated with any travelling disturbances. The chains of sensors sampling the density field will investigate the baroclinic component of the response. A CTD survey was conducted concurrently.

Beaufort Sea studies funded by the Office of Energy Research and Development concentrated on the understanding of ocean dynamics as it applies to the prediction of the drift of sea ice over periods of a few days. The focus is on the response of the ocean to momentum input from a moving ice field and to the feed-back of momentum to the ice cover from the resulting ocean circulation. This study is expected to permit improved ice motion prediction.

The small scale ice/ocean interaction project conducted with OERD resources is investigating the direct interaction between the underside of the ice sheet and the underlying water column with the aim of defining the ice/water drag coefficients.

(c) Circulation and Climate

Eleven ocean climate monitoring cruises, including three in 1984, have been made along Line P, Line R (northern line) and associated lines since the withdrawal of the weatherships from Station P in 1981.

The characteristics of both the annual and interannual variability of steric height off the Pacific coast of Canada have been described using time-series observations. In the open ocean (beyond continental slope) the temperature effect dominates the annual change of steric height. Along the coastal region (continental shelf to continental edge) the salinity effect controls the height. In the transitional region (continental slope) temperature and salinity effects both affect, almost equally, the total steric height. There is little evidence that large-scale offshore circulation of the Sub-Arctic gyre is relevant to the annual cycle of mean sea level along the coast. In contrast, there is evidence that the cycle of coastal baroclinic currents can account for this annual cycle.

A review of the annual and inter-annual variability of ocean currents of the mid-latitude North Pacific Ocean, i.e. East Kamchatka Current, Coastal Branch of Oyashio, Alaskan Stream, Alaska Current, California Current, Central and Western Pacific, Kuroshio Extension and Oyashio Extension, has been made using current fluctuations occurring between 1950 and 1981.

Several problems relating to the study of ocean circulation processes were investigated using theoretical and numerical methods. These included: baroclinic instability, plankton patchiness, and irregular sidewall boundaries in geostrophic flows. Work on baroclinic instability used numerical methods to integrate the equations of multiple-layered quasigeostrophic flow using spectral transform techniques. In experiments performed in the near super-critical baroclinic shear regime, a quasistationary eddy/wave field has been obtained which exhibits long period energy vacillation with systematic poleward heat transport and vertical momentum exchange.

Theoretical studies of dispersion processes stimulated an analysis of the TWERLE high-altitude balloon pair data and matching high altitude wind fields. The objective is to demonstrate that relative dispersion in quasigeostrophic turbulence is a non-local process.

(d) Upper Layer Processes

Field work for Project SUPER (Subarctic Pacific Ecoystem Research) was carried out during May 1984 in conjunction with scientists from IOS Ocean Ecology and the University of Washington. Vital atmospheric data were collected from surface moorings and temperature data were collected from four thermistor chains from 6 to 200 m depth. Although storms reduced the amount of FLY (microscale profiler) turbulent mixing data, over 100 profiles were completed. This first large data set obtained with FLY will allow testing and refinement of the semi-automatic data-processing routines.

(e) Forescasting Methods

Analyses of the Fraser River plume field observations and upper layer numerical model were completed.

Trials of the Georgia and Juan de Fuca Straits model confirmed earlier experience of the remarkable sensitivity of the modelled tides to adjustments of frictional dissipation. With modifications, a successful calibration was achieved for the combined non-linearly interactive M_2 and K_1 tides.

Trials of the three-dimensional numerical Georgia/Juan de Fuca model included an analysis of the flow field that presages the onset of non-linear instability and the effects of mesh sizes. Courant number, time splitting and strain rate determined eddy viscosities.

A linear superposition method was developed for objective interpolation between observed tidal elevations inshore of the Queen Charlotte Islands, using independent component solutions computed with a finite-difference model.

A 100-year flood risk map for Tuktoyaktuk was developed for Environment Canada and development of a finite-difference barotropic model of the Northwest Passage was advanced.

(f) Observing Methods

Instrumentation development and assessment included tests of the Guildline Mk IV CTD temperature and conductivity sensors. The tests were designed to elucidate the response characteristics of the sensors over a fall speed range of 0.25 to 1.8 m/s. A preliminary analysis of the results indicates a close agreement between the measured response of the conductivity cell and the predictions of the general response theory.

Studies of ambient noise in the ocean are being pursued to determine the source and propagation characteristics of natural sound in the ocean from which we might learn more about physical processes, especially air-sea interaction, and also learn how to use ambient noise to infer meteorological conditions.

The IOS Doppler velocity profiler data collected in Observatory Inlet have been used to explore various features of hydraulic flow over a sill, including the transition between different regimes with changing tidal conditions. The results have been used for comparison with an analytical and a numerical model of internal hydraulics.

Field testing of acoustic backscatter instrumentation with high speed digitization was carried out in 1984 on the submarine USS Dolphin. Although the data logging and related components functioned well, the results demonstrated a fundamental problem in that the sonar returns were contaminated in the near field by backscatter from the submarine. However, useful data were obtained, showing echoes from bubble clouds near the ocean surface. In a second cruise, more appropriate transducers were used which resulted in minimizing backscatter from the submarine.

The first ocean test of the acoustic scintillation interferometer was carried out. First indications are that the test was very successful, demonstrating its potential for probing a range of oceanographic processes including mean flow, small scale variability, transverse flow and the mean temperature fluctuations.

The major activity of the remote sensing group at IOS in 1984 was the evaluation of the Fluorescence Line Imager, a new type of optical sensor with programmable spectral bands, designed as part of Canada's space program. Test flights have demonstrated the instrument's flexibility to form images and to record the optical spectra from different targets.

(g) Tidal and Current Surveys

Three cruises in 1984 continued the study of circulation in northern B.C. waters which was started in 1982. The current meter data gathered in 1982 and 1983 in Queen Charlotte Sound and Hecate Strait reveal a circulation pattern dominated by the winds.

Current surveys at Nakwakto Rapids and at several sites in Seymour Inlet were completed in order to improve predictions for these fast-flowing narrows.

A year-long study of Campbell River estuary was started in July 1984. The study involves measurement of tides, currents, salinities, and temperatures through a variety of tide and river discharge conditions. The purpose is to determine how man-made changes to the estuary might affect salmonid feeding habitat.

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VIII GLACIER STUDIES

Compiled by: R.M. Koerner

1. Summary

Routine mass balance studies continued in the west, the high and mid-Arctic and northern Labrador, giving good coverage of all glacierized areas in Canada. However, the mid-Arctic study has ended after 16 years and almost all studies in the west may be terminated because of termination of support from B.C. Hydro for several glaciers and reduced Federal Government support for others. This constitutes a major setback to one of the world's most continuous and extensive glacier records. It comes at a time when anthropogenic effects may be changing our climate; glacier measurements are a good way to monitor that change. UBC's effective programme on surging glaciers continues and awaits a predicted surge. A study of the ice shelves fringing Canada's Arctic Ocean shores has been extended and eastern Canada's most southerly glaciers continue to be monitored and surveyed. Ice core studies in the Yukon and the high Arctic are continuing to give information on past climatic changes and the extent and history of atmospheric pollution in those remote regions. The important and intensive study of icebergs, their mode of drift and effect on offshore structures continues. While important academically, iceberg studies are highly relevant to the oil industry working in offshore locations.

2. Polar Continental Shelf Project, Energy, Mines and Resources, Canada (B.T. Alt, J. Bourgeois, D. Fisher, R. Koerner, M. Parnandi, K. Langley)

Work has continued on the three-dimensional model of the Laurentide ice sheet in terms of accumulation and ablation rates on its surface and temperatures at its base. Pollen analysis of bulk samples melted at over 100 m depth in an old borehole has revealed relatively high pollen concentrations in ice near the bottom of Agassiz Ice Cap in Northern Ellesmere Island. An oxygen-isotope/vapour transport model was developed and contributes to an understanding of major isotope changes in ice cores. The historic past in the high Arctic has been considered in terms of climatic change as deduced from ice cores. The Franklin period (1845-1859) experienced some of the severest climatic conditions of the past 800 years. Some of the glacier mass balance records for the past 20 years were studied in relation to areal and volume changes of the glaciers, in particular Meighen Ice Cap. In the field the mass balance of four high Arctic ice caps was remeasured. A 127 m surface-to-bedrock core was drilled from the top of a flowline on Agassiz Ice Cap and 80 litre samples melted from over 100 m depth were collected in a five-year old borehole 1 km away.

3. National Hydrology Research Institute (NHRI), Glaciology Division, Environment Canada (D.H. Lennox, C.S.L. Ommanney, A. Champoux, J.W. Clarkson, G. Holdsworth, O. Mokievsky-Zubok, J. Power)

Glacier inventory work on the Stikine/Iskut area and on the Yukon Glaciers is now complete. A tripartite inventory of Glacier National Park about 1850, 1951-2 and 1978 is almost complete. An air photo interpretation of part of the Columbia Icefield was completed. Inventory work on the McGregor River basin has been started.

Shallow core sampling was carried out on Seward Glacier, near Mt. Logan. Snow Dome, Columbia Icefields, was visited for planning of future core studies. Work continues on the Mt. Logan core. The core studies are important for studies of long range pollutant transport, atmospheric CO^2 changes in the past 150 years and regional climatic change over a longer period. Lowell Glacier was visited for ground truth coverage to facilitate interpretation of Landsat imagery covering the last surge. Two glacier dammed lakes in B.C., Natava Lake and Flood lake, were observed; the latter filled and discharged in July. No future monitoring is planned.

Several Glaciers were measured for mass balance. In B.C., Andrei, Alexander, Yuri, Tiedemann, Bridge, Sykora, Zavisha and Sentinel Glaciers had positive balances while Bench, Place and Helm Glaciers had negative balances. Meteorological and river flow level data were collected by automated techniques in the Bridge River Glacier area. In Alberta, Peyto Glacier suffered a negative balance for the eighth successive year. D. Collins (Manchester University, U.K.) collected water chemistry data at Peyto and several surrounding streams to determine their composition and flowpath. A monopulse radar was used to measure glacier thickness in the accumulation zone. Work continues on modelling the run-off of Peyto Glacier using a new version of the UBC watershed model.

4. Karl E. Ricker Ltd., St. Joe Canada Inc. B.C., B.C. Institute of Technology (K.E. Ricker, W. Tupper, D. Jones)

Another detailed map of Wedgemount Glacier (N. Garibaldi Park) was produced by contouring the oblique aerial photography of 1947. The snout position and two velocity profiles on this glacier were resurveyed; an average 1977-84 retreat of 2.5 m/a was measured. Photogrammetric work on 1928 photos will allow volume changes since then to be computed.

Continued recession of Fyles Glacier (Central Coast Mts.) caused the predicted (by Ricker) outburst of Ape Lake. Release of 46 x 10(6) m^3 of water caused considerable damage downstream. A study of the nature of the outburst and recurrence in the future was undertaken in association with the Geological Survey of Canada and the University of British Columbia.

Estimates of the surface velocity of East Arm Glacier (St. Elias Mts., B.C.) were made by comparison of the position of moraines on aerial photographs taken in both 1949 and 1976. Calculated velocities of 39-52 m/a were corroborated by field measurements in 1983. Massive sulphide boulders, downstream of the snout, were shown to have a subglacial source.

5. University of British Columbia, Department of Geophysics and Astronomy (G.K.C. Clarke, G.M. Cross, F.H.M. Jones, M.G. Maxwell, B.B. Narod, B.T. Prager, J. Schmok, R.D. Russell)

Trapridge Glacier (Y.T.) last surged about 1945 and is expected to surge again within a few years. A large wave-like bulge has formed in the middle region of the glacier and is propagating downglacier at 25 m/a. The bulge is at the boundary between warm-based ice upstream and cold-based ice downstream. The glacier was resurveyed and measurements of the fluid permeability of the basal till made in the km^2 region of thick till deposits downstream from the bulge. A new impulse radar transmitter was successfully tested on the same glacier. Work on a micro-processor controlled back-portable system that records data on digital cassettes is almost complete.

Airborne radar sounding data from Ellesmere Island (N.W.T.), Mt. Wrangell (Alaska) and

Mt. Logan (Y.T) are being used to test various digital signal enhancement methods; these include two-dimensional filtering and wave migration.

A study is being made of basal processes in glaciers, in particular the accretion of ice and entrainment of debris at the glacier-bed interface. The work involves analyses of water quality, crystal fabric, debris properties and isotopic fractionation of D/H and $^{16}O/^{18}O$. Over 400 samples from the Back and Trapridge Glaciers (Y.T.) have been analysed. The oxygen isotope analyses are being performed on the automated system at the University of British Columbia.

Cores from 23 small lakes within the basin of former glacier-dammed Lake Alsek (Y.T.) were taken to study sedimentary deposits of past outburst floods.

6. Memorial University of Newfoundland, Department of Geography (R.J. Rogerson)

Mass balance work was continued on four cirque glaciers in the Torngat Mts. of northern Labrador. As in 1983, mass balance was strongly negative. The snow-line in early July was close to its end-of-season position in 1983 and snow depths in the accumulation basins seldom exceeded 1.5 m. Winter snowfall in the Torngat Mts. must have been slight. The summer was cool and dry and by the end of the summer snow remained only at the foot of couloirs and in shaded gullies. In addition radio-echo sounding, hammer seismic and resistivity methods were used to measure ice thickness on the glaciers. The glaciers are between 100 m and 200 m thick at their thickest points.

7. University of Calgary, Department of Geography (M.O. Jeffries, H.V. Serson)

In spring a snowmobile traverse was completed between Point Moss and Nansen Sound, Northern Ellesmere Island. Ground truth data of the ice shelves and landfast sea ice were gathered along a 450 km line. Ice conditions vary from 2 m thick first-year ice to ice shelves 100 m thick. In M'Clintock Inlet, Ayles Fiord, Milne Fiord, Yelverton Bay and Nansen Sound there are large areas of old sea ice more than 20 years old and up to 10 m thick. Cores were obtained for salinity, stable isotope and tritium analysis. An air photography survey was undertaken in July and complete coverage was obtained for Ward Hunt Ice Shelf and Milne Ice Shelf from 3000 m. Almost complete coverage was obtained for Ayles Fiord. In addition, single flight lines were flown from Point Moss to Cape Albert Edward and across the mouth of Yelverton Bay.

8. University of Ottawa, Department of Geography (P.G. Johnson, G. Binda)

A study of the glacier hydrological and suspended sediment regime of Peyto Glacier, Alberta, continued. It was found that the high magnitude/low frequency event of flood and landslide observed in 1983 is the major process of change in the glacier terminus/proglacial zone. The events are climatically and glaciologically forced and largely unpredictable. A relationship between sediment load and changes in subglacial channels was found. Meltwaters in Peyto Creek had low solute concentrations. Attached cationic concentrations, with calcium the most readily absorbed, reflect the residence time of the suspended sediment within the sub-glacial system. The suspended sediment load from Slims River, draining Kaskawalsh Glacier in Kluane National Park, was found to exhibit the same extreme fluctuations in concentration, total load and attached ionic loading found elsewhere. The sediment loads are a function of sediment availability and contact with meltwaters and are unpredictable.

The formation of rock glaciers which are not cored by glacier ice is probably dominated by high magnitude processes. A number of mechanisms of formation have been identified in the Ruby Range, Southwest Yukon which confirm observations from the St. Elias Mts. from the late 1970's and early 1980's.

9. Trent University, Watershed Ecosystems Programme (W.P. Adams)

Mass balance measurements were made on White Glacier, Axel Heiberg Island, N.W.T. in early May. Stakes were redrilled and extended over the entire glacier.

10. University of Minnesota, Barnes Ice Cap Project (R. LeB. Hooke, G.W. Johnson)

Thirty stakes along a 10.2 km flow line between the margin and divide of Barnes Ice Cap were measured for mass balance (covering the 1981-82 and 1982-83 balance years) and surveyed to determine vertical and horizontal displacement for the 1982-84 period. Analysis of our own data and Holdsworth's data from 1970 shows the ice cap is now 2.6 m thinner near the divide and 5.3 m thinner near the margin than in 1970. There is no detectable change in thickness at 4.5 km from the divide. The 1981-83 mass balance was -0.38 g/cm. Most of this loss was in 1981-82 as there was firn beneath the 1984 snowpack. This work will not be continued thereby ending 14 years of field work on the ice cap.

11. University Waterloo, Department of Geography (J. Gardner)

Ice surface velocity, meltwater discharge and bergschrundt temperature studies were carried out on 'Boundary Glacier' (Banff National Park). This research is a component of a comprehensive sediment budget of a small, high altitude drainage basin. Radiocarbon dating evidence indicates that expansion of the glacier began prior to 4000 years BP and that throughout the past 4000 years it has been significantly larger than at present.

12. Memorial University of Newfoundland, Ocean Engineering Research Group (D.B. Muggeridge, D.W. Bass, M. Booton, V.M. Arunachalam, K. Shirasawa, N.P. Riggs, R.T. Dempster, C.C. Hsiung, A.F. Aboul-Azm, D.V. Reddy, M. Arockiasamy, P.S. Cheema, J.H. Lever, E. Reimer, D. Diemand, N. Hookey, G.R. Peters)

Various studies were undertaken related to iceberg geometry and effects particularly on offshore structures; they include the following. Investigation of the drift of idealized icebergs, prediction of iceberg drift, Monte Carlo simulation of iceberg shapes and their impact probabilities, wave-induced motions of small icebergs and bergy bits, optimal estimation and prediction of iceberg trajectories, iceberg draft and instability, motion analysis of an iceberg in regular waves.

13. Université de Sherbrooke (Jean-Marie Dubois, A. Champoux)

Une étude du comportement historique et actuel des glaciers du Parc national des Glaciers a été entreprise en Colombie-Britannique. Ce mémoire de M.Sc. est effectué à base de photo-interprétation de diverses couvertures de photographies aériennes.

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IX HYDROLOGY

Compiled by: Secretariat, Associate Committee on Hydrology,
(Executive Secretary - G.J. Young)

1. Introduction

This report is a compilation of activities on hydrology for the period July 31 1983 to July 31 1984. It covers both research and operational activities but does not include glacier studies which are reported in Chapter VIII. Hydrometeorological activities are also addressed separately in Chapter VI.

The long range transport of air pollutants (LRTAP) has for some time been recognized as one of the most serious threats to the water environment. It continues to share the top spot on the list of Canadian water related concerns with the leaching of toxic chemicals into rivers and lakes from landfill sites. The LRTAP concern has been particularly evident in the form of acid rain, however, there is also concern over the very significant amount of polluting substances that are deposited directly from the air into large water bodies such as the Great Lakes. One of the more seriously toxic contaminated areas, the Niagara River, has been the subject of a joint Can/US study since 1981. The Can/US Niagara River Toxics Committee will be issuing its report in late October. The report will contain recommendations on control programs and on long-term water quality monitoring programs that will allow evaluation of the effectiveness of the toxic contamination control programs. The only particularly extreme hydrologic event during 1983/84 was a severe drought affecting southwestern Saskatchewan. The Swift Current area of the province experienced the lowest October to April precipitation in 98 years.

2. Federal Government Departments

The Canadian federal government has appointed an Advisory Committee on Federal Water Strategies to study Canadian water resource issues and advise the federal government on long-term strategies to manage the issues within its jurisdiction. Two hundred and thirty briefs were presented at 22 locations across the country. The final report is scheduled for publication on August 1 1985.

Many federal departments have been involved in water management activities during the past year. Some of the more important are Environment Canada, Fisheries and Oceans, Regional and Industrial Expansion, Indian and Northern Affairs, Transport, National Health and Welfare, External Affairs, Public Works (CMHC) and Energy, Mines and Resources. Space limitations do not permit comprehensive reporting of all water-related work undertaken during the past year by these departments.

(a) Environment Canada

The principal department from the freshwater point of view is Environment Canada with its Environmental Conservation Service, Environmental Protection Service and Atmospheric

Environment Service. The Environmental Conservation Service, Inland Waters Directorate (IWD) conducts its day to day programs under the Canada Water Act and the International River Improvements Act. It has a headquarters office at Ottawa and regional offices at Vancouver, Regina, Burlington, Quebec, and Halifax. IWD's role involves the development, planning for, and participation in national and international river basin programs, including a national flood damage reduction program. It conducts special water quality investigations, research on water quality, quantity and socio-economic aspects of freshwater resources, and maintains inventories relating to the quantity and quality of surface and ground waters. Much of IWD's hydrologic work is carried out at its two national research institutes - the National Hydrology Research Institute (NHRI) and the National Water Research Institute (NWRI), and in its Water Resources Branch.

The National Hydrology Research Institute (NHRI) is based in Ottawa with subsidiary offices in Calgary and Vancouver and at a number of other locations in central and western Canada. The Institute is scheduled to be relocated in Saskatoon, Saskatchewan in 1986 where it will be the principal tenant in the new National Hydrology Research Centre (NHRC).

The Surface Water Division investigates watershed processes, in particular those that characterize elements of the hydrologic cycle other than the ground water regime, and develops and tests precipitation-runoff models. Hydrologic processes in alpine, prairie and permafrost environments are of particular interest. Studies of these processes include those on the interaction between Arctic streams and permafrost, on lake dynamics and flooding in the Mackenzie Delta and an interrelated group of studies on freeze up, break up, ice jamming, and other fluvial processes in the Liard and Mackenzie Rivers and the Mackenzie River delta. Modelling activities include the design of statistical streamflow forecasting models with and without climatic forecasting ability; the analysis of the sampling, time-dependent and distribution properties of rainfall-runoff models; the development of a drainage model for the Mannes-Domain drains in Manitoba; the development of a physically based model of water flow in snow-covered terrain; the sensitivity analysis of a passive microwave snow cover model to a range of snow cover and soil moisture conditions; and the operational testing of a modified UBC precipitation-runoff model that accounts for contributions of meltwater from glacierized areas. This division also conducts remote sensing studies including the application of gamma ray, radar and passive microwave to the measurement and observation of snowpack water equivalent, the use of aerial photography for surface water velocity measurements in rivers with moving ice, and the application of conductivity and time domain reflectometry to ice thickness and soil moisture measurement. The division is also responsible for the Agricultural Land Drainage Research project which is being carried out cooperatively with the Ground Water Division. The major long-term objective is to gain an understanding of the hydrologic effects of both surface and subsurface modifications to drainage in agricultural areas. Other studies in agricultural areas include the effects of snow management practices on surface and ground water supplies and the contribution of sloughs and potholes to ground water recharge and salinization.

In snow and glacier environments the Surface Water Division studies movement of water through mountain snowpacks and evaluates mass, energy and water balances for selected glaciers in the Cordillera. In addition, it is responsible for the long-term undertaking to prepare a complete inventory of Canadian glaciers. A special study in support of the Canadian Climate Program involving glacier ice coring near Mount Logan, Canada's highest mountain, is yielding information on past climatic changes and on levels of atmospheric contamination. The Canadian Glacier Inventory project was recently reviewed to establish the nature and extent of the work to be done and the resources available to carry it out. On the basis of the review, a deadline date in 1992 was set for completion of the inventory. Subsequently, more manpower became available to work on the inventory on a short-term basis and the deadline date has been advanced to September, 1990. Reviews were also initiated of the division's snow and ice property and mass balance studies. Resignation of the two key scientists in the snow and ice properties project led to a decision to terminate NHRI activities in this area and the review has been left in a preliminary draft form. The mass balance review is in an intermediate draft form but enough information has been obtained to suggest that mass balance studies at the major field site - Peyto Glacier - should be temporarily suspended to allow full time to be given to data analysis and determination of the value and significance of this particular mass-balance study. This suspension will take effect in the 1985-86 fiscal year and will

continue until analysis and appraisal have been completed. Related field studies in central and northern British Columbia that are furnishing knowledge that will be required for assessing the contribution of glacier melt to stream runoff in basins proposed for hydroelectric power are also under consideration. This has become more urgent since B.C. Hydro recently withdrew the financial and logistic support they have been providing for some years up to and including the 1984 field season.

The Ground Water Division is very heavily involved in studies of contaminant transport in subsurface waters and the geochemical controls that influence this transport. Major investigations are under way in the Niagara area, where subsurface migration of toxic contaminants from chemical dumps is a serious hazard to Canada's boundary waters, and at the Gloucester site (near Ottawa) where toxic materials seeping from a federal waste disposal facility are threatening the contamination of nearby aquifers. Contaminant transport studies have been conducted at a number of other sites and have included tracer investigations at Chalk River, Ontario; arsenic contamination at various locations in Nova Scotia, New Brunswick and Ontario; and pesticide contamination near Osoyoos, British Columbia. A major research project sponsored by Atomic Energy of Canada Limited is studying the ground water aspects of the underground disposal of nuclear wastes in crystalline rocks. The effect of the ground water/aquifer system in mitigating the adverse effects of acid rain is under investigation, principally at a field site near Sault Ste. Marie. In the North, research is directed towards ground water discharge and recharge under permafrost conditions; and towards studies of the effect on the ground water regime of engineering structures and developments such as pipelines and roads. A number of pre-existing studies have been phased out (e.g. mining hydrology) in order to free resources for the urgent new contaminant related work.

The National Water Research Institute (NWRI) of the Inland Waters Directorate is an environmental research organization at the Canada Centre for Inland Waters (CCIW) in Burlington, Ontario, and is part of the Department of the Environment. There are regional offices of NWRI in Winnipeg and Vancouver.

The Institute carries out a program of research and development to provide the necessary information and understanding of water systems for water management problems or opportunities in Canada. Building on this program of research and development, it seeks to advance, apply and disseminate scientific and engineering knowledge obtained from the research programs. The work includes field and laboratory research on problems of natural or man-modified aquatic regimes and contracted research. Problems investigated are of national scope or are related to specific geographical sites referred by other agencies within or from outside the Department of the Environment. Advice and information are provided through publications, consultative services to other government agencies, service on scientific and technical committees of the government or government-supported institutions such as the International Joint Commission, and through scientific services such as calibrations, analytical services, instrument testing, methodology documentation, and interlaboratory quality control services.

In October 1974, the Canada Centre for Inland Waters was designated by the World Health Organization as its Collaborating Centre on Surface and Ground Water Quality (WHO/CC). The main functions of the WHO/CC are coordination of international technical assistance programs to the developing countries and representation of Canada's freshwater interests in international forums.

The Environmental Contaminants Division investigates in the field and in the laboratory, the pathways, fate and effects of contaminants. Its five sections are concerned with Organic Pathways, Organic Properties, Inorganics, Radionuclides and Acid Deposition.

The Hydraulics Division undertakes research into all aspects of the hydraulics of inland waters. This includes research and model development for physical processes and phenomena in lakes, rivers, and reservoirs, including geophysical processes and ice. It develops systems and methods to measure environmental variables in the field or laboratory, develops and improves equipment to obtain samples of water or sediment, designs and manufactures prototypes of equipment and sensors and calibrates scientific equipment - in particular current meters and sediment samplers.

The Aquatic Ecology Division is concerned with environmental degradation of Canadian waters due to eutrophication, acidification, and infestation by aquatic weeds. It is organized in three multidisciplinary sections: Ecological Impact, Great Lakes Rehabilitation, and Nutrient Pathways.

The Aquatic Physics and Systems Division conducts a program of research involving experimental measurements, environmental modelling via numerical simulation, and theoretical studies. All of this work is directed towards understanding the inter-relationship of fluxes of dissolved and suspended materials and water movements due to physical processes such as circulation, turbulent mixing and convection, transmission and scattering of light. Its four sections are Physical Limnology, Environmental Simulation, Environmental Optics, and Data Management.

The Analytical Methods Division is responsible for long and short term research to advance knowledge of chemical and microbiological methodologies, including sample collection and preservation techniques, in water, suspended material, sediment, effluents and biota. Technology transfer of completed methods to the IWD operational laboratories or other clients such as federal, provincial, university and industrial laboratories as well as international standards agencies is considered an integral part of any development study. The method is presented to the DOE Water Quality Branch National and Regional Laboratories in a format suitable for inclusion in the WQB Analytical Methods Manual. The Microbiological Laboratories Section publishes and maintains its own manual, Methods for Microbiological Analysis of Waters, Wastewaters and Sediments Manual. This document is used by water quality laboratories in many countries. The current distribution list is over 600. The division also offers limited analytical support to other scientists within CCIW requiring specialized equipment or facilities which are only available within the Analytical Methods Division. Such support includes high resolution gas chromatography-mass spectrometry, high pressure liquid chromatography, flow injection analysis, use of the Clean and Hazardous Chemicals Laboratory and various microbiological services.

The Technical Operations Division provides a wide variety of technical support to the field research studies of NWRI, its regions and, where possible, to other departments, agencies and universities. Areas of responsibility include field measurement, sample collection and some basic analyses of physical, chemical, biological parameters and sediments from freshwater systems aboard major research ships, launches, shore-based field parties and diving operations. The division is also responsible for the preparation, modification, field use and maintenance of a wide variety of mechanical, electronic and hydraulic sampling and data acquisition systems. The division arranges for the acquisition and scheduling of major research ships, launches and land sites, and the co-ordination of all NWRI field research studies to ensure effective and efficient use of technical staff, vehicles and equipment. The division also ensures a high level of safety for all field operations.

The Water Resources Branch of Environment Canada is composed of two Divisions, namely, the Water Survey of Canada Division and the Hydrology Division.

The Water Survey of Canada Division is the agency responsible for the collection of water quantity data from over 3500 active sites in Canada of which this division operates in excess of 2650. To oversee such a large network, the Water Resources Branch has eight regional offices and employs more than 300 engineers and technicians to maintain the gauging stations and interpret and compile the data. The regional offices at Dartmouth, Longueuil, Guelph, Winnipeg, Regina, Calgary, Yellowknife and Vancouver collect the field data in accordance with national standards, carry out the computations necessary to transform the raw field data into a format suitable for dissemination and then pass the data to the headquarters unit located in Hull. This unit is responsible for maintaining the water data (streamflows, water levels and sediment data) from 3500 active and 3700 discontinued stations in a central national water data bank named HYDAT. This bank contains over 83 000 station-years of streamflow data, 20 000 station-years of water level data, and 2000 station-years of sediment discharge data. The headquarters unit is also charged with the responsibility of developing manuals of procedures, guidelines, and standards for the field collection and office compilation of the water data. Data are published in an annual series of eight surface water data books, a biennial series of eight historical streamflow and water level summaries, an annual series containing sediment data,

and a historical summary of sediment data every five years.

It has long been recognized that water data are essential to sound water management and that the efficiency of data collection programs is enhanced significantly by combining networks and standardizing methodology. Consequently, in April 1975, uniform cost-sharing Water Quantity Survey Agreements were implemented with all provinces and with the Department of Indian and Northern Affairs for the territories, whereby the Water Survey of Canada conducts the Canada-wide program. These agreements recognize that water quantity data may be collected to meet federal needs, provincial needs, or a combination of needs. Hence, funding for the operation of the networks is provided according to each party's needs. The provinces conduct some field surveys, usually on a short-term basis, for preliminary feasibility studies and for water quality purposes. However, in the province of Quebec, Environnement Québec is the principal operator under the federal-provincial cost-sharing agreement. Water quantity data collected by Canada in the province of Quebec is limited to the federal network operated by the Water Survey of Canada regional office in Longueuil. Companies, boards, and commissions responsible for the operation of hydroelectric plants, the regulation of river flows and water levels, and management of wildlife areas, also collect water data related to the operation of their facilities. Data that are collected to national standards are published and included in the national (HYDAT) data bank. Other data are referenced to identify the source of supply.

In a continuing effort to provide data to meet federal, provincial, and user needs, the Water Survey of Canada is continually reviewing and updating its data collection, computation, and dissemination procedures to make use of the latest technology. Consequently, the Water Survey of Canada has embarked on an ambitious program of installing satellite data collection platforms (DCPs) at selected sites to improve monitoring and to provide timely data. In support of this program and to improve the procedures used to compute and compile the data, minicomputer systems have been installed at each of the regional offices. These are only two of the many aspects which are being implemented by the Water Survey of Canada to improve services to the Canadian hydrologic community.

The responsibilities of the Hydrology Division are to analyse and interpret data collected in the nationwide stream-gauging program and to provide advice and consultation to the Water Survey of Canada concerning the evaluation and planning of the hydrometric network. The objectives of the Division are to produce reports that interpret the basic data and provide information to the hydrologic community in a suitable form for planning and design purposes, and to improve the effectiveness and efficiency of hydrometric data collection activities through the use of analytical techniques. The analytical techniques may include transferring information from gauged sites to ungauged sites, estimating daily streamflows by flow routing or statistical methods, or determining the accuracy of the daily streamflows relative to the measurement frequency and operating budget for the stream-gauging program. The analytical techniques are used to determine the number, type, location, period of record, and operation schedule of stations for economically meeting designed areal coverage and accuracy requirements. The Hydrology Division at its Ottawa Headquarters is primarily responsible for developing analytical techniques and guidelines for evaluating the hydrometric network and for analyzing and interpreting the basic data. This technology is transferred to the eight regional offices through dissemination of procedural manuals, visits to regional offices, and training courses. The Headquarters Hydrology Division also provides a consultation service and carries out joint studies with the regional offices. In addition, it operates the Canadian HOMS National Reference centre which is part of the World Meteorological Organization program for the organized transfer of hydrological technology among more than 70 countries of the world. Besides the general responsibility for planning and managing water resources of significant national interest, the federal government has a mandate for collecting data and maintaining inventories relating to surface and subsurface water, pollutants and contaminants, fisheries and aquatic ecosystems, atmospheric water, and snow and ice.

The Water Quality Branch of Environment Canada is responsible for providing ambient water quality data and interpretive information on international, interprovincial and other waters of significant national interest. It operates a monitoring program through its regional offices by collecting samples from some 670 stations across Canada, analysing these samples in the national laboratory and entering the data in the computerized National Water Quality Data Bank (NAQUADAT). These data are used to define the health of Canada's

water resources, delineate areas of pollution, detect emerging pollution problems, identify transboundary movement of pollutants, provide baseline water quality data for environmental assessments of proposed developments, formulate regulations, develop water quality criteria and objectives, develop water pollution abatement programs and evaluate the effectiveness of such abatement programs, and meet the federal government's obligations under applicable legislation, federal-provincial and international agreements and treaties. The National Water Quality Data Bank (NAQUADAT) contains data from some 5000 locations in Canada. It stores the results of environmental analyses and other data about the samples and sampling locations, and produces a large variety of graphical and statistical reports.

The recent consolidation of the water quality laboratories in the Canada Centre for Inland Waters at Burlington has enabled the Branch to meet the heavy demands for water quality analyses, resulting from federal-provincial water quality monitoring agreements, and to respond to the changes required in the analyses of parameters due to the change in emphasis from major ion and eutrophication constituents to toxic chemicals such as dioxins, polynuclear aromatic hydrocarbons, pesticides and heavy metals. Surface waters represent the major class of samples analyzed in these laboratories but other aquatic substrates such as precipitation, sediment and aquatic organisms are also analyzed. Approximately 50 000 samples are analyzed annually for over 500 000 physical, chemical and biological parameters.

In addition to monitoring water quality and making this information available, the Water Quality Branch recommends water quality objectives for Canada. A water quality objective is expressed either as a concentration of a constituent or as a description of the body of water. The Water Quality Branch publication entitled Guidelines for Surface Water Quality contains summaries of important information on the harmful and beneficial effects of various substances on the major uses of water such as irrigation and livestock watering, raw public water supplies, aquatic life and wildlife, and the food industry. The interaction of other water parameters and toxic chemicals and their sediment chemistry is also discussed.

The Water Quality Branch has participated on regional, national and international committees and task forces in setting water quality objectives for the Great Lakes, the Saint John River, the St. Croix River in New Brunswick, the Red River in Manitoba, and the Poplar River in Saskatchewan. The Guidelines for Recreational Water Quality published by Health and Welfare Canada had direct input from the Branch. Interprovincial waters, rivers and lakes in national parks, Indian reserves, and the Territories also receive Water Quality Branch attention.

The Systems Division of the Water Planning and Management Branch added enhancements to the Environment Canada One-Dimensional Hydrodynamic Model for simulating flow through aboiteaux and over dykes, and for passing flow through defined flood channels from overtopping points in the river network to downstream points where these flood overflows eventually rejoin the regular river network. This new routine was successfully tested on the Salmon and North rivers network in the Truro, N.S. region. This same model complemented by the moving boat technique of measuring discharges was applied to Fraser River studies to determine sediment transport. The water quality routine of this model was found to be superior to the division's previously used combination of the HEC-2 and WATQUAL models in simulating dissolved oxygen of the boundary waters of the St. Croix River between Maine and New Brunswick.

Under the Federal Energy R&D program, the Engineering and Development Division of the Water Planning and Management Branch initiated a two-phase project in 1983-84 to develop hydrologic design methodologies for the determination of design flow and flood magnitudes at ungauged small-scale hydro sites to improve their economic viability by reducing costs to developers for site specific hydrologic studies. The phase I study completed in the 1983-84 fiscal year, developed the methodologies applicable for the prefeasibility site screening stage studies for coarsely defined hydrologic regions throughout Canada. This methodology determines available streamflow (mean flow, time distribution and storage effects) and flood magnitudes, given readily available basic physiographic and climatic data obtainable from published maps and information. A two-volume report Documentation Report and Application Manual including the computer model is now available. Development of the methodologies for feasibility level studies will be initiated in 1984-85 in the Phase II study.

Resulting from a request from the Inquiry on Federal Water Policy, the Division initiated a study to compute estimates of mean annual runoff and the 95 and 5 percent exceedence values, for 40 regions and sub-regions of Canada. A full report is expected to be ready for publishing in the latter part of 1985.

The Branch has recently completed a preliminary version of a computer procedure 'Interactive Procedure for Automated Retrievals' (IPAR), for the retrieval of hydrometric and sediment data from the Water Resources Branch national data bank HYDAT. An enhanced version of the procedure is under development in conjunction with WRB. This will be available at a future date for public users who would maintain an account number with the Computer Science Centre, Department of Energy, Mines and Resources.

Implementation of the national Flood Damage Reduction (FDR) Program in cooperation with the provinces and territories continued. The aim of the program is to discourage future flood vulnerable developments in designated areas by having the senior levels of government withhold support for such developments. By July 1984 maps prepared and designations made covered 300 communities in Newfoundland, Nova Scotia, New Brunswick, Quebec, Ontario, Manitoba, Saskatchewan and the Northwest Territories. All maps produced are referenced in Environment Canada's WATDOC system.

National Parks Branch, Parks Canada, is the lead agency in the Canadian Heritage Rivers System (CHRS), established in January 1984. The Branch plays primarily a coordinating role in this cooperative federal-provincial/territorial program aimed at conserving heritage rivers of Canadian significance. Rivers are nominated to the system on the basis of their natural, historical, or recreational value. Nominations are made by the government agency responsible for management of the river to a board composed of representatives from each participating government. Rivers designated to the system are managed by the agency originally having jurisdiction, according to the conservation objectives of the CHRS. To date six provinces and both territories have agreed to participate in the system; British Columbia, Alberta, Quebec and Prince Edward Island have not yet joined. Parks Canada has direct responsibility for Canadian Heritage Rivers located within national parks. Four such rivers have so far been nominated.

The Canadian Wildlife Service carried on activities to preserve endangered waterfowl habitat, research into effects of waterborne and other pollutants on wildlife, and research on aquatic ecology and limnology in national parks.

The Environmental Protection Service develops regulations for specific industrial waste discharges, administers nutrient controls, regulates production of environmental contaminants and monitors environmental aspects of federal facilities and activities.

(b) Department of Agriculture

The Department of Agriculture's Canadian Forestry Service conducts hydrologic research some of its regional research centres.

(i) Great Lakes Forest Research Centre

Twenty small catchments, 4 to 70 ha, in the Algoma district of Ontario, are being monitored for precipitation, throughfall, streamflow, forest floor percolate, soil percolate at four levels and for total output of the small feeder streams. This is part of a multi-agency, multi-disciplinary study whose purpose is to look at terrestrial, aquatic and fisheries parameters with respect to acid rain. Eight small catchments are being monitored for flow and water chemistry east of Lake Nipigon where black spruce is being harvested by both clearcut and strip-cut methods. This is a continuation of work conducted from 1972 to 1976 in jack pine at the Experimental Lakes Area near Kenora where clearcutting was the only harvesting system in use.

(ii) Northern Forest Research Centre

The Oldman River Management Committee recommended that a pilot scale test be conducted to prove the feasibility of using forest cutting techniques to increase water yield from a large watershed (large interpreted as greater than 125 square kilometres).

The Alberta Forest Service looked for an area of suitable size in the Oldman River Basin. Because of previous cutting or existing commitments to land uses other than timber harvest, a suitable area could not be found there. However, three such areas have been located in the South Saskatchewan River Basin. A report has been prepared outlining the selection process and giving a rough estimate of the costs involved.

The selection of Mount Allan as the site for the downhill ski events during the 1988 winter Olympic Games has placed the Marmot research program into a state of extreme uncertainty. The status of Marmot during the next few years now seems to be stabilized. The phase one development plan for the games does not infringe on either the Twin or Middle Creek catchments. The Alberta Forest Service has given the assurance that they will support maintaining the integrity of the Twin and Middle Creek catchments through the fall of 1986. No developments in those areas are foreseen until after 1988. It is hoped to continue data collection until the treatment effect has been properly evaluated, or until the catchment has been made unusable.

(iii) Pacific Forest Research Centre

Research continued during 1983-84 on the Carnation Creek project. A pilot study to detail subsurface water movement pathways and rates on steep slopes was initiated. Summer measurements of groundwater levels in the valley bottom were taken as part of an on-going study. A major (100 year? event) rain storm generated several debris torrents and has prompted further study of mass wasting in the watershed.

Pilot studies to determine the fate of urea fertilizer applied on snow have been conducted at Spillimacheen (near Golden) and Green Mountain (near Nanaimo). The meteorological stations were maintained at these sites, but will be removed during the summer of 1984.

(c) Department of Energy, Mines and Resources

The Geological Survey of Canada is working on a wide range of subjects more or less closely related to hydrology. These include: seismic reflection techniques for locating buried valleys and aquifers, vegetation - snow patch relationships in the high Arctic, permafrost and ground ice map, tree-ring chemistry - flood frequency, permafrost in arctic beaches, recent sediments in lake basins and tectonic disturbances, hydrologic parameters - stream bed grain size relationships, properties and distribution of permafrost, airborne gamma-ray snow surveys, lake sediment geochemistry, stream sediment geochemistry, relationship between metal content of surface waters and geological environment, geological characterization of Canadian lakes, Quaternary paleoecological studies of the Great Lakes, failure of natural dams, catastrophic flood events in the Cordillera, composition, origin, and diagenesis of gases in lake sediments, isotopic composition of sediments, pore waters and marks as surrogate for palynology, pathways of migration and fixation of uranium in arctic lakes, relationship between dissolved helium in groundwater and major tectonic features, development of groundwater sampling and downhole analytical equipment, and geophysical studies of geothermal energy resources in southwestern British Columbia in co-operation with B.C. Hydro and Earth Physics Branch, EMR. In addition, the Geological Survey provides background information and geological support to the nuclear waste management research program and the acid rain research program.

Work related to hydrology is undertaken by the Earth Physics Branch in four main areas: geothermics, geothermal energy, permafrost studies, and crustal dynamics studies.

The movement of groundwater has a profound effect on the thermal regime of the upper part of the earth's crust, particularly in sedimentary basins, areas of mountainous terrain, and oceanic spreading centres and rift zones. Hydrothermal systems, driven by volcanic heat are responsible for the deposition of sulphide minerals on the sea floor and the filling of fractures with mineral deposits in continental volcanic zones. Migration of water in sediments exerts a considerable control on the thermal maturation of hydrocarbon material to oil or gas and on the eventual accumulation of fossil fuel deposits.

Geothermal energy relies on the coincidence of water and high temperature, and its exploitation depends on the production of hot groundwater or steam. The low-temperature

geothermal resource (50-150°C) in Canada is very large and tends to be greatest in the areas where oil and gas are also plentiful. Geothermal studies also seek to improve knowledge of permafrost distribution and the processes on- and offshore that contribute to both its presence and changes with time. The phenomenon of water migration associated with freezing, frozen or thawing soils is a research focus. Field research includes monitoring at a number of test sites along and associated with the Norman Wells to Zama Lake pipeline as well as distributed through the permafrost regions in general. Facility and laboratory experiments include contracted studies on soil freezing around a chilled pipeline at Calgary, Alberta, and Caen, France, and fundamental studies of the processes of ice lensing in soil. In a broader sense extensive maps of permafrost distribution have been under development, a distribution which seems at least partially related to ground water movement.

The interaction between ground water and mechanical effects in the Earth's crust is of interest in crustal dynamics studies. Currently this interaction is being investigated in connection with possible earthquake mechanisms and also to characterize fractures for the Canadian Nuclear Fuel Waste Management Program through the observed response of pore fluids to earth tide stresses.

The Geographical Services Division, Surveys and Mapping Branch, is preparing a new map of drainage basins in Canada, at a scale of 1:7 500 000 for inclusion in the 5th Edition of the National Atlas of Canada. The Topographical Survey Division, Surveys and Mapping Branch, provides technical advice concerning flood plain mapping to Environment Canada as part of the Flood Damage Reduction Program and/or manages flood plain mapping contracts.

3. Newfoundland

Acres Consulting Services Ltd. (St. John's office) examined severe flood events in southern Newfoundland for Newfoundland and Labrador Hydro, as part of an overall assessment of flood handling strategies in the Bay d'Espoir hydro system. Probable maximum flood studies were performed in cooperation with the Atmospheric Environment Service of Environment Canada. Acres also prepared a storm water management plan for the site of St. John's Airport and adjoining outfall areas. The plan assessed the impact of future airport development on surface runoff and water quality, and prepared engineering design recommendations on major drainage courses which will be implemented as development proceeds. The field program included monitoring of water quality and quantity for baseline data, with measurements also taken during peak events. The EPA Storm Water Management Model (SWMM) was used to model the system from the data base inputs. Pollutographs and hydrographs were produced for simulated design events based on various storm return periods up to 100 years.

MacLaren Plansearch in association with Fenco Newfoundland Ltd., carried out a hydrotechnical study of the Exploits River. A computerized ice process model based on meteorological and river geometry inputs was developed to simulate the production, accumulation and progression of ice in the river.

4. New Brunswick

The Water Resources Branch of the Department of the Environment is active in assessing the Province's water resources, in flow and flood forecasting and in encouraging applied research on ice mechanics and ice jam problems. Considerable experience has been gained in the application of remote sensing techniques to snow distribution estimation for use in flood forecasting.

The New Brunswick Subcommittee on River Ice has been established with members from the N.B. Departments of the Environment and Transportation, Environment Canada and the N.B. Electric Power Commission under the Flood Forecasting Technical Committee. The main goals of the subcommittee are related to the collection of data on river ice and the promotion of ice related research. The Third National Workshop on the Hydraulics of River Ice was held in Fredericton on June 20-21, 1984. The workshop was sponsored by the N.R.C.C. Subcommittee on Hydraulics of River Ice in association with the N.B. Subcommittee on River Ice and the University of New Brunswick. A two day short course on river ice engineering

preceded the workshop. The workshop offered an excellent atmosphere for discussion and exchange of information on ice research and river ice problems.

The Water Resources Branch was involved in organizing an airborne monitoring program of snow water equivalent within the Saint John River Basin. The gamma-ray technique was used by two aircraft, one from the National Hydrology Research Institute, Environment Canada and one from the National Weather Service U.S.A., to measure the snow water equivalent within the basin. Ground measurements of the water equivalent were also performed over several calibration lines. Satisfactory comparison between the airborne and the ground truthing data was obtained.

Hydrological analyses have been carried out for various watersheds in the Province in connection with hydrotechnical studies under the Canada-New Brunswick Flood Damage Reduction Program.

The long-term Nashwaak Experimental Watershed Project located in central New Brunswick is continuing. The project began in 1970 and was designed to determine the impact of certain forest management practices on environmental quality and on the hydrology of the watershed. The management of the project is provided by a Technical Committee which is comprised of university researchers and government representatives.

Flow duration analysis of discharge data is being carried out for nearly 100 active and discontinued hydrometric stations. A lowflow analysis is also being prepared for all hydrometric stations having more than ten years of records. These two reports will be available soon.

The dam inventory and inspection program continued in 1983/84 with the support of the Canada Works program. Inspection and field visit reports have been completed for more than 300 of the 500 dams in N.B.

The Water Resources Branch is also actively involved with the Canadian Advisory Committee on Remote Sensing. Several workshops on remote sensing activities were held at the University of New Brunswick. Also, several remote sensing displays were shown at various locations in the City of Fredericton.

Snow cover mapping using NOAA satellite imagery is now being produced by a local New Brunswick firm. The development of the local expertise was undertaken in cooperation with the Atmospheric Environment Service of Environment Canada, the National Weather Service, and the Canada Centre for Remote Sensing. This remote sensing technique is being used operationally for flood forecasting along the Saint John River, N.B.

Flood flow analysis and water surface profiles along Marsh Creek in southern New Brunswick were evaluated. The report addresses the flood flow storage problem within the watershed, evaluates the impact of the loss of available storage on flooding, and evaluates the present flood protection along Marsh Creek as a result of the various improvements carried out under the Flood Damage Program Agreements.

In an effort to protect water supply watersheds, the Water Resources Branch is involved with the production of 16 digital maps covering Turtle Creek and Chamcook Lake watersheds. These maps will be produced by the Maritime Resource Management Service (MRMS) by interpreting aerial photos at scale 1:10 000. Various land use characteristics such as property, infrastructure, forest, agriculture, etc. will be identified on these maps. A parallel field study is also underway to identify specific activities within these watersheds such as gas stations, industries, farms, etc. These activities will eventually be placed on the watershed maps. In the meantime, a project is being undertaken under the Technology Enhancement Program to define and detect changes within watersheds using Landsat MSS and digital analysis. This is being done in cooperation with CCRS, MRMS, and U.N.B.

A groundwater data review is being undertaken in order to facilitate the process of identifying future groundwater network requirements in New Brunswick.

The Environmental Services Branch continued its acid rain monitoring program. Three precipitation stations were located in rural areas where the monthly data are analyzed for

pH. Four stations are located in an urban area forming an event type network. Snowmelt chemistry analysis was also undertaken to determine the pH concentrations. General water quality monitoring on various rivers and lakes throughout the province was carried out to determine the background conditions as well as the effects of domestic and industrial effluents.

The University of New Brunswick's Department of Civil Engineering has been investigating flow characteristics through bends in laboratory and natural channels and evaluating the effect of width/depth and radius/width ratios on shear stress distribution in 60 degree bends. Sand dune size and distribution in the Saint John River at Oromocto has been evaluated. Studies related to estuarine problems such as the ice process as affected by large tidal range and the sediment distribution as affected by the construction of barrages have been undertaken. A study on drain spacings and their effect on the drainage of agricultural land has been concluded. Various studies related to river ice processes were undertaken; these include the determination of ice undersurface and channel bottom roughness from measured velocity profiles, and the prediction of ice break-up and the associated flood stage.

At the Department of Forest Resources, several researchers are continuing collaborative research in the Nashwaak Experimental Watershed Project. The project, designed to determine the effects of clearcut harvesting on a small headwater stream, commenced in 1970, and was treated experimentally in 1978-1979. Impact and recovery continue to be monitored. Water and energy balance, streamflow regime, snow cover, water chemistry, including acidity of precipitation, and throughfall and soil moisture, are being studied. A number of research papers and project reports are available. Several non-university organizations are also involved in the project.

MacLaren Plansearch in association with Fenco and Geocon carried out a hydrotechnical study of the Norton area which is subject to flooding by the Kennebecasis River. Design flows were estimated using historical flow records on the main river and sub-regional flood frequency analysis was conducted for the ungauged tributaries.

5. Nova Scotia

The Technical University of Nova Scotia's Centre for Water Resources Studies continued the Halifax Urban Watersheds Program, with monetary support and assistance from NSERC, the Technical University, and cooperating government agencies. Three full years of water quality data has been collected and preliminary water and chemical mass balances have been derived. Work continued on development of appropriate data acquisition systems, including evaluation of a rain gauge system developed at McMaster, and manufacture of a data logger to CWRS specifications. The Models OTTHYMO and CONHYMO have been applied to the watersheds, and will be calibrated as appropriate data become available. Projects were initiated on the hydrogeology of the system and on hydrodynamic modelling of the lakes. Research on on-site sewage disposal and rain water cistern systems continued. Advisory panels on research and education related to these topics, and to erosion and sediment control, have been active.

6. Quebec

During the past year, research at the Université du Québec à Chicoutimi has focussed on stochastic characterization of short-time increment rainfall for urban drainage applications. A stochastic method has been proposed for estimating the mean temporal pattern of storms. A study has been conducted to develop a probability distribution function for mean rainfall over an area. Research has continued with Ecole Polytechnique de Montréal to study the hydrology of small watersheds.

7. Ontario

Hydrological research in the Department of Civil Engineering at Queen's University involves the following projects: real-time flood forecasting for flood damage reduction and for reservoir regulation using stochastic and dynamic models, development of urban runoff models (both quantity and quality), development of urban design storms, development of models for agricultural drainage, hydrologic frequency analysis and the development of

interactive hydrologic simulation programs for microcomputers. The Department of Geography is studying the characteristics of the radiation and energy balances for forest and logged sites at the Petawawa National Forestry Institute, Chalk River. Various forms of the combination model for evapotranspiration are being examined.

Hydrological research at the University of Toronto is conducted in the departments of Civil Engineering, Geography and Urban and Regional Planning, the Faculty of Forestry, the Institute for Environmental Studies and Scarborough College. Studies include the statistical analysis of meteorologic data, the development of probability-based, analytical urban drainage models, micro-computer applications of urban drainage models, Great Lakes water balances, and groundwater contamination.

Most hydrological research at Trent University is undertaken in conjunction with the Watershed Ecosystems graduate program offered jointly by the Geography and Biology Departments. Research over the past year has focussed on the hydrology and water chemistry of small wetland, agricultural and urbanizing catchments, and on hydrological and biological aspects of snow and lake ice cover in the Peterborough region, in Muskoka-Haliburton, in Labrador, and on Axel Heiberg Island, N.W.T. A study of ice jams on the Liard-Mackenzie is also underway.

The University of Waterloo's Department of Civil Engineering is currently involved in research on the use of remote sensing data from satellites in hydrology and water resources. This includes studies to estimate river basin characteristics and meteorological inputs, and a study on the use of GOES imagery to assess the characteristics of tropical cyclones and forecast their movement. Studies using computerized continental data banks as a basis for generalization of hydrologic characteristics have covered large areas in North and South America (the Amazon River Basin). A UNESCO sponsored project on linking information systems totally or partially devoted to hydrology and water resources, into a water related informative system at a global scale (WRINGS), is currently underway.

At York University's Department of Geography studies are underway into the biogeochemistry of stream ecosystems. Current research focuses on processes of nitrogen transport and transformation in rivers, and the influence of nutrient dynamics in hydrologic source areas on stream water chemistry. Research is also being carried out to evaluate the evaporation in the Hudson Bay Lowlands, on the effects of advection on the latent heat flux and active-layer development, and to evaluate instrumentation suitable for evaporation estimates in cold regions.

The Niagara Falls Office of Acres Consulting Services Ltd. has prepared an atlas for the Ontario Ministry of Natural Resources entitled Water Quantity Resources of Ontario. This volume contains hydrological information in map and graphical form, and is intended to reach a wide audience.

A study was undertaken for Environment Canada, Inland Waters Directorate entitled Hydrological Design Methodologies for Small-Scale Hydro at Ungauged Sites - Phase I. Regional methods were developed and tested for most parts of Canada to estimate flow duration curves, turbinable flow curves and design flood parameters at ungauged sites. Estimation procedures developed are suitable for reconnaissance-level studies of small-scale hydro development.

Also for Environment Canada's Inland Waters Directorate a study was carried out entitled "Assessment of Water Supply Constraints to Energy Development - Phase III". The study examined the balance between water supplies and demands for energy and agricultural development, focusing on the prairie provinces, where potential shortages are most severe.

Acres concluded a study for the Canadian Electrical Association of river ice behavior on the Peace River in Alberta and the Gatineau River in Quebec. These rivers are subject to rapid variations in flow during the winter months as a result of upstream hydroelectric project operations. Shoreline hinging of the ice cover was emphasized during the study.

MacLaren Plansearch, a member of the Lavalin Group, has carried out a number of hydrological studies in 1983-1984. These include: low flow augmentation study of the Spanish River system using the HEC-5 model to develop an optimal operating strategy to meet

target flows for water quality and maximize both hydropower and recreation potential; flood plain mapping studies of Shoreacres Creek watershed in Burlington using the latest OTTHYMO model and of Bell Creek watershed in Belleville using the HYMO model with modification for urban conditions; the assessment of pre- and post-development flow conditions for the CN Caso Yard in Windsor; drainage study of Maple Hill Creek in Waterloo to assess the effect of urbanization on flooding; PMP analysis to design channel diversion works for a hazardous waste disposal site in Edgemont, North Dakota; the deregulation of the Muskoka River watershed to optimize the operation of the system using a water balance model; the development of flood forecasting procedures for the operation of Lake Nipissing and also for some Muskoka River lakes; and an infiltration study of the Hemlo gold mine tailings in Northern Ontario.

8. Prairies

During the past year the Prairie Farm Rehabilitation Administration (PFRA) has been involved in conducting water supply and flood studies for the design of proposed water development projects and in providing flood potential analyses for existing projects under the PFRA Dam Safety Program. No research studies have been undertaken, but PFRA has continued to collect limited basic hydrometric data under PFRA's Spring Runoff Monitoring Program. In addition, a limited number of sites have been monitored to obtain rainfall runoff data resulting from severe rainstorm events.

9. Manitoba

At the Manitoba Department of Natural Resources Phase One of the Canada-Manitoba Flood Forecasting Agreement has been completed and a Canada-Manitoba Flood Forecasting Centre has been established to perform studies and to apply flow forecasting procedures under the Agreement. The major component of Phase One was a Pilot Project conducted in the Boyne River Watershed to determine which runoff model would be most suitable for application in the Red, Assiniboine and Souris River watersheds in Manitoba. The HSPF, SSARR, SLURP and MANAPI models were calibrated on the Boyne River using three years of data and were verified on three spring runoff events from other years. The HSPF (Hydrologic Simulation Program - Fortran) model was selected for application under Phase Two, based mainly on its rigorous representation of physical processes and on its somewhat superior performance. Other activities under Phase One included studies to determine suitable channel routing procedures for tributaries and for major river channels and studies to determine suitable field instruments and data transmission methodologies for real-time hydrometeorological data acquisition. A full report on Phase One should be available in early 1985. Phase Two of the Agreement has been approved and work has begun toward application of the HSPF model on selected tributaries of the Red, Assiniboine and Souris River watersheds. Phase Two is scheduled to extend until March 1986.

Collection of hydrometeorological data continued in the Domain Drain and Mannes Drain watersheds. These data will be used to determine the effects of drainage improvement and land use changes on the water balance components of a watershed. Drainage works are being installed in the Domain Drain watershed while the adjacent Mannes Drain watershed will be left unchanged to provide a "control" watershed for this study. Environment Canada's National Hydrology Research Institute is the lead agency in the experimental design and analysis of this project.

Water quality tests associated with the Elie Aquifer Enhancement Project have revealed levels of agricultural chemicals in the La Salle River that are of concern to public health authorities. This circumstance has resulted in postponing indefinitely any experimental water transfer from the La Salle River to the Elie Aquifer.

Pumping tests were carried out in the sand deposits associated with the glacial lake plain of the Souris River Basin to provide more quantitative information on the hydraulic characteristics of the Oak Lake Aquifer. These data will be used to gain a better understanding of the water supply capability of the aquifer using modelling techniques. Both groundwater studies are being carried out under terms of the Canada-Manitoba Interim Subsidiary Agreement on Water Development for Regional Economic Expansion and Drought Proofing.

10. Saskatchewan

The Saskatchewan Water Corporation is a new entity in water resources management in the province. On June 30 1984, the Government of Saskatchewan proclaimed the Water Corporation Act. Of primary importance to the corporate concept is the management, administration, development and control of water by watershed and the delivery of programs at the local level. At the same time a central body of expertise has been maintained to deal with forecasting and operation planning for major river systems, interjurisdictional water matters and broad regional management objectives.

The Hydrology Service of Saskatchewan Water Corporation undertook a study of regional flood frequency analysis. The study resulted in the development of regional relationships for frequency flows based on a number of climatic and physiography parameters. Innovative computer techniques were used to correlate and extend hydrometric records within Saskatchewan. Station by station correlation and data extensions yielded a comprehensive, long-term data base for the single station frequency analysis. Stepwise regression techniques were applied to linearized dependent and independent variables to yield regression equations for numerous regions for predicting flows from ungauged basins.

The Hydrology Service has undertaken to co-operate with the Saskatchewan Research Council to use the Dipix remote sensing interpretive and analytical equipment for determining the areal extent of snow cover, snowpack density and depth, depressional storage and artificially drained areas of a basin. Of primary interest to the Hydrology Service are real-time applications for flood and operational forecasting, resource data base creation and maintenance and specific data aquisition requirements for detailed water resources.

At the University of Saskatchewan hydrologic research activities are conducted in the Colleges of Agriculture and Engineering and in the Department of Geography. The Saskatchewan Research Council and other Government agencies, housed on campus, also are involved in research efforts.

At the College of Engineering members of the Civil Engineering Department are studying the unsteady flow of water through porous media layers using a physical model. The objectives are to better define the processes of interflow and snowmelt runoff and to evaluate methods of solution of the appropriate differential equations. A finite difference model of the conditions of flow through and on a hillslope is being tested and improved. Some work is being done on sediment production from agricultural lands and on scour around obstacles in a mobile boundary river.

Research on ground water recharge and soil salinity changes due to irrigation are continuing in the Agricultural Engineering Department.

At the Saskatchewan Institute of Pedology, as part of the Innovative Acres Farmlab program, the effect of different stubble management practices on overwinter soil water recharge is being evaluated. The studies are carried out at 40 farmer cooperatives and in some cases the effects of deep fall tillage on snowmelt recharge are studied. In ongoing erosion studies the current emphasis is on trying to draw up a soil loss and gain balance for two small watersheds, and on analyzing climatic records to assess the wind- and water-erosion indices.

A program to determine the cause of soil salinity on individual farms and to recommend management practices to deal with the problem is underway. The investigation involves a thorough review of all existing data for the farm (e.g. all aerial and hydro-geological information) followed by intensive on site surveying and drilling to determine the local hydrogeology. In many instances waterbearing strata at depths of 20 m or more appear implicated.

The Saskatchewan Research Council's Environmental Sector's thrust this year has been towards water quality and quantity and biota in the area of uranium tailings, urban centres, and small and large water supplies. In the uranium tailing studies, abandoned and active uranium tailings have been instrumented and samples taken. The findings have been stored in a micro-computer system for retrieval by the Canadian Uranium Tailings Program

(DEMR and Saskatchewan Health Research Board). The sector has been active in providing data on urban flooding in Saskatoon and on water quality problems in Saskatoon, Lake Diefenbaker, Regina, Moose Jaw, Beaver River and Red Deer River. One thousand dugouts which were built in 1968 and were examined in 1974 are being sampled again 15 years later to determine their water supply capacity. Climate change models are also being used when examining Saskatchewan water supplies.

The Resources Sector has completed the bedrock and aquifer mapping of southern Saskatchewan. The new thrust is toward surface drift mapping for surficial groundwater supplies and aggregate supplies. The North Battleford, Saskatoon and Weyburn map sheets are in various stages of completion. Work is continuing to use the data from an extensive system of groundwater observation wells for groundwater modelling.

The major research activities of the Division of Hydrology continue to be centered on Snow Hydrology and Infiltration to Frozen Ground. Snow drifting research is designed to determine the seasonal drift rates and the evaporation/sublimation losses from snowcover by wind transport. Field measurements of snowcover accumulation, depth and water equivalent, are being conducted on different stubble management practices such as alternate height stubble, hi-low and leave strip cutting, to assess their trapping efficiency.

A process-oriented field study into infiltration to frozen ground has been undertaken over the past six years and sufficient data are now available to allow some generalizations concerning snowmelt infiltration to frozen soils on the prairies. For example, infiltration rates and amounts to 'uncracked' soils are governed by the frozen moisture content of the shallow surface layer (0-30 cm in depth) and significant overwinter changes (freeze-up to the time-of-melt) in soil moisture occur in the soil profile as a result of water migration in response to freezing and/or movement of water from the soil into the snowcover or atmosphere.

The NWS Sacramento River Forecast System model is currently in operation on the division's computer. It is being used as a means of transferring the results of the field studies to management agencies. Extensive revision of the land phase subroutine is being undertaken as a result of the infiltration studies.

A major thrust of the division's research in the past was the melt of the shallow prairie snowpack. The first phase of this work is complete and sufficient data have been accumulated to allow the development of accurate melt indices for specific prairie applications. Both the continuous snowcover and snow patches have been examined. The second phase of this work is an examination of the areal variability of melt rates.

MacLaren Plansearch continued the monitoring of several streamflow gauging stations and analysis of the output at the Dawn Lake and Canoxy properties in northern Saskatchewan for input to an environmental impact assessment. In association with Fennell Cochrane Lavalin, the firm undertook further study of the proposed Rafferty Reservoir on the Souris River, including the effect of a dual connection between Rafferty and Boundary Reservoirs to meet water supply and flood control needs.

11. Alberta

Alberta Environment's Hydrology Branch started the processing and evaluation of Marmot Creek Research data into a physically based water balance system, using the complementary relationship areal evapotranspiration model (CRAE), which was developed by F.I. Morton, in a water balance equation.

Spring Creek Research watershed data have been used to develop a runoff model which describes storage effective drainage (SED) relationships of the basin. The SED runoff model is now being expanded to produce predicted hydrographs of single storm events. The objective of the study is to provide a physically based predictive runoff model that will describe the hydrologic variability between post- and pre-land use changes imposed upon the basin.

The Hydrogeology Branch of the Earth Sciences Division, is continuing its geophysical and drilling activities to enhance the ability to predict groundwater behaviour in Central

Alberta. The Branch is involved in the detailed evaluation of groundwater potential and delineation of the hydrostratigraphy in the vicinity of Bonnyville, Grand Centre, and the Cold Lake Air Weapons Range. In conjunction with these activities, the Branch is developing an optimization model to determine the long term optimal yield of the Cold Lake aquifer system. By specifying appropriate objective functions and constraints, optimal groundwater withdrawals from the subsurface system can be determined by a finite-element-based linear programming model.

The Hydrogeology Branch is also collecting water level and hydrochemical data from over 150 observation wells located throughout the province. The collected data are used for identification of groundwater resources, feasibility of fluid injection, and effects of in-situ process of heavy oil production on groundwater.

The River Forecast Centre has been involved in two research and development projects aimed at operational hydrology. Research on the best techniques for estimating rate of snowmelt in an alpine environment has been conducted. Data from the Marmot Creek research watershed were used to compare temperature index, snow pillow, and energy budget approaches. This work will be published as a master's thesis at the University of Saskatchewan at Saskatoon.

Development of a prototype weather radar processing system for flood forecasting application is now virtually complete. This work was done largely by the Atmospheric Sciences Department of the Alberta Research Council for the River Forecast Centre. The system will become fully operational in 1985.

The River Forecast Centre continues to develop and improve its techniques for forecasting floods and water supply, and for monitoring streamflow behaviour. The Centre uses an interactive version of the SSARR (Streamflow Synthesis and Reservoir Regulation) hydrology computer model for much of this work.

The River Engineering Branch completed the following Flood Risk Mapping Projects; Bow River, Elbow River, and Nose Creek through Calgary. The flood risk maps show the floodway/floodplain boundaries for the 1:100 year flood. The published reports give the details on hydrologic and hydraulic analysis done for the project: i) Elbow River at Bragg Creek, detailed flood risk mapping for the Town of Bragg Creek was completed; ii) Red Deer River through Drumheller valley, flood risk maps for the 1:100 year flood for the Drumheller valley, including Drumheller, were prepared.

Flood protection studies were done for the Elbow River through Calgary and Athabasca/Clearwater Rivers through Fort McMurray. These studies investigate various structural flood mitigative measures (dykes, channelization, etc.) to reduce flood damage. Extensive ice freeze-up and break-up monitoring was done for the Peace River through the Town of Peace River and the Athabasca and Clearwater Rivers through Fort McMurray. The objective was to minimize flooding and property damage due to possible ice jams.

During the past five years, the Survey Branch has been installing a real time hydrometeorological network mainly in the Eastern Slopes of the Rockies. The main purpose of the network is to improve the flow forecasting capabilities of the Department and also to provide a data base in an area where basic data have been very scarce. The network which is now 90% complete consists of 48 meteorological stations all of which are equipped with automatic rain gauges (Fischer and Porter). Thirty-one of the stations monitor temperature and 14 of the stations are multi-parameter stations, measuring parameters such as relative humidity, wind, and the water equivalent of snow. In addition, the department has equipped 18 hydrometric stations run by Environment Canada with telemetry. Of the 66 stations in the hydrometeorological network, 38 are equipped with data collection platforms using the GOES system. A system to process the data from the network, as they are received, is being developed and this system will be fully operational by 1985. The data from the Fischer and Porter gauges and the water level data are being published through Environment Canada on an historical basis.

Since the early 1970's, Alberta Environment has maintained a hydrometeorological network in the Peace-Athabasca Delta to monitor water levels and flows. At the present time there are 52 hydrometric stations, 35 of which are miscellaneous sites and 17 are

recording stations. Four of the recording sites provide continuous flow data and are operated by Environment Canada. In addition to the hydrometric network there is a miscellaneous sediment program and a meteorological network. The meteorological network is comprised of six snow courses, one snow pillow, one evaporation pan, and several storage gauges.

All the continuous water level data are published through Environment Canada on an annual basis in Surface Water Data-Alberta. All other data are available through the Technical Services Division of Alberta Environment.

12. British Columbia

The B.C. Ministry of the Environment continued development of regional peak flow estimating procedures and provided peak flow estimates for ungauged streams for floodplain management and stream crossing design. Hydrologic input to Provincial Strategic Plans was completed. Assessments of the hydrologic impact of past and proposed developments were made for several community water supply watersheds. Estimates of dependable water supply for various drought durations and return periods were made for irrigation projects. A network of three automated snow pillow stations has been installed in the Fraser River Basin using the GOES Data Collection System. The principle role of this network will be to monitor snowmelt on a daily basis to improve runoff forecasting especially during the spring freshet period. The Ministry maintains a network of 145 observation wells to monitor water level and water quality fluctuations in unconsolidated and bedrock aquifers and carries out groundwater investigations related to water supply, drainage, and waste disposal problems.

13. Yukon

The Water Resources Division of the Department of Indian and Northern Affairs - Yukon Region continued operation of its Hydrometric Program by monitoring flows at 24 locations throughout the Territory, primarily on small streams to supplement data collected by the Water Survey of Canada. A Historical Data Summary (1975-83) was compiled for publication in September 1984. With assistance from the Atmospheric Environment Service 11 precipitation stations and 41 snow course stations were operated for water management purposes, and a monthly snow survey bulletin was published throughout the winter. The Division participated in the Yukon River Basin Study Hydrology Component which produced four study reports: Hydrometeorologic Data Network Assessment, Winter Ice Cover, Natural Flooding, and Hydrologic Modelling.

Various hydrometeorological data collection networks were assessed (WSC and INAC hydrometric, AES and INAC meteorologic and B.C. Environment and INAC snow course) to determine their adequacy to meet present and future site specific and baseline requirements including hydroelectric, mining and linear facilities developments, flood forecasting and reservoir operation.

Winter ice cover was studied with the objective of determining downstream effects of proposed hydroelectric development on freeze-up and break-up processes and subsequent flooding. The study included the documentation of freeze-up and break-up of the Yukon River between Whitehorse and the international boundary downstream of Dawson. Flood prone areas in populated and remote regions of the Yukon River basin were identified and recommendations made for floodplain mapping and protection. A modelling study examined the downstream effects of various hydroelectric development scenarios.

The Division was also involved in the Mackenzie River Basin Study which is at the implementation stage of several recommendations including the establishment of an integrated monitoring network and spring flood studies on the Liard River. An experimental watershed was established and monitoring undertaken for the purpose of calibrating hydrologic models for transfer to ungauged locations.

Work has started on the development of peak design flow estimating methodology and an associated design manual for placer mining activities.

14. Bibliography

A cross referenced, abstracted guide to 1490 recent Canadian hydrology and water resource publications (for the most part 1982/84) is available from G.A.D. Greene, Secretary, Associate Committee on Hydrology, c/o Environment Canada, Inland Waters Directorate, Ottawa, Ontario, K1A 0E7 (see mailing card at end of this volume).

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X MINING GEOPHYSICS

Compiled by: Norman R. Paterson and Stephen W. Reford

1. Introduction

Twenty-five organizations reported research in mining geophysics in 1984, the same number as in 1983. The apparent level of effort is distorted by a lack of information from several organizations in both the private and government/university sectors. Total expenditure reported in 1984 was $5.85 million, comprising $4.85 million from industry, $0.7 million from government and $0.3 million from universities. A corresponding 1026 person-months of research employment was divided between industry with 668 months, government with 264 months and universities with 94 months. Within industry, $3.15 million was spent by three companies: Scintrex, Phoenix Geophysics and EDA Instruments. Since no information was reported by some of the larger companies or by a number of companies supported by the Ontario Government's Exploration Technology Development Fund (ETDF) Program, it is likely that the total industrial effort is at least 50% higher than the amount reported. The ETDF support amounts to approximately $1.0 million annually. It is

interesting to note that industry's reported level of expenditure is slightly higher than in 1983. However, the amount of time devoted to R&D is only slightly more than half the amount stated for 1983. We do not believe that this is due to higher salaries but, rather, to increased direct costs such as electronic supplies and computer services. Level of effort in the government and university sectors is also understated, no figures being available from the Ontario Geological Survey, and no reports submitted by several of the major universities. However, the available information suggests that the level of effort has been maintained from 1983 to 1984. Research is underway in all areas of instrumentation, survey methods and interpretation. Those fields of study most often discussed are: airborne electromagnetics, ground and airborne magnetics, induced polarization and (audio) magnetotellurics. A highly successful symposium, on the use of computers in data acquistion and processsing/interpretation, was held in Toronto in January 1984. A second successful symposium, on the role of geophysics in gold exploration, was held in Val d'Or in November 1984.

INDUSTRY

2. Barringer Research Limited, Rexdale, Ontario (R. E. Lett)

Parallel tests of the COTRAN and INPUT airborne electro-magnetic systems over known ore bodies in Wisconsin continued during the year and confirmed the increased sensitivity and penetration capabilities of the COTRAN system. Significant improvements to a semi-quantitative technique for clay mineral analysis based on bi-directional reflectance radiometry has resulted in the development of the CLAYPAK system. The system comprises a Barringer ratioing radiometer, Epson HX-20 microcomputer and software designed to deconvolve mineral target reflectance spectra. Using this system, rapid direct estimations of clay mineral contents are possible in the field. This technology will be available on a commercial basis by mid-1985. During 1984, this company devoted 52 person-months and $125 000 to these projects.

3. Dighem Surveys and Processing Incorporated, Mississauga, Ontario (S. Kilty, D. C. Fraser)

Development continued on the four coil, high frequency system (50 000 Hz) and the development of a practical inversion technique, to extend the capabilities of an airborne helicopter exploration and mapping system. The inversion software has been used on an experimental basis utilizing data acquired at research areas for Atomic Energy of Canada Limited and for bathymetric depth mapping for the United States Naval Oceanographic Group. Development of a digital receiver console for the DIGHEM III/IV systems commenced in December 1983. This receiver will sample the incoming EM data at a 100 Hz sample rate, then filter and stack the information, and output the data to a digital recorder. It is hoped that this will significantly improve the signal-to-noise ratios of present helicopter EM technology. Thirty person-months are being devoted annually to these projects.

4. EDA Instruments Incorporated, Toronto, Ontario (S. C. Kirkby, H. Wondergem, C. Elliot, G. Slover, S. Grover)

Development of the 'OMNI PLUS' combined ground VLF, magnetometer and gradiometer system is underway. The VLF system is microprocessor-based, requires no orientation of the sensor, measures the in-phase and out-of-phase components for all three axes, measures the total field amplitude and dip (more accurately than conventional systems), and can be integrated with the existing OMNI IV 'Tie-line' magnetometer/gradiometer technology. The design and a prototype of the 'K-2' magnetic susceptibility meter have been completed and production is currently underway. This meter has increased sensitivity, will output in either cgs or SI units, and possesses a multiple averaging capability. Field testing is currently being conducted to verify objectives of the development of a "pocket" IP-resistivity meter. The pocket-sized meter will measure the chargeability and resistivity of drill core and rock samples without the need for sample preparation. Hardware design is currently under consideration for a radon daughter/working level monitor and a radon gas monitor, both portable, continuous reading and memory based. A total of 100 person-months and $500 000 in R&D are being devoted annually to these projects.

5. GEM Systems Incorporated, Don Mills, Ontario (I. Hrvoic, J. Myzyk, A. Pirmohamed, C. Apostolopoulos, P. Halbersma, D. Beltrame, D. Webster)

Development of the portable Overhauser magnetometer model GSM-9 has been completed. The past year has seen the general upgrading of characteristics of the unit with the addition of analog output, an internal trigger, a reliable RF source and optimised sensor parameters. Development of the portable memory magnetometer model GSM-18 continues. New software has been added to the existing instrument, including computer communications, data presentation and simpler operating procedures. The mechanical packaging has been improved. The development of the airborne Overhauser magnetometer model GSM-11 is in the final stages. The symmetrical version of the proton oscillator has been completed resulting in improved reliability, simplicity, relaxed tolerances of the electronics and improved signal-to-noise ratio. The signal processing unit has been completed. A project to develop a tridirectional Overhauser airborne gradiometer (model GSM-11GH4) is about half completed. Four proton oscillators, producing continuous proton precession signals, are placed in a special bird with three fins at 120° angles. The proton frequencies are counted in a special signal processor. Magnetic fields and three gradients, along with on-line noise levels, are determined and readied for recording. Gradient noise levels of 25 pT/m are expected. This project is supported by an Ontario Ministry of Natural Resources (ETDF) grant. A total of 44 person-months and $190 000 in R&D are being devoted annually to these projects.

6. Geonics Limited, Mississauga, Ontario (J. D. McNeill, M. Bosnar, G. Levy)

Research and development continue to be carried out on the use of electromagnetic techniques for both geological mapping and the direct detection of conductive orebodies. Research is being carried out in both the time and frequency domains using both large loops and magnetic dipoles and sources. Some of the research is supported by a National Research Council Canada IRAP Grant. Sixty person-months are being devoted annually to this work.

7. Geotech Limited, Markham, Ontario (W. R. Thuma, E. Morrison, N. Valleau, J. S. Holladay, P. Wessler, J. Nunno, B. Pavlik, I. Hrvoic)

A project to develop a 'Through Ice Bathymetry System' (TIBS) was initiated in 1984. This system, destined for use by the Canadian Hydrographic Service, will continuously measure the depth of sea water and the thickness of sea ice to a depth of 50 m from a low flying helicopter towing an EM bird. Extensive modelling has validated the concept and hardware design is well advanced. The system should be operational in late 1985 or early 1986. The extension of the current four frequency in- and quadrature-phase helicopter EM system in the EMEX-1 to seven in the EMEX-2 will be a major improvement in the overall interpretational capability now possible with HEM systems. This project, partially supported by an Ontario Ministry of Natural Resources (ETDF) Grant, is expected to produce a system which will be test flown in early 1985. With assistance from two other equipment manufacturers, Geotech designed, manufactured and test-flew the first helicopter-borne high sensitivity vertical magnetic gradiometer. The system, now referred to as the GRAD-1, produces better than 0.02 nT gradient fourth differences under actual survey conditions with a 3 m sensor separation. A total of 145 person-months and $300 000 in R&D are being devoted annually to these projects.

8. Hardy Associates (1978) Limited, Calgary, Alberta (W. J. Scott, A. E. Kay, F. K. Maxwell)

During the current year, development work concentrated on lowering the noise level in the MICRO-WIP induced polarization system, to improve performance in salt-water environments. Successful trials were held on the east coast in October. Field surveys were carried out at two sites in Saskatchewan for brine migration studies. The work included DC resistivity and inductive conductivity measurements. Results were used in conjunction with control wells to model responses and to assess the detectability of varying concentrations of brines at varying depths.

A project is underway to study the resistivities of Canadian soils. The objective of this project is to define a representative sample population of Canadian soils, and perform laboratory and field measurements of electrical resistivity. The field measurements will

be carried out on selected sites during different climatic seasons using both electromagnetic and electrical techniques. Laboratory apparatus for measuring resistivities of soil samples at different temperatures was designed and implemented. Both the laboratory and field measurement will be completed in the spring of 1985. Funding is being provided by the Canadian Electrical Association under Project No. 143T250. A total of 10 person-months and $160 000 in R&D are being devoted annually to these projects.

9. IFG Corporation, Brampton, Ontario (W. R. Thuma, D. Blohm, M. Hamalainen)

With funding support of the Ontario Ministry of Natural Resources (ETDF) Grant Program, IFG continued the development of the MAGLOG magnetic properties logging system. It is a portable multi-parameter slimhole logging system which will simultaneously and continuously measure the three vector components of the magnetic field, bulk magnetic susceptibility, differential self potential, EM conductivity and fluid temperature. The MAGLOG System uses advanced high sensitivity ringcore fluxgate sensor technology coupled with a CMOS microprocessor and electronics. The system is scheduled for field trials in early 1985. Nine person-months and $42 000 in R&D are being devoted annually to this project.

10. Kenting Earth Sciences Limited, Ottawa, Ontario (R. W. Stemp, M. Best, T. Payne, S. Baker, J. Bremner, J. Wilson, J. Irvine)

During 1984, development continued on the Kenting SWEEPEM airborne electromagnetic system designed by Shell. The major hardware hurdles have been passed and the Canso is currently flying various test sites to determine system performance. The system has a horizontal transmitting loop and two receiving coils (X and Z) mounted in a towed bird. System bandwidth is currently 100 Hz - 5 kHz. The transmitted waveform is a pseudo-random sequence and is readily modified to obtain a desired frequency spectrum. Using an array processor and FFT techniques, the transmitted and received signals are correlated and deconvolved to produce the in and out of phase frequency response of the earth and its impulse response. It is expected that the system will be available commercially in early 1985. In the last quarter of 1984, Kenting commenced development of two additional vertical magnetic gradiometer systems: (i) a second fixed-wing installation in a Navajo aircraft; and (ii) a helicopter-borne system. A total of 32 person-months and $220 000 in R&D are being devoted annually to these projects.

11. Paterson, Grant and Watson Limited, Toronto, Ontario (N. R. Paterson, D. J. Misener, F. S. Grant, S. W. Reford, I. N. MacLeod, E. Baranyi, R. B. Hearst, P. W. Walker, M. Sahib, R. M. Blaiklock)

With the assistance of an ETDF grant from the Ontario Ministry of Natural Resources, the company continued with a program to develop a comprehensive computer software library for both internal and public geophysical interpretation applications. Development and refinement of a number of methods introduced in 1982 or 1983 continued. These include the SPECMAP method, developed with the assistance of Dataplotting Services Inc., for ternary colour mapping of three-channel (U, K, Th) radiometric data, the GEMINV method, for inversion of multi-channel, frequency-domain ground EM data to an n-layered earth model, and the SUSMAP method, for space-domain calculation of magnetic susceptibility at a variable depth surface. Recent enhancements to this software include the adaptation of GEMINV to handle tilt angle/ellipticity data as well as in-phase/quadrature data. The methods continue to be applied on a production basis.

The MAGMOD inversion method for the modelling of total field and vertical gradient magnetic data by individual source parameter optimization is being upgraded with the addition of singular value decomposition (SVD) analysis. A significant amount of effort continues to be directed toward the development of an extensive library of applications software for personal computers. Existing software has been upgraded and a number of new programs introduced. Significant improvements have been made to the MAGMAP software, an all-purpose frequency domain filtering program which facilitates the application of common processes to gridded magnetic or gravity data. A total of 24 person-months and $110 000 in R&D are being devoted annually to these projects.

12. Phoenix Geophysics Limited, Willowdale, Ontario (L. Fox, M. Yamashita, R. Anderson, B. Sternberg, L. Rijo)

A controlled source audio magnetotellurics (CSAMT) system has been developed, specifically a 3 kW DC 10 kHz transmitter, multichannel CSAMT receiver coil, software and field procedures. Field testing has been conducted at Cavendish, Nighthawk Lake and overseas. The computer aspect of a 16-channel magnetotellurics (MT) system has been upgraded with HP 9000-based software development and field testing. The software's capabilities include data acquisition, processing and automated editing, as well as 2-D MT inversion. A total of 84 person-months and $650 000 in R&D are being devoted annually to these projects.

13. Questor Surveys Limited, Mississauga, Ontario (A. Becker, P. G. Lazenby)

In order to fully explore the potential benefits of airborne electromagnetics, a state of the art time domain system was installed and tested on a DC-3 aircraft. The system consists of a high power, variable pulse width transmitter and digital detector. It yields high quality estimates of both the vertical and horizontal components of the transient secondary fields that are sensed by receiver coils carried in a towed bird. This year's activities focussed on the development of new software for the microprocessor, further flight testing over the Nighthawk Lake site and experimentation with new applications for the system. Perhaps the most interesting results were obtained in a bathymetry test off Nova Scotia where it was shown that time domain airborne electromagnetics can be used to map the depth of sea water to an accuracy of about ± 2 m in water depths up to 30 m. Twenty-four person-months and $200 000 in R&D are being devoted annually to this project.

14. Sagax Geophysics, Montreal, Quebec (M. A. Vallée, P. Bérubé, D. Couture)

Research was focussed on the development of microcomputer software as an interpretation tool for induced polarization (I.P.). A program that simulates the responses of various I.P. survey arrays, such as dipole-dipole, gradient, pole-dipole and PPL, has been developed. The PPL is an electrode array developed by the company for gold exploration in the Canadian Shield. Its cost is lower than that of standard arrays, and it gives better localisation of the anomaly source. The new software should help in the understanding and use of the PPL technique. Six person-months are being devoted annually to this project.

15. Sander Geophysics Limited, Kanata, Ontario (G. W. Sander, N. McGowan, T. Chow, R. Archer)

The company has completed the design of a new Overhauser magnetometer. Two of the magnetometers are used in a helicopter borne gradiometer consisting of a fixed towed bird system, with a vertical separation of three meters between the two magnetometers. The instrument is capable of measuring the earth's magnetic field, with a resolution of 0.005 nT, taking two measurements per second. Gradiometer measurements are made with the same resolution and with a noise level approaching this resolution. A total of 48 person-months and $350 000 in R&D are being devoted annually to this project.

16. Scintrex Limited, Concord, Ontario (H. O. Seigel)

Work continued on several fronts on the Luminex method for measurement of mineral luminescence. In the laboratory, progress has been made on relating the photoluminescence of minerals to the appropriate activator elements, with interesting connotation for the recognition of alteration zones associated with certain types of mineral deposits. The airborne instrumentation was extensively modified to increase the number of spectral and temporal channels, as well as to reduce noise due to optical and electronic sources. At the year's end, an airborne test program in the southwest USA was initiated. In ground instrumentation, a borehole logging probe (LG-3) was built and interfaced with the IGS-2 acquisition system. Some initial tests have been conducted with the LG-3 for use in grade control in the tungsten mine of Cantung Mines. Work is proceeding on the integration of additional geophysical sensors with the IGS-2 dedicated portable control and data acquisition system. VLF (magnetic and electric field) developments, including the field measurement system and base station units, were completed during 1984. Progress was made

as well in applications software for the automatic processing and presentation of IGS-2 data. Basic studies are underway with the objective of improving the operating characteristics of optically pumped magnetometer sensors. Some of these studies are being supported by NASA in relation to the Geopotential Research Satellite, to be launched later this decade. A total of 60 person-months and $2 000 000 in R&D are being devoted annually to these projects.

GOVERNMENT

17. Geophysics/Geochemistry Section, Ontario Geological Survey, Ministry of Natural Resources (D. R. Wadge, R. B. Barlow, D. H. Pitcher, D. H. Krentz, V. K. Gupta)

During the 1984 summer field season, survey and research activity continued on the Night Hawk geophysical test range near Timmins, Ontario, and included interpretation work on data collected in recent years and new field work using the UTEM III system. A number of instrument manufacturing companies carried out independent testing programs.

An airborne electromagnetic-magnetic survey was flown for the Ontario Geological Survey and released publicly in May of 1984. This INPUT survey covered an area of approximately 3550 km^2 from the Black River-Matheson (BRIM) area to the Ontario-Quebec border. Two projects commenced this year utilizing the results of the electromagnetic data directly and indirectly. Firstly, reprocessing of the digital, airborne, time domain data produced a filtered difference (Channel 1-Channel 2) map which was, after interpretation, found to yield an accurate outline of the deeper sections of lacustrine clays in the area. Secondly, a ground electromagnetic technique was developed for the purpose of identifying small-scale buried valleys in clay covered areas. The two techniques can be used as an aid to develop an optimum strategy for conducting overburden drilling programs.

A gravity surveying program has been initiated by the Ontario Geological Survey to map the deeper geological and structural characteristics of the Abitibi greenstone belt for the purpose of arriving at a better understanding of its evolution and associated mineral deposits. Section staff established approximately 2000 new gravity stations in the Kirkland Lake, Larder Lake and Matheson area (8000 km^2). Density determinations were carried out on approximately 850 rock specimens collected during the survey work.

18. Resource Geophysics and Geochemistry Division, Geological Survey of Canada, Department of Energy, Mines and Resources (A. G. Darnley, K.A. Richardson, Q. Bristow, B. W. Charbonneau, K. L. Ford, R. L. Grasty, P. B. Holman, P. G. Killeen, C. J. Mwenifumbo, A. K. Sinha)

In support of gamma-ray spectrometric methods, material was located for an international thorium standard. The material, collected from a britholite vein in the Oka carbonatite, is being prepared for distribution by the International Atomic Energy Agency. A number of airborne radiometric test strips were investigated to relate changes in the emitted gamma-ray spectrum to soil moisture content and to study the increase in radon emanation with decrease in soil grain size. An integrated geophysical project conducted over a radiometric anomaly in Algonquin Park disclosed a previously unknown carbonatite intrusion along the Nipissing trend, containing extremely high concentrations of thorium, rare earths, barium, and anomalous levels of several other metals. Airborne gamma-ray surveys were flown in northern Saskatchewan and Manitoba, and eastern Quebec to fill in gaps in reconnaissance coverage of Canada, and detailed surveys were flown in central New Brunswick and southeastern Newfoundland under Federal Provincial Mineral Development Agreements.

Development of the application of borehole geophysical techniques to mineral exploration continued with the addition of magnetic susceptibility logging as a new physical parameter for correlation with gamma-ray, induced polarization (I.P.), resistivity, self-polarization (S.P.), and temperature log data. Designs for construction of coal logging calibration facilities have been completed for implementation in 1985. Successful demonstrations of the application of borehole pulse EM and mise-à-la masse techniques in underground environments were conducted. An experimental pole-dipole time domain borehole I.P. system, developed by the GSC, is being field tested. The signal is digitized in the probe. Complete spectral waveforms are acquired at 4 millisecond sample

intervals. The transmitter current level is computer controlled to maintain an approximately constant received signal level. I.P., resistivity and S.P. are computed from the data. The system has also been synchronized with a HUNTEC 3000 volt I.P. transmitter to provide mise-à-la-masse measurements. Field tests of the magnetic wave tilt method (using a Maxiprobe EM system, at 10 to 60 kHz) were conducted in western Ontario for discrimination between shallow and deep conductors, and determination of conductor orientation. A total of 264 person-months and $700 000 in R&D are being devoted annually to these projects.

UNIVERSITIES

19. Department of Geophysics and Astronomy, University of British Columbia (W. F. Slawson, L. E. Fisk, T. Watanabe, B. B. Narod, R. D. Russell, P. Whaite, J. R. Bennest, K. Cover, R. Krider, Z. Gao)

A survey method of electromagnetic induction using powerlines as a source is being studied. Exact solutions for the field components of an elevated straight-line current source were found and evaluated using Fast Fourier Transform (FFT) algorithms. The data from a preliminary survey (Gold River, Vancouver Island) were interpreted to have as a source, a 1400 m thick resistive (14 000 ohm-m) layer overlying a more conductive (1200 ohm-m) halfspace. Tank model experiments carried out at the University of Victoria illustrated the effect of shallow, lateral inhomogeneities.

Electromechanical prospecting methods are being studied. The department's laboratory investigations have demonstrated that certain quartz-gold ores exhibit remarkably large piezoelectrical properties. Optical and X-ray methods are currently being used to elucidate this phenomenon. Using Soviet-made instruments, mine-site studies have confirmed Soviet results, that seismic sources can excite quartz or sulphide veins into generating easily detectable electromagnetic fields.

The department has completed an exact theory of the function of the fluxgate magnetometer. This theory is being extended to include multifilar gradient sensors. Current design studies include: (i) true differential fluxgate sensors for gradiometry; (ii) direct toroidal field sensing for ocean-bottom tellurics; (iii) noise mechanisms in fluxgate sensors; and (iv) solid state electrometers.

20. Institute of Earth and Planetary Physics, University of Alberta (D. Rankin, F. Pascal, R. Singh, F. W. Jones, H. L. Lam, M. Ertman)

Magnetotelluric studies continue, using a large field database acquired over the past several years. Refined interpretational techniques, including an inversion method first presented in 1982, have produced consistent and repeatable results on the data processed to date. The perturbation of uniform and non-uniform electromagnetic fields by two-dimensional and three-dimensional electrical conductivity anomalies is being investigated by a numerical method. The 3-D numerical program has been adapted to a new processor, allowing for a larger grid size and more detailed models. Work on local models is underway, and both electric and magnetic fields, as well as perturbation and induction arrows, are being calculated.

21. Department of Geology and Geophysics, University of Saskatchewan (D. Gendzwill, D. Reding, A. Prugger)

An inversion scheme for EM-34 soundings using a microcomputer (Apple II^+) has been developed. The program uses a pre-calculated space of apparent conductivities. The space is searched for closest fit to an observed data set and a final solution obtained by linear interpolation. The software is used in routine evaluation of roof slab thickness in potash mines. Micro-seismic studies in potash mines are underway. Seismic monitoring equipment installed in the mines is used to detect micro-seismic emissions related to stress developed from mining. Twenty-four person-months and $30 000 in R&D are being devoted annually to these projects.

22. Department of Earth Sciences, University of Manitoba (W. Moon, D. Messfin, A. Carswell, J. Owusu, D. Hall, T. Millar)

The seismic modelling experiment for the application of high resolution seismic methods in mining exploration is completed. The results obtained using the asymptotic ray approach indicate that a detailed seismic-structural mapping of the north range environment of the Sudbury Basin will provide a viable means for the exploration of deep-seated ore deposits in the area. Field testing of the above research is planned in the Sudbury area. A multi-offset vertical seismic profiling (VSP) experiment for the mapping of subsurface fracture zones was completed at the A.E.C.L. Underground Research Laboratory site, Pinawa, Manitoba. With the aid of the Radon transform wavefield separation technique, the processed VSP data clearly outlined the fracture zones.

Surface and drillcore magnetisation studies are underway in the Bakers Narrows - Snow Lake area of Manitoba. Surface and drill core susceptibilities are being used to sample rock units, estimate mean magnetisations of these units, and relate them to airborne vertical gradient surveys being interpreted by the Manitoba Geological Services Branch. It is hoped to be able to predict surface and near surface magnetisations beneath anomalies measured over a nearby area under Paleozoic cover. Seven person-months and $20 000 in R&D are being devoted annually to this project.

23. Department of Geophysics, University of Western Ontario (A. E. Beck, D. L. Marcotte, G. C. McGill, W. Morris, H. C. Palmer, L. Mansinha, M. E. Gregotski)

Studies of the interpretation of three-component gradient magnetics are underway. An airborne three-component gradiometer system was developed, and has been operated experimentally for five years, by the National Research Council. Processing algorithms are being developed that use the combined data sets to describe the magnetic field more accurately and thoroughly than the customary total field data set flown with the same survey specifications. Interpretation algorithms are being developed that depend on the calculation of gradient responses for simply shaped sources in order to determine parametric equations as an aid to inverting observed data. Subsequent to the development of these algorithms, a data set from the Arnprior, Ontario area will be processed and analyzed.

A method to incorporate paleomagnetic data in the interpretation of magnetic data is being developed. It takes the form of an interpretational software package which accounts for the effects of remanent magnetisation and self-demagnetisation. The program is interactive and will model magnetic anomalies as a "long ribbon" or "tabular prism". The software will be tested on data acquired from Levack Township, Sudbury, Ontario. Forward filters to transform the apparent resistivity function over a layered half-space into the resistivity transform have been derived for a number of sample intervals. The filters have no apparent Gibbs' oscillations and hence require no phase shift. Some of this work is supported by the Natural Sciences and Engineering Research Council of Canada (NSERC).

24. Geophysics Laboratory, Department of Mineral Engineering, École Polytechnique, Montreal, Quebec (G. Pouliot, R. Bazinet, J. Legault, M. A. Vallée, R. Darling, P. Trudel, M. Chouteau, L. Mayrand)

Research continued into the magnetotelluric (MT) study of research areas in the Canadian nuclear fuel waste management program. A new audio magnetotelluric (AMT) survey was completed over a different part of the RA-4 (Atikokan) Atomic Energy of Canada Limited test site. The new site was found to be much more fractured than the site studied in 1983.

A new generation tensor MT system is under development. The design phase is now being completed. Instrumentation and techniques are being developed for high frequency (up to 1 MHz) MT surveys. The method will be useful in high resistivity shield environments and for civil engineering applications. Various prospecting techniques for locating orebodies in long "structural" conductors, located by INPUT surveys, are being evaluated. Results obtained in the 1983 field season were analyzed and the original hypotheses were tested by drilling and by scale model studies. This work will continue next year. A program of induced polarization (I.P.) scale model studies is in progress in order to develop better I.P. interpretation tools.

An MT scale modelling facility, for the study of 3-D structures, is under construction. Last year, forty-four tensor MT stations were measured in a study of the Abitibi Belt. They have been interpreted and reveal a conducting structure in the deep crust. The problems encountered in using the AMT method for mineral exploration are being evaluated. Problems under study include scalar results versus tensor results, topographic effects and station density. Numerical simulation is being used to analyze the various responses. A total of 46 person-months and $235 000 in R&D are being devoted annually to these projects.

25. IREM/MERI (Mineral Exploration Research Institute), Montreal, Quebec (M. Chouteau)

Ten tensor MT sounding stations were recorded in the frequency band 0.005 to 250 Hz in the Charlevoix Crater region. Forty scalar AMT measurements were also made in the range of 14 to 5000 Hz. Analysis is underway in order to reveal the deep structure of the crater, and the structure of the related faults, in order to obtain a better understanding of the mechanisms for local seismicity. The project is being conducted in collaboration with École Polytechnique, under a contract with the Earth Physics Branch of the Department of Energy, Mines and Resources. Three person-months and $10,000 are being devoted annually to this project.

26. Geophysics Laboratory, Department of Geological Sciences, McGill University, Montreal, Quebec (O. G. Jensen, P. T. LaFleche)

An underground electromagnetic (EM) transillumination system using an ultrahigh frequency (UHF) (445 MHz) signal has been tested in the Big Nickel Mine, Sudbury, Ontario. Useful signals have been received over distances approaching 100 metres through the intervening rock mass. An attenuation resolution of approximately ± 1 dB over a range of more than 80 dB has been achieved. This system is a demonstration prototype for the eventual construction of a UHF-EM borehole transillumination instrument for use in borehole mineral exploration and rock properties surveys for nuclear waste disposal siting. Fourteen person-months and $14 000 in R&D are being devoted annually to this project.

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GUIDELINES FOR THE EDITOR AND REPORTERS
CANADIAN GEOPHYSICAL BULLETIN

1. The Canadian Geophysical Bulletin is an annual report of geophysical research and development activities in industry, government and universities in Canada. Its main purpose is to inform geophysicists in Canada and abroad of current projects, developments and publications in their own and related areas. At the same time, it provides an overview for those outside the earth science disciplines of the extent and directions of scientific research activity in this subject in Canada.

2. The Bulletin shall be made up of a collection of chapters authored by reporters named by the Editor, after consultation with the National Correspondents.

3. The Editor will review the chapter titles on an annual basis to ensure that together they continue to cover the full range of geophysical activities in Canada. He will then set a maximum length for each chapter after consideration of the following: (i) the total length of the Bulletin, cover to cover shall not exceed 200 pages; (ii) the importance of the chapter topic in both the national and international community; (iii)the number and productivity of Canadian workers in the field.

4. Each chapter shall begin with an index, include a one-page summary written by the appropriate reporter, followed by a succinct account of current activities and conclude with a list of reports and papers that have appeared in print during the previous calendar year. Abstracts, current year material and material in press or preparation will not be listed. Scientific publications in a recognized government series and appearing in the year under review may be included in the list of references. Theses accepted as part of a recognized graduate degree program during the year under review should also be included in the list of references.

5. The accounts of current activities are listed in each chapter under headings for each reporting research group. Each of these items should include a brief statement of current activities. Lengthy statements of results obtained will not be allowed. The latter should be abbreviated to not more than two or three typewritten lines.

6. Copy-ready material will be prepared by the Earth Physics Branch of EMR from clearly presented text supplied by the Editor not later than March of the year following that covered by the Bulletin. Reporters should supply the Editor with final, complete chapters that have been proof read. The layout, headings, sub-headings, references, etc. should follow the style of CGB Volume 36. If possible, chapters should be prepared on a Wang word processing unit and a diskette of each chapter provided to the Editor.

7. The Bulletin will be published by the Earth Physics Branch of Energy, Mines and Resources Canada as early as possible in the year following that which the material covers.

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BULLETIN CANADIEN DE GÉOPHYSIQUE

1. Le Bulletin canadien de géophysique est un rapport annuel des activités de recherche et de développement géophysiques de l'industrie, du gouvernement et des universités au Canada. Son but principal est d'informer les géophysiciens au Canada et à l'étranger des recherches, des développements et des publications en cours dans leur propre domaine ou dans des domaines connexes. De plus, il fournit à ceux oeuvrant en dehors des disciplines des sciences de la Terre une vue d'ensemble sur l'étendue et les directions de la recherche scientifique dans ce domaine au Canada.

2. Le Bulletin consistera en un ensemble de chapitres rédigés par des rapporteurs nommés par le rédacteur en chef après consultation avec les correspondants nationaux.

3. Le rédacteur en chef révisera les titres des chapitres sur une base annuelle afin de s'assurer que ceux-ci couvrent bien la totalité des activités géophysiques au Canada. Il fixera ensuite une longueur maximale pour chaque chapitre en tenant compte des considérations suivantes: (i) la longueur totale du Bulletin ne doit pas excéder 200 pages d'une couverture à l'autre; (ii) l'importance du contenu du chapitre tant sur le plan national que sur le plan international; (iii) le nombre et la productivité des travailleurs canadiens dans ce domaine.

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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.

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