Energy, Mines and Resources Canada
Earth Physics Branch

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

CANADIAN GEOPHYSICAL BULLETIN

BULLETIN CANADIEN DE GEOPHYSIQUE

Volume 28

December/décembre 1975
Ottawa, Canada

CANADIAN GEOPHYSICAL BULLETIN

BULLETIN CANADIEN DE GEOPHYSIQUE

Volume 28

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

Publié par le Comité National Canadien pour l'Union Internationale de Géodésie et de Géophysique du Conseil National de Recherches du Canada

December/décembre 1975
Ottawa, Canada

MEMBERS OF THE CANADIAN NATIONAL COMMITTEE

FOR THE

INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

Dr. K. Whitham	Chairman, Earth Physics Branch, EMR, Ottawa	(CGU)
Mr. N. Hussain	Secretary, Space Research Facilities, NRC, Ottawa	
Prof. A.E. Beck	University of Western Ontario, London	(CGU)
Prof. D.I. Gough	University of Alberta, Edmonton	(CGU)
Prof. R.D. Russell	University of British Columbia, Vancouver	(CGU)
Dr. J.G. Tanner	Earth Physics Branch, EMR, Ottawa	(CGU)
Dr. B.W. Boville,	Atmospheric Environment Service, DOE, Downsview	(CMS)
Prof. R. List	University of Toronto, Toronto	(CMS)
Dr. W.R. Baragar	Geological Survey of Canada, EMR, Ottawa	(GAC)
Dr. I.C. Brown	Inland Waters Directorate, DOE, Ottawa	(ACH)
Prof. P.A. Forsyth	University of Western Ontario, London	(DASP/CAP)
Dr. L.M. Lauzier	Canadian Committee on Oceanography, DOE, Ottawa	(CNC/SCOR)
Dr. P.M. Leblond	University of British Columbia, Vancouver	(CNC/SCOR)
Mr. L. O'Brien	Surveys and Mapping Branch, EMR, Ottawa	(CIS)
Mr. M. Slivitsky	Executive Council, Government of Quebec, Quebec	(ACH)

Ex-Officio

Prof. B.W. Currie	University of Saskatchewan, Saskatoon	Canadian Coordinator for the IMS Program
Prof. R.M. Farquhar	University of Toronto, Toronto	Editor, Canadian Geophysical Bulletin
Prof. G.D. Garland	University of Toronto, Toronto	Vice President, IUGG
Dr. J.D. Keys	National Research Council, Ottawa	Chairman, NRC Committee on GARP
Prof. R.A. Price	Queen's University, Kingston	Chairman SC/IGP
Dr. R.W. Stewart	Ocean and Aquatic Sciences, DOE, Victoria	President, IAPSO

Honorary Members

Dr. C.S. Beals	Manotick, Ontario
Mr. F. Davies	Ottawa, Ontario
Dr. B.T. Denis	Ste-Foy, Quebec
Dr. H.B. Hachey	St. Andrews, N.B.
Dr. D.A. Keys	Deep River, Ontario
Mr. R.G. Madill	Victoria, B.C.
Dr. D.C. Rose	Brockville, Ontario

MEMBRES DU COMITE NATIONAL CANADIEN

POUR

L'UNION GEODESIQUE ET GEOPHYSIQUE INTERNATIONALE

Dr. K. Whitham	Président, Direction de la physique du globe, EMR, Ottawa	(UCG)
Mr. N. Hussain	Secrétaire, Installations de recherches spatiales, CNRC, Ottawa	
Prof. A.E. Beck	Université Western Ontario, London	(UCG)
Prof. D.I. Gough	Université de l'Alberta, Edmonton	(UCG)
Prof. R.D. Russell	Université de la Colombie-britannique, Vancouver	(UCG)
Dr. J.G. Tanner	Direction de la physique du globe, EMR, Ottawa	(UCG)
Dr. B.W. Boville	Service de l'environnement atmosphérique, EC, Downsview	(SCM)
Prof. R. List	Université de Toronto, Toronto	(SCM)
Dr. W.R. Baragar	Commission géologique du Canada, EMR, Ottawa	(ACG)
Dr. I.C. Brown	Direction générale des eaux intérieurs, EC, Ottawa	(CAH)
Prof. R.A. Forsyth	Université Western Ontario, London	(DAPS/ACP)
Dr. L.M. Lauzier	Comité canadien d'océanographie, EC, Ottawa	(CNC/SCOR)
Dr. P.M. Leblond	Université de la Colombie-britannique, Vancouver	(CNC/SCOR)
Mr. L. O'Brien	Directions des levés et de la cartographie, EMR, Ottawa	(ICL)
Mr. M. Slivitsky	Conseil exécutif, Gouvernement du Québec, Québec	(CAH)

Ex-Officio

Prof. B.W. Currie	Université de Saskatchewan, Saskatoon	Coordinateur Canadien pour l'IMS
Prof. R.M. Farquhar	Université de Toronto, Toronto	Rédacteur, Bulletin Canadien de Géophysique
Prof. G.D. Garland	Université de Toronto, Toronto	Vice Président, UIGG
Dr. J.D. Keys	Conseil National de Recherches, Ottawa	Président, CNRC Comité pour GARP
Prof. R.A. Price	Université Queen's, Kingston	Président SC/IGP
Prof. R.W. Stewart	Sciences océaniques et aquatiques, EC, Victoria	Président, IASPO

Membres Honoraires

Dr. C.S. Beals	Manotick, Ontario
Mr. F. Davies	Ottawa, Ontario
Dr. B.T. Denis	Ste-Foy, Québec
Dr. H.B. Hachey	St. Andrews, N.B.
Dr. D.A. Keys	Deep River, Ontario
Mr. R.G. Madill	Victoria, C.-B.
Dr. D.C. Rose	Brockville, Ontario

INTRODUCTION

The Canadian Geophysical Bulletin Volumes 1 to 26 for the years 1948 to 1973 was published by the Associate Committee on Geodesy and Geophysics of the National Research Council of Canada. Responsibility for the Bulletin was passed to the Canadian National Committee for the International Union of Geodesy and Geophysics commencing with Volume 27 for 1974.

The Bulletin provides an overview of the scientific activity including a bibliography in a variety of geophysical disciplines in Canada: the current issue, Volume 28, covers the calendar year 1975. The Bulletin also provides a basis for national reports to the IUGG and to the Associations of the IUGG. It is widely distributed to readers inside and outside Canada.

As in the past, reports have been generally grouped under disciplines for which there are Associations in the IUGG. There are also chapters on Glacier Research, Isotope Studies and Geochronology, and Exploration Geophysics, recognizing the special interest in these subjects in Canada. The report on Geodynamics reflects Canadian participation and progress in the International Geodynamics Project. The brief report on Mathematical Geophysics, appearing this year for the first time, reflects the setting up of a division by that name within the recently formed Canadian Geophysical Union. As its name suggests, the new division is not strongly discipline oriented, and readers should also refer to other relevant chapters for more information about the areas mentioned in the Mathematical Geophysics section.

Reports on Oceanography and Volcanology are not available for 1975. It is hoped that this defect in the Bulletin's coverage will be remedied in future volumes.

The reports have been collected and compiled with the assistance of members of the Canadian Geophysical Union, the Division of Aeronomy and Space Physics of the Canadian Association of Physicists, the Canadian Meteorological Society, the Canadian Institute of Surveying and the Associate Committee on Hydrology. It has been produced and distributed by the Earth Physics Branch of the Department of Energy, Mines and Resources at the request of the Canadian National Committee for the International Union of Geodesy and Geophysics and the Canadian Geoscience Council.

Requests for individual copies and back issues when available should be directed to The Secretary, The Canadian National Committee for the IUGG, National Research Council of Canada, Ottawa K1A 0R6. There is no charge for the Bulletin, but the Canadian National Committee appreciates receiving similar national or international reports in exchange.

R.M. Farquhar
Editor

INTRODUCTION

Les volumes 1 à 26 du Bulletin Canadian de Géophysique ont été publiés par le Comité Conjoint de Géodésie et de Géophysique du Conseil National de Recherches du Canada. En 1974 (vol. 27) la publication de ce "Bulletin" est devenue la responsabilité du Comité National Canadien de l'Union Géodésique et Géophysique Internationale.

Le "Bulletin" donne une vue d'ensemble de l'activité scientifique au Canada dans diverses disciplines de la géophysique; il comporte également une bibliographie. Le présent volume (28) est pour l'année 1975. Le "Bulletin" sert de base aux rapports nationaux auprès de l'U.G.G.I. et auprès des Associations de l'U.G.G.I. Il bénéficie d'une distribution universelle.

Comme par le passé, les rapports ont été groupés sous les disciplines pour lesquelles il existe des Associations au sein de l'U.G.G.I. On y traite également de Glaciologie, études des Isotopes et la Géochronologie ainsi que de l'Exploration Géophysique, faisant ressortir l'intérêt spécial de ces sujets au Canada. Le rapport sur la Géodynamique reflète la participation canadienne et les progrès réalisés dans le projet international d'étude de la Géodynamique. Le court rapport sur les Mathématiques de la Géophysique, apparaissant cette année pour la première fois, annonce l'établissement d'une discipline portant ce nom, récemment formée par l'Union Canadienne de Géophysique. Comme sont nom laisse prévoir, cette nouvelle discipline n'est pas fermement orientée; le lecteur devra donc se reporter à d'autres chapitres pertinents pour renseignements additionnels relativement aux sujets mentionnés dans la section de Mathématiques de la Géophysique.

Il n'y a past de rapport sur l'Océanographie ni sur la vulcanologie pour l'année 1975. Nous espérons que cette carence sera corrigée dans les prochains volumes.

Les rapports ont été rédigés et rassemblés avec l'aide des membres de l'Union Canadienne de Géophysique, de la Division d'Aéronomie et de Physique Spatiale de l'Association Canadienne des Physiciens, la Société Canadienne de Météorologie, l'Institut Canadien des Arpenteurs et le Comité Conjoint pour l'Hydrologie. Ils ont été publiés et distribués par la Direction de la physique du globe, Ministère de l'Energie, des Mines et des Ressources à la demande du Comité National Canadien de l'Union Géodésique et Géophysique Internationale et le Conseil Canadien des Sciences de la Terre.

Addressez vos demandes pour copies du volume courrant ou pour les volumes antérieurs, à Le Secrétaire, Comité National Canadien de l'U.G.G.I., Conseil National de Recherches du Canada, Ottawa, K1A 0R6. Le "Bulletin" est distribué gratuitement, mais le Comité National Canadien apprécie vivement recevoir les rapports similaires Nationaux et Internationaux à titre d'échange.

R.M. Farquhar
Rédacteur en chef

TABLE OF CONTENTS

TABLE DES MATIERES

1(A) GEODESY

Compiled by: D.B. Thomson

1. Geodetic Survey of Canada

Extension and densification of the primary levelling network was continued, 2057 new bench marks being established and 1032 old bench marks re-established; a total of 3,127 km of new levelling and 1,283 km of relevelling was run. Two short lines of levels were re-run in the Mica Dam and Bennett Dam areas in British Columbia to study subsidence. Stability checks of bench marks at 90 water gauge sites along the St. Lawrence-Great Lakes waterways between Gaspé, Québec, and Thunder Bay, Ontario, were made as a continuing yearly program. An extensive levelling program was undertaken in Nova Scotia which completed the relevelling and densification in the province. A new line of levels was run across Anticosti Island, Québec. A network of levels was started in the township of Hamilton-Wentworth, Ontario, that will be completed in 1976. A new line was established in the Bigstone River to Ilford to Shamattawa area in northern Manitoba. The Mackenzie River levelling, which was started in 1972, was extended to a point 100 km south of Arctic Red River. A 2400 km loop in northern British Columbia was closed with a new line of levels from Watson Lake, Yukon, to Kitwanga, British Columbia.

Extension and densification of the horizontal control network was continued. A total of 80 new first-order and 301 second-order horizontal control points were established. First-order networks were extended and densified at Calgary, Alberta, and Sudbury, Ontario. A first-order traverse between existing networks in northern Ontario was established. The program of distance measurement to improve the accuracy of existing networks was continued with most of the work being concentrated in Québec. A second-order traverse network was established on Victoria and Banks islands and the existing traverses strengthened. In northern British Columbia second-order traverses were run to strengthen existing networks. Second-order stations were positioned by traversing on the Queen Charlotte Islands under a contract to a commercial survey company.

A total of 8 first-order and 12 second-order Laplace stations were observed as orientation control for horizontal networks. In addition, 22 stations were observed for deflection as part of the program to better determine the geoid, including an east-west geoid profile, in Canada. The observations for the east-west chain of deflection stations across the country are at an approximate spacing of 40 km, and remain incomplete in southern British Columbia.

A study of corrections to astronomic Laplace and deflection observations was completed, and a project to update the observations was begun. Corrections were derived for latitude, longitude and azimuth observations since 1915, and computed according to the various catalogues in use. An analysis of re-observed latitudes and longitudes revealed a systematic difference of 1 arc second of longitude between original determinations and re-observed values using the FK4 system (Vamosi, 1975).

A digital astro-printer is under development to automate and improve astronomic observations. Preliminary tests indicate satisfactory results.

Work on geoid representation was continued. The 99-coefficient algebraic polynomial developed at the University of New Brunswick (Merry, 1975) was tested. New methods for estimating the geoid and deviations of the vertical were studied (Lachapelle, 1975a). The application of least squares collocation to the determination of the geoid using deviations of the vertical and gravity anomalies was studied and several covariance functions necessary in connection with the use of least squares collocation were proposed. The method was tested on

two long astrogeodetic profiles across Canada (Lachapelle, 1975b). A method for estimating deviations of the vertical from a combination of topographic-isostatic deviations of the vertical and geopotential coefficients was developed (Lachapelle, 1975c). The method is especially well suited for application in mountainous areas and along coast-lines where topography has a significant effect on deviation. Numerical results are reported (Lachapelle, 1975a, 1975c). A spherical harmonics expansion of the isostatic reduction potential, which is needed in the method was also developed (Lachapelle, 1975d). The method is rigorous within the usual spherical approximations made in physical geodesy. Global direct and indirect effects calculated from such a spherical harmonics expansion are presented in the appendices to Lachapelle (1975d).

The gyro-theodolite was used to establish 8 azimuths in the Northwest Territories and the Yukon where Doppler satellite positions have been added to existing networks. Ten gyro-theodolite azimuths were measured at lock sites on the Rideau Canal.

The Mekometer was used to measure new baselines at Calgary, Edmonton, Victoria and Toronto for testing and calibrating electronic distance measuring instruments. Seven existing baselines were remeasured. The total number of these baselines now stands at 18.

The Ground Elevation Meter (GEM) was used to establish lower order elevations along 1600 km of roads in western Québec. All lines were run in both directions, and the average instrument rate was 70 km per day.

Tests were conducted on the Inertial Surveying System (ISS). The system was mounted in a small four-wheel drive vehicle except for a brief helicopter test. The tests consisted of runs on the United States Defence Mapping Agency test range at Los Angeles, normal and cold weather runs on a test net at Ottawa, high temperature runs in the high topographic relief and irregular gravity of the Okanagan Valley in British Columbia, and helicopter runs in Manitoba. During the tests, some modifications were made to the hardware and software, and results were significantly improved. The test results show that the ISS can determine intermediate positions at a linear rate of 15 to 20 km per hour on wheels and 80 to 100 km per hour in a helicopter. The accuracy of position is better than 50 cm in horizontal and vertical coordinates. Deviation of the vertical can be determined with an error of about 1 arc second in the meridian and prime vertical components. In summary, the ISS is judged to give about second-order geodetic horizontal accuracy and elevations suitable for 1:20,000 mapping with several times better productivity than conventional methods.

The ISS was employed in surveys of some Indian Reserves in the prairie provinces and in 1:50,000 mapping control work in southern Ontario. The latter covered 1772 km of lines in 148 hours of operation (excluding warm-up and alignment) to establish 151 second-order positions.

The Doppler satellite survey was continued in 1975 to cover the Yukon, British Columbia, Alberta, Saskatchewan, Manitoba and Ontario. Of the total of 78 stations occupied, 7 had been previously positioned by Doppler, 45 were on existing first-order triangulation stations, 10 of which were observed simultaneously with the United States National Geodetic Survey along the Canada-U.S. boundary. All other stations were coincident with or tied to existing survey points.

The Doppler satellite program is to be continued in 1976 to complete the coverage of the country at a spacing of 200 to 500 km.

The Doppler satellite data reduction computer programs were completed and documented (Kouba et al, 1975b; Lawnikanis, 1975a,b,c). Observed data reduced in station groups gives an estimated standard deviation in position relative to neighbouring stations of about 1 metre. Relative station accuracy from broadcast ephemeris and precise post-tracking ephemeris is equivalent when reduction is made in station groups (Kouba, 1975b; Kouba et al, 1975a).

A study of the accuracy of height determination by means of Doppler satellite observations was initiated (Kouba, 1975a).

A significant portion of the resources of Geodetic Survey of Canada is now directed towards a re-adjustment of the horizontal control system. Adjustment of the Canadian primary framework is planned for 1977, with adjustment of secondary networks to follow. Participation in the

continental North American adjustment also continues.

Computer programs GALS and HAVOC (which was obtained from the United States Defence Mapping Agency) were modified in preparation for adjustment of the Canadian networks. Adjustment of large networks is in sections using correlated position equations at junction stations.

The program to automate the national Geodetic data file is continuing. About 20 percent of the estimated 150,000 stations in the manual file are compiled on the automated file and about half are validated. Further refinement and testing of the software remains to be made. Approximately 5000 requests for control survey data were filled via the manual file. Data issued included 7000 vertical control quadrangle booklets and 500,000 individual pages of control data.

2. National Research Council, Division of Physics

Photogrammetric Research Section

Research has been continued in the field of refraction and its application in geodesy. Progress was reported in Saastamoinen (1975).

Time and Frequency Section

Since January 1, 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 0.7 seconds of the astronomical time UTI. The first leap second occurred at the end of June 1972, and subsequently at the end of December 1972, 1973, 1974, and 1975.

The value of DUTI, which is the difference between UTI and UTC, is included in code in the broadcast of the NRC Canadian Time Service on CHU. The format of the CHU broadcast is given in the Time Service Bulletin B-27, and is identical for the three CHU frequencies 3,330 kHz, 7,335 kHz and 14,670 kHz. A series of bulletins TF-B- announce relevant changes, such as DUTI and leap seconds, several weeks in advance.

3. Environment Canada, Bedford Institute of Oceanography

Phase Lag in Line Measurement by Radio Groundwave

Accurate distance measurement depends on exact knowledge of radio wave propagation velocity, which is usually expressed as the amount by which the actual wave lags behind a theoretical wave travelling at vacuum velocity. By comparing relatively short line measurements made by Lambda Decca with all seawater path, against virtually the same lines extended inland and measured by Loran-C, we have made coarse phase lag measurements for 100 kHz over the terrain of Newfoundland and Labrador.

Integration of Navigation Systems by Kalman Filter

Fresh from studies at the University of New Brunswick, S.T. Grant is developing techniques of integrating seagoing Satnav, range-measuring Loran-C, and ships speed log and gyro. Whereas the usual approach is to combine the results produced by each sensor, this integration will be at the level of the observations.

Tidal Observations on Scotain Shelf

The Tidal Section at the Bedford Institute of Oceanography has obtained a number of high quality sets of tidal observations on the Scotian Shelf; at the following locations:

A)	Banquereau Bank	(44°35'N, 57°41'W)	957 hours
B)	Lahave Bank	(42°54'N, 64°14'W)	382 hours
C)	Sable Bank	(43°50'N, 59°57'W)	651 hours
D)	Cabot Strait	(46°35'N, 59°45'W)	358 hours

The data from these moorings will be used to support on-going research on the propagation of the tide on the shelf, and as an aid in constructing good cotidal charts for tidal reductions

for hydrographic surveying based on a suitable reference port.

4. Canadian Petroleum Association

Survey Technology Equipment

The Sub-Committee on Navigation is preparing an extensive study on navigation as related to the Petroleum Industry in Canada. The study will attempt to bring together land, sea and air navigation and positional requirements by industry. Its prime concern is the lack of navigation available in the High Arctic. The study includes investigation to new developments on the horizon - such as Navstar, Inertial Survey Systems and the present Doppler Satellite Systems. The brief is expected to be forwarded to Mr. Cloutier of the Ministry of Transport late in 1976.

5. Université Laval

- Recherche sur la solution des problèmes géométriques reliés au système de balayeur multi-spectral des satellites ERTS.

- Recherche sur les possibilités d'utilisation des photographies SKYLAB pour la triangulation aérienne. Le système développé à partir des paramètres du SKYLAB et de photographies à haute altitude a permis d'améliorer la solution.

- Recherche sur les méthodes de compensations en étapes des grands réseaux géodésiques horizontaux.

- Elaboration et évaluation de méthodes de mesures pour l'implantation de tunnels sous le lit du St-Laurent à la hauteur de Ste-Foy et Beauport.

- En photogrammétrie, des recherches ont été également poursuivies sur la stabilité des centres de perspectives et sur la précision de la détermination des coordonnées des centres de perspectives.

- En cartographie des recherches se sont poursuivies sur l'élaboration d'un système cartographique pouvant convenir à une organisation urbaine de moyenne grandeur, et sur la conception et la réalisation d'une série de cartes économiques du Québec.

6. University of New Brunswick

Continued work on the rigorous adjustment of large horizontal geodetic networks. The areas of emphasis being: data files of observed terrestrial data, systematic errors in distances, methods of introducing multiple direction sets (Chamberlain, 1975) and introduction of weighted doppler satellite points into the adjustment. Further development of a software package to perform the network adjustment (Thomson and Chamberlain, 1975).

The combination of terrestrial and satellite geodetic networks was investigated further (Thomson and Krakiwsky, 1975) and some preliminary results were computed. Using a new model and a phased least-squares estimation procedure, the coordinate system rotations and terrestrial network rotations caused by systematic errors were separated and evaluated. Work on these topics is still continuing.

Research continued on the use of laser in precision measurements and development of new instruments and techniques for deformation measurements using precise alignment surveys. Preliminary results have been reported in Chrzanowski et al. (1975). A project on monitoring tectonic movements in the Peruvian Andes was initiated in 1975 jointly between the University of New Brunswick, the University of Alberta (Dr. E. Nyland) and the Peruvian Institute of Geophysics. A geodetic micro-network was established and measured at an elevation of 4500 m in a tectonically active area. Different EDM instruments had been tested for the surveys at such high elevation. This project will continue for several years to come.

A critical review of existing and possible map projection systems for the Maritime Provinces has been carried out and findings are reported in Hamilton et al. (1975a and 1975b).

Work continued on the densification of deflections of the vertical using gravity data for the purpose of astrogravimetric geoid determination. Refinements of the results, based on the surface fitting techniques, using higher order polynomials and the new gravity data are being done. The doppler satellite determined geoidal heights are used as constraints in the geoid computations. The resulting astrogravimetric geoid as well as a computed astrogeodetic geoid are used to investigate the systematic errors introduced in terrestrial geodetic networks by neglecting the rigorous reductions of observed data to the reference ellipsoid. Research into these areas is continuing.

Investigation continued on the relations between the geocentric and geodetic datums (Vanicek, 1975a). Findings on questions connected with the alignment of geodetic and satellite coordinate systems to the average terrestrial system are reported in Wells and Vanicek (1975).

Work continued in the field of vertical crustal movements and results are given in Vanicek (1975b). Investigation of sea level time variations and its use in detecting vertical crustal movements has been carried out. The analysis of earth-tide results collected from the two tiltmeter stations in southern New Brunswick is still continuing.

Investigation of the influences of the actual gravity variations on the heights deduced from precise levelling and currently used in Canada has been carried out. These influences - beyond the theoretical gravity considerations - have been modelled and tested using actual gravity data based on the 1930 International System. Results of this research is reported in Nassar and Vanicek (1975); Nassar (1975). Also, a technique is developed to enable the determination of geographical areas where the gravity influence on heights is significant. Refinements of techniques and results using the new EPB gravity data file - based on the 1967 International System - is still continuing.

7. Memorial University of Newfoundland

Several years ago Aoki and Kakuta calculated that frictional (electromagnetic or viscous) torques acting across the core-mantle boundary as the Earth precessed could tilt the equator toward the ecliptic plane at a rate $\simeq$ 0".1 - 0".3 cy^{-1}. M.G. Rochester has shown that the effect is simply explained in principle by the fact that dissipation at the core-mantle interface causes the precessing angular momentum vector of the liquid core to lag behind the plane of the Earth's axis of figure and the normal to the ecliptic, thus giving rise to a gyroscopic torque which can be balanced only by a rotation of the whole Earth about the direction to the vernal equinox, i.e. by a decrease in the obliquity. However a more recent analysis of lunar occultation observations by Duncombe and van Flandern yields a discrepancy of no more than 0".01 $\pm$ 0".08 cy^{-1} between the observed secular rate of change of the obliquity and that due to calculated planetary perturbations of the ecliptic plane. The apparent contradiction is explained by Aoki's neglect of inertial fluid coupling between the core and mantle, due to the ellipticity of their interface. An extension of Poincare's model of a perfect liquid core inside a rigid mantle, allowing for elasticity of the mantle and the combined effects of inertial and dissipative coupling during precession, gives a rate of decrease of the obliquity $\lesssim$ 0".0003 cy^{-1}, far below the level of detectability by current astronomical observations. Unless the actual value of the core viscosity approaches the extreme upper limit ($\sim 10\ m^2\ sec^{-1}$) set by Toomre (1974), dissipative core-mantle coupling can be neglected in modelling the dynamical evolution of the Earth-Moon system.

8. BIBLIOGRAPHY: GEODESY

1. Appleby, W.E. Navigation Requirements for Geophysical Operations in Canada. Canadian Aeronautics and Space Institute, Ottawa, Canada - November 18-20 (1975).

2. Chamberlain, C.A. Multiple Direction Sets in Geodetic Networks, B.Sc.E. Thesis, Dept. of Surv. Eng., U.N.B., Fredericton (1975).

3. Chrzanowski, A., Jarzymowski, A. and Kaspar, M., Precision Alignment Methods in Deformation Measurements Using Laser. A paper presented at the International Symposium on Deformation Measurements, September, Krakow, Poland (1975).

4. Frandsen, B.W. Traversing Sverdrup Basin Ice. Canadian Aeronautics and Space Institute, Ottawa, Canada - November 18-20 (1975).

5. Hamilton, A.C., Chrzanowski, A and Vanicek, P. A Critical Review of Existing and Possible Map Projection Systems for the Maritime Provinces. Dept. of Surv. Eng., U.N.B. Unpublished Report, Fredericton (1975a).

6. Hamilton, A.C., Chrzanowski, A., Vanicek, P. and Castonguay, R. Map Projections Grid Coordinates and Geo-codes. A paper presented at the Commonwealth Survey Officers Conference, Cambridge (1975b).

7. Hittel, A. Canadian Co-operative Satellite Programs. Meeting of the Canadian Geophysical Union - University of Waterloo, Ontario, May 15-17 (1975).

8. Hittel, A. Application of Doppler Satellite Control for Photogrammetric Mapping in Alberta, Canada. Space Centre, Toulousse, France. May 23-27 (1975).

9. Hoganson, C.E. The Canadian National Positional Control Data File. Presented at the annual convention of the Canadian Institute of Surveying, Fredericton, June (1975).

10. John, S. Time Dependence of Geodetic Networks. A paper presented at the 68th Annual Meeting of the C.I.S., June, U.N.B., Fredericton (1975).

11. Kouba, Jan. Doppler Satellite Control in Establishing Geodetic Control Networks. Presented at the Canadian Geophysical Union, Waterloo, Ontario, May (1975b).

12. Kouba, J. and Boal, J.D. Information Derived from Geodetic Doppler Satellite Surveys in Canada. Presented at the Canadian Institute of Surveying annual convention, Fredericton, June (1975a).

13. Kouba, J. and Boal, J.D. Program GEODOP. Geodetic Survey of Canada, Ottawa (1975b).

14. Krakiwsky, E.J., and Vanicek, P. Geodesy in Canada - 1971-1974 (Canadian National Report to IAG), IUGG, Grenoble, France, August (1975).

15. Lachapelle, G. Determination of the Geoid Using Heterogeneous Data. Doctoral dissertation, Graz. Published as Folge 19, Mitteilungen der geodätischen Institut der Techaischen Universität Graz (1975a).

16. Lachapelle, G. Astrogravimetric Levelling by Least Squares Collocation. Presented at the XVI General Assembly of the International Association of Geodesy, Grenoble, France (1975b).

17. Lachapelle, G. Prediction of the Deviations of the Vertical Using Heterogeneous Data. Presented at the XVI General Assembly of the International Association of Geodesy, Grenoble, France (1975c).

18. Lachapelle, G. A Spherical Harmonics Expansion of the Isostatic Reduction Potential. Presented at the Sixth Symposium on Mathematical Geodesy, Siena, Italy (1975d).

19. Lawnikanis, P. Program PREDOP. Geodetic Survey of Canada, Ottawa (1975a).

20. Lawnikanis, P. Program PREPAR. Geodetic Survey of Canada, Ottawa (1975b).

21. Lawnikanis, P. GEODOP Utilities Programs. Geodetic Survey of Canada, Ottawa (1975c).

22. Makow, D.M. New Devices for Precise Angle and Length Measurement Using Special Capacitors and Voltage Dividers. IEEE Transactions on Instrumentation and Measurement, IM-23, No. 4 (1974).

23. Masry, S.E. and Vanicek, P. Derivation of Camera Rotations from the LTN-51 Inertial Navigation Systems, Dept. of Surv. Eng. Tech. Rep. No. 24, U.N.B., Fredericton (1975).

24. Merry, C.L. Studies Toward an Astrogravimetric Geoid for Canada. University of New Brunswick (1975).

25. Nassar, M.M. and Vanicek, P. Levelling and Gravity, Dept. of Surv. Eng. Tech. Rep. No. 33, U.N.B., Fredericton (1975).

26. Nassar, M.M. Heights and Gravity. A paper presented at the 68th Annual Meeting of the C.I.S., U.N.B., Fredericton, June (1975).

27. Rochester, M.G. The Effect of the Earth's Liquid Core on the Obliquity, EOS, Trans. Amer. Geophys. Union,56, 973 (1975) (abstract).

28. Saastamoinen, J. On the Reduction of Electro-Optical Distance Measurements with Reciprocal Vertical Angles. IAG 16th General Assembly, Grenoble (1975).

29. Thomson, D.B. and Chamberlain, C.A. UNBSA - A Rigorous Computation Procedure for Extensive Horizontal Geodetic Networks. A paper presented at the 68th Annual Meeting of the C.I.S., U.N.B., Fredericton (1975).

30. Thomson, D.B. and Krakiwsky, E.J. Alternative Procedures for the Combination of Satellite and Terrestrial Geodetic Networks. Contributions of the Earth Physics Branch 45, No. 3 (1975).

31. Vamosi, S. Corrections to be Applied to Astronomic Observations in Canada. Preliminary report (1975).

32. Vanicek, P. Report on Geocentric and Geodetic Datums. Dept. of Surv. Eng. Tech. Report No. 32, U.N.B., Fredericton (1975a).

33. Vanicek, P. Vertical Crustal Movements in Nova Scotia as Determined from Scattered Geodetic Relevellings. Tectonophysics, 29 (1975b).

34. Vanicek, P. (edit.). Proceedings of CGU Symposium on Satellite Geodesy and Geodynamics. Publications of the Earth Physics Branch, Volume 45, no. 3 (1975b).

35. Vanicek, P. Satellite Geodesy and Geodynamics. Encyclopedia of Soil Science and Applied Geology (1975f).

36. Wells, D.E. and Vanicek, P. Alignment of Geodetic and Satellite Coordinate Systems to the Average Terrestrial System. Bull. Geodesique No. 117, Sept., Paris (1975).

37. Wells, D.E., Krakiwsky, E.J., Thomson, D.B. and Kouba, J. Review of Doppler Satellite Positioning in Canada. Invited Paper, the First Venezuelan Congress of Geodesy, Maracaibo, Venezuela, Dec. (1975).

I(B) GRAVITY

Compiled by: M.R. Dence
Earth Physics Branch, EMR

1. Introduction

Following the recommendations adopted at the second Annual Business Meeting of the Canadian Geophysical Union at Waterloo, Ontario, on May 15, 1975, Dr. J.G. Tanner, Earth Physics Branch, was appointed National Reporter for the subdivision of Gravity. As there is no subdivision for Geodynamics, items from the Earth Physics Branch previously reported in the Canadian Geophysical Bulletin under Geodynamics are included in this chapter.

2. Earth Physics Branch

(a) Gravity Standards

The systematic inspection and updating of control stations in the National Gravity Net is now in its third year. Approximately 700 stations in the Maritimes, Eastern Quebec, the western Arctic archipelago and British Columbia have now been updated or replaced. The field work and preparation of station descriptions is now carried out under contract. Revised gravity values and station descriptions are available through the Gravity Division retrieval system.

Under the auspices of the Pan American Institute of Geography and History (PAIGH) and in cooperation with the Inter-American Geodetic Survey office in Panama, the Gravity Division has compiled and adjusted a gravity reference network of some 1000 stations in Latin America. A catalogue of station descriptions and principal facts, now in the final stages of compilation, is expected to be made available for distribution by PAIGH during the coming year.

As a result of a resolution passed at the Grenoble meeting of the International Association of Geodesy, the Earth Physics Branch has been requested to set up a technical service for the maintenance of the International Gravity Standardization Net (IGSN). This will involve the use of existing EPB facilities to maintain a data bank of IGSN observations, local re-adjustments of IGSN based on new observations and the maintenance of station descriptions. New data will be relayed to EPB through the International Gravimetric Bureau in Paris who will also act as the central distribution agency for revised IGSN information.

(b) Gravity Data Base

A software system has now been developed for the adjustment and melding of data from shipborne gravity surveys. Known as ASSOB (Adjustment of Sea Surface Observations), the system provides data editing, least squares crossover adjustment with scale and drift unknowns and data display capability.

A new level of the gravity retrieval system (SYS76) has been developed and tested. Implementation is now underway. SYS76 has been designed in such a way as to reduce the complexities of file maintenance and reprocessing by incorporating raw field observations into the reduced data set. The system also provides improved quality control capability and more flexible interactions with the ASSIB and static gravity reduction systems. A report generator capability will permit users to create files in any format desired and including any selection of the 22 parameters available in the master file record.

(c) Gravity Data Processing

During 1975 several programs for editing, displaying and interpreting gravity data have been completed or revised. Most are for internal use but some are available upon request. One program (TRANS) transforms data from geographic to cartesian (plot) coordinates in the required projection and prepares the data for contouring. Using the General Purpose Contouring Program (GPCP), PAC produces a contour map from irregularly distributed data points (up to 10,000 points). Another program (EDIT) calculates block averages and their standard deviations. Using the standard deviations, it compares the averages with neighbouring averages to locate 'suspect' values. A program which calculates a moving average was also developed to locate 'suspect' values in shipborne gravity data. Another program named PROFILE permits display of ship track data in several modes.

Three programs are available upon request. One computes terrain corrections (TERRAIN) using digitized elevation data obtained at regular intervals. Another (UP) calculates the upward continuation of the gravity field given at regular intervals. The third program (2-DIM) is a revised version of a formerly available program.

(d) Gravity Map Production

A French language version of the new 1:5,000,000 Bouguer Anomaly Map of Canada (GMS 74-1) was published in 1975. Indices Nos. 1 and 2 show gravity maps of the Bouguer Gravity Map Series published to January, 1976. In addition, Hamilton Inlet, 156-74, is available as a Free Air anomaly map. Six new Bouguer gravity anomaly maps were printed in 1975, covering areas in northeastern Quebec and Labrador. They will be published as Gravity Map Series Nos. 157 to 162 inclusive.

(e) Gravity Surveys

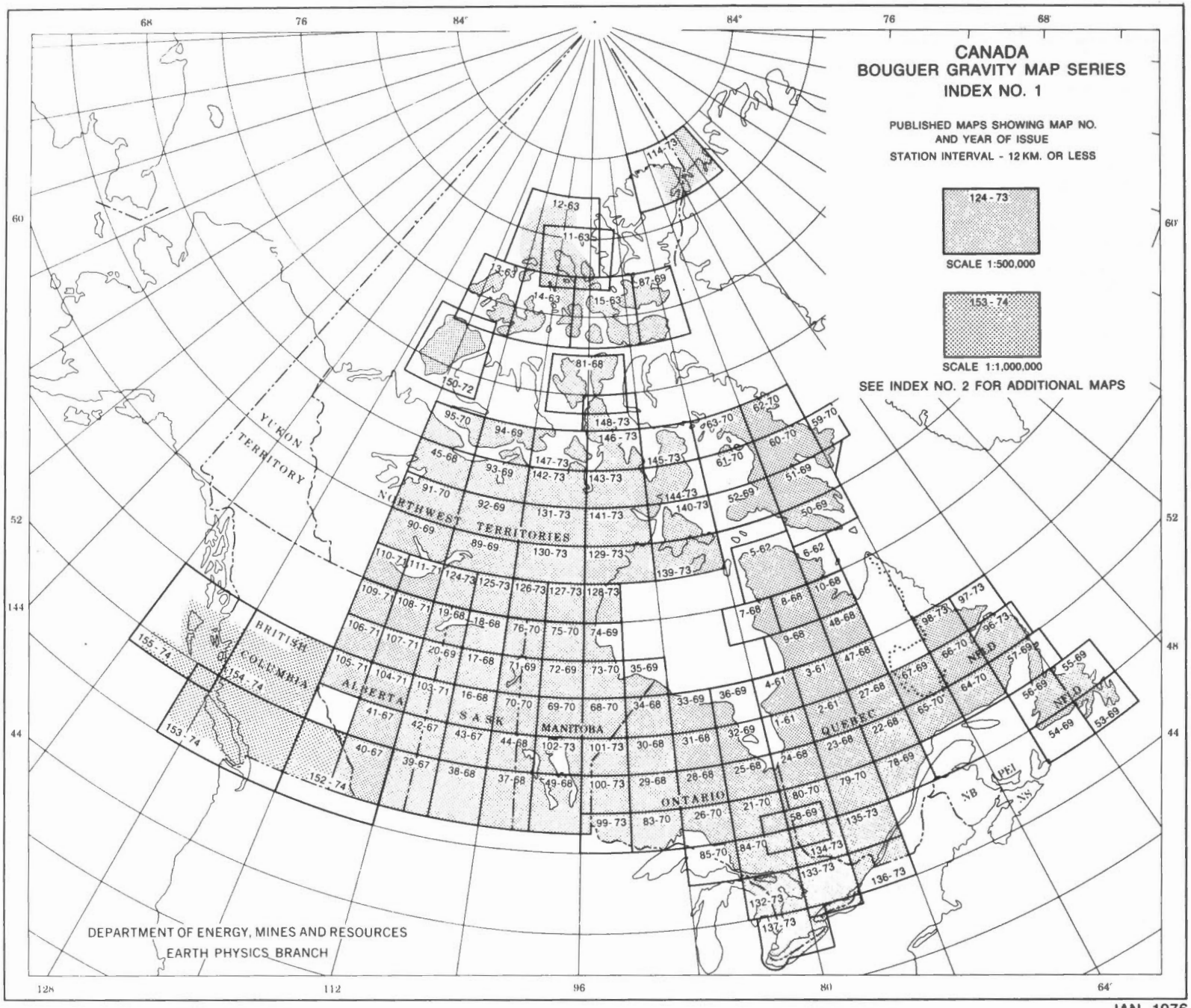
During 1975, approximately 2000 new gravity stations were occupied over the Canadian Mainland, and 31,000 line kilometres of shipborne surface gravity meter surveys were logged in coastal waters. Surveys were carried out in the following areas:

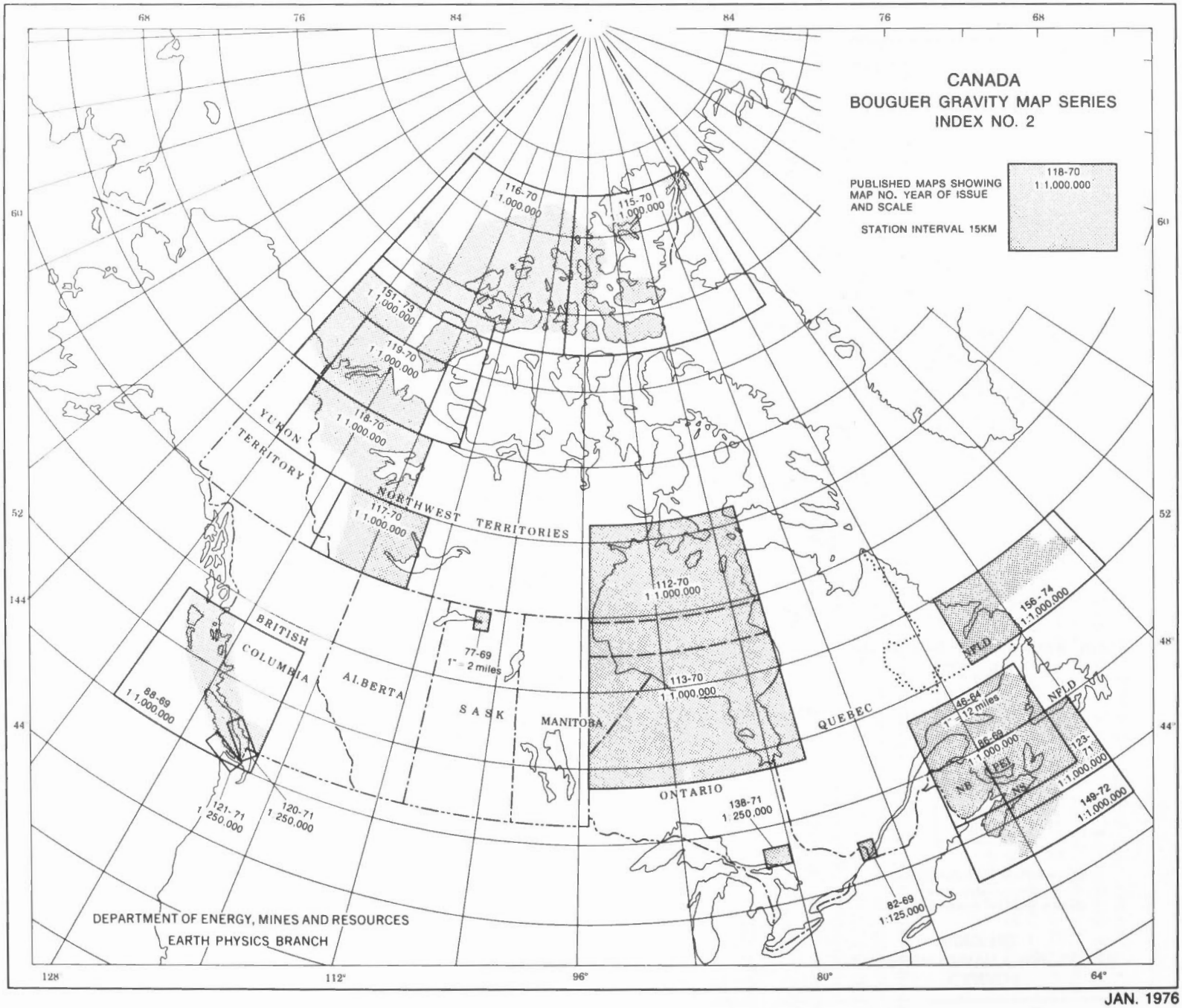
(i) *British Columbia*

During April and May, and again in September, a total of approximately 10,000 kilometers of shipborne gravity measurements were made in the coastal area immediately west of Vancouver Island. The area surveyed is between 48° north latitude and is bounded to the west by the 1000 meter depth contour. Average profile track spacing is about 5 km.

(ii) *Hudson Bay*

Between July 30 and October 10 approximately 20,000 line kilometers of shipborne gravity meter measurements were completed in Hudson Bay in cooperation with the Canadian Hydrographic Service, Department of the Environment (CHS-DOE). Average line spacing was 45 km. As part of this survey, three short signature lines were observed. These are located at the southern extremities of Mansel and Belcher Islands and adjacent to the entrance to Churchill, Manitoba.


CANADA
BOUGUER GRAVITY MAP SERIES
INDEX NO. 1
PUBLISHED MAPS SHOWING MAP NO.
AND YEAR OF ISSUE
STATION INTERVAL - 12 KM. OR LESS
124 - 73
SCALE 1:500,000
153 - 74
SCALE 1:1,000,000
SEE INDEX NO. 2 FOR ADDITIONAL MAPS
YUKON TERRITORY
NORTHWEST TERRITORIES
BRITISH COLUMBIA
ALBERTA
SASK
MANITOBA
ONTARIO
QUEBEC
NFLD
PEI
NS
NB
DEPARTMENT OF ENERGY, MINES AND RESOURCES
EARTH PHYSICS BRANCH
JAN. 1976


CANADA
BOUGUER GRAVITY MAP SERIES
INDEX NO. 2
PUBLISHED MAPS SHOWING MAP NO. YEAR OF ISSUE AND SCALE
STATION INTERVAL 15KM
118-70 1:1,000,000
116-70 1:1,000,000
115-70 1:1,000,000
151-73 1:1,000,000
119-70 1:1,000,000
118-70 1:1,000,000
117-70 1:1,000,000
YUKON TERRITORY
NORTHWEST TERRITORIES
112-70 1:1,000,000
113-70 1:1,000,000
77-69 1" = 2 miles
BRITISH COLUMBIA
ALBERTA
SASK
MANITOBA
ONTARIO
QUEBEC
88-69 1:1,000,000
121-71 1:250,000
120-71 1:250,000
138-71 1:250,000
82-69 1:125,000
156-74 1:1,000,000
NFLD
46-64 1" = 12 miles
86-69 1:1,000,000
PEI
NS
NB
123-71 1:1,000,000
149-72 1:1,000,000
DEPARTMENT OF ENERGY, MINES AND RESOURCES
EARTH PHYSICS BRANCH
68
76
84
60
52
144
44
128°
112°
96°
80°
64°

JAN. 1976

(iii) *James Bay*

The first phase of a joint project involving EPB, the Canadian Hydrographic Service, and the Ministry of Transport commenced early in 1975 with the objective of completing the regional gravity and bathymetry coverage of James Bay in two winter field seasons. Hampered by some of the worst ice conditions in recent years, only 415 gravity measurements were completed. As with other "on ice" surveys, station spacing averaged 6 km.

(iv) *Beaufort Sea*

512 new gravity stations and water depths were observed by a helicopter supported party from the ice covering Beaufort Sea west of Banks Island. As in previous surveys, station spacing was maintained at 6 km intervals. A very early break-up of the Beaufort Sea ice in late March forced an early termination to this project, which was designed to complete the offshore gravity surveys adjacent to the Island.

(v) *Victoria Island*

A small party operating from a field camp shared with the Geodetic Survey of Canada completed the regional gravity coverage on Victoria Island by observing 640 new stations. Average station spacing throughout the island is 10-12 km.

(vi) *Quebec*

In September, approximately 450 gravity stations at a spacing of 2-4 km were observed along a profile over the Lac Fournier and Romaine River anorthositic massifs, located about 200 km northeast of Sept Isles. A comprehensive rock sampling program formed part of this field project.

(f) Gravity Interpretation Studies

In 1975 interpretation studies using gravity and related data concentrated on the Arctic, offshore areas and the Canadian Shield.

(i) *Arctic (Sverdrup Basin)*

A study of vertical motions in Arctic regions during Phanerozoic time is in progress. Published stratigraphic and paleontologic data from Eurasian and North American polar regions has been collected with the goal of determining the time-space history of large and rapid changes in subsidence rates in all Arctic regions. This information, combined with what is presently known of Arctic tectonics and recent compilations of polar wandering data over Phanerozoic time from regions north of 60^{o}N, will be used to place constraints on probable geologic processes that significantly influenced the evolution of Arctic regions since the end of Precambrian time.

(ii) *Arctic (Continental Margin)*

Regional and deep structure, supported by drill hole, gravity, and seismic evidence, was interpreted along five profiles - one across the Mackenzie Delta and four across the continental margin. Isostatic compensation has reduced the gravity effect of most structures but gravity anomalies are still sufficient to outline two major sedimentary basins - one very extensive and thick (> 10 km) underlying the continental margin and Mackenzie Delta and the other narrow and shallow east and southeast of the Arctic Coastal Plain. A basement ridge separating these basins along the eastern side of the Arctic Coastal Plain was outlined by a trend of relative gravity highs.

An arcuate belt of prominent, elliptically-shaped, free air gravity highs (peak values >100 mgal) over the continental break outlines an uncompensated region of mass excesses. These mass excesses can be explained by pro-grading wedges (>2 km thick) of Quaternary and possibly Tertiary sediments that have displaced seawater and act as a load on the crust rather than by the alternative concepts of an uncompensated ridge or high density material in the basement.

(iii) *Arctic and Norway (Continental Margins)*

A belt of prominent, elliptically-shaped, positive free air gravity anomalies (peak values >100 mgal) generally is found over the continental margin. These anomalies can be explained by a prograded wedge of Quaternary and Tertiary sediments acting as an uncompensated load on the crust. The sum of this gravity effect and the edge effect anomaly between continental and oceanic crusts in isostatic equilibrium (Airy) accounts for most of the gravity high along the break (80 mgal). Basement ridges, high density belts in the basement, mantle ridges, or carbonate banks may account for the remaining unexplained portion of the residual anomaly (20 mgal). Several sections across the Canadian Polar margin and the Norwegian continental margin have been studied and are compared.

(iv) *Northwest Territories*

Ten Bouguer anomaly maps (1:500,000) covering a large part of the Churchill structural province of the Canadian Shield to the north and northwest of Hudson Bay were compiled from a total of 3,698 gravity stations. There is a correlation between positive gravity anomalies and granulite terrains on Boothia and Melville peninsulas. Continuity of a zone of anomalously dense crust from Baker Lake to Southampton Island and perhaps as far east as Coats Island is inferred from an easterly alignment of positive gravity anomalies. This zone is expressed at the surface by high grade metamorphic terrains intruded locally by anorthosite and gabbro. In the Ogden Bay region the correlation between gravity anomalies and granulities is not so clear. Major negative gravity anomalies are related to granitic plutons which lie within a broad regional gravity low extending from north of Baker Lake to Melville Peninsula. Although there is also a general correlation in trend and location between major Aphebian fold belts and this broad regional gravity low, there is generally little correlation between individual fold belts and the anomalies.

(v) *Western Superior Province*

A study of major late Aphebian faults cutting the margin of the western Superior craton and exhibiting large dextral offsets suggests that they are a direct result of collision between suturing Superior and Churchill plates. Following initial collision in northern Quebec (Cape Smith belt) and in Ontario (west of James Bay), the Winisk River fault developed and suturing continued along the Fox River belt of the circum-Superior suture. Development of the Kenyon structure, another major shear zone, and subsequent faults, permitted further plate convergence to accommodate the stepped form of the edge of the Churchill plate. In this way the Superior craton was progressively sliced as suturing proceeded from east to southwest. The fault directions were controlled by pre-existing transform faults linking segments of a consuming trench system at the edge of the Churchill plate. Final stages of convergence and collision resulted in thickening of the Churchill plate and major sinistral motion along the Thompson-Owl River shear zone.

(vi) *Labrador Trough*

The Labrador Trough is a linear fold-belt marking the junction of the Superior and Churchill Structural Provinces in northern Quebec. Gravity profiles across the Trough are characterized by gently decreasing anomalies over the Superior Province reaching a minimum beneath the Trough and thence increasing abruptly over the Churchill Province to a level some 15 mgal higher than the Superior. Superimposed on this higher level are several broad maxima parallel to the Trough, one of which corresponds to an extensive outcrop of migmatites.

The gravity profiles may be interpreted in terms of a relatively elevated Conrad discontinuity beneath the Churchill Province isostatically compensated by a thickened lower crust. Such a model is consistent with basement reactivation following collision of the Superior and Churchill continental plates. Collision results in crustal thickening by ductile flow in the upper mantle and consequent partial melting in the lower crust leads to differentiation of the crust into a refractory lower part and potash rich upper part separated by a zone of migmatites.

The geological history of the Labrador Trough, and its present day structure as deduced from gravity studies, is consistent with a sequence of events involving the gradual closure of a small ocean dividing the Superior and proto-Churchill crustal plates in Aphebian times. The closure was effected by subduction beneath the Churchill culminating in collision during the Hudsonian Orogeny and the formation of the present structural configuration after deep erosion.

(vii) *Grenville Suture*

It has been suggested, on palaeomagnetic grounds, that Grenvillia was separated from Interior Laurentia 1,150 m.y. ago and rejoined it about 1,000 m.y. ago to form the present day Canadian Shield. This hypothesis requires that a suture exists within the Grenville Province south of a region of Grenville rocks which are metamorphosed equivalents of rocks within the adjacent, older structural provinces, and north of sampling sites used to determine Grenvillia poles. Geological evidence for such a suture is lacking. However, supporting evidence for a suture is provided by gravity data. An extensive (1,200 km) linear negative gravity anomaly follows the Grenville Front from Lake Mistassini to the Grenville. It has been interpreted in terms of Superior-type crust (34 km thick) in steep contact with Grenville-type crust (39 km thick and 0.06 g/cm^3 denser). The contact which dips to the south is believed to represent a cryptic suture.

(viii) *Kiglapait Basic Intrusion, Labrador*

A three-dimensional gravity interpretation of the Kiglapait layered basic intrusion on the coast of northern Labrador has been completed. This pear-shaped (plan view) intrusion is 33 km long and measures 27 km at its widest extent. It is believed to have a lopolithic form with a maximum depth of over 8 km. The greater part of the intrusion corresponds closely with a large positive gravity anomaly (maximum amplitude ~45 mgal), but correlation between gravity and the intrusion is poor over the northeastern part of the body. The theoretical gravity effect of the intrusion was computed using the model developed by geologists, and this was compared with the observed anomaly. A residual gravity map was then obtained from the two gravity fields. A circular negative (-25 mgal maximum amplitude) residual anomaly is present over the southeastern outcrop of the intrusion, which is invaded by numerous dykes and pods of granite. This anomaly has been interpreted in terms of a large granite body extending from sea level to several kilometers depth (up to 7.5 km depending on the model). The geological interpretation of the form of the remaining larger part of the intrusion has been closely supported by the gravity analysis.

(ix) *Combined Analysis of Global Gravity and Magnetic Anomalies*

Previously reported work indicated a correlation between some global gravity and magnetic features such that where the strength of the total magnetic field is enhanced the gravity field is diminished and vice versa. The location of and relationship between the sources of the anomalies is not clear. The high ratio of magnetization contrast to density contrast of approximately 50 emu/gm rules out common sources in the crust. Spherical harmonic amplitude spectra suggest that the gravity anomaly sources lie no deeper than about 1,100 km in the mantle whereas the magnetic anomaly sources probably lie within the outer core. The gravity and magnetic anomaly sources may be produced by lateral temperature variations of the order of 100°K with positive total field magnetic anomalies being produced by electromagnetic induction in anomalously hot regions of the earth's core and lower mantle and negative gravity anomalies produced in anomalously hot areas of the mantle. There is no obvious correlation between the low degree harmonics of the magnetic field and the low degree harmonies of the gravity or heat flow fields.

(x) *Crater Studies*

As part of a combined study of the Manicouagan crater by members of EPB, Johnson Space Center and Lunar Science Institute, Houston, J.F. Sweeney is analysing gravity data from the area. The crater anomaly extracted from the complex regional field features an anomaly at approximately -8 mgal over the peripheral trough which defines the structure, with the anomaly becoming less negative towards the centre of the structure, except over the anorthosite massifs which form the central peak cluster. Various structural models are being examined for fit against the gravity data.

(g) Physical Geodesy

The effect of the truncation error of Stokes' function in geoidal computation was examined in some detail for 20 computation points. It seems that between 8^{o} angular distance (which is used in some cases to obtain local detail of the geoidal height) and the first zero of the Stokes' function around 40^{o}, there are several meters of contribution to the geoidal height.

M.K. Paul has developed an analytical method of predicting point and mean anomalies using a local bivariate covariance function. The concept of bivariate character is introduced to take care of any possible directional variation of the covariance function. This covariance function has been constructed for an appropriate function of the gravity anomalies instead of the anomalies themselves. As a result, analytical formulae for the prediction of mean gravity anomalies and their standard deviations over blocks bounded by parallel and meridians have been devised.

(h) Dynamic Gravimetry

In addition to an active marine operation as reported elsewhere, research in dynamic gravimetry continued with the study of the potential of the LaCoste and Romberg Inertial Platform for providing navigation in addition to Eotvos correction using data from the Parizeau "73" cruise. Preliminary results indicated that agreement between inertial and Hi-fix positions is better than 185 m with 30 min. updates. Work is continuing to evaluate the effect of increasing the update interval. Also a new more precise gyro is being installed in an attempt to improve the accuracy of Eotvos corrections and position measurements.

The dynamic gravimeter was tested aboard a North Star Aircraft operated by the National Research Council of Canada. The primary objective was a preliminary feasibility study to determine if the gravimeter could be operated in this environment. This objective was not only met but also a complete data set was collected which is currently under evaluation. The results are extremely encouraging and suggest that a further fully instrumented test is warranted.

(i) Geodynamics

(i) *Gravity Tides and Ocean Loading in Southern Alaska*

W. Zürn, L. Slichter (I.G.P.P., University of California, Los Angeles) and C. Beaumont (EPB) have analyzed tidal gravity observations (made by W. Zürn) from 5 stations in Southern Alaska in order to determine whether the anomalous observations are related to regional Earth structure. It is found that more than 80 percent of the anomaly at each station is explained by ocean tide loading. The residuals, all less than 0.5 μgal, do not correlate with position relative to the subduction zone south of Alaska. Furthermore, finite element modelling indicates that a down-going lithospheric plate will perturb the earth tide by less than 1 percent; approximately 0.2 μgal.

(ii) *Nanogravimetry: Measurement of Temporal Changes in the Gravitational Field*

A. Lambert, C. Beaumont and P. Weiss have made six nanogravity surveys in two coastal areas of Eastern Canada to study the gravity changes associated with seasonal groundwater fluctuations. The repeated surveys made with a LaCoste and Romberg model D gravimeter, D6, demonstrate that 1) Seasonal changes in gravity differences ($\sim$100 nm/s^2) at Cap Pele, New Brunswick, a region of relatively simple hydrogeology, are in good agreement with well and piezometer measurements and 2) the corresponding changes ($\sim$120 nm/s^2) at York Point, Prince Edward Island, a region of complex hydrogeology, suggest a different interpretation of seasonal groundwater flow to that inferred from piezometer measurements alone. The results demonstrate that nanogravimetry has practical application in hydrology, and that normal variations in groundwater may obscure gravity changes associated with tectonic movements and earthquake precursory effects. When normal variations in groundwater are not significant, the results demonstrate that tectonic gravity changes as small as 20-40 nm/s^2 between two sites may be detected at the 90 percent confidence level with the LaCoste and Romberg D meter. Such a gravity change corresponds to a free air change in elevation of 1 cm.

The work will be extended in 1976 to include a precise gravity survey of the region surrounding the Manic 3 dam site, near Baie Comeau, Quebec, the location of earthquakes induced by reservoir loading. It is hoped that with a combination of first order levelling and nanogravity observations we will be able to detect both the secular response of the crust to loading and any significant vertical movements or groundwater mass redistribution that may be precursors to further earthquake activity.

(iii) *Analysis of Tidal Strain Observations*

Chris Beaumont in collaboration with Jon Berger of I.G.P.P., University of California, San Diego, has analysed strain observations from seven sites in the continental United States and compared the results with the homogeneous tides predicted for a radially stratified earth including the effects of ocean tide loading.

They have extended the analysis to include lateral imhomogeneities in structure. The results demonstrate that the topographic and geologic corrections are as large as ±25 percent of the homogeneous strain tide for some of the strainmeter sites examined. Cavity effects are normally less than 5 percent unless the strainmeters are installed transversely in tunnels. Contour plots of the topographic effects for each site show that the effects may exceed ±50 percent of the homogeneous strain for pathologic cases.

It is concluded from an error analysis of the calculations that a theoretical model which includes local perturbations due to lateral imhomogeneities, in addition to the load and earth tides, explains the observations. However, the errors in the observations, and errors due to the poor knowledge of the deep ocean tides in particular, prevent strain observations from providing useful measures of whole Earth elastic properties (Love numbers) or anelasticity.

In addition to earth tides, the results demonstrate that secular strain, in situ stress and seismic strain must all be corrected for site effects.

(iv) *Laser Ranging Measurements to GEOS-3*

This is an investigation into the feasibility of measuring earth tidal deformations from laser ranging data supplied by NASA and involves both Earth Physics Branch and UNB staff. During the year, accuracy requirements and the perturbing effects of the ocean tide were worked out by Bower and preliminary tests were carried out on GEOS-2 data by Halpenny and Bower. A new analysis strategy suggested recently by Vanicek and Nesbo of UNB and requiring simultaneous ranging measurements from 3 sites is presently being evaluated.

(v) *Continuous Observations of Gravity, Tilt and Strain*

Bower, Lambert and O'Brien completed a report summarizing the analysis of earth tide gravity measurements made in Ottawa and Alert, N.W.T. during the period 1967-1974. This series of measurements included simultaneous operation of Canadian and American government gravimeters which effectively relates Canadian tidal gravity measurements to the same datum as U.S.A. and European measurements.

Measurements with the long-baseline hydrostatic tiltmeter made during the year by Bower revealed an average drift of 12 nanoradians per day, downwards toward the southeast. A second series of measurements began recently with improved instrumentation and larger diameter connecting pipes.

Labrecque has operated two 5-metre-long quartz rod strainmeters in parallel for several months in different tunnels of an underground mine. The purpose of the measurements is to evaluate installation and calibration techniques.

Measurements of water-level variations in a deep, cased well were recorded during the year and Bower is attempting to relate the measurements to volumetric strain due to earth tides, to loading by the atmosphere, and to the hydrological parameters.

(vi) *Coast Tidal Loading Measurement*

Tilt measurements at two sites near the Bay of Fundy were carried out cooperatively by the UNB (Vanicek) and the Earth Physics Branch (Bower). Preliminary results from the site nearer Fredericton indicate a loading tilt of 70.0 ± 5.0 nanoradians due mainly to Bay of Fundy semidiurnal tides. This result is being compared to predictions based on crustal models used for earlier measurements in Nova Scotia by Beaumont and Lambert. Results from the site nearer the Bay of Fundy, which would permit a more sensitive analysis of loading effects, have so far not been usable because of high noise levels. This noise seems to be slowly decreasing.

(vii) *Ocean and Ice Tilt Measurements*

During April and May 1975, as part of the Canadian contribution to the AIDJEX program, ocean tilt and ice tilt measurements were carried out in the Beaufort Sea. The ocean tilt is a direct measure of the pressure gradient force and it was determined using a pair of biaxial hydrostatic levels. The ice tilt was measured to study the relationship between tilt angle and drift velocity. It is proportional to the bending stress of the ice floe and it was determined by means of the same hydrostatic levels, as well as with portable pressure levels. In addition, continuous recordings were made of the earth's magnetic field, gravity, and ocean depth. The latter two parameters were recorded until the end of September when the ice floe, on which the main camp was located, broke up. Magnetometer, gravimeter and acoustic sounder have since been moved to a satellite camp.

(viii) *Polar Motion Observations*

The Earth Physics Branch continued to operate polar motion observatories near Ottawa and Calgary gathering astronomical and satellite Doppler data for studies of polar motion, earth rotation and plate kinematics.

The astronomical photographic zenith tube (PZT) data were regularly communicated to the international time (BIH) and polar motion (IPMS) services. The satellite Doppler observations were transmitted daily to the Dahlgren Polar Monitoring Service.

The PZT observations in Ottawa since 1956 and in Calgary since 1968 have been transferred to computerized files on magnetic tapes for permanent storage and efficient retrieval.

An on-line mini-computer system has been used to automate satellite Doppler data acquisition, processing and communication; the system including computer station control and generalized computer satellite Doppler data files will be completed in 1976.

(ix) *Global Plate Motions*

Assuming that "hot spots" define plate motions relative to the mantle, it can be shown that there is a net rotation, or flow, or lithospheric material with respect to the mantle and that this flow is determined mainly by the motion of the Pacific plate. Conservation of matter requires a net, possibly deep-seated, return flow about the same axis. About 45 m.y. ago the Pacific plate underwent a major change in its direction of motion. Coincident with this change, the reversal frequency of the Earth's magnetic field nearly doubled. This suggests some sort of connection between plate motions at the surface and deep-seated fluid motions in the earth's core. There seems to have been little or no motion of the palaeomagnetic dipole with respect to hot spots since the Tertiary Period but prior to that, the palaeomagnetic pole was displaced some 25° west along the 90°W meridian in the Cretaceous Period. It is speculated that wandering of the palaeomagnetic pole may occur during magnetic quiet periods but the physical reason for this is not clear.

3. Atlantic Geoscience Centre

Following the demise of M/V MINNA in 1974, the hydrographic/geophysical survey was carried by the M/V MARTIN KARLSEN, a considerably smaller ship. It was anticipated that the ship's motion would give rise to large cross-coupling errors, so that in order to minimize data loss, two Gss-2 gravimeters were used. The two gravimeters were mounted facing in opposite directions so that their mean output might be free of cross-coupling errors. A cross-coupling computer was also used in conjunction with one meter. Although the earlier part of the cruise

was carried out in good weather, the sea state was sufficient during the latter stages of the cruise to introduce cross-coupling errors of more than 50 mgal. The magnitude of these errors was reduced to less than 5 mgal by the use of data from the two meters, and the inferred values of cross-coupling were used to check the calibration of the cross-coupling computer. The suspected non-linearity of the latter was confirmed, but the dynamic calibration resulted in more reliable use being made of data from the cross-coupling computer. MARTIN KARLSEN completed the southern portion of the regional survey of Labrador Sea begun by MINNA last year at 40 km line spacing off northern Newfoundland and southern Labrador. The northern portion of the regional survey was also completed this season by HUDSON. The data from the entire regional survey is being used by S.P. Srivastava in his investigation of the crustal structure and history of Labrador Sea. Data from the southern area, where interlining has been carried out, is about to be submitted to contractors for preparation of Natural Resource maps.

The MINNA survey of 1973 (see GSC Paper 74-1B, p. 156) east of Newfoundland did not extend inshore because of poor navigation in that area. This year, HUDSON completed coverage between MINNA '73 and the coastline with a line spacing of about 5 miles. In addition to the collection of gravity data, seismic reflection (airgun + high resolution sparker), magnetometer and magnetic gradiometer work was also carried out. This work forms the basis for an investigation by R.T. Haworth of the extension of geological trends northeast from Newfoundland. The gravity highs reported by Miller and Deutsch (Memorial University) along the margin of Notre Dame Bay continue northeastward, but the gravity values do not go higher within the Bay itself as had been anticipated. The gravity gradient in White Bay was shown to be continuous with the high gradient passing through Hare Bay, this gravity change possibly being due to the crustal contrast between the Western Platform and the Central Mobile Belt. Another region of high gravity values east of Hare Bay, and similar to the values northeast of Notre Dame may represent an area of ancient oceanic crust, the possible source of the Hare Bay allochthon.

Gravity data were also collected on a series of lines run in the Newfoundland Basin, southeast of the Grand Banks. This survey was primarily devoted to a magnetic survey of the area for evaluation of seafloor spreading models, but the gravity data will be used in conjunction with refraction sonobuoy information in interpretation of the crustal structure of the continental margin in that area.

C.E. Keen is involved in a study of the use of Backus-Gilbert techniques in the inversion of gravity data to put limits on possible density distributions in models of continental margins. The theoretical work has been applied in analysis of the gravity data collected on the Nova Scotian margin where good seismic refraction control exists.

Preparation of 1:250,000 Natural Resource Maps continued in 1974 with the submission to a contractor of all data collected on the Tail of the Banks prior to 1974. These maps are still being produced. The receipt of maps from the contractor covering the MINNA '73 survey area means that maps exist, at a scale of 1:250,000 (or 1:1,000,000 where data coverage is sparse), for the whole of the east coast south of 51°N. Of the 1:250,000 map areas, only those on the Grand Banks north of 49°N have not yet been published. A general compilation and interpretation of all this data at a scale of 1:1,000,000 is now available (GSC Paper 75-9).

4. Nova Scotia Research Foundation Corporation

The Nova Scotia Research Foundation Corporation in-house gravity program was severely curtailed in 1975. No field work was carried out. Preliminary specifications have been drawn up for updating and expanding the computerized gravity data reduction, storage and retrieval system.

A commercial gravity survey was carried out as part of a potash exploration program near Sussex, New Brunswick. A gravimeter and auxillary equipment was rented to a mineral exploration company for work over part of a Carboniferous Windsor basin in Nova Scotia.

5. Ontario Division of Mines

The Geological Branch of the Ontario Division of Mines had conducted gravity surveys over several areas of the Precambrian Shield in Ontario. The immediate objectives of these surveys are to acquire detailed gravity data over several Early Precambrian metavolcanic belts for the purpose of determining their three-dimensional structural configurations. It is planned, even-

tually, to collect enough gravity data over a wide corridor in Northwestern Ontario extending across the Uchi, English River, and Wabigoon Sub-provinces of the Superior Province. The analysis of these data when combined with other geological and geophysical information will provide a better understanding of the evolution and structural characteristics of this part of the Shield and its mineral deposits. As part of this program, detailed gravity surveys have been conducted in the Sturgeon Lake and the Birch-Uchi-Confederation Lakes area. A gravity survey in the Red Lake area is planned for 1976.

The Sturgeon Lake survey was conducted in 1974 and covered an area of 4600 km^2 bounded by Latitudes 49°45' to 50°15'N and Longitude 90°15' to 91°30'W. 1274 gravity stations were observed with an average distribution of one station per 3.65 km^2. The resulting Bouguer gravity map, published in 1975 (Barlow, et al. 1975, a) at a scale of 1:126,720 (1 inch to 2 miles) comprises gravity contours drawn at 2.5 milligal intervals superimposed on a geological base. Further analysis of the data is underway.

A field party, with fixed-wing and helicopter aircraft support established 2537 gravity stations in the Birch-Uchi-Confederation Lakes areas, Northwestern Ontario in 1975 (Barlow, et al. 1975, b). This area of approximately 12870 km is bounded by Latitudes 50°40'N to 51°45'N and Longitudes 91°45'W to 93°15'W. The station distribution varied from 1 station per 2.6 km in areas of metavolcanic and metasedimentary rocks to 1 station per 8 km in areas of granitic rocks. The average station density over the entire area was 1 per 5 km . During the survey, 1272 bedrock specimens were collected for density measurements. In addition, 97 gravity stations were observed along Highway 105 which extends across parts of the Uchi and English River Sub-provinces between Red Lake and Vermilion Bay. Analysis of the data collected is under way.

The results of earlier gravity surveys by R.S. Middleton in Northeastern Ontario are now available, and include a description of the gravity control network established in the Timmins, Matheson and Cobalt areas (Middleton, 1975) and an interpretation of a gravity survey carried out in the Timmins-Matheson area (Middleton, 1976).

6. University of Toronto

No gravity field work was done on the Superior Province Geotraverse in 1975. However, the Ontario Division of Mines survey of the Sturgeon Lake area has just been released and it is being interpreted by T. Dusanowskyj as an M.Sc. project. Mr. Dusanowskyj worked on the survey in summer '74. The gravity data seem to be very useful in pointing out which intrusions are minor features. The volume and depth extent of the volcanics can also be estimated. The interpretation should be completed in spring '76.

The gravity interpretation of the Basket Lake-Indian Lake area completed last year by Z. Szewczyck has been submitted for publication to CJES.

7. University of Western Ontario

By using magnetic and gravity methods of analysis, S.J. Kilty in a B.Sc. thesis attempted to interpret the anomalies found in the Timmins area of Northern Ontario. The data used comes from maps published by the Geological Survey Branch of the Department of Energy, Mines and Resources. Maps used are from the 42A series and include magnetic, gravity and topographic maps.

Gravity interpretation was done by the use of a three-dimensional computer gravity program, and was used to determine the shape, size and depth of anomalous bodies. This program is based on the density contrasts between the anomalous mass and the surrounding host rocks, the depth of the body and its depth extent and shape. Depth estimates (to the top of the anomalous mass) are obtained from the geological map. To determine the shape of the body, the gravity program produces an anomaly cross-section. By curve matching, a suitable geometry may be obtained to match observed anomalies. Finally, the geophysical data is correlated with the known geology.

8. University of Manitoba

The gravity survey of the Aulneau batholith and surrounding greenstones was extended to the north during the 1974 field season to incorporate a major portion of the greenstones underlying the northern Lake of the Woods area, a portion of the southern English River gneisses, and the marginal areas of Dryberry and Dogtooth Lake batholiths. One thousand and four gravity stations

have now been established in this area.

There is an excellent spatial correlation between Bouguer anomalies and the rock bodies of different specific gravities. The low specific gravity granitic plutons (Aulneau, Dryberry, Dogtooth Lake), and the low specific gravity gneisses in the English River belt coincide with relatively lower Bouguer anomalies. The high specific gravity units of the greenstones (basalts and gabbros) coincide with the highest Bouguer anomaly values. The intermediate specific gravity greenstones are characterized by intermediate Bouguer anomalies.

The geology and specific gravities have served as a basis for modelling the distribution of upper crustal masses in three dimensions, using vertical right angle prisms, the depths of which can be varied. The present analysis is of a relatively simple model; all prisms extend to a depth of 12 km and the specific gravity within each prism is constant. Comparison of the theoretical anomalies with the observed Bouguer anomalies shows a strong correlation in anomaly pattern, which is less striking when relative anomaly magnitudes are compared. The degree to which the theoretical and observed anomalies coincide is a measure of the degree to which the mass model accounts for the observed anomalies. The degree of coincidence can be ascertained by the preparation of a residual anomaly map which expresses the observed Bouguer anomalies minus the theoretical Bouguer anomalies.

The residual map indicates that the model requires adjustment, particularly east and west of the Aulneau batholith, and within the greenstone belt along the contact with the Dryberry and Dogtooth Lake bodies. There is also a strong suggestion of the presence of a NW-SE regional residual gradient which has not been accounted for.

Attempts are now being made to refine the model through the introduction of:

(a) regional variations in crustal thickness

(b) variable prism depth and vertical variations in prism specific gravity.

The results of seismic and magnetic studies in this area, and the interpretation of stratigraphy and structure within the greenstone belt will be used to place limits on the dimensions of the prisms in the refined model.

During the summer of 1975 the area surveyed in the Aulneau area was extended to the west by adding 115 stations in the Shoal Lake area near the Manitoba-Ontario boundary. In addition, a detailed gravity survey at 200 ft. intervals was run over the Fox River sill in conjunction with a project with the Manitoba Mines Branch. Modelling and interpretation on both projects is now in progress.

9. University of Calgary

A gravity survey in the Mount Eisenhower area, Banff-Kootenay National Parks has been carried out by R.D. Borowski as a M.Sc. thesis project.

Contrasting models of the deep structure of the Southern Canadian Rocky Mountains have been proposed. Most models have depicted 'thin-skinned' tectonic styles in which thrust sheets are piled up west to east above a décollement on a passive crystalline basement. In contrast, the possibility of 'thick-skinned' tectonics, in which the basement is not passive but is actively involved in the deformation, has recently been postulated. The two models are significantly different in their implications with respect to supracrustal shortening and palinspastic reconstructions.

Published sections were used to depict the two alternatives as they apply to the structure of the Mount Eisenhower area of Banff National Park. They indicated the possibility that a gravity survey conducted here could provide evidence in favour of one or the other models, provided sufficient density contrasts in the rock types involved existed. In order to test the applicability of the gravity method to the problem, density determinations on 254 samples were made. Several areas were sampled to obtain representative values for those rock types involved. The density information obtained was favourable, and so the gravity survey was conducted.

Standard correction procedures were applied to the measured gravity data and a corrected

gravity profile was obtained. The terrain correction was seen to be the limiting factor in the accuracy of the corrected gravity profile.

The two models depicted in the cross-sections were then tested by a two-dimensional gravity dot chart to see how well they did, or did not, agree with that measured gravity profile. Other possible models were tested as well.

The conclusion was that the thin-skinned model was clearly in excellent agreement with the gravity and density information obtained, while the thick-skinned model (after Eisbacher, Carrigy, and Campbell, 1974) was not. The latter model's geometry, however, could be modified to produce reasonable agreement with the observed gravity, while still retaining its thick-skinned nature. Thus, while the thin-skinned model is the most fully in agreement with all the data presented here, the thick-skinned model cannot be conclusively ruled out.

10. Memorial University of Newfoundland

H.G. Miller and E.R. Deutsch have completed a gravity project in the coastal area bordering western Notre Dame Bay, Newfoundland (C.G.B., 1974), under a research agreement with the Department of Energy, Mines and Resources. A total of 385 new gravity stations were occupied, with mean spacing of 2.5 km. The data reveal that the observed steep positive gradients of the Bouguer anomalies previously found on the coast and islands of eastern Notre Dame Bay (C.G.B., 1970) continue to coastal areas of western Notre Dame Bay. The observed anomalies may represent the gravity signature of a Palaeozoic lithospheric plate margin: this possibility can soon be tested when analysis of ship surface gravity data obtained by Bedford Institute in 1975 on Notre Dame Bay itself becomes available. Dr. Miller participated in the collection of these data by CSS Hudson. From the interpretation of the land-based gravity results, it was demonstrated that a dense rock layer, presumably of Lower Paleozoic ophiolitic rock exposed on the Notre Dame Bay coast, continues beneath two of the tectono-stratigraphic zones of Newfoundland and that the boundaries of at least one of these zones should be significantly modified. A joint paper on this work was given by Dr. Miller at the 1975 Geological Association of Canada meeting in Waterloo.

11. Université Laval

M.K. Séguin a entrepris la mise en plan de toutes les données gravimétriques existantes au début de l'année 1975 dans la région des Appalaches du sud du Québec limitée par les latitudes 45°00' et 46°30'N, et les longitudes 71°00' et 73°00'W. A partir des quelque 1300 points de mesures emmagasinées sur ruban magnétique à la Division de la gravité de la Direction de la Physique du Globe à Ottawa, on a créé une matrice de quelque 4800 points (60 x 80 points) à l'intérieur de l'aire étudiée.

Après avoir conçu et réalisé des programmes mathématiques de mise en réseau et de contour automatique avec traçage numérique, on a pu réaliser une carte de Bouguer et des cartes régionales et résiduelles de cette même aire. En collaboration avec A. Grenon et C. Delbos (étudiants en maîtrise), des modèles géophysiques sont maintenant élaborés et la réponse gravimétrique est comparée aux valeurs observées de Bouguer et l'écart type est calculé. En élabore actuellement de tels modèles pour tenter d'expliquer le "haut" gravimétrique correspondant à l'axe de Sutton (anticlinorium de Sutton-Green Mountain), à la zone ophiolitique de Thetford Mines et de Magog ainsi qu'à une région près de Windsor, où la nature géologique de l'anomalie positive de Bouguer est inconnue.

12. University of British Columbia

G. Spence, R.M. Ellis and R.M. Clowes have interpreted a recent gravity survey carried out in and adjacent to the Rocky Mountain Trench in the Radium area. The survey was undertaken to test a particular interpretation given in a seismic P-wave study. As one of three explanations of a prominent time delay in the 6.5 km/s branch of a seismic refraction survey in the Rocky Mountain Trench, Bennett et al.(1975) (see publications) suggested a high-angle crustal fault crossing the trench near Radium. If the density contrast between basement and cover rocks is 0.1 g/cm^3, a gravity anomaly of approximately 18 mgal should be observed. The principal feature of the survey data, which were reduced to terrain-corrected Bouguer anomaly values, is a pronounced low which coincides with the trench throughout the survey area. Thus the data are not consistent with the proposed fault model. The low is due to Cenozoic fill and interpreta-

tion by two-dimensional modelling indicates the thickness of fill is about 550 m to the north and 420 m to the south of Radium. As a result of this survey, two alternative hypotheses to explain the seismic data must be reconsidered. These are the existence of a crustal low velocity zone and a major deformation of the basement and overlying rocks due to the trench being an ancient zone of weakness.

D.A. Sketchley and R.M. Clowes have completed the interpretation of a gravity survey carried out over the immediate area surrounding the igneous body at Little Mountain, Vancouver. Standard reductions have been applied to the data to obtain a terrain-corrected residual Bouguer anomaly map. An iterative modelling procedure was carried out using computer programs based initially on two-dimensional and subsequently on three-dimensional algorithms. The final model obtained suggests the igneous body may be likened to a broad, asymmetrical cone roughly 500 m in diameter attached to the underside and near the edge of a polygonal slab at or near the surface and approximately 60 m thick. Consideration of this gross shape together with geological data suggests the igneous body probably results from an upwelling of magma to produce a lava flow of small volume.

13. Bibliography: Gravity

1. Barlow, R.B., Wadge, D.R., and Dusanowskyj, T.J. Bouguer Gravity map of the Sturgeon Lake area, district of Kenora and Thunder Bay, Ontario Division Mines, Prelim. Map p. 1050 Geophys. Ser. (1975a).

2. Barlow, R.B., Gupta, V.K., and Wadge, D.R. Gravity Survey of the Birch-Uchi-Confederation Lakes area, district of Kenora, in Summary of Field Work, 1975, by the Geological Branch, eds. V.G. Milne, and others: Ontario Division of Mines, MP63, p. 141-143 (1975b).

3. Beaumont, C. and Berger, J. An analysis of Tidal Strain Observation from the United States of America: I. The Laterally Homogeneous Tide, Bull. Seism. Soc. America, v. 65, p. 1613-1629 (1975).

4. Gibb, R.A. Collision tectonics in the Canadian Shield, Earth Planet. Sci. Letter 27, p. 378-382 (1975).

5. Gibb, R.A., and Halliday, D.W. Gravity measurements in southern district of Keewatin and southeastern district of Mackenzie, N.W.T., Gravity Map Series, Earth Physics Branch, Nos. 124-131 (1974).

6. Gibb, R.A., and Halliday, D.W. Gravity measurements in northern district of Keewatin and parts of district of Mackenzie and District of Franklin, N.W.T., Gravity Map Series, Earth Physics Branch, Nos. 138-148 (1975).

7. Goodacre, A.K. Broad structure of the central and northern Nova Scotian continental shelf (Abst.), in Canada's Continental Margins and Offshore Petroleum Exploration, eds. C.J. Yorath, E.R. Parker, and D.J. Glass, Can. Soc. Petrol. Geol., Mem. 4, p. 895 (1975).

8. Haworth, R.T., and MacIntyre, J.B. The gravity and magnetic fields of Atlantic Offshore Canada, Marine Science Paper 16, Geological Survey of Canada, Paper 75-9, 22 pp. & 4 maps (1975).

9. Haworth, R.T., Poole, W.H., Grant, A.C., and Sanford, B.V. Marine geoscience survey northeast of Newfoundland, in Report of Activities, Geol. Surv. Can. Paper 76-1A (1976).

10. Middleton, R.S. Gravity control network in the Timmins-Matheson-Cobalt areas, district of Cochrane and Timiskaming, Ontario Division Mines, GR. 127 (1975).

11. Middleton, R.S. Gravity Survey of Geological structures in the Timmins and Matheson Area, district of Cochrane, Timiskaming, and Sudbury, Ontario Division Mines, GR 135 (1976).

12. Paul, M.K. Satellite doppler solutions in terms of a single parameter, Bull. Géodesique, 116, p. 131-142 (1975).

13. Popelar, J., Sim, S.B., and Wheeler, M.O. PZT Observations of time and latitude, Ottawa and Calgary, 1974. Geodynamics Series, Earth Physics Branch, Bull. No. 66 (1975).

14. Sobczak, L.W. Gravity and deep structure of the continental margin of Banks Island and Mackenzie Delta, Can. J. Earth Sci., 12(3), p. 378-394 (1975).

15. Sobczak, L.W. Gravity anomalies and passive continental margins, Canada and Norway, in Canada's Continental Margins and Offshore Petroleum Exploration, eds. C.J. Yorath, E.R. Parker, and D.J. Glass, Can. Soc. Petrol. Geol., Mem. 4., p. 743-761 (1975).

16. Stacey, R.A. Structure of the Queen Charlotte Basin, in Canada's Continental Margins and Offshore Petroleum Exploration, eds. C.J. Yorath, E.R. Parker, and D.J. Glass, Can. Soc. Petrol. Geol., Mem. 4., p. 723-741 (1975).

17. Stephens, L.E. and Cooper, R.V. Results of a shipborne gravity survey of Amundsen Gulf, Geol. Surv. Can., Paper 75-1, Part B, p. 325-327 (1975).

18. Thomas, M.D., and Tanner, J.G. Cryptic suture in the eastern Grenville Province, Nature, v. 256, p. 392-394 (1975).

19. Valliant, H.D. (editor). Gravity Research in Canada January 1, 1971 to December 31, 1974. National Report to the 16th Annual Assembly of the IUGG and IAG, Grenoble, France (1975).

II SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR

National Reporter: E.R. Kanasewich

1. Canadian Seismograph Stations
2. Canadian Seismicity
   - (a) Canadian Earthquakes
   - (b) Strong Motion and Earthquake Engineering
3. Earth Physics Branch
   - I Seismology
     - (a) Studies of Continental Lithosphere
     - (b) The Whole Earth
     - (c) Seismological Instrumentation
   - II Physics of the Earth's Interior
     - (a) Heat Flow and Heat Production
     - (b) Permafrost Studies
     - (c) Geothermal Energy
4. University of Alberta
   - I Seismology
     - (a) Theoretical Studies
     - (b) Experimental Studies
     - (c) Instrumentation
   - II Physics of the Earth's Interior
     - (a) Induced Stress
     - (b) Geodynamics
5. University of British Columbia
   - I Seismology
     - (a) Lithospheric Studies
     - (b) The Whole Earth
     - (c) Seismic Sources and Wave Propagation
   - II Physics of the Earth's Interior
6. Dalhousie University
   - I Seismology
   - II Physics of the Earth's Interior
7. McGill University
   - I Seismology
     - (a) Theoretical Studies
     - (b) Experimental Studies
8. Memorial University
   - I Physics of the Earth's Interior
     - (a) Geodynamics
     - (b) Heat Flow
     - (c) Thermodynamics of the Liquid Core
9. University of Saskatchewan
   - I Seismology
   - II Physics of the Earth's Interior
10. University of Toronto
    - I Seismology
      - (a) Theoretical Studies
      - (b) Experimental Studies
11. University of Western Ontario
    - I Seismology
      - (a) Theoretical Studies
      - (b) Experimental Studies
      - (c) Instrumentation
    - II Physics of the Earth's Interior
      - (a) Geodynamics
      - (b) High Pressure Studies
      - (c) Heat Flow
12. Canadian Seismological Mission to China
13. Research and Technical Personnel
14. Bibliography

1. Canadian Seismograph Stations

The seismograph facilities administered by the Earth Physics Branch of the Department of Energy, Mines and Resources, Ottawa, are listed in Table 1. Other stations being operated by Universities on an occasional basis are also listed. The new regional station at Igloolik (IGL), N.W.T. was opened on September 3, 1975. A regional station at La Grande II (LGQ), Quebec, will become operational in 1976.

P arrival data read at all standard stations are sent by daily telegram to Ottawa. These data are made available by dialed computer access to the National Earthquake Information Service (NEIS), United States Geological Survey, Denver, Colorado, for its epicentre determination program. Similar data, but in computer printout format, are sent to other international organizations.

All standard and regional station seismograms are microfilmed in Ottawa by the Canadian Government Public Archives and copies of the 35 mm microfilm are deposited with the U.S. Department of Commerce, NOAA, EDS Solid Earth Data Division in Boulder, Co. 80302, which answers requests for Canadian seismograms.

The Eastern Canadian Telemetered Network (ECTN) has been in operation since January 1974. Short-period vertical outstations are presently located at Ottawa and at Maniwaki (MIQ), Montreal and Manicouagan (MNQ), Quebec. This is an all-digital system which employs a gain-ranging analogue to digital converter at all outstations and 1200 baud digital transmission to Ottawa, where a PDP11/15 computer formats the data, produces a continuous visual record and saves selected events in digital form.

Installation of the Western Canadian Telemetered Network (WCTN), centered on the Victoria Geophysical Observatory, was begun in June, 1975. The central processor for the WCTN is a PDP 11/40 computer. Outstation hardware is identical to that of the ECTN. Victoria, Port Alberni and Haney have been operating continuously since September 1, 1975. Pender Island is in the final stages of commissioning.

The operation of three temporary LP digital stations in the Cordillera terminated at the end of October 1975 and instruments were transferred to Ottawa for deployment in Eastern Canada in 1976.

A portable SP vertical seismograph station was operated for the EPB on Northern Somerset Island N.W.T. by the Institute of Sedimentary and Petroleum Geology GSC during a two-month summer field program in 1975.

Table 1 Canadian Seismograph Stations

	STATION CODE	STATION	LATITUDE N	LONGITUDE W	COMMENT
	STANDARD	STATIONS	(Energy Mines and Resources)		
1.	ALE	Alert, N.W.T.	82.48	62.41	
2.	BLC	Baker Lake, N.W.T.	64.32	96.02	
3.	EDM	Edmonton, Alta.	53.23	113.36	Univ. of Alberta
4.	FCC	Fort Churchill, Man.	58.76	94.09	
5.	FFC	Flin Flon, Man.	54.73	101.98	
6.	FRB	Frobisher Bay, N.W.T.	63.74	68.55	
7.	FSJ	Fort St. James, B.C.	54.44	124.26	
8.	INK	Inuvik, N.W.T.	68.29	133.50	
9.	LHC	Thunder Bay, Ont.	48.42	89.27	
10.	MBC	Mould Bay, N.W.T.	76.24	119.36	
11.	MNT	Montreal, P.Q.	45.51	73.63	
12.	OTT	Ottawa, Ont.	45.40	75.72	

13.	PHC	Port Hardy, B.C.	50.71	127.44	
14.	PNT	Penticton, B.C.	49.32	119.62	
15.	RES	Resolute, N.W.T.	74.69	94.91	
-	SCB	Scarborough, Ont.	43.72	79.24	closed since 1973
16.	SCH	Schefferville, P.Q.	54.82	66.79	
17.	SES	Suffield, Alta.	50.40	111.05	
-	SFA	St. Féréol, P.Q.	47.13	70.83	closed July 31, 1975
18.	STJ	St. John's, Nfld.	47.58	52.74	
19.	VIC	Victoria, B.C.	48.52	123.42	
20.	YKC	Yellowknife, N.W.T.	62.48	114.48	

Regional Stations (Energy, Mines and Resources)

21.	CHQ	Charlesbourg, P.Q.	46.89	71.30	
22.	HAL	Halifax, N.S.	44.64	63.60	
23.	IGL	Igloolik, N.W.T.	69.38	81.80	new Sept. 3, 1975
24.	LGQ	La Grande, P.Q.	-	-	new - 1976
25.	MCC	Mica Creek, B.C.	52.05	118.59	
26.	PBQ	Poste de la Baleine, P.Q.	55.28	77.74	
27.	POC	La Pocatière, P.Q.	47.36	70.04	
28.	QCC	Queen Charlotte, B.C.	53.26	132.09	
29.	QCQ	Quebec City, P.Q.	46.77	71.28	
30.	SIC	Sept -Iles, P.Q.	50.17	66.74	
31.	SUD	Sudbury, Ont.	46.47	80.97	
32.	UNB	Fredericton, N.B.	45.95	66.64	
33.	WHC	Whitehorse, Yukon	60.74	135.10	

Eastern Canadian Telemetered Network (ECTN) (Digital recording, Single Component)

(Energy, Mines and Resources)

34.	MIQ	Maniwaki, P.Q.	46.37	75.97	Installed Feb., 1974
35.	MNQ	Manicouagan, P.Q.	50.53	68.77	Installed Nov., 1974
11.	MNT	Montreal, P.Q.	45.51	73.63	Installed Feb., 1974
12.	OTT	Ottawa, Ont.	45.40	72.72	Installed Feb., 1974

Western Canadian Telemetered Network (WCTN) (Digital Single Component Recording)

(Energy, Mines and Resources)

36.	HYC	Haney, B.C.	49.27	122.57	Installed Sept., 1975
37.	PIB	Pender Island, B.C.	48.82	123.32	Operational in 1976
38.	ALB	Port Alberni, B.C.	49.27	124.82	Installed Sept., 1975
19.	VIC	Victoria, B.C.	48.52	123.42	Installed Sept., 1975

Yellowknife Array, N.W.T.

19 elements of short period vertical recording (Analog Telemetry)
3 elements of long period vertical recording

39.	YKA array	Yellowknife	62.493	114.605	Center

Mica Dam, B.C. Telemetered Array (Analog Single Component)
(University of British Columbia)

40.	BLU	Blue River, B.C.	52.1533	119.2763	Helicorder
41.	MCC	Mica Creek, B.C.	52.0517	118.5853	
42.	CUM	Mt. Cummins, B.C.	52.0869	118.2117	
43.	DAI	Mt. Dainard, B.C.	52.1986	118.3845	
44.	TAB	Tabernacle Mtn., B.C.	51.7512	117.7617	
45.	THO	Mt. Thompson, B.C.	52.6892	119.1208	

Variable Aperture Seismic Array (VASA) - Temporary Sites

(Digital Record) - University of Alberta

46.	EAT	Eatonia, Sask.	51.1852	109.3155	Summer 1974 only
47.	FOR	Foremost, Alta.	49.2557	111.5055	" "
48.	HAN	Hanna, Alta.	51.4508	112.0622	" "
49.	SUF	Suffield, Alta.	50.3950	111.0417	" "
50.	VUL	Vulcan, Alta.	50.3672	113.3637	" "
51.	CLA	Clandonald, Alta.	53.7533	110.6903	Summer 1975 only
52.	SML	Smoky Lake, Alta.	54.1667	112.3958	" "
53.	KIL	Killam, Alta.	52.7833	114.9000	

1. Canadian Seismograph Stations (continued)

The annual publication formerly entitled "Seismological Bulletin" has been renamed "Canadian Seismograph Operations", starting with the 1974 report. It contains summary information on seismograph installations operated by or for the Division of Seismology and Geothermal Studies, Earth Physics Branch. This information includes a brief description of the various types of seismograph installations, data produced, data processing procedures, availability of station data and records, instrumental changes in the Network and calibration curves.

Several Canadian universities operate seismographs for special studies, which are not part of the Canadian network.

2. Canadian Seismicity

(a) Canadian Earthquakes

Preliminary bimonthly reports on Canadian seismicity prepared by the Earth Physics Branch, Ottawa are circulated about six to nine months in arrears to organizations interested in Canadian earthquakes. These include the National Earthquake Information Service in the United States, International Seismological Centre in the United Kingdom and a number of Canadian and American universities. Catalogues of Canadian earthquakes for the years 1968, 1973 and 1974 are in press. Catalogues for the years 1971 and 1972 will be published in 1976.

Data on all located Canadian earthquakes for 1974 and following years will be included in the Bulletins of the International Seismological Centre. Previously, data on only the larger earthquakes were included.

To date (Nov. 1975) several minor earthquakes have been reported felt in southern Canada. These occurred in British Columbia near western Vancouver Island on March 31 at 05:48 (all times GMT) and in the Strait of Georgia on November 30 at 10:48; in southwestern Quebec near Maniwaki on July 12 at 12:37 and in northeastern Quebec near Manicouagan on October 23 at 21:17. Three minor earthquakes in the Northern United States were felt in border regions of southern Canada. These occurred in northern Montana on Feb. 4 at 01:32 and in northern New York State on June 9 at 18:39 and November 3 at 20:54.

Seismic activity in northern Canada in 1975 continues as in past years with moderate earthquakes in the Queen Elizabeth Islands, northern Yukon, Baffin Island and near Wager Bay, N.W.T.

G.C. Rogers of the EPB has been studying the magnitude 5 earthquake that occurred near Tofino, B.C. on March 31, 1975. The depth was normal. No aftershocks larger than magnitude 2 occurred. The focal mechanism solution indicates predominantly strike-slip faulting with a pressure axis consistent with north-south compression in the region.

R.B. Horner, A.E. Stevens, H.S. Hasegawa and G. Leblanc of the Earth Physics Branch are completing a study of the Maniwaki, Quebec, earthquake on July 12, 1975, magnitude m_b 4.3. It was located in an earthquake zone that trends northwest-southeast through the Ottawa-Montreal region in which earthquakes the size of the Maniwaki event occur at an average rate of once every two or three years. This earthquake caused no damage but was felt to distances of about 200 km, on the average, from the epicentre. Travel-time curves suggested constant apparent Pn, Sn and Lg velocities of 8.26 ± 0.04, 4.72 ± 0.03 and 3.62 ± 0.01 km/s, respectively, out to epicentral distances of 1200 km. The travel-time curves also suggested a focal depth of 14 ± 4 km. Yellowknife Array data indicated a second arrival 7.3 s after the initial P onset, which was interpreted as either sP or pP and indicated a focal depth of 15 or 20 km, respectively. A P-nodal focal mechanism solution, the first for any event in this zone, indicated a thrust mechanism on a northwest-southeast striking plane. Theoretical vertical Rayleigh-wave amplitude spectrums when compared to the observed amplitude spectrums suggested a focal depth of 8 to 10 km, a seismic moment of 1.7×10^{22} dyne-cm, an average dislocation of the order of 1/2 to 2 cm and a stress drop of the order of 1 to 8 bars. In terms of the aftershock sequence, the main shock exhibited the properties of a high stress drop earthquake.

A.E. Stevens, M.N. Bone and R.B. Horner of the EPB conducted an aftershock field survey of the Maniwaki earthquake of July 12, 1975, and also an intensity survey in the epicentral region. Three portable SPZ seismographs were deployed within 11 hours of the main shock and monitoring continued for 3-1/2 days. About 13 aftershocks were recorded, nine within 24 hours of the main shock. The largest aftershock had magnitude M_L 1; most had magnitudes between M_L -1 and 0. A preliminary analysis of the aftershock hypocentres suggested an active volume of no more than one km in diameter at a depth of 17 km. Although the source region appeared to be constant in space, the mechanism of energy release was not constant, since the ratios of maximum P and S amplitudes recorded at the field stations were not similar for all the aftershocks.

A magnitude 4-1/2 earthquake on November 30, 1975 located 25 km west of Vancouver was felt on southern Vancouver Island and the adjacent mainland, from Tofino to Chilliwack and from Victoria to Sechelt. This earthquake, the first in the immediate area, was recorded on the new telemetry network at the Victoria Geophysical Observatory. This network should provide an interesting contribution to the study of earthquakes in the Strait of Georgia.

A.E. Stevens has critically examined contemporary newspapers, scientific reports and seismograms concerning 28 events in the two catalogues of earthquakes of Eastern Canada and adjacent areas for the periods 1534-1927 and 1928-1959 (Smith, 1962;1966), some of which also appear in catalogues of United States earthquakes. Seven entries have been deleted from the catalogues, only typographical errors have been corrected for three events and no changes were made to two catalogued events. The maximum reported intensity of 10 events and the magnitude of five events were significantly reduced, affecting 14 earthquakes. The location of four events was revised. These alterations have been made to the master tape file of earthquakes in or near Canada in the period 1568 to 1974, which may be purchased from the Division of Seismology and Geothermal Studies, EPB, EMR, Ottawa. Information on the alterations is available on request. The earthquake catalogues have not yet been systematically re-examined.

G. Leblanc and G.G.R. Buchbinder of the EPB have completed the first part of their analysis of the 1974 microearthquake survey in the La Malbaie, Quebec region. Compared with the 1970 experiment, the 1974 survey has given results of a superior quality, due to the larger number of stations deployed. Nonetheless, the results of both surveys are quite similar. In brief, the zone of seismic activity was almost contained in the St. Lawrence River, between Baie-St. Paul and St.-Siméon; the small events, with M_L between -1.0 and 3.0, occurred at an average rate of one every two days; and the focal depths varied between 2 and 22 km.

One important new result is that six events were well enough recorded by the field net-

work to give P-nodal focal mechanism solutions, the first ones for the region. These solutions are not identical; their complexity is consistent with the complex local tectonic features. The study will be published in 1976.

G.C. Rogers of the EPB monitored the Meager Creek geothermal area in southwestern B.C. for microearthquake activity for 730 hours during the winter of 1974-75 and again for approximately three months during the summer of 1975. Very few events were detected. There seems to be no correlation of microearthquakes with the hotsprings.

R.J. Wetmiller of the EPB, in a recent study of larger Baffin Bay earthquakes, has found that the strong alignment of such epicentres through Baffin Bay parallel to Baffin Island as seen on epicentre maps of data prior to 1965 is somewhat misleading. It is based entirely on older data which can be subject to serious mislocations and is not complemented by a similar trend in more recent but smaller magnitude seismicity determined since the expansion of the Canadian Network in the 1960's. Very few earthquakes occur on the oceanic part of central Baffin Bay; such events are easily identified by the lack of an Lg phase of ground motion recorded at nearby seismograph stations. Nares Strait, between Ellesmere Island and Greenland, appears to be almost completely aseismic over its entire length. Davis Strait, similarly, appears aseismic, but the coverage of the modern network is still weak in this area and some smaller magnitude earthquakes may have gone unlocated. No earthquake with magnitude greater than 4 is known to have occurred in Davis Strait.

P.W. Basham, D.A. Forsyth and R.J. Wetmiller of the EPB have studied the record of historical seismicity (1899-1974) in Canada north of latitude 60°N and made correlations of seismicity trends with other geophysical features. Epicentre clusters in the continental shelf-slope north of Borden Island and in the Beaufort Sea are associated with major free-air gravity anomalies; the earthquakes appear related to the action of sediment loads on deeper geologic structures. The northern Keewatin, Boothia Uplift and Sverdrup Basin geologic structures are reflected directly in the seismicity. In the eastern Arctic the seismicity is consistent with the inferred mode of glacial rebound based on free-air anomalies; the seismicity is coincident, not with the broad areas of maximum uplift, but with the bordering and intervening areas, i.e., with zones of possible maximum stress gradient. In each of these areas contemporary tectonic forces can also be assumed to be acting on a variety of intraplate structural features.

D.H. Weichert of the EPB has studied the value of the CANSAM system for Canadian seismicity. For event detection, location and mechanism in the Yukon and Arctic, the array can make an important contribution, supplementing data available from the Canadian Seismograph Network, and is also valuable for other parts of the country.

(b) Strong Motion and Earthquake Engineering Studies

G.C. Rogers of the Earth Physics Branch continues to supervise development of the strong-motion seismograph network in western Canada. The present network consists of 31 accelerographs, 61 seismoscopes and 7 peak recording accelerographs, some of which are private instruments under the care of the EPB. The phasing-out of the Fairey accelerographs, the original model deployed in Canada, was completed in 1975. An earthquake near Tofino, B.C., on March 31, 1975 produced five very low amplitude seismoscope records.

G. Leblanc and F. Anglin of the EPB have spent considerable time in the surveillance of local seismicity in the Manicouagan region, where Hydro-Quebec has several large reservoirs. The seismograph station MNQ between Manic 5 and Manic 3, which is telemetered to Ottawa, has been a very helpful monitor. With the cooperation of Hydro-Quebec, it became possible to identify as microearthquakes some events near Manic 3 in mid-September that were unaccounted for by local construction blasts. These turned out to be foreshocks of an m_b 4.3 main event on October 23, 1975, which was followed by a long sequence of aftershocks. The filling of the Manic 3 reservoir had started on August 5, 1975. This seismic activity constituted the first case known in Canada of seismicity induced by the impounding of a large reservoir. Three portable seismograph stations were deployed around the Manic 3 reservoir immediately after the main shock. This case is now under intensive study.

G. Leblanc has continued to advise the Société d'Energie de la Baie James about seismic monitoring prior to reservoir loading. The operation of a local seismograph station at La

Grande 2 has been delayed due to setbacks caused by difficulties at the LG-2 site.

W.G. Milne and M.J. Berry of the EPB presented a review of possible induced seismicity in Canada to the First International Conference on Induced Seismicity held in Banff, Alberta, from September 15 to 19, 1975. Their review showed that up to the Fall of 1975 the only definite Canadian examples of induced seismicity in mines were rockbursts experienced in northern Ontario and Quebec, possibly some tunnel collapses in southern Vancouver Island and some mine 'bumps' in southwestern Alberta and eastern British Columbia. The Snipe Lake, Alberta, earthquake of March 8, 1970, might have been induced by high-pressure water injection in an oil field; it appeared to be the only Canadian example of this type of event. At the time of the Conference, no known induced earthquakes in Canada had been caused by reservoir loading.

W.G. Milne of the EPB has prepared new acceleration attenuation curves for western Canada and a set of corresponding velocity curves, which have been used to draw a preliminary set of contours of the respective ground motions in the Strait of Georgia region. The new contour lines for acceleration do not differ much from those used for the 1970 National Building Code. It is interesting to note that the shape of the velocity contours is very similar to that of acceleration.

P.W. Basham, A.E. Stevens, D.H. Weichert, H.S. Hasegawa and M.J. Berry of the EPB have been working within the Canadian Nuclear Association Subcommittee that has been charged with drafting a Canadian Standards Association Code entitled "Seismic Design Requirements for CANDU Nuclear Power Plants". Their primary task is drafting those sections of the code that describe the seismological investigations and define the design basis seismic ground motion for purposes of earthquake-resistant design of plant structures and components.

P.W. Basham and D.H. Weichert have investigated the design basis seismic ground motion for nuclear power plant sites in New Brunswick and Ontario. Work is continuing to delimit the zones of earthquake occurrence in eastern Canada, which may be applicable to future power sites.

Within the joint AECL/EMR Committee on geological storage of radioactive waste, P.W. Basham is exploring the seismicity and earthquake hazard evaluations required for a prototype waste disposal facility.

H.S. Hasegawa has generated theoretical Fourier amplitude spectra of ground acceleration (FS) using a deterministic model of faulting. The theoretical curves were compared with actual FS curves of three northwest United States earthquakes. The selected FS curve for the 1935 Helena, Montana, earthquake, magnitude 6, consisted almost entirely of "direct" shear waves. The selected curve for the 1949 Western Washington earthquake, magnitude 7.1, had residuals at mid-frequencies (near 1 Hz) that were attributed to local soil effects. The selected curve for the 1965 Puget Sound earthquake, magnitude 6.5, was much higher than the theoretical, both at mid- and high-frequencies. The inherent problem in separating source mechanism contribution from travel-path complexities at high frequencies made it difficult to determine whether a deterministic model was appropriate for these larger-magnitude earthquakes.

Professor P. Gouin, from Haile Sellassie I University in Addis Ababa, Ethiopia, spent almost three months at the Victoria Geophysical Observatory on a project to determine a seismic probability map for Ethiopia, which was supported by the Canadian International Development Research Centre.

R.M. Ellis, H. Dragert and others at the University of British Columbia have continued observations with the telemetered seismometer array in the Mica Dam Reservoir area. It has now been in operation for almost three years, continuously monitoring local seismic activity. A 1-1/2 year moderately active period beginning in 1973 was followed by a 6 month quiet period, which gave way to low-level activity again in April 1975. This regional seismicity appears to follow historical patterns and, as yet, no correlation with the loading and unloading cycle of the reservoir is apparent.

Explosion data over a period of 240 days beginning in December, 1973, show a small apparent (1% to 2%) decrease of P-wave velocities in the confluence area; again, no correl-

ation with reservoir loading can be seen. Analysis of explosion data has also suggested possible refinements of the basic velocity model used for hypocenter determinations in the Mica Reservoir region.

The variable aperture seismic array (VASA) operated by E.R. Kanasewich at the University of Alberta was operational in central Alberta during the summer of 1975. The teleseismic data is being used for $dT/d\Delta$ analysis. The digital recording field stations were at Killam, Clandonald and Smoky Lake, Alberta. The telemetered digital data from EDM formed the fourth station in the array.

3. Earth Physics Branch (EMR, Ottawa) - I Seismology

(a) Studies of Continental Lithosphere

At the Earth Physics Branch 12 sites of the 1974 summer seismicity experiment in the La Malbaie, Quebec, area were reoccupied in September 1975. The 1974 calibration shot (2500 kg - Hydromex) detonated in a shallow water-filled quarry was repeated. Arrival times at the sites were within ± .020 seconds of the 1974 times, which was within the estimated probable error. A 500 kg (Hydromex) shot, detonated in a drilled hole 50 meters in depth, was also recorded at the 12 sites. It is hoped that further shots from this location, repeated at several month intervals, may be recorded as an investigation of the dilatancy phenomena. Travel-time variations expected for a magnitude 6 earthquake should far exceed experimental errors with the explosion source.

A reversed reflection/refraction profile within the boundaries of the Charlevoix Crater was also recorded in September 1975. Shots of 50 kg each were detonated in drilled holes (near Clermont and St. Urbain) into a profile consisting of 42 multiple-geophone traces spaced over 22 kilometers. These data have not yet been processed.

The network of stations set up to record earthquakes in the La Malbaie region in 1974 also recorded mine blasts from Thetford Mines and St. Urbain. These refraction records have been digitized, but are not sufficient to define local crust structure. They will be used in conjunction with earthquake and other available refraction-reflection information for the area to study local crustal structure.

A paper by J.A. Mair and J.A. Lyons of the EPB describing the 1972 and 1973 seismic reflection profiling at Ahbau Lake, B.C. using both dynamite and the vibroseis technique will be submitted for publication in December 1975.

J.A. Mair and D.A. Forsyth of the EPB have reduced the refraction data collected in the Sverdrup Basin during the 1972 and 1973 field seasons. Final publication must await release permission from the industries involved.

The crustal reflection survey planned for Williston Lake, B.C. in April 1975 was cancelled.

C. Wright of the EPB is studying methods and techniques that are already or might be used for determining the stress field and stress changes within the earth's crust. Special emphasis is being placed on methods applicable in regions such as eastern Canada where few earthquakes give focal mechanism solutions.

A large explosion was fired at a point 160 km west of Vancouver Island near an active earthquake zone as part of a continuing program to calibrate the regional seismograph network in order to provide more accurate earthquake epicentres.

(b) The Whole Earth

G. Buchbinder of the Earth Physics Branch has submitted for publication a study on P residuals over Canada. The principal results were: the Canadian station residuals varied over 1.4 seconds; they decreased with tectonic age at the station, and, where heat flow data exists, the station residuals increased with increasing heat flow; the observed variations in heat flow were sufficient to account for a large part of the residuals. Thus the upper mantle under extensive regions in Canada is laterally inhomogeneous. A velocity model of

the mantle valid towards the northwest of Canada was obtained.

C. Wright and J.A. Lyons of the EPB are using adaptive processing and other techniques for measuring $dT/d\Delta$ and azimuth to confirm the existence of radial velocity anomalies in the lower mantle, particularly at depths close to 1250 and 2700 km. Small radial velocity anomalies produce triplications in the $dT/d\Delta$ curve for which the arrivals may often be so close together in time (< 1 second) that the $dT/d\Delta$ and azimuth measurements at arrays such as Yellowknife are made on interfering pulses. Using synthetic interfering wavelets, criteria based on the numerical and statistical properties of $dT/d\Delta$ and azimuth measurements and the waveforms of the P arrivals are being developed for distinguishing between single arrivals and interfering waves with slightly different arrival vectors.

C. Wright has completed a study of P'P' and its precursors recorded at the Yellowknife Array over the distance range 44° to 62°. The widely scattered distribution of azimuth values and the early arrival times of the main P'P' energy at distances less than 50° implied that asymmetric P'P' was an important constituent of precursors to P'P'. The P'P' group of waves does not, therefore, give reliable estimates of the depths of shallow reflecting discontinuities within the upper mantle. The main value of the P'P' phase and its precursors may be in studying lateral variations in the 650 km discontinuity and in investigating scattering structures in the uppermost layers of the earth.

G. McMechan of the EPB has studied the structure of the mantle beneath the Canadian Shield through a comparison of real and synthetic seismograms and, with J.J. Sinclair, has compiled a catalogue of 50 upper mantle P-wave models.

H.S. Hasegawa of the EPB is studying the theoretical epicentral ground deformation of two British Columbia earthquakes that were strongly felt on Vancouver Island and/or the lower mainland of British Columbia. Theoretical contour maps of elevation change, strain and tilt were generated for the 1946 Strait of Georgia earthquake magnitude 7.3, and the July 5, 1972 Vancouver Island earthquake, magnitude 5.7. The calculated elevation change in the epicentral region due to the 1946 earthquake, which had a predominantly dipslip source mechanism, was appreciable, being about 15% of the assumed value of 200 cm for the dislocation vector at the source. On the other hand, the calculated elevation change due to the 1972 earthquake, which was predominantly strike-slip, was less than 1% of the estimated slip vector of 120 cm.

The EPB continued its efforts in seismological detection and discrimination of underground nuclear explosions. In 1975 a tripartite conference was held in Ottawa and Yellowknife, where seismologists from Sweden, Japan and Canada reviewed individual and cooperative projects. H.S. Hasegawa and P.W. Basham of the EPB have continued their study of the potential for nuclear test evasion by multiple nuclear explosion detonation to simulate earthquake characteristics.

D.H. Weichert of the EPB and M. Henger of the Bundesanstalt für Bodenforschung, Germany, completed an evaluation of the 1974 Canadian Seismic Monitor (CANSAM) results during the six winter and spring months. The detection threshold is m_b 4.0-4.1 at a 50% false alarm rate. During summer and fall, organized surface-wave noise originating on Great Slave Lake brings this detection level to m_b 4.6-4.7. A special feature of CANSAM is the non-linear beamforming used for detection, which lowers the false alarm rate of the automatic detector.

A.J. Wickens of the EPB has written a set of computer programs based on a paper by D.D. Jackson (1972) for the generalized inversion of linear systems. A specific application was made to the inversion of surface-wave data from the LP network in southern British Columbia. The procedure sets bounds on resolution and variance of model parameters.

C.M. Keith, a post-doctoral fellow at the EPB, is investigating the effects of anisotropy in the mantle and/or crust on the propagation of the body waves. Programs based on an extension of the Thomson-Haskell matrix formalism are being used to compute theoretical seismograms and crustal transfer functions for plane-layered structures incorporating anisotropic layers of general elastic symmetry and orientation. The possibility of monitoring an earthquake zone, made anistropic by crack production due to dilatancy, using crustal transfer functions is being investigated.

G. McMechan of the EPB has studied the effects of upper mantle structure on the short-period spectra of body wave trains and in a joint project with S.K. Dey-Sarkar (presently at the University of Toronto) has extended the Quantized Ray Theory formulation for the computation of synthetic body-wave seismograms to allow computations for non-zero focal depths. Another completed project involved the generalization of ray parameter - distance curves and their application to non-trival ray problems.

G. McMechan is completing two studies on the effects of crustal structure on the passage of teleseismic P-wave trains and on the effects of crustal structure on the shear wave and its precursors. The latter is a joint project with G. Emms of the University of British Columbia. G. McMechan is currently investigating the jump in travel-time intercept as a function of focal depth to determine the velocity-depth distribution within a low-velocity zone.

(c) Seismological Instrumentation

R.B. Hayman, F. Kollar and M.N. Bone of the Earth Physics Branch are proceeding with the development and procurement of a range of seismic instrumentation modules. Designs for a digital clock and a regional station power supply have been completed.

Development is well under way on the 'Back Pack' digital recording package, which will be used on refraction and reflection surveys and as a stand-alone station in an event-triggered mode. A COSMAC microprocessor will control recording onto a high-density cassette transport. The system will have three seismic channels and be battery powered. Present plans are to evaluate the units during the AIDJEX experiment in the spring of 1976.

A graphic display and several other peripherals have been added to the PDP 11 Software Development System at Ottawa, which is used to support research program development for real-time seismic processors at Ottawa, Yellowknife and Victoria. Significant effort is continually devoted to on-going maintenance, support and improvement of seismic data acquisition and processing systems used at permanent stations and in field projects.

The Yellowknife on-line array processor (CANSAM) has been operating in a routine manner during 1975 producing a daily event log and digital magnetic tape records of triggered events. Recently, a 300 baud data link has been added to permit access to the current event log from Ottawa over the public telephone network. Analogue tapes are still being recorded to back up the digital system.

Earth Physics Branch - II Physics of the Earth's Interior

(a) Heat Flow and Heat Production

At the Earth Physics Branch several regional studies of the geothermal nature of the crust are being completed. In the Maritime Provinces a combination of data from the Earth Physics Branch and Dalhousie University reveal the dominant effect of the heat production of Devonian granitic plutons.

The heat flow and heat generation from the Superior Province of the Shield show that this area cannot be regarded as part of the geothermal province of the Eastern United States. It is necessary to consider the meaning of the concept of geothermal provinces in a terrain that is entirely metamorphic and that is old enough to have lost a great deal of its radioactivity by the normal process of decay.

The World Heat Flow data compilation has been completed and the data are available in computer-compatible form from the World Data Centres.

The results of these three projects will be available in print shortly.

At the EPB T. Lewis has analysed for thorium, uranium and potassium some cores and surface samples representing the crust at heat flow sites as well as surface samples from profiles across the southern Canadian Cordillera and part of the Churchill Province. M. Grant has used a portable gamma-ray spectrometer to delineate large changes in the heat production of surface rocks near some heat flow sites in the Superior Province. L. Matthews has

also used a portable spectrometer to measure variations in radioactivity of rocks at the Brenda and Bethlehem Copper (Heustis Pit) Mines in B.C.

The first heat flow measurements in boreholes into the basaltic oceanic crust were obtained on leg 37 of the Deep Sea Drilling Project on the mid-Atlantic ridge. The results confirm the values found in the sedimentary parts of the holes. The heat flow in three holes, one to 540 m depth into basaltic basement, and from three ocean probe measurements all in one sediment pond on 3.5 m.y. old ocean floor is 0.6 ± 0.1 μcal $cm^{-2}s^{-1}$. This value, which is much lower than the 4.0 μcal $cm^{-2}s^{-1}$ predicted by theoretical conductive cooling plate models, requires extensive hydrothermal circulation in the oceanic crust. In one hole, seawater appeared to be flowing down to a deep permeable horizon that probably was part of a hydro-thermal system.

R.D. Hyndman and J.F. Lewis made ocean heat flow measurements on the continental rise and slope off Nova Scotia and off the southern Grand Banks. The variations were small off the latter, which is a transform faulted margin, but were large off Nova Scotia, which is a rifted margin. The variations are ascribed to thermal refraction by high conductivity salt, the sedimentary "ridge complex" under the slope. The salt was deposited as evaporite when only a narrow restricted gulf had opened between North America and Europe. By the time the southern Grand Banks margin was formed, there was free circulation and no further evaporite deposition.

R.D. Hyndman and D.S. Rankin of Dalhousie University with A.M. Jessop and A.S. Judge of the EPB have made borehole heat flow and radioactive heat generation measurements in Atlantic Canada. The results show Nova Scotia to be part of the stable eastern North America thermal province with a "mantle heat flow" of about 0.8 μcm $^{-2}s^{-1}$. This value is slightly higher than for the Canadian Shield but much lower than for the Cordillera of western North America.

(b) Permafrost Studies

At the Earth Physics Branch a program of deep borehole temperature measurements in wells either acquired from or suspended by resource companies has been continued. During 1975, 17 new sites were logged for the first time, making a total of 45 northern wells logged during the year. As a result permafrost thickness measurements are now available for 70 sites in the Canadian north, of which 32 are in the Arctic Islands and 25 in the Mackenzie Delta. The results of these measurements are providing not only a determination of permafrost thickness, important to regulatory agencies and resource companies but also a new understanding of permafrost dynamics and its relationship to terrestrial heat flow, surface temperature history and surface morphology.

Shallow temperature observations in the Mackenzie Valley have been completed for the present and the emphasis has been switched to the Arctic Islands and the Keewatin area, in particular, along the proposed Polar Gas Pipeline Route.

Observations at the former sites might be repeated in five years time since climatic variation appears to play an important role in determining the surface temperature in marginal permafrost areas. Small programs of shallow temperature observations have been commenced with D.I.N.A. to investigate the frost heave of an artificial island, with D.P.W. to investigate coastal processes at Tuktoyaktuk and with G.S.C. at the Involuted Hill south of Tuktoyaktuk.

In the spring a one-day seminar on the "Shallow Thermal Regime" was organized in conjunction with the G.S.C. A group of specialists was gathered together to determine the major deficiencies in our understanding of the subject. The general consensus of the meeting was that field measurements are still essential, because theoretical methods are not yet adequate to predict the thermal regime, and that a very great need exists for additional studies of coupled heat and mass transfer under northern conditions. These needs are being partially met through the TEP-2 program of the "Environmental-Social Program on an Arctic Pipeline", co-ordinated by the Geothermal Service, EPB.

Measurements of the thermal properties of rocks and soils, both frozen and unfrozen, are being made on a continuing basis. For many locations no cored material is available on

which to make these measurements and drill-cuttings must be used instead. Research is continuing on improved techniques of determining in situ thermal properties from measurements on the cuttings and from the analysis of well-logs.

To investigate the effect of shorelines on permafrost distribution, measurements of underground temperature and thermal properties of rocks have been made at on- and off-shore sites at Little Cornwallis Island, N.W.T. and in the Mackenzie Delta. The distribution of permafrost in the two areas is highly dependent on the surface history in the past hundred thousand years.

In a similar fashion investigations of offshore permafrost in the Beaufort Sea, in conjunction with G.S.C. and the Beaufort Sea Project F-1 of D.O.E., have shown its dependence on past surface temperature history. Investigations to date indicate that permafrost is degrading at a temperature marginally below $0^{\circ}C$ with the exception of that beneath very shallow water (<2m) and in very deep water (>40m). Beneath deeper water the degrading section may be present at depth but a thin layer of permafrost, more recently aggraded, may also be present near the sea-bottom.

Numerical analysis techniques are being applied to the problem of the thermal disturbance of the rock surrounding a well during drilling. A comparison of the borehole data with the mathematical analysis will enhance the understanding of our own logs and will provide a basis for improved drilling techniques and the design of future production wells.

The possible occurrence of natural gas as a frozen hydrate is of increasing concern to northern drillers. Calculated equilibrium temperature curves had been used to predict the possible depth extent of hydrate for gases of different compositions in various areas of northern Canada. The analysis is similar in nature to an earlier attempt to predict the thickness of permafrost.

(c) Geothermal Energy

The Earth Physics Branch is the lead agency for coordination of research into geothermal energy resources in Canada. So far activities have consisted of drawing up a programme of resource assessment for Canada, providing advice and assistance to a consultant in work in southwestern British Columbia, providing advice to C.I.D.A., and maintaining an awareness of developments in other countries and in programmes of international cooperation.

4. University of Alberta - I Seismology

(a) Theoretical Studies

Dr. M. Razavy and Dr. M. Hron are investigating a number of inversion methods that have been developed in nuclear scattering theory for their applicability in seismology. Various techniques are being programmed and the results of the different methods will be compared to define their range of validity and accuracy. The perspective of the effort is to restrict the number of assumptions about the velocity behavoir. Furthermore the inversion for a laterally inhomogeneous medium is being attempted.

A new technique of solving the inverse problem of seismology has been described recently by Bessonova, Fishman Ryabayi and Sitnikova. This so called TAU method is being developed further by Dr. E.R. Kanasewich and Mr. A.C. Bates. The limits of the function $\tau(p)=T(p)-pX(p)$, where p is the ray parameter, T the travel time, and X the epicentral distance, are mapped into limits in the velocity-depth plane. The function τ (p) is estimated from observed times and distances of body wave data using the fact that $\tau(p)$ is the singular solution of Clairaut's equation with free term T(X). A new method of inverting seismic data using the function $\tau(p)$ has been developed in which $\tau(p)$ limits are assumed to be piecewise second order polynomials in p. As errors in travel time data become large, interpretation of the Clairaut equation, for the purpose of $\tau(p)$ estimation, may become ambiguous. Our alternate procedure for τ (p) is as follows: for each branch of the travel time curve, T, observations are fitted to a family of second order polynomials in X. The families of curves are then mapped in the $\tau(p)$ plane. The TAU method has been applied to Early Rise data recorded by various research laboratories to obtain velocity models showing lateral variations. The role of the interpreter is less critical in biasing the models so

obtained. Low velocity layers may be incorporated in the inversion process.

Comparison of synthetic seismograms computed with the help of asymptotic ray theory with real data from exploration seismology clearly demonstrated that the asymptotic ray theory is the most suitable method to be used for the numerical modelling of the seismic response of complicated geological structures.

The main effort of the group was therefore directed towards the further development of asymptotic ray theory in order to make it applicable to more realistic media. We also undertook the development of alternate high frequency approximations for the regions where ray theory cannot be used.

Having in mind the influence of anisotropy of hydrocarbon-bearing structures on seismic waves a theoretical study of dynamic properties of body waves in anisotropic media was initiated by Mr. P. Daley and Dr. F. Hron. Theoretical formulae for reflection and transmission coefficients of seismic plane waves were obtained together with the coefficients of head waves. Their dependence on the degree of anisotropy was studied. The formula will be used in the program for the computation of synthetic seismograms for anisotropic media, which is currently under development.

Mr. L. Marks and Dr. F. Hron undertook the development of a high frequency approximation for the amplitudes of interference head waves. Theoretical formulae based on the Sommerfeld integral in the complex plane were obtained for all types of interference head waves, including a triple interference of P-head wave, S-head wave and a related reflected wave. High frequency approximations of these formulae in terms of parabolic cylinder functions are being incorporated into existing programs.

Dr. F. Hron has finished the optimisation of ray generating algorithms being used for automatic partial ray expansions. Rays, once computed, are stored into the files and scanned by the computer during the seismogram computation. In case of parallel or spherical layers tables of groups of kinematic and dynamic analogs are used instead. It was found that dynamic properties of groups of dynamic analogs have completely different character from those of individual waves.

(b) Experimental Studies

Dr. E. Nyland and Mr. E.J. Roebroek have devised a computer automated system for extracting travel time information from the data tapes of the International Seismological Centre. Travel times can be analysed for delays in various three dimensional volumes of the earth. The technique has been applied in Western Canada to determine areas of uniform upper mantle and others where a relict subducting plate may be present.

Dr. E.R. Kanasewich and Mr. J. Havskov are using P, S, ScS and PcP phases to search for lateral inhomogeneities in the mantle.

As a consequence of discussion at a conference with Peruvian colleagues, Dr. E. Nyland has implemented a joint project with Instituto Geofisico del Peru for the experimental study of creep on active faults by geodetic methods. The first set of field measurements has been carried out at elevation of 4000 m near the city of Huancayo in the Peruvian Andes by Dr. Nyland. A second set 6 months later involved colleagues from the University of New Brunswick.

The variable aperture seismic array (VASA) has been operated in southern Alberta and Saskatchewan in the summer of 1974 and in central Alberta in the summer of 1975. The earthquake data are being analyzed using a COVESPA filter for wave slowness and azimuth by Dr. E.R. Kanasewich and Mr. A.C. Bates. Both P and S codes of some 200 events are being analyzed.

(c) Instrumentation

(i) Seismic Event Monitor Development and construction of 20 seismic systems is being carried out by Dr. E.R. Kanasewich, Mr. M.D. Burke and Mr. L. Ramsdell. This digital system will record on magnetic tape a short section of events detected by a vertical Mark Pro-

duct L-4 seismometer and the corresponding WWVB time signal. The systems are being designed to operate on low power from a battery supply in remote locations for periods of several weeks. A microprocessor is being used to detect events and control the system.

(ii) A radio telemetry system including controls by a Tl 980 mini-computer is being built to update the variable aperture seismic array.

(iii) The data link from the observatory to the Physics Department is being upgraded with an extension of the memory on the PDP-11 from 12,000 words to 28,000 words.

(iv) Together with Dr. J. Rogers of the Low Temperature group, Dr. Jones and Mr. Park are building a Stacey-type mercury tiltmeter to be used for measuring earth tides and local tilts. Some programs for the analysis of such data have been acquired from Dr. C. Beaumont of the Earth Physics Branch and these have been adapted for use in the University of Alberta computer. Also, data have been obtained from Professor P. Melchior from one station in Belgium and these will be analysed by Mr. Park. It is intended that in future a number of tiltmeters will be built and measurements will be conducted in the Rocky Mountains and Great Plains of Alberta.

University of Alberta - II Physics of the Earth's Interior

(a) Induced stress in the crust

Dr. E. Nyland, Mr. R.J. Withers are investigating the nature of time dependent strain with induced stress from large artificial lakes. Efficient methods of two dimensional fast-Fourier computation techniques have been applied to the modelling problem. The aim is to investigate the possibility of predictive seismic risk from the effects of loading.

(b) Geodynamics

Dr. E. Nyland and Mr. T. Spanos are using a variational principle to deduce the behavior of rocks under non-elastic deformation in earthquake focal regions. It appears possible to show how the viscous flow is modified by the diffusion of heat generated in the viscous deformation. The results of this investigation may be applied to viscous mantle rocks. The theoretical development may be extended to applied engineering problems including the flow of tar sands.

Dr. E.R. Kanasewich has made a study which demonstrates the type of ordering and symmetry present in the system of plates of lithosphere on the surface of the earth. It is shown that the Pacific and African plates are approximately circular with a radius of 60°. The tectonic pattern is dominated by these two major plates, exactly antipodal to one another in the form of a dipole. Between the two "circular" plates is a ring of elliptical plates with irregular boundaries but an organized geometrical interrelationship. The average major and minor axes of the "elliptical" plates, measured at the center of the earth are $62^{\circ} \pm 6$ and $30^{\circ} \pm 5$ and the major axes are oriented at angles of 56° to lines joining the center of the African plates. This organized distribution of the major plates is most likely the result of convection currents involving the entire mantle from the lithosphere to the core. To a firstapproximation it may be modelled by third order spherical harmonics.

5. University of British Columbia - I Seismology

(a) Lithospheric Studies

W.B. Cumming and R.M. Clowes have completed acquisition of data along a seismic refraction profile extending across southern B.C. The profile is partially reversed and utilizes mine blasts of Kaiser Resources Ltd. near the Alberta-B.C. border as the eastern energy source. Blasts of Lornex Mining Corp. and Bethlehem Copper Corp. in the Highland Valley, east of the Fraser River valley, provide the energy source at the western end. Seismograms at distances from 3 km to 400 km have been recorded with maximum station intervals of 15 km. Preparation of the seismic data, recorded on FM magnetic tape, for digitization and subsequent analysis and interpretation is in progress.

G. Spence and R.M. Clowes are proceding with interpretation of the set of S-wave data which were recorded along a profile extending 540 km up the southern Rocky Mountain Trench from the Kaiser Resources mine site. The interpretation will be integrated with the P-wave study recently completed and a recent gravity study.

At the University of British Columbia a marine seismic system for recording near-vertical incidence to wide-angle reflected waves and refracted waves with penetration from the ocean bottom to the upper mantle (deep seismic sounding or DSS) has been developed. Signals from six individual hydrophones suspended at 45 m depth from a 600 m cable trailed behind the receiving ship and the WWVB time code are recorded in digital form. The shooting ship detonates charges ranging from 2.3 kgm to 280 kgm and records the direct arrival plus WWVB time code on a strip chart recorder and FM analog tape. This seismic system is being used to investigate structure and characteristics of the oceanic crust and upper mantle, particularly off the coast of British Columbia.

S. Knize and R.M. Clowes are continuing with the analysis and interpretation of the data recorded off Queen Charlotte Sound and west of Vancouver Island during 1973. Deconvolution techniques have been applied to some data, but the slight increase in S/N ratio above that obtained from zero-phase bandpass filtering did not warrant the considerable increase in effort and computing time which was required. Velocity spectra calculations were also attempted but due to the errors associated with origin times and the fact that we do not record a true expanding profile, the velocity interpretations by this method were suspect.

However, visual phase correlations on both the reflection and refraction record sections have been made, enabling velocities to be determined. Average and interval velocities for the material from the ocean bottom to at least the top of the oceanic layer have been determined from the reflection seismic sections. The existence of the boundaries is confirmed on one near-vertical incidence continuous seismic profile of about 6 km length in each of the two areas.

The refraction data have been interpreted by careful phase correlation of first and secondary seismic arrivals. The results are in acceptable agreement with those obtained from the reflection data. The amplitude information in the seismic data is being utilized to refine the velocity structure through the use of synthetic seismogram calculations.

S. Malecek and R.M. Clowes have nearly completed the analysis of refraction data from two reversed DSS profiles about 75 km long which were recorded in the region of Explorer Ridge during 1974. Interpretation of the seismic data recorded at distances beyond 4 km has utilized both travel-times and amplitudes. The profile run across the ridge showed no anomalous behaviour as the ridge was crossed; the profile on Juan de Fuca plate, paralleling the ridge exhibited travel-time branch offsets and delays. These have been interpreted as due to faulting with a vertical component of offset of about 4 km. The reversed upper mantle velocities are 7.85 and 7.30 km/s in directions perpendicular and parallel to the ridge. Anisotropy is proposed to explain these different velocities. Compared with crustal sections from other ridge areas, the data require a thick (up to 6 km) oceanic layer near the ridge crest. The total depth to the base of the oceanic crust varies between 9 and 11 km except in the faulted region. Velocity gradients within the crustal layers are required to explain the amplitude variations along the profiles.

R.M. Clowes, during the summer of 1975, recorded a series of three reversed DSS profiles in Winona Basin, a deep water sedimentary basin west of the northern end of Vancouver Island. In addition to the usual expanding type of profile, 8 sub-critical incidence reflection profiles were recorded with the specific aim of determining velocity structure within the sedimentary sequence. For comparative purposes, three vertical incidence continuous seismic profiles using a 300 cu. in. air gun and a single channel streamer were recorded along the tracks of the three reversed DSS profiles.

(b) The Whole Earth

At the University of British Columbia, W. Moon and R.A. Wiggins (now at Western Geophysical Company, Houston) have been developing a variational formulation of free oscillation problems for the most general rotating, laterally heterogeneous, spheroidal earth

model. The algorithm developed has been successfully tested agains R.A. Wiggins' (1968, 1974) solution for the simple spherical, radially heterogeneous earth model. This algorithm has been extended to three dimensional spherical coordinates and the effect of rotation and crude lateral heterogeneity is added. At present, the application to a realistic sophisticated earth model is limited due to the size of computer memory and cost, and needs further development. This powerful method can be extended to study other geodynamic problems such as core oscillations and earth tide problems, if it is necessary.

J.C. Davies and T.J. Ulrych of U.B.C. are studying the splitting of the free oscillations of the earth. The data are also being analysed for possible undertone oscillations.

(c) Seismic Sources and Wave Propagation

P. Somerville has determined source parameters of two shallow earthquakes by the time-domain analysis of short-period teleseismic recordings. For each event, the effect of the receiver crust was deconvolved from a set of globally distributed recording using the homomorphic method. The resulting seismograms were compared with the form of the elastic wave radiation computed from Savage's model of radially spreading rupture on a plane elliptical fault surface.

This time-domain approach has permitted the determination of several kinematic parameters pertaining to the dynamics of rupture that are not ordinarily evaluated from spectral analysis. These parameters are rupture velocity, the direction of furthest rupture propagation, and the duration of a ramp dislocation time function which was prescribed to be the same everywhere on the fault surface.

In cooperation with R.A. Wiggins (now at Western Geophysical Company, Houston), a general linear inverse scheme has been applied to investigate how well and in what manner the parameters of the source model are determined by the observations. This analysis yields best fitting models, the range of acceptable parameter values, and the distribution of information concerning specific parameters that is contained in specific observations.

A consistent discrepancy between the observed and model seismograms during the first half-cycle of motion is attributed to the incorrect prescription of the dislocation time function. It is suggested that a space-dependent function determined theoretically by Kostrov in 1964 would tend to remove this discrepancy.

T.J. Ulrych and R.W. Clayton have further explored the duality of maximum entropy spectral analysis and autoregressive decomposition and have investigated the relationship of this spectral technique to mixed moving average autoregressive schemes.

University of British Columbia - II Physics of the Earth's Interior

At the University of British Columbia, K.D. Aldridge is continuing his work on core dynamics. Maintenance of the geodynamo requires some distribution of velocity in the earth's fluid outer core. If we model the outer core as a homogeneous fluid in which the temperature gradient exceeds the adiabatic gradient then a dynamo driven by convection is possible. However, if this temperature condition is not fulfilled then convection is impossible and the only possible radial motions are oscillatory. In this case we must examine the role of internal gravity waves and inertial waves in relation to the dynamo problem.

Aldridge has studied a limiting case of this problem in which the core is neutrally stratified and the effects of rotation alone are considered. Those oscillations of a rotating fluid which owe their existence to rotation are called inertial oscillations and are described by the Poincaré equation. Since this equation is hyperbolic and conditions at the inner core and outer core boundaries are specified, the problem is said to be ill-posed. It follows that there is no guarantee that inertial oscillations will exist in the outer core at least in the inviscid limit. Some laboratory experiments have shown conclusively that the axisymmetric class of inertial oscillations does exist in a spherical shell geometry and these experiments have been interpreted analytically with a certain variational principle.

It has been suggested that the observed westward drift of the non-dipole part of the geomagnetic field may be due to the propagation of hydromagnetic waves in the fluid outer core.

Recent work has shown that under certain conditions these hydromagnetic waves are also described by the Poincaré equation for the non-axially symmetric inertial oscillations of a rotating fluid. We are pursuing the study of these oscillations both experimentally and analytically in order to understand their role in the geodynamo problem.

6. Dalhousie University - I Seismology

M.J. Keen, K. Sullivan and B. Hall at the Department of Geology have worked with scientists at the Atlantic Geoscience Centre on problems concerned with the Newfoundland Basin. Among their contributions have been to set the analysis of wide angle reflection information and refraction information from (expendable) sonobuoys in order. They are using the "ray parameter" and "direct" methods for reflection data, and using this reflection information to deal more adequately with the refraction data. This should lead (1) to a detailed knowledge of the sediments of the Newfoundland Basin, and (2) to a knowledge of the upper part of the crust beneath the Basin.

Louis Blinn, working with Charlotte Keen of the Atlantic Geoscience Centre, has completed his M.Sc. thesis titled "Analysis of Surface Waves on the Reykjanes Ridge". His research involved obtaining Rayleigh and Love wave dispersion curves in the period range 8 to 30 sec from earthquakes propagating along the ridge crest and inverting these to obtain models of the shear velocity structure beneath the ridge. The results show a low velocity zone at about 40 km depth.

The work is significant because:

(1) it showed that analysis of surface waves down the length of a ridge is a useful tool: (not attempted before), and

(2) it confirmed the essence of Oldenburg and Parker's lithosphere models which were uncertain because of "constants" which had to be assumed.

Dalhousie University - II Physics of the Earth's Interior

R.D. Hyndman of Dalhousie University has related the bathymetry and crustal structure of the Labrador Sea to the activity of the Davis Strait volcanic hot spot to the north. There are deep marginal sedimentary basins in the Sea extending to the region of Davis Strait. In contrast the basement in the central part of the Sea shoals toward the Strait. The difference is explained by the central part of the Sea being formed while the Davis Strait hot spot was active, producing increased vulcanism and crustal thickness. The sea floor along the margins was produced before the hot spot became active about 60 m.y. ago, so has normal crustal thickness and thus normal basement depth, which with sediment loading can reach 10 km below sea level.

R.D. Hyndman of the Dalhousie University has completed 15 heat flow measurements in the inlets of southwestern British Columbia using the ocean probe technique, which have outlined a band of low heat flow parallel to the continental margin. The band extends from the coast 200 km inland to the heads of the major inlets. The heat flux is about half that further inland. From west to east, the heat flow transition is marked by a major magnetic anomaly, by the change from high to low gravity and to high recent regional uplift. The low heat flow band is over the region where the cold oceanic lithosphere slab being subducted under the margin acts as a heat sink. At greater depths the slab starts to melt producing upwelling and high heat flow further inland.

R.D. Hyndman of Dalhousie University with colleagues from other institutions has obtained heat flow measurements in a number of deep boreholes drilled into the sediments of the deep ocean floor by the Deep Sea Drilling Project. The results generally substantiate the values found by the standard ocean probe technique but the deep holes show a smaller scatter of values.

R.D. Hyndman of Dalhousie University with colleagues from other institutions has measured the physical properties of compressional and shear velocity, electrical resistivity, bulk and grain density, porosity and water content and thermal conductivity on a large collection of basalt samples and a few gabbros and serpentinized peridotites recovered by drilling on the mid-Atlantic ridge near 37°N. Samples were recovered to 582 m into basaltic basement in one hole, and rocks that may be representative of the lower crust were recovered from another hole.

The mean compressional velocity of the basalts of 5.94 km/s agrees well with previous fresh unweathered seafloor basalts. However, it can be reconciled with the much lower average upper crustal (layer 2) seismic refraction velocities generally observed, only by the presence of extensive large-scale fracturing and voids in the crust. The laboratory velocities of the gabbros are consistent with upper layer 3 (oceanic layer) refraction velocities. Lower layer 3 refraction velocities are consistent with a composition of a mix of gabbro and unserpentinized peridotite. Poisson's ratio for little weathered basalts is found to decrease systematically with decreasing velocity. The observed relation predicts a Poisson's ratio of 0.28 for a layer 2 refraction compressional velocity of 5.0 km/s and 0.24 for a layer 2a velocity of 2.8 km/s. Poisson's ratio from refraction measurements should distinguish between low-velocity fractured basalt and similar velocity sediments, since the latter should have much higher Poisson's ratios.

The mean electrical resistivity of the basalts is 220 ohm-m at 25°C. A close dependence of resistivity on porosity and a moderate increase in resistivity with pressure suggest conduction primarily through pore fluid. The basalt resistivity decreases rapidly with increasing temperature, the mean becoming about 20 ohm-m at 100°C and about 5 ohm-m at 150°C.

The mean basalt bulk density is 2.795 gm/cm^3, the mean porosity is 7.8% and the mean thermal conductivity is 3.97 mcal cm^{-1}s^{-1} °C^{-1}.

Malcolm Drury, working with R.D. Hyndman (now with the Earth Physics Branch, Victoria) has investigated problems concerned with the conductivity of igneous rocks obtained on various legs of the Deep Sea Drilling Project. He has so far conducted experiments on changes in conductivity with porosity, pressure and temperature. He concludes that, at low pressures and temperatures, conductivity is principally a function of the pore-water, but at higher pressures and temperatures, of semiconduction through clay-minerals and, possible, iron oxides.

7. McGill University - I Seismology

(a) Theoretical Studies

O.G. Jensen and S. Mercure at McGill have determined the effect of attenuation and dispersion on the complex cepstrum of the common homomorphic transformation (i.e. Z-transform, logarithm, inverse Z-transform). In the near ideal condition of low additive and convolutional seismic noise, the cepstrum of a seismogram can be deconvolved to obtain crustal layers Q's. O.G. Jensen and P. Klivokistis are now extending the technique to optimize the deconvolution of attenuation-dispersion information from noisy seismograms. Marine seismic exploration data from the Laurentian Fan region off Southern Newfoundland will be analysed using the optimum homomorphic deconvolution technique.

O.G. Jensen has obtained a method for solution of the induction of seismic motions in a layered crust by astrophysical gravitational wave sources. In recent years, geophysical techniques have been discounted or overlooked in the quest for detection of gravitational waves largely as a result of some low sensitivity estimates based upon simplistic homogeneous earth models. The new work has shown that resonance effects due to the interaction of seismic and gravitational waves with the crustal layering can enhance the seismic sensitivities by one to several orders of magnitude in the 1 Hz band. Furthermore, the analysis suggests that certain torsional free modes might be excitable by gravitational radiation and possess resonance qualities limited only by elastic attenuation. Seismic antennae are now found to be as sensitive as other gravitional wave antennae in current use and provide the additional feature of opening up a new frequency band.

(b) Experimental Studies

O.G. Jensen and V.A. Saull are preparing portable seismic equipment to monitor small earthquakes in the region of Montreal Island. As well, these portable seismographs will be used for detailed refraction surveys of the locale. Seismic sources will be provided by several quarries near Montreal.

8. Memorial University - I Physics of the Earth's Interior

(a) Geodynamics

D.J. Crossley at Memorial University of Newfoundland is continuing the work on the dynamics of a rotating compressible, stratfied liquid core. Extension of the general formulation to unstable (convecting) and mixed (stable and unstable regions) core models yields totally different spectra for the Coriolis coupled solutions compared to the stable core spectrum. Of course severe truncation of the coupled system of equations is still the dominant problem with the spheriodal-torsional Fourier expansion of the displacement field in a rotating system. In an attempt to understand the morphology of the eigenspectrum of real Earth models, the general method has been applied to the simple case of a uniform, incompressible rotating fluid shell for which the spectrum is the inertial wave regime. However the allowed zones in the spectrum of the full problem persist into this simplied situation and no correspondence with known inertial wave solutions has been found. It seems clear that in the difficult period range of 3 hrs. to > 12 hrs. a change in representation of the displacement field expansion is necessary. The nature of the transition is yet to be demonstrated theoretically. The predicted eigenspectrum for a rotating sphere is still uncertain but a result has been found which shows that for waves confined to any particular latitude the critical limiting period is half the local Foucault pendulum period.

(b) Heat Flow

At Memorial University of Newfoundland, J.A. Wright has begun a study of heat flow and heat production at localities in central and western Newfoundland. Preliminary heat flow results indicate that the heat flow in the central mobile belt is low, corresponding with the interpretation of the area as a plate margin. Work on correlating the heat production is beginning.

(c) Thermodynamics of the Liquid Core

J.M. Gilliland has calculated estimates of the Gruneisen parameter γ for a liquid Fe core, using the (quantum-statistical) electron theory of metals. This work is an advance on that of Irvine & Stacey, since the structure-independent part of the Helmholtz free energy is taken into account. Numerical calculations yield $\gamma \geq 1.5$ just below the core-mantle boundary, and $\gamma \geq 1.2$ in the lower half of the liquid core.

9. University of Saskatchewan - I Seismology

Z. Hajnal and I. Sereda continued crustal seismic reflection studies over the souther part of the Nelson Gravity Trend. Standard reflection data revealed several salt collapse structures, a basement high, and an intrusive body in the crystalline rocks in this area. The expanding spread data is under extensive data processing. An attempt is made to eliminate strong reflected refraction events by application of the deconvolution process. A novel approach is under design to extract velocity information from crustal reflection data.

In 1975, D. Gendzwill has continued studies of salt deposits in Saskatchewan. A report is in preparation for the Howe Lake Structure (Christiansen and Gendzwill) which is considered to be post glacial in age and caused gy ground water action related to a salt solution-collapse feature.

Additional seismic work supported by several potash companies has been successful in locating and detailing various geological features of significance so that mine planning can be improved.

University of Saskatchewan - II Physics of the Earth's Interior

M.S. King of the Department of Geological Sciences, University of Saskatchewan, Saskatoon, in collaboration with P.J. Kurfurst, of the Geological Survey of Canada, is studying the physical properties of a number of rock types at permafrost temperatures. Analyses are being made of several laboratory measurements on rock specimens subjected to triaxial loading conditions. These measurements include the velocities and attenuation of compressional and shear waves, the relationship between static and dynamic elastic properties and the electrical resistivity and

phase-angle relationships as a function of frequency.

M.S. King is studying a microseismic technique for predicting the failure of roofs and pillars in Saskatchewan potash mines. The occurrence of clay seams in the evaporites adjacent to the ore often presnets problems in strata control, causing local failure of the mine roof. The microseismic energy released by the rock prior to failure is monitored underground; the results to date indicate that this is a promising method for predicting such potentially dangerous rock falls and also the state of stress in mine pillars.

M.S. King is developing acoustic-wave techniques for use underground to locate and delineate geologic discontinuities adjacent to mine workings and to determine the stability of mine pillars. A controlled-pulse reflection system has been used successfully in a Saskatchewan potash mine, and a borehole acoustic-velocity logging system has been developed and successfully field-tested in hard and soft-rock mines.

10. University of Toronto - I Seismology

(a) Theoretical Studies

C.H. Chapman has extended the generalized ray method to vertically inhomogeneous medium. The Earth flattenging transformation and the plane-wave expansion have been investigated in more detail so that errors can be quantified, and it has been shown that the momogeneous layer approximation is unnecessary. Theoretical seismograms from inhomogeneous media are computed with a depth integral rather than a sum of many rays reflected from thin layers. As a result, it was shown that even as the layers become infinitesimal, the once-reflected signals do not converge to the geometrical amplitude. However, including multiply reflected signals, the series converges rapidly. Using this theory, a first-motion approximation has been obtained which reduces to geometriacal ray theory when the latter is valid, but remains useful at caustics and shadows. The same results can be obtained by three apparently unrelated methods and is applicable to other types of wave propagation. S.K. Dey-Sarkar and C.H. Chapman are developing this new approximation for any earth model and will then apply it to the inverse problem.

(b) Experimental Studies

The main program being carried out by G.F. West and R. Young for 1975 in the Superior Province Geotraverse was the recording of mine blasts along a recording array on Highway 599. The recording array straddled the Sturgeon Lake - Savant Lake Greenstone belts and crossed the English River Oneiss belt. Thirty-four recording sites were occupied. Blasts were recorded on the whole line from Reverse Mine in the Mesabi iron range, from Griffiths Mine near Red Lake, and from Mattabi and Falconbridge mines near Sturgeon Lake. Blasts from Steep Rock and Caland Mines near Atikokan were recorded along two thirds of the line. A total of about 220 individual seismograms have been obtained. Besides the main recording array, a fixed base station was operated at Sturgeon Lake for all blasts, and at the end of the program, timing from the mine sites to the base station was established. Strong secondary arrivals which apparently are critical reflections from the M and an intermediate discontinuity have been observed on many of the seismograms.

The use of mine blasts rather than our own explosions simplified the field program in many ways and seems to be yielding good seismograms. The field work takes much longer, however, because blasting is not very frequent. This year's program required three months of field work. The interpretation work will continue until about '77.

J. Wright and G.F. West have continued the interpretation study of field data obtained in the summers of '73 and '74. The study has included much construction of synthetic seismograms. The previously indicated two-layer crustal structure is strongly supported by the new studies, and details of velocity gradients in the lower and upper crust also are being derived. This work should be completed early in 1976.

M. Godlewski and G.F. West have obtained Rayleigh and Love wave dispersion curves for paths in N.W. Ontario for three earthquakes. These are currently being interpreted and seem to be consistent with a fairly standard continental shield velocity model for crust and upper mantle. This work will be completed in spring '75.

11. University of Western Ontario - I Seismology

(a) Theoretical Studies

F.K. Maxwell has studied the Scattering of Elastic Waves by a Cylindrical Cavity.

Attempts to detect and map underground cavities have not been very successful. The reasons for the lack of success lie in the complexity of the geological setting of caves and in the lack of knowledge of the interaction of elastic waves and cavities.

Many caves may be approximated mathematically by a cylinder of infinite length and zero density surrounded by an elastic medium. The amplitude of the elastic waves scattered from the cavity are expressed in terms of an infinite series involving Hankel functions. The amplitude of scattered compressional waves was computed around the perimeter of a circle concentric with a cavity which was 1.5 wavelengths in diameter.

A two-dimensional model was constructed by machining a hole in the centre of an aluminum alloy disc. Piezoelectric transducers were mounted around the perimeter to serve as sources and detectors of elastic waves. The signal from the detector was amplified and sampled by a boxcar detector. The output from the boxcar detector was recorded by an X-Y recorder and by a digitizing system which produced a magnetic tape recording. The digitized signal was Fourier analyzed to determine the amplitude of the scattered waves at the frequency of the incident wave.

The agreement between the computed scattering amplitudes and the measured scattering amplitudes is poor. This probably reflects slow changes in the nature of the transducer mountings over a period of several months. Although the precision of the measurement of the amplitudes is much greater than that attained with field equipment, the errors are still sufficiently large to obscure the scattering pattern in many cases. Scattering of seismic waves from cavities with a diameter of the same order of magnitude as the wavelength of the compressional waves will not provide diagnostic information with presently available field equipment.

R.F. Mereu has formulated a new deconvolution and wave shaping time-domain digital filter designed and capable of molding any given wavelet "exactly" into any desired waveform. This filter differs from other time-domain inverse filters in that (i) no equations are solved, (ii) no Z transform polynomials are divided, (iii) it can produce an error-free output with a "finite" number of weights. Its design is carried out entirely in the time-domain by a series of successive convolution operations which begin with the original digitized values of wavelet to be deconvolved. These operations have the effect of slipping sets of zeros in between the data points to produce a sequence of widely spaced spikes. The filter is then truncated and normalized, such that its output contains only one spike of unit amplitude. The final step of the wave-shaping design is carried out by convolving the spiking filter with the desired output. Minimum, maximum and mixed delay wavelets may be handled with equal ease. Since the input parameters needed to design this filter are identical to those needed to design the Weiner filter, and since the desired output can be of any shape, the filter has wide applications to problems involving signal contraction enhancement and prediction.

(b) Experimental Studies

The reflection data, which was studied by D.T.C. Yuen, were obtained from the Seis-Ex Company (Dolphin Project, Sombra Township, Lambton Country, S.W. Ontario, 1972). In an earlier analysis of this data, by the Digitech Limited, a 'reef-like' structure was seen on their time cross-section, but a test hole revealed no anomalous structures.

The aim of this thesis was to try to resolve this problem. The data was re-processed using several digital signal enhancement techniques. Some improvement of the signal to noise ratio was achieved by the application of one of, or a combination of the deconvolution and bandpass filters. The time-term method, employed to determine the thickness of the overburden, showed that the static corrections were constant. After normal moveout corrections were applied to the data, the six-fold stacking CDP method was employed to produce a time-cross-section, but this method was not a success in this study. On the other hand, velocity filtering proved to be a much more effective method for identifying reflectors. Seven events

were identified in this section. The interpretation of the subsurface geology showed agreement with the known structures, and confirmed the finding of the well-logs in that there was no evidence for a 'reef-like' structure.

The geodynamic processes associated with the motion of lithospheric plates depend very much on the nature and position of the upper mantle phase transition zones. We are making regional array studies to determine variations in the physical properties of the upper mantle structures. Over 350 earthquakes (distance 14^{o}-36^{o} and azimuth 0^{o}-360^{o}) recorded at the Gauribidanur array (GBA) were selected from the NOAA epicentre listings. These events were transcribed from the original analog tapes on to another tape at the array research centre, Blacknest, England during the summer of 1974. R.F. Mereu and A. Ram have also used over 100 events from the Aleutians and California regions recorded at the Yellowknife array (YKA). An analysis of the first 36 seconds of the P wavetrain, which was done using the adaptive processing techniques described in the last Annual Report, has revealed that there is considerable evidence for a larger low velocity, low Q layer along the oceanic paths as compared to the continental paths. The existence of both "400 Km" and 650 Km" discontinuities has been confirmed for almost all the regions studied with the exception of the Himalayan region (Azimuth 0^{o}-80^{o}) where a broad high velocity gradient zone replaces the "650 Km" discontinuity.

Our results when compared with those obtained from a similar study involving Warramunga array (WRA) data from Australia show significant differences in the positions of the travel time branches especially for the 20^{o}-25^{o} distance range. Further results involving slowness and azimuthal anomalies and residuals are now in the process of being analysed.

J.W. MacDonald has designed an experiment to determine the feasibility of performing attenuation studies in a waveguide. Two measures of attenuation are sought: the specific attenuation constant "Q" and the attenuation coefficient alpha. The value of Q has been found (by other authors) to be constant over a wide frequency range for any given material and this experiment was conceived to verify this fact for a noncohesive material such as dry silica sand.

A small transducer is used to set a long column of sand (of variable dimensions) into vibration over frequencies ranging from 60 to 550 Hertz, or until the signal is completely attenuated. The amplitude of the signal at any given distance and frequency is picked up by a piezoelectric detector which feeds into a Vrms amplifier/meter. Amplitude readings are normalized with respect to a near-source reference detector of the same type.

Three different waveguide constructions provided three values of Q ranging from a low of 1 to a high of 6. Q was found to be constant over the frequency range used. The value of Q obtained for the final waveguide, 1.0, is the most accurate since resonance effects in the containing waveguide, poor coupling and other errors due to column geometry were minimized in this trial. Results show that the experiment was successful and that further work is warranted.

(c) Instrumentation

R.F. Mereu has set up a three-station short-period seismic array near London, Ontario. The stations are approximately 20 to 35 Km apart and are located at (i) the base of Fanshawe Dam (ii) the Radio Science Centre Observatory site near Delaware, and (iii) the Astronomy Department Observatory site near Elginfield. Seismic signals from these stations are amplified at two levels and are multiplexed and telemetered directly via phone lines to the University where they are recorded both on a visual recorder and on a system of commercial audio tape recorders which is capable of recording 24 channels of multiplexed data over a 24 hour recording period. The primary purpose of the array is to study lateral inhomogeneities in the mantle from $dt/d\Delta$ measurements of teleseisms.

University of Western Ontario - II Physics of the Earth's Interior

(a) Geodynamics

P.Y. Shen and L. Mansinha have developed a general mathematical theory for the dynamics of the earth. Since the facts that the outer core is liquid and the earth is rotating have

been taken into account, the hydrodynamic equations for the outer core are correct to first order in the ellipticities of the surfaces of equal density. To separate the variables in the equations of motion, the method of spherical harmonic expansion has been used. The resultant ordinary linear differential equations showed coupling among spheroidal and toroidal fields; however, the nature of the coupling was such that for spheroidal deformation of a specific degree, it was sufficient to consider only the coupling effects from toroidal fields of neighboring degrees.

Using earth models with uniform polytropic cores, the theory was applied to free spheroidal oscillations of the earth of degree two as well as the earth tides. Two types of free core oscillations were found to exist for all three earth models used. The first type which we call the 'core modes', has spheroidal fields as the dominant components in the outer core and frequency spectra characteristic of the density stratification in the outer core. The second type, which we call the 'toroidal modes', has large toroidal fields in the outer core and consequently sizable spheroidal fields in the mantle due to the ellipticity of the core-mantle boundary. The frequency of a toroidal mode is insensitive to the density distribution in the outer core.

Due to the existence of free oscillations, the tidal response of the earth exhibits resonance patterns. Two important cases have been found. 1. Resonance of diurnal tides at a toroidal mode of period 23.88337 hours. This effect is observed astronomically through the nutations associated with diurnal tides. Good agreement between the observations and the present theoretical results demonstrate the dynamic effects of the liquid core. 2. Resonance of semi-diurnal tides at a core mode of period about 12 hours. The period of this core mode depends strongly on the density stratification in the outer core. Therefore, this resonance is important for the study of the core structure.

(b) High Pressure Studies

During 1974-75 the high pressure laboratory facilities for H.H. Schloessin and A.E. Beck have been substantially improved by the installation of 1000-ton capacity cubic press. The latter is of the inverted ram type, designed and constructed by H. Tracy Hall Incorporated. It allows measurements on samples of large volume, with dimensions of up to 3/4", embedded in 2 1/2" cubes of pyrophyllite. Auxiliary equipment provides a a.c. current control (up to 1000 amperes) for internal heating. Anvils are electrically insulated, and cooled by oil circulations. The equipment is suitable for studies of mechanical thermal, electrical and physiochemical properties.

Limited machine time can be made available to outside users wishing to include high pressure aspects in their research, by arrangement with Drs. A.E. Beck and H.H. Schloessin.

In contrast to previous high hydrostatic pressure investigations of the ferroelectric properties of triglycine sulphate and Rochelle salt crystals, the present experiments by G.W.J. Timco were performed using a solid media high pressure device. The use of a solid 'virtually clamps' the crystal under study, thereby setting boundary conditions similar to those found in the earth's interior. The results of the experiments show that ferroelectric hysteresis is possible in physically clamped crystals.

Although not an earth material, triglycine sulphate was chosen for study since single crystals can readily be grown and it exhibits the behaviour of a "typical" ferroelectric. The pressure was generated with a H.T. Hall cubic press and the ferroelectric hysteresis was displayed via the conventional Sawyer-Tower circuit. In general, the results agree well with those previously measured in fluid media devices and, in particular, are in accord with Devonshire's phenomenological theory of ferroelectricity. With increasing pressure, at constant temperature, the coercive field continually increases, whereas the spontaneous polarization increases at first, then decreases, thereby producing a broad maximum in the polarization-pressure curve at ~15 - 16 kbar. The hysteresis loop exhibits anomalous behaviour above ~20 kb and disappears altogether at 25 - 30 kb, depending upon the applied electrical potential. This disappearance, although it could represent a transition to the para-electric phase, is interpreted in terms of a clamped-suppression phenomenon and long switching times. The Curie temperature shows less of a pressure dependence than that previously reported, exhibiting a relative maximum at ~15 kb and 65^{o}C.

The experiments on Rochelle salt indicate that the stress generated with a solid high pressure transmitting medium is not sufficiently hydrostatic to enable the observation of the ferroelectric hysteresis in these crystals, due to their extreme anistropic stress sensitivity.

Using the new 1000-ton cubic press the detectability of transitions has been tested by N.S. Brar and H.H. Schloessin for 2 1/2" and 1 1/4" sample cells. Subsequent studies were carried out in the quartz, coesite and the calcite I/II/III aragonite transitions. The latter were extended to other carbonates having the calcite structure, such as magnesite and siderite. The temperature dependence of the transition pressures was determined by in-situ electrical resistivity measurements as well as before and after X-ray diffraction analysis. Line broadenings observed in the untransformed fractions of calcite and magnesite have been of particular interest as an indication of dislocation and stacking fault formation in the course of mostly sluggish structure transitions.

With the completion by D.M. Darbha and H.H. Schloessin of several series of steady state lattice thermal conductivity measurements on samples of α-quartz cut parallel to basal, first order prism and rhombohedral planes, its anisotropic conductivity coefficients have been determined. From these a cross section through the conductivity surface has been constructed and its deformation with pressure and temperature has been analysed. To assess the conductivity range of materials of olivine composition, comparative measurements were made of olivine single crystals, as well as on polycrystalline olivines and dunites of different origins.

Studies were undertaken by H.H. Schloessin and Z. Dvorak as part of the physical properties determinations of Joides Leg 37, Deep Drill samples. The dependence upon pressure up to ~60 Kb and temperature up to ~1800°C has been determined with the 1000-ton cubic press. The dependence on temperature up to ~500°C and relative vapour pressure of H_2O has been measured in a high vacuum system designed for B.E.T. type measurements. Changes from room temperature to ~500°C affect changes in the electrical conductivity by 6-7 orders of magnitude. A conductivity variation with the same range of 6-7 orders of magnitude can be achieved by passing from high vacuum (~10^{-7} torr) to saturation vapour pressure of H_2O at room temperature. In comparison the change in conductivity with pressure is small, amounting to ~1/2 order of magnitude for a change of 50Kb at room temperature and increasing to ~1 1/2 order of magnitude at temperatures >700°C. The pressure and temperature coefficients for the lattice thermal conductivity of dry basalts have been determined for pressures ranging from 19 to 56Kb. Using electrical resistivity and Pt/Pt 10% Rh thermocouples as indicators, the onsets of melting on heating and solidification on cooling have been observed at different pressures between 38 and 60 Kb. The interval between liquidus and solidus temperatures is of the order of 250K; it broadens with increasing pressure.

Following completion of ferroelectric hysteresis loop observations on clamped triglycine sulphate single crystals subjected to high pressures in solid media, some exploratory examinations have been made by G.W. Timco and H.H. Schloessin of the dielectric properties of some ferroelectric ceramics under pressure. These ceramics resemble potentially ferroelectric earth materials (a) in exhibiting ferroelectric properties in the form of polycrystalline and multi-component compacts and (b) in varying dielectric properties corresponding to changes in grain size, residual microstresses, and externally applied stress. Dielectric peak broadening and changes in transition temperature have been observed for PZT-4 and PZT-5 transducer materials between 30 and 60 Kb. The feasibility of high resolution dielectric constant determinations in multi-anvil high pressure devices (cubic press) by means of a General Radio 1620-AP capacitance measuring assembly is presently under investigation.

(c) Heat Flow

Measurements of thermal conductivity and heat production by C.C. Chang and A.E. Beck of the samples is continuing on a part time basis. Although measurements will not be complete for some time, a qualitative correlation between heat flow and heat production variations in the borehole has appeared; as with the earlier work in the UWO borehole the variations are not quantitatively self consistent.

Previous work (Mustonen, 1967) suggested that the terrestrial heat flow varied significantly in a small area of 5 km^2, and found no explanation for the variation. Work by

T.J. Lewis was undertaken to define the variation in the heat flow and to explain it. The heat flow was measured in over seventy boreholes drilled for mineral exploration in a pile of old volcanic flows. The variation in the measured heat flow was much larger than possible errors in measurement. It was possible to divide the study area into two simple areas in which the average heat flows were .69 μcal cm^{-2} s^{-1} (29 mWm^{-2}) and .80 μcal cm^{-2} s^{-1} (33 mWm^{-2}). It was shown that variations in heat production and thermal conductivity are unlikely to cause the observed differences in heat flow. Extrapolated surface temperatures from deep temperature measurements in boreholes do not change as the heat flow varies, indicating that differing surface temperatures have not caused the variation in heat flow. But small amounts of water flowing down fissures for long periods of time could have removed significant heat, reducing the heat flow in the rock above. This process can explain all the observations, and it is shown that flow contacts do have water flowing along them. Consequently the terrestrial heat flow representing this area is .85 μcal cm^{-2} s^{-1} (35.6 mWm^{-2}) ±7%, the maximum observed value; a correction for changes in the past surface temperature increases this value to .93 μcal cm^{-2} s^{-1} (39. mWm^{-2}).

This study emphasizes the value of multiborehole heat flow determinations and the relation of observations to the local geology. Sampling boreholes at fixed intervals for conductivity determinations may be a poor procedure in regions of complex geology. The determination of past changes in air temperatures by fitting models to observed temperatures in single boreholes is shown to be of questionable value.

Temperature measurements were completed by A.E. Beck in two boreholes to a depth of 1 Km and work has commenced on the conductivity measurements. From the early results it has been found that contrary to what was reported last year, the heat flow in the area may be quite normal. Extraordinarily high temperature gradients, up to 140°C/Km, were observed in some sections of the boreholes which led to the original estimate of a high heat flow. However, it is found that these gradients are associated with coal bearing formations which have very low thermal conductivity. Because of the very wide range of temperature gradients encountered in the Roma boreholes an attempt is being made to develop a new logging tool. The basic assumption is that the heat flow along a borehole will not vary by more than about 20% and that variations in temperature gradient can therefore be regarded as variations in thermal resistivity. Already it has been demonstrated that the thermal resistivity logs can be used to interpret ambiguous electrical resistivity logs - to such an extent that one horizon picked from an electrical log was found to be mispicked by 90 meters.

Since the usefulness of using thermal resistivity logs would be much enhanced if the temperature gradient could be recorded continuously an attempt by J.G. Conaway and A.E. Beck is being made to develop an instrument which will do this job. The basic principles are to continuously log temperature in a borehole lowering the probe at a constant rate, to regard the time constant of the thermistor probe as a filter function, to use this filter function to deconvolve the results to give temperatures that are accurate to a few thousandths of a degree centigrade and then convert this information directly to a plot of temperature gradient vs. depth.

The investigation into the effects of different forms of surface contacts which might be encountered in divided bar measurements, and reported last year, has been extended by A.E. Beck to cover other common errors. Out of this work an experimental correction curve has been developed which can be applied to the Maxwell model for computing thermal conductivities so that the Maxwell model can now be extended to much larger porosity values and thermal conductivity ratios than was possible before.

12. Canadian Seismological Mission to China

A Canadian seismological delegation visited the People's Republic of China between October 17th and November 11th, 1975. The visit was the result of an exchange program in which Chinese seismologists visited Canada last year. The return visit was at the invitation of the Academia Sinica and the State Seismological Bureau. Members of the Canadian delegation were Dr. K. Whitham (leader), M.J. Berry and W.G. Milne from the Earth Physics Branch, Department of Energy Mines and Resources and Professor A. Heidebrecht, McMaster University and Professor E.R. Kanasewich, University of Alberta. Over 6,000 miles of travel were made within China by plane, train and automobile. Major visits were made at Peking, Harbin, Sian, Shenyang (Mukden), Anshan, Yingk'ou, Kunming and Kuangchou (Canton). Short stops were also made at Yanku, Chengtu and

Nanking. A visit to the Feb. 4, 1975 earthquake at Haich'eng which had been predicted and in which people were evacuated prior to the earthquake were highlights of the visit.

13. Research and Technical Personnel, Earth Physics Branch, Department of Energy, Mines and Resources (Division of Seismology and Geothermal Studies)

RESEARCH MANAGER

M.J. Berry

RESEARCH SCIENTISTS

Anglin, F.M.
Basham, P.W.
Buchbinder, G.G.R.
Hasegawa, H.S.
*Hyndman, R.D.
Jessop, A.M.
Judge, A.S.
Kollar, F.
Leblanc, G.
Lewis, T.J.
Mair, J.A.
Milne, W.G.
Stevens, A.E.
Weichert, D.H.
Wetmiller, R.J.
Wickens, A.J.
Wright, C.

PHYSICAL SCIENTISTS

Bone, M.N.
*Collier, J.
*Culumovic, L.
Forsyth, D.A.
Halliday, R.J.
Hayman, R.B.
Horner, R.B.
Lyons, J.A.
McMechan, G.A.
Rogers, G.C.
Shannon, W.E.
Taylor, A.E.

TECHNICAL OFFICERS

†Aikin, S.
Allen, V.S.
Bennetts, H.J.
*Burns, P.
*Carter, J.W.
†Cedarstrand, C.
Compton, B.A.
†Dyke, H.D.
†Edwards, J.
†Emmerson, D.R.
Grogan, R.T.
Guérin, M.J.
Lombardo, F.
*Mahaney, L.
Reynolds, J.C.
Schieman, D.J.
Styles, V.M.
Thomas, J.T.
Tyrlik, W.
Vesa, A.

SEISMOGRAPH STATION OPERATORS

Alexander, J.R. (MBC)
Browne, T.S. (FSJ)
†Brulotte, L. (YKC)
Daniels, M. (ALE)
Jensen, O.J. (BLC)
Marsh, L. (FFC)
Monsees, D.J. (YKC)
†Racine, J.B. (SFA)
Stilborn, J.R. (RES)
Wilde, M.H.J. (PNT)

POSTDOCTORATE FELLOWS

Keith, C.
Purushothamaraj, P.

EXCHANGE SCIENTIST

Henger, M. (Germany)

EXCHANGE STUDENT

Bergeron, R.

EXCHANGE TECHNICAL OFFICERS

Leyu, Chong Hua (Malaysia)
Abutiate, V. (Ghana)

SUMMER STUDENTS

Arseneault, R.
Cardinal, P.
Grant, M.
Konowalchuk, T.
Matthews, L.

*joined staff in 1975
†left staff in 1975

University of Alberta - Personnel Involved in Seismology Oriented Program (also Physics of the Earth's Interior)

Department of Physics

FACULTY

G.L. Cumming
D.I. Gough
F. Hron
F.W. Jones
E.R. Kanasewich
E. Nyland

POSTDOCTORATE FELLOW

M. Hron

GRADUATE STUDENTS

Y. Claude Athias
D.C.Y. Au
Alan C. Bates
Garth Churney
P.F. Daley
Jens Havskov
Joseph S.K. Lee
Larry W. Marks
C.U. Park
Tim J. Spanos
Ken F. Sprenke
Ed J. Roebroek
Robert J. Withers

ENGINEER

M.J. Burke

STATION OPERATOR

C.M. McGavin

COMPUTING ASSISTANT

C.H. McCloughan

ELECTRONIC TECHNICIANS

E. Madson

L.G. Ramsdell

RESEARCH ASSISTANTS (PART TIME)

W.I. Gough
D. Sample
L. Lewis

SUMMER STUDENTS

R. Adler
D. Spanos
Mrs. E. Hiob
E. Hiob

University of British Columbia - (Incomplete listing of personnel in Seismology and Physics of the Earth's Interior)

GRADUATE STUDENTS

G. Spence
D.A. Sketchley
L.R. Lines
T.N. Bishop

FACULTY

R.M. Clowes
R.M. Ellis
T.J. Ulrych

RESEARCH ASSOCIATES

H. Dragert
K.D. Aldridge

Dalhousie University - Seismology and Physics of the Earth's Interior

Personnel

GEOLOGY AND OCEANOGRAPHY DEPARTMENT

M.J. Keen
J.M. Hall
F. Aumento
D.B. Clarke
P.H. Reynolds
G.K. Meucks
C. Beaumont

GRADUATE STUDENTS

O.Y. Abdel-Aal
K. Appleton
M. Drury
B. Hall
P. Newman
R. Parrott
D. Plause

C. Pride
V. Stukas
K. Sullivan

TECHNICIANS

J. Clark
G. Johnson
R. Iuliucci
T. Milligan

University of Saskatchewan

RESEARCH ASSOCIATE

D. Epp

GRADUATE STUDENT

I. Sereda

FACULTY

D.J. Gendzwill
Z. Hajnal
M.S. King

SUMMER STUDENTS

J. Maul
E. Stacey

University of Toronto

(Incomplete list)

FACULTY

C.H. Chapman
G. West
G.D. Garland

University of Western Ontario

GRADUATE STUDENTS

J.A. Grant
D.J. Hearty
F.K. Maxwell
G.W. Timco
T.C. Yuen

J.A. McCance
N.S. Brar
J.G. Conaway
D.M. Darbha
A. Ram
P.Y. Shen
C.C. Chang

S.C. Majumdar
T.J. Lewis

FACULTY

L. Mansinha
R.F. Mereu

H.H. Schloessin	P.Y. Shen	B. Price
A.E. Beck		
	TECHNICIANS	ELECTRONIC TECHNICIANS
POSTDOCTORATE FELLOWS		
	W. Dias	J. Brunet
Z. Dvorak	D. Lacina (part-time)	G. West

14. Bibliography: Seismology and Physics of the Earth's Interior

1. Ade-Hall, J.M., Aumento, F., Hyndman, R.D., Melson, W.G., Bougault, H., Dmitrev, L., Fischer, J., Robinson, P.T., Wright, T.L., Miles, G.A., Flower, M.T., and Howe, R.C. Sources of magnetic anomalies on the Mid-Atlantic Ridge. Nature, 255, 389-390, 1975.

2. Aldridge, K.D. Inertial waves and the Earth's outer core. Geophys. J. 42, 337-345, 1975.

3. Aldridge, K.D. Conservation of angular momentum in a rotating fluid. Physics Teacher 12, 493-494, 1974.

4. Aldridge, K.D. and Jacobs, J.A. Mortality curves for normal and reversed polarity intervals of the earth's magnetic field. J. Geophys. Res. 79, 4944-4947, 1974.

5. Beck, A.E. An improved method of computing the thermal conductivity of fluid filled sedimentary rocks. Geophysics, 41, 133-144, 1976.

6. Bennett, G.T., Clowes, R.M. and Ellis, R.M. A seismic refraction survey along the southern Rocky Mountain Trench, Canada. Bull. Seism. Soc. Amer. 65, No. 1, 37-54, 1975.

7. Berry, M.J. and Forsyth, D.A. Structure of the Canadian Cordillera from seismic refraction and other data. Can. J. Earth Sci., 12, 182-208, 1975.

8. Bhattacharyya, P.J., Hyndman, R.D. and Keen, M.J. The Mid-Atlantic Ridge near 45°N. XXIII. Analysis of bathymetric and magnetic data. Can. J. Earth Sci., 12, 337-346, 1975.

9. Chapman, C.H. Generalized ray theory for an inhomogeneous medium. Geophys. J.R. Astr. Soc. 36, 673-704, 1974.

10. Chapman, C.H. The turning point of elastodynamic waves. Geophys. J.R. Astr. Soc., 39, 613-621, 1975.

11. Crossley, D.J. and Smylie, D.E. Electromagnetic and viscous damping of core oscillations. Geophys. J.R. Astr. Soc., 42, 1011-1033, 1975.

12. Crossley, D.J. The free-oscillation equations at the centre of the earth. Geophys. J.R. Astr. Soc., 41, 153-163, 1975.

13. Crossley, D.J. and Gubbins, D. Static deformation of the earth's liquid core. Geophys. Res. Letters, 2 (1), 1-4, 1975.

14. Crossley, D.J. Core undertones with rotation. Geophys. J.R. Astr. Soc, 42, 477-488, 1975.

15. Cumming, G.L. and Chandra, N.N. Further studies of reflections from the deep crust in southern Alberta. Can. J. Earth Sci. 12, 539-557, 1975.

16. Davies, L.M. and Chapman, C.H. Some numerical experiments on the inverse of discrete travel-time data. Bull. Seism. Soc. Amer., 65, 531-539, 1975.

17. Davies, L.M. and Chapman, C.H. Inversion of discrete travel-time data. Bull. Seism. Soc. Amer.

18. Erickson, A.J., Von Herzen, R.P., Sclater, J.G., Girdler, R.W., Marshall, B.V. and Hyndman, R.D. Geothermal measurements in deep-sea drill holes. J. Geophys. Res., 80, 2515-2528, 1975.

19. Ganley, D.C. and Cumming, G.L. A seismic reflection model of the crust near Edmonton, Alberta. Can. J. Earth Sci. 11, 101-109, 1974.

20. Gutowski, P.R. and Kanasewich, E.R. Velocity spectral evidence of upper mantle discontinuities. Geophys. J. 36, 21-32, 1974.

21. Hajnal, Z., Stauffer, M.R. The application of seismic reflection techniques for subsurface mapping in the Precambrian Shield near Flin Flon, Manitoba. Can. Jour. of Earth Sci. vol. 12, No. 12, 1975.

22. Halliday, R.J., Shannon, W.E., Lombardo, F. and Compton, B. Seismological bulletin, January-December 1973. Seism. Ser. Earth Phys. Br., No. 68, 197 p., 1974.

23. Hamza, V.M. and Beck, A.E. Analysis of heat flow data - vertical variations of heat flow and heat producing elements in sediment. Can. J. Earth Sci. 12, 996-1005, 1975.

24. Hasegawa, H.S. Seismic ground motion and residual deformation near a vertical fault. Can. J. Earth Sci., 12, 523-538, 1975.

25. Hashizume, M. Surface wave study of earthquakes near northwestern Hudson Bay, Canada. J. Geophys. Res., 79, 5458-5468, 1974.

26. Horner, R.B., Milne, W.G. and McMechan, G.A. Canadian earthquakes - 1970. Seism. Ser. Earth Phys. Br., No. 69, 43 p., 1975.

27. Hron, F., Kanasewich, E.R. and Alpaslan, T. Partial ray expansion required to suitably approximate the exact wave solution. Geophys. J. 36, 607-625, 1974.

28. Hron, F. Computation of kinematic characteristics of seismic waves for homogeneous layers separated by curvilinear boundaries. Geophys. J.

29. Hron, M. and Chapman, C.H. Seismograms from Epstein transition zones. Geophys. J.R. Astr. Soc. 37, 305-322, 1974.

30. Hron, M. and Chapman, C.H. The "Shadow" from a velocity reversal. Bull. Seism. Soc. Amer., 64, 25-32, 1974.

31. Hyndman, R.D. Marginal basins of the Labrador Sea and the Davis Strait hot spot. Can. J. Earth Sci., 12, 1041-1045, 1975.

32. Hyndman, R.D. Heat flow measurements in the inlets of southwestern British Columbia. J. Geophys. Res., 81, 337-349, 1976.

33. Hyndman, R.D., Aumento, F., Melson, W.G., Hall, J.M., Bougault, H., Dmitriev, L., Fisher, J., Flower, M., Howe, R.C., Miles, G.A., Robinson, P.T. and Wright, T.L. Seismic structure of the oceanic crust from deep drilling on the Mid-Atlantic ridge. Geophys. Res. Lett., 3, 201-204, 1976.

34. Jacobs, J.A. and Aldridge, K.D. The Earth's interior and the Earth's rotation. In Growth Rhythms and the History of the Earth's Rotation, Wiley, 337-351, 1975.

35. Jessop, A.M. Geothermal energy. Geos., 2-4, Spring 1975.

36. Jessop, A.M. Energy R & D Program statement. Task V: Exploit renewable energy resources, Program 4: Geothermal energy. Geothermal Ser. Earth Phys. Br., No. 4, 1975.

37. Jessop, A.M. and Judge, A.S. Temperature and heat flux measurements through permafrost as a geophysical tool. In: Symposium on Permafrost Geophysics, NRC Technical Memorandum 113 (Ed. Collett and Brown), 17-27, 1974.

38. Judge, A.S. The occurrence of offshore permafrost in northern Canada. In: The coast and shelf of the Beaufort Sea (Ed. Reed and Sater), Arctic Inst. of N.A., 427-437, 1974.

39. Judge, A.S. Geothermal studies in the Mackenzie Valley by the Earth Physics Branch. Geothermal Ser. Earth Phys. Br., No. 2, 1975.

40. Kanasewich, E.R., Ellis, R.M., Chapman, C.H. and Gutowski, P.R. Reply to Comments on 'Seismic array evidence of a core boundary source for the Hawaiian volcanic chain' by C. Wright. J. Geophys. Res. 80, 1920-1922, 1975.

41. Kanasewich, E.R., Siewert, W.P., Burke, M.D., McCloughan, C.H. and Ramsdell, L. Gain ranging analog or digital seismic system. Bull. Seism. Soc. Amer. 64, 103-113, 1974.

42. Kanasewich, E.R., Hron, F. and Alpaslan, T. Teleseismic response of a multi-layered dipping media using asymptotic ray theory. Can. J. Earth Sci. 11, 1661-1668, 1974.

43. Kanasewich, E.R. Time sequence analysis in geophysics, 2nd Edition, Univ. of Alberta Press, p. 364, 1975.

44. Kanasewich, E.R. and Gutowski, P.R. Detailed seismic analysis of a lateral mantle inhomogeneity. Earth Planet. Sci. Letters 25, 379-384, 1975.

45. Kanasewich, E.R. Plate tectonics and planetary convection. Can. J. Earth Sci. 13, 331-340, 1976.

46. King, M.S., Bamford, T.S. and Kurfurst, P.J. Ultrasonic velocity measurements on frozen rocks and soils. Proceedings of a Symposium on Permafrost Geophysics, Assoc. Committee on Geotechnical Research, Tech. Memo No. 113, Nov. 1974.

47. King, M.S. and McConnell, B.V. Fracture evaluation by acoustic logging in dry boreholes. Proc. 15th Symposium on Rock Mechanics, in press, 1975.

48. King, M.S., Probran, V.S. and McConnell, B.V. Acoustic borehole logging system. Proc. 9th Canadian Rock Mechanics Symposium, p. 21-51, 1974.

49. MacAuley, H.A., Hunter, J.A. and Judge, A.S. Mapping of sub-seabottom permafrost in Mackenzie Bay, N.W.T. G.S.C. Report of Activities 75-1B, 1975.

50. McMechan, G.A. and Workman, W.G. P-wave amplitudes and magnitudes between 10^{o} and 35^{o}. Bull. Seism. Soc. Am., 64, 1887-1899, 1974.

51. McMechan, G.A. Amplitude constraints and the inversion of Canadian Shield Early Rise explosion data. Bull. Seism. Soc. Am., 65, 1419-1433, 1975.

52. McMechan, G.A. Mantle structure and short period body wave spectra at intermediate epicentral distances. Geophys. J., 44, 269-274, 1976.

53. Mereu, R.R. (with Hunter, J.) Computer model studies of seismic reflection coefficients for the base of the permafrost layer. Geol. Surv. Can., Paper 74-1, 1974.

54. Mereu, R.F. A study of the effect of Q in the observation of upper mantle travel-time branches using adaptive processing techniques. Exploitation of Seismograph Networks, edited by K.G. Beauchamp, NATO Advanced Study Institute Series E: Applied Sciences - No. 11, Noordhoff-Leiden 471-488, 1975.

55. Mereu, R.F. and Ram, A. A computer program package for the analysis of array data using adaptive processing methods. Exploitation of Seismograph Networks edited by K.G. Beauchamp, NATO Advanced Study Institute Series E: Applied Sciences - No. 11, Noordhoff-Leiden 327-339, 1975.

56. Nyland, E. and Roebroek, E.J. P-wave residuals in western Canada. Can. J. Earth Sci. 12, 174-181, 1975.

57. Nyland, E. and Roebroek, E.J. Bounds on the P velocity for the whole moon. Nature 253, 179-180, 1975.

58. Nyland, E. Body force calculations for subsidence of the Po Valley. Pure Appl. Geophys.

59. Nyland, E. and Withers, R.J. A fast method for computing load induced stress in the earth. Geophys. J., 44, 689-698, 1976.

60. Rao, R.U.M. and Jessop, A.M. A comparison of the thermal characteristics of shields. Can. J. Earth Sci. 12, 347-360, 1975.

61. Rogers, G.C. and Bennetts, H.J. A simple monitoring device for strong motion seismographs. Bull. Seism. Soc. Am., 65, 1502-1503, 1975.

62. Schloessin, H.H. Corrugations on the core boundary interfaces due to constitutional supercooling and effects on motion in a predominantly stratified liquid core. Phys. of the Earth and Planet. Interiors, 9, 147-156, 1974.

63. Schloessin, H.H. and Dvorak, Z. Physical properties of samples from the JOIDES, Leg 37. DSDP Initial Report, in press.

64. Shannon, W.E., Lombardo, F., Compton, B. and Halliday, R.J. Canadian seismograph operations - 1974. Seism. Ser. Earth Phys. Br., No. 70, 71 p., 1975.

65. Simpson, D.W., Mereu, R.F. and King, D.W. An array study of a p wave velocities in the upper mantle transition zone beneath Northeastern Austrailia. Bull. Seism. Soc. Am., 64, 1757-1788, 1974.

66. Stevens, A.E., Milne, W.G., Horner, R.B., Wetmiller, R.J., Leblanc, G. and McMechan, G.A. Canadian earthquakes - 1968. Seism. Ser. Earth Phys. Br., No. 71, 39 p., 1976.

67. Taylor, A.E. and Judge, A.S. Geothermal data collection - Northern wells 1974. Geothermal Ser. Earth Phys. Br., No. 3, 1975.

68. Timco, G.W. and Schloessin, H.H. Ferroelectric studies in solid media high pressure devices. High Temperatures - High Pressures, v. 6, in press 1974.

69. Ulrych, T.J. and Bishop, T.N. Maximum entropy spectral analysis and autoregressive decomposition. Revs. Geophys. Space Phys. 13, No. 1, 183-200, 1975.

70. Waddington, E.D. and Chapman, C.H. Numerical seismograms for wave trapping structures near the core boundary. Can. Jour. Earth Sci., 11, 598-602, 1974.

71. Weichert, D.H. Reduced false alarm rates in seismic array detection by non-linear beamforming. Geophy. Res. Lett., 2, 121-123, 1975.

72. Weichert, D.H., Basham, P.W. and Anglin, F.M. Explosion identification and monitoring. Proc. of the NATO A.S.I. Series, Series E: Applied Sciences, No. 11, 383-395, 1975.

73. Weichert, D.H. The role of medium aperture arrays: the Yellowknife system. Proc. of the NATO A.S.I. Series, Series E: Applied Sciences, No. 11, 167-195, 1975.

74. Wetmiller, R.J. The Quebec-Maine border earthquake, 15 June 1973. Can. J. Earth Sci., 12, 1917-1928, 1975.

75. Wetmiller, R.J. Canadian earthquakes - 1973. Seism. Ser. Earth Phys. Br., No. 72, 51 p., 1976.

76. Whitham, K. The estimation of seismic risk in Canada. Geoscience Can., 2, 133-140, 1975.

77. Whitham, K. and Hasegawa, H.S. The estimate of seismic risk in Canada. Pub. Earth Phys. Br., 45, No. 2, 1975.

78. Wright, C. Comments on 'Seismic array evidence of a core boundary source for the Hawaiian linear volcanic chain' by E.R. Kanasewich et al. J. Geophys. Res., 80, 1915-1919, 1975.

79. Wright, C. Lateral variations in the upper mantle beneath the Yellowknife array and near the core-mantle boundary from observations of various P phases. Proc. of the NATO Advanced Study Institutes Series: Series E: Applied Sciences, No. 11, 513-525, 1975.

80. Wright, C. The origin of short-period precursors to PKP. Bull. Seism. Soc. Am., 65, 765-786, 1975.

81. Wright, C. and Lyons, J.A. Seismology, $dT/d\Delta$ and deep mantle convection. Geophys. J., 40, 115-138, 1975.

III HYDROLOGY

Compiled by: Dr. I.C. Brown
Environment Canada

1975, like 1974 continued to be a year of change in hydrology due to organizational changes and tighter budgets which further emphasized the need for practical applications on an operational basis rather than research. Despite these limitations the total activity in hydrology has increased to such an extent that a listing in this publication of all hydrological projects being undertaken in Canada is no longer possible and these would have to be obtained through various published bibliographies or through data systems.

The newly formed National Research Council Associate Committee on Hydrology commenced activities and has set up two sub-groups, the Sub-Committee on Glaciers and a Working Group on the Hydraulics of Ice-Covered Rivers.

A major activity of the Associate Committee on Hydrology was the holding of the Canadian Hydrology Symposium: 75 in Winnipeg August 11-14. This meeting reviewed the progress in Hydrology in Canada during the International Hydrological Decade Period. Broader developments in Canada during the period were reported in 36 invited papers while the remaining 37 papers reported in more detail on individual IHD projects. In summing up the Chairman pointed out that about 25% of the time at this meeting was spent on Surface Water Hydrology whereas 10 years before it would have been 75%. Water Quality and the Effect of Man's Activities on the Hydrological Cycle showed promise of becoming central focuses of hydrology. During this period also a common language had appeared for the hydrological community in Canada and this was emphasized during the meeting by the presence of most participants at all sessions rather than just when their speciality was being discussed. Modelling has become a widely used tool but still leaves the problem of measuring the parameters required as input to the models and this has resulted in considerable attention being paid to improving our ability to measure. This is particularly noticeable in the attention being paid to measurements in the Arctic and related to environmental aspects of hydrology. Among the many improved methods for data collection and data handling possibly the one that has advanced most rapidly has been the use of remote sensing not only to get information in remote areas but to extend point information to areal coverage.

In the field of remote sensing attention was concentrated on measurement of percentage area covered by snow and on methods of converting this to depth of snow or water equivalent of snow. A workshop on Remote Sensing of Snow Cover was held at CCRS, Ottawa January 13-15 and provided detailed information on current methodology and technology in this field which indicated that remote sensing of snow cover is one of the most advanced practical applications of remote sensing to hydrology and is being used more and more on an operational basis. WMO demonstration projects of remote sensing of hydrometeorological elements for water management are well underway in the drainage basins of the Columbia River, Saint John River, Lake of the Woods and Souris River. At present they are looking at percent area covered by snow but related studies are trying to expand this to identify depth of snow or water equivalent. The most promising method seems to be a combination of ground measurements with airborne gamma attenuation techniques and satellite imagery. Studies were also started during the year to apply remote sensing to the measurement of soil moisture and groundwater.

Cold climate hydrology continues to receive considerable attention in Canada particularly in connection with developments related to pipelines and highways in the North. An International Symposium on the Thermal Regime of Glaciers, sponsored by the Sub-Committee on Glaciers and ICSI was held at Simon Fraser University April 8-10. A cooperative effort in the study of northern research basins was commenced by workshop at Edefors, Sweden, which proposed continuing cooperation in such studies.

An International Symposium on the Geochemistry of Natural Waters sponsored by the International Association of Geochemistry and Cosmochemistry, IAHS and Canada Centre of Inland Waters was held at Burlington, Ontario August 18-20.

Canadian Hydrologists have been active during the year in IAHS projects many of which are cooperative with Unesco's IHP and WHO's OHP program and with other UN agency programs related to water.

IV (A) GEOMAGNETISM

Compiled by D.I. Gough

1. Geomagnetic Surveys
2. Interpretation of Magnetic Surveys
3. Magnetic Charts and Compilations
4. Magnetic Observations and Instruments
5. Magnetic Disturbances and Pulsations
6. Electromagnetic Induction in the Earth
7. Paleomagnetism, Rock Magnetism and Tectonomagnetism
8. Core Dynamics
9. Magnetosphere Studies

1. Geomagnetic Surveys

(a) Atlantic Geoscience Centre, Bedford Institute of Oceanography

A magnetic survey of an area 120 by 120 nm was completed in the Newfoundland Basin in an attempt to determine early plate motions between the Bay of Biscay-Iberian peninsula area and the Grand Banks of Newfoundland. The survey included seismic reflection and expendable sonobuoy refraction measurements as well as magnetic measurements in order to correlate basement topography with the magnetic anomalies and to obtain depths to basement. The survey demonstrates that the anomalies are lineated approximately north-south and preliminary anomaly identification indicates that they belong to the Keithley sequence of magnetic anomalies - 135 to 110 mybp.

During a multidisciplinary cruise to the Labrador Sea a substantial amount of magnetic data was collected in the Labrador Sea and off the southwest margin of Greenland. Bathymetry, gravity and magnetic data were collected along tracks spaced 40 km apart in the northern Labrador Sea as part of the regional geophysical coverage of the area started last year (see Geophys. Bull. Vol. 27) by M/V MINNA.

M/V MARTIN KARLSEN was on charter to the Canadian Hydrographic Service (replacing M/V MINNA) in continuation of the multiparameter survey of the Labrador Sea. Bathymetry, gravity and magnetic data were collected along 24,000 km of track south of the area covered by MINNA in 1974. This work, together with that carried out by CSS HUDSON in the northern Labrador Sea, completed broad regional coverage of the entire Labrador Sea at a line spacing of 40 km and began interlining on the continental margin of Labrador. CSS HUDSON also completed a survey of the area northeast of Newfoundland and inshore of the MINNA 1973 survey (Macnab, 1974). Bathymetry, gravity and magnetic data were collected along over 8,000 km of track, with a linespacing of 8 km. The data collected on all these cruises have been submitted to contractors for preparation of Natural Resource maps of Bouguer and free air gravity anomaly, magnetic anomaly and total magnetic field, for the area south of 52°N and west of 48°W. Maps from data collected in 1973 for the area south of 50°N have been submitted to the Canadian Hydrographic Service for final drafting. These maps should be published in the spring of 1976.

(b) Earth Physics Branch

As part of a continuing study of magnetic secular variation, 25 repeat stations were occupied in British Columbia, Alberta, Saskatchewan and the Northwest Territories. In addition to these, two new stations were established at Masset, B.C., and Tyrell Lake, N.W.T.

In order to provide a longer perspective on secular variation in Canada, three magnetic stations of historical significance were recovered as closely as possible, at Fort Vermilion, Alberta (established by Lefroy in 1844), at Fort Resolution, N.W.T. (Franklin in 1825 and Lefroy in 1844) and at Fort Confidence, N.W.T. (Richardson in 1848).

Portable variometers providing a digital record of declination, the horizontal component and the vertical component were operated for several days at each station, to reduce uncer-

tainties caused by diurnal variation and magnetic disturbances. Absolute measurements of magnetic declination, inclination and total intensity provided baseline control.

2. Interpretation of Magnetic Surveys

(a) Atlantic Geoscience Centre

Magnetic data collected in the Labrador Sea have been compiled to decipher the geometry and time of opening of the Labrador Sea. Several fracture zones have been delineated from the combined analysis of gravity, magnetic and seismic data in this region. The magnetic data in the central and south Labrador Sea show definite lineations and the magnetic anomalies can be correlated with computed anomalies based on Heirtzler et al, (1968) time scale. Based on the trends of the fracture zones and on the identification of magnetic anomalies a two-phase opening history of the Labrador Sea has been suggested. During the first phase, most likely in the late Cretaceous (72-62 m.y.) about two thirds of the Labrador sea was formed and anomalies 31 to 25 were formed during this time. A second phase of seafloor spreading in the Labrador Sea occurred between 60-38 m.y. with the formation of a triple junction southwest of Greenland. There was simultaneous spreading in the Labrador Sea, in the newly formed Reykjanes ridge, and along the extinct ridge in the Norwegian Sea. The spreading in the Labrador Sea stopped at about 38 m.y.

The results of the magnetic and seismic survey (See Geophy. Bull. Vol. 27), in the quiet magnetic zone off eastern Canada show: (a) that two reversals occur within the quiet zone and that modelling of the magnetic anomalies indicates that the crust beneath the quiet zone was formed by seafloor spreading; (b) that the intensity of magnetization of the basalts ranges from 0.004 to 0.005 amu cm^{-3}, comparable with values observed in oceanic basalts except near the ridges. The exception is the material within the reversed zones where intensity values are near zero. The low intensity is attributed to viscous remanent magnetization or to contamination of these narrow zones by widespread intrusives during periods of predominantly normal magnetic fields.

The Keithley sequence of magnetic anomalies has also been mapped and continued northward to near the southwestern margin of the Grand Banks. Using Mesozoic time scales for rocks on land, the anomalies within the quiet zone and to the east of it have been dated and spreading rates computed. Comparisons have been made with the seafloor spreading history south of the New England Seamounts.

The HUDSON cruise northeast of Newfoundland concentrated on the preparation of a geological map of the area. This was achieved through the combined use of seismic reflection and magnetic field data. Seismic reflection data provided continuity in the mapping of sedimentary rocks of presumed Carboniferous age. However, the Ordovician-Silurian rocks of Brulington Pensinula and Norte Dame Bay are seismically opaque, although there are large magnetic anomalies associated with some units. The continuation of these anomalies across areas where seismic penetration was obtained indicated extension of the older units in the subsurface. The Cape St. John volcanics appear to continue in a fault-bounded ridge trending northeast from Cape St. John, and thence in a northerly trend along 55°W. The rocks of the Fleur de Lys supergroup lie in a continuous belt west of the Cape St. John volcanics, and in the north lie immediately offshore of the Hare Bay allochthon.

(b) Earth Physics Branch

Examination of airborne three-component magnetometer data obtained during surveys in 1969, 1970, 1972 has continued. A compilation of the data from these surveys was described in Geophysical Bulletin No. 26. Subsequent efforts have included attempts to define more clearly the very long wavelength components which may be related to large scale lithospheric structures. Upward continuation and polynomial surface fitting techniques have been applied. Residuals relative to the IGRF are dominated by features of wavelengths of about 4,000 to 5,000 km and amplitudes of about 400γ; these are primarily non-lithospheric in origin. Residuals relative to field models of maximum degree 13 or 14, maximum wavelengths about 3,000 km, show a long wavelength field which correlates with known major tectonic provinces and in part with the patterns of shorter wavelength residuals.

The extensive coverage over Canada and environs prompted the use of the above data as a test comparison with satellite magnetometer data obtained for lithospheric studies. A continuing joint study with personnel of Goddard Space Flight Center, NASA, shows generally good correlations between the satellite data and the long wavelength components in the airborne data over Canada and Scandinavia. Refinements on both the reduction of the satellite data and on the identification of the broad-scale features in the airborne data are proceeding.

In a joint study with personnel of G.S.C. Vancouver, correlations have been made between vertical component residuals, rock magnetic properties, and geology in the southern Coast Plutonic Complex and part of Vancouver Island, B.C. Although a 200 km long, intense, magnetic anomaly correlates with high magnetizations found at the surface, the evidence indicates that there is a deeper more highly magnetic unit, which may have little or no visible expression at the surface. The intense positive anomaly is in a region of anomalously low heat flow.

An iterative method for magnetic anomaly interpretation has been developed. Multiple right rectangular prisms are used in a non-linear least-squares technique to model the anomaly data. Any parameter of each prism may be allowed to change or remain fixed at the discretion of the interpreter, and links between corresponding parameters in different prisms may be specified.

(c) Université Laval

M.K. Séguin a entrepris une analyse spectrale des données aéromagnétiques de la région de la Gaspésie et du Golfe Saint-Laurent dans la province de Québec. Cette étude entreprise en collaboration avec J.N. Sénéchal (thèse de mâitrise) indique que l'analyse spectrale bidimensionnelle est aussi précise et souvent plus utile que l'analyse spectrale 3D en ce qu'elle permet d'obtenir en plus grand nombre de points déterminant la profondeur du socle, et par la même occasion, un meilleur estimé de l'épaisseur de la couverture sédimentaire.

M.K. Séguin a terminé l'étude des cartes aéromagnetiques du secteur sud des Appalaches du Québec. L'interprétation, effectuée dans le domaine spatial au lieu du domaine des nombres d'onde utilisé dans le secteur nord des Appalaches du Québec, a été entreprise en collaboration avec un groupe d'une trentaine d'étudiants sous-gradués de Génie Géologique, de Génie Physique et de Géologie. Cette analyse détaillée qui comprend au-delà de 100 profils magnétiques a permis de déterminer les dimensions (longueur, largeur, épaisseur, extension vers le bas), l'attitude (direction et pendage) ainsi que les propriétés magnétiques (moment et susceptibilité magnétique) des diverses masses causitives.

3. Magnetic Charts and Compilations

(a) Earth Physics Branch

Magnetic charts of Canada for epoch 1975.0, showing declination, inclination, horizontal, vertical and total intensity and their annual change, were published on a Lambert conformal projection at a scale of 1:10,000,000.

The 1975 charts are based on a mathematical model derived from a least-squares fit to approximately 54,000 component-observations made between 1955 and 1974. The model is in the form of polynomial functions of latitude, longitude and time. The map area (31 million square kilometers) was divided into equal quadrants, with 10 percent areal overlaps. Each quadrant was fitted with polynomials for X, Y cos θ and Z, where X is the north component, Y the east component, Z the vertical component and θ the latitude. The terms in latitude and longitude extended to the sixth degree, but the terms in time extended only to the third degree. Consistency of the X and Y models according to Maxwell's curl equation was ensured by analysing X and Y cos θ together. The r.m.s. fit to over 99 percent of the data was 188nT.

A magnetic chart of the Canadian Arctic for 1975.0 was prepared for the Canadian Hydrographic Service (Map No. 10200). It outlines, in general, the area where the ordinary magnetic compass is erratic, and the area where it is useless. Lines of equal magnetic declination and its mean daily range are shown. The scale is 1:7,500,000.

A comparative study of several spherical harmonic field models and annual mean data from magnetic ovservatories in Canada and nearby regions emphasizes that an adequate description of secular change is of paramount importance in the usefulness of a field model for the reduction of magnetic surveys over large areas and separated in time by several years. Although the problems in North America are not as great as those in some other regions, errors up to about 50 nT per year are found in some areas, with eastern Canada having even greater errors. Field models of maximum degrees 13 and 14, derived from POGO satellite data (1965-1970) were found to have the smallest errors (up to 10 nT per year) for the interval which included several large-scale three-component airborne surveys (1969, 1970, 1972), at observatories in or near the survey areas. However, as expected, the errors produced by the use of these models increase rapidly after this time. The revised IGRF2 (provisional coefficients derived using the formula adopted by the IAGA 1975 resolution) shows a marked improvement over the original IGRF in its description of the secular change at most observatories studied, except in eastern Canada, where the description is sometimes worse (for example, in the total force secular change at Ottawa).

4. Magnetic Observations and Instruments

(a) Atlantic Geoscience Centre

Temporal variations of the earth's magnetic field were monitored at Bedford Institute of Oceanography, Dartmouth (May-July 1975). Data collected during this period are reduced and available to users.

Magnetic variations were also monitored in Newfoundland Basin for two weeks by housing a battery operated proton precession magnetometer in moored surface buoy and letting the sensor pre float on the sea surface. The recordings from this experiment together with those from St. John's Observatory will be used in applying correction to the marine magnetic data collected in Newfoundland Basin.

During the survey northeast of Newfoundland, trials were conducted with a Geometrics marine gradiometer. The gradiometer uses two 1/8 nT sensitivity magnetometers that have an extremely "clear" signal. The two sensors are separated by 170 m and were towed 210 m behind the ship. No problems with the electronics were encountered. The manufacturer-supplied junction between the streamer and the shipboard installation was a source of problems, but when bypassed, good results were obtained. The towing cable was provided with a polystyrene jacket to provide flotation to keep the two sensors at the same level in the water. The flotation jacket appeared to work well although the resulting 5 cm diameter cable was difficult to handle.

The ship effect provided a roughly constant bias to the measured gradient that had to be eliminated by data processing. When this correction had been made the gradient was integrated to provide a total magnetic field profile supposedly independent of diurnal variations. Preliminary analysis indicated the difference between the "diurnal free" profile and the profile as recorded by one of the gradiometer sensors gave a residual profile which was more related to the variations in the total field than to the diurnal variations as recorded on land. It seems that a second order effect is involved, and work to discover its cause and eliminate it is continuing.

(b) Earth Physics Branch

Eleven magnetic observatories operated throughout the year, at Mould Bay, Resolute Bay, Cambridge Bay and Baker Lake in the Arctic; at Yellowknife, Churchill and Great Whale River in the auroral zone; and at Victoria, Meanook, Ottawa and St. John's in southern Canada. A new magnetic observatory at White Shell, Manitoba, 100 miles east of Winnipeg, began operation in August 1975, but in November was still producing data of unsatisfactory reliability. In a new arrangement, designed to reduce costs, the magnetic sensors are housed in small insulated shelters instead of the usual non-magnetic building.

At all of the above stations except Mould Bay, an Automatic Magnetic Observatory System (AMOS) records three components of the magnetic field plus total intensity once per minute in digital form on magnetic tape. The tapes are sent to Ottawa at the end of the month for editing by computer. Daily checks are made of the operation of the AMOS installations by

telephone from Ottawa by means of the Telephone Verification System. Standard photographic magnetograms are produced by all observatories except Cambridge Bay, Yellowknife, St. John's and White Shell. For these four stations, magnetograms in standard format are constructed by plotting the edited one-minute digital values.

Microfilm copies of magnetograms for all observatories are sent monthly to World Data Center A in Boulder, Colorado, with edited versions of the digital magnetic tapes.

In addition to the standard magnetic observatories eight magnetic variation stations (without absolute control) were operated during 1975 on a line from White Shell through Churchill to Alert on Ellesmere Island. Digital data loggers will be installed at these stations in 1976 in preparation for the International Magnetospheric Study (IMS).

(c) University of British Columbia

H. Ueda has designed and constructed a 3-component induction magnetometer, using inexpensive IC operational amplifiers. A gain of about 88 db has been attained. Coupled with a high-μ metal core coil sensor designed by T. Watanabe, the system sensitivity is about 3 volt p-p/γ/sec. It is high enough to detect pulsation signals at mid-latitudes and, of course, at auroral latitudes. According to the test at Thompson, Man., the system is stable also: thermal drift which is of a time scale of several hours or more is less than ±0.1 volt versus a full voltage swing of about 10 volt. The frequency response is flat from dc to about 1.7 Hz. The roll-off above this is due to a high-cut filter to reject 60 Hz. man-made noise.

Ueda (1975) has examined performance of a few high-μ metal core coils in comparison with an air-core coil. No signal distortion has been detected, as expected from the non-linear behavior and hysteresis of the high-μ core material. Ueda and Watanabe interpreted the results, based on the theory of demagnetizing factor. For core materials of a very high value of permeability, the sensitivity of the coil becomes independent of the permeability but is determined by the geometry of the core. If it is cylinder-shaped, the sensitivity is approximately proportional to the square of the length of the core but is much less dependent on its diameter. These have been checked experimentally.

Ueda and Watanabe (1975 a) have also considered several problems about sensitivity and frequency response of induction magnetometers and have worked out a theory about their calibration. They (1975 b) have also completed the use as a sensor of an induction magnetometer.

5. Magnetic Distrubances and Pulsations

(a) Defence Research Establishment Pacific

Micropulsation activity levels, sampled from 1969 to 1974 near Medicine Hat, Alberta between about 0.05 and 1 Hz. in a single (x) component, can be made available on 9-track 800 BPI magnetic tape. The data consists of a measure, recorded each minute, of the activity level in each of eight pass bands in the interval. The relative independence of activity near 1 Hz. compared to that near 0.05 Hz. has been well defined in the data. At the same time, there is a clear correlation overall between the daily AFR index and the corresponding maximum activity levels even though the received frequencies are decidedly different.

Detailed information on the data records is contained in DREP Technical Memorandum 74-1, available on request. Sampled outputs from a few of the analysis programs are included in the report.

Currently, micropulsations are being recorded at Resolute Bay, Cornwallis Island. Signals received by a broad-band metal-core coil detector in the X-axis are fed to a slow-speed analog magnetic tape which will be digitized for analysis at a later time.

(b) Earth Physics Branch

(i) *Bays and Pulsations*

J.C. Gupta studied the relationship of geomagnetic bays and pulsations, using the

normal-run magnetograms from Fort Churchill. He found four main classes of bays at Churchill: (1) sleeping bays - those with little activity of any kind associated with them, (2) loaded bays - those with several substorms superimposed, (3) pulsating bays - those which exhibit pulsations throughout their duration, and (4) transition bays - those which change from positive to negative, or vice versa, during their couse. Frequently, combinations of two of the above classes are found; they are called twin bays. Characteristics of each class of bays were investigated in detail and compared for the maximum sunspot year 1970 (R = 102.4) and the minimum sunspot year 1964 (R = 10.2).

In addition, Pc5 pulsation substorms for both 1970 and 1964 were studied. It was noticed that in a number of cases pulsation substorms followed a bay (generally a negative bay) if the latter was preceded by a precursor.

A comprehensive model of the magnetosphere has been developed which seems to explain in large part of the generation and the characteristics of the bays and pulsation substorms. A cross-spectrum analysis of the Pc5 and H-component hourly values indicated that the amplitude of Pc5 pulsations is affected considerably by variations in the conductivity of the ionosphere.

(ii) *Solar and Lunar Variations*

In cooperation with S.R.C. Malin, J.C. Gupta computed the ionospheric current system for the eight most quiet days of the IGY/C, using the methods of spherical harmonic analysis. Special emphasis was given to the longitutdinal variation of the Sq-current system.

A technique is being developed to compute solar and lunar variations from the one-minute digital values now available from magnetic ovservatories instead of hourly mean values. It is expected that the new technique will permit the derivation of these variations from time series of much shorter duration than were necessary in the past.

The Chapman-Miller method, which essentially computes solar and lunar harmonic coefficients, has been developed further to give the effect on solar and lunar variations of such geophysical variables as sunspot number, lunar distance, magnetic activity and seasonal effects.

(iii) *Auroral Currents*

Optical, particle, electric and magnetic field measurements obtained across several arcs at 03UT on February 28, 1974 are used to calculate electrojet and Birkeland currents. The near simultaneous observations were made during a coordinated experiment which involved ground, rocket (VB-39) and satellite (ISIS II) measurements. An ionosphere model consisting of 5 arcs, which were seen only by the rocketborne plasma probes (Dr. A.G. McNamara) and the auroral scanner (I.W.H. Robertson), together with the vector electric field measurements (Dr. B.A. Whalen), was used to calculate the currents. Magnetic field calculations along the trajectory for this current system compared favourably in structure and range ($\sim$1500 nT) with the unreduced spin probe measurements (Dr. J.A. Koehler). Careful analysis of the magnetic data from the Churchill line of stations (max. perturbation of 70 nT) could not resolve the multiple electrojets determined by the above methods, but the integrated values of the electrojet current determined by the two methods were the same. Intense Brikeland currents ($\sim 1 \times 10^{-4} \mu$ A/m^2), which undoubtedly exceeded the current-carrying capacity of the ambient plasma above 2000 km ($\sim 2 \times 10^{-6}$ μA/m^2), coincided with the arcs. Plasma instabilities probably occurred in these regions and accelerated the particles which caused the arcs.

(c) University of British Columbia

Research has focused on magnetic pulsations. Preparation for an IMS project of observing magnetic pulsations at many stations in Western Canada has been in progress. An induction magnetometer, inexpensive and yet excellent in performance, has been successfully designed. A preliminary field work to test the magnetometer has been carried out at Thompson, Manitoba. A survey of man-made magnetic noise has also been made there and at four other candidate sites. On the theoretical side, we have been investigating relations between magnetic pulsations

and several other magnetospheric and interplanetary phenomena such as auroral displays, VLF radio emissions and solar wind magnetic field fluctuations. Elucidation of such relationships will be useful to pin down mechanism of pulsations.

(i) *Pre-IMS research*

Our IMS programme to perform many station observation of pulsations in Western Canada is a cooperative project with a research team headed by Dr. T. Oguti, Geophysics Research Laboratory of the University of Tokyo and Dr. R.E. Horita, Department of Physics of the University of Victoria. Six researchers from these three groups have carried out pre-IMS field research at Thompson and Star Lake, both in Manitoba. The induction magnetometers of both U. of Voctoria and U.B.C. were tested and found satisfactory. Dr. Oguti and his associates from U. of Tokyo tested at Thompson their TV camera system for auroral observations, and also a VLF radio receiver which has facilities of determining direction of an incident radio wave. Both systems worked well. The only difficulty we encountered at Thompson was due to man-made EM noise. It was so high, preventing us from doing our observation near the town. Especially noise affected the VLF receiving system. We had to set up a temporary station more than ten miles away from the town, supplying power by ourselves with a generator. Frequency of the power generated was found too variable to secure a stable imaging of aurorae. A regulator is necessary for the future operations.

We also carried out a survey of noise level at three other locations in Manitoba: Fort Churchill, Gillam and Norway House. Every location was found to be quiet enough. We thus came to a conclusion that simultaneous observation is feasible at the five stations in Manitoba, providing that the problem about the power supply is soluble - we expect this will be solved without much difficulty.

(ii) *Post midnight continuous pulsations and on-off switching aurorae*

Watanabe, who stayed five months for his study leave at the Geophysics Research Laboratory of the University of Tokyo, worked with Oguti, analyzing pulsation data and the data of concurrent auroral activities both obtained at the Syowa Station, Antarctica, in 1971. Post midnight continuous pulsations with a quasi period of 10 $\sim$ 30 sec. were found to be concurrent with so-called pulsating aurorae. It was found that a pulsating aurora propagates poleward with a speed of 10 $\sim$ 30 km/sec. while changing its luminosity. One poleward propagating aurora was found to correspond to one magnetic pulse. It has thus become clear that the magnetic pulsation is in fact a series of magnetic pulses. Each pulse has a characteristic polarization. It is best defined on the D-Z plane. As an aurora approaches the Syowa Station from lower latitudes, the magnetic field deflects downward and westward. A westward ionospheric current system and its local enhancement moving poleward, due to the increased ionospheric conductivity by impinging auroral particles, seem to give rise to the observed magnetic polarization.

(iii) *Daytime Pc 2-4 pulsations and solar wind magnetic field fluctuations*

G. Nourry made spectral analyses of magnetic pulsations near Calgary, Alberta and of concurrent magnetic field fluctuations in solar wind observed by the satellites IMP D and F. The pulsations recorded at the ground station are generally of the Pc2-4 types, most common "daytime" pulsations. The data were picked up from an interval from August to November 1967. Spectral analyses were made in a period range approximately from 5 sec. to 150 sec. The magnetic signals either on the ground or in space were found to consist of many spectral peaks. The peaks of wave events in space and on earth correspond almost one-to-one with each other. In both spectra there is a sharp decrease in power for frequencies greater than approximately 0.05 Hz. This last feature is more conspicuous for ground spectra.

(iv) *ELF emissions and Pi 2 pulsations*

The Alouette 2 satellite discovered a new type of ELF emissions which has a diffuse spectrum covering a frequency range from 50 Hz. the lower cutoff frequency of the receiver, to above the local proton gyrofrequency. Location of this new type emission has been investigated in relations to concurrent Pi 2 magnetic pulsations. A region of

occurrence often spans a latitudinal range of several degrees and usually has a sharp boundary at the lower-latitude end. The position of the lower-latitude termination falls in a range of invariant latitudes from 50° to 70° on the night side of the Earth, and on the day side, from 70° to 80°. The positions of the lower-latitude terminations change systematically with the dominant period of the concurrent Pi 2 pulsation, but not with Kp. Dependence of the positions with the Pi 2 period seems to indicate that most ELF emissions take place in the vicinity of the inner boundary of the plasma sheet.

6. Electromagnetic Induction in the Earth

(a) Earth Physics Branch

(i) *Magnetometer Array Studies*

North American Central Plains Conductivity Anomaly

Alabi, Camfield and Gough (1975) have published the short-period (1/4 to 2 h) results of the array operated jointly by the University of Alberta and the Earth Physics Branch in 1972. They postulate that the crustal conductor traces a major continental fracture zone from the exposed Precambrian in the Southern Rockies in Wyoming, northward beneath the Paleozoic sediments to skirt the eastern edge of the Black Hills in South Dakota, and further northward in the basement to the exposed Precambrian of the Churchill Province in Saskatchewan.

Digitizing is in progress for an analysis of the daily variation to compare this array with the 1969 project (Camfield and Gough, 1975) which gave the unusual result of an anomaly in Z but not in Y at stations near the conductor.

Saguenay - Laurentide Array, Quebec

In the context of Branch investigations in this region of fast downward crustal movement and enhanced seismicity, and in support of a permanent magnetotelluric station near La Malbaie, a magnetometer array was planted in the triangular area defined by Trois-Rivières, Tadoussac and Lac St. Jean. Twenty-three Gough-Reitzel instruments, made available to us through the generosity of Prof. D.I. Gough at the University of Alberta, recorded variation fields in July and August 1975. A preliminary scan of the films reveals no major anomalies, i.e. no Z reversals. Data from the array are being edited.

(ii) *Geomagnetic Variation Studies over Banks Island, the Continental Margin of the Arctic Ocean and other Northern Regions*

Banks Island

Between March 28 and April 25, 1974 the three components of the earth's geomagnetic field variations were recorded simultaneously at nine locations on two perpendicular profiles in the western Canadian Archipelago. One profile, consisting of four stations extended from southwest Banks Island to Mould Bay. The second extended from the northern centre of Banks Island to approximately 270 km over the continental margin on the polar ice. Polar Continental Shelf Project provided logistics and transportation in this area.

The in-phase induction arrows in general point to the west and indicate current concentrations in or beneath the Arctic Ocean. The deeper the water (up to 3 km) the more the induction arrows are attenuated, however there is no reversal. Preliminary results from the AIDJEX ice station 600 km offshore show a similar behavior. The induction arrows show a strong coast effect but show no evidence of the continental break which begins approximately 150 km offshore under 500 m of water. The large suppression in Z at periods less than one hour is observed at ocean stations and at the inland station on Banks Island and is characteristic of the Mould Bay anomaly. The coastal stations do not show the Z suppression but this is accounted for by the coast effect. Two-dimensional model studies indicate a highly conductive crust and upper mantle under the continental margin and under western Banks Island.

The profile will be extended into Victoria Island early in 1976 to locate the boundary of the anomaly and to determine the inductive response of the Precambrian Minto Arch.

Northern Yukon Territory

Fluxgate magnetometers 40 km apart were operated in a line along 69°N geomagnetic latitude, extending 320 km from northwest Yukon Territory across the Richardson Mountains to the central Mackenzie Valley. The array operated for 18 days in July 1975, recording three components of the magnetic variations on digital magnetic tape at a sampling interval of 20 seconds. A preliminary examination of data from three of the stations has given no clear evidence of an induction anomaly.

Ellef Ringnes Island

A strong anomaly of the Mould Bay type, characterized by a pronounced suppression of vertical-component variations with periods of 5 to 30 minutes, has been found at Isachsen, on Ellef Ringnes Island, N.W.T. There is no indication of a similar effect at King Christian Island, 110 km to the south, or at Meighen Island, 160 km to the northeast. Two-dimensional models are currently being examined in an attempt to explain the rather sparse observational data.

Eastern Ontario

Five fluxgate magnetometers were operated for 25 days spaced 140 km apart on a line from the central Haliburton Highlands (near Minden, Ontario) to Kingston. Three components were recorded digitally, once per minute. The line crosses a possible suture zone in the Grenville Province. The data have not been examined at this writing.

(iii) *Geomagnetic and Magnetotelluric Observations Northeast of Quebec City*

Digital recordings were made of variations of geomagnetic and telluric fields at four stations northeast of Quebec City in October 1974. The data were analysed by making use of the transfer function and the impedance tensor methods. Conductive channelling of electric currents induced elsewhere by the northward magnetic field and lateral variations in conductivity of the earth were evident from observations of the telluric fields. Also, electric currents induced by the vertical magnetic field exist and their flow pattern is similar to that of currents which are induced by the horizontal magnetic field. However their effect on the impedance tensor elements appears to be small.

Transfer functions were influenced by several factors including the conducting St. Lawrence River, lateral variations in crustal conductivity and the conduction of electric currents. Anomalous vertical magnetic fields due to electric currents induced by the vertical field seem to be observed, although their amplitude is small. These studies indicate a probable three-dimensional structure which has a high conductivity for the crust in the Precambrian Shield and is to the west of a boundary striking NNE-SSW in the eastern section of the Laurentides Park.

In this area, close to the auroral electrojet zone, transfer functions do not always represent induction anomalies because of high coherence between the vertical and horizontal components of the inducing field. However stable transfer functions relative to those at designated reference station were obtained by taking differences between transfer functions at the reference and temporary stations. It was also found that stable transfer functions could be obtained if daytime variations only were analysed since this eliminates the large influence of the auroral electrojet.

(iv) *Changes in Magnetic and Telluric Fields in a Seismically Active Region near La Malbaie, P.Q.*

A project for detecting electrical resistivity changes in crustal rocks by measuring variations of the magnetic and telluric fields with periods longer than one minute has been in operation since October, 1974 in a seismically active region near La Malbaie. Changes in amplitude and direction of up to 20% and 3° in the telluric fields have been

observed for variations having periods ranging from 5 to 120 min. A change with a duration of approximately one year seems to be a predominant feature. Superposed on it, a more rapid change with a duration of a few months was observed in late spring and early summer. This change showed a history similar to a premonitory change as expected from a model of dilatancy with fluid diffusion but no earthquake greater than magnitude 3 has taken place in the survey area. The change is perhaps related to conductivity changes in the salt water of the St. Lawrence River caused by spring run-off or temperature changes. However the magnetotelluric method provides a useful means of detecting changes in electrical resistivity in the upper crust. It should be noted that no significant changes in the magnetic field results were observed. A reference station 67 km to the west, far from the St. Lawrence River, was established in October 1975. This will determine whether observed changes in amplitude and direction of telluric fields are caused by the change in resistivity of the St. Lawrence River.

(b) University of Alberta

The electrical conductivity distribution in the solid Earth continues to be studied by the magnetotelluric method, by means of two-dimensional arrays of magnetometers and through numerical model calculations.

(i) *Magnetometer Array Studies*

Western North America

The three array studies of 1967-1969, whose results are in the literature, show an approximately northsouth-aligned conductive ridge in the upper mantle beneath the Wasatch fault zone, with its north end at the Yellowstone volcanic centre; and another north-south thickening of the conductive upper mantle under the Southern Rockies and Rio Grande Rift. A highly-conductive layer 100 km or more in thickness underlies the region south of 43°N and west of the Rockies and both seismological and electromagnetic evidence indicate that a thick layer of partial melting exists there. In a recent paper Camfield and Gough showed that the region west of the Rockies, in Washington and British Columbia, differs from the prairie region of eastern Montana and southern Saskatchewan, mainly in the presence of a conductive layer 10-15 km thick in the upper mantle. The boundary between the "thick-conductor" and "thin-conductor" regions runs east-west near $43^{\circ} \pm 1^{\circ}$N. Dr. Gough is working on the interpretation of these structures in terms of recent plate tectonics. South of 43°N there has been much greater recent heating, possibly associated with override of the mantle region which underlay the East Pacific Rise in Tertiary time. The thin conductive region north of 43°N may be characteristic of the continuing subduction between $40\ 1/2^{\circ}$N and 50°N. Further array study in Oregon, Idaho, Washington and southern British Columbia is clearly desirable and is under consideration.

Substorm fields array study

Observations were made in 1974 by J.R. Bannister and D.I. Gough with an array of 30 three-component magnetometers in northern Alberta and the Northwest Territories. Six events which involved currents crossing the array, and so giving clear reversals of the vertical field, have been selected from the very large bulk of data, and are being digitized and edited through our automatic reader system. Fourier transform coefficients have been mapped for one event and show no large conductivity anomalies in the solid Earth under the array. This means that a one-dimensional layered structure can probably be assumed. It probably also means that good separations of the fields due to internal and external currents will be achieved. Modelling of the magnetosphere-ionosphere currents, and of a conductivity-depth profile in the Shield region, will follow.

The Fourier maps, at period 1 hour, show an east-west current and some indication of a Birkeland-type field-aligned current at one end. Fourier maps provide only one approach to the problem, which involves distinguishing between time- and longitude-dependence of the fields, and maps of instantaneous fields in the time domain will also be tried.

Southern Africa

Papers dealing with two magnetometer arrays, operated in Southern Africa in 1971, are in the literature. Mr. J.H. de Beer has been in the Institute through 1975, on secondment from the South African National Physical Research Laboratory. With Drs. Gough and van Zijl he has advanced an interpretation of an electrical conductivity anomaly, which joins the middle Zambezi valley to the Okavango Delta in Botswana and then strikes westward across South West Africa, as marking an extension of the Luangwa Rift (Nature, 225, 678, 1975). The enhanced conductivity could be associated with high mantle temperatures or with a fracture zone in the lithosphere. High seismicity correlates with the high conductivity. Mr. de Beer is working on the modelling of normal (non-anomalous) time-varying fields in terms of one-dimensional conductivity structure, and is relating such South African array deep-sounding results to direct-current resistivity deep soundings made in the region by the NPRL.

Dr. D.W. Oldenburg is working with Mr. de Beer on the application of Backus-Gilbert inverse theory to the Schlumberger resistivity data secured by the NPRL by means of very long power lines in southern Africa. Progress has been made toward inversion to resistivity as function of depth.

Instrumentation for magnetometer arrays

An automatic film scanner-editing system is in routine use and a paper giving its main features is in press in the Journal of Geomagnetism and Geoelectricity (authors: Burke, Alabi and Gough). The final-editing part of the system, in the University Computer Centre, has recently been greatly improved through the introduction of a new and better graphic terminal.

A new quartz clock, using the electronics of a digital wrist-watch, has been developed for the magnetometers. The switching electronics for the magnetometer has been incorporated with the clock in a sealed unit. The prototype is under test and the magnetometers are expected soon to have the new clock-switching units.

(ii) *Numerical Modelling Studies*

A numerical method is being used by Dr. Jones to investigate earth models with lateral variations in conductivity. Both two-dimensional and three-dimensional finite-difference programs have been developed to study the perturbations of geomagnetic fields by such conducting inhomogeneities.

At present three-dimensional numerical results are being compared with analogue model measurements made in collaboration with Dr. H.W. Dosso and Mr. W. Nienaber of the University of Victoria and Dr. L.K. Law of the Dominion Astrophysical Observatory. Numerical and analogue model results for a Vancouver Island model will be compared with observational data. Dr. Ramaswamy and Dr. Jones are carrying out the numerical calculations, Dr. Dosso, Dr. Ramaswamy and Mr. Nienaber the analogue model measurement and Dr. Law and Mr. Nienaber the field data acquisition and analysis.

Dr. Ramaswamy and Dr. Jones are also concerned with the topographic effect on electromagnetic fields at the surface of the earth and are pursuing a study to investigate these effects near three-dimensional topographic features.

The effects of sources of finite dimension are being studied by Mr. Hibbs and Dr. Jones. Mr. Hibbs has developed a two-dimensional Fourier technique to obtain a general source configuration, and a general program to enable easy representation of any two-dimensional source has been developed. This project has been extended to three-dimensional models and an investigation of induction arrows related to three-dimensional bodies and non-uniform sources is underway. Also, Mr. Hibbs, along with Dr. Jones and Dr. Ramaswamy at the University of Alberta and Dr. Dosso at the University of Victoria, are making comparisons between analogue model results from the University of Victoria and numerical results for a non-uniform source field over a three dimensional inhomogeneity.

Further program development has been undertaken and a three-dimensional modelling program has been produced which can be used on a relatively small computer. This new program has been employed in a joint project with Dr. J.E. Lokken of the Defence Research Establishment Pacific to investigate sea channel and irregular coastline effects. The solution of the perturbation problem in three dimensions in H has been studied as well as the solution of the problem in E.

(iii) *Numerical Modelling Studies of the Thermal Regimes of Downgoing Slabs*

Dr. Jones and L. Sydora have developed a numerical program to study the thermal regimes of downgoing lithospheric slabs in subduction zones and the associated heat flow. This program is an adaptation of the method of Minear and Toksoz and is more general in that slabs with various dip angles may be considered as well as slabs that may change their dip angle at depth. This project is in collaboration with Dr. R. Lambert of the Department of Geology and the methods developed will be used to study heat production and the effects on earth materials near subduction zones.

(iv) *Magnetotelluric Studies*

Drs. D. Rankin, D. Kao and R. Sigal are continuing to study statistical methods and interpretational techniques. In particular an improved method of data analysis has been developed which allows the use of lower quality data in some cases, and in all cases gives improved criteria for data acceptability. The recording systems have been completed and are functioning satisfactorily.

The magnetotelluric method has been applied as a technique for geothermal exploration over the Marysville, Montana heat flow anomaly. This work was carried out as a joint project with the University of Utah and Southern Methodist University. Collaboration with Utah is being continued this year with a M.T. study in the Sawtooth Mountains of Utah.

This method is being applied in earthquake prediction in a joint project with Cal. Tech. and the Jet Propulsion Laboratory in the Los Angeles area. A double set of equipment including a complete magnetotelluric system and a satellite telluric system have been deployed and data will be accumulated over an 18 month period in the first phase of this project.

The Black Hills anomaly has been surveyed in some detail, an anomaly has been mapped and reports have been prepared.

Statistical studies using the continuously recorded data transmitted from the University of Alberta geophysical observatory at Leduc, Alberta, are also being continued.

(c) Université Laval

(i) *Electromagnetisme*

Les travaux de recherche effectués en électromagnétisme par M.K. Séguin ont surtout porté sur l'interprétation de levés électromagnétiques héliportés pour la prospection de formations de fer magnétiques à haute teneur dans lesquelles l'aimantation rémanente naturelle fausse l'interprétation semi-quantitative à partir de levés magnétiques aéro- ou héliportés. L'interprétation semi-quantitative à quantitative des données électromagnétiques héliportées permet d'obtenir avec une précision relative acceptable les dimensions et la teneur de la masse fortement aimantée (riche en magnétite).

M.K. Séguin a conçu et construit un modèle électromagnétique de type Slingram pouvant simuler des levés terrestres, héli-ou aéroportés. Construit de manière à obtenir une grande précision des mesures, ce modèle sophistiqué en est maintenant au stage des améliorations techniques. En collaboration avec P. Montambault (partie d'un travail de maîtrise) et de G. Voyer (étudiant sous-gradué), on procède à l'amélioration des composantes mécaniques du modèle ainsi qu'à la mise en oeuvre de l'acquisition et du traitement digitaux des données obtenues à l'aide de ce modèle.

(ii) *Methodes electriques et thermiques*

Région de Schefferville

M.K. Séguin a utilisé les méthodes de résistivité électrique, du potential spontané et thermique en surface et dans les trous de forage dans la région de Schefferville au cours des années 1969-75 pour délimiter en trois dimensions les zones de permagel discontinu. Cette étude a pris fin cette année.

Lac Minto

Depuis la fin de 1974, M.K. Séguin fait partie intégrante du Centre d'Etudes Nordiques de l'Université Laval. Les travaux de terrain durant la saison d'été 1975 ont été effectués dans la région du lac Minto (57° 30°N, 75° 30°W). En collaboration avec G. Lambert (ingénieur physicien) et R. Laplante (étudiant sous-gradué), on a effectué des levés de résistivité électrique en courant continu et en courant alternatif, des levés de polarisation spontanée et provoquée dans le domaine temporel et enfin des levés thermiques. Après avoir calculé l'épaisseur du molisol et celle du pergélisol on a procédé à une étude statistique de l'épaisseur du permagel en fonction des types de terrain, à savoir: terrasses boisées, terrasses déboisées, roc dénudé, lacs, buttes cryogènes, palses minéralogènes, structures d'effondrements, etc. En tenant compte du système de drainage, de la topographie, de la végétation, de l'exposition au vent et du type de sol, on parvient à classifier les épaisseurs de permagel dans divers secteurs de l'aire étudiée. Ces épaisseurs varient entre 0 et 30 m. C'est donc dire qu'à une latitude de 57° 30'N et à une altitude d'environ 250 m, le pergélisol est discontinu et relativement mince sur le plateau central du Nouveau Québec.

(d) University of Toronto

(i) *Natural fields*

A cooperative field programme with the University of Waterloo, was carried out during the summer of 1975. Twelve magnetic variation stations were established on two profiles across the Appalachians, in New York and New England. The purpose of this work was to fill the gap between previous studies in eastern Canada, and the line of Edwards and Greenhouse (1975) across the Southern Appalachians. The latter measurements had indicated an extremely high conductivity in the crust, whereas the crust of eastern Canada is more "normal". In addition, the profiles cross the southern extension of the Logan thrust, along the line of Lake Champlain and the Hudson River. Some of the stations were observed with new digital recording equipment, built at the University of Toronto, and incorporating Datel tape recorders. Earth currents were measured at four stations.

(ii) *Controlled source experiment*

An unused power line, eighteen miles long, was made available during 1975 by the Ontario Hydro Electric Power Commission. The line is located about 25 miles east of Toronto, where the Precambrian surface lies at a depth of about 700 feet. This line has been energized with both continuous square-wave currents, and with pulses of pseudo-random width. Mesurements of the vertical and horizontal magnetic fields have been made at distances up to 25 km from the line. When the pseudo-random width pulses are used, the detecting magnetometer (of milligamma sensitivity) is connected to a HP Correlator, into which is also fed the identical random-width signal. The effects of earth structure are manifested by lags in the cross-correlogram. An interpretation of the initial observations gives a conductivity structure consistent with the known geology, and the later portions of the curves are now being analyzed to investigate the deeper conductivities.

(iii) *Interpretation*

The procedure of applying hypothetical events to induction arrows has been employed in a re-analysis of the study of the British Isles (Bailey and Edwards, in press). The new analysis shows that regional EW current flow is channelled along lines that coincide

remarkably well with trends of the Caledonian orogeny in Ireland, England and southern Scottland. Furthermore, the indications of highest conductivity are over regions which were independently suggested to include ancient ocean floor.

(iv) *Audiofrequency Magnetotelluric and Crustal Sounding*

This work is being done by D.W. Strangway, A. Koziar, A. Kryzan and J.D. Redman. Koziar has essentially completed his Ph.D. thesis. The crustal structure in the Geotraverse area appears to consist of a three-layer earth, conductive at surface but underlain by several kilometers of very resistive material. At a depth of several kilometers the resistivity drops sharply indicating a significant change in rock type.

A major new project was initiated with G.T.E.-Sylvania to provide resistivity data in connection with the proposed submarine communication system to operate at 75-80 hz. The problem faced in the design of the system is to determine the resistivity over large sections of the crust. Surveys were conducted with support from military helicopters in the Nevada Test Site and Bombing Range and at the White Sands Missile Range in New Mexico. A large amount of data was collected and is now being processed to develop the interim report. At the same time a survey was conducted in Wisconsin to check the results obtained against other methods. The Wisconsin site is the location of the prototype transmitter and has been studied by many other methods. The results from Wisconsin are similar to those from the Geotraverse area implying that the crustal section seen is a common feature of the shallow Precambrian crust.

New instrumentation to operate digitally is now in its preliminary design phase.

(v) *Electrical Sounding in Permafrost and Glaciers*

Work by D.W. Strangway, A. Koziar, J. Rossiter, J.D. Redman and J. Wong, on permafrost and glaciers, is a direct outgrowth of the Apollo 17 sounding experiment and of a set of magnetotelluric instrumentation originally built for Kennecott some years ago. The radio frequency interference method used on the moon continues to be of significant use to us in studying both glaciers and permafrost. Glacier data collected some time ago are still being analyzed with some success at determining depth rather precisely using automated methods. At the same time using model experiments the influence of scattering is being determined. The audio-frequency magnetotelluric method has proven to be a remarkably useful tool for permafrost sounding even in the presence of the summer active layer. This work is documented in a recent paper in Science and is part of the thesis by Koziar. Experiments are planned for the spring to try both methods in the absence of an active surface layer.

(vi) *Electrical Properties of Permafrost and of Lunar Supplies*

D.W. Strangway, G.R. Olhoeft and J. Wong are working on the dielectric properties of lunar samples in the frequency range from 100 hz to 10 Mhz, essentially completed with the publication this year of several summary papers which attempt to state our knowledge of the electrical properties of the outer 100 meters of the moon. This information has also been related to the radar sounding techniques used to study other planets. The laboratory developed for these studies has also been used to study permafrost samples supplied by the Geological Survey of Canada. This has resulted in the recognition of the complex frequency dependence of frozen clays in the audio frequency range. This study formed the Ph.D. thesis of G.R. Olhoeft who has now joined the U.S.G.S. in Denver. Our current studies involve further investigation of the more complex clay minerals and their behaviour under frozen conditions. Co-operative studies on lunar samples with G.R. Olhoeft at radar frequencies are being initiated.

(vii) *Electrical Properties of Rocks and Sulphide Minerals*

S.F. Nowina for his master's thesis is examining the use of dielectric constant anisotropy as a tool for fabric study. This work is being done in vacuum treated samples which are heated to drive out any residual moisture. Preliminary results show consistent anisotropic effects that are readily detectable and represent the effect of the rock-forming minerals.

The initial study of the electrical properties of sulphide minerals as a function of temperature has been completed and written up for publication. A new study of the complex resistivity spectra of sulphides is being initiated in which the temperature dependence will be studied. This work will be used to correlate with multi-frequency field studies.

(e) University of Victoria

Theoretical and analogue model studies of electromagnetic induction are continuing at the University of Victoria, with participation of Drs. H.W. Dosso, J.T. Weaver, C.R. Brewitt-Taylor, V. Ramaswamy, V.R. Green, M. Nicoll and W. Nienaber.

Work is progressing on the development of a comprehensive computer program for solving three-dimensional induction problems using a modification of the finite element method rather than finite differences. The program is already working in two-dimensional form and has been used to investigate the possibility of induced electric currents in the ocean being coupled to the mantle through the earth's crust. Earlier results of an approximate analytical treatment of this problem were verified by the numerical solution. An exact mathematical solution to a two-dimensional problem of this type has also been found for the H-polarization case.

The model work includes studying the response of embedded conducting bodies as well as the coast effect problem. In collaboration with Dr. S.O. Ogunade, University of IFE, ILE-IFE, NIGERIA, the problem of a conducting sphere embedded in the lower layer of a two layer conductor for an overhead vertical dipole is being studied both analytically and with the aid of an analogue model. Analogue model studies of possible conductivity models for the "Rheingraben anomaly" have been carried out in collaboration with Dr. R. Winter, Inst. für Geophsik der Universität Göttingen, Germany. Further analogue model studies are underway in collaboration with Mr. R. Hibbs and Dr. F.W. Jones, University of Alberta, Edmonton, on the effect of non-uniformity of source fields over a conductivity anomaly.

The possible channeling of electric currents, induced in the deep ocean, through the straits separating Vancouver Island and the B.C. mainland is being studied using analogue model measurements, magnetotelluric field measurements and numerical calculations. Simplified island models (circular and square islands) consisting of an island near a continental coastline have been studied both by analogue model and numerical model methods. Further, a scaled model of Vancouver Island and the surrounding region is being studied using both analogue and numerical methods. The results will be compared with magnetotelluric measurements for pairs of stations carried out in collaboration with Dr. L.K. Law. The island problems are being studied in collaboration with Dr. L.K. Law, Earth Physics Branch, Department of Energy, Mines and Resources, Victoria and Dr. F.W. Jones, University of Alberta, Edmonton.

7. Paleomagnetism, Rock Magnetism and Tectonomagnetism

(a) Earth Physics Branch

The coherent polar path developed from the Laurentian Shield in 1974 for the interval -2,200 to -1,800 m.y. has now been extended to -2,300 m.y. to include new data from the Huronian. Of particular interest has been the discovery of five magnetizations in Huronian and Nipissing rocks and the resolution of the "Nipissing" problem. Work in collaboration with the University of Toronto on resetting of remanent magnetization during burial and heating has yielded the conclusion that magnetization will generally not resist the temperature conditions associated with high greenschist facies metamorphism.

Much effort has been directed towards the study of magnetic overprints and the different methods (combining thermal, chemical, alternating field and two-stage cleaning techniques with vector analysis) that can be used to dissect polyphase magnetizations. This work has been rewarding and has shown that the use of two or three cleaning techniques may provide important information about the detailed geological history of rocks. Analytical methods developed have been described in a series of papers published or submitted for publication in 1975; these include studies of Whitestone anorthosite and diorite, Flin Flon-Snow Lake Greenstone Belt, Otto Stock, Big Spruce Complex (in collaboration with the Geological Survey of Canada) and Nipissing diabase.

A review of results of the Precambrian of North America (in collaboration with GSC) is to

appear shortly in the Phil. Trans. Roy. Soc.. The experimental work on the Labrador Trough (Quebec) and the Jacobsville Sandstone (Ontario and Michigan State) has been completed and will be submitted for publication. The work on the Canso Group (Nova Scotia) which is part of a large program for establishing a magneto-stratigraphic sequence in the Upper Paleozoic rocks of the Maritimes is nearing completion.

Work on iron ore formations in the Gagnonville area (Quebec) is leading into a study of the magnetic characteristics of very large grained hematite with possible correlation of very low remanent coercive forces and very high blocking temperatures.

Work is continuing on Lac Croche Complex and on two major anorthositic intrusions (Michikamau and Harp Lake) in Labrador in collaboration with the G.S.C.; work is also continuing on the Rapitan Group of Mackenzie Mountains in Yukon and N.W.T. and rock collections from the Belcher Islands. Experimental work has been started on the Precambrian Toby Conglomerate and Mount Nelson Formation of British Columbia, diorite bodies of Devonian age in the Appalachian system (Mount Peyton, Newfoundland), Silurian red beds of the Botwood Group (Newfoundland), Silurian argillites of the Mascarene Group (New Brunswick) and Devonian rocks of the St. Georg intrusions (New Brunswick).

L'échantillonnage de 1975 est varié et comprend les unités suivantes: l'archéen de Saglek Fjord au Labrador; le précambrien du Supergroupe du Lac des Esclaves (T.N.O.); des roches sédimentaires et volcaniques précambriennes de la baie de Cameron (T.N.O.); la formation de fer de Snake River au Yukon; des grès rouges et laves de Dingle en Irlande; des calcaires ordoviciens de la péninsule de Fort au Port (Terre Neuve); des grès rouges siluriens et dèvoniens de l'ile de Somerset (T.N.O.); des roches sédimentaires et ignées, siluriennes et dévoniennes, de la région d'Arisaig (Nouvelle-Ecosse); des grès rouges de la formation dévonienne de Lake Branch (Québec); et des roches jurassiques de la Baie des Exploits (Terre-Neuve).

Le catalogue des résultats paléomagnétiques du précambrien a paru en 1975 et le catalogue du paléozoique, du mésozoique et du tertiaire sera disponible en 1976.

A study of the build-up of viscous magnetization in rocks at elevated temperatures is continuing. Rocks have been maintained at fixed temperatures up to 300°C in the earth's magnetic field for periods of time up to several months. At intervals the rocks were cooled (thus stabilizing the magnetizations acquired at the elevated temperature) and the magnetizations were measured. The magnetizations normally increase approximately linearly with the logarithm of time. The rate of increase (i.e. the magnetic viscosity coefficient) is quite variable from rock to rock, and at present no clearcut correlations with other magnetic properties and grain structure have been determined. Enhancement of viscous magnetization may be a potent source of magnetic anomalies in the deep crust, and rocks which have originated at considerable depths are being studied, ranging from granitic rocks to pyroxene gabbros and granulites.

(b) Memorial University of Newfoundland

At the Geomagnetic Research Laboratory, E.R. Deutsch, G.S. Murthy and R.R. Patzold completed detailed magnetic studies of 46 basalt cores recovered during Deep-Drill '74 (Leg 37) of the Deep Sea Drilling Project in the North Atlantic (C.G.B., 1974). Properties measured include NRM, Q-ratios, low field hysteresis (Raleigh loops), high-field hysteresis at 20°C and -196°C, NRM decay through AF and stepwise and continuous thermal demagnetization, susceptability vs. temperature, Curie point, and domain state through the Lowrie-Fuller test. Samples from one of the holes (335) showed stable, steeply inclined, reverse remanence, whereas over a thick section of the deep hole (332B) the NRM fluctuated between +ve and -ve shallow inclinations, indicating that there the observed surface anomalies required a more deepseated magnetic contribution than proposed in "thin-layer" models. In most of the samples, the magnetic carrier was found to be pure or cation-deficient, stable-single domain (titano) magnetite; only one clearly showed multidomain magnetite and in one sample a low-coercivity VRM associated with a spectacular Hopkinson-type susceptability peak at about 100°C was attributed to the presence of fine particles showing superparamagnetic properties. This is quite different from the conclusions on Pacific basalt cores from DSDP Leg 34 (C.G.B., 1974; Deutsch and Patzold, 1975), where two thirds of all samples had shown SP behavior and low Koenigsberger ratios, so that caution is needed in using the results in magnetic anomaly interpre-

tation. Results from these two DSDP studies were reported in 1975 at the G.A.C. Annual Meeting, Waterloo; the 16th General Assembly of I.U.G.G. Grenoble, and the Joides IPOD symposium on the Nature of the Oceanic Crust, La Jolla (Deutsch and Patzold, 1975; Murthy et al, 1975; Deutsch et al, 1975). Related work on oceanic basalts measured by Dr. C. Radhakrishnamurty of the Tata Institute of Fundamental Research, Bombay, in a joint study with Deutsch and Murthy, was reported by Dr. Radhakrishnamurty at I.U.G.G., Grenoble. It was found that hysteresis properties may be used to distinguish magnetite grain-size effects from a "true" solid-solution state in titanomagnetite and that the existence of the latter may be less common in basalts that is generally believed.

As a complement to these investigations on natural basalts, P. Guntur and G.S. Murthy are studying the magnetic properties of synthetic samples of magnetite with controlled grain sizes. Experimental investigations include obtaining the Rayleigh loops, high field hysteresis, k-T curves, M-T curves and the Lowrie-Fuller test for single-domain, multi-domain nature. Experiments are in progress.

J.P. Hodych is engaged in theoretical and experimental studies of the effect of stress upon the magnetization of rock. In the past year, a single-domain theory for the effect of uniaxial load upon remanence was developed. In the coming year, emphasis will be upon experiments to determine the cause of the anomalous stress-induced changes observed in the susceptibility and remanence of some rocks of high coercive force.

G.S. Murthy continued studies of the magnetic properties of the anorthosite massifs of the northern hemisphere. In addition to the Egersund anorthosite and farsundite from southern Norway (with E.R. Deutsch) work during this year included investigation of stable remanence in the Nain anorthosite, Labrador. Samples from 21 sites of various facies of anorthosites from this area have yielded a mean paleopole at 18^{o}N, 144^{o}W ($\delta p=3\frac{1}{2}^{o}$, $\delta m=6^{o}$). This pole position is slightly north of the established pole position for the 1400 m.y. old rock units from the Canadian Shield. G.S. Murthy and K.V. Rao obtained mean pole positions for the western Newfoundland anorthosites. The Indian Head pole lies at $9\frac{1}{2}^{o}$S, $158\frac{1}{2}^{o}$E and is comparable to the pole positions obtained by other workers for the anorthosites from the Grenville Province of the Canadian Shield. This suggests there might be no relative rotation between western Newfoundland and the Grenville Province part of the Canadian Shield. The Steel Mountain anorthosite yields a pole position at $22\frac{1}{2}^{o}$N, 138^{o}E which seems to be representative of a lower Paleozoic magnetization.

E.R. Deutsch and K.V. Rao completed various paleomagnetic studies on Lower Paleozoic rocks in Newfoundland (C.G.B., 1974). Their results on the St. George's (Lower Ordovician) limestones, the Bradore (Lower Cambrian) sandstones, and the Cloud Mountain (latest Precambrian?) basalts, when compared with data from rocks of similar age in interior North America, fail to lend support to Wegener's proposed 30^{o} anticlockwise rotation of Newfoundland, though a smaller rotation ($5\text{-}10^{o}$) cannot be ruled out. These results were reported in 1975 at the G.A.C. Annual Meeting, Waterloo, and at the I.U.G.G. Grenoble.

J.P. Hodych is continuing his studies of the magnetic properties of the Alpine-type ultramafics of Newfoundland. This past year, work was done on the ultramafics of the eastern half of the mobile belt. Aeromagnetic interpretation was shown to support the view that these rocks represent ancient upper mantle under oceanic crust rather than mantle diapirs. These ultramafics look to be amenable to paleomagnetic techniques which will be applied to them in the coming year.

G.S. Murthy has started during the summer of 1975 paleomagnetic investigations of the granitic intrusions from Central Newfoundland with a twofold purpose: 1. to see if granites, with careful demagnetization experiments, can be used for paleomagnetic purposes, 2. to obtain paleomagnetic poles which may be used in interpreting the ages of these granite bodies. Four granitic intrusions from central Newfoundland were sampled. Laboratory work is in progress.

G.S. Murthy is conducting paleomagnetic and rock magnetic investigations of a Mesozoic dike swarm from northwest Greenland (north of Umanak) in collaboration with the Greenland Geological Survey. The dike swarm seems to be having a primary component of magnetization around (160^{o}, -61^{o}) with 50% of the dikes having a superposed secondary component close to the present Earth's field. The secondary component is removable by alternating field demagnetization. Work is in progress.

(c) University of Alberta

Precambrian and Palaeozoic formations

Work on extensive collections (about 200 sampling sites) of the Great Slave Supergroup (1600-1900 m.y.) is going ahead under the direction of M.E. Evans. One paper concerning a detailed study of an ancient geomagnetic polarity transition has been published and two others concerning the Stark and Tochatwi Formations have been submitted for publication. Measurements on the Akaitcho River Formation are now complete and the pole position obtained is concordant with those deduced from formations of similar age from other parts of the Canadian Shield. Samples have been collected from sites in the Western River Formation which occurs in the sedimentary basin centered on Bathurst Inlet. Preliminary measurements look very promising and suggest the presence of at least one geomagnetic polarity reversal.

Initial processing of a collection of Cambrian red beds (Arctomys Formation) has been completed after much effort both in the field (due to remote access) and in the laboratory (due to friable samples requiring impregnation). So far the results are very disappointing, being typified by wide scatter of remanence directions even after careful thermal cleaning.

Quaternary formations

C.J. Oberg and M.E. Evans are working on collections from seven localities in Alberta, British Columbia, Washington and Montana. The ages represented range from 12,000 to 30,000 years. Results can be expected to help determine the spectrum of geomagnetic variations, and distinct magnetic signatures may also prove useful in regional geological studies. So far we have concentrated on sections which should contain records of the so-called Gothenburg "flip" found in Sweden, and the Lake Mungo Excursion found in Australia. Our results indicate a wide swing in declination which may represent the Gothenburg event, but we find no evidence for the Lake Mungo event. This latter conclusion is based on data from pairs of samples collected from 37 horizons throughout a 7 m thick section, representing some 9-10,000 years. The data obtained are highly internally consistent and appear ideally suited to geomagnetic spectral studies. The Watson-Beran test indicates a high degree of sequential ordering (>99% probability), as would be expected from secular variation. Periodic oscillations in declination occur and Fourier analysis reveals strong peaks corresponding to periods of about 2,000 and 900 years.

Rock Magnetism: Intergrowths as a source of stable remanence

Recognition that magnetite intergrowths are a common carrier of stable remanence in igneous rocks has prompted a series of detailed investigations by P.M. Davis and M.E. Evans of their magnetic properties. Previous work demonstrated that subdivision of titanomagnetite grains into magnetite/ulvospinel intergrowths enhances their magnetic hardness and hence their time stability. Current studies involve the more commonly occurring magnetite/ilmenite intergrowths. Basalt samples containing homogeneous titanomagnetite grains were oxidized in air to form such intergrowths.

A variety of magnetic properties of these grains are virtually indistinguishable from those of a synthetic sample containing the same volume fraction of acicular single-domain Fe_3O_4 particles, but contrast markedly to the properties of 6 μm (pseudo-single domain) magnetites. In particular the ratio of saturation remanence to saturation magnetization (I_{RS}/I_S) was found to be 0.30 compared to 0.33 and 0.04 respectively. Under non-demagnetizing conditions this ratio increases to 0.51 and is not significantly different from the theoretical value of 0.50 predicted by classical Stoner-Wohlfarth theory for a population of randomly oriented uni-axial single domain grains. The observed reduction is entirely explicable in terms of localized array demagnetizing fields arising from surface poles. It is therefore concluded that the magnetic intergrowths commonly observed in sub-aerial basalts may be regarded as arrays of interacting single-domain particles capable of carrying a strong remanent magnetization stable over geological intervals of time.

Qualitative evidence that the reduction in I_{RS}/I_S proceeds by rotation of the spontaneous magnetization from easy axes is provided by anisotropy of low field susceptibility measurements, and this aspect of the work is currently under quantitative scrutiny.

Tectonomagnetism

Dr. P.M. Davis is working on the detection of tectonomagnetic changes in the earth's magnetic field which depends on eliminating fluctuations caused by ionospheric and magnetospheric activity. This is achieved to first order by taking simple differences in total fields measured at proton precession magnetometer stations since it is assumed that the incident fluctuations are plane waves and so should cancel. However such difference records are found still to contain noise which is highly correlated to extraterrestrial magnetic activity. Regression techniques using component field variations which identify the direction dependence of the difference field fluctuations have been successfully used further to reduce the noise. Application of this technique to proton-precession difference field records obtained on Kilauea volcano, Hawaii reveals a base line change of approximately 1.4 gammas (1.4 nT) coincident with an eruption, which is not otherwise observable in the uncorrected data. Trends in the data over the eleven and five months, preceding and following the event respectively, are being evaluated in terms of stress induced magnetic changes within the volcano structure. This work has been carried out in collaboration with Dr. John Olson of the Space Physics Group.

Magnetic anisotropy and rock fabric

Work on the Precambrian Martin Formation has been completed by A. Rahman, D.I. Gough and M.E. Evans and the results published. They demonstrate the successful application of magnetic anisotropy measurements to the determination of rock fabrics for use in paleocurrent analysis. Following this initial success the method has been extended to a thick sequence of Proterozoic sediments preserved in the Athapuscow Aulocogen (East Arm of Great Slave Lake). Approximately 300 samples form the Great Slave Supergroup have been measured and these yield a coherent pattern of principal susceptibility axes which confirms previous geological interpretations of the sedimentary history of this basin. Processing of these data is now complete and they are currently being prepared for publication.

Other on-going projects include a study of a section through the Cretaceous Cardium Sandstone representing a profile along the tectonic gradient from the eastern foothills into the Alberta Rockies. The aim is to determine if and how magnetic anisotropy responds to ancient stress fields. Preliminary measurements are also under way on the McMurry Formation which is the main reservoir for the Athabasca Oil Sands. If initial measurements look promising a more thorough sampling scheme is envisaged, which will hopefully yield useful depositional history and paleoenvironment data.

(d) Université Laval

Fosse du Labrador

M.K. Séguin a continué les études paléomagnétiques entreprises depuis 1968-69 dans les secteurs sud, centre et nord de la Fosse du Labrador. Dans le secteur sud qui a été affecté par l'orogénèse grenvillienne, les recherches paléomagnétiques ont été centrées sur une étude régionale des itabirites magnétiques et du gabbro de Shabogamo localisés entre Mt. Wright et le lac Sawbill. En collaboration avec M. Munoz-Cazayus (étudiant en maîtrise) on a entrepris une étude détaillée des itabirites magnétiques de deux gisements de fer dont la géologie est très bien connue. Très peu de désaimantation est requise pour retracer le paléopôle à l'intérieur des itabirites.

Dans le secteur centre, M.K. Séguin a effectué les études paléomagnétiques complètes des formations de fer (Sokoman) de la région de Schefferville, et des volcaniques de Murdoch et du lac Patu en collaboration avec M.A. Côté (ingénieur physicien). Une étude des volcaniques de Nimish intercalés aux formations de fer de Sokoman vient d'être complétée par M.K.-Seguin en collaboration avec G. Lambert. (ingénieur-géophysicien).

Dans le secteur nord, une étude des volcaniques de la région comprise entre Fort McKenzie et Fort Chimo est en cours.

Appalaches du Québec

M.K. Séguin a entrepris les premiers travaux paléomagnétiques de la région des Appalaches

du Sud du Québec en 1973. La première étude entreprise avec R. Laurent a trait aux propriétés magnétiques des laves à coussinets de la zone ophiolitique de Thetford-Mines. Une étude beaucoup plus détaillée et volumineuse entreprise par M.K. Séguin en 1974 et reliée à la précédente est maintenant terminée.

Les études paléomagnétiques en cours dans ce même secteur comprennent: 1) les laves coussinées ordoviciennes de la région de Drummondville-Actonvale-Granby, 2) les laves coussinées cambriennes de St. Flavien-Manseau-St-Sylvestre-Ste-Hénédine, 3) la série péridotite-dunite-gabgro-laves coussinées et diabases des complexes ophiolitiques de Thetford-Mines et d'Asbestos, 4) les laves du groupe de Caldwell (Cambrien), 5) les laves à coussinets du complexe ophiolitique de Thetford-Mines (étude détaillée) et 6) les péridotites et laves coussinées de la région du mont Albert en Gaspésie.

Ces diverses études ont été entreprises avec D. Lafond (étudiant en maîtrise), G. Lambert (ingénieur physicien) et R. Laplante (étudiant sous-gradué).

(e) University of Toronto

(i) *Lunar and Planetary Studies*

Magnetism in Meteorites

D.W. Strangway and M. Lanoix have initiated a pilot program to study the magnetic history recorded in meteorites. Initial work is on the Allende meteorite a primitive sample believed to represent the earliest phases of solar system accretion.

Magnetism in Lunar Samples

D.W. Strangway, G.W. Pearce and G.S. Hoye continue efforts to study the history of the moon's magnetic field. The main focus is on the reconstruction of the intensity of the ancient lunar magnetic field. Several samples have been studied using the Thellier-Thellier technique and consistently give values of about 1000 to 2000 gammas. These low values tend to support the models of cold accretion of the moon in the presence of an early primordial field. The low values are also in distinct contrast to those obtained by other investigators using non thermal techniques. We attribute this to viscous effects in the samples. A related study involves the study of Apollo 17 boulders in which a clear indication of thermal overprinting is present suggesting two stages of magnetization.

Models of Lunar and Planetary Evolution

A recent model of thermal evolution of the moon has been proposed by D.W. Strangway, H.N. Sharpe and J.C. Rylaarsdam. In this model the moon accreted cold and was magnetized at that time. It subsequently warmed up slowly leaving only remnants of magnetization in crustal rocks. The model proposed meets most of the major constraints imposed by our knowledge of the moon. Recently we have extended this study to consider the planet Mercury in a paper to be published shortly. As part of this study we have also modelled the possible causes of lunar orbital anomalies relating these to the properties measured on returned samples.

Paleointensities of the Terrestrial and Lunar Magnetic Fields

A facility has been established at Erindale College for investigating the strength of the terrestrial magnetic fields at various times in the past. The apparatus has been used by D. Dunlop for paleointensity determinations on some JOIDES basalt core samples and L. Pesonen is presently working with Sibley sediments baked by Keweenawan diabase dikes in cooperation with H. Halls and G.W. Pearce. G.W. Pearce, G.S. Hoye and D.W. Strangway are nearing completion on paleointensity determinations of 3 lunar samples, two of which are from the same boulder. These are suggesting a magnetic field at the lunar surface of about 0.05 Oe at the Apollo 16 site about 4.0 b.y. ago.

We plan to continue lunar paleointensity determinations and also, with the thermal demagnetization technique, to examine thermal magnetic overprinting that is thought to occur

in some Apollo 17 breccia samples. We expect to begin paleointensity work with some archeological material supplied by the University of Toronto Anthropology Department.

Lunar Paleofield Intensity

The central question in lunar magnetic studies is the intensity of the moon's magnetic field before about 3300 m.y. Reliable paleointensity estimates have been difficult to obtain because the lunar rocks tend to alter irreversibly on heating. For this reason, some groups have abandoned traditional heating methods in favour of room-temperature analog methods in which the properties of TRM are simulated by those of ARM. Monika Bailey, with D.J. Dunlop and M.F. Westcott-Lewis has shown that the ARM/TRM intensity ratios predicted by existing theories are in poor agreement with experimental data for both fine-grained and coarse-grained magnetite. Moreover, the ratio is strongly field-dependent for fields less than a few oersteds, and small errors in determining the average blocking temperature (a necessary input parameter for the theory) cause large errors in paleointensity. ARM analog methods should be regarded as yielding only order-of-magnitude paleointensity estimates. As a result, a number of published paleointensity values for the moon are very dubious.

(ii) *Paleomagnetism*

Magnetism of the Ocean Crust

Christopher Hale and David Dunlop have measured paleomagnetic directions, paleofield intensities, viscous magnetization and hysteresis characteristics for twenty-two basalts and gabbros sampled as deep as half a kilometer within the oceanic crust. The rocks were drilled near the Mid-Atlantic Ridge at 37°N by the 'Glomar Challenger' during Leg 37 of the Deep Sea Drilling Project. They represent the deepest penetration ever of the oceanic crust.

At site 335 (crust about 16 m.y. old), the remanent magnetizations are reversed and steeply dipping, in agreement with the negative linear magnetic anomaly at the ocean surface. However, at site 332 (crust about 3.5 m.y. old) remanences are weak, have shallow inclinations and reverse numerous times down the core. We have tested the hypothesis that the site 332 rocks were magnetized at the time of a polarity transition or field excursion by examining whether the paleofield intensity for site 332 rocks is abnormally low compared to that for site 335 rocks. This does not appear to be the case. In fact, some low paleointensities are found at both sites and are associated with rocks whose primary remanences have undergone pronounced viscous decay.

There seem to be two classes of submarine basalts. Type 1 basalts behave reversibly when heated, are very soft and viscous, and have a single low (150-200°C) Curie point. The predominant magnetic carrier seems to be coarse-grained, multidomain titanomagnetite. Type 2 basalts undergo large irreversible chemical changes when heated, are hard and non-viscous, and contain both high- and low-Curie-point phases. The significant additional component in type-2 rocks seems not to be lamella-subdivided titanomagnetite but powder magnetite in volcanic glasses altered by sea water.

Pseudo-Single-Domain Particles

Monika Bailey has demonstrated the onset of pseudo-single-domain (PSD) magnetic moments in multidomain magnetite particles less than about 15 μm in size from measurements of anhysteretic remanent magnetization (ARM). The PSD range is known from thermoremanent magnetization (TRM) measurements to extend from 0.05 μm to 15 μm in magnetite, a size range that includes the carriers of stable natural remanence in a great many paleomagnetically useful rocks.

The Preisach diagram, in which coercivity and particle interactions are profiled along orthogonal axes, also changes its character with the onset of PSD moments. For particle sizes well below 15 μm (2 μm, for example), the contours follow the coercivity axis closely in typical single-domain fashion. With increasing particle size, there is a gradual transition to truly multidomain contours above 15 μm. The multidomain contours are approximately perpendicular to the coercivity axis and reflect the

large interaction among domains in a multidomain particle.

Monika Bailey had shown earlier that the Lowrie-Fuller test, in which the relative stabilities of weak-field TRM or ARM and strong-field remanences are compared, distinguishes between the presence and absence of PSD moments in multidomain particles and not between single-domain and multidomain particles as claimed by Lowrie and Fuller. She has now provided a rationale for the test, based on modelling the AF demagnetization process on the Preisach diagram. In simple terms, an exponential-type AF demagnetization curve, which is very frequently associated with unstable paleomagnetic behavior, leads to a "multidomain-type" Lowrie-Fuller test while most other types of curve produce "single-domain-type" Lowrie-Fuller tests. Thus the Lowrie-Fuller test is not in fact an independent test of domain structure, but an expression of the shape of the coercivity spectrum.

Precambrian Paleomagnetism

In cooperation with Drs. E. Irving and G. Pullaiah of the Earth Physics Branch, EMR, Kenneth Buchan and David Dunlop have been investigating the temperature-time regimes which natural remanences of various Curie points and blocking temperatures can survive. The aim of the study is to calibrate thermal remagnetization under conditions of burial metamorphism. Natural remanence carried by magnetite is unlikely to survive middle-greenschistfacies metamorphism but a primary remanence due to hematite could survive middle-amphibolite-grade metamorphism if mineralogical changes are not too severe.

Applying the results to Grenville rocks, none of the multiple magnetization components in the Haliburton intrusions appears to be primary. In the Magnetawan metasediments, directional stability is lost between 615 and 660°C. This blocking-temperature range seems to mark the upper limit of remagnetization of hematite under high-amphibolite conditions. Numerically, it is in good agreement with calculated temperatures.

Multi-component magnetizations in Archean rocks of the greenstone and gneiss belts just west of Lake Superior also seem to record metamorphic overprinting of the primary remanence. The best results to date have come from the diapiric Shelley Lake granite of Quetico Park, in which an Archean remanence and a Kenoran orogeny (2500 m.y. BP) overprint seem to be superimposed. Many volcanic rocks in the area seem to have been remagnetized at the time of the 1100 m.y. Keweenawan volcanism in the nearby Lake Superior basin.

Dr. Glenn Berger, working jointly with Dr. Derek York and Dr. Dunlop is beginning Ar^{40}/Ar^{39} dating of the Grenville and Archean rocks in an attempt to date the multiple magnetizations. If successful, this work would also date an ocean-closing event believed by many to be recorded by the Grenville paleopoles.

Miscellaneous Problems in the Minerology and Petrology of Alkalic Rocks and Carbonatites

J. Gittins is studying diverse aspects of the petrology of alkalic rocks and carbonatite complexes such as magnetite-orthopyroxene relations, olivine-clinopyroxene relations in carbonatites and nepheline syenites, the evolution of the Obedjiwan nepheline syenite complex, Quebec, the evolution of carbonatitic-kimberlitic rocks, the stability fields of certain new minerals, studies of amphibole-biotite-clinohumite relations in carbonatites, and alkali amphiboles in peralkaline granites.

The Use of Demagnetization Circles in Paleomagnetism

If a rock sample containing two components of magnetizations is magnetically cleaned either by AC or thermal means, successive resultant magnetization vectors will all lie within a plane, providing of course that the two components do not have the same coercivity or blocking temperature spectrum. On a stereonet the resultant vectors will define an arc of a so-called remagnetization circle. If one component is more scattered than the other (eg. a primary component) before structural unfolding, or a secondary component after unfolding, remagnetization circles from samples of different sites will tend to converge to two points. The direction of one of these points will define that of

one of the remanence components. H.C. Halls has devised a method to obtain the best estimate of this intersection point, based on least-squares fitting great circles to points on a sphere. Firstly great circle planes are fitted to the vectors defining each remagnetization circle, and the process is then repeated on the vector normals to the planes. A statistical analysis of the method is presently being examined in conjunction with Dr. J.E. Lebel of the Mathematics Department, so that confidence limits can be assigned to the directions obtained.

Providing that sufficient structural diversity exists, and the times of primary and secondary formation bracket the period of folding, the minimum data required to uniquely define the relative ages and directions of the two components are magnetization vectors defining portions of great circles. If structural diversity is insufficient or if the dispersion in one component is greater than the other due to factors other than structure (e.g. secular variation) then additional data is required to obtain a unique solution. These data may be in the form of stable endpoints and prior knowledge from previous studies of the primary direction.

The least squares method described (Halls, 1975) has other potential uses, not only in paleomagnetism but also in plate tectonics and structural geology.

A Shock-Induced Remanent Magnetization from the Slate Islands, Lake Superior

Paleomagnetic studies of Keweenawan igneous rocks from the Slate Islands reveal a prominent secondary component of magnetization which is attributed to the passage of a shock wave following a meteorite impact (Halls, 1975). More than 60 samples, collected from 12 sites in Keweenawan lavas and dikes, each yielded upon AC magnetic cleaning above 100 oe, successive magnetization vectors which defined arcs of great circles. These so-called remagnetization circles indicate the presence of two components of magnetization with different coercivity spectra. Before structural unfolding (SU) all the remagnetization circles tend to converge to a common point. The point of best intersection, calculated using a least squares method (see previous abstract) gives the direction of the secondary component ($D=85^{o}$, $I=47.5^{o}$).

A number of samples yielded, in addition, stable end-points. These points correspond to the primary direction because on SU they become more tightly grouped with a mean direction ($D=135^{o}$, $I=58.2^{o}$) within 10^{o} of primary directions found elsewhere for Keweenawan rocks. The convergence of the remagnetization circles before SU is, however, not entirely due to structural diversity, because converging circles are still observed within sample populations collected from flows with similar structural attitude. It therefore seems that dispersion arising from causes other than structure (e.g. secular variation) is very much less in the secondary component compared to the primary. This observation suggests that the secondary remanence was formed very rapidly, at least in a time interval short compared with periods of scatter-inducing secular variation.

During the course of further sampling on the islands this past summer, it was found that 11 rocks on the islands are locally intensely shatter-coned and cut by anastamosing breccia dikes carrying shatter-coned fragments. Shatter-cones around the periphery of the largest island point radially inwards indicating that the shock centre lay in the middle of the island. Preliminary paleomagnetic data on newly-collected breccia samples show a single, stable remanence with a direction within 10^{o} of $D=85^{o}$, $I=47.5^{o}$. This result, together with the unusually low dispersion in the secondary component and the presence of shatter-cones, are convincing evidence that a remanence was produced by a shock event. The occurrence of planar features in quartz grains suggest shock pressures (at least 100 kbar) which are considerably above those produced by volcanic phenomena (R.A.F. Grieve, personal communication, 1975). Hence, the shock event is thought to be a meteorite impact and the Slate Islands to be the central uplift of a complex crater. A circular depression in the lakefloor partially surrounds the islands and may represent the remains of the crater itself. Studies are presently under way in conjunction with Dr. D. York in the Geophysics Division to obtain the age of the impact event using controlled heating $A_{40} - A_{39}$ methods.

Paleointensity Studies of Keweenawan Igneous Rocks

Paleomagnetic studies on Keweenawan rocks over the past 10 years have revealed an apparently well defined magnetic stratigraphy composed of units with both normal and reversed polarity. There are at least two polarity changes in the Keweenawan sequence, of which the younger one (from reversed to normal polarity) has been detected throughout the Lake Superior region.

A characteristic of this reversal is its asymmetry; both magnetization directions lie in a single vertical plane, but the reversed (upward) magnetization has much steeper inclination than the normal (downward) one. Of particular concern in the interpretation of Keweenawan paleomagnetism is whether the change to shallower inclinations reflects a movement of the continent to lower latitudes. If the latter interpretation is correct, and the earth's magnetic field during Keweenawan time was dipolar like the field today, the intensity of the field should decrease toward lower latitudes. On this model the difference in inclination between the normal and reversed directions is such that the reversed intensity should be greater than the normal one by about 50%.

Paleointensity studies of normal and reversed Keweenawan igneous rocks are thus being undertaken by L.J. Pesonen, H.C. Halls and G.W. Pearce to exaimine the credibility of the above model. Suites of oriented samples have been obtained from the Thunder Bay area, across 22 intrusive contracts where Sibley/Rove sedimentary rocks are baked by Logan sills and dikes. Initial results reveal paleointensity curves (obtained by the Thellier-Thellier method) which comprise two linear segments of differing slopes. Preliminary interpretation suggest that the higher temperature segment is due to the baking episode whereas the low temperature line reflects a later partial remagnetization. Calculated paleointensities for reversely magnetized rocks range from 0.9 to 1.3 oe (N=3) and for normally magnetized rocks 0.3 to 0.7 oe (N=2). Since only 5 samples have been measured to date it is too early to say whether this difference in paleointensity of the reversed and normal rocks is significant.

A Paleomagnetic Study of the Copper Harbor Conglomerate, Michigan

Oriented cores have been field-drilled from 210 mafic lava pebbles within the Copper Harbor Conglomerate in the Michigan Native Copper District. Samples were taken from four sites at similar stratigraphic levels along strike in the conglomerate. The aim of the project, by H.C. Halls and H.C. Palmer, is to check the extent to which the formation has been remagnetized, by performing a detailed paleomagnetic conglomerate test. The results are potentially important from two viewpoints:

(a) Previous reconnaissance conglomerate data and asymmetry of Keweenawan reversals suggest (Palmer, 1970) there is a significant secondary component of magnetization present in Keweenawan igneous rocks throughout the Lake Superior region. This component, however, has never been reported from either AC or thermal cleaning experiments. If indeed a secondary component is present which cannot be removed by magnetic washing, it may be a phenomenon that occurs in other mafic igneous rocks. Since many paleomagnetic studies of these rock types exist in the literature, it is possible that an undetected secondary component may be leading to significant errors in published primary directions. Preliminary data on our conglomerate pebbles indicate they indeed have been partially remagnetized as there is a clear departure from randomness in pebble remanence directions. The main objectives now are to show whether this component can be detected by detailed magnetic cleaning and also to determine its cause.

(b) The entire Keweenawan sequence on the Keweenawan Peninsula appears to have been affected by a hydrothermal event sometime after cessation of mafic igneous activity and after much of the lakeward tilting of the sequence had occurred. Associated with this late-stage event is native copper mineralisation in the Portage Lake Volcanics beneath the Copper Harbour Conglomerate and also local copper sulphide emplacement in fine-grained sediments above the conglomerate. An important test of the origin of the secondary component is to see if there is a positive correlation between its magnitude (as determined from the degree of pebble direction randomness) and the level of hydrothermal alteration. Con-

ceivably regions of greater secondary intensity along strike within the conglomerate may overlie areas of high copper mineralisation in the older Portage Lake lava sequence. Paleomagnetic measurements could thus serve as a useful exploration tool, especially in areas of the Keweenawan Peninsula where the volcanics are poorly exposed.

Paleomagnetism of the Baraga County Dike Swarm, Michigan

The Keweenawan rift system in the Lake Superior region is bordered in many areas by diabase dike swarms which parallel the axis of the rift and dip at steep angles towards it. The Baraga dikes in northern Michigan constitute the only major swarm on the south side of the rift. They are strongly magnetic and give rise to linear negative aeromagnetic anomalies, some of which can be traced for more than 70 miles.

An early paleomagnetic study by Graham (1973) showed, as expected, from the aeromagnetic data, that the dikes were reversely magnetized. However, the paleomagnetic pole position he obtained plotted at the apex of the Logan Loop (a hairpin-shaped apparent polar wandering curve derived largely from Keweenawan data). Graham's data were based on samples from only two dikes, and rigorous magnetic cleaning to remove stray components was not performed. The purpose of the present investigation, by L.J. Pesonen and H.C. Halls, is thus to check Graham's pole position, because it is the only one which if verified would place constraints on the position of the apex and hence the depth of the Logan Loop.

A total of 65 oriented samples were obtained, comprising 5 samples from each of 13 dikes. After alternating field cleaning to 400 oe, the mean direction of remanent magnetization for the 13 dikes was $D=109^{\circ}$, $I=-70.5^{\circ}$, with the semi-angle of the 95% confidence cone being 4.0°. The mean direction gave a pole position at Lat. $46.3^{\circ}N$, Long. $139.8^{\circ}W$. These results show that the true Baraga dike pole is almost $30^{\circ}W$ of Graham's original determination, and now coincides almost exactly with the mean pole position of the Lake Nipigon and Thunder Bay Logan sills (Palmer, 1970; Robertson and Fahrig, 1971). If the margins of the Keweenawan rift are restored to a pre-drift position, the Baraga dikes are in close proximity to the Logan sills. It is therefore possible that the Baraga dikes were feeders for some of these sills, or at least were part of the same igneous event. This phase of magmatism appears thus to have been concentrated at the apex of the horseshoe-shaped Keweenawan rift system, and from the position of its paleopoles on the Logan Loop seems to have occurred at an early stage in the development of the rift.

Paleomagnetism of the Sibley Series

Oriented samples from 15 sites within the Sibley Series have now been obtained from the Thunder Bay area. H.C. Halls and R.A. Facer aim to test whether normal and reversed polarities recorded by Robertson (1973) occur at definite stratigraphic levels within the sequence. All samples have been obtained from Sibley exposures remote from baking by cross-cutting Logan dikes and sills.

Alternating field cleaning on pilot specimens from each side suggests that the reversely magnetized units reported by Robertson lie within or are stratigraphically equivalent to, the lowermost Pass Lake Formation of Franklin (1975). The results are as yet inconclusive because necessary thermal cleaning has been delayed owing to construction of a bulk-run furnace.

Magnetic Properties of Artificially Shocked Basalt Samples

H.C. Halls and R. Gibbons have shocked a number of oriented basalt samples in the laboratory at a variety of pressures up to 300 kbar. The purpose of this project is to monitor any changes in the magnetic properties which have occurred after shocking and to use such changes as possible criteria to distinguish shock-induced remanences from other types naturally acquired by rocks.

(f) University of Windsor

Symons, D.T.A., Dept. of Geology, University of Windsor

(i) Paleomagnetism of Grenville-Southern-Superior province rocks for ore genesis, geotectonic, and geochronologic studies. Studies were undertaken on a variety of rock units in the 2.4 to 2.0 b.y. range. See: Cdn. J. Earth Sci. 12, p. 940-948 and Geology 3, p. 303-306.

(ii) Paleomagnetism of plutonic rocks in the Cordillera to interpret their geochronology. Studies were confined to plutonic rocks in the Kitimat-Prince Rupert area of the Coast Ranges. See: J. Geophys. Res., 80, p. 2622-2626.

Stupavsky, M., and Symons, D.T.A., Dept. of Geology, Univ. of Windsor

(i) Paleomagnetic Instrumentation. A thermal demagnetizing apparatus has been constructed by placing a thermally insulated oven in a series of nested Mu metal cans. The performance of the equipment is similar to that of the newly marketed Schonstedt model. The second major improvement results from the construction of a magnetically shielded room (10'x6'x8') built with cheap electrical grade steel. A magnetic field reduction exceeding 99% results from inducing a remanence in the walls that cancels out the ambient field.

Gravenor, C.P., and Stupavsky, M., Dept. of Geology, University of Windsor

(i) Paleomagnetic studies of Lake Wisconsin tills. Studies were undertaken on till units along the shores of Lake Huron and Lake Erie. See: Geol. Soc. Amer. Bul., 85, p. 141-144 and p. 1233-1236.

(ii) Characterization of tills using magnetic susceptibility. Studies were continued into the use of susceptibility for differentiating till units and of magnetic fabric for examining processes of till deposition. See: Can. J. Earth Sci., 10, p. 1068-1078, and Geol. Soc. Amer. Bul., 85, p. 433-436.

(g) University of Western Ontario

Diabase Dikes Southwest of Sudbury (Palmer)

Olivine diabase dikes southwest of Sudbury yield two paleomagnetic groupings. Twenty-nine sites have a mean direction of 263°, $+\frac{1}{2}^{\circ}$ (Sudbury dike direction) with a corresponding paleopole at 166°W, 5°S ($\alpha 95=4^{\circ}$), whereas sixteen sites, generally near and within the Grenville Province, yield a mean direction of 113°, $+30^{\circ}$ (Grenville Front direction) with a corresponding paleopole at 20°W, 3°S ($\alpha 95=9^{\circ}$). Although a few of the sites possessing the Grenville Front direction may be carrying a high temperature TRM as evidenced from baked contact studies, the majority have had their original TRM unblocked during prolonged heating during the 1.0 by Grenville thermal event. Evidence for this hypothesis is provided by sites situated between those exhibiting the Sudbury dike direction only and those possessing the Grenville Front direction only; in these transitionally located sites both directional components can be isolated by progressive AF demagnetization.

K-Ar Age Studies and Petrochemistry of Sudbury Dikes (Merz)

Barbara Merz has begun a study of the Sudbury dikes used in the paleomagnetic study (above) with respect to K-Ar age distribution. In addition major and minor element variations are being measured in those dikes to see if there is evidence for multiple periods of dike intrusion.

Paleomagnetism of Jurassic and Cretaceous Rocks from Chile (Palmer, MacDonald)

A collection of field drilled cores from Chilean Jurassic and Cretaceous rocks was made during the summer of 1974. These serve to supplement the earlier collection of block samples which yielded internally consistent directional results. The routine paleomagnetic work on the new collection is underway.

Keweenawan Conglomerate Tests (Palmer, and H.C. Halls, University of Toronto)

During the summer of 1975 over 200 oriented samples of conglomerate clasts were collected

from conglomerate layers within the Copper Harbor conglomerate of the Keweenawan Peninsula of Michigan. The sampling was designed, by collecting close to and far away from overlying lava flows, to discriminate between local and regional baking effects on the acquisition of secondary remanence in Keweenawan lavas. The data obtained to date suggest that a regionally imposed secondary remanence is present in the Keweenawan lavas and that the direction of the secondary remanence is in the appropriate orientation to have produced the asymetric normal and reversed polarities observed in Keweenawan lava sequences.

Paleomagnetism of the Rapitan Formation (Morris)

Preliminary measurements have been completed on the suite of samples collected in the 1974 field season and additional samples were collected during the 1975 field season, working with the Earth Physics Branch who are continuing the project.

Magnetization of Isua Supracrustal Sequence of Greenland (Carmichael)

The magnetization of the oriented blocks is complicated with some being very intensely magnetized on the surface possibly by lightning. Both AF and thermal demagnetization are being used to try to recover an original magnetization for paleointensity studies.

8. Core Dynamics

(a) University of Alberta

(i) *Experimental studies*

Maintenance of the geodynamo requires some distribution of velocity in the Earth's fluid outer core. If we model the outer core as a homogeneous fluid in which the temperature gradient exceeds the adiabatic gradient then a dynamo driven by convection is possible. However, if this temperature condition is not fulfilled then convection is impossible and the only possible radial motions are oscillatory. In this case we must examine the role of internal gravity waves and inertial waves in relation to the dynamo problem.

K.D. Aldridge has studied a limiting case of this problem in which the core is neutrally stratified and the effects of rotation alone are considered. Those oscillations of a rotating fluid which owe their existence to rotation are called inertial oscillations and are described by the Poincare equation. Since this equation is hyperbolic and conditions at the inner core and outer core boundaries are specified, the problem is said to be ill-posed. It follows that there is no guarantee that inertial oscillations will exist in the outer core at least in the inviscid limit. Some laboratory experiments have shown conclusively that the axisymmetric class of inertial oscillations does exist in a spherical shell geometry and these experiments have been interpreted analytically with a certain variational principle.

It has been suggested that the observed westward drift of the non-dipole part of the geomagnetic field may be due to the propagation of hydromagnetic waves in the fluid outer core. Recent work has shown that under certain conditions these hydromagnetic waves are also described by the Poincare equation for the non-axially symmetric inertial oscillations of a rotating fluid. We are pursuing the study of these oscillations both experimentally and analytically in order to understand their role in the geodynamo problem.

A study on the inertial oscillations of a fluid in a cylinder during spin-up from rest has recently been completed. The dependence of inertial oscillation frequency on time since a cylindrical container began rotating from rest is established experimentally for several axially symmetric modes of oscillation. The oscillations were excited by including a sinusoidal perturbation in the rotation speed of the container which served to establish an exchange of fluid between the viscous boundary layers and the interior. The interior is set into oscillation by the boundary layer flow and the resulting axial pressure differences are used to establish the amplitude of the inertial oscillation. The best agreement between our experiments and the theoretical work by Lynn (1973) on the time-dependence of inertial oscillation frequency occurs for the lowest frequency

modes. From a limited study on amplitude of the inertial oscillations it appears that the growth rate of these disturbances is such that e^{-1} of the ultimate amplitude is achieved after one and a half spin up times from the time that the container is switched on. No non-linear effects in perturbation amplitude for the dependence of inertial oscillation frequency on time were found for the perturbation amplitudes used in these experiments.

(ii) *Theoretical Hydrodynamics*

The stability of a horizontal layer of dielectric fluid under the simultaneous action of a vertical D.C. electric field and a vertical temperature gradient has been studied analytically. From a geophysical standpoint, the problem of the onset of convective instability in a dielectric fluid under the simultaneous action of an electric field and a temperature gradient is of particular interest, since the electric field can provide the driving force in laboratory models of thermal convection in the Earth's core. Traditional laboratory experiments in thermal convection are restricted by the fact that they must be carried out in the uniform gravitational field of the earth. If the driving force is instead an electric field which can be shaped to have the point symmetry of the actual gravitational field of the earth's core for example, then the above restriction can be removed.

Linear stability theory has been applied by M. Takashima and K.D. Aldridge to the problem of the onset of convective instability in an infinite layer of poorly conducting dielectric fluid confined between two horizontal rigid planes under the simultaneous action of a vertical D.C. electric field and a vertical temperature gradient. Both the dielectric constant and the electrical conductivity of the fluid are assumed to be functions of temperature. Applying approximations analogous to the usual Boussinesq approximation, an equation of sixth order with space-varying coefficients and the relevant boundary conditions are derived. Under the assumption that the neutral state is a stationary one, the method of power series expansion is used to obtain the eigenvalue relationship which is then computed numerically. It is shown that (1) the temperature dependence of the dielectric constant has no significant effect on the fluid layer; (2) when the electrical conductivity is assumed to be a linear function of temperature, the electric field exhibits a stabilizing effect on the fluid layer; (3) when the electrical conductivity is assumed to be a quadratic function of temperature, the electric field can exhibit a strongly destabilizing effect on the fluid layer and the numerical results in this case coincide with the existing experimental results as to the order of magnitude.

9. Magnetosphere Studies

(a) University of Alberta

During the past year the space physics group, led by G. Rostoker, has concentrated on analysis of meridan line magnetometer data, and has joined with D.I. Gough and J.R. Bannister in the studies of longitudinal scale structure of electrojet and micropulsation activity using data from a two-dimensional array of magnetometers. While, at the present time, the group is only operating one observatory (Fort Smith), the magnetometer systems used in earlier meridian line studies are presently being refurbished for use during the International Magnetospheric Study (1976-1979). During this period, the group will operate seven observatories arrayed in a cross configuration. Combined with the Churchill and Alaska lines, the Alberta array will constitute a powerful tool for the study of magnetospheric activity at high latitudes. Data from the station line will be made available through the World Data Centre to all experimenters. Dr. D.W. Oldenburg will join the group at the beginning of 1976 and will be responsible for the operation of the station array, as well as participating in the data analysis. Dr. Oldenburg is presently applying linear inversion techniques to gain information on the quantitative aspects of current flows responsible for high latitude magnetic activity. Dr. K. Kawasaki has recently joined the group and will be continuing his ongoing studies of current systems associated with high latitude geomagnetic activity.

In collaboration with R. Bostrom (The Royal Institute of Technology, Stockholm, Sweden), G. Rostoker has developed a theoretical model for the generation of Birkeland currents which penetrate the nightside auroral oval. Their theory predicts an electric field configuration in the magnetotail which is significantly different from models proposed to date. Based on

this electric field configuration, Dr. Rostoker has developed a theory for the formation of the plasma sheet, which contends that hydrodynamic forces drive the plasma mantle material into the center of the tail where it is forced through the action of pressure gradients to flow towards the earth as a "backward jet". Together with M. Hron, Dr. Rostoker has demonstrated the existence of an eastward electrojet in the dawn sector, which flows immediately equatorward of the convection westward electrojet. It is found that both the eastward jet and the westward convection jet to the north map into the plasma sheet. In collaboration with R.P. Sharma and M. Hron, Dr. Rostoker completed a study of the relationship of thermal plasma peaks at 1400 km to the auroral (convection) electrojets. It was found, using ISIS 2 topside sounder data and magnetometer meridian line data, that in the evening sector there was a peak in thermal plasma density above the poleward half of the eastward electrojet. In the morning sector, the peak in thermal plasma density tended to occur across the entire electrojet region.

In collaboration with G. Rostoker, Dr. J.V. Olson has found that Pi 2 pulsation onsets, maximum amplitudes and the broadest spectral features are associated with the poleward boundary of the substorm electrojet. A current study has produced evidence that a significant amount of the energy in the dominant spectral components is produced in the electrojet itself. Pc3-4 micropulsations formed the basis of a joint study by Dr. Olson with E. Greenstadt of TRW Laboratories of Los Angeles. This study attempted to verify certain correlations reported between the state of the magnetic field in the solar wind and dayside continuous micropulsations. No consistent correlation was found, which would seem to indicate that individual event correlations reported earlier by other investigators may have been fortuitous. Finally, Dr. Olson has been involved in a study of possible contamination, produced by magnetic storms, of the magnetic records taken during activity. The study is continuing with Dr. P. Davis of the Institute in an attempt to remove the contaiminating signals and thereby increase the probability of detecting seismic and volcanic disturbances in magnetic records.

R.P. Sharma has initiated a study of the relationship between solar-magnetospheric effects and tropospheric weather disturbances. The solar parameters used were solar sector boundaries, as swept past the earth by the solar wind and the magnetic disturbances. Three meteorological parameters were studied, viz. polar zonal indices, atmospheric pressure at Fairbanks, Alaska and minimum temperatures at Edmonton. Preliminary studies indicate that all the three parameters show a marked correlation with solar sector boundaries and magnetic disturbances.

Dr. Sharma is also studying field-aligned irregularities in the topside ionosphere using data recorded by Canadian satellites Alouette 1, II and ISIS 1 and II. In particular, the spatial-temporal variations and the effect of magnetic disturbances on the occurrence of these irregularities are under investigation.

D.D. Wallis, in collaboration with G. Rostoker and C.D. Anger (University of Calgary), has continued his investigations of the relationship between the visible aurora and the auroral electrojets. They suggest that discrete arcs poleward of the electrojet found previously to be unassociated with measureable magnetic perturbations result from a depressed ionospheric electric field in the volume seen by the nagnetometer.

Utilizing the inversion programs developed by Dr. D.W. Oldenburg, the current density profiles of several electrojets in the evening have been studied. The general characteristic of the current density profile is a broad (5 to 15^{o} of latitude) region of low current density (consistent with those limits derived from the ΔZ perturbation extrema) with a superimposed narrow region of no more than one to two degrees in width of much larger current densities. These narrow current enhancements are frequently found in direct association with discrete arc systems, but sometimes occur between them. Dr. Wallis has now left the Institute and has joined the Department of Physics in the University of Calgary as a Research Associate.

Three doctoral projects are in varying stages of completion within the space physics group.

R.G. Wiens is completing a study of the development of the substorm westward electrojet. He has shown that the electrojet develops in a stepwise fashion, with each new segment being generated to the north and west of the preceding one. He is relating the character of the

auroral forms generated in conjunction with each step, to the characteristic development of the associated electrojet element, and will model the current flow associated with the developing electrojet.

T.J. Hughes has been investigating net current flow into and out of the portion of the ionosphere through which the auroral electrojets flow. He finds net upward current flow in the pre-midnight quadrant concentrated near the poleward border of the eastward electrojet, while the entire morning sector features net downward current flow spread approximately uniformly across the westward electrojet region. He is presently modelling the current flow in the high latitude regions of the ionosphere using inversion techniques developed by D.W. Oldenburg in the space physics group.

H.L. Lam is concluding his study of Pc 5 micropulsation activity, and has found a striking relationship between the behavior of the ionospheric electrojets and the pulsations themselves. In particular he finds that several frequency components in the Pc 5 spectrum may peak near one latitude, and this latitude lies within the electrojet regime. Changes in electrojet magnitude and position have a distinct effect on the character of the pulsational activity, and it is suggested that oscillations in the electric circuits representing the current loops associated with the electrojets are a source of at least a portion of the Pc 5 micropulsation spectrum.

10. Bibliography: GEOMAGNETISM

1. Alabi, A.O., P.A. Camfield and D.I. Gough: The North American Central Plains conductivity anomaly, (in press).

2. Aldridge, K.D.: Inertial waves and the Earth's outer core, Geophys. J. 42, 337-345, 1975.

3. Annan, A.P., W.M. Waller, D.W. Strangway, J.R. Rossiter, J.D. Redman and R.D. Watts: The Electromagnetic Response of Low-loss, 2-layer, Dielectric earth for horizontal Electric Dipole Excitation, Geophysics, 40, 285-298, 1975.

4. Armstrong, J.C., S.-I. Akasofu and G. Rostoker: A comparison of satellite observations of Birkeland currents with ground observations of visible aurora and ionospheric currents, J. Geophys. Res. 80, 575-586, 1975.

5. Bailey, M.E.: The magnetic properties of psuedo-single-domain grains, M.Sc. thesis, University of Toronto, 1975.

6. Bailey, R.C. and R.N. Edwards: The effect of source field polarization on geomagnetic variations in the British Isles. Geophys. J.R. Ast. Soc., (in press).

7. Bingham, D.K. and M.E. Evans: Precambrian geomagnetic field reversal, Nature 253, 332-333, 1975.

8. Boetzkes, P.C. and D.I. Gough: A spinner magnetometer for susceptibility anisotropy in rocks, Can. J. Earth Sci. 12, 1448-1464, 1975.

9. Brewitt-Taylor, C.R.: A model for the Coast-Effect, Phys. Earth Planet. Int., 10, 151-158, 1975.

10. Brewitt-Taylor, C.R.: Self-potential prospecting in the deep oceans, Geology, September, 1975.

11. Buchan, K.L. and D.J. Dunlop: Paleomagnetism of the Haliburton intrusions: superimposed magnetizations, metamorphism and tectonics in the late Precambrian, J. Geophys. Res. (in press).

12. Burke, M.D., A.O. Alabi and D.I. Gough: A digital converter and editing system for photographic analog data, J. Geomag. Geolectr., (in press).

13. Camfield, P.A. and D.I. Gough: Anomalies in daily variation magnetic fields and structure under northwestern United States and southwestern Canada, Geophys. J. 41, 193-218, 1975.

14. Carmichael, C.M. and H.M. Sullivan: National report for Canada, Geomagnetism and Aeronomy, 1971-1974, 107 pages, Earth Physics Branch, Ottawa, 1975.

15. Couillard, R. and E. Irving: Paleolatitude and reversals: evidence from Cretaceous period. Geol. Assn. Canada Special Paper No. 13, p. 21-29, 1975.

16. Carnes, J.G., D.W. Strangway and W.A. Gose: Field-strength dependence of the viscous remanent magnetization in lunar samples, Earth and Plante. Sci. Letters, 26, 1-7, 1975.

17. Davis, P.M.: The volcanomagnetic anomaly field above a centre of dilation, J. Geomag. Geoelectr. (in press).

18. Davis, P.M. and M.E. Evans: Interacting single domain properties of magnetite intergrowths, J. Geophys. Res., (in press).

19. Davis, P.M. and F.D. Stacey: Direct measurement of magnetostriction in rocks using capacitance micrometry, Geophys. J., (in press).

20. De Beer, J.H., D.I. Gough and J.S. Van Zijl: An electrical conductivity anomaly and rifting in southern Africa, Nature 225, 678-680, 1975.

21. Deutsch, E.R., R.R. Pätzold and G.S. Murthy: Paleomagnetism of the Leg 37 basalts; in P.T. Robinson, editor, Initial Reports of the Deep Sea Drilling Project, vol. 37, Washington, U.S. Government Printing Office, (in press).

22. Deutsch, E.R. and R.R. Pätzold: Magnetic properties and domain state of basalt cores from the Nazca Plate, in Reports of the Deep Sea Drilling Project, vol. 34, eds. S.R. Hart and R.S. Yeats, Washington (U.S. Government Printing Office), 1975, (in press).

23. Dunlop, D.J., M.E. Bailey and M.F. Westcott-Lewis, Lunar paleointensity determination using anhysteretic remanence (ARM): a critique, Proc. 6th. Lunar Sci. Conf., Geochim. Cosmochim. Acta, Suppl. 6, (in press).

24. Dunlop, D.J. and C.J. Hale: Magnetic properties of Leg 37 basalts and a determination of paleomagnetic field intensity, Initial Reports of the Deep Sea Drilling Project, vol. 37 (in press).

25. Dunlop, D.J. and Buchan, K.L.: Paleomagnetics in the southern Geotraverse region, Geotraverse Workshop, paper 27, Toronto, Feb. 1975.

26. Dunlop, D.J. and E.D. Waddington: The field dependence of thermoremanent magnetization in igneous rocks, Earth Planet. Sci. Lett., 25, 11-25, 1975.

27. Edwards, R.N. and J.G. Greenhouse, 1975. Geomagnetic variations in the eastern United States: Evidence for a highly-conducting lower layer?, Science, 188, 726-728, 1975.

28. Evans, M.E., K.K. Bingham and E.W. McMurry: New Paleomagnetic results from the upper Belt-Purcell Supergroup of Alberta, Can. J. Earth Sci. 12, 52-61, 1975.

29. Frisillo, A.L., G.R. Olhoeft and D.W. Strangway: Effects of Vertical Stress, Temperature and Density on the Electrical Properties of Lunar Samples 72441, 12, 15301, 38 and a Terrestrial Basalt, Earth and Planetary Science Letters, 24, 345-356, 1975.

30. Garland, G.D.: Correlation between electrical conductivity and other geophysical parameters, Phys. Earth Plan. Int. 10, 220-230, 1975.

31. Goldstein, M.A. and D.W. Strangway: Audio frequency magnetotellurics with grounded electric dipole source, Geophysics, 40, 669-683, 1975.

32. Gupta, J.C.: Long period Pc5 pulsations. Planet Space Sci., 23, p. 733-750, 1975.

33. Halls, H.C.: Shock-induced remanent magnetization in late Precambrian rocks from Lake Superior. Nature, 225, 692-695. 1975.

34. Haworth, R.T.: The development of Atlantic Canada as a result of continental collision - Evidence from offshore gravity and magnetic data. In: Canada's Continental Margins and Offshore Petroleum Exploration. Ed. C.J. Yorath, E.R. Parker and D.J. Glass. Can. Soc. Petrol. Geol. Memoir 4, 59-77, 1975.

35. Haworth, R.T., and B.V. Sanford: Paleozoic geology of northeast Gulf of St. Lawrence, Geolog. Surv. Can. Paper 76-1A, 1975.

36. Haworth, R.T., W.H. Poole, A.C. Grant and B.V. Sanford: Marine geoscience survey, northeast of Newfoundland, Geol. Surv. Can. Paper 76-1A, 1975.

37. Horita, R.E., B.P. Smith, T. Watanabe, R.E. Barrington and F.H. Palmer: ELF emissions observed near the plasmapause and plasma sheet, J. Atmos. Terr. Phys. 37, 1263-1269, 1975.

38. Hoye, G.S. and M.E. Evans: Remanent magnetizations in oxidized olivine. Geophys. J. 41, 139-151, 1975.

39. Irving, E. and P.L. Lapointe: Paleomagnetism of Precambrian rocks of Laurentia. Geoscience Canada, 2, p. 90-98, 1975.

40. Irving E. and J. Hastie: Catalogue of paleomagnetic directions and poles, second issue: Precambrian results 1957-1974, Geomag. Series Earth Phys. Br. No. 3, 1975.

41. Jones, F.W. and J.E. Lokken: Irregular coastline and channelling effects in three-dimensional geomagnetic perturbation models, Phys. Earth Planet. Int. 10, 140-150, 1975.

42. Keen, C.E., D.L. Barrett and D.E. Heffler: Some aspects of the ocean-continent transition at the continental margin of eastern North America, Geol. Surv. Can. Paper 74-30, 2. 189-192, 1975.

43. King, L.H., R.D. Hyndman and C.E. Keen: Geological development of the continental margin of Atlantic Canada, Geoscience Canada, 2, 26-35, 1975.

44. Koziar, A. and D.W. Strangway: Magnetotelluric sounding of permafrost, Science, (in press), 1975.

45. Kristjansson, L. and J.P. Hodych: A simple ballistic magnetometer, American Journal of Physics, 43 pp. 465-6, 1975.

46. Kurtz, R.D. and G.D. Garland: Magnetotelluric measurements in eastern Canada, Geophys. Journ. Roy. Astron. Soc., (in press).

47. Lanzerotti, L.J., C.G. Maclennan, H. Fukunishi, J.K. Walker, and D.J. Williams: Latitude and longitude dependence of storm time Pc5 type plasma wave. J. Geophys. Res., 80, p. 1014-1018, 1975.

48. Loomer, E.I.: Annual report for magnetic observatories-1970. Geomag. Series Earth Phys. Br. No. 2, pp. 87, 1975.

49. Macnab, R.F., and S.P. Srivastava: A regional geophysical survey of the Labrador Sea, Geol. Surv. Can. Paper 75-1A, 177-179, 1975.

50. McGlynn, J.C. and E. Irving: Paleomagnetism of early Aphebian diabase dykes from the Slave Structural Province, Canada. Tectonophysics, 26, p. 23-38, 1975.

51. McWilliams, M.O. and D.J. Dunlop, Precambrian paleomagnetism: magnetizations reset by the Grenville orogeny, Science, 190, 269-272, 1975.

52. Murthy, G.S. and E.R. Deutsch: A new Precambrian paleomagnetic pole for Europe, Phys. Earth Planet. Interiors, (in press), 1975.

53. Murthy, G.S. and K.V. Rao: Paleomagnetism of Steel Mountain and Indian Head anorthosites

from western Newfoundland, Canadian J. Earth Sci., 13, (in press), 1975.

54. Murthy, G.S., E.R. Deutsch and R.R. Pätzold: Inferences on the magnetic domain state of Leg 37 basalts: in P.T. Robinson, editor, Initial Reports of the Deep Sea Drilling Project, vol. 37, Washington U.S. Government Printing Office, (in press), 1975.

55. Niblett, E.R.: Electromagnetic induction in the earth, Geoscience Canada, 2, p. 47-51, 1975.

56. Oguti, T. and T. Watanabe: On-off switching aurorae and geomagnetic pulsations, Accepted by J. Atmos Terr. Phys., 1975.

57. Olhoeft, G.R., and D.W. Strangway: Dielectric Properties of the first 100 meters of the Moon, Earth and Planetary Science Letters, 24, 394-404, 1975.

58. Olhoeft, G.R., D.W. Strangway and G.W. Pearce: The effects of water on the Electrical Properties of Lunar fines, Proc. of the 6th Lunar Science Conf., (in press), 1975.

59. Olhoeft, G.R.: Electrical properties of permafrost, Canadian Journal of Earth Sciences, (in press).

60. Olhoeft, G.R.: Electrical Properties of Rocks, Proc. of NATO symposium on Physical Properties of Rocks and Minerals, (in press).

61. Olson, J.V. and G. Rostoker: Pi2 pulsations and the auroral electrojet, Planet. Space Sci. 23, 1129-1139, 1975.

62. Palmer, H.C. and A.Hayatsu: Paleomagnetism and K-Ar dating of some Franklin lavas and diabases, Victoria Island, C.J.E.S. 12, pp. 1439-1447, 1975.

63. Papezik, V.S., J.P. Hodych, and A.K. Goodacre: The Avalon Magnetic lineament: A possible continuation of the Triassic dike system of New Brunswick and Nova Scotia, C.J.E.S., 12, pp. 332-5, 1975.

64. Park, J.K.: Paleomagnetism of the Flin Flon-Snow Lake Greenstone Belt, Manitoba and Saskatchewan. Can. J. Earth, Sci., 12, 1272-1290, 1975.

65. Pullaiah, G., E. Irving, K.L. Buchan and D.J. Dunlop: Magnetization changes caused by burial and uplift, Earth Planet. Sci. Lett., (in press).

66. Pullaiah, G. and E. Irving: Paleomagnetism of the contact aureole and late dikes of the Otto Stock, Ontario, and its application to early Proterozoic apparent polar wandering Can. J. Earth Sci., 12, p. 1609-1618, 1975.

67. Rahman, A., D.I. Gough and M.E. Evans: Anisotropy of magnetic susceptibility of the Martin Formation Saskatchewan, and its sedimentological implications, Can. J. Earth Sci. 12, 1465-1473, 1975.

68. Ramaswamy, V., W. Nienaber, H.W. Dosso, F.W. Jones and L.K. Law: Numerical and analogue model results for an island situated near a coastline, Phys. Earth Planet. Int. (in press).

69. Ramaswamy, V. and H.W. Dosso: Effect of a Conducting Overburden on the Fields of a Buried Dipole Source, Can. J. Phys., 53, 598-609, 1975.

70. Rankin, D., I.K. Reddy and K. Schneider: On the interpretation of continuous resistivity distributions in the magnetotelluric method, Geophys. J. (in press).

71. Reddy, I.K. and D. Rankin, Magnetotelluric response of lateral inhomogeneous and anisotropic media, Geophysics, (in press).

72. Ross, D.I., C.E. Keen and B.R. Pelletier: Geology and Geophysics of Baffin Bay, Geol. Surv. Can. Paper 74-30, 2, 247-258, 1975.

73. Rossiter, J.R., D.W. Strangway, A.P. Annan, R.D. Watts, and J.D. Redman: Detection of thin layers of Radio Interferometry, Geophysics, 40, 299-308, 1975.

74. Rostoker, G. and R. Böstrom: A mechanism for driving the gross Birkeland current configuration in the auroral oval, J. Geophys. Res., (in press).

75. Rostoker, G. and M.P. Hron, The eastward electrojet in the dawn sector, Planet. Space Sci., (in press).

76. Rostoker, G., Studies of magnetic substorms using ground based, balloon, rocket and satellite observations, Proc. Symposium on European Sounding Rocket and Scientific Balloon Activity at High Latitudes, ESRO Special Publ. 107, 125-140, 1975.

77. Rostoker, G., J.C. Armstrong and A.J. Zmuda: Field aligned current flow associated with the intrusion of the substorm-intensified westward electrojet into the evening sector, J. Geophs. Res. 80, 3571-3579, 1975.

78. Rostoker, G., J.L. Kisabeth, R.D. Sharp and E.G. Shelley: The expansive phase of magnetospheric substorms, 2. The response at synchronous altitude of particles of different energy ranges, J. Geophys. Res. 80, 3557-3570, 1975.

79. Seguin, M.K.-: Paleomagnetic study of the Murdoch formation and gabbroic intrusives in the Thompson Lake and Menihek formations, Central Labrador Trough. Abstract, 28th Meeting, Geological Association of Canada, p. 853-854, Waterloo, Ontario, 1975.

80. Seguin, M.K.-: and R. Laurent: Petrological Features of Pillow-Lavas from the Thetford-Mines Ophiolite (Quebec). Can. Journ. of Earth Sciences, Vol. 12, No. 8, p. 1406-1421, 1975.

81. Seguin, M.K.-: Conception et construction d'un four électrique de désaimantation des roches, Abh. d. Braunsch. Wissens, Gesells., Band XXIV, s. 61-78, 1975.

82. Seguin, M.K.-: Détermination de la géométrie et des propriétés du pergelisol discontinu de la région de Schefferville. Abstract, 9th Meeting, Geological Society of America, North-Central Section, Vol. 7, No. 6, p. 853; Waterloo, Ontario, 1975.

83. Seguin, M.K.-: Exploration of magnetic taconite and itabirite with integrated aeroelectromagnetic and magnetic methods. Abstract, 37th Meeting European Association of Exploration Geophysicists, p. 40-40a.

84. Seguin, M.K.-: - 2 articles dont le contenu se rattache à cette recherche publiés dans Geophysical Prospecting et magyar Geofizika, (1975a, 1975b).

85. Sharp, R.D., E.G. Shelley and G. Rostoker: A relationship between synchronous altitude electron fluxes and the auroral electrojet, J. Geophys. Res. 80, 2319-2324, 1975.

86. Srivastava, S.P.: Seafloor spreading history of the Labrador Sea, Geol. Surv. Can. Paper 75-1A, 185, 1975.

87. Srivastava, S.P.: An assessment of the methods used in applying diurnal correction to marine magnetic data, Geol. Surv. Can. Paper 75-1A, 1975.

88. Strangway, D.W. and G.R. Olhoeft: Electrical Properties of Planetary Surfaces, Trans. Roy Soc. of London, (in press).

89. Strangway, D.W.: New Techniques in Geophysical Exploration for minerals, Technology Review, 35-37, May, 1975.

90. Strangway, D.W., G.W. Pearce and G.R. Olhoeft, Magnetic and Dielectric Properties of the Moon, Proc. of Soviet-American Conference on Cosmochemistry of the Moon and Planets, NASA Special Publication, 1975.

91. Strangway, D.W., J.C. Rylaarsdam and A.P. Annan: Magnetic Anomalies near Van de Graaff

Crater, Proc. of the 6th Lunar Science Conf., (in press), 1975.

92. Stuckless, S.K., Aeormagnetic expression of rocks of the eastern half of the mobile belt of Newfoundland, B.Sc. thesis, Physics Department, Memorial University of Newfoundland, 1975.

93. Takashima, M. and K.D. Aldridge, The stability of a horizontal layer of dielectric fluid under the simultaneous action of a vertical d.c. electric field and a vertical temperature gradient, Q.J. Mech. Appl. Math. (in press).

94. Thomson, D.J. and J.T. Weaver: The Complex Image Approximation for Induction in a Multilayered Earth., J. Geophys. Res., 80, 123-129, 1975.

95. Trigg, D.F.: A high-capacity, low-power data logger, Geomag. Series Earth Phys. Br. No. 1, 11 pp., 1975.

96. Ueda, H.: A comparison of a ferromagnetic core coil and an air core coil as a sensor head of the induction magnetometer, M.Sc. Thesis, U.B.C., 1975.

97. Ueda, H. and T. Watanabe: Several problems about sensitivity and frequency response of an induction magnetometer, Sci. Rept. Tohoku Univ., Ser. 5, Geophys. 22, 107-127, 1975.

98. Ueda, H. and T. Watanabe: Comments on the anti-resonance method to measure the circuit constants of a coil used as a sensor of an induction magnetometer, Sci. Rept. Tohoku Univ., Ser. 5, Geophys. 22, 129-135, 1975.

99. Ueno, H., E. Irving and R.H. McNutt: Paleomagnetism of the Whitestone anorthosite and diorite, the Grenville Polar Track, and the relative motions of the Laurentian and Baltic Shields, Can. J. Earth Sci., 12, p. 209-226, 1975.

100. van der Linden, W.J.M.: Crustal attenuation and seafloor spreading in the Labrador Sea, Earth and Planet. Sci. Lett. 27, 409-423, 1975.

101. van der Linden, W.J.M., and S.P. Srivastava: Crustal study of the Labrador continental margin, Geol. Surv. Paper 75-1A, 187, 1975.

102. Wallis, D.D.: Comparison of auroral electrojets and the visible aurora, Earth's Magnetospheric Processes, (in press).

103. Wallis, D.D., C.D. Anger and G. Rostoker: The spatial relationship of the auroral electrojets and the visible aurora in the evening sector, J. Geophys. Res., (in press).

104. Weins, R.G. and G. Rostoker: Characteristics of the development of the westward electrojet during the expansive phase of magnetospheric substorms, J. Geophys. Res. 80, 2109-2128, 1975.

IV(B) AERONOMY

Compiled by: Dr. E.J. Llewellyn,
Dr. A.H. Manson,
Editors, Aeronomy Newsletter

1. University of Alberta

Institute of Earth and Planetary Physics

i) *Electrojet and Micropulsations (G. Rostoker)*

During the past year the space physics group has concentrated on analysis of meridian line magnetometer data, and has joined with Dr. D.I. Gough and Mr. J.R. Bannister in the studies of longitudinal scale structure of electrojet and micropulsation activity using data from a two-dimensional array of magnetometers. While, at the present time, the group is only operating one observatory (Fort Smith), the magnetometer systems used in earlier meridian line studies are presently being refurbished for use during the International Magnetospheric Study (1976-1979). During this period, the group will operate seven observatories arrayed in a cross configuration. Combined with the Churchill and Alaska Lines, the Alberta array will constitute a powerful tool for the study of magnetospheric activity at high latitudes. Data from the station line will be made available through the World Data Center to all experimenters. Dr. D.W. Oldenburg will join the group at the beginning of 1976 and will be responsible for the operation of the station array, as well as participating in the data analysis. Dr. Oldenburg is presently applying linear inversion techniques to gain information on the quantitative aspects of current flows responsible for high latitude magnetic activity. Dr. K. Kawasaki has recently joined the group and will be continuing his ongoing studies of current systems associated with high latitude geomagnetic activity.

In collaboration with R. Boström (the Royal Institute of Technology, Stockholm, Sweden), G. Rostoker has developed a theoretical model for the generation of Birkeland currents which penetrate the nightside auroral oval. Their theory predicts an electric field configuration in the magnetotail which is significantly different from models proposed to date. Based on this electric field configuration, Dr. Rostoker has developed a theory for the formation of the plasma sheet, which contends that hydrodynamic forces drive the plasma mantle material into the center of the tail where it is forced through the action of pressure gradients to flow towards the earth as a "backward jet". Together with M. Hron, Dr. Rostoker has demonstrated the existence of an eastward electrojet in the dawn sector, which flows immediately equatorward of the convection westward electrojet. It is found that both the eastward jet and the westward convection jet to the north map into the plasma sheet. In collaboration with R.P. Sharma and M. Hron, Dr. Rostoker completed a study of the relationship of thermal plasma peaks at 1400 km to the auroral (convection) electrojets. It was found, using ISIS 2 topside sounder data and magnetometer meridian line data, that in the evening sector there was a peak in thermal plasma density above the poleward half of the eastward electrojet. In the morning sector, the peak in thermal plasma density tended to occur across the entire electrojet region.

In collaboration with G. Rostoker, Dr. J.V. Olson has found that Pi2 pulsation onsets, maximum amplitudes and the broadest spectral features are associated with the poleward boundary of the substorm electrojet. A current study has produced evidence that a significant amount of the energy in the dominant spectral components is produced in the electrojet itself. Pc3-4 micropulsations formed the basis of a joint study by Dr. Olson with E. Greenstadt of TRW Laboratories of Los Angeles. This study attempted to verify certain correlations reported between the state of the magnetic field in the solar wind and dayside continuous micropulsations. No consistent correlation was found, which would seem to indicate that individual event correlations reported earlier by other investigators may have been fortuitous. Finally, Dr. Olson has been involved in a study of possible contamination of the magnetic records taken during earthquakes and volcanic activity produced by magnetic storms. The study is continuing with Dr. P. Davis of the Institute in an attempt to remove the contaminating signals and thereby increase the probability of detecting seismic and volcanic disturbances in magnetic records.

R.P. Sharma has initiated a study of the relationship between solar-magnetospheric effects and tropospheric weather disturbances. The solar parameters used were solar sector boundaries, as swept past the earth by the solar wind and the magnetic disturbances. Three meteorological parameters were studied, viz. polar zonal indices, atmospheric pressure at Fairbanks, Alaska and minimum temperatures at Edmonton. Preliminary studies indicate that all the three parameters show a marked correlation with solar sector boundaries and magnetic disturbances.

Dr. Sharma is also studying field-aligned irregularities in the top-side ionosphere using data recorded by Canadian satellites, Alouette I, II and ISIS I and II. In particular, the spatial-temporal variations and the effect of magnetic disturbances on the occurrence of these irregularities are under investigation.

D.D. Wallis, in collaboration with G. Rostoker and C.D. Anger (University of Calgary), has continued his investigations of the relationship between the visible aurora and the auroral electrojets. They suggest that discrete arcs poleward of the electrojet found previously to be unassociated with measureable magnetic perturbations result from a depressed ionospheric electric field in the volume seen by the magnetometer.

Utilizing the inversion programs developed by Dr. D.W. Oldenburg, the current density profiles of several electrojets in the evening have been studied. The general characteristic of the current density profile is a broad (5 to 15^{o} of latitude) region of low current density (consistent with those limits derived from the ΔZ perturbation extrema) with a superimposed narrow region of no more than one to two degrees in width of much larger current densities. These narrow current enhancements are frequently found in direct association with discrete arc systems, but sometimes occur between them. Dr. Wallis has now left the Institute and has joined the Department of Physics in the University of Calgary as a Research Associate.

Three doctoral projects are in varying stages of completion within the space physics group.

R.G. Wiens is completing a study of the development of the substorm westward electrojet. He has shown that the electrojet develops in a stepwise fashion, with each new segment being generated to the north and west of the preceding one. He is relating the character of the auroral forms generated in conjunction with each step, to the characteristic development of the associated electrojet element, and will model the current flow associated with the developing electrojet.

T.J. Hughes has been investigating net current flow into and out of the portion of the ionosphere through which the auroral electrojets flow. He finds net upward current flow in the pre-midnight quadrant concentrated near the poleward border of the eastward electrojet, while the entire morning sector features net downward current flow spread approximately uniformly across the westward electrojet region. He is presently modelling the current flow in the high latitude regions of the ionosphere using inversion techniques developed by D.W. Oldenburg in the space physics group.

H.L. Lam is concluding his study of Pc5 micropulsation activity, and has found a striking relationship between the behaviour of the ionospheric electrojets and the pulsations themselves. In particular he finds that several frequency components in the Pc5 spectrum may peak near one latitude, and this latitude lies within the electrojet regime. Changes in electrojet magnitude and position have a distinct effect on the character of the pulsational activity, and it is suggested that oscillations in the electric circuits representing the current loops associated with the electrojets are a source of at least a portion of the Pc5 micropulsation spectrum.

2. University of British Columbia

Department of Geophysics and Astronomy

(Aeronomy Group - H. Veda, T. Watanabe, G. Nourry)

Research has focussed on magnetic pulsations. Preparation for an IMS project of observing magnetic pulsations at many stations in Western Canada has been in progress. An induction magnetometer, inexpensive and yet excellent in performance, has been successfully designed. A preliminary field work to test the magnetometer has been carried out at Thompson, Manitoba. A survey of man-made magnetic noise has also been made there and at four other candidate sites. On the theoretical side, we have been investigating relations between magnetic pulsations and several other magnetospheric and interplanetary phenomena such as auroral displays, VLF radio emissions and solar wind magnetic field fluctuations. Elucidation of such relationships will be useful to pin down mechanism of pulsations.

Each of the research activities mentioned above is explained in more detail as follows.

(i) *Magnetic Instrumentation*

H. Ueda has designed and constructed a 3-component induction magnetometer, using inexpensive IC operational amplifiers. A gain of about 88 db has been attained. Coupled with a high-μ metal core coil sensor designed by T. Watanabe, the system sensitivity is about 3 volt p-p/γ/sec. It is high enough to detect pulsation signals at mid-latitudes and, of course, at auroral latitudes. According to the test at Thompson, Manitoba, the system is stable also: thermal drift which is of a time scale of several hours or more is less than $\pm$ 0.1 volt versus a full voltage swing of about 10 volt. The frequency response is flat from dc to about 1.7 Hz. The roll-off above this is due to a high-cut filter to reject 60 Hz man-made noise.

Ueda (1975) has examined performance of a few high-μ metal core coils in comparison with an air-core coil. No signal distortion has been detected, as expected from the non-linear behaviour and hysteresis of the high-μ core material. Ueda and Watanabe interpreted the results, based on the theory of demagnetizing factor. For core materials of a very high value of permeability, the sensitivity of the coil becomes independent of the permeability but is determined by the geometry of the core. If it is cylinder-shaped, the sensitivity is approximately proportional to the square of the length of the core but is much less dependent on its diameter. These have been checked experimentally.

Ueda and Watanabe (1975a) have also considered several problems about sensitivy and frequency response of induction magnetometers and have worked out a theory about their calibration. They (1975b) have also completed the theory of the anti-resonance method to determine circuit constants of a coil used as a sensor of an induction magnetometer.

(ii) *Pre-IMS Research*

Our IMS programme to perform many station observations of pulsations in Western Canada is a cooperative project with a research team headed by Dr. T. Oguti, Geophysics Research Laboratory of the University of Tokyo and Dr. R.E. Horita, Department of Physics of the University of Victoria. Six researchers from these three groups have carried out a pre-IMS field research at Thompson and Star Lake, both in Manitoba. The induction magnetometers of both U. of Victoria and U.B.C. were tested and found satisfactory. Dr. Oguti and his associates from U. of Tokyo tested at Thompson their TV camera system for auroral observation, and also a VLF radio receiver which has facilities of determining direction of an

incident radio wave. Both systems worked well. The only difficulty we encountered at Thompson was due to man-made EM noise. It was so high, preventing us from doing our observation near the town. Especially, noise affected the VLF receiving system. We had to set up a temporary station more than ten miles away from the town, supplying power by ourselves with a generator. Frequency of the power generated was found too variable to secure a stable imaging of aurorae. A regulator is necessary for the future operations.

We also carried out a survey of noise level at three other locations in Manitoba: Fort Churchill, Gillam and Norway House. Every location was found to be quiet enough. We thus came to a conclusion that simultaneous observation is feasible at the five stations in Manitoba, providing that the problem about the power supply is soluble - we expect this will be solved without much difficulty.

(iii) *Post Midnight Continuous Pulsations and On-Off Switching Aurorae*

Watanabe, who stayed five months for his study leave at the Geophysics Research Laboratory of the University of Tokyo, worked with Oguti, analyzing pulsation data and the data of concurrent auroral activities both obtained at the Syowa Station, Antarctica, in 1971. Post midnight continuous pulsations with a quasi period of 10 ~ 30 sec were found to be concurrent with so-called pulsating aurorae. It was found that a pulsating aurora propagates poleward with a speed of 10 ~ 30 km/sec while changing its luminosity. One poleward propagating aurora was found to correspond to one magnetic pulse. It has thus become clear that the magnetic pulsation is in fact a series of magnetic pulses. Each pulse has a characteristic polarization. It is best defined on the D-Z plane. As an aurora approaches the Syowa Station from lower latitudes, the magnetic field deflects downward and westward. A westward ionospheric current system and its local enhancement moving poleward, due to the increased ionospheric conductivity by impinging auroral particles, seem to give rise to the observed magnetic polarization.

(iv) *Daytime Pc2-4 Pulsations and Solar Wind Magnetic Field Fluctuations*

G. Nourry made spectral analyses of magnetic pulsations near Calgary, Alberta and of concurrent magnetic field fluctuations in solar wind observed by the satellites IMP D and F. The pulsations recorded at the ground station are generally of the Pc2-4 types, most common "daytime" pulsations. The data were picked up from an interval from August to November 1967. Spectral analyses were made in a period range approximately from 5 sec to 150 sec. The magnetic signals either on the ground or in space were found to consist of many spectral peaks. The peaks of wave events in space and on earth correspond almost one-to-one with each other. In both spectra there is a sharp decrease in power for frequencies greater than approximately 0.05 Hz. This last feature is more conspicuous for ground spectra.

(v) *ELF Emissions and Pi2 Pulsations*

The Alouette 2 satellite discovered a new type of ELF emissions which has a diffuse spectrum covering a frequency range from 50 Hz, the lower cutoff frequency of the receiver, to above the local proton gyrofrequency. Location of this new type emission has been investigated in relation to concurrent Pi2 magnetic pulsations. A region of occurrence often spans a latitudinal range of several degrees and usually has a sharp boundary at the lower-latitude end. The position of the lower-latitude termination falls in a range of invariant latitudes from 50^{o} to 70^{o} on the night side of the Earth, and on the day side, from 70^{o} to 80^{o}. The positions of the lower-latitude terminations change systematically with the dominant period of the concurrent Pi2 pulsation, but not with Kp. Dependence of the positions with the Pi2 period seems to indicate that most ELF emissions take place in the vicinity of the inner boundary of the plasma sheet.

3. University of Calgary

Department of Physics

(i) *Atmospheric Thermal Emissions (A.W. Harrison)*

Observations of atmospheric thermal emissions 7 - 15μ were made during the summer, 1975. A spectral resolution of 200 A was employed and the emission measured at different elevations.

Specific features due to H_2O can be identified. Simultaneous balloon soundings of temperature, pressure, and humidity have enabled comparison to be made between the measured emission and that predicted from the radiation transfer equation using the statistical Goody model for the H_2O transmission function.

Mr. R. Lakeman has started work towards a Ph.D. degree and will be engaged in Fraunhofer line filling-in studies. To date a diurnal pattern of this Ring effect has been established for prominent lines in the visible region. Electronic scanning of the spectrum using a new ITT Vidissector is the technique employed.

(ii) *ISIS Satellite Activities (C.D. Anger, L.L. Cogger, J.S. Murphree, D.D. Wallis, M.C. Moshupi, I.W. Robertson, S. Ismail, S. Babey)*

A. Operations

We have been actively involved in planned coverage by the ISIS optical experiment during moon dark periods in early November and December when conditions are optimum. Special attention has been given to coverage for ground-based ionospheric electrical field measurements at Chatanika, T.V. measurements at Spitzbergen, and coincidence between ISIS and Atmospheric Explorer Satellite (CD).

B. Analysis

D.D. Wallis has been studying the relation between the diffuse aurora and the electrojet using data from the ISIS and from the University of Alberta Magnetometer chain. He has found that the eastward electrojet in the evening sector is contained within the diffuse aurora, and is currently attempting to extend this study to include cases where Birkeland current data are available and where temporal development of the aurora can be traced.

J.S. Murphree and M.C. Moshupi are carrying out a study to define the characteristics of the diffuse auroral oval. A statistical analysis is underway to establish the equatorward and poleward boundaries of the diffuse oval as a function of magnetic time and activity. J.S. Murphree is continuing the study of ratio (5577/3914) morphology in the diffuse oval as a function of magnetic activity.

L.L. Cogger and S. Ismail are investigating the sun-aligned arcs which have been observed in the ISIS polar cap data. They are also trying to distinguish broad auroral type emissions from airglow so the polar cap airglow can be compared with the midlatitude intensities.

(iii) *Rocket Experiment*

Iain Robertson completed his M.Sc. thesis based on the analysis of dual scanning photometer data from Rocket VB 27 and is currently finishing processing of data from Rocket VB 39. A more comprehensive analysis of these flights is being pursued as his Ph.D. program.

(iv) *Aeronomy Projects at the Arecibo Observatory*

L.L. Cogger is continuing to collaborate in experiments at the Arecibo Observatory. Specific studies which are nearing completion are:

(a) the aeronomical determination of the efficiency of $O(^1D)$ production by dissociative recombination of O_2^+, using densities, temperatures and ion velocities obtained by incoherent scatter,

(b) determination of the quenching rate of $O(^1D)$ from 6300A observations during an ionospheric modification experiment and

(c) E-region density variations deduced from coincident measurements of the 5577A intensity and Doppler temperature, and the ion-neutral collision frequency.

(v) *C.D. Anger/University of California*

C.D. Anger, who is currently on sabbatical leave at the University of California, San

Diego, has been comparing ISIS optical data with data from Chatanika, (with Joe Doupnik and Peter Banks) and Atmospheric Explorer optical instruments (with Paul Hays who is also spending his sabbatical at the University of California, San Diego), and is planning similar comparisons with particle data in cooperation with Carl McIlwain. He has also been developing and pursuing interests in atmospheric electric fields, and in particular the feasibility of continued atmospheric measurements using high altitude kites and tethered balloons, man-powered and wind-powered vehicles.

4. Department of Energy, Mines and Resources

Earth Physics Branch

(i) *Auroral Currents (J.K. Walker)*

Optical, particle, electric and magnetic field measurements otained across several arcs at 03 UT on February 28, 1974 are used to calculate electrojet and Birkeland currents. The near simultaneous observations were made during a coordinated experiment which involved ground, rocket (VB-39) and satellite (ISIS II) measurements. An ionosphere model consisting of 5 arcs, which were seen only by the rocket-borne plasma probes (Dr. A.G. McNamara) and the auroral scanner (I.W.H. Robertson), together with the vector electric field measurements (Dr. B.A. Whalen), was used to calculate the currents. Magnetic field calculations along the trajectory for this current system compared favourably in structure and range (~1500 nT) with the unreduced spin probe measurements (Dr. J.A. Koehler). Careful analysis of the magnetic data from the Churchill line of stations (max. perturbation of 70 nT) could not resolve the multiple electrojets determined by the above methods, but the integrated values of the electrojet current determined by the two methods were the same. Intense Birkeland currents (~1 x 10^{-4} $\mu A/m^2$), which undoubtedly exceeded the current carrying capacity of the ambient plasma above 2000 km (~2 x 10^{-6} $\mu A/m^2$), coincided with the arcs. Plasma instabilities probably occurred in these regions and accelerated the particles which caused the arcs.

Eight low powered digital data loggers will be installed along the Churchill line next summer for the IMS program. Following is a list of magnetic stations and other known equipment on the Churchill line.

The Churchill Line (mid 1976)

Station	Symbol	Equipment+ (Recorder*)	Geographic Lat. ° '	Geographic Long. ° '	Geomagnetic Lat. °	Geomagnetic Long. °
Alert	AT	V(A)	82 30	62 30	85.9	168.2
Resolute	RB	O(A,D,T),I(A)RI(A) PR(A,D),IL	74 42	94 54	83.1	287.7
Shepherd Bay	SHB	V(A,D),RI(A,D),P(A,D)	68 45	93 45	78.3	312.4
Baker Lake	BL	O(A,D,T)	64 20	96 02	73.9	314.8
Rankin Inlet	RI	V(A,D)	62 48	92 20	72.9	321.9
Eskimo Point	EP	V(A,D)	61 06	94 04	71.1	321.8
Ft. Churchill	CHR	O(A,D,T),I(A),R(A,D) RI(A),AS,PR(A,D),5L	58 48	94 06	68.8	322.5
Herchmer	HER	V(D),P(D)	57 24	94 06	67.5	323.3
Gillam	GIL	V(A,D),P(D)	56 21	94 25	66.2	323.4
Thompson	TMP	V(A,D),R(A,D),P(A,D)	55 46	97 50	65.4	319.3
Norway House	NOR	V(A,D),P(D)	53 59	97 50	63.6	320.3
Kenora	KEN	I(A)	49 48	94 24	60.0	326.4
Whiteshell	WS	O(A,D,T)	49 45	95 15	59.9	325.3

Canadian Magnetic Observatory Network 1975

Station	Symbol	Equipment+ (Recorder*)	Geographic Lat.N.	Geographic Long.E.	Geomagnetic Lat.N.	Geomagnetic Long.E.
Baker Lake	BL	O(A,D,T)	64.3	264.0	73.9	314.8
Cambridge Bay	CB	O(A,D,T)	69.1	255.0	76.7	294.0
Ft. Churchill	CHR	O(A,D,T)	58.8	265.9	68.8	322.5
Great Whale R.	GW	O(A,D,T)	55.3	282.25	66.8	347.2
Meanook	ME	O(A,D,T)	54.6	246.7	61.9	300.7
Mould Bay	MLB	O(A)	76.2	240.6	79.1	255.4
Ottawa	OT	O(A,D,T)	45.4	284.45	57.0	351.5
Resolute Bay	RB	O(A,D,T)	74.7	265.1	83.1	287.7
St. John's	JO	O(A,D,T)	47.6	307.3	58.7	21.4
Victoria	VI	O(A,D,T)	48.5	236.6	54.3	292.7
Yellowknife	YK	O(A,D,T)	62.5	245.5	69.1	292.8
Whiteshell	WS	O(A,D,T)	49.8	264.75	59.9	325.3

* A = analogue
D = digital
T = telephone telemetry

\+ O = Magnetic Observatory
RI = Riometer
V = Magnetic Variometer
AS = All Sky Camera

I = Ionosonde
R = Auroral Radar
PR = Partial Reflection Ionosonde
P = Photometer
L = Rocket Launchers

(iii) *Solar and Lunar Variations (J.C. Gupta)*

In cooperation with S.R.C. Malin, the ionospheric current system has been computed for the eight most quiet days of IGY/C, using the techniques of spherical harmonic analysis. Special emphasis was given to the longitudinal variation of the Sq-current system.

A technique is being developed to use the one-minute digital values from observatories for computing solar and lunar variations. This technique will permit derivation of these variations for much shorter durations than used in the past.

The Chapman-Miller method, which essentially computes solar and lunar harmonic coefficients, has been further developed to give the effect on solar and lunar variations of such geophysical variables as sunspot number, lunar distance, magnetic activity and seasonal effects.

(iv) *Observatories (E.I. Loomer)*

The Division of Geomagnetism of the Earth Physics Branch operates magnetic observatories at Mould Bay, Resolute Bay, Cambridge Bay and Baker Lake in the Canadian Arctic; at Yellowknife, Churchill and Great Whale River in the auroral zone; and at Victoria, Meanook, Ottawa, St. John's, and Whiteshell (100 miles east of Winnipeg) in southern Canada. All observatories except Mould Bay record three components of the magnetic field digitally on magnetic tape at one minute intervals. Photographic records in standard magnetogram format are produced at all observatories except Yellowknife, Cambridge Bay, St. John's and Whiteshell. For these four observatories magnetograms in standard format are constructed by plotting the edited one-minute digital values. Copies of magnetograms for all observatories are sent regularly to World Data Centre A, Boulder, Colorado, U.S.A. In addition, pen-and-ink fluxgate charts are available for the arctic station of Alert.

5. Environment Canada - Atmospheric Environment Service

i) *Experimental and Theoretical Studies (W.F.J. Evans, J.B. Kerr, J.R. Latimer, T. McElroy, R.S. O'Brien, R.A. Olafson, C.L. Mateer, D.I. Wardle, G. Shah, J. Williamson)*

Experimental and theoretical studies of the stratosphere are continuing in the Atmospheric Processes Research Branch, in order to assess the effects of anthropogenic activities such as freon usage and SST operations on the ozone layer.

The results of the 1974 balloon flights of PROJECT STRATOPROBE conducted from Churchill in July have been analyzed. Altitude distributions of ozone, nitric acid, nitrogen dioxide, nitric oxide, temperature and number density as well as solar ultraviolet flux were measured simultaneously. The observed ratios of the key nitrogen constituents are consistent with CIAP recommended photochemical schemes. The total odd nitrogen mixing ratio was found to be about 10 ppbv, supporting the value assumed or computed in most stratospheric models. Essentially, the results of STRATOPROBE I verify that the nitrogen photochemistry schemes assumed in stratospheric pollution models are valid.

In 1975, four flights of STRATOPROBE II were made in August from Yorkton, Saskatchewan. Four new flight instruments were developed and incorporated into the payload. The nitrogen chemistry experiment was successfully repeated on two flights and partially on a third; these measurements will be comapred with the 1974 nitrogen chemistry results. A new chlorine experiment configuration to define the current chlorine chemistry of the stratosphere by taking simultaneous measurements of freons, hydrochloric acid, chlorine monoxide and nitric oxide together with ozone and temperature was flown on two flights. Samples of stratosphere air were obtained for laboratory analysis, for freons and a remote sensing measurement of chlorine monoxide may have been achieved.

Long path absorption photometers to measure nitrogen dioxide and water vapour were flown on rocket VB-41 on December 6, 1974 from Cape Parry and on rocket S-16/1 from Kiurna, Sweden on March 13, 1975. Analysis of the data is proceeding to obtain the water vapour and NO_2 mixing ratio profiles in the stratosphere. An aircraft experiment to observe the time variation of NO_2 and O_2 ($^1\Delta$) during a solar eclipse during a flight from St. John to Montreal on a Ministry of Transport Jetstar was conducted on December 13, 1974.

Ground based observations of NO_2 have been continued at Toronto and at Yorkton during the STRATOPROBE II operation. Observational testing and development of the new ozone network spectrophotometer is continuing.

Daily surface-based measurements of total atmospheric ozone, made with the Dobson ozone spectrophotometer, continue at Churchill, Edmonton, Goose, Resolute and Toronto. The vertical ozone profile from the earth's surface to about 30 km is measured by balloon sounding with the Brewer-Mast electro-chemical sonde each Wednesday at the first four of the above noted stations.

Numerical experiments were carried incorporating oxygen-hydrogen-nitrogen-chlorine chemistry in a two-dimensional radiative-photochemical-transport model to investigate the possible potential effects of man-made sources of chlorofluoromethanes (freons) on the stratospheric ozone balance and its climate. The meridional stratospheric distributions of ozone, HO_x, N_2O, NO_x, CF_2Cl_2, $CFCl_3$, Cl_x, temperature and mean circulation were computed simultaneously for summer and winter seasons and the global depletion of total ozone due to the introduction of chlorofluoromethanes and their dissociation of products was assessed under steady state conditions. Additional experiments are now under way using the time dependent approach to the freon-ozone problem. This approach allows modelling of the time evolution of the distributions of above trace gases and of the global ozone depletion under varying conditions of freon injection rates into the atmosphere.

6. National Research Council of Canada - Communications Research Centre

(i) *ISIS Group (H.G. James, C.H. Whitteker, D.B. Muldrew)*

Work on the VLF phenomenon "saucer", so named because of its hyperbolic shape in the

amplitude-frequency-time displays from the ISIS radio receivers, has been written up and submitted for publication. The data have been interpreted in terms of a small source of emission. A ray-tracing technique has been applied to deduce the spatial dimensions of the source, typically 0.5 km horizontally by no more than 10 km vertically. Total power radiated is about 10 milliwatts. The article proposes a model for the source in which suprathermal electrons flow through a region where they engage in a whistler-mode instability with background electrons.

The ISIS I and ISIS II spacecraft occasionally rendezvous in places where simultaneous telemetry coverage is available from two ground stations. Radio wave propagation experiments between the two spacecraft have been carried out using the topside sounders at low and medium frequencies. The electromagnetic Z, O and X modes have been identified in the data and they have been observed to propagate over satellite separations of up to a few thousand kilometers. The data base also contains a few notable examples of intersatellite whistler-mode propagation when the separations were less than 500 km. In these cases, considerable temporal dispersion of the 100 μsec sounder pulses is observed. For all types of propagation, we are examining pulse shapes, delay times and absolute signal levels in relation to parameters like antenna orientation and wave mode in order to make some conclusions about the launching, propagation and detection of these waves.

G.H. Whitteker has more or less completed a numerical time-dependent model of the topside ionosphere that he has been working on for some time. It is a one-dimensional model (the vertical dimension) and is appropriate to high latitudes, where the magnetic field is approximately vertical, and where O^+ ions are dominant over most of the altitude range considered (150 to 2500 km). The model is used to calculate the response of the topside and F layer ionosphere to transient low energy (100 eV) electron precipitation. In its present form, the model starts with an assumed neutral atmosphere, and assumed solar uv input (not essential, but it allows the formation of a steady state), a lot of rate constants, and some elementary physics. The inertia of the plasma is not ignored. The result is an ionosphere that looks something like the real ionosphere in the steady state, and, hopefully, responds to disturbances something like the real one. Disturbances propagate upward and grow in amplitude much like gravity waves do, limited eventually at high altitude by ion viscosity. Vertical motions can become quite violent, appraching the speed of sound in the plasma. Response times are of the order of 10 minutes, but the topside takes much longer than this to settle down completely.

In December 1974, G.H. Whitteker participated in the NRC rocket flights from Cape Parry as watcher of bottomside ionograms. The idea here is that the extra ionization produced by the energetic electrons precipitated in the region of the magnetospheric cleft gives rise to an oblique echo can then serve as an indication of the position of the cleft. There was some success with this, although optical data, when they are available, give much less ambiguous answers. The strongest, most persistent ionosonde echoes seemed to be associated with maxima in the 6300 A scans, but not the weaker, more transient ones. A preliminary post-mortem comparison of echo ranges with scanning photometer data, done by Fokke Creutzberg of NRC, shows some correlation between the two, but nothing really overwhelming. The biggest problem with an ionosonde is that it is an omnidirectional device, with all the ambiguity that implies.

The ISIS group has on hand a collection of data from various experimenters on the quiet winter polar cap ionosphere. Much of the data set is very untidy, but one feature that stands out is a rather good correspondence between brigh emission features in 6300 A and density maxima at high (1400 km) altitude. This is hardly surprising, since both phenomena, at high latitudes, result primarily from soft particle precipitation (which is also observed).

Another interesting observation during this experiment was that of a topside plasma line. This probably results from the coupling of the O-wave heater into a Z wave at the O-wave reflection height. This Z wave traverses the F-region peak and, at the height in the topside ionosphere where the wave frequency is slightly greater than the plasma frequency, decays parametrically.

An ionospheric modification experiment took place at Arecibo in April 1975. Confirmation of a lower-height plasma line, LHPL, was obtained. The Langmuir waves responsible for this

line exist at one or more discrete heights a few to several kilometers below the height of the waves responsible for the existence of the normal plasma line. The LHPL has been observed consistently at the two lowest heater frequencies of 5.1 and 5.625 MHz; it has not been observed at frequencies ranging from 6 to 10 MHz. Unlike the normal plasma line, there is no detectable ion line associated with LHPL and the downshifted LHPL (detected at frequencies downshifted from the radar frequency by approximately the plasma frequency) is 4 to 5 dB stronger than the upshifted LHPL. These results can be explained by an ionospheric model in which the electron density has a quasi-periodic variation through the heated region and in which field-aligned irregularities exist.

7. National Research Council of Canada - Herzberg Institute of Astrophysics - Planetary Sciences Section

(i) *Auroral Spectra and Photometry I (R.L. Gattinger, A. Vallance Jones)*

A further campaign was carried out in February 1975 at the Ft. Churchill Auroral Observatory. Good spectra were obtained in the 9000-11000 Å region with a liquid N_2 cooled S-1 tube. We hope to complete studies of this region in the coming winter. In the 7000-9000 Å region height effects in the $v' \geq 2$ progressions of O_2 atmospheric bands were studied and it was found that these progressions do not show the enhancement in relative intensity with height shown by the $v' = 1$ progression. This suggests that the $v' = 1$ level of $O_2 b^1\Sigma$ is much more strongly quenched than higher vibrational levels.

A further 10 nights of observation with the 1.27μ photometer yielded only small enhancements over the nightglow intensity; this was expected since no sufficiently intense substorms were observed. A search for NO continuum enhancements was likewise negative, possibly for the same reason.

A vibrational level population rates of the Vegard-Kaplan bands have been studied from the 3150-4500 Å spectra. It was concluded that the quenching rate coefficient must increase strongly with v'. A range of possible values of the quenching coefficient was defined but the exact value is dependent on atmospheric composition and auroral height profile.

(ii) *Auroral Photometry II (F. Creutzberg)*

The 5-channel meridian scanner, Hβ tilting filter meridian scanner, and all-sky camera were taken to Cape Parry, NWT in December 1974 as part of the cleft expedition. Extensive measurements were made over a period of 16 days in the 06-10 hrs and 12-18 hrs MLT window. No satisfactory hydrogen data were obtained because of poor local observing conditions and contamination.

A study of the morphology of cleft emissions in the post-noon period and a correlation with ionosonde measurements is in progress.

(iii) *IMS Project (R.L. Gattinger, F. Creutzberg, F.R. Harris, A. Vallance Jones)*

Preparations are underway, in collaboration with Ken Paulson and Ray Montalbetti of Saskatoon for observations of proton aurora during the IMS years. A chain of meridian scanners on the Churchill-Thompson-Broadview line with additional scanners displaced in longitude at Lac Laronge and possibly Saskatoon is planned. Programs for presenting the proton aurora data as time latitude intensity-shaped plots are being tested. These programs will be applied initially to data obtained in the past several years on the Gillam-Churchill line.

(iv) *Auroral Rocket Photometry (F.R. Harris)*

Photometers were flown on one rocket in 1975. This launch occurred in quiet nighttime aurora at Churchill. The experiment was recovered undamaged and will be used again.

(v) *All-Sky Cameras (A.G. McNamara)*

Routine operation of 35 mm all-sky cameras for morphological and correlative studies is being continued at Churchill, Moosonee, and Great Whale River. These will also be operated

during the IMS period.

(vi) *Radio Aurora (D.R. McDiarmid, F.R. Harris, A.G. McNamara)*

One of the events investigated in our study of the relationships between radio aurora, visual aurora and ionospheric currents consisted of an interesting sequence of four spatially and temporally connected magnetospheric substorms. In two of the substorms, two parallel westward electrojets were observed to develop during the initial part of the expansion phase. In another, the expansion phase consisted of the development of a westward electrojet westward and equatorward of the pre-existing current system. A paper describing this sequence is in press. The relationships listed above have been determined for this event and are both consistent with previous work and capable of reasonable explanation. It was found that aspect sensitivity was not critical in limiting the region where radio aurora was observed.

Currently we are beginning a study of high latitude radio aurora observed in the interval of late morning and early afternoon.

An improved auroral radar is under development for installation at the stations presently operating. The new radars will have full Doppler spectra capability, and the radar operation and data acquisition functions will be under control of a mini-computer. It is planned to have the new systems operational during the IMS interval.

(vii) *Rocket Measurements of Auroral Plasma (A.G. McNamara)*

Plasma probe experiments have been prepared for flights in three rockets to be launched from the Churchill Research Range during the winter 1975/76.

(viii) *Meteorite Recovery (A.T. Blackwell, A.A. Griffin, I. Halliday)*

The 12 camera stations of the MORP network were in routine operation during 1975. About 200 bright meteors have been photographed from two or more stations since the network began and the rate of addition is about 50 per year. One meteor in September 1975 is of marginal interest for a very small meteorite fall. A useful by-product of the network was a pre-discovery observation of Nova Cygni 1975 on August 29 during the rise to maximum brightness.

(ix) *Cosmic Dust Studies (R. Wlochowicz)*

Magellan, the balloon-borne micrometeoroid collecting experiment, has been flown for the third time for a three day period out of Palestine, Texas in October of this year. The principal purpose of this flight was to resolve the possible contamination problems in the system to establish a signal-to-noise level for the experiment. A microbalance capable of measuring the accumulation of mass with a resolution of the order of 10^{-7} gm was substituted for the regular collection surface in the first sampling pan. Preliminary results indicate that the collection funnel sheds particles every time that the shaker attached to it is activated and that the amount of material shed is unpredictable. A comparison of particle types collected in this and the previous two flights is in progress.

Electron microscope examination of the collection surfaces from rocket flight AAF-VI-04 showed that the puzzling features observed optically were surface imperfections of various types. A chemical analysis by means of the energy-dispersive X-ray technique of about 100 particles selected from the collection surfaces indicated three or four groups of particles with relatively distinct chemistry. An attempt will be made to establish the origin of these particles with the aim of determining which were collected above 30 km altitude.

(x) *Infrasound from Meteors (B.A. McIntosh, M.D. Watson, D.O. ReVelle)*

Ability to record low frequency pressure waves generated by large meteors permits the detection of meteorite entry on a round-the-clock basis. An array of 4 detectors was established near Saskatoon during late summer of 1975. The system is designed to respond to infrasound generated by large meteorites, so as to complement most effectively the Meteorite Observation and Recovery Project (MORP) network of cameras. Atmospheric pressure variations

(via noise-reducing spatial filters) are recorded digitally on magnetic tape on a continuous basis. The infrasonic detectors have a pass band from 0.02 Hz to 0.2 Hz, a dynamic range of about ±16 microbar, and a resolution of 1/8 microbar.

A recording system at Springhill Meteor Observatory consists also of a 4-microphone array, but is oriented toward detection of smaller meteoroids. One acoustic signal detected on December 14, 1974 and having a dominant frequency of 2 Hz and an amplitude of 8 microbar is believed to be associated with a large meteor recorded by the Springhill radars. Estimates of the meteor mass (1 kg) from the radar echo duration are in agreement with mass calculated from the blast-wave theory of ReVelle.

Theoretical studies of the complex dynamics/thermodynamics of meteor entry have been concerned with producing a realistic model of meteorite ablation and then linking that with the pressure-wave generation mechanism. Little is known of the complex physical and chemical processes that can occur, for example in radiative heat transfer under conditions of turbulent flow at hypersonic velocities. Deductions from pressure waves observed on the ground require coupling of the entry-dynamics model with theory of propagation and attenuation in a temperature and wind-stratified atmosphere.

(xi) *Meteor Research (B.A. McIntosh, I. Halliday, P.M. Millman)*

Routine recording of meteors was continued at Springhill Meteor Observatory and at Shiels Meteor Station in the cooperative program with Dudley Observatory (Albany, N.Y.) and Smithsonian Astrophysical Observatory (Cambridge, Mass.). Observations made with a sensitive closed-link T.V. system are combined with those of our normal grating spectrographs, the Super-Schmidt camera, and two backscatter radars.

A proposal in the literature that super-rotation of the atmosphere can be attributed to the transfer to the atmosphere of excess angular momentum of meteoroids was shown to be false both on theoretical and observational grounds.

Analysis of a 10-year continuous series of radar observations of the Quadrantid meteor shower showed considerable flux variation from year to year, but no pattern that could be tied to the orbital period, i.e. the longitudinal structure of the stream.

The decay rate of a radar echo from an underdense meteor trail is an approximate measure of atmospheric density and hence the height at which the echo occurred. An analysis of 18,000 meteor echoes showed very little detailed height structure with regard to time or to mass of the meteoroids. Since the velocity of each meteor is not available in our observations, the wide velocity distribution seems to smear out all other height variations.

Recombination has been shown to have very little influence on mass-distribution and height-distribution parameters derived from this data.

Cooperation with the Space Sciences Laboratory of the NASA Marshall Space Flight Center in Huntsville, Ala. has continued. Analysis of the best Geminid meteor spectra, recorded with the SEC Vidicon at Mt. Hopkins, Arizona, in December 1972 has been completed and work has commenced on the reduction of the Vidicon spectroscopic records of close to 1000 meteors obtained in Mt. Hopkins in December 1974.

8. University of Saskatchewan

Institute of Space and Atmospheric Studies

(i) *Auroral Studies (D.J. McEwen)*

An electron spectrometer flown from Cape Parry on December 6, 1974 recorded the electron influx as the rocket traversed completely through the cleft region and into the polar cap. The data have been analyzed, yielding a detailed picture of the particle structure of the cleft during a dayside aurora. Total energy influx was quite variable and as high as 10 ergs/cm^2 sec.

Electron and optical data from two recent flights (II-128 and VB-34) have been analyzed. On the II-128 flight the rocket was immersed in a broad homogeneous aurora at apogee (131 km) and definitive measurements were obtained of the electron flux incident and the optical emissions produced. Dr. Venkatarangan (Research Associate) has been involved in these studies. A 0.4 meter extreme UV spectrometer is being constructed for flight in early 1976 to study the auroral spectrum in the region 250-1250 A. This will form part of an auroral payload which has already had three flights with recovery.

(ii) *Solar UV Measurements*

During the summer of 1/4 meter spectrometer was aboard three AES balloon flights from Yorkton, Saskatchewan, to record the solar spectrum from 1820 to 3150A. Good data were obtained, particularly in the window region from 1900 to 2200A. These provide a sensitive measure of ozone content above the balloon and on the second flight, with a slow controlled descent, there should be a measure of the ozone height profile. These measurements were part of the comprehensive study of minor constituents in the stratosphere being conducted by AES.

(iii) *The International Magnetospheric Study (B.W. Currie)*

Plans are progressing satisfactorily for Canadian participation. Two lines of magnetometers, parallel approximately to geomagnetic lines of longitude will complement the regular geomagnetic observatory program. One operated by the Division of Geomagnetism of the Department of Energy, Mines and Resources will pass through Churchill; the other financed by the National Research Council and supervised by Dr. G. Rostoker (University of Alberta) will pass through Edmonton. A third longitudinal line (University of Alaska) will have magnetometers located at places in the Canadian Arctic Archipelago. A latitudinal line (U.S.A.) to the south of the auroral zone is still in the planning stage. Auroral radars, all-sky cameras and photometers will also be operated continuously at several locations. A number of campaigns or expeditions are planned to study special events - particularly in the cleft region of the magnetosphere, and geomagnetic substorms. Each may last for several weeks. Several will involve instrumented rockets and high-flying balloons. B.W. Currie expects to put together a bulletin which will describe in detail Canadian IMS activities and also other IMS activities on Canadian territory by non-Canadians. This should be ready for distribution by March 1976. It should be useful to those planning expeditionary campaigns - possibly to change the proposed times so as to get the maximum return from their data through collaboration with others, and at times when spacecraft are recording complementary data in the magnetosphere.

Attached to IMS Newsletter No. 4 (December 1975) was a list of possible spacecraft collecting IMS data. This included both spacecraft currently in orbit, and those which will be launched during the IMS. The nature of the IMS related experiments aboard them is indicated. Also attached is a summary of the plan for IMS data services provided by the Boulder Data Center for Solar-Terrestrial Physics. Readers who do not receive IMS newsletter and wish a copy of either or both of these should write to B.W. Currie, Institute of Space and Atmospheric Studies, University of Saskatchewan, Saskatoon, Saskatchewan.

(iv) *Dynamical Studies of the Mesosphere and Lower Thermosphere (J.B. Gregory, A.H. Manson, D.G. Stephenson)*

The studies of mean winds, the effects of stratospheric warmings, and the role of gravity waves, in the altitude range 60-110 km, has been continued. Results of all these studies have been published in a series of papers with the general title "Winds and Wave Motions to 110 km at Mid-latitudes". During the winter of 1974-75, a series of daily observations were made of the winds at Saskatoon (52°N). These observations have permitted a study in better detail than hitherto available of the local effects of stratospheric warmings. For the major warming of December '74-January '75, cross correlations and cospectral analysis revealed that the wind pattern was perturbed to at least 100 km altitude. These observations have been continued throughout the remainder of 1975, and are being submitted to analysis.

All the above observations have been made by the drifts technique, applied to partial radiowave reflections. The capability of this system for intensive soundings (12/hr) will be further exploited in future in studies of tides and gravity waves. In addition, the technique is subject to continuous review in an attempt to improve its efficiency, e.g. in

the reduction of computing requirements; and also to determine the form of treatment of data e.g. over what time period averaging is desirable, that gives best compromise between reliability of derived wind vectors, and time resolution.

(v) *Precipitation Studies*

Studies have been made in the past of the precipitation of auroral particles at this location (L = 3.9). These studies are now being resumed, with more extensive instrumentation. The partial radiowave reflection system is to be extended by the erection of a broad antenna, to permit transmissions up to 6 MHz. The use of higher frequencies will allow observations to be made when intense particle precipitation causes excessive absorption on the present working frequency of 2.2 MHz. The sounding system is now in operation on a 24 hour basis to permit derivation of electron density profiles, and from these to examine the incidence of precipitation, particularly in darkness hours.

(vi) *Electric and Magnetic Fields (J. Koehler)*

J. Koehler was on sabbatical leave in Sydney, Australia from July 1974 to July 1975. Working with the Australian Department of Science, he participated in work concerning the direction of arrival of ionosonde echoes. This research was part of a project to determine the nature of the relationship between anomalous trans-equatorial radio propagation and the appearance of spread-F along the propagation path.

Work on ionospheric electric and magnetic fields has been carried on by two graduate students. Some excellent rocket flights have been made during recent years. In particular, the data from VB-39 is being analyzed jointly by ourselves and J.K. Walker, Energy, Mines and Resources.

The microbarograph installed at Cree Lake, Saskatchewan, in July 1974 appears to be operating satisfactorily. It is hoped that several photometers and a magnetometer can be installed there in 1976. This work is being done as a cooperative project with G. Sofko to study some of the possible processes by which energy is transferred from the ionosphere to lower regions.

(vii) *Infrared Aeronomy (E.J. Llewellyn)*

The observations of the 1.27μ oxygen emission at the end of the arctic winter, mentioned in the previous issue, were successfully made from a Nike-Apache launched from Kiruna Sweden in March 1975. These measurements, together with those of other experimenters, have permitted a complete measurement of the ozone height profile from the ground to 100 km. An extensive analysis of the overlap regions is being made to reduce any systematic error in the measurements and derived concentrations.

The infrared spectrometer was again flown as part of the Stratoprobe payload and provided many spectra in the near infrared region. However, to improve the resolution, and possibly identify the concentration of some important minor constituents in the stratosphere, a Michelson interferometer is being prepared for balloon operation. Preliminary tests of the instrument have been made and it is hoped to have useful spectra in the near future.

The role of non-equilibrium concentrations in the atmosphere is being further studied and the possible existence of ClO in high vibrational levels is being investigated. It is also intended to make the same type of study in connection with some molecular auroral emissions.

9. The University of Western Ontario

Centre for Radio Science, Department of Physics

(i) *Ionospheric Irregularities*

The dual frequency differential angle-of-arrival system is now working well. This system which continuously measures the angular difference between the apparent positions of an orbiting satellite as seen at two frequencies (150 MHz and 400 MHz) permits rather detailed

examination of electron density gradients in the ionosphere. The system can detect refraction angles (essentially of the 150 MHz signal) of about 0.05 milliradians. A portable (transportable?) version of the system was taken to Cambridge Bay for about ten days in August (by J.A. Fulford). Many hours of recordings were obtained relating both to the polar cap ionosphere and to the passage of the magnetospheric cleft. The quality of the records has been verified and analysis started but about all that can be said about the results at this time is that for a frequency of 150 MHz and sometimes for 400 MHz the ionospheric gradients were sufficiently strong to exceed the normal full-scale sensitivity of the system (about 5 milliradians). During the experiment the full-scale sensitivity was increased to about 15 milliradians and even this was occasionally exceeded. *(Forsyth, Fulford, Woods)*

Also some very old angle-of-arrival records from ISIS-1 have finally yielded to analysis. The most interesting of the results refer to scattering (strong refraction) from isolated cylindrical irregularities in the F-region. While it usually has been thought that such irregularities could only be detected when they lie along the line-of-sight to the satellite there appear to be occasions when irregularities exist in the ionosphere over London which are sufficiently strong to be detected (at a frequency of 136 MHz) even when they are many degrees away from the direct line-of-sight. For such situations it is not possible (as it is for line-of-sight observations) to deduce the absolute electron density profile of the irregularity, but it is obvious that the irregularities are much stronger than those previously analyzed and evidence of the existance of such irregularities adds a new dimension to the interpretation of satellite scintillation observations. *(Forsyth, Doan)*

(ii) *Radio Aurora*

Two coherent pulse radar systems operating at a frequency of 108 MHz are being constructed to fly in BBVI rockets from Churchill in 1976. The objective of the Churchill firings is to test the system by trying to detect the two-stream instability in the auroral plasma (the Farley-Buneman instability which gives rise to so-called ion-acoustic waves). The ultimate objective is to fly the radar in the polar cap and cleft disturbed ionosphere in order to detect and examine the magnetospherically generated electric fields which should give rise to this same instability in the "normal" polar E region. *(Forsyth)*

(iii) *Travelling Ionospheric Disturbances*

Electron content and angle of arrival fluctuations in signals from geostationary satellites have been discontinued pending the return of the ATS 6 satellite to North American longitudes. It is expected that this vehicle will return in July 1976 and if so the dual frequency differential angle of arrival system will be utilized. *(Lyon, Webster)*

A theoretical study of the effects of ground reflections upon observations of the above type indicates that at times interpretation of the observations may be in error (Jones, Webster). Equipment is being readied to receive signals from the ATS 3 satellite using several different antenna heights to test the theoretical findings. *(Lyon and Webster)*

Results from the HF Doppler oblique sounding measurements in the Ottawa-London path have some puzzling implications. The occurrence of multivalued dopplers and bearings on the oblique path is much less frequent than simple modelling of reflection from a 'corrugated' ionosphere predicts: to confirm this the doppler measurements are being repeated on one frequency with improved frequency resolution. Also the correspondence between the observed doppler shifts and the group path changes is often not as expected for a simple moving reflector; consideration is being given to developing a new sounder with much improved range resolution. *(Lyon)*

(iv) *Meteor Studies*

The intensifier-vidicon camera has now been in operation for almost three years and considerable quantity of observational data has been amassed. Analysis so far has been directed at the determination of the mass distribution and the light curves of meteors. A second camera of improved design has been developed. The resolution appears to be better than that of the prototype model. Simultaneous observations with both systems are planned to enable triangulation to be performed so that the heights and velocities can be calculated for individual meteors. Considerable effort is also being put into developing new and

elegant methods of the determination of radiant activity. The proposed procedures are being tested using monté carlo methods and when optimized will be applied to real data. *Jones, Hawkes, Morton)*

10. York University

Centre for Research in Experimental Space Science *(G.G. Shepherd)*

(i) *ISIS Satellite Studies*

Several cooperative studies are underway and nearing completion. One, on the optical dayside emissions features 6300A intensity contours stretched to overlay on Dr. Anger's spin photos obtained in the 5577A emission. Another, on observed ionospheric cleft characteristics, finds that O^+ produced in the cleft region is dominant there at 1400 km, but that inside the polar cap He^+ becomes the dominant ion at that altitude. There is some evidence that the convective flow pattern at the cleft is controlled by the interplanetary field direction. In a third study, on the August 4, 1972 storm an 18 kR SAR arc was observed at the poleward boundary of a region of isotropic 150 heV protons. This unusual SAR arc was formed locally during storm buildup - presumably at the point of interaction of inwardly diffusing protons with the plasmapause. Frank Thorkettle completed his Ph.D. thesis on ISIS software.

(ii) *Cape Parry Expedition, December, 1974*

A preliminary report has been submitted to GRL and further analysis is underway. The most striking result was the appearance of atomic nitrogen 5200A emission inside the polar cap, probably as a result of convective flow of molecular ions from the cleft but perhaps also influenced by neutral winds as well.

(iii) *Other Rocket Studies*

Ashley Deans has completed his analysis of optical data from VB-34, from which atomic oxygen densities and the production processes of the 5577A emission were studied. The atomic oxygen densities were unusually low at that time. Michael Walten is also obtaining oxygen densities from Dr. Young's fluorescence probe, flown on the same payload.

(iv) *IMS Plans*

Plans are underway for a ground based observing expedition, probably to Sach's Harbour, in December, 1976.

11. Bibliography: Aeronomy

1. Anger, C.D. Aurora. McGraw-Hill Yearbook of Science and Technology (1975).

2. Blackwell, A.T., Feldman, P.A., Griffin, A.A., and Halliday, I. "A pre-discovery observation of Nova Cygni 1975". J. Roy. Astron. Soc. Canada, 69, 241 (1975).

3. Evans, W.F.J., Kerr, J.B. and Wardle, D.I. The AES Balloon Measurements Project; Preliminary Results. Proceedings of the Fourth CIAP Conference, Cambridge, Massachussetts, February (1974).

4. Gattinger, R.L. and Vallance Jones, A. Observed intensity ratios of the N_2 IPG bands in aurora. In Atmospheres of Earth and Planets, ed. B.M. McCormac, D. Reidel Publishing Co., Dordrecht-Holland, 319-322 (1975).

5. Grahn, S., Witt, G., Mathews, A., Pruchniewicz, P.G. and Llewellyn E.J. Coordinated ozone measurements in the Polar Troposphere, Stratosphere and Mesosphere from Balloon and Sounding rockets. MISU, Stockholm (1975).

6. Gregory, J.B. and Manson, A.H. "Winds and Wave Motions to 110 km at Mid-latitudes. II. Mean Winds at 52°N, 1969-73. J. Atmosph. Sci., 32, #9, 1667 (1975).

7. Gregory, J.B. and Manson, A.H. "Winds and Wave Motions to 110 km at Mid-latitudes. III. Response of Mesospheric and Thermospheric Winds to Major Stratospheric Warmings. J. Atmosph. Sci., 32, #9, 1676 (1975).

8. Griffin, A.A. The dynamics and orbit of an iron meteoroid. J. Roy. Astron. Soc. Canada, 69, 126, (1975).

9. Gupta, J.C. Period variations of Pc5 pulsations at high latitudes. Astrophys. and Space Sci., 31, 91 (1975).

10. Gupta, J.C. Long period Pc5 pulsations; Planet. Space Sci., 23, 733 (1975).

11. Harris, F.R., McDiarmid, D.R. and McNamara, A.G. Relationships between radio aurora, visual aurora and ionospheric currents during magnetospheric substorms. IAGA Bulletin No. 36, 384 (1975).

12. Horita, R.E., Smith, B.P., Watanabe, T., Barrington, R.E., and Palmer, F.H. ELF emissions observed near the plasmapause and plasma sheet. J. Atmosph. Terr. Phys., 37, 1263 (1975).

13. Lanzerotti, L.J., Cogger, L.L. and Mendillo, M. Latitude dependence of ionosphere total electron content observations during sudden commencement storms. J. Geophys. Res., 80, no. 10, 1287 (1975).

14. Lanzerotti, L.J., Maclennan, C.G., Fukunishi, H., Walker, J.K. and Williams, D.J. Latitude and Longitude Dependence of Storm Time Pc5 Type Plasma Wave. J. Geophys. Res., 80, 1014 (1975).

15. Loomer, E.I. Annual Report for Magnetic Observatories - 1970. Geomagnetic Series No. 2 of the Earth Physics Branch (1975).

16. Lui, A.T.Y., Anger, C.D., Venkatesan, D., Sawchuk, W. and Akasofu, S.-I. The topology of the auroral oval as seen by the ISIS 2 scanning auroral photometer. J. Geophys. Res., 80, no. 13, 1795 (1975).

17. Manson, A.H., Gregory, J.B., and Stephenson, D.G. "Winds and Wave Motions to 110 km at Mid-latitudes. IV. Coupling Between Internal Gravity Waves and the Mean Flow. J. Atmosph. Sci., 32, #9, 1682 (1975).

18. McIntosh, B.A. Comment on "Superrotation of the upper atmosphere by global deposition of meteoroids". Planet. Space Sci., 23, 891 (1975).

19. Millman, P.M. and Clifton, K.S. SEC vidicon spectra of Geminid meteors, 1972. Can. J. Phys., 53, 1939 (1975).

20. Olson, J.V. and Rostoker, G. Pi2 pulsations and the auroral electrojet. Planet. Space Sci., 23, 1129 (1975).

21. Rao Vupputuri, R.K. The Impact of Anthropogenic Sources of freons (chlorofluoromethanes) on the Meridional Structure of the Stratosphere and Ozone Distribution. Internal Report, Atmospheric Environment Service, Downsview, Ontario, Canada (1975).

22. ReVelle, D.O. Studies of sounds from meteors. Sky and Tel., 49, 87, (1975).

23. ReVelle, D.O. Meteor generated infrasound, Science, 189, 394 (1975).

24. Rostoker, G., Armstrong, J.C. and Akasofu, S.-I. A comparison of satellite observations of Birkeland currents with ground observations of visible aurora and ionospheric currents, J. Geophys. Res., 80, 575 (1975).

25. Rostoker, G., Kisabeth, J.L., Sharp, R.D. and Shelley, E.G. The expansive phase of magnetospheric substorms, 2. The response at synchronous altitude of particles of different energy ranges, J. Geophys. Res., 80, 3557 (1975).

26. Rostoker, G., Armstrong, J.C. and Zmuda, A.J. Field-aligned current flow associated with the intrusion of the substorm intensified westward electrojet into the evening sector, J. Geophys. Res., 80, 3571 (1975).

27. Rostoker, G. and Hron, M. The eastward electrojet in the dawn sector. Planet. Space Sci., 23, 1377 (1975).

28. Sharma, R.P. and Muldrew, D.B. Seasonal and longitudinal variations in the occurrence frequency of magnetospheric ionization ducts, J. Geophys. Res., 80, 977 (1975).

29. Sharp, R.D., Shelley, E.G. and Rostoker, G. A relationship between synchronous altitude electron fluxes and the auroral electrojet, J. Geophys. Res., 80, 2319 (1975).

30. Shepherd, G.G., Creutzberg, F., Delana, B., Gerard, J.C. and McEwen, D.J. Rocket launch into dayside cleft aurora from Cape Parry, NWT, December 6, 1974. EOS Trans. Amer. Geophys. Union, 56, 431 (1975).

31. Ueda, H. and Watanabe, T. Several problems about sensitivity and frequency response of an induction magnetometer, Sci. Rept. Tohoku Univ., Ser. 5, Geophys. 22, 107 (1975).

32. Ueda, H and Watanabe, T. Comments on the anti-resonance method to measure the circuit constants of a coil used as a sensor of an induction magnetometer, Sci. Rept. Tohoku Univ., Ser. 5, Geophys., 22, 129 (1975).

33. Vallance Jones, A. and Gattinger, R.L. The $O_2(b^2\Sigma_g^+) - X(^2\Sigma_g^-)$ system in aurora. J. Geophys. Res., 79, 4821 (1974).

34. Walker, J.K., Creutzberg, F., Gattinger, R.L., Harris, F.R. and McNamara, A.G. Substorm currents, joule heating and possible instabilities determined from electric field and ionospheric measurements. Trans. A.G.U., 55, 11, 1010 (1974).

35. Wiens, R.G. and Rostoker, G. Characteristics of the development of the westward electrojet during the expansive phase of magnetospheric substorms. J. Geophys. Res., 80, 2109 (1975).

V. ISOTOPE STUDIES AND GEOCHRONOLOGY

Compiled by: P.H. Reynolds

1. University of Alberta - Department of Physics

Investigators

G.L. Cumming, J. Gray, P. Thompson, D.W. Davis

I. Instrumentation

(a) Pb mass spectrometer

This machine is currently being converted to the peak-switching mode. Data will be recorded on magnetic tape as at present, but in a form suitable for on-line analysis by a mini-computer which will be added as soon as funds are available.

(b) High sensitivity Sr spectrometer

Redetermination of the ^{87}Rb half-life is nearing completion, using a Spiralton detector. A fast amplifier has been built in order to improve the dead-time losses in the counting system. Peak switching and data readout are computer controlled, although some difficulties in the peak switching have been experienced due to the high resolution and consequent narrow peaks required to separate hydrocarbon peaks from the Sr.

II. Isotope Studies

(a) Deep sea drilling project

Sr analyses on rocks from DSDP Leg 37 were carried out at Canberra (Cumming). Comparison with data on the same material from the University of British Columbia and at Oxford indicate that major exchange with sea-water has taken place particularly in the near surface rocks. Between laboratory intercomparisons show that excellent agreement is possible when the data are properly normalized and corrected for instrumental mass discrimination.

Pb measurements made at Zurich (Cumming) indicate that the Pb composition is variable and fits a two-stage anomalous lead line of essentially zero age in marked contrast with most other oceanic basalt data. However the least radiogenic lead from a rock with 20 ppm Pb (contrasting with the remaining rocks which have 0.5 - 1.0 ppm) has ratios which yield a model age of about 550 m.y. Thus a more complex model is required and this implies that the rock from which oceanic ridge material originates is not homogeneous mantle, but has evolved over the past 550 m.y.

Whole rock oxygen isotope ratios were measured on twenty-four samples from DSDP Leg 37 (Gray and Lambert). The mean δO^{18} for hole 332A is 7.3 (relative to SMOW). For hole 332B it is 7.8 and for hole 335 it is 9.0. These figures correspond to altered basalts with 1-3 weight percent H_2O. It is provisionally concluded that these basalts have suffered O^{18} enrichment, probably via formation of "clays" rather than via carbonates, to the extent of up to 15% "clay" in the case of the samples with highest δO^{18}.

Thorium and uranium analyses were carried out using the delayed neutron technique at McMaster University, Hamilton, Ontario (Gray). K/U ratios (Lambert) vary widely averaging 33,000 in 335, 22,500 in the "low Zr, high Mg" subset of 332A and B and 11,000 in the "high Zr, low Mg" subset. These high ratios suggest U loss particularly in 335. The mean U figure, 0.180 ppm is rather higher than previous determinations from DSDP 17 and DSDP 15. Th is comparatively poorly determined by the delayed neutron method when in low concentrations, but the arithmetic mean is 0.48 ppm and the mean Th/U is 2.7 for those samples with Th above the detection limit. This agrees well with the Th/U ratio of 2.6 as deduced from the Pb isotope data.

(b) Pb from the Caribbean

Pb isotope measurements on ore deposits of late Mesozoic age carried out in cooperation with S.E. Kesler (University of Toronto), indicate that the isotopic composition is correlated with the existence of Paleozoic basement, the more radiogenic lead being found in areas where basement is present. Although the data are not conclusive they support the suggestion of significant crustal contributions in the development of these ore leads.

(c) Oil and natural gas studies

In collaboration with S. Burnie (Geology Department) an extensive S^{34}/S^{32} isotope study of sour gases sampled from D-3 pools within the Upper Devonian of Alberta has been carried out. A significant correlation exists between the inverse of the square of the reservoir temperature and the S^{34} difference between Upper Devonian sulphate and sour gases from the Upper Devonian Leduc reservoir. A model has been proposed for the generation of H_2S in D-3 reefs and is being prepared for publication (Burnie and Gray).

Some 250 C^{13}/C^{12} isotope analyses on oil and natural gas from Alberta have been carried out by S. Burnie and J. Gray. Significant variation in the δC^{13} of the various fractions (CH_4, C_2H_6 and C_3H_8) of natural gas is evident. Interpretation of these data will be carried out in the near future.

(d) Climatic significance of O^{18}/O^{16} isotope ratios in tree rings

Oxygen isotopic analysis of cellulose in tree rings is being carried out on trees from selected areas in western Canada for which climate information is available covering a period of about 100 years (Gray and Thompson). Preliminary results point to a good correlation between O^{18}/O^{16} in cellulose and mean annual temperature, with a coefficient of approximately 1.2 °/oo/°C. More extensive studies are now under way (including D/H measurements) to determine the fractionation factors involved in the production of cellulose by photosynthesis together with the effects of isotopic composition of the source water.

Department of Geology
Investigator:
H. Baadsgaard

1) U-Th-Pb, Rb-Sr and K-Ar on rocks and minerals from the Amitsoq Gneiss, West Greenland.

2) U-Th-Pb on zircons from major stratigraphic units of the Precambrian of the Godthaab District, W. Greenland and Isua supracrustals.

3) K-Ar dating of Cretaceous bentonites with a view towards:

   a) establishing disconformities in the stratigraphic sequence and estimating rates of sedimentation. (with G.D. Williams)

   b) dating magnetic reversals in the Cretaceous. (with J.F. Lerbekmo)

4) U-Th-Pb on zircons from late intrusives and volcanics in the Flin Flon area. (R. MacQuarrie)

5) Kinetics of Rb-Sr transfer in biotite and muscovite in a heated adamellite. (S. Kesmarky)

6) S, C isotopic variation in the thermal maturation of oil, western Alberta. (S. Burnie)

7) K-Ar reconnaissance geochronology of an unmetamorphosed ancient Archean gneiss within the Churchill (Hudsonian) metamorphic Province (U-Th-Pb, Rb-Sr eventually). (with F. Koster, R. Lambert)

8) A Rb-Sr and K-Ar study of metamorphic minerals in the Central Kootenay Arc, Kootenay Lake, B.C. (with S. Winzer)

9) U-Th-Pb dating of zircons from the Ancient Precambrian Saglek Bay gneisses, Labrador. (with K. Collerson)

   a) A study of the Rb-Sr, Th-U-Pb isotope systematics in minerals during the metamorphism of these ancient rocks.

10) A redetermination of the half-life of Rb^{87} by isotopic measurement of Sr^{87} in greater than 16 year old pure $RbClO_4$. (D. Davies)

11) K-Ca and Rb-Sr systematics in carnallite, halite and sylvite from the Devonian salt deposits in Saskatchewan.

12) a) U-Th-Pb dating on:

      a) Allanites from Fiskenaesset, W. Greenland. (R. Lambert and L.W. Day)

      b) Borrowdale volcanics, Britain. (R. Lambert)

   b) Rb-Sr dating on:

      a) Borrowdale volcanics, Britain. (R. Lambert)

      b) Snowdon volcanics, Britain. (R. Lambert)

2. University of British Columbia - Department of Geophysics and Astronomy

Investigators

R.D. Russell, W.F. Slawson, M. Yamaguchi, R.D. Meldrum, T.K. Ahern, M. Baron, D.J. Birnie and P. Shore

The Mass Spectrometer Laboratory of the Department of Geophysics and Astronomy houses three 12-inch mass spectrometers operated by this Department and an AEI MS10 operated by the Department of Geological Sciences. There are four small chemical laboratories for sample preparation and processing, as well as a laboratory used by the Department of Geological Sciences for potassium analyses for potassium-argon geochronology. Our laboratory cooperates very closely with Dr. R.L. Armstrong, Department of Geological Sciences. Much of the rubidium-strontium work has been transferred to Dr. Armstrong's laboratory, with our laboratory concentrating on the analysis of oxygen and lead.

Major scientific achievement in 1974 was a success of JOIDES deep sea drilling experiment, co-sponsored by Canada through Dalhousie University. Our laboratory, collaborating with Dr. R.L. Armstrong of the Department of Geological Sciences, and with the assistance of Professor M. Yamaguchi of Kyushu University, completed analyses of lead and strontium isotopic ratios for a number of core samples. In addition, rubidium-strontium ratios were determined as well as a similar number of lead concentrations. No clear-cut patterns emerged from these analyses, apart from the fact that the lead analyses appear to lie below the primary growth curve as has been observed for other samples of similar origin.

Earlier studies of bidirectional lead isotope mixing models, by Russell, and by Russell and Birnie, have been extended in a manuscript already presented to the IUGG in Grenoble, France. In particular, whereas the model of Russell and Birnie had assumed instantaneous proportioning of uranium between the two reservoirs at the time differentiation began, the newer models provide for a delayed transport of uranium and thorium, as well as lead. The additional flexibility to the model provides the possibility of having a differentiation beginning as early as 4,000 million years ago. In essence, the model is as follows:

The earth was formed approximately 4500 million years ago, but remained hot and unstable near the surface until a time, which may have been approximately 3700 million years ago, when stable configurations of the earth's surface could be formed and preserved. In particular, it is assumed that the mechanisms of plate tectonics could begin at that time and semi-independent systems could be preserved from which continental and oceanic materials could be derived. The well-known lead-207 discrepancy in isotopic measurements requires that there be at least two such systems, and that they have been identifiable for at least 3000 million years. It is possible that down-thrust slabs in the vicinity of island arcs provide a curtain across which there is little material transport.

The major material transport takes place from a system which is referred to as a residual mantle to a system referred to as the protocrust. The mechanism for this transport is probably the addition through fractional crystallization of materials at the oceanic ridges, followed by a second fractional crystallization in the region of island arcs through which material is added to the protocrust. It can be shown that, if there is approximate equilibrium between the material loaded onto the plate at the ridge with its source, and approximate equilibrium between the material removed from the ridge to the protocontinent, that the transport can be represented by first order rate constants. Smaller in magnitude, but of considerable importance to the model, is a return flow from the continent's protocrust to the residual mantle, probably through the addition of continental detritus carried down in the trenches. Observed isotopic patterns can be reproduced by a number of choices of parameters. Typical of these are characteristic transport times for uranium and thorium of about 300 million years and for lead, of about 900 million years.

Stable isotope studies into several new areas began this year. Tim Ahern collected eighty-three surface samples of ice and twenty-six samples taken between the ice surface and one hundred and twenty feet during the month of June 1975 from the Steele Glacier, Yukon Territory. The samples were taken from near the equilibrium line to slightly more than halfway to the present terminus. It is hoped that the isotopic analysis of these samples will give insight into the three-dimensional flow in the Steele glacier. It is believed that this is the first three dimensional isotopic study of a major surging glacier. Samples were taken both above and below the confluence of the Steele and Hodgson glaciers and if isotopic differences exist between the ice of these glaciers it may be possible to measure the frequency and number of surges of the Hodgson by studying the isotopic patterns in the lower Steele. This isotopic method would be very useful near the terminus of the glacier where the entire surface is dirt covered and makes it impossible to see looping moraines.

Tim Ahern and Mark Baron, with the cooperation of the Atmospheric Environment Service, undertook a project to study the isotopic variations in rain in southern British Columbia from the West Coast of Vancouver Island to the Alberta border. Approximately three hundred precipitation samples were collected at seventeen locations during the month of January 1975. It is hoped that the isotopic content of these samples will demonstrate both the familiar altitude effect and also the depletion of the heavy isotope as the storm moves inland. Weather records from the Atmospheric Environment Service have allowed single storm systems to be tracked quite reliably and to give an estimate of the temperatures aloft where the precipitation originated.

Tim Ahern, Terry Harris and Bob Pritchard have completed a study of oxygen exchange between water and the calcium carbonate in eggshells. As expected the isotopic composition of the eggshell changed exponentially with time when the isotopic composition of the drinking water was changed. The half-life of the exponential response was found to be approximately two days which is what one predicts from a simple isotopic mixing of water within the hen. This project demonstrated a very simple use of non-radioactive tracers to study a biological process.

Tim Ahern has begun work on a physical model of water flow in cold snow using the data from the project described in last year's Annual Report. The main feature to be included in the model is that isotopic variations in cold snow measured on Mount Seymour, British Columbia were enhanced when liquid water enriched in oxygen-18 flowed through the snow. It is therefore reasonable to assume that water flow in cold snow can create isotopic variations which could be mistaken for seasonal variations and thus cause errors when using isotopic techniques to study climatic changes.

There are also indications that melting and recrystallization play an important part in mass movement in cold snow, that isotopic fractionation plays an important role in the freezing of water in cold snow and that the transfer of water in snow cannot always be treated as a steady state process but that non-equilibrium effects must be considered. All of these features should be included in any physical model of water flow in cold snow.

Some minor changes will be made to the oxygen mass spectrometer in the near future. These include replacing a mercury diffusion pump by a 110 liter per second noble ion pump, re-designing the dual collector assembly to put both Faraday cups in the focal plane and altering the sample inlet system to allow more rapid sample analysis.

Department of Geology
Investigator: R.L. Armstrong

R.L. Armstrong currently is funded by an NRC operating grant for "Geochronometry of Cordilleran Igneous and Metamorphic Rocks". More specifically we have in progress at the moment a program to obtain Sr isotope data for late Cenozoic volcanic rocks from throughout the Cordillera. About 40 samples from Mount Garibaldi and other volcanoes near Vancouver have been analysed (portions of a Ph.D. thesis of N. Green and postdoctoral research project of B. Watters from Capetown, South Africa). Also completed are suites from the Wrangell Mountains and Mount Edziza (supplied by J. Souther, G.S.C.). Rb-Sr studies on several batholith-metamorphic rock complexes are in progress (Mt. Raleigh and Garibaldi Park portions of the Coast Mountains - G. Woodsworth, G.S.C., and N. Green, Ph.D. candidate, Princeton to Okanagan Lake complex - P. Petö, P.D.F., Hogem Batholith - G. Woodsworth, G.S.C. and T. Eade, Honours Student, Geophysics). R.B. Maxwell, M.Sc. candidate, is working on Sr isotopes in sulfide minerals and ultramafic nodules - both problems concerned with Sr in very low concentration but with potential great interest. G. Medford of Cominco is studying Sr isotopes in carbonate host rocks and mineralized Pb-Zn deposits, a project that overlaps with R.B. Maxwell's in that both are looking at Pine Point. R. Parrish, D. Runkle, P. Solbert, and G. Ditson will be working on geochronometry (K/Ar and Rb/Sr) in their respective M.Sc. thesis areas (Wolverine Complex, Coast Mountains near Kitimat, Vernon area, ore deposits in SW B.C.). Samples have been collected by R.L. Armstrong from the Ecstall Pluton and high grade gneiss core of the Coast Mountains near Prince Rupert, several plutons near Oliver on the west side of the Shuswap Complex, and by C. Godwin from the Klotassin batholith in the Yukon. Rb/Sr work on these suites will in some cases be followed by U/Pb dating of zircons. N. Green and J. Harakal have been K/Ar dating the young volcanic rocks of the Garibaldi area. A suite of young mineralized porphyries from scattered Cordilleran localities from Washington to Alaska is being K/Ar dated for V. Hollister, Duval Corp., and minerals from blueschist localities in Alaska and Washington are being dated for R.B. Forbes, Univ. of Alaska, and E.H. Brown, Western Washington State College, respectively.

3. The University of Calgary

Investigators

Department of Physics: H.R. Krouse, H.M. Brown
Department of Geology: F.A. Campbell, R.B. Farquharson
Department of Biology: E.J. Laishley

Projects (with participants from other laboratories in brackets):

(a) Geological

(i) Sullivan Ore Body; S-isotopes

(ii) Mid-Atlantic Cores (DAGS); S-isotopes in sediments show large ^{34}S depletions in pyrites. In hard rocks ^{34}S is less depleted with depth tending to $\delta^{34}S = 0$, the range associated with magmatic sulphides

(iii) Devonian Gas Wells in Alberta; C, S, O, H, and N isotopes (Brian Hitchon, Research Council of Alberta)

(iv) H isotopes in oils; Dr. G. Lyon from Rafter's Lab., Lower Hutt, New Zealand, recently completed a year's sabbatical here studying this subject

(v) Springs in the MacKenzie Valley; S-isotopes (R.O. van Everdingen, Inst. of Sed. and Pet. Geol., Calgary)

(vi) Sulphur Isotope Geothermometry; (Ian Lange, U. of Montana)

(vii) Kerogens and Bitumins; C and S isotopes (Brian Hitchon, Research Council of Alberta)

(viii) Sulphides in Skarn Deposit, Northern Vancouver Island; S-isotopes

(ix) Porphyry Copper Deposits in the Highland Valley, Southern British Columbia; S-isotopes (W. MacMillian, B.C. Dept. of Mines)

(b) Meteorology, Hydrology, Glaciology

(i) Marmot Creek Basin, Alberta; H isotopes used to study surface and sub-surface runoff contributions to streams

(ii) Central Sierra Mountains; H isotopes used to study dynamics of snowpacks

(iii) Spring Creek Basin; H isotopes used to study surface and sub-surface runoff contributions to streams, (with G. Holecek, Alberta Environment)

(iv) Creighton Watershed, Sask.; H isotopes used to study snow melt runoff, (with H. Steppuhn, Univ. of Sask.)

(c) Environmental

During this past year considerable effort has been directed towards projects initiated by UNISUL--The University of Calgary Interdisciplinary Sulphur Research Group. Our laboratory has been mainly concerned with S-isotope abundances in the environmental studies of UNISUL but has also contributed to the development of new techniques (listed under (e)).

(i) Chemistry of Gas Plant Plumes; S-isotopes in $SO_4^{=}$ and SO_2 collected by helicopter

(ii) High volume air sampling at ground level around Sulphur Plants

(iii) Water-Soil interactions

(iv) S-isotopes in mosses, lichens, soils, and trees in the vicinity of Gas Plants, (J.D. Bewley, Dept. of Biology, The U. of Calgary; Alan Legge, Environmental Sciences Centre, Kananaskis, Drake Hocking, Environment Canada).

(d) Microbiological

Studies are continuing on the N, C, and S isotope fractionation by *Clostridium pasteurianum* as part of the UNISUL effort.

(e) Instrumental

(i) Development of High Volume Atmospheric Sampling Techniques

(ii) Development of a fast S-isotope mass spectrometer capable of handling small samples

(iii) Development of a radio-isotope technique for determining small sulphur concentrations.

The above development work is carried out under UNISUL. In addition, the solid source mass spectrometer has been rebuilt to accommodate a rapid sample insertion probe allowing samples to be processed approximately every 30 minutes. A T.I.980 computer is being programmed to control several of the mass spectrometers simultaneously.

4. Carleton University - Department of Geology and Department of Physics

Investigators

K. Bell, T.J.S. Cole, D.P. Menagh, J. Blenkinsop

In collaboration with Dr. R. Macdonald of the Precambrian Section, Saskatchewan Dept. of Mines, we have begun a program of dating of samples from the Pelican Narrows and Amisk Lake areas of Saskatchewan. The project represents an extension of our earlier work, in conjunction with the G.S.C., on the Flin-Flon Snow Lake greenstone belt, which our results showed to be Aphebian. The rocks being studied include those of the Amisk volcanics, and related instrusives. We are hoping to resolve discrepancies posed by earlier geochronology in this region.

We are continuing our cooperation with geologists at Memorial University of Newfoundland in dating granitoid rocks from the eastern part of the island. Our latest results substantiate our previous conclusion that intrusive activity in that region is mostly Silurian-Devonian, but we have also obtained further evidence of Carboniferous magmatism and Carboniferous or younger deformation. A Cambrian age on a granite which straddles the boundary between the Central Mobile Belt and Avalon Zone shows, however, that the boundary was established in its southern part by this time, and that some gneisses from the Central Mobile Belt are Cambrian or older.

We have also begun a project at Buchans, in which we hope to date the host rocks (volcanics) of the ore deposits, and the neighbouring granitoid rocks to the north and west. This work is being carried out in conjunction with geologists at Memorial University and at Buchans, and is funded by ASARCO. Our results will form the basis of our contribution to the "Buchans Anniversary Volume" which will be published within the next year or so.

Further work in Newfoundland, in cooperation with the Dept. of Energy and Mines, includes the dating project in the Burlington Peninsula and work in the Fortune Bay area on the south coast. In the former project, we have uncovered more evidence of Carboniferous magmatism and/or deformation, and have obtained results which contradict suggestions of pre-Ordovician orogeny in the area.

5. Dalhousie University - Department of Geology

Investigators

P.H. Reynolds, V.J. Stukas, R.J.E. Parrott, W. Clay

K-Ar and $^{40}Ar/^{39}Ar$ Dating

During the past year, graduate student V. Stukas has been continuing his $^{40}/39$ studies of Late Precambrian volcanic rocks from the Avalon Peninsula, Newfoundland. In all units so far examined, the argon released at temperatures up to 1000°C has an apparent age of ≃400 my and hence appears to date a secondary thermal event. Gas released at still higher temperatures yields ages in the vicinity of 800 my, dates which are probably geochronologically significant. This apparently datable mineral is probably plagioclase. By carrying out very detailed stepwise outgassing experiments, we are attempting to more fully understand the age spectra.

Graduate student R. Parrott has completed an M.Sc. study of basalts from West Greenland and from Baffin Island, the samples having been selected from D.B. Clarke's collections. The West Greenland samples yielded consistent $^{40}Ar/^{39}Ar$ data and a mean age of 60 my. Baffin Island results are more scattered and indicate the presence of excess radiogenic argon. Late-stage lamprophyric intrusions from Ubekendt Island, West Greenland appear to be 20-30 my younger than the basalts.

Graduate student, E. Olojo (Department of Physics) has completed an M.Sc. thesis entitled "$^{40}Ar/^{39}$ dating of dikes from the Frontenac Axis and the Grenville polar loop". Olojo was able to combine his radiometric results with Park and Irving's published paleomagnetic data and obtain an absolute age calibration of the Grenville loop.

Graduate student, P. Rice (Department of Geology) has completed a detailed $^{40}/39$ study of selected samples taken from an igneous rock core which had been drilled on the island of Bermuda (Dalhousie University, Deep Drill 1972). He has been able to substantiate an earlier suggestion of ours, that a major portion of this volcanic pedestal is indeed as old as the surrounding sea floor (that is, about 100 my old).

Additional projects (both conventional K-Ar and $^{40}Ar/^{39}Ar$) include:

i) dating of Cenozoic volcanics from North Africa and from Thailand (with J.M. Hall, Department of Geology and S.M. Barr, University of Chiengmai, Thailand)

ii) dating of Nova Scotian granites and slates (with D.B. Clarke, G.K. Muecke, M. Zentilli, Department of Geology).

6. University of Manitoba - Department of Earth Sciences

Principal Investigator: G.S. Clark, Department of Earth Sciences.

Investigators: Jon Scoates, Werner Weber, Manitoba Mines Branch; P. Pushkar, Wright State University; Gregory S. Horne, Wesleyan University; K.V. Subbarao, Indian Inst. of Tech., Bombay; Sha-Pak Cheung, University of Manitoba.

(a) Strontium Isotope Studies

Geochemical and magnetic studies on the St. Mary Islands, Arabian Sea

The rocks of St. Mary Islands (13°19'30"-13°23'10";74°40'15"-74°41'30") off the western coast of India include dacites, rhyodacites, rhyolites, and granophyres. Strontium isotope ratios have been completed for six samples and the values range from 0.7058 to 0.7066. Their results seem to agree with additional geochemical results which suggest a crustal derivation of the volcanics. (Subbarao and Clark).

(b) Rubidium-strontium geochronology

(i) Pre-Cretaceous rocks of northwestern Honduras: The basement terrain in the Sierra de Omoa

The Sierra de Omoa lies just south of the Caribbean coast in northwestern Honduras. Rb-Sr total rock ages have been determined for selected metamorphic and plutonic rocks in the region to assist the detailed field studies of G.S.H. Comprehensive regional

studies accompanied by the isotopic results have been quite successful in revealing the chronology of events involved in the evolution of the basement complex of the region (late Precambrian - early Paleozoic to late Tertiary). (Horne, Clark, and Pushkar).

(ii) Oxford Lake-Gods Lake Region, Manitoba

This area occurs within the northern part of the Superior Province in Manitoba. The isotopic work was initiated as a result of detailed field mapping by the Manitoba Mines Branch (see Elbers, F.J., Greenstone project, in; Summary of Field Work, 1973, Man. Mines Br. Geol. Rept. 2/73). The area is underlain by volcanic-sedimentary series and interjacent granitic areas - orthogneisses and younger granites. It is possible, in the field, to distinguish between pre-, syn-, and postkinematic intrusions. The purpose of the age study is to establish the absolute ages and age relations of these igneous rocks. Initial results from granitoid clasts from a basal conglomerate (Oxford Lake Conglomerate) suggest a derivation from basement rocks having a minimum age of 2800 m.y. The best-fit "isochron" from several scattered data points gives an apparent age of 3100 m.y. (Clark and Sha-Pak Cheung).

(iii) Fox River Greenstone Belt, Manitoba

Rubidium-strontium total-rock ages are being determined on volcanic rocks adjacent to the Fox River (ultramafic) sill (Scoates, R.F.J., Ultramafic Rock Project, in; Summary of Field Work, 1975, Man. Mines. Br. Geol. Paper 2/75, p. 22). The greenstone belt lies within the northeastern part of the Superior Province in Manitoba. Initial measurements have been obtained on rhyolite tuff which occurs as a narrow layer (less than 100 m wide) in contact with the south marginal series of the Fox River sill. Isotopic work is also in progress for the gneissic (granitic) rocks adjacent to the greenstone belt. (Scoates and Clark).

7. McMaster University - Departments of Geology, Physics and Chemistry

(a) Rb/Sr Isotopic Studies

(i) Mistastin Lake Crater

This structure is a suspected impact crater which contains exceptionally good exposures of melt rock. A Rb-Sr isochron on the Mistastin Lake pluton (adamellite + mangerite) yields 1347 ± 15 m.y. Geochemical balance calculations indicate that the melt rocks are mixtures of the above granitic rocks and anorthosite. Their age is 40 m.y. (K-Ar) but they generate a pseudo Rb-Sr isochron with apparent age of 1605 m.y. Impact derived melts do not appear amenable to Rb-Sr dating. (M. Marchand and J.H. Crocket).

(ii) Sudbury Irruptive

New geochronology data has been obtained for various rocks from the Sudbury Irruptive by the Rb-Sr technique. Melt rocks from the Onaping Formation yield isochrons of 1891 and 1782 m.y. Granite and quartzite inclusions in the Onaping yield ages of 1495, 1429 (2 suites of granite inclusions) and 1601 m.y. respectively. The plagioclase micropegmatite yields an isochron of 1361 m.y. The Onaping rocks clearly demonstrate open system behaviour with respect to Rb/Sr and the plagioclase micropegmatite has possibly experienced re-equilibration in response to a late metamorphic event. (M. Marchand and J.H. Crocket).

(iii) Kakagi Lake (Kenora area, Ontario)

A study of a small Archean granitic stock (Little Stephen Lake) and its associated felsic volcanics is in progress. The objectives are to test the volcanics for open or closed system behaviour with respect to Rb/Sr if an isochron can be obtained for the

presumed parental stock. (M. Wolff and J.H. Crocket).

(iv) Andean Orogenic Zone

Our reconnaissance study of Sr^{87}/Sr^{86} variations across the Andes of Central Chile, has shown that ratios increase with decreasing age, from 0.7025 to 0.7080. Pb isotopic analyses of some of these same rocks, show a similar pattern, in that the young (<20 m.y.) volcanics have relatively high Pb^{206}/Pb^{204} and Pb^{208}/Pb^{204} values. (R.H. McNutt, J.H. Crocket (A. Clark, E. Farrar, Queen's University)).

(v) Archean Greenstone and Gneiss Belts

Geochemical studies and field mapping indicate that the "younger" diapiric granitic plutons can be bimodally classified into stocks showing differentiation by autometasomatism and by multiple intrusion. The effects of autometasomatism on Rb/Sr systematics are now being investigated. (D. Birk and R.H. McNutt).

(vi) Rb/Sr and O^{16}/O^{18} Comparative Studies on Archean Greenstones

Representative regions of both greenstone and gneiss belts have been sampled to establish distribution patterns of oxygen isotope ratios. This will be combined with strontium isotope ratios, major and trace element data to hopefully establish chemical evolution models for the Archean crust. (F. Longstaffe, R.H. McNutt, H.P. Schwarcz).

(b) Stable Isotope Studies

(i) Sulphur Isotope Studies

Observational, experimental and theoretical studies are continuing of the sulphur isotope effects produced in 1) the bacterial reduction of sulphate, 2) sediment diagenesis, and 3) oil generation, maturation, and migration.

Experimental studies are under way of kinetic and equilibrium isotope effects involved in the dissociation of troilite and in other inorganic reactions involving sulphur.

Isotope ratios in Archean banded iron-formations are being used to characterize depositional conditions and provide information on the possible role of living organisms in the early Precambrian. This work is being extended to include carbon isotope measurements. Lunar and meteorite studies are continuing. (C.E. McEwing, J. Monster, C.E. Rees, D.L. Scott, and H.G. Thode).

(ii) Sulphur-Isotope Studies of Archaean, Massive, Volcanogenic Ore Deposits

Detailed study of the Millenbach ore deposit at Noranda, P.Q. and similar deposits, reveal a consistent isotopic behaviour, which can be modelled according to several possible genetic schemes. Distinctive differences occur between the Archean deposits and analogous (?) Phanerozoic or late pre-Cambrian deposits. (P.G. Coomer and H.P. Schwarcz).

(iii) Oxygen and Sulphur Isotopic Studies of Evaporites

$\delta^{18}O$ and $\delta^{34}S$ in evaporite sulfates of Recent age from Abu Dhabi sabkha are not strongly intercorrelated, in general, although both variables show marked variation. Areal patterns can be recognized. Fractionation between brine and crystals is larger than typically observed in experimental measurements. Ancient evaporites show similar variations in some cases, though other deposits (e.g., Salinan of Ontario) are remarkably uniform and display some correlation between $\delta^{18}O$ and $\delta^{34}S$, possibly of bacterial origin. (E. Olson and H.P. Schwarcz).

(c) Paleotemperature Studies of Cave Deposits

Deposits of travertine from deep inside limestone caves are being analysed for their age of deposition (using $^{230}Th/^{234}U$ method) and their stable isotopic composition. These data permit us to construct curves of relative temperature variation in the caves through the past 300,000 years. These data reflect surface climatic changes during the latter part of the Pleistocene. They are especially valuable because they give data about the continents, where local and regional climatic shifts during the Pleistocene were especially intense. Fluid inclusion D/H ratio measurements permit estimation of the isotopic composition of ancient rain and snow. (A.E. Fallick, R.S. Harmon, M. Gascoyne, H.P. Schwarcz and D.C. Ford).

(d) Archaeological Dating

Using the $^{230}Th/^{234}U$ method and related techniques, cave sites in North America, Europe and Israel are being studied to establish absolute time data for the evolution of Upper Paleolithic and Neolithic man. (H.P. Schwarcz).

(e) Rare Gas Isotopic Studies

Extensive measurements are being made of inert gases dissolved in terrestrial waters. Oceanic measurements of He^3, He^4 and Ne appear to be a promising way of determining deep water flow, while measurements of H^3 and He^3 provide a way of "dating" (tritium-He^3 ages) water in the oceans above the thermocline, in lakes and in ground water. A method of prospecting for U and Th based on dissolved helium in ground water is in progress.

Age determinations using the Xe^{133}-Xe^{136} method for certain rocks and zircons are in progress. The method employed is to irradiate the specimen with neutrons, thereby implanting Xe^{133} at the U-sites, and then to perform temperature heating experiments to determine the relative release rates of Xe^{133} and Xe^{136} (from spontaneous fission of U). For some specimens already dated by U-Pb, the Xe^{133}-Xe^{136} method appears to be capable of seeing through superimposed metamorphism which has reset the U-Pb dates. (W.B. Clarke, Z. Top and A. Teitsma).

8. Queen's University - Department of Geology

Investigators

E. Farrar, S.L. McBride, D.A. Archibald, R.J. Knight

Several geochronological investigations are currently underway:

(a) A study of the chronology of intrusion and mineralization in the Bolivian and northern Chilean Andes has become focussed on mineral age discordances observed in some batholiths. The $^{40}Ar/^{39}Ar$ technique is being employed to try to resolve these discordances (S.L. McBride, E. Farrar).

(b) A K-Ar geochronological study of the south-eastern part of the Kootenay arc (British Columbia) is in progress. The research is concentrated on the Bayonne Batholith and surrounding metamorphic rocks. The aim of this research is to determine the age relations of the intrusions comprising the batholith and thereby to determine the role of the batholith in the structural and metamorphic history of the area. (D.A. Archibald, E. Farrar).

(c) A continuing investigation into the problems of initial argon in amphiboles of the Tulameen complex in southern B.C. through the use of the $^{40}Ar/^{39}Ar$ incremental heating technique. (E. Farrar).

(d) An attempt is planned to determine whether evaporite minerals may be used as geochronometers. The $^{40}Ar/^{39}Ar$ technique will be used. (R.J. Knight, E. Farrar).

9. University of Toronto - Department of Physics

I. K-Ar Studies

Investigators

D. York, R. Bottomley, C.M. Hall, J.A. Hanes

(a) ^{40}Ar-^{39}Ar Dating of Impact Structures - (R. Bottomley, D. York)

Recent field work coupled with mineralogical studies of shocked rocks indicates that some large, roughly circular features on the earth's crust (up to 100 km diameter) were probably caused by impacts of large meteorites moving with cosmic velocities. A good number of these ($\sim$30) are to be found in Canada, mostly in the shield areas.

A series of impact generated melt rocks and shocked country rocks from a number of these sites will be dated by ^{40}Ar-^{39}Ar with a two-fold objective:

(1) to obtain reliable dates of the formation of these structures;

(2) to see if the impact process leaves any characteristic signature on the argon isotope distribution in the shocked target rocks.

As well as being dated, the rocks will be examined petrologically by personnel of the Earth Physics Branch of the Department of Energy, Mines and Resources.

This type of study will supplement the successful ^{40}Ar-^{39}Ar work that has been done on the returned lunar rocks, many of which were formed during the great impact episode early in the moon's history (~4 b.y. ago). Hopefully, information about the distribution in time (and possibly new information about the impact process itself), will help to illuminate this phenomenon which has played such an important part in the past history of the Moon, Mars, Mercury, and probably the Earth as well. In addition, precise ages of these craters will give good estimates of the erosion rate on the Canadian Shield.

(b) K-Ar Dating of Young Rocks - (C.M. Hall, D. York)

During 1975, we have continued work on using the K-Ar radioactive dating technique on extremely young igneous rocks. Several analyses have been made for some recent Japanese basalts.

Unfortunately, in several of these samples, significant quantities of extraneous argon were found. An attempt has been made to isolate the phase responsible for this excess Ar. In particular, plagioclase of grain size - 150+200 mesh was separated out and analysed. However, the very low yield of such separates has prevented a conclusive analysis from being made.

Several analyses were made on a sample from the Olby flow in the Puy-de-Dome region of France. This is a contemporary of the Laschamp geo-magnetic reversal event and I have attempted to improve the K-Ar date for this event. Results have been encouraging. For five separate fusions, a consistent age of about 50,000 years has been found. Thus, the precision of the mass spectrometer, the fusion system and a new data handling package has been demonstrated.

In an effort to reduce atmospheric argon contamination, several low temperature (ca 400°C) gas fractions were analysed to see if most of the atmospheric Ar was surface bound. Unfortunately, very little Ar came off at this temperature and at higher temperatures, significant quantities of radiogenic Ar are likely to be removed.

Work has started on preparing very fine-grained mineral separates. This is doubly difficult because most standard mineral separating techniques are ineffective for extremely fine-grained samples and under most circumstances, the crushing of a mineral to extremely small grain size greatly increases the amount of atmospheric argon contamination.

(c) ^{40}Ar-^{39}Ar Study of Thermal Metamorphic Events - (J. Hanes, D. York)

An ^{40}Ar-^{39}Ar geochronologic study is being carried out in our laboratory on Precambrian diabase dikes in the Superior province of the Canadian Shield. Two intersecting dikes in Munro Township, Ontario, in the Abitibi greenstone belt were selected for this dating technique on a well-exposed geologic contact and to relate the results to previous paleomagnetic work (carried out by Dr. E. Irving, Energy, Mines and Resources, Ottawa, Canada; unpublished).

Specifically, a N-S trending 80 foot wide Matachewan dike (Rb/Sr age of 2690 m.y.) is cut by an NE-SW trending 250 foot wide Abitibi dike (Rb/Sr age of 2157 m.y.). Paleomagnetically, the Matachewan dike has been reset by the Abitibi intrusion to a distance of 80 feet from the contact, beyond which Matachewan directions are retained. Pure magnetite appears to be the carrier of the remanence.

In our laboratory, we have been conducting multi-step ^{40}Ar-^{39}Ar runs on coarse-grained samples from the two dikes and from the adjacent gabbroic country rock. Initially, whole-rock chunks were used, but preliminary data indicated the advisability of preparing mineral separates.

The most interesting result thus far is revealed by the felsic (feldspar) separates from some samples which yield plateaus (on "age vs fraction ^{39}Ar released" plots), over much of their gas release, at 1700-1800 m.y. This suggests that the feldspars may have been reset by a Hudsonian thermal event in the Superior province which is not evident geologically. Independent paleomagnetic work on the nearby Otto stock (Irving, 1975) lends support to this idea.

The mafic separates appear more retentive of their argon, and are characterized, in the Matachewan samples, by plots ("age vs ^{39}Ar released") which climb steadily to a final age around 2-4 b.y. This could represent a minimum age for the crystallization of the Matachewan dike. In the Abitibi dike, the pyroxene separate defines a plateau, over 50% of the gas release, of 2050 m.y., i.e., a minimum crystallization age. In all samples, excess argon does not seem to be a problem.

The Matachewan samples indicate a considerably more complex geochronologic relationship than suggested by the simple magnetic behaviour. There is evidence from various samples of three "events": 1) the (possible) primary crystallization age (a minimum value), 2) the Abitibi resetting event at 2.1 b.y., 3) the "Hudsonian" thermal event. However, there is no readily apparent relationship between the observed age relationships and distance of the samples from the contact.

Future work, now in progress, will include a closer examination of 1) feldspar separates to substantiate the implied Hudsonian event, 2) pyroxene separates in an attempt to obtain a primary Matachewan plateau age, 3) the petrologic relationships as a possible indicator of argon retentivity. As well, whole-rock chilled margin samples and country-rock pyroxenite samples will be studied to ascertain their suitability for study.

II. Uranium and Lead Studies

Investigators

R.M. Farquhar, I. Fletcher, Y.F. Huang

(a) Lead Isotope Ratios in Grenville Sulphides - (I. Fletcher, R.M. Farquhar)

The first stage of a study of lead isotope ratios in minerals from Grenville and associated rocks has been completed. Ten samples from volcanogenic sulphide minerals, vein type sulphide occurrences and from disseminated sulphides in overlying Paleozoic rocks have been analysed using a solid source 90°, 30 cm radius of curvature magnetic analyser mass spectrometer. Within experimental uncertainties, the data are linearly distributed on a $^{207}Pb/^{204}Pb$ - $^{206}Pb/^{204}Pb$ plot and give a slope of $0.116 \pm .009$. The least radiogenic leads (both of the volcanogenic type) lie distinctly below the average

terrestrial growth curve defined by strati for sulphide deposits. On the basis of a single stage growth model, the oldest lead has an age of 1280 m.y. The slope of the secondary isochron can be interpreted as the addition of radiogenic lead generated between 1300 m.y. and 1000 m.y. The lead isotopic ratios of these Grenville and related rocks are all significantly different from the ratios for sulphides in the main ore body at Balmat New York, but a significant number of the published data points for lead from Grenville feldspars lie on the sulphide isochron, or define a parallel isochron displaced in the direction of higher $^{207}Pb/^{204}Pb$ ratios. A paper is being prepared in which these features are presented and discussed in more detail.

Further isotopic analyses of sulphide lead and feldspar leads are planned in an effort to clarify the situation.

(b) Determination of Uranium by Fission Track Counting - (Y.F. Huang, R.M. Farquhar)

During the past year and a half, a technique has been developed for measuring very low (p.p.b.) uranium contents using solid state fission track recorders, with the Slowpoke nuclear reactor as a source of thermal neutrons. An automatic spark counting circuit has been designed and built, and as a test of the method the determination of the uranium contents of several silica-rich rocks (agate, flint, jasper, quartz, and opal) has been carried out. For each sample, a plot of observed counts against increasing concentration is linear, and the slope of the line, relative to that for a glass standard, gives the U content of the sample. Not including the uncertainty in the uranium content of the reference, the precision of the technique is within ±8% (standard error) of the mean. The design of the spark counting system, experimental procedure, and results are included in a thesis. U contents range from 27 ppb (Quartz) to 260 ppb (Jasper).

Sections of the specimens under study are being prepared with a view to determining (1) the distribution of U in the samples using fission track maps, and (2) the possibility of observing fossil tracks due to the natural fission decay of ^{238}U.

10. University of Western Ontario - Department of Geophysics

Investigators

A. Hayatsu, B. Merz

(a) Determination of Initial ^{36}Ar Content - (A. Hayatsu)

In order to apply the K-Ar isochron method, samples must be free from atmospheric argon contamination. Crushed and homogenized aliquots of samples of basalt and diabase were analysed for ^{36}Ar after various storage times, baking temperatures and baking times. It has been found that samples with particle size greater than 100 mesh, freshly crushed or stored in vacuum can be baked under vacuum to remove atmospheric argon contamination without loss of radiogenic argon. With such procedures initial ^{36}Ar content can be determined uniquely and reproducibly. This makes it possible to apply the isochron method to K-Ar dating in a way exactly analogous to its use in Rb-Sr dating.

The study will be extended to other rock types as well as mineral samples with particular reference to the contamination acquired during mineral separation.

(b) Age of the Sudbury Dykes - (B. Merz)

A conventional K-Ar study on the Sudbury diabase dykes is in progress. Ages mostly in the range 1100 to 1400 m.y. have been found where the dykes lie well within the Southern province. Dykes in and immediately adjacent to the Grenville Province have apparent ages of 850 to 1150 m.y. A zone in which the diabases yield highly variable apparent ages, including some greater than 1800 m.y., separates the two age groups.

11. Bibliography: Isotope Studies and Geochronology

1. Armstrong, R.L., Precambrian (1500 m.y. old) rocks of central Idaho - the Salmon River arch and its role in Cordilleran sedimentation and tectonics, Am. Jour. Sci., 275A, 437-467 (1975).

2. Armstrong, R.L., Episodic volcanism in the central Oregon Cascade Range: Confirmation and correlation with the Snake River Plain, Geology, 3, 356 (1975).

3. Armstrong, R.L., Leeman, W.P., and Malde, H.E., K-Ar dating, Neogene volcanic rocks of the Snake River Plain, Idaho; Am. Jour. Sci., 275, 225-251 (1975).

4. Brown, H.M. and Krouse, H.R., Development of a high volume sampler for gaseous and particulate sulphur compounds in the atmosphere, Proc. Alberta Sulphur Gas Workshop II, Kananaskis, Alberta, Jan. 16-17, 50-57 (1975).

5. Charlton, R.B., Gray, J. and Sandhu, H., Modelling precipitation processes with stable isotopes, Proc. 9th Annual Canadian Meteorological Society Congress, Atmosphere, May (1975).

6. Craig, H., Clarke, W.G. and Beg, M.A., Excess He^3 in deep water on the East Pacific Rise, Earth Planet. Sci. Letts., 26, 125-132 (1975).

7. Cumming, G.L. and Tsong, F., Variations in the isotopic composition of volatilized lead and the age of the western granodiorite, Yellowknife, N.W.T., Can. J. Earth Sci. 12, 558-573 (1975).

8. Davies, G.R. and Krouse, H.R., Carbon and oxygen isotopic composition of late Paleozoic calcite cements, Canadian Arctic Archipelago - preliminary results and interpretation, Geol. Surv. Can. Paper 75-1, Part B, 215-220 (1975).

9. Davies, G.R. and Krouse, H.R., Sulphur isotope distribution in Paleozoic evaporites, Canadian Arctic Archipelago, Geol. Surv. Can. Paper 75-1, Part B, 221-225 (1975).

10. Hage, K.D., Gray, J. and Linton, J.C., Isotopes in precipitation in northwestern North America, Monthly Weather Review, 103 (1975).

11. Harmon, R., Thompson, P., Ford, D.C. and Schwarcz, H.P., Uranium series dating of speleothems: a review, Nat. Speleol. Soc. Bull., 37, 21-33 (1975).

12. Hattersley-Smith, G., Krouse, H.R. and West, K.E., Oxygen isotope analysis in accumulation studies on an ice cap in northern Ellesmere Island, N.W.T., IAHS Publication of Snow and Ice Symposium, IUGG, Moscow, IAHS-AISH Publ. 104, 123-128 (1975).

13. Hayatsu, A. and Palmer, H.C., K-Ar isochron study of the Tudor Gabbro, Grenville Province, Ontario, Earth Planet. Sci. Lett., 25, 208-212 (1975).

14. Laishley, E.J., McCready, R.G.L., Bryant, R. and Krouse, H.R., Stable isotope fractionation by *Clostridium pasteurianum*, Proceedings of the Second International Symposium on Environmental Biogeochemistry in Environmental Biogeochemistry (J.O. Nriagu, Ed.) (Science Publishers Inc.: Ann Arbor, Mich.), 327-349 (1975).

15. Lusk, J., Campbell, F.A. and Krouse, H.R., Application of sphalerite geobarometry and sulphur isotope geothermometry to origin of the Quemont Mine, Noranda, Quebec, Econ. Geol., 70, 1070-1083 (1975).

16. McCready, R.G.L., Laishley, E.J. and Krouse, H.R., Stable isotope fractionation by *Clostridium pasteurianum*. 1. S^{34}/S^{32}: Inverse isotope effects during $SO_4^=$ and $SO_3^=$ reduction, Can. J. Microbiol., 21, 235-244 (1975).

17. McNutt, R.H., Crocket, J.H., Clark, A.H., Caelles, J.C., Farrar, E., Haynes, S.J. and Zentilli, M., Initial Sr^{87}/Sr^{86} ratios of plutonic and volcanic rocks of the Central Andes between latitude 26° and 29° South, Earth Planet. Sci. Lett., 27, 305-313 (1975).

18. Mitchell, R.H. and Krouse, H.R., Sulphur isotope geochemistry of carbonatites. Geochim. Cosmochim. Acta, 39, 1505-1513 (1975).

19. Palmer, H.C. and Hayatsu, A., Paleomagnetism and K-Ar dating of some Franklin lavas and diabases, Victoria Island, Can. J. Earth. Sci., 12, 1439-1447 (1975).

20. Rees, C.E. and Thode, H.G., Sulphur concentrations and isotope ratios in Apollo 16 and 17 samples, Proc. Fifth Lunar Sci. Conf., Geochim. Cosmochim. Acta, Suppl. 5, Vol. II, 1963-1973 (1974).

21. Rowley, P.D., Williams, P.L., Schmidt, D.L., Reynolds, R.L., Ford, A.B., Clark, A.H., Farrar, E. and McBridge, S.L., Copper mineralization along the Lassiter Coast of the Antarctic Peninsula, Econ. Geol., 70, 982 (1975).

22. Russell, R.D., Mass discrimination in the measurement of lead isotope reference samples. Geochemical J., Japan 9: No. 1, 47-50 (1975).

23. Teitsma, A., Clarke, W.B. and Allègre, C.J., Spontaneous fission-neutron fission: A new technique for dating geological events, Science, 189, 878-880 (1975).

24. Thompson, P., Ford, D.C. and Schwarcz, H.P., U^{234}/U^{238} ratios in limestone cave seepage waters and speleothem from West Virginia, Geochim. Cosmochim. Acta, 39, 661-669 (1975).

VI METEOROLOGY AND ATMOSPHERIC SCIENCE

Compiled by: Dr. G.A. McBean

1. Introduction

In 1975 the level of activity in meteorology and atmospheric science remained much the same as in the past few years. A major experimental undertaking was the Stratospheric Balloon Project run by AES in conjunction with several universities. This study constituted a large part of the effort to understand the effects of Freon in the stratosphere. On the international scene, Canadian participation in GARP and the new Precipitation Enhancement Project continued. Canada was also host to the first session in the "Living with Climatic Change" program.

The Scientific Committee of the Canadian Meteorological Society, which took over the function of the former NRC Subcommittee, was quite active, holding three meetings in 1975. A wide range of topics were discussed and several important recommendations made. The Committee's subcommittee, the GARP Scientific Committee, made a significant input into Canadian GARP plans. Continued activity by these committees is to be encouraged as they will likely have a beneficial effect on the science in Canada.

The disturbing financial problems referred to in last year's report are continuing and the forecasts for the future are not optimistic. It is now, more than every before, necessary to critically examine our programs and decide on priorities in all areas. It is also a time when new and innovative approaches are needed.

2. The Canadian Meteorological Society

The Society held its Ninth Annual Congress at the University of British Columbia from May 28-30. The theme session of the Congress was entitled "The Role of the Pacific Ocean in the Climate of North America". This theme was particularly appropriate as the society welcomed the participation of a large group of Canadian oceanographers to the Congress. This participation included three joint meteorology/oceanography sessions as well as a series of parallel concurrent technical sessions on specialized topics within the disciplines. The society took further steps to enhance this collaboration by establishing an oceanographic division and appointing an associate editor for oceanography to the editorial committee of "Atmosphere".

"Atmosphere", the scientific journal of the Canadian Meteorological Society, has continued to grow in stature as the Canadian scientific community has become aware of some of the advantages of this medium for the publication of scientific results, in both meteorology and oceanography. The Society is committed to continue to improve this important activity.

The Society awarded its President's Prize to Dr. Gordon McBean, the Prize in Applied Meteorology to Dr. Roger Daley and the Graduate Study Prize to Mr. Geoffrey Strong. Citations were awarded to the Staff of the CBC program "As it Happens" for its outstanding contribution to public awareness of environmental concerns, to the Alberta Environmental Conservation Authority for its work in environmental ethics and to Lydia Dotto as science writer for the Globe and Mail, in recognition of her outstanding reporting of environmental issues. The Society continues to benefit from a substantial grant from the Government of Canada through AES.

3. The University of Alberta

(i) *Wet and Dry Deposition*

Nutrient loadings in precipitation and in dry deposition are being sampled and analyzed for four stations in the Edmonton and Cooking Lake Moraine area of central Alberta. Nitrogen and phosphorous compounds, pH, conductivity, hardness, and several ions are included in the analysis. Attempts will be made to relate loadings to sources and to selected meteorological variables.

(ii) *Micrometeorology*

Active programs in 1975 included measurements of airflow modification over a step change in surface evaporation and sensible heat flux, continuation of evaporation studies at Lake Wabamun, Alberta and detailed planning for micrometeorological field measurements on vegetated and unvegetated sand slopes in Northern Alberta. The latter project is under the direction of the Department of Botany and is concerned with the long-term stability of tailings pond dike vegetation.

(iii) *Precipitation Physics*

Work on the following projects is now completed. M. Morrow has finished a dissertation on the time-resolved properties of point hailfalls. M. Oleskiw is winding up an experiment to grow artificial rime deposits on simulated plate-type ice crystals. A. Beattie has applied stereophotogrammetry in a novel way with imprecisely aligned cameras, to determine the fallspeeds of hailstones. Work is continuing in the following areas. E. Lozowski is examining the question of the required network density for surface measurements of hailfall parameters. Improved stereophotogrammetric methods are being developed to examine the tumbling of natural hailstones in situ. Finally a project to examine variations in the ring structure of a large sample of giant hailstones is also in progress.

L. Cheng has completed an M.Sc. thesis involving a numerical model to study the accretion of supercooled cloud droplets by an ice crystal represented by an oblate spheroid. Work continues toward modelling this process using a hexagonal plate to represent the ice crystal. Hail initiation studies are also being done by stable isotope analysis of precipitation samples. Hail damage studies correlating radar returns to surface sensors are being done by P. Wrenshall and F. McDougall under the supervision of R. Charlton.

(iv) *Environmental Studies*

Environmental impact assessments for a satellite airport (Villeneuve) and a proposed city park (Hermitage) were completed and an environmental overview of a proposal coal mining operation was completed. These studies covered climate, air quality and noise. Participation in the Athabasca Oil Sands meteorology and Air Quality Study will probably involve cloud physics, numerical modelling of the airshed, and weather satellite studies.

(v) *Synoptic Scale Studies*

Research in synoptic meteorology concentrated on relating cloud patterns observed from satellites with weather systems in the Arctic and Western Canada. J. Alexander examined the moisture, temperature and vertical velocity characteristics of cold lows in the high Arctic, with the aid of infra-red imagery received by the University of Alberta Satellite Laboratory. He deduced moisture and temperature distributions from the cloud masses associated with these vortices, and he calculated vertical velocities by two independent methods.

Using satellite data, D. Oracheski is completing a study of weather systems crossing the Western Cordillera. Attention is focussed especially on the effect of mountains on cloud bands generated by Pacific storms.

G. Vickers has completed a thesis on lee cyclogenesis related to diffluence in the mid-troposphere. He examined the character of the low at 700 and 500 mb, and found it to be diffluent in the mean at both levels. The maximum spreading of the height contours occurs at about 120°W longitude. The most favourable configuration for less cyclogenesis is that in which the trough-ridge system straddles the mountains, with diffluence from trough to ridge.

The Satellite Laboratory carried out research and development on mini-computer processing of satellite data, under contract to the Atmospheric Environment Service. The contract required development of algorithms to produce stepwise radiance-sliced and enhanced imagery from APT scanning radiometer data in near real-time. The algorithms have been designed for implementation on minicomputers with cores of not more than 16K words, and disks of not more than one megaword.

4. The Alberta Research Council

The research program of the Atmospheric Sciences Division, in support of the on-going Alberta Hail Project, comprised studies on the fine scale radar structure of hailstorms, the polarization properties of precipitation, the modelling of hailstorms, the hailstorm-environment interactions, the characteristics of hailfalls, and the silver content of precipitation. In support of the research and operational program, a comprehensive computer facility was developed for the logging, the reduction, the display and the analysis of the massive data bank collected during the field program.

Studies related to the fine scale structure of precipitation as revealed by the polarization diversity radar are now being extensively documented. The radar data indicate the existence of fine scale convective patterns, which provide a common basis for the production of hail among all hailstorms. These results oppose earlier considerations which suggest that general differences in radar patterns are related to differences in hail production mechanisms. The implications are strong, especially with respect to cloud seeding for hail suppression where the intent is to promote beneficial competition among hail embryos; to provide more complete coverage of seeding reagent within storms, the results suggest that the frequency of occurrence and the areal coverage of seeding along the edges of storms be increased in Alberta.

Stereophotogrammetry is used in an attempt to relate the fine scale radar reflectivity patterns to visual features of the hailstorms. Procedures and equipment construction for the analysis of stereophotographic data are now complete. Data from one storm were reduced and preliminary results support the conclusions, drawn from the fine scale radar analyses, that some mechanisms critical for hail production do depend upon the fine scale nature of convective storms. Moreover, data collected during 1975 appear (at least preliminarily) to corroborate the conclusion that fine scale convective patterns are relevant in all types of storms. Since the time dependence of fine scale convective pattern development can be interpreted in terms of time dependent updrafts, it appears that all hail production may also be related to time-dependent updrafts.

An electromechanical raindrop spectrometer (distrometer) was tested during the field program, after a fully portable data acquisition system was designed and built. The results of this summer show that the data acquisition rate will have to be substantially increased. However, qualitative raindrop size distributions were obtained for several precipitation situations. These data will be combined with radar and rain gauge data in an effort to calibrate the radar to measure rainfall amounts, and to use the radar to distinguish between hydrometeor types. Finally the development of computer programs to calculate the scattering properties of raindrops has been initiated. These programs will be applied to the distrometer data in an attempt to relate radar and raindrop data. In addition, the scattering programs will be expanded to help resolve the polarization properties of various types of precipitation.

The numerical simulation program initiated in 1975, began with the introduction into the field project of a second one-dimensional, steady-state cloud model as an added tool in the forecasting and the evaluation programs. It was found that the accuracy of predictions from both models, the LMA and the Hirsch, is severely limited by difficulties in forecasting the afternoon

temperature and moisture conditions from a morning sounding. But soundings, closer in space and time to convective activity, obtained with the mobile radiosonde system proved invaluable in overcoming this problem at least from the evaluation point of view. Model predictions correlate fairly highly with measurements when more representative soundings and aircraft observed cloud base characteristics are used as input. Thus, it appears hopeful that model predictions can provide useful covariates for stratifying the data for the statistical evaluation of a seeding experiment.

The hailstorm environment study, initiated in 1974, is concerned with determining what atmospheric and topographic conditions are associated with the development of hailstorms and how the atmosphere and hailstorms interact. From this study, some insight into how the ambient atmosphere might be controlling the structure and the morphology of a storm should be obtained. An important requirement is a better knowledge of the temperature, humidity and wind profiles throughout the depth of the troposphere in the hailstorm breeding grounds, usually the foothills, and in the vicinity of developing, mature or decaying hailstorms. Over the past two years, a unique mobile rawinsonde system has been developed at AR in order to collect these data in these relevant locations. During this first field program, many valuable data were collected, both in the foothills and in the vicinity of hailstorms.

The study of the dispersion of silver iodide generated in cloud seeding experiments was continued. The analysis of 1925 precipitation samples collected in summer 1974 yielded the following results. Contamination of an area by cloud seeding in an adjacent area was observed on six occasions when the seeded storms were relatively close to the boundary between the two areas. The horizontal dispersion of Ag, observed in precipitation, is generally wider in cases of cloud top than in cases of cloud base seeding. This suggests widely different trajectories for AgCl nuclei injected into storms by the two methods and substantial scavenging of the nuclei by rainfall in the case of base seeding.

High concentrations of Ag are generally observed in areas of rain only, rarely in hailswaths. Finally the Ag concentration in hailstorms collected off the ground decreases from the edges to the embryo. Except in very few cases, the Ag concentration at the center is at or below background level. Clean hailstone samples collected this year will be analyzed to verify these results.

The study to relate hailfall parameters to hail damage to crops of varying type and maturity was continued this year. In an effort to gather the data necessary to quantitatively express these correlations, a dense hailpad network of 121 stations in 360 sq. mi. was operated during the summer. Besides increasing the density of hailpads in the area from the previous year, 8 additional wind stations were operated in the network for a total of 10. Considerable data on hailstone characteristics were gathered from the network while data on precipitation variables and crop damage were obtained from volunteer observers within the network. To address the problem of fine scale discontinuities of hailfalls on the surface a micro-dense network of 27 hailpads in 1 sq. mi. was operated during this summer. This study should provide a more accurate description of these discontinuities for Alberta storms. Two mobile sampling units were again utilized this year to intercept hailstorms and collect hail and rain samples, expose hailpads and collect wind information during the storms. These direct field measurements in the dense network and from the mobile units, by determining the range of variations in natural hailfalls, will help correlate radar measurements of storm output with measurements of hailfall characteristics. Moreover, if seeding results in changes in radar measures, these changes must be related to the impact energy patterns observed on the ground. Such relationships are critical to the evaluation of seeding by radar measurements.

Efforts to define more sensitive evaluation methods for the hail suppression test continued. New evaluation concepts, based on the use of time-integrated radar measures and total hailfall parameters, were developed. A first test of these new concepts, based on the comparison of "growth factors", computed from radar echo tops of 1972 hailstorms appears promising. These methods will be further tested with radar and hailfall data collected in summers 1974 and 1975.

The double mass evaluation method, previously applied to hail suppression projects in southern France and in Texas, has been applied to historical insurance data in Alberta. The analysis is in its final stage and the results to date suggest a decrease in losses in the Three Hills area between 1960 and 1968. This suggested decrease cannot however be confidently and undoubtedly attributed to cloud seeding. Other possible causes are being evaluated. This study again strongly emphasizes the critical need for strong correlations established between accurately measured

physical parameters of hailstorms, of hailfall and of cloud seeding variables for the evaluation of hail suppression experiments.

In an attempt to discover such correlations, several other analytical methods are considered. The results of some preliminary analysis of Model Output Statistics are encouraging. Further investigation is in progress using 1974 data from a randomized design. The possibility of using extreme value statistics has been considered. Further development in this area depends on the solution of some problems relating to the measures to be used and to the sampling method.

5. The Saskatchewan Research Council

As described in last year's report, research programs have continued in pesticide droplet drift and deposition from the atmosphere, in the water budget of the Quill Lakes drainage basin, and in phenological investigations of crop-weather relationships for new grain varieties. Two further hydrometeorological studies neared completion during the year, viz. a study of evaporation from small sloughs and pot-holes, and an investigation of storm rainfall, runoff and drainage loading characteristics for a highway underpass system.

Greater emphasis on air pollution has resulted from a commitment of SRC to undertake environmental impact assessments. This has led to several studies of potash dust effluent and deposition patterns around several of the potash mines, increased emphasis on herbicide monitoring during the crop spraying season in an endeavour to identify particular source regions and specific chemical formulations, and further research on airborne grain dust levels around prairie grain elevators. This last topic, undertaken under an AES contract led to a close day-by-day monitoring of air concentrations and deposition rates within a small village, and attempts to correlate the findings with both atmosphere stability parameters and grain-handling details (i.e. source strength). This work is still being analysed. Identification of possible biological components of the effluent such as mold cells, bacteria and spores is also underway. A study of air pollution problems around animal feed lots is also underway, together with research on the related soil and water interactions. Finally a preliminary investigation of atmospheric electric field changes that may be associated with air pollution slurries was carried out.

Other activities undertaken at SRC in the past year include a detailed wind climate analysis for its potential as a source of energy in Saskatchewan, and a report for the World Meteorological Organization on the prospects and problems of weather modification as an aid to agricultural water needs and crop production. This last study was in connection with the development of WMO's Precipitation Enhancement Programme.

6. McMaster University - Department of Geography

(a) Estimation of incoming global solar radiation from standard meteorological variables

A simple model has been developed (Davies, Schertzer and Nunez, 1975) which performs well in southern Ontario and is to be tested shortly with data from other environments which include data from GATE.

(b) Evaporation studies using the combination model

Evaporation from cropped surfaces is studied within the framework of modern versions of the Penman combination model. Data collected for a soyabean field in 1974 are being analysed currently.

(c) Energy balance studies in the Canadian tundra and subarctic

Models have been developed which estimate accurately summertime evaporation from dry and wet tundra surfaces and shallow lakes. This work is being extended to areas of open lichen woodland where the effects of burning are also being investigated.

(d) Elevated temperature inversions and their interaction with atmospheric pollution

Studies into vertical radiation and temperature profiles and their interaction with elevated temperature inversions including the effects of pollutant build-up and dissipation in the Hamilton area.

7. National Research Council - National Aeronautical Establishment

A program of field trials and numerical modelling pertaining to the vertical dispersion of gaseous and aerosol pollutants from ground-based sources is carried on. The experimental technique involves the use of the NAE instrumented T-33 jet aircraft for turbulence measurements and gas chromatographic instrumentation which may be aircraft or ground vehicle-mounted for on-site measurement of meteorological tracer gas concentrations. For aerosols, cascade impactors are employed for determining the change of droplet-size spectrum with height in an oil-aerosol plume. The program includes a parametric study of the conditions under which droplets of a prescribed mass and diameter may behave analogously to a gaseous material.

8. The University of Toronto

(a) Department of Mechanical Engineering

The turbulent structure of wind over large urban areas.

Using lakeshore and inland sites, measurements are being carried out at moderate elevations (10m.), to determine the coherent features of the wind in the natural boundary layer, which are generated by the roughness of the downtown city core of Metro Toronto. Tests are being restricted to on-shore winds and comparisons made of the turbulence structure, before and after encountering the buildings. Space-time correlation techniques are being used to identify the large-scale eddies and their convection speeds. Measurements of the 3 components of velocity as well as temperature are being taken using sonic and hot-wire anemometers, and data are being sampled and processed digitally. The characteristics of the dissipation range of the turbulence are also being determined.

(b) Cloud Physics

The evaluation of the Swiss hail experiments proceeded. A whole series of mechanisms were found by which water is lost from a surface of a growing hailstone, thus reducing the collection efficiency to values as low as 10%. The dependence of the collection efficiency of icing cylinders and rotating and gyrating spheroids was established. It is of particular interest to notice the variation of E with pressure. An investigation of bubble and crystal structure of artificially grown hailstones showed no relation to icing conditions. First direct measurements of longitudinal heat transfer coefficients of rotating spheres showed an influence of the secondary motion of the heat balance.

The data of fragment distributions and probabilities of colliding drops were applied to the modelling of rain. It was shown that in warm rain large drops already break up at diameters below 2 mm. The 'critical' sized drops ($\sim$ 5 mm) mentioned in the literature do not exist. In cold rain, melting of smaller hailstones produces large drops which, due to their short residence time in the atmosphere, do not all break up and disappear on the way to the ground. These results really give a first appreciation after Langmuir of what may happen during rain formation in nature.

The development and application of a time dependent theory for droplet collisions in shear has not produced any explanation of the Jonas-Goldsmith experiment. However, new concepts on collision-collection are under consideration.

A series of experiments was performed to decide on the possibility of condensation nuclei multiplication by activation and reevaporation. The results were negative and indicated that the size threshold of condensation nuclei counters are higher than generally assumed.

(c) Atmospheric Electricity

The mobility of ions produced by evaporation of charged droplets was the object of a preliminary study by a time-of-flight method. An experimental setup combining a mobility analyzer with a mass analyzer (quadrupole mass spectrometer) has been installed and is being adjusted and calibrated.

A theoretical investigation was done on the conditions under which ion evaporation from charged droplets can occur.

(d) Thermal Convection

Work was done on numerical modelling of thermal convection.

(e) Mesoscale

The interactions between cumulus clouds and large-scale weather systems are under investigation. Several topics in the area have been studied during the year.

(i) Relationships between cumulus cloud population and large-scale mean thermodynamic stratifications.

(ii) Effects of the life-cycles of cumulus clouds on large-scale heat and moisture budgets.

(iii) Cumulus cloud population in a trade-wind weather situation and the formation of the trade inversion layer.

Two other categories of mesoscale phenomena are under active investigation. The first is concerned with small and medium scale orographic phenomena: downslope and storms, mountain wave momentum flux and wave drag, critical level absorption, etc. and the work is directed towards the development of a parameterization scheme for the incorporation of such effects into the G.C.M. The second is involved with the problem of the mechanism by which warm sector cumulus convection may be organized into lines roughly parallel to an advancing or stagnant cold front. e.g. squall lines, arc clouds, etc. Both analytical and numerical models have been constructed.

(f) Boundary Layer

In the area of boundary layer meteorology both linear and non-linear models have been investigated in the search for an explanation of the highly anisotropic nature of turbulence in the stable, nocturnal, P.B.L., as seen for example by acoustic and F.M.C.W. radar systems.

(g) Geophysical Studies of Earth-Ice-Ocean Interaction During Climate Change

In order to study the geophysical effects of a climatic change, a complete spherical, self gravitating, visco-elastic model of the planet has been designed and employed in a number of studies of the response of the ocean-ice-earth system to the last major Pleistocene deglaciation. The model has been used to infer the viscosity of the deep planetary mantle, to determine the temporal evolution of ocean basin bathymetry, and to refine existing knowledge of the distribution of glacial ice. It is expected that this model will eventually impact strongly upon paleo climatic studies and the CLIMAP project.

(h) Seasonal Energy Balance

A model of seasonal energy balance was developed.

9. The University of Waterloo

Work is continuing with an 8-level primitive equations model which includes large-scale precipitation and release of latent heat, longwave radiation from clouds and water vapor, orography, surface and internal friction, input of heat and water vapor from water surfaces, and parameterized convective precipitation. A technique has been designed to compute absorption of solar radiation, both at the ground and within the atmosphere. In the past year the model has been used to study Alberta cyclogenesis, improved techniques for specifying air pollution potential, snowfall to the lee of the Great Lakes, east coast cyclogensis and sensitivity of prognoses to varying the number of radiosonde stations used in the initial analysis. Predictions have been made for 6 to 36 hrs. with grid sizes of 47.5 to 190 km.

The 8-level primitive equations model described above is being applied to study the phenomenon of east coast cyclogensis using the AMTEX data over the East China Sea. The 1975 AMTEX period (Feb. 1975) was much better than the 1974 one. In the 1975 AMTEX period, several excellent examples of east coast cyclogensis occurred. Presently, numerical simulations are under way

with the Feb. 14-16, 1975 case. These Asian cyclones are very similar to the North American phenomena, the so-called Hatteras Lows, which develop explosively and give severe weather to the maritime provinces. The best cases of Hatteras Lows in the past two winters are probably Feb. 16-18, 1974 and Mar. 2-3, 1975. The special AMTEX data will permit verification of and improvements to the computation of surface winds, fluxes of heat, water vapor and momentum, and precipitation rates. This should improve understanding and prediction of cyclogenesis off Canada's Atlantic, Pacific and Arctic shores. The 8-level model is also being applied to predicting lake-effect snowfall in the leee of Lake Huron, using a grid size of 47.5 km. This is important for weather forecasting, flood prediction and water management. This study will result in improved methods for computing parameterized convection over the Great Lakes and enhancement of precipitation due to frictional convergence and orographic uplift as the clouds move on-shore. There should be mutual benefit between this study and the AMTEX investigation.

A 1-level primitive equations model has also been designed to calculate small-scale topographi effects on winds, using grid sizes of 5-20 km. The input data are the large-scale temperature and pressure fields provided either by synoptic analyses or prognoses. The model is capable of simulating phenomena such as orographic channelling, effects due to atmospheric stability, land and se breezes, influences caused by frictional convergence, and upslope and downslope winds. Studies are presently underway using data from the Atmospheric Environment Services' meso-meteorological network over metropolitan Toronto.

Applications of the 1-level primitive equations model discussed above include computing air pollution potential, small-scale quantitative precipitation forecasting, fighting incipient forest fires (provided the heat source doesn't cause the hydrostatic equation to be invalidated), and calculating wind-generated waves, thermocline depths, water-levels near shore, surface currents, and motion of ice and oil spills. The continuing study over Toronto is primarily directed to improving calculation of air pollution potential.

A method of calculating surface temperatures from a heat-balance method is being designed. This uses calculations from the 8-level model, including the downward flux of solar radiation. However, the technique will also have relevance to the small-area model.

Research is underway to focus attention on (a) the diffusion of heat and moisture from large sources such as scrubbed plumes, smeltering operations, mechanical and natural draft cooling towers, (b) the trajectory and diffusion of buoyant plumes from very tall stacks such as the I.N.C.O. Sudbury stack of 1200 ft.

(a) The work on moist plumes is a continuation of studies initiated in 1971 with the objective of determining the dynamical behavior and environmental impact of moist plumes originating from scrubbed industrial effluents for the removal of SO_2 and other water soluble gases and cooling towers as effective waste heat disposal mechanisms. The effluent from banks of mechanical draft cooling towers is often entrained into the wake and subsequently diffused to ground level. Nuclear power plants often release waste gases from vents located at various points on the reactor building. These gases also are entrained into the wake of the structure and diffused to ground level. Thus an understanding of wake diffusion in the lee of structures would enable better estimation of ground level concentrations of excess humidity (in the case of cooling towers) and other gaseous pollutants (in the case of nuclear plants). This then effects containment design and site boundary limits for nuclear plants.

Experiments on the diffusion in the wake of some simple structures are being carried out at the pilot stack facility located on the north campus of the U. of W. This facility is presently equipped with the necessary micrometeorological tower and instrumentation. In accordance with past experience injected SO_2 is used as a tracer. Detection is by means of a sin-x SO_2 analyzer.

(b) The diffusion of buoyant plumes originating from sources high above ground is governed by atmospheric turbulence quite different in character to that found nearer the surface. Calculation of the subsequent dilution rate and trajectory of the plume must include the effects of a variable wind direction with height. To date there is little comprehensive experimental evidence on plume behavior from such sources. A good understanding of this problem would enable better estimates and optimization stack heights for large sources of industrial pollutants

An aerial pollutant sampling package suitable for installation in a Cessna 172 aircraft

has been developed in a previous atmospheric diffusion study. A limited full-scale aerial sampling program is being carried out on the I.N.C.O. plume at Sudbury. This was, however, preceded by further analysis of data previously gathered over the city of Hamilton and data obtained at Sudbury by the Atmospheric Environment Service.

The diffusion of contaminants released from tall stacks will be simulated with a numerical diffusion model. Incorporation of the variation of atmospheric turbulence and mean wind with height throughout the planetary boundary layer will be included to estimate the effect of cross-wind shear on diffusion. The model will subsequently generate the necessary standard deviation of mass required as input into the simpler Gaussian plume models. Comparison of model predictions with available observations will be made. A limited number of measurements on the cross-sectional shape of the Sudbury plume will be made with an aircraft mounted instrument package.

10. The University of Western Ontario

A pulsed ruby lidar was assembled and first operated from the U.W.O. Physics Building in 1970. A number of preliminary observations on the atmosphere adjacent to the lidar, and along horizontal radials over the city of London, demonstrated its competence in resolving profiles of extinction coefficient and particle mass- and number-concentration at ranges up to 10 km in relatively clear air. The analysis of some 2000 profiles over one year of observations indicated that natural thermal plumes, occurring commonly in neutral thermal stability above roadways, construction sites and paved surfaces, carried particulates from the ground upwards into the urban atmosphere. More recently, the project has developed along two lines: the establishment of this lidar as an operational system to provide survey maps of particulate concentration over the city of London, and to assess the precision of the lidar in indicating particulate concentration profiles. For the former, the rooftop mounting of the transmit-receive optics has been improved through the incorporation of a precise turntable mounted upon a stable cement pad, and a stepping motor system of controls with precision gearing for the azimuth and elevation of these optics. An electronic transient digitizer with dedicated PDP-11 Computer has been obtained for rapid recording of the lidar signatures, and an extensive computer program has been developed to recover and plot the particulate concentration profiles from the digital records. Currently, the lidar is being operated routinely in scanning selected sectors of the city, in order to relate concentration profiles to the march of local weather systems through the city. The precision of the lidar in deriving concentration profiles currently is being examined through detailed analysis of the lidar equation, through auxiliary sampling of the air with various types of particle counters, and through a laboratory study of the aging of particulates in a humid environment with a laser nephelometer. The latter work is being carried out in coordination with Prof. J.L. Sullivan of the U.W.O. Faculty of Engineering Science.

11. The University of Windsor

A group headed by Dr. J.W. McConkey is studying the dissociation of atmospheric molecules with particular reference to the stratosphere and the ozone layer; pollutants such as the halocarbons are of particular interest. Single particle detection techniques for low energy neutral metastable particles are being developed. Techniques employed involve time of flight and mass spectroscopy. Preliminary reports of some of this work have appeared and fuller details have been submitted for publication.

12. McGill University

Department of Meteorology

(a) The penetration of planetary scale atmospheric waves into the stratosphere has been investigated by means of steady state quasi-geostrophic models. The interaction between the two major zonal wave harmonics has been examined and found to be relatively important in the model atmosphere. Linear versions of the model are being used to determine how the vertical resolution and the formulation of the upper boundary condition affect the structure of the forced planetary waves.

The propagation of Rossby waves from a source region in the middle latitudes to the southern latitudes is being investigated by means of a nonlinear numerical barotropic model. The main interest is on the structure of the flow near the critical latitude where the zonal phase

speed of the wave equals that of the zonal flow and the extent to which wave energy can cross this latitude. The next step will be to examine how the vertical propagation of Rossby waves is affected by critical levels.

Methods of parameterizing the turbulent flux of heat and momentum at the earth's surface are being tested in large scale atmospheric models.

Numerical experiments with the pseudospectral model have continued especially with regard to the effects of polar filtering on the solutions. A one-dimensional semi-implicit scheme is presently in the process of testing. The model has also been extended to two layers in order to investigate baroclinic effect.

(b) Stimulus for some of the cloud physics research in the Department of Meteorology is provided by the Alberta Hail Project, a joint program in which McGill participates along with the Atmospheric Environment Service, Alberta Research, and the Alberta Interim Weather Modification Board. The purpose of the Project is to determine whether seeding thunderstorms with silver iodide can alleviate hail damage. During the past year both observational and theoretical aspects of the problem have been pursued at McGill. Seeding experiments from 1972 and 1973, hitherto unanalyzed, have been studied in great detail, using radar data and surface reports. Analysis is also underway on selected cases from the summer of 1975, the first year of good coverage with digitized radar data. The theoretical work seeks to determine whether plausible adjustments in the microphysical properties of clouds will affect the development of hail.

(c) The problems of climate change and effects on climate by inadvertent or deliberate changes in the surface environment have been studied with the help of computer models which simulate the surface-atmosphere energy exchange processes.

Particularly the region of James Bay has been investigated to ascertain the effects on the local climate of the creating of artificial lakes. This work is continuing, as is an examination of a proposed water diversion scheme in Sudan and its possible effect on available water downstream in the Nile.

Research has been undertaken on the hydrological effects of logging, and the results of calculations using a forest energy exchange model have been published.

(d) At the McGill Radar Weather Observatory, progress has been made during the year in producing numerical maps of precipitation, from a high-speed line printer, giving (*a*) flux at specified altitude, (*b*) hydrological accumulation, (*c*) forecast maps a very few hours ahead, (*d*) the shadow cast by the precipitation in the hypothetical emission of microwaves from a geostationary communications satellite, (*e*) the equivalent of (*a*) for Tropical Atlantic observations, summer 1974 (GATE). Complementing the precipitation records for the summer season, lightning was located by radio triangulation.

Macdonald College

(a) Possible effects of atmospheric ions (both small and Langevin ions) on diseases, germination, and physiology of plants are being studied. Preliminary experiments show that small positive ions, at relatively high concentrations of about 3×10^4 ions/cm^3, have a marked positive effect on the resistance of barley plants to the net blotch disease. Experiments are being planned to establish a threshold concentration of atmospheric ions below which the effects are not visible. A possible mechanism via which ions may interact with plant life is also being explored.

(b) Energy budget studies of live plants and plant communities are being carried out, on a continuing basis, by means of microwave radiation and a wind tunnel. Plant responses to microwave induced thermal stresses are providing us with some new insights into the physiological mechanisms of stomatal opening or closing. Field applications of microwave energy to apples and grapes in order to accelerate sugar production and also as an agent of frost protection are being investigated.

(c) Air-temperature regimes (maximum/minimum temperatures at heights up to six feet) in growing corn are studied and compared with those nearby over short grass. Early in the growing

season, with a low Leaf Area Index, in-crop maximum temperatures decrease with height, just as they do all season over grass; but later, as the Leaf Area Index increases, a transition is observed to an inversion regime.

(d) Based on electrochemical model experiments, hypotheses are proposed on the connection between the boundary-layer resistance at a plate (e.g. the ground) and easily-measured parameters of the turbulent flow adjacent to that plate. The hypotheses were tested in laboratory and field experiments on the heat loss of heated ground-based plates in various types of vegetation. Heat transfer coefficients could be predicted with a standard deviation of 13% from measured friction velocities.

13. Université du Quebec

(a) Titre du Projet: Etude comparative sur l'application de différentes méthodes de calcul de la formation et de la fonte du manteau neigeux.

Résumé: L'étude vise à l'élaboration d'un modèle mathématique des phénomènes d'accumulation, d'évolution, de fonte et d'écoulement de l'eau de fonte de neige, fondé sur les lois physiques des échanges énergétiques entre l'air et un milieu poreux hétérogène (la neige) et entre ce même milieu et le sol. Ce but sera atteint après avoir solutionné:
1 - les aspects théoriques du problème;
2 - l'estimation des données manquantes;
3 - la vérification des résultats.

(b) Titre du Projet: Etude des processus énergétiques régissant les relations entre les valeurs d'ETP à l'échelle locale et l'estimation d'ETR à l'échelle régionale.

Résumé: La simulation des débits d'un bassin versant à l'aide d'un modèle déterministe demande la connaissance de l'évapotranspiration réelle (ETR) régionale. Ainsi que les études antérieures de Bouchet puis de Riou en France et ensuite de l'auteur l'ont démontré, une approche originale est possible.

Il s'agit de revoir les relations énergétiques existant entre la mesure locale de l'évapotranspiration potentielle ETP et l'ETR moyenne de la région au centre de laquelle se fait cette mesure d'ETP.

Les études poursuivies depuis quelques années à partir de la relation de Bouchet ont abouti à la formation d'équations dont l'aptitude à évaluer ETR pour des pas de temps de un (1) à quelques jours devra être vérifiée.

On étudiera aussi la possibilité d'utiliser les renseignements fournis par les satellites de détection (LANDSAT 1 et 2, NOAA, ...) afin de compléter les mesures prises au sol pour évaluer l'évapotranspiration réelle régionale.

(c) Titre du Projet: Modèle stochastique pluie-débit transposable à l'aide des caractéristiques physiographiques.

Résumé: La principale activité sur ce projet a été de développer une série d'équations expliquant les différences de précipitation à l'aide des caractéristiques topographiques telles que: distance à la mer, altitude, effet bouclier, etc.

(d) Titre du Projet: Etude de la qualité des eaux atmosphériques sur le bassin de la Yamaska (P.Q.).

Résumé: Nous avons opéré sur le bassin de la Yamaska au cours des années 1974-75 (16 mois) un réseau d'acquisition de données de qualité des eaux atmosphériques. Le réseau comportait 20 stations d'échantillonnage, chacune correspondant à un territoire de 246 km^2. Les précipitations, recueillies en composites mensuelles, ont été analysées pour les paramètres suivants: Ca, Mg, Na, K, SO_4, Cl, NO_3, NH_4, N_{org}, $O\text{-}PO_4$, P_{hyd}, P_{tot}, C_{org}, C_{inorg}, pH, conductivité, Fe et Mn. Ces données serviront au calcul du bilan matière, à l'évaluation de la représentativité spatiale des stations, à l'évaluation des apports intrinsèques au bassin et à la rationalisation du réseau de collecte des eaux atmosphériques.

(e) Titre du Projet: Influence des particules contaminantes sur le bilan thermique du manteau nival en période de fonte.

Résumé: La présence de particules d'origine aérienne et de substances organiques telles que les hydrocarbures peuvent jouer un rôle important dans le régime de fonte du manteau neigeux à proximité des centres urbains. L'étude entreprise vise à évaluer l'influence des contaminants particulaires et organiques sur le bilan thermique du manteau nival et à suivre l'évolution des contaminants à l'interface neige-air au cours de la période de fonte; les paramètres étudiés sont les suivants: les caractéristiques météorologiques, l'albedo et les paramètres physico-chimiques tels la conductivité, dureté, C_{inorg}, pH, NO_3, NH_4, N_{org}, C_{org}, hydrocarbures, spectre U.V., la turbidité, les résidus et le spectre granulométrique.

14. Service de la Météorologie, Ministère des Richesses Naturelles du Québec

En 1975, le Service de la Météorologie du Québec a poursuivi les études et les projets déjà décrits les années passées dans le "Bulletin canadien de géophysique".

Quelques projets nouveaux ont été entrepris:

(a) Climatologie

- Températures quotidiennes et saison sans gel pour la période 1941-70: il s'agit d'un programme de calcul des valeurs moyennes quotidiennes des températures minimales, moyennes et maximales avec leur écarts-types, ainsi que les températures extrêmes quotidiennes. Nous calculons aussi les dates de début et de fin de la saison sans gel pour deux niveaux de probabilité.

- Fréquence des précipitations: il s'agit de dresser des tableaux des fréquences de dépassement de certains seuils de précipitation.

(b) Traitement des données

- Pluviographes à auget basculeur: le projet consiste à définir une méthode d'interprétation des diagrammes de pluviographes à auget basculeur par un lecteur optique et à procéder par la suite à un traitement mécanographique.

- Pluviographe Fisher and Porter: analyser soigneusement les possibilités du pluviographe Fisher and Porter pour déterminer une méthode de lecture optique des rubans perforés. Analyser les données ainsi dépouillées pour obtenir le maximum de renseignements sur les intensités et fréquences de précipitation.

(c) Hydrométéorolgie

- La valeur statistique des relevés nivométriques: analyse du procédé d'échantillonnage de la neige au moyen de lignes d'échantillonnage.

15. Bedford Institute of Oceanography

Wind stress and heat exchange studies over ice in the Beaufort Sea were continued in April, 1975 as the Bedford Institute of Oceanography contribution to the Arctic Ice Dynamics Joint Experiment.

In September and October, 1975 a series of instrumentation comparisons were carried out at the south beach of Sable Island in cooperation with Prof. S. Pond, on sabbatical leave from the University of British Columbia. This was to evaluate wind, temperature and humidity sensors for next year's Stable Platform experiments (refer to p. 49 of the 1973/74 Biennial Review of the Bedford Institute of Oceanography).

16. The Atmospheric Environment Service

(a) Meteorological Services Research Branch

(i) *General Program*

The Meteorological Services Research Branch is organized to provide support for the expansion and improvement of the forecast services of the AES. This organization now includes a new effort in support of redesigning the basic AES operational environmental observing system to make it more efficient mainly through inclusion of advances in technology such as those in the area of remote sensing from weather satellites. The basic program of the Branch is one of applied research including some more fundamental aspects where necessary. A good deal of the effort is directed toward increasing the degree of automation of Canada's entire operational forecasting system. In total, the program brings together 'mission-oriented' research covering a rather broad spectrum of development, application and engineering-test-implementation studies in the following areas.

Large-scale dynamic prediction in numerical atmospheric modelling and development of atmospheric forecast systems.

Operational forecast research dealing principally with the process of deriving user oriented forecasts of weather elements from twice-daily large-scale predictions and continuous local or regional information.

Prediction of environmental phenomena which are in large degree, controlled by the weather such as atmospheric pollution, wind-waves and ice at sea or on inland waters.

Small-scale processes research embracing planetary boundary layer dynamics, aeronautical meteorology, the meteorology of weather effects on man's activities and structures, and remote sensing, including the application of new types of data.

Design of integrated automated systems for producing forecasts entirely by computer, right from recognition of all data including the latest, right through large scale NWP, through more regional and local processes complete to the final forecast products and to systems for their distribution and access to them.

Observational network design test system is the title of a system, design of which is well advanced, to carry out a new program to provide quantitative answers on major changes that could be made in Canada's meteorological observing networks. This information will be an important factor in the future decisions that the Service will continually be making in the development and operations of its costly observational networks.

Balanced programs in all the above areas are either taking shape or well underway and all will be well-developed within the next couple of years. Current projects and interests are described below and are designed to fit in with the evolving general program.

(ii) *Specific Areas and Studies*

(a) Refinement of the RPN semi-implicit primitive equations model continued throughout the year, with most of the effort being expended on the spectral version which, because it can be contained entirely in core, is more efficient on the Cyber-70 system. The complete program, which is used in a number of research applications both in RPN and elsewhere, is highly flexible as to configuration and physical effects. Provided the combination selected will fit inside memory, it can be run as a hemispheric or global model, with rhomboidal truncation as high as wave number thirty and up to ten arbitrary levels in sigma coordinates. Physical effects can include topography, surface friction, ocean heating, latent heating, precipitation, moist convective adjustment, radiation, evaporation, vertical diffusion of momentum, horizontal diffusion of temperature and/or vorticity, and time smoothing. A package for computing boundary layer fluxes and screen-level temperatures is under development.

Initialization is from isobaric analyses of height, temperature, wind components and dew point depression. The version selected for operational implementation in CMC has five levels, truncation at wave-number 20, and a forty minute time step and will produce 60-hour hemispheric forecasts in about 8 minutes. A higher resolution version with more physics will require about one hour for 120 hour forecasts.

The limited-area grid-point version of the model, which is identical with the spectral version except for horizontal differencing, proved too expensive for operational application for an area as large as the CMC forecast area (nearly half the hemisphere). It is being redesigned for application in high-resolution local forecasting.

(b) The three-dimensional optimum interpolation data assimilation scheme was put into routine operation at the CMC in October 1975. Ten levels of height, temperature and wind data are assimilated simultaneously at six-hourly intervals into a forecast atmosphere generated by a seven-level hemispheric grid-point version of the RPN model. Dew-point depression and sea-surface temperature analyses are generated separately.

(c) In other research, a successful integration of a primitive equations barotropic model was obtained using finite element techniques. A variation in grid-length by a factor of ten across the grid did not generate any numerical problems.

Investigations of the response of various theoretical models to baroclinic instability have been undertaken.

(d) The first version of a computerized prediction support system for the Beaufort Sea and adjoining areas, to assist in off-shore oil drilling operations, was installed and put into trial operations on computer facilities at the Arctic Weather Central. The system incorporates Regional update numerical modelling, weather and weather-dependent environmental (ice motion and wave height) prediction procedures. Development continued on a manual intervention capability for incorporation in the system.

(e) A real-time Regional update system incorporating comprehensive verification procedures was developed for Eastern Canada as a test-bed for further development work in regional numerical modelling and weather element prediction procedures. It is being operated hourly on the computer at the Canadian Meteorological Centre for access through local computers or terminals.

(f) Development continued on operational prediction-modelling for areas about 3500 km to a side, with boundary information supplied by large-scale models, and making use of the latest hourly and asynoptic data, such as satellite data including vertical temperature profile radiometer soundings. Work was concentrated on the introduction of improved analysis and numerical procedures for improved performance.

(g) Development on a physical-dynamical planetary boundary-layer prediction model has proceeded to the point of real-time testing. The model has physical effects parameterized on a regional scale and with 7 levels in the lowest two kilometers of the atmosphere to yield detailed vertical profiles of moisture temperature and winds for input to the prediction of boundary layer cloudiness and precipitation air pollution potential, air pollutant concentrations and local weather elements.

(h) Development continued on an improved small area model for predicting local winds, on a scale of about 5 km, for potential application in urban area air pollution prediction, predicting channelled winds and sea-breezes in coastal areas, predicting winds induced by strong sea-surface temperature gradients in marine areas and predicting katabatic-anabatic winds in rough terrain. The model operates by adjusting on a fine mesh grid the low-level geostrophic wind predicted by a large scale model for the area on the basis of detailed information on local terrain and thermal gradients near the earth's surface.

(i) Development continued on objective, physical-statistical procedures for field and point-predictions of weather elements using outputs from large-scale and regional update numerical weather prediction models, latest weather reports and application of a broad range of statistical procedures utilizing physically-significant meteorological and geophysical parameters.

(j) Data-resource development continued, with emphasis on computer-accessible files of data for operating Regional update models and generating predictor sets for weather element and weather-dependent environmental prediction procedures. The data are designed for ready extraction and selection of sub-sets useful for individual research projects

and range from mesometeorological information for local areas to files of hourlies, synoptics and upper air reports and analyzed and predicted grid-point fields derived or predicted from these data for all Canada, adjacent waters and much of the U.S. A complete set of such data has been developed for the Beaufort Sea area with hourly values of all data and fields used in Regional prediction.

(k) Development commenced on a trajectory model to meet Canadian needs for tracking air parcels in 3-dimensional space for forecast periods out to 24 or 36 hours, taking into account sources and sinks of heat and moisture and boundary layer processes. This work was undertaken primarily for application in the prediction of air quality and specific weather elements, particularly severe local weather associated with large convection.

(l) Survey studies were completed on observational network test systems and evaluation methodology to determining the effects of adding, removing or restricting stations, on errors due to scales not resolved by the network and on the impact of various configurations of observational facilities.

(m) Development continued on an automated real-time radar-echo prediction methodology for very short range predictions (0 to 3 hours) of weather radar precipitation echoes and plans were made for operational testing of the procedure at a major weather office.

(n) The Aeromet Experimental Facility in Woodbridge is nearly complete. Measurements of wind and turbulence structure in the planetary boundary layer will be carried out using the fifteen 10-meter towers and one fifty-meter tower which comprise the facility. A wind tunnel model of the site has been completed and is awaiting testing. Comparisons of full scale and wind tunnel data will be performed for the purpose of evaluating the validity and faithfulness of wind tunnel simulation techniques currently in use.

(o) Field measurements at a typical urban STOLport are being carried out in support of an MOT investigation of wind effects on the handling characteristics of STOL aircraft during landing and take-off. A wind tunnel model of this STOLport is also under construction and will be used in an attempt to simulate in the laboratory the winds measured in full scale.

(p) A program involving the development of a micro-computer for the climatological estimation of turbulence statistics has been undertaken and is nearing completion. Boundary layer parameterization studies are being carried out using data from Australian and Canadian (NRC) field experiments. A study into the mesoscale convergence structure associated with moth migration is also under way.

(q) A remote sensing program utilizing acoustic sounding techniques is at present in the initial planning stage.

(r) Meteorological satellite data continues to be acquired from U.S. weather satellites at the Satellite Data Laboratory, AES Headquarters. During 1975 this laboratory was equipped to directly acquire and reproduce data from the Very High Resolution Radiometer (VHRR) via the UHF "S" Band High Resolution Picture Transmission (HRPT) service operating on the I-TOS series of meteorological satellites.

Infrared and visual imagery from the VHRR sensors on NOAA 3 and 4 spacecraft is now acquired and archived on a routine basis for operational and research applications. The laboratory has developed the capability to digitize and computer process this data to remove earth curvature distortions and to reformat the imagery suitable for transmission over standard facsimile circuits to user weather offices. Imagery of the Arctic and Gulf of St. Lawrence areas is reproduced and transmitted over a dialed broadband circuit by laser facsimile equipment to Ice Forecast Central at Ottawa. The laboratory also has the capability to acquire WEFAX, reformatted data from the Visual Infrared Spin Scan Radiometer (VISSR) system, on the SMS 1 and 2 and the GOES 1 geostationary weather satellites.

(b) Air Quality and Inter-Environmental Research Branch - Measurement Techniques and Systems

A method is currently being developed for the continuous monitoring of ground-level freon concentrations. The technique involves an automatic gas chromatographic system using an elec-

tron capture detector. Good separation of Freon 11 and Freon 12 has been accomplished at background concentrations. The system will be operational as soon as an accurate time and calibration system is completed.

Equipment has been assembled and some preliminary measurements made on the solar spectral irradiance and sky spectral radiance at wavelengths between 300 and 400 nanometers. The measurements should provide basic information for both photochemical smog evaluation and for the optimization of dispersive correlation spectrometers used for the passive remote sensing of air pollutants. After further development it is planned to make some detailed radiation analysis at various points in Canada and to compile an atlas of zenith sky spectral radiance as a function of sky conditions and time of year.

Activities in the Correlation Spectrometer area have proceeded along two different lines. In the first, a special point monitor is being developed to measure the kinetics and mechanism of photochemical smog formation. The evaluation of the various rate constants will enable the development of special chemical models for the formation of oxidants in polluted urban atmospheres.

The second project concerns the development of a computer model to calculate the optimum correlation functions (spectrometer masks) for any given set of measurement conditions. It is expected that the spectral radiance studies mentioned above will then permit the construction of a more sensitive and stable remote sensor for air pollution.

An air-sampling device which employs special filtering techniques has been built to collect and separate sulphur in atmospheric particulate matter from sulphur in the gas phase. The apparatus will be used along with an isotope-dilution analysis technique to measure the concentration of sulphur in air at background levels where conventional monitoring techniques are too insensitive.

Demand for the AES minisonde has necessitated the development, under contract, of a version suitable for commercial production in large quantities. Prototypes from this project are currently under test. A modified minisonde has also been developed to serve as an indicator of the intensity of thermal turbulence versus height.

Atmospheric Pollutant Processes

Field studies in pollutant dispersion were carried out at Sudbury in June and in the Canso Strait area in August. At Sudbury, the rise and diffusion of the plume from the 380 meter smelter stack was compared with detailed measurements of vertical atmospheric structure, while at the Strait of Canso, surface air quality was studied in relationship to the complex meteorology of the region.

The earth's surface receives materials from the atmosphere in gaseous and particulate form and in precipitation. Increasing attention is being directed to assessing the relative importance of these deposition processes under various combinations of material, surface characteristics and meteorological conditions. Deposition in precipitation appears to be the most important single contributor in most cases and field work this year was largely confined to the precipitation chemistry field. The year saw the completion of a field test of automatic precipitation collectors plus a comparison of results obtained with precipitation-only and bulk (precipitation plus dustfall) collectors. Work has begun to expand the AES precipitation chemistry network in order to investigate regional differences in the wet deposition of the major ions across Canada.

Air Quality Modelling

An air pollution potential climatology for Canada has been completed. This study utilized four years of upper air data from 46 stations to derive a climatology of maximum mixing height, wind speeds through the mixed layer and ventilation coefficient.

A review of all existing urban and regional models is being conducted in order to assess their relevance to Canadian conditions, and modify them or develop new models where appropriate.

Air Pollution Effects

An assessment of the impact of air pollution on ecosystems as part of the Saint John Regional Study is in progress. In this study lichens are being used as sensitive indicators of air quality. An Index of Atmospheric Purity based on species frequencies, distributions and coverage is being developed. Samples of lichens are being analyzed for atmospheric pollutants such as sulphur and heavy metals.

A fumigation episode in Saint John, New Brunswick was evaluated in terms of vegetation damage. This study was carried out at the request of the New Brunswick Department of the Environment. Extensive plant damage was characterized and related to sulphur dioxide emissions from two possible local emission sources. A report is now completed.

A contract arrangement has been made with the University of Guelph to derive field operational criteria under different meteorological conditions for desirable air quality based on injury by air pollution to agricultural crops.

Studies are continuing to establish the effects of air pollutants on Arctic vegetation under various meteorological conditions. A contract with Laurentian University was completed and it established that C^{14} fixation, potassium content and pigments of Mackenzie Valley lichens will not be affected by 0.6 ppm for 1 hour, 0.24 ppm for three hours and 0.05 ppm for 24 hours. An additional contract is in progress with the University of Guelph to further investigate these interactions.

A position paper entitled "Guidelines for the development of air quality objectives for heavy metals" was prepared and presented to the Air Pollution Control Association, Ontario Section, Annual Meeting.

Environmental Assessments

Air quality impact assessments have been made for several new proposed large industrial developments. A methodology is being developed to solve such problems, utilizing existing surface and upper air data, on a routine basis.

The Branch is playing a substantial role in the large comprehensive research study on the environmental impact of extensive development of the Alberta Oil Sands area. A meteorological monitoring system has been designed and will be installed early in 1976.

Ten stations are now being operated at rural and remote locations across Canada as part of the global air quality monitoring network of the World Meteorological Organization. The objective is to develop long-term records on background atmospheric composition. Special emphasis is placed on those constituents which may influence climate. All stations measure atmospheric turbidity and collect precipitation samples for subsequent chemical analysis. During 1975 Alert, N.W.T. and Sable Island were extensively tested for suitability as CO_2 sampling sites. Flask samples are now being obtained at both stations and analyzed for CO_2 concentration by the Ocean Chemistry Division of DOE in Victoria, B.C. Arrangements were made with the Geophysical Monitoring for Climatic Change group in NOAA to obtain nuclei counts from one of the Ocean Station Papa Weather ships during 1976.

Hydrometeorological Research

The Branch has been active in several hydrometeorological research activities throughout Canada, many of these projects being in cooperation with other federal, provincial or international agencies. As part of the WMO international study of the application of satellites to the analysis of snow cover, Canada and the United States selected four large international basins for joint study - the Saint John, Lake-of-the-Woods, Souris and Columbia. NOAA/VHRR and LANDSAT imagery, in conjunction with ground truth data, are being used to develop techniques for interpreting remotely sensed data related to mapping the continuous snow line and areas of patchy snow.

Research into other applications of remote sensing included data retransmission from remote hydrometeorological stations via satellite, and testing of a portable gamma spectrometer for use in providing basin surveys of soil moisture and snowpack water content.

As a contribution to the activities of the WMO/CIMO Working Group on Precipitation, Evaporation and Soil Moisture, comparison studies on international methods of measurement are being conducted at the Woodbridge Research Station. This program includes the comparison of several types of soil moisture neutron meters, various international snow gauges, and different types of evaporation pans. An assessment of current techniques of snowfall and snowpack measurement is in progress at the Cold Creek Hydrometeorological Research Station. The objectives of this project include a comparison of the gauge catch of different snow gauges used in Canada as compared to the accumulation of fresh snowfall on the ground, and a comparison of the accuracy of various snow samplers used in Eastern Canada where shallow snowpacks are characterized by crusts and ice layers within the pack and at the ground surface.

Research support continued in the cooperative Alberta Watershed Research Program. A new phase in the research project at Marmot Creek Experimental Basin began with commencement of selective tree cutting in one of the sub-basins. The Cold Creek Research Basin studies continued with the emphasis on winter snow accumulation-ablation processes. The WMO World Weather Watch study of the Saint John Basin is another international cooperative study initiated during the year. Its purpose is to investigate and optimize meteorological inputs into hydrologic basin models.

Mean annual water balance maps of evapotranspiration and derived precipitation have been completed for inclusion in the IHD Hydrologic Atlas of Canada. The balance components have been estimated for over 1200 grid areas of 10^4 km^2 covering the entire country.

Consultation and advice were provided on hydrometeorological impacts of man's activities in connection with the federal government's Environmental Assessment and Review Process (EARP) as applied to various types of large development projects across Canada.

Biometeorological Research

Projects to investigate the interaction of plant factors with meteorological parameters were undertaken.

Infra-red scanner data collected by helicopter were used to map frost hazard variability over the Niagara peninsula.

Support was again provided to the Canadian Forestry Service in a major study of spruce budworm migration in New Brunswick. The field program included the collection of temperature and wind data in the lower atmosphere by sondes tracked by theodolite and a sensitive radar.

Boundary Layer Research

The main activity in Boundary Layer Research in 1975 was a continuing involvement in the GARP Atlantic Tropical Experiment, GATE. After the successful data collection phase of 1974, there was a vast amount of data to be analysed within the constraints of internationally agreed-upon procedures and schedules. Several staff members spent the past year working full time on this project. The PDP 11/20 minicomputer has also been fully utilized since early in the year. Observations of surface and upper air conditions, all components of radiation and details of the boundary layer have been and are still being processed towards the March 1976 deadline. Most of the schedules have been met and in this regard Canada is one of the few countries that can make this claim.

In addition to the data processing, GATE scientific studies were begun. The spatial variability in the tropical marine boundary layer was investigated. A new method for quality control of radiation data was developed. Over the next few years, several other scientific investigations are planned to optimize the output of the GATE.

The tethered balloon system, which was developed for the GATE, has been extensively redesigned and will be used in the Alberta Oil Sands Project and other experiments in the future.

Another area of activity was in modelling, both in the wind tunnel and numerically on the computer, the boundary layer flow over a change in surface conditions, particularly roughness. A report on the mathematical approach will appear soon in the Canadian Meteorological

Research Report series.

In the past, many experimental studies have been conducted and valuable data collected, but it is only when the results are analysed and reports published that the studies are of any value to the scientific, or any other community. Proper analyses take some time and the results may appear a considerable time after the experiment. Two such experiments were the Suffield Experiment of 1971 and the International Field Year on the Great Lakes of 1972. A continuing study on the budget of turbulent kinetic energy near the surface, using data from the Suffield experiment, produced the first results on the stability variation of the velocity-pressure interaction terms. It was shown that the term was an increasingly important source of turbulent energy as instability increased. Other results pertained to the approach towards local isotropy. Using the IFYGL data set the variation of the turbulent intensities and turbulent fluxes over Lake Ontario were investigated. The effects of bands of capillary waves on the surface fluxes were also studied. Because of the high quality and completeness of these data sets further studies are ongoing or planned.

(c) Atmospheric Processes Research Branch

(i) *Numerical Studies Division*

General Circulation Modelling:

Modelling of the Global Atmosphere is being carried out using a spectral space representation and a semi-implicit time scheme.

Efforts are being made toward the areas of (1) the Boundary Layer (2) the Hydrological Cycle, (3) Moist Convective Adjustment, (4) Parameterization of sub-grid scale inertial effects, (5) long wave radiation, and (6) Spectral Diagnostics.

Parameterization of Sub-Grid Scale Processes for Internal Turbulence:

A wavenumber dependent viscosity model to simulate the large scales of motion and to consider the small unresolved scales with respect to their gross statistical interaction with the larger scales has been formulated for the Galerkin equations.

Stratospheric Pollution Modelling:

Additional experiments have been carried out with the 2-dimensional stratospheric radiative-photochemical-transport model, under steady state conditions, to determine the impact of artificially induced NO_x perturbations by high altitude aircraft and anthropogenic sources of freons on stratospheric ozone distribution and temperature structure.

Two-Dimensional Climate Modelling:

A two-level zonally averaged Quasi-Geostrophic Model is being used for climate studies.

One-Dimensional Climate Modelling:

A version of the Sellers-Schneider-Gal-Chen energy balance model is being modified to include a highly idealized abyssal ocean circulation.

Probability Forecast Methods:

Time series of climatic records are being analyzed, both in time and space, to provide further information on statistical characteristics of climate and for possible use in prediction.

Climatic Trends in the Northern Hemisphere:

Mean temperature trends in the lower troposphere over the N. Hemisphere north of $25^{o}N$, are studied for the period 1949-74.

Canadian Climatic Changes in the 20th Century:

Canadian Climatological data such as temperature, precipitation and radiation records were analysed synoptically in order to distinguish anomaly patterns with a view to delineating changing climatic 'scenarios' in the 20th Century.

Solar Variability and Geophysical Events:

Gross effects of solar variability and geophysical events such as aurora, solar X-ray flares and polar-cap-absorption by nitric oxide in the D and lower E regions have been studied under steady state conditions.

(ii) *Experimental Studies Division*

Stratospheric Measurements Program:

The results of the 1974 balloon flights of PROJECT STRATOPROBE conducted from Churchill in July have been analyzed. Altitude distributions of ozone, nitrogen dioxide, nitric oxide, temperature and number density as well as solar ultraviolet flux were obtained simultaneously. The observed ratios of the key nitrogen constituents are consistent with CIAP recommended photochemical schemes. The total odd nitrogen mixing ratio was found to be about 10 ppbv., supporting the value assumed or computed in most stratospheric models. Essentially, the results of STRATOPROBE I verify that the nitrogen photochemistry schemes assumed in stratospheric pollution models are valid.

In 1975, four balloon flights of STRATOPROBE II were made in August from Yorkton, Saskatchewan. Four new flight instruments were developed and incorporated into the payload. The nitrogen chemistry experiment was successfully repeated on two flights and partially on a third; these measurements will be compared with the 1974 nitrogen chemistry results. A new chlorine experiment configuration to define the current chlorine chemistry of the stratosphere by taking simultaneous measurements of freons, hydrochloric acid, chlorine monoxide and nitric oxide together with ozone and temperature was flown on two flights. Samples of stratospheric air were obtained for subsequent laboratory analysis for freons and nitrous oxide. Remote sensing measurements of freon II and chlorine monoxide may have been achieved.

Long path absorption photometers to measure nitrogen dioxide and water vapour were flown on rocket VB-41 on December 6, 1974 from Cape Parry and on rocket S-16/1 from Kiurna, Sweden on March 13, 1975. Analysis of the data is proceeding to obtain the water vapour and NO_2 mixing ration profiles in the stratosphere. An aircraft experiment to observe the time variation of NO_2 and O_2 ($^1\Delta$) during a solar eclipse during a flight from St. John to Montreal on a Ministry of Transport Jetstar was conducted on December 13th, 1974.

Ground based on observations of NO_2 have been continued at Toronto and at Yorkton during the STRATOPROBE II operation. Observational testing and development of the new ozone network spectrophotometer is continuing.

Radiation:

The National Atmospheric Radiation Centre (NARC) calibrated 120 radiometers during this period. An intercomparison of working standard pyranometers was held at Mt. Kobau during August. A standard Angstrom pyrheliometer was carried to the Fourth International Pyrheliometric Comparisons at Davos, Switzerland, in October for comparison with other world standards. The Volz type sunphotometer has been redesigned and a working model is now being tested and calibrated.

Ozone:

Daily surface-based measurements of total atmospheric ozone, made with the Dobson ozone spectrophotometer, continue at Churchill, Edmonton, Goose, Resolute and Toronto. The vertical ozone profile from the earth's surface to about 30 km is measured by balloon sounding with the Brewer-Mast electrochemical sonde each Wednesday at the first four of the above noted stations.

A.E.S. in cooperation with the W.M.O. manages the World Ozone Data Centre to collect and publish data from the Global network. All available data are stored in the Centre's archives on magnetic tapes or cards for use by scientists on demand.

(iii) *Cloud Physics Research Division*

Cloud Physics/Weather Modification Program

The joint program begun in 1974 in cooperation with the Canadian Forestry Service and the National Aeronautical Establishment to assess the potential of weather modification as a means of suppressing large forest fires saw major expansion in 1975. A two week seeding experiment conducted from Yellowknife, N.W.T. which was undertaken to test the logistics and capabilities of a two aircraft cloud seeding/monitoring system proved successful. Data obtained from seeding five cumuliform clouds is being analyzed to provide a first assessment of the potential of using rain enhancement for forestry purposes in Canada.

No direct research activities were undertaken by the Cloud Physics Research Division in the Alberta Hail Project. However, financial support to this project provided radiosonde observations at Rocky Mountain House and Penhold plus weather information and forecast services at Penhold. Additionally, research grants and contracts to the University of Toronto supported research in hail studies and related cloud physics problems.

Radar Meteorology Studies

Hardware and software of the C-Band research weather radar with dedicated computer system were further developed and improved with 3 - dimensional (space) data being recorded on magnetic tape on a semi-operational basis during the year for radar-precipitation studies. Coincident raindrop distribution measurements over the rain season were made in clear view of the radar using a Joss distrometer and one experiment using an airborne drop measurement system was performed for intercomparison and precipitation development studies. The K-Band radar system was operated intermittently and is now recording data on a magnetic tape medium.

Convection modelling

A three-dimensional, non-hydrostatic, dry convection model with a coordinate transformation for topographical effects was completed. Work is continuing on verification of this model and on the inclusion of cloud microphysics using distribution functions to solve the equations of condensation and coalescence.

Atmospheric Electricity

Atmospheric electricity measurements are being made at the Station for Atmospheric Experiments to study the meteorological and other geophysical effects. A V.L.F. analyser is currently in operation to measure sferics activity over the North American Continent.

(d) Meteorological Applications Branch

The Meteorological Applications Branch continued in 1975 with its traditional activities of quality control, processing, publishing, and archiving of weather data and the provision of climatological information and services. Many projects in applied meteorology were completed and new ones begun during the year. A variety of projects, including analyses of data from the Beaufort Sea and the International Field Year for the Great Lakes (IFYGL), the establishment of an agrometeorological network in the Yukon and the Northwest Territories, and the preparation of several scenarios on the impact of climatic change, were just some of the highlights of the Branch's activities in 1975.

(i) *Climatological Services Division*

The Climatological Services Division continued its work of publishing historical and statistical climatological data, and providing climatological information and consultation. Over 11,400 requests for climatological data, information, and advice were

serviced during the year.

In 1975, Climatic Normals, Volume III - Wind, was published. Volume 1-SI - Temperature (Celsius) and Volume 2-SI - Precipitation are nearing completion and should be available in the early part of 1976. More than 5,000 pages of historical data were published in regular periodicals during the year. Microfiche Series 002, Hourly Abstracts for the period 1953-1972 was completed for 80 selected stations. Series 003, Temperature and Precipitation for the full period of record up to and including 1972, was completed for 4731 stations across Canada. Regional Offices have been supplied with duplicate copies of all microfiche for stations in their respective regions.

(ii) *Network Standards Division*

At the close of 1975 there were 2,446 climatological stations, 313 principal stations, and 20 automatic stations operated by the Atmospheric Environment Service. A completely revised edition of "MANUPP, Manual of Upper Air Observations" was published. The Data Quality Section continued normal control procedures to ensure that the archived data was of the highest quality. For the same reason, the Data Standards Section continued its responsibility for recommending standard instruments and observing procedures. A computer method for producing tables for reduction of pressure to sea level was developed, eliminating the laborious and time-consuming method which had been used since the inception of the barometry program.

(iii) *Computing Centre Division*

The Computing Centre is responsible for creating and maintaining an archive of climatological data which spans a period of over 125 years. This data file from Canadian stations contains close to 100 million records, of which over 80% are archived on magnetic tape (800 b.p.i., 9 track). These archives are quality-controlled and current. There are 25 different record types which together encompass all weather elements. The time-scale ranges from hourly to monthly.

A prime objective of the Computing Centre is to make these climatological data readily available to anyone and in a form convenient for computer processing and decision-making.

(iv) *Hydrometeorology and Marine Applications Division*

The Hydrometeorology and Marine Applications Division is the national centre of competence in AES for the application of meteorology to the solution of problems related to both the fresh and salt water environment.

During 1975 the Hydrometeorological Services Section directed much of its effort toward the computerized scanning and analysis of radar photographs taken during the International Field Year for the Great Lakes (IFYGL). The long-duration recording precipitation gauge network (Fischer and Porter) now includes 106 gauges, 18 of which were operated in northern Ontario for a federal-provincial study of water resources in that province. Several analyses of major rainstorms were published, as well as two bi-annual issues of the publication, Supplementary Precipitation Data. An index to all storms analysed in the Storm Rainfall in Canada series was published. Two major studies of critical meteorological conditions for maximum flows of rivers were conducted and reports were prepared. These studies were in support of dam projects on the Peace River below the Bennett Dam and on the Churchill River at Gull Island in Labrador.

The Hydrometeorological Projects Section continued its work to improve the input of observed and forecast meteorological data to flood-forecasting models. Most of the effort was directed toward two studies: one, a World Meteorological Organization/World Weather Watch Project to assess the application of meteorology to hydrology in the Saint John River Basin; the other, in conjunction with the Inland Waters Directorate of Environment Canada, was to assist in the design and application of a flood-forecasting model for the Ottawa River. In order to improve snowmelt predictions for mountainous areas, the relationship of actual snow evaporation-sublimation measurements to standard meteorological parameters was assessed over a two-year period of daily observations.

Monthly water budgets were computed from the limited observations of six benchmark basins operated during the International Hydrological Decade.

Data processing and analysis of data collected during IFYGL occupied much of the attention of the Lakes and Marine Applications Section during 1975. All data from the Canadian shoreline network were quality-controlled and deposited in the Data Banks by November. Three analytical IFYGL studies were started; namely, synoptic studies, climatological ratios, and mass-transfer evaporation. Four synoptic situations of interest to the forecaster in the Great Lakes area were selected: fog over the lake in early spring, frontal thunderstorms during the summer, cold frontal passage in early fall, and a thermal low situation in early winter. The climatological ratios project involves the comparison of reliable meteorological observations from all available ships, towers, buoys, and coastal chains with simultaneous observations overland at upwind meteorological stations. Modified mass-transfer estimates of evaporation were obtained for each day of IFYGL and compared with numerous other methods of estimating evaporation. Other activities for which final reports were submitted included a climatological study for Environment Canada's Working Group on deep-water oil ports, an environmental climatology of Lakes Huron and Superior for the IJC water-quality reference group, and a wind-wave analysis for the Beaufort Sea. The ART program for observing surface water temperatures continued throughout 1975, with 42 lake surveys, 4 St. Lawrence Seaway surveys, and 5 additional surveys of the St. Lawrence River for the Province of Quebec.

(v) *Applications and Consultation Division*

The main thrust of this Division's activities is to investigate and provide solutions to the various problems which result from the interaction of weather and climate upon national pursuits, such as exploration and development in the Arctic, new industrial development, forestry and agriculture, and the recreation and tourism industry in Canada. A recent challenging facet of these activities has been a study of probable climatic change and its consequences. Climatic scenarios for the period from 1880 to 2000 were prepared for such historical climatic events as occasions of drought and periods of changing climate with extremes of temperature and precipitation in order to show the possible effects on mankind in the future.

In support of the Beaufort Sea Project, several studies, which considered the interrelationships of wind, waves, atmospheric stability, evolution of weather systems, and structural icing, were completed. Work continued on a comprehensive climatic study of the Canadian Arctic Islands and adjacent waters. The Arctic Section also undertook the initial coordination of a fundamental textbook on snow.

The Industrial Meteorology Section completed the first phase of the Airport Handbook, consisting of means and extremes of temperature and precipitation and diurnal variations of ceiling and visibility categories.

The STOL-port wind synthesis programme was developed and tested, in order to generate wind tabulations where only a limited amount of data are available. A computer programme was written to provide a summary of heating degree-days for selected stations across Canada. Field work and consultation services were provided in support of ice loads on transmission lines.

The Agricultural and Forest Meteorology Section continued work on the production of a handbook which will provide textual and tabular information on the application of meteorology and climatology to Canadian agriculture and forestry. A final report on the inversion study of an apple orchard near London, Ontario is being prepared. Familiarization work with various crop models is underway; one of these is a yield probability model based on precipitation for selected stations in the Prairie Provinces.

A project to map the agricultural climate of the Yukon and the Northwest Territories was begun, with collaboration from the Department of Indian and Northern Affairs. About 50 climatological stations were installed and monitored during the growing season. These data were supplemented by mobile temperature and humidity surveys.

The physical climatology section started or completed a number of recreation-

tourism climate projects during 1975. Regional climatic studies required for the installation of recreation-tourism facilities were completed for the Prairie Provinces and Newfoundland-Labrador. Climatic studies of national parks, concerning visitor activity, construction sites, wildlife and vegetation species, intended to aid in park management, were completed for Riding Mountain, Manitoba, and are in the final stages of completion for Auyuittuq, N.W.T.

Several maps dealing with temperature, precipitation, and snow cover were completed during the year for the Canadian International Hydrological Decade Atlas.

An attempt is being made to reconstruct the Canadian climate record by utilizing historical sources and "proxy" methods of climatic dating. In this, because climatic parameters are very important in the northern regions, particular emphasis is being placed on the Mackenzie District and Yukon Territory.

17. Bibliography: Meteorology and Atmospheric Science

(a) Journal Articles

1. Alexander, W.G. and Wortman, D.B.: Static and Dynamic Characteristics of XPL Programs. University of Toronto Computer, 8, No. 11, pp. 41-46 (1975).

2. Allcock, G. and J.W. McConkey: Time of Flight Study of Molecular Dissociation by Electrons Bull. Amer. Phys. Soc. 19, 1188 (1974). (abs.).

3. Anlauf, K.G.: High Ozone Concentrations Measured in the Vicinity of Toronto, Canada. Atmospheric Environment, 9, 1137 (1975).

4. Austin, G.L. and A. Bellon: The use of digital weather radar records for short term precipitation forecasting. Q.J. Roy Met. Soc. 100, 650, (1974).

5. Austin, L.B. and G.L. Austin: Techniques for the calculation of attenuation from precipitation for single station and path diversity satellite communication systems from digital radar data. Radio Science, 11, December, (1975).

6. Babin, G.: Blizzard of 1975 in western Canada. Atmosphere, 28:2:70-75. April 1975.

7. Barthakur, N.: Leaf Temperatures under Controlled Environmental Conditions. Int. J. Biometeor. 19, 21-23 (1975).

8. Bergeron, G.: La mesure de l'enneigement. Ressources, Vol. VI, No. 2, Mars 1975.

9. Bergeron, G.: Les valeurs de l'enneigement au Québec. Feuillet météorologique, Vol. XIV, No. 11, Novembre 1975.

10. Boer, G.J.: Zonal and Eddy Forms of the Available Potential Energy. Tellus, 27, 5, (1975).

11. Boer, G.J., and H.L. Steinberg: Fourier Series on a Sphere. Atmosphere 13, 4, (1975).

12. Cho, H.-R.: Cumulus Cloud Population and its Parameterization. Pure App. Geophys., 1975.

13. Cho, H.-R., C.H. Liu and K.C. Yeh: Nonlinear Internal Waves in the Atmosphere. J. Acoustic Soc. Am., Vol. 57, No. 1, p. 14-19, (1975).

14. Crowe, R.B.: Recreation, Tourism and Climate - A Canadian Perspective. Weather, 30:8:248-254. Aug. 1975.

15. Danard, M.B. and A.C. McMillan: Sensitivity of predictions of cyclogenesis to perturbations in initial upper air temperatures. Mon. Wea. Rev., 103, 856-865, (1975).

16. den Hartog, G. and K.M. King: A Free Floating Boundary Layer Shear Stress Meter. Boundary Layer Meteorology, 8, p. 101-107, (1975).

17. Davies, J.A., W. Schertzer and M. Nunez: Estimating global solar radiation. Boundary Layer Meteorology, 9, 1, 33-52, (1975).

18. Dube, P.A., K.R. Stevenson, G.W. Thurtell and H.H. Neumann: Steady State resistance to waterflow in corn under well watered conditions. Canadian Journal of Plant Science, 55, 941-948, (1975).

19. English, M.: Numerical Model Predictions for the Alberta Hail Project. J. of Weather Mod. Dec., (1975).

20. Ferland, M.G.: Etude climatologique d'une partie des Cantons de l'Est. Feuillet météorologique, Vol. XIV, No. 4, Avril 1975.

21. Gal-Chen, T. and R. Somerville: On the Use of a Coordinate Transformation for the Solution of the Navier-Stokes Equations. J. Comp. Phys., 17, 209-228, (1975).

22. Gal-Chen, T. and R. Somerville: Numerical Solution of the Navier-Stokes Equations with Topography. J. Comp. Phys., 17, 276-310, (1975).

23. Godson, W.L.: Is the earth getting hotter or colder? Canadian Geographical Journal, 90:5:42-48. May 1975.

24. Goyer, G.G.: An overall strategy for the evaluation of hail suppression experiments. J. Rech. Atmos. May - June, (1975).

25. Goyer, G.G.: Time integrated radar echo tops as a measure of cloud-seeding effects. J. Appl. Meteor. 14, 1362-1365, (1975).

26. Goyer, G.G.: Comments on "Time integrated radar echo tops as a measure of cloud-seeding effects." J. Appl. Meteor. 14, 1367, (1975).

27. Gray, J., K.D. Hage, and H.W. Mary: An automatic sequential rainfall sampler. Rev. Scient. Instruments, 45(12), 1517-1519, (1974).

28. Hage, K.D.: Urban-rural humidity differences. J. Applied Meteorol., 14(7), 1277-1283, (1975).

29. Hage, K.D.: Averaging errors in monthly evaporation estimates. Water Resources Research, 11(2), 359-361, (1975).

30. Hage, K.D., J. Gray, and J.C. Linton: Isotopes in precipitation in northwestern North America. Monthly Weather Review, 103(11), 10 pp., (1975).

31. Hamblin, P.F. and J.R. Salmon: On the Vertical Transfer of Momentum in a Lake. Mémoires société Royale des Sciences de Liège. 6 série, tome VII, pp. 211-239, (1975).

32. Howroyd, G.C. and P.R. Slawson: The characteristics of a laboratory produced turbulent Ekman layer. Boundary Layer Meteor., 8, 201-219, (1975).

33. Kolomeychuk, R.J., D.C. McKay and J.V. Iribarne: The Fragmentation and Electrification of Freezing Drops. J. Atm. Sci., 32, 974-979, (1975).

34. Lamb, P.: L'eau, source d'énergie... mais cause d'innondations. Ressources, Vol. VI, No. 5, Septembre 1975.

35. Lambert, S.: A high resolution study of the sea-breeze front. Atmosphere; 12, 97-105, (1975).

36. List, R. and H. Melling: Plume Convection Over an Urban Area as Observed by Acoustic Echo Sounding. Atmosphere, 12, No. 4, 144-153, (1974).

37. Lozowski, E.P., M.M. Oleskiw, and T.M. Morrow: Hail photography: an example of the use of high speed techniques under adverse conditions. J. Soc. Mot. Pic. Tel. Engr., 84, 18-23, (1975).

38. Markey, K.L. and G.G. Goyer: Airborne infrared radiometry and hailswaths. J. Appl. Meteor. 14, 1366-1375, (1975).

39. Marshall, J.S. and E.H. Ballantyne: Weather surveillance radar. J. Appl. Meteor. 14, 1317-1338, (1975).

40. Maxwell, B.J. and J.V. Iribarne: Charge Saturation in Splashing of Large Drops on Solid Spheres. J. Chem. Soc., Faraday Trans. I, 71, 1033-1040, (1975).

41. McBean, G.A., and R.D. Paterson: Variations of the turbulent fluxes of momentum, heat and moisture over Lake Ontario. J. Phys. Oceano., 5, 523-531, (1975).

42. _____, and J.A. Elliott: The transport of energy by turbulence and pressure and the turbulent energy budget. J. Atmos. Sci., 32, 753-766, (1975).

43. _____: Turbulent fluxes over Lake Ontario during a cold frontal passage. Atmosphere, 13, 37-48, (1975).

44. _____, and M.A. Tilley: Reply to R.C. Wanta on "An application of spectrum analysis to synoptic-pollution data". Atmospheric Environment, 9, 370, (1975).

45. _____: Comments on "Limitations of the eddy correlation technique for the determination of turbulent fluxes near the surface". Boundary Layer Meteorology, 9, 361-2, (1975).

46. McCaughey, J.H. and J.A. Davies: Energy exchange in a corn canopy. Canadian Journal of Plant Science, 55, 691-704, (1975).

47. McTaggart-Cowan, J.D. and R. List: An Acceleration System for Water Drops. J. Atmos. Sci., 32, 1395-1400, (1975).

48. McTaggart-Cowan, J.D. and R. List: Collision and Breakup of Water Drops at Terminal Velocity. J. Atmos. Sci., 32, 1401-1411, (1975).

49. Merilees, P.E.: Numerical experiments with the pseudospectral method in spherical coordinates. Atmosphere, 12, 77-96, (1975).

50. Merilees, P.E. and H. Warn: On energy and enstrophy exchanges in two-dimensional nondivergent flow. Journal of Fluid Mechanics, 69, part 4, pp. 625-630, (1975).

51. Merilees, P.E.: The effect of grid resolution on the instability of a simple baroclinic model. Monthly Weather Review, 103, 101-104, (1974).

52. Munn, R.E.: Suspended particulate concentrations: spatial correlations in the Detroit-Windsor area. Tellus, 27, 397-405, (1975).

53. Munn, R.E.: The oxidant climatology of Canada. In Photochemical air pollution: formation, transport and effects, NRC, Ottawa, No. 14096, pp. 53-70, (1975).

54. Neralla, V.R., and M.B. Danard: Incorporation of parameterized convection in the synoptic study of large-scale effects of the Great Lakes. Mon. Wea. Rev., 103, 388-405, (1975).

55. Newark, M.J.: The relationship between forest fire occurrence and 500 mb long-wave ridging. Atmosphere, 13:1:26-33, (1975).

56. Overend, Ralph, G. Paraskivopaulas, Janice R. Crawford and H.A. Wiebe: The Role of Excess Kinetic Energy in the Reactions of O ('D) Atmos., Can. J. Chem., 53, 1915-1921, (1975).

57. Phillips, M.L. and R.E. Munn: Crops and forests as sources and sinks for air pollution. In Progress in Plant Biology, 1, Swets and Zeitlinger, Amsterdam, pp. 311-331, (1975).

58. Phillips, M.L. and R.E. Munn: The control of air quality. In Progress in Plant Biology, 1, Swets and Zeitlinger, Amsterdam, pp. 335-348, (1975).

59. Polavarapu, R.J.: Massive tropical weather study may help avoid future cyclone tragedies. Science Forum, 8, Number 6, 8-11, (1975).

60. _____, and T.S. Murty: Reconstruction of some of the early storm surges on the Great Lakes. Journal of Great Lakes Research, 1, Number 1, 116-129, (1975).

61. Proctor, J.T.A., W.J. Kyle and J.A. Davies: The Penetration of global solar radiation within apple trees. Journal of the American Society for Horticultural Science, 100, 40-44, (1975).

62. Robertson, David: Reply to comments on Monte Carlo Simulations of Drop Growth by Accretion.J. Atmos. Sci. 32, 1639, (1975).

63. Schuepp, P.H. and K.D. White: Transfer Processes in Vegetation by Electrochemical Analog. Boundary Layer Meteorol., 8, 335-358, (1975).

64. Shaw, R.H., G. den Hartog, K.M. King and G.W. Thurtell: Measurements of Mean Wind flow and three dimensional turbulence intensity within a mature corn canopy. Journal of Agricultural Meteorology 13, No. 3, 419, (1974).

65. Smil, V.: Energy and Air Pollution: USA 1975-2020. Journal of Air Pollution Control Association 25, No. 3, 233-6, (1975).

66. Smith, S.D. and E.G. Banke: Variation of the sea-surface drag coefficient with wind speed. Quarterly Journal of the Royal Meteorological Society, 101, 665-673, (1975).

67. Storr, D. and H.L. Ferguson: On the ambiguity of Bowen Ratios over freezing and melting surfaces. Journal Applied Meteorology. 13, No. 4, p. 509-511, (1974).

68. Storr, D. and G. den Hartog: Gamma - The Psychrometer Non-Constant. Journal of Applied Meteorology. 14, No. 7, (1975).

69. Storr, D: Comments on 'Accuracy of Precipitation Measurements for Hydrologic Modelling' by Lee W. Laison and E.L. Peck. Water Resources Research, 11, No. 2, 377-378, (1975).

70. Suckling, P.W., J.A. Davies and J.T.A. Proctor: The transmission of global and photosynthetically active radiation within a dwarf apple orchard. Canadian Journal of Botany, 53, 1428-1441, (1975).

71. Thomas, M.K.: Climatology in Environment Canada - 1975. Climatological Bulletin, 17, 38-42. April 1975.

72. Ting, C.L., D.R. Hay: On the heat flux and Friction velocity in free convection near the ground. J. Atmos. Sci., 32, 637-638, (1975).

73. Vowinckel, E., and S. Orvig: Répercussions Météorologiques découlant de Modifications naturelles ou délibérées de la Surface - Principes généraux et prospectives, région de la Baie de James. Cahiers de Géographie de Québec, 18, No. 45, 445-461, (1974).

74. Vupputuri, R.K.R.: Seasonal and Latitudinal Variation of N_2O and NO_x in the Stratosphere. J. Geophys. Res., 80, 9, (1975).

75. Wigley, T.M.L.: A numerical analysis of the effect of condensation on plume rise. J. Appl. Meteor., 14, 1105-1109, (1975).

76. Wigley, T.M.L.: Condensation in jets, industrial plumes and cooling tower plumes. J. Appl. Meteor., 14, 78-86, (1975).

77. Wigley, T.M.L., and P.R. Slawson: The effect of atmospheric conditions on the length of visible cooling tower plumes. Atmos. Env., 9, 437-445, (1975).

78. Wojtiw, L.: Hailfall and Crop Damage in Central Alberta. J. of Weather Mod., (1975).

(b) Other Papers

1. Alberta Research Council: Atmospheric Sciences Division, (1975): Current research on Alberta hailstorms. Progress Report 1974-1975, June.

2. Allcock, G. and J.W. McConkey: Abstr. IX I.C.P.E.A.C., Seattle, 2, 820, (1975).

3. Anderson, R.S., 1975: Polarization measurements at 16.5 GHz in stratiform and convective precipitation. Preprints, 16th Radar Meteorology Conference, 425-426. American Meteorological Society, Boston.

4. Anlauf, K.G., M. Lusis, H.A. Wiebe and R.D.S. Stevens: Oxidant Formation in the Toronto Region . VIII International Conference on Photochemistry, Edmonton, Canada (Aug. 7-13, 1975).

5. Anlauf, K.G., M.A. Lusis, H.A. Wiebe and H.P. Sanderson: Mobile Air Quality Monitoring . Zephyr, (Oct. 1975).

6. Asselin, R.: DPR's Plans and Achievements in Support of an Advanced Forecast and Observational System. Proceedings of Third Annual Forecast Research Symposium, June 16-18, 1975. AES Headquarters, 4905 Dufferin St., Downsview, Ontario, 10 pp.

7. Austin, G.L. and M. Haynes: Comparative study of Maritime Tropical and Temperate Continental Patterns. p. 202.

8. Ballantyne, E.H. 1974: The addition of height to a weather surveillance radar PPI. Tech. Rept. MWT-9, Stormy Weather Group, McGill University, Montreal.

9. Barr, W. and F.H. Nicholson: Annotated bibliography of McGill Sub-Arctic Research Papers and Theses 1954-1974. McGill Sub-Arctic Research Papers, 26, 98 p.

10. Bellon, A. and G.L. Austin, 1975: Short term automated radar prediction. A.E.S. Contract report.

11. Bellon, A. and G.L. Austin: Short range precipitation forecasting using digital radar records. p. 345.

12. Bennett, R.C. and R. List: Lake Breeze Detection with an Acoustic Radar. 16th Radar Meteorology Conference, Houston, Texas, 1975, p. 260-262.

13. Bergsteinsson, J.L.: A regional climatology of Saskatchewan for wind power. Saskatchewan Research Council, Saskatoon. SRC Report P 75-11; Sept. 1975.

14. Berry, R.L., D.M. Whelpdale and H.A. Wiebe 1975: Precipitation sampling in Canada by the Atmospheric Environment Service. Presented at the 9th Annual Congress of the Canadian Meteorological Society, Vancouver, May.

15. Berry, R.L., D.M. Whelpdale and H.A. Wiebe 1975: An evaluation of collectors for precipitation chemistry sampling. Presented at the WMO Expert Meeting on Wet and Dry Deposition (WADEM), Toronto, November 17-21.

16. Bhartendu: Correlation of the atmospheric electricity parameters near the ground and the geomagnetic index Ap. Sixteenth General Assembly of the International Union of Geodesy and Geophysics, Grenoble, France, 1975.

17. Boer, G.J., 1975: Research Activities in Climatic Change. Can. Met. Soc., 9th Annual Congress, Vancouver.

18. Boer, G.J., N. McFarlane, R.K.R. Vupputuri, 1975: Numerical Modelling Activities in the Atmospheric Processes Research Branch. Stanstead Seminar, Lennoxville.

19. Bourque, D.A. and W. Physick: Observational Network Simulation Studies with a Regional Model in the Beaufort Sea. Proceedings of Third Annual Forecast Research Symposium, June 16 - 18, 1975. AES Headquarters, 4905 Dufferin St., Downsview, Ontario, 7 pp.

20. Boyce, F.M.: The effects of stratification and diffusion in the flushing of persistent dissolved contaminants in lakes and reservoirs. Flushing of Lakes and Reservoirs. January 1975.

21. Catchpole, A.J.W.: A Spring Singularity in Global Radiation Beneath Overcast Skies in the Canadian Prairies . Meteorological Magazine, October 1975.

22. Charlton, R.B., 1974: Climate, Air Quality and Noise at the Proposed Villeneuve Airport. L.G.L. Ltd. and Transport Canada, 70 pp. Published in edited form in 1975 by Transport Canada as part of a Preliminary Environmental Assessment Statement.

23. Charlton, R.B., B. Janz and J. Toogood, 1974: Climate of Alberta (Chapter 2 of Alberta Farm Guide). At Queen's Printers, Pub. Date, spring, 1976.

24. Charlton, R.B., 1975: Climate, Air Quality and Noise at the Proposed Hermitage Parksite. L.G.L. Ltd. and Edmonton Parks and Recreation Dept., 90 pp. To be published in 1976 by the City of Edmonton as part of a park plan for Hermitage Parksite.

25. Charlton, R.C., J. Gray and H. Sandhu, 1975: Modelling Precipitation Processes with Stable Isotopes. Ninth Congress C.M.S., Vancouver.

26. Cho, H.-R.: Cumulus Cloud Activity and the Large-Scale Moisture Field in the Tropics. Ninth Tech. Conference on Hurricanes and Tropical Meteorology of the AMS, Key Biscayne, Miami, Florida, May 27-30, 1975.

27. Chung, Y.-S., and E.C. Jarvis: Automation Prediction of Surface Temperature. Proceedings of Third Annual Forecast Research Symposium, June 16-18, 1975. AES Headquarters, 4905 Dufferin St., Downsview, Ontario, 10 pp.

28. Crabbe, R.S.: Some Environmental Measurements of the Vertical Spread of Pollutants from Low-Level Sources. National Research Council of Canada, LTR-UA-28, April 1975.

29. Daley, R.: A Galerkin Procedure for Short-Range Global Numerical Weather Prediction. Proceedings of Third Annual Forecast Research Symposium, June 16-18, 1975. AES Headquarters, 4905 Dufferin St., Downsview, Ontario, 12 pp.

30. Davies, D.: Historical Benefits of R & D as shown by Threat Score Evaluations of the Operational CMC Forecasts from December, 1972 to November, 1973. Proceedings of Third Annual Forecast Research Symposium, June 16-18, 1975. AES Headquarters, 4905 Dufferin St., Downsview, Ontario, 7 pp.

31. Davies, D.: Small Scale Moisture Effects Based on the Mesoscale Eddy Mixing Length. Proceedings of Third Annual Forecast Research Symposium, June 16-18, 1975. AES Headquarters 4905 Dufferin St., Downsview, Ontario, 9 pp.

32. Delage, Y.: Surface Heat and Moisture Fluxes in DPR Forecast Models. Proceedings of Third Annual Forecast Research Symposium, June 16-18, 1975. AES Headquarters, 4905 Dufferin St., Downsview, Ontario, 8 pp.

33. den Hartog, G. and H.L. Ferguson, 1975: National Water Balance Maps of Evapotranspiration and Precipitation. In: Proceedings Canadian Hydrology Symposium, Winnipeg. Aug. 11-15, 1975.

34. Donelan, M.A.: Are aquatic micrometeorologists delivering the goods, or is the over-water drag coefficient far from constant? Symp. on Modelling of Transport Mechanisms in Oceans and Lakes, CCIW, Burlington. October 1975.

35. Evans, W.F.J., J.B. Kerr and D.I. Wardle: The AES Balloon Measurements Project; Preliminary Results. Proceedings of the Fourth CIAP Conference, Cambridge, Massachussetts, February, 1974.

36. Fanaki, F.H. 1975: On the Strait of Canso Field Study. Presented at the 9th Annual Congress of the Canadian Meteorological Society Meeting, Vancouver, May.

37. Ferguson, H.L. and E.I. Mukammal, 1975: AES/WMO Pan Evaporation Research Project. In: Proc. Canadian Hydrology Symposium, Winnipeg, August 11-15, 1975.

38. Ferguson, H.L. and F.K. Hare, 1975: The Water Balance and its Applications. In: Proc. Canadian Hydrology Symposium, Winnipeg. August 11-15, 1975.

39. Ferguson, H.L. and G. den Hartog, 1975: Meteorological Studies of Evaporation of Perch Lake, Ontario. In: Hydrological Studies on a Small Basin on the Canadian Shield (ed. P.J. Barry) pp. 418-448.

40. Findlay, B.F.: Snow Maps for the Canadian Hydrological Atlas. Proc. Western Snow Conference 1975, San Diego, Cal. 13 pp. 1975.

41. Findlay, B.F. and R.A. Treidl: Climatic aspects of sub-polar regions. Manuscript of paper for presentation to the 7th International Congress, International Society of Biometeorology, University of Maryland. Aug. 1975.

42. Forsyth, P.A., E.W. Halayko, D.R. Hay, and J.A. Fulford, 1975: "CRS Radiosonde" Centre for Radio Science, U.W.O. London. Report to the NATO Special Programme Panel on Radiometeorology, Brussels.

43. Girard, C. and R. List: The Fall of Precipitation Particle Zones. Conference on Cloud Physics, Tucson, Arizona, Oct. 21-24, 1974, published by the Amer. Meteor. Soc., p. 223-226.

44. Girard, C.: An Adjustment Procedure to Compute both Large and Small Scale Precipitation for Use in Primitive Equations Models. Proceedings of Third Annual Forecast Research Symposium, June 16-18, 1975. AES Headquarters, 4905 Dufferin St., Downsview, Ontario, 8 pp.

45. Goodison, B.E. 1975: Snow Studies at Cold Creek: Testing and Evaluation of Gauges Used in Canada for Fresh Snowfall Measurement . Proc. Canadian Hydrology Symposium, Winnipeg. August 11-15, 1975.

46. Goodison, B.E., 1975: Standardization of Snow Course Data: Reporting and Publishing . Proc. Eastern Snow Conference.

47. Hamblin, P.F., M.A. Donelan and F.C. Elder: Determination of the Aerodynamic Drag Coefficient from Wind Set-up. (IFYGL). Proc. 17th Conf. Great Lakes Res. 1974: 778-788. Internat. Assoc. Great Lakes Res.

48. Hamblin, P.F., N.G. Freeman and T.S. Murty: Helmholtz Resonance in Harbours of the Great Lakes. Proc. 17th Conf. Great Lakes Res. 1974: 399-411. Internat. Assoc. Great Lakes Res.

49. Hamblin, P.F.: Some Recent Advances in the Physical Limnology of Canadian Lakes and Reservoirs. Proc. Canadian Hydrology Symposium, Aug. 11-14, 1975. Winnipeg.

50. Hamblin, P.F.: Upwelling in a model of an intermontane lake. International Association of Theoretical and Applied Limnology, No. 19, Stuttgart. October 1975. pp. 88-96.

51. Hamblin, P.F.: Short Period Tides in Lake Ontario (IFYGL). Proc. 17th Conf. Great Lakes Res. 1974: 789-800. Internat. Assoc. Great Lakes Res.

52. Hamblin, P.F. and F. Penicka: Finite Element Model of Steady State Wind-Driven Circulation in a Lake. Proc. Symposium on Modelling of Oceans and Lakes, Ocean and Aquatic Sciences, Central Region, CCIW, Burlington. October 20-22, 1975. (Extended Abstract)

53. Harley, W.S. and T.E. Jakobsson, 1975: Climatic trends in the Northern Hemisphere. Can. Met. Soc., 9th Annual Congress, Vancouver.

54. Harley, W.S. and T.E. Jakobsson: Climatic trends in Northern Hemisphere. Zephyr, 6-11. June 1975.

55. Hendryt, B.L. Barge and G.C. McCormick, (1975): The Degree of Common Alignment of Hydrometeors. Preprint, 16th Radar Met. Conf. Houston, Texas. AMS, Boston, Mass.

56. Horita, M.M. and L.E. Parent, 1975: The Automation of the British Columbia Fire Weather Forecast Program. Meteorological Services Research Branch. 3rd Annual Forecast Research Symposium.

57. Houde, A.: Les zones climatiques du Québec. Annuaire du Québec, Bureau de la Statistique du Québec, 1974.

58. Isaac, G.A., J.I. MacPherson, and L.B. MacHattie, 1975: Forest fires and cumulus clouds. National Research Council Report, NAE MISC 51, 26 p.

59. Kershaw, K.A., W.R. Rouse and B.T. Bunting: The impact of fire on forest and tundra ecosystems. Contract Report, ALUR, Dept. of Indian and Northern Affairs, Ottawa, pp. 81.

60. Leighton, H.G., and V.A. Pissimanis, 1975: Effects of entrainment and freezing on cloud droplet evolution. McGill Univ. Stormy Weather Group Sci. Rep. MW-83, 31 pp.

61. List, R.: The Warm-Rain Mechanism - Its Modelling and Modification. Proceedings WMO Technical Conference on Typhoon Modification, Manila, October 15-18, 1974, WMO - No. 408, p. 1-8.

62. List, R.: Education and Training in Weather Modification. Proceedings WMO/IAMAP Symposium on Education and Training in Meteorology and Meteorological Aspects of Environmental Problems, Caracas, February, 1975, WMO/TRS/Doc. 16, p. 1-15.

63. Lozowski, E.P., and G.S. Strong, 1975: On the calibration of hailpads. Ninth Congress C.M.S., Vancouver.

64. Lozowski, E.P., 1975: An Alberta weather modification survey. The Albertan Geographer, 11, 1-11.

65. Lozowski, E.P., and A.G. Beattie, 1975: Field measurements of hailstone aerodynamics. Ninth Congress C.M.S., Vancouver.

66. Marshall, J.S.: Research at the McGill Radar Weather Observatory, 1 Sept. 72 to 31 Aug. 75. Final Contract Report to Air Force Cambridge Research Laboratories.

67. Maybank, J., K. Yoshida, and S.R. Shewchuk: Investigation of airborne graindust emanating from a prairie grain elevator and its subsequent drift and deposition pattern. Saskatchewan Research Council, Saskatoon. SRC Report P 75-4 March 1975.

68. McCooeye, M., G. Gardner, and L. Elias: In-Situ Technique for Measurement of Atmospheric Tracer Gases. National Research Council of Canada, LTR-UA-31, September 1975.

69. Millan, M.M., 1975: A critical study of mercury electro-optical detection methods and their airborne operation. Proceedings of the 1st International Mercury Congress, University of Barcelona, Barcelona, Spain.

70. Millan, M.M., 1974: The concept of fumigation in air pollution and its importance in Spain. Economia Industrial, December Issue, Spanish Ministry of Industry.

71. Milton, J.D. and A.J.W. Catchpole: Bright Sunshine Hours and Atmospheric Particulate Matter Content. read at World Meteorological Office Symposium on Meteorology as Related to Urban and Regional Land-Use Planning, held at Asheville, North Carolina, 3rd-7th November, 1975 (published in the Symposium Proceedings).

72. Moodie, D.W. and A.J.W. Catchpole: Environmental Data from Historical Documents by Content Analysis; Freeze-Up and Break-Up of Estuaries on Hudson Bay 1714-1871 . Manitoba Geographical Studies No. 5, (1975), 119 pp Sponsored by Atmospheric Environment Service, Environment Canada.

73. Muller, F.B.: Beaufort Sea Computerized Prediction Support System. Proceedings of Third Annual Forecast Research Symposium, June 16-18, 1975. AES Headquarters, 4905 Dufferin St., Downsview, Ontario. 6 pp.

74. Munn, R.E., 1975: Environmental monitoring systems: design, operation and intellectual input from SCOPE . In: Proc. Symp. on Petroleum and Environmental Conservation . pp. 297-310.

75. Munn, R.E., 1975: Global atmospheric monitoring systems . In: GARP Pub. Series No. 16, The Physical Basis of Climate and Climate Modelling , WMO, pp. 258-265.

76. Munn, R.E. and D.M. Whelpdale, 1975: Global air pollution. Presented at the International Congress of Scientists on the Human Environment, Kyoto, Japan, November 16-26.

77. Neiboer, E., D.H.S. Richardson, K.J. Puckett and F.D. Tomassini: The Phytotoxicity of Sulfur Dioxide in Relation to Measurable Responses in Lichens . (1975) Proceedings of Annual Meeting, Society of Experimental Biology, Liverpool, U.K. Seminar Title - Effects of Air Pollutants on Plants.

78. Nikleva, S.: Fire weather program in British Columbia. Environment Canada, Atmospheric Environment Service, Pacific Region. 1975. 30 p.

79. Ogura, Y. and H.-R. Cho: A Semi-Empirical Model of the Trade Wind Inversion. Ninth Tech. Conference on Hurricanes and Tropical Meteorology of the AMS, Key Biscayne, Miami, Florida, May 27-30, 1975.

80. Peltier, W.R.: Viscous Gravitational Relaxation of 'Real' Newtonian Earth Models. Invited lectures in the Proceedings of W.H.O.I. Summer School in Geophysical Fluid Dynamics, August, 1975.

81. Peltier, W.R., R. Lindzen, F. Einaudi and W.H. Hooke: Waves in SESAME. A report prepared for the SESAME Advisory Committee on the importance of wave studies.

82. Perrier, M.G.: Influences de Modifications de Surface sur le Climat (Région de la Baie de James). McGill University, Publications in Meteorology, No. 116, 1975, 132 pp.

83. Phillips, M.L. and H.P. Sanderson: Development of Air Quality Objectives for Heavy Metals . ARQA-20-75, Proceedings - Annual Meeting of APCA - Ontario Section, Toronto, Ontario (April 20-22, 1975).

84. Physick, W.L. and D.A. Bourque: An Evaluation of Various Reference Atmospheres for Four-Dimensional Assimilation and Observational Network Design Experiments. Proceedings of Third Annual Forecast Research Symposium, June 16-18, 1975. AES Headquarters, 4905 Dufferin St., Downsview, Ontario, 7 pp.

85. Reinelt, E.R., P.H. Hof, D. Oracheski and J. Broszkowski, 1975: Research studies of numerical enhancement of APT scanning radiometer data for application to Arctic weather and ice prediction. Final Report, DDS (AES) Contract OSV4-0183, Atmospheric Environment Service, Downsview, 206 pp.

86. Robertson, David, 1975: The trajectories of particles growing by accretion of cloud droplets. McGill Univ. Stormy Weather Group Sci. Rep. MW-84, 16 pp.

87. Rogers, R.R., 1975: Models -- their theoretical and physical foundations. Invited paper presented at 16th General Assembly of URSI, Lima, Peru.

88. Schaefer, D.G., 1975: Climatic Fluctuations in the Fraser River Delta-Steveston, British Columbia, 1896-1974. 9th Annual Congress Canadian Meteorological Society.

89. Shewchuk, S.R.: A preliminary report on the electrostatic technique of plume tracing. Saskatchewan Research Council, Saskatoon. SRC Report P 75-5. January 1975.

90. Special Report Session on the A.E.S. Stratospheric Balloon Project. Physics in Canada,

31, 30-31, (1975).

91. Staniforth, A. and H. Mitchell: Finite-Element Integrations of the Barotropic Primitive Equations. Proceedings of Third Annual Forecast Research Symposium, June 16-18, 1975. AES Headquarters, 4905 Dufferin St., Downsview, Ontario, 1 p.

92. Storr, D. and G. den Hartog, 1975: Basin Water Balance Studies in the Rocky Mountains and Foothills of Alberta. In: Proc. Canadian Hydrology Symposium.

93. Sullivan, J., E.M. Rasmusson and H.L. Ferguson, 1975: Atmospheric Water Balance over Lake Ontario, October 30 - November 14, 1972 . Proc. 18th Great Lakes Conference, International Association of Great Lakes Research.

94. Summers, P.W. and D.M. Whelpdale, 1975: Acid precipitation in Canada. Presented at the First International Symposium on Acid Precipitation and the Forest Ecosystem, Ohio State University, Columbus, May.

95. Summers, P.W., 1975: Sampling precipitation from heavy convective storms. Presented at the WMO Expert Meeting on Wet and Dry Deposition (WADEM), Toronto, Ontario, November 17-21.

96. Takashima, T. and C.I. Taggart: Computational Procedure of the Emergent Radiation by the Atmosphere in the Region Ranging from Ultra-violet to Infrared Radiation. Proceedings of Third Annual Forecast Research Symposium, June 16-18, 1975. AES Headquarters, 4905 Dufferin St., Downsview, Ontario, 10 pp.

97. Taylor Alt, Bea: The energy balance climate of Meighen Ice Cap, N.W.T. Vols. I & II. Polar Continental Shelf Project, Department of Energy, Mines and Resources, Ottawa, 1975, 67 pp. and 101 pp.

98. Thomas, J.E.: An energy budget model of the Coniferous Forest Biome for determining the hydrologic impact of logging . McGill University, Publications in Meteorology, No. 115, 1975, 153 pp.

99. Thomas, M.K.: A century of Canadian meteorology. Environment Canada. Atmospheric Environment Service, Annual Record of Operations, 1971-72 (1975). p. 1-20.

100. Thomas, M.K.: Climatic change, humbug or a warning? The Forecaster, 35:1:7-10. March 1975.

101. Thomas, M.K.: Forecasting climate and beyond. Zephyr, March 1975. p. 1-2.

102. Venkatesh, S.: Wind-Wave Forecasting in the Beaufort Sea. Proceedings of Third Annual Forecast Research Symposium, June 16-18, 1975. AES Headquarters, 4905 Dufferin St., Downsview, Ontario, 9 pp.

103. Vupputuri, R.K.R., 1975: Seasonal and Latitudinal Variations of CF_xCl_y (freons) and Cl_x (Cl,ClO, and HCl) in the Stratosphere and Their Impact on Stratospheric Ozone and Temperature. Can. Met. Soc., 9th Annual Congress, Vancouver.

104. Whelpdale, D.M. and P.W. Summers, 1975: The role of the Atmospheric Environment Service, Environment Canada in studies of atmospheric sulphur compounds. Presented at the Alberta Sulphur Gas Research Workshop II, Kananaskis, Alberta, January 16-17.

105. Whiting, J.: Evaluation and interpretation of ERTS imagery for Big Quill Lake. Saskatchewan Research Council, Saskatoon. SRC Report E 75-3, February 1975.

106. Whelpdale, D.M., 1975: Particle sampling techniques. Presented at the SCOR/NAS Workshop on Tropospheric Transport of Pollutants to the Ocean, Miami, December 6-12.

107. Yacowar, N., 1975: Probability forecasting using finely tuned analogs . Presented to the Fourth Conference on Statistics and Probability in Tallahasse, November 1975.

108. Wojtiw, L., (1975): Climatic Summaries of Hailfall in Central Alberta (1957-1973), Atmospheric Sciences Report 75-1, Alberta Research.

109. Wojtiw, L., (1975): Climatology of Hailstorms in Alberta, Preprints NHRE.

110. Wojtiw, L. and E.P. Lozowski, (1975): Record Canadian Hailstones, Bulletin of the American Meteorological Society. Dec.

(c) Other Publications

1. Clodman, J.: Final Technical Report, Real-Time Environmental Prediction System. DOE Internal Report, December, 1975.

2. Cork, H.F.: Evaporation from Tobin Lake. Prairie Hydrometeorological Centre Report No. 14, Environment Canada, Atmospheric Environment Service.

3. Cork, H.F.: Maximum Temperatures for Snowmelt Computations, Regina, Saskatchewan. Prairie Hydrometeorological Centre Report No. 12, Environment Canada, Atmospheric Environment Service.

4. Cork, H.F.: Temperature and Evaporation on Lake Diefenbaker, 1974. Prairie Hydrometeorological Centre Report No. 13, Environment Canada, Atmospheric Environment Service.

5. Muller, F.B.: Beaufort Sea Prediction System Design. AES Internal Report, December, 1975.

6. Pollock, D.M. and T.F. Gigliotti: Critical Meteorological Conditions for Maximum Flows on the Pine, Beatton & Halfway Rivers in B.C. with an estimate of Associate Conditions for the Peace River above the WAC Bennett Dam. 1975. (Unpublished report)

7. Pollock, D.M. and W.L. Ranahan: A Study of the Meteorological Factors for Maximum Flows in the Churchill River at Gull Island, Labrador. Environment Canada, Atmospheric Environment Service. 1975. (Unpublished report)

(d) Technical Memoranda

Heavy Rainfall - District of Mackenzie - Two Case Studies
Author - F.R. Bowkett
TEC-812

Visibility Through Various Obscuring Media as Determined by the Videograph
Authors - B.E. Sheppard and W.L. Clink
TEC-813

Surface Friction in a Two-Level Prediction Model
Author - L.O. Mapanao
TEC-814

Monthly Means and Deviations from Normal of Temperature and Precipitation in the Lake Ontario Basin During IFYGL
Authors - D.W. Phillips and J.A. McCulloch
TEC-815

A Fortran Program to Solve the Bretschneider Wind-Wave Relationship for Deep Water
Author - M.E. Lalande
TEC-816

Transmissometer Redesign
Authors - W.R. Smith and J.H. Stone
TEC-817

Icing
Author - A.H. Osborne
TEC-818

Eigenvector Derived Temperature and Precipitation Patterns in the Maritimes
Authors - E.W. Brandon and R.T. Dyer
TEC-819

The Development of a Prototype Ambient Light Sensor for Use in the Runway Visual Range System
Author - Brian Sheppard
TEC-820

The Severe Storm of April 3, 1974 at Windsor, Ontario
Author - E.H. Roete
TEC-821

(é) Canadian Meteorological Research Reports

The IHD Mountain Transects Project - Part II
Instrumentation Problems and Data Record 1967-1972
Authors - H.L. Ferguson, H.I. Hunter and D.G. Schaefer
CMRR 1/75

Initial Experiments with a RUM Using a Free Surface Primitive Equations Model
Author - F.J. Winninghoff
CMRR 2/75

On Regional Update Modelling - Progress Report No. 1
Author - F.J. Winninghoff
CMRR 3/75

On the Modelling of the Atmospheric Boundary Layer Over a Sudden Change of Surface Roughness
Author - R.K. Lo
CMRR 4/75

Deep Water Wind-Wave Relationships - A Series Solution Approach
Author - S. Venkatesh
CMRR 5/75

METEOROLOGICAL TRANSLATIONS PUBLISHED DURING 1975

A Volume of Selected Papers on the Ice Nucleating Efficiency of Various Cloud Seeding Agents
Authors - B.M. Bashkirova, I.A. Molotkova, T.A. Pershina, Yu.P. Sumin, N.V. Topopova, V.G. Morachevskii, N.A. Dubrovich, A.N. Potanin, A.G. Popov, Nikandrov, N.V. Bychkov, T.N. Gromova, D.D. Stalevich and T.S. Uchevatkina.
MT-27

A Volume of Selected Papers on the Uses of Radar in Cloud Physics Measurements
Authors - M.T. Abshaev, Yu.A. Dadali, E.M. Sal'man, S.B. Gashina, R.A. Anchugova, T.V. Ivanova, N.F. Kotov, B.R. Yakilev, K.S. Zhupakin.
MT-28

(f) Documentation Sheets

DS # 1-75 - List of Climatological Studies.

DS # 2-75 - Climatological Station Census - December 31, 1974.

DS # 3-75 - Readings in Applied Meteorology - Part 2: Collections.

DS # 4-75 - Readings in Applied Meteorology - Part 3: Papers and Articles.

DS # 5-75 - Readings in Climatic Change - Part 1: Books.

DS # 6-75 - Publications in Hydrometeorology and Marine Applications.

DS # 7-75 - Meteorological Studies of Climatic Fluctuations in Canada 1917-1960 - An Annotated Bibliography Compiled by M.K. Thomas.

DS # 8-75 - Addendum No. 1 to Selected Publications in Climatology and Applied Meteorology (DS # 3-74).

DS # 9-75 - Weather Observing Stations Above 4000 Feet and 3000 Feet.

DS #10-75 - List of CLI Circulars.

DS #11-75 - A List of Stations Preparing Monthly and Annual Meteorological Summaries.

CDS

CDS #1-75 (revised) - Normals of Temperature and Precipitation for Stations Preparing Monthly Meteorological Summaries (SI Units).

CDS #2-75 - Normals of Heating Degree-Days Below 18°C for Stations listed in the "Monthly Summary of Degree-Days".

CDS #3-75 - A Wall Penetration Map of Canada.

(g) Climatological Circular Series

CLI #1-75 - An Index to Storm Rainfall in Canada.

CLI #2-75 - Storm Agnes in the Lake Ontario Basin, June 20-25, 1972 (An IFYGL Study).

CLI #3-75 - An Inventory of Climatic Data Sheets and Documentation Sheets.

Climatological Studies

Thomas, M.K.: Recent Climatic Fluctuations in Canada. Climatological Studies No. 28, Environment Canada, Atmospheric Environment Service, Toronto. 1975. 92 p.

Manuals

MANNUPP - Manual of Upper Air Observations, July 1975.

METNET - Data Acquisition Reference Manual Planning of Meteorological Observational Networks, March 1975.

Tables

Psychrometric Tables (Interim Edition) 6 volumes.

AES Conversion Tables (Conversion to SI).

Other

Hourly Data Summaries - Kamloops A, and Thompson A

Canadian Normals Volume 3 - Wind.

VII GEODYNAMICS

Compiled by: G. Ranalli
Carleton University

1. Structure and Organization of the International Geodynamics Project

2. Canadian Contributions to the Geodynamics Project

The Geodynamics Project is an international research program coordinated by the Inter-Union Commission on Geodynamics (ICG). The ICG has been established by the International Council of Scientific Unions at the request of the International Union of Geodesy and Geophysics and of the International Union of Geological Sciences. The project is in some respects an offshoot of the Upper Mantle Project, and at present the year 1979 is envisaged as the completion date. The aim of the Geodynamics Project is the elucidation of the past and present dynamics of the solid Earth, with emphasis on internal processes affecting surface features. Canadian participation in the Geodynamics Project is coordinated by the Canadian Subcommittee for Geodynamics. The purpose of this note is to acquaint interested persons with the structure and organization of the Geodynamics Project, with the main Canadian objectives, and with some of the Subcommittee activities during 1974/75. Because of its multi-disciplinary nature, much of the Canadian contribution to the project is covered under the appropriate discipline elsewhere in this Bulletin, and therefore only information of a general character will be given here.

1. Structure and Organization of the International Geodynamics Project

The ICG is organized into ten working groups. The topic of interest, chairman, and Canadian members (if any) of each working group are listed here:

Working Group 1: Geodynamics of the Western Pacific-Indonesian Region

Chairman: S. Uyeda, Earthquake Research Institute, University of Tokyo, Tokyo 113, Japan

Working Group 2: Geodynamics of the Eastern Pacific Region, Caribbean and Scotia Arcs

Chairman: R.P.R. Cabré, S.J., Observatorio San Calixto, Casilla 5939, La Paz, Bolivia.
Canadian members: R.L. Chase, Department of Geological Sciences, University of British Columbia, Vancouver, British Columbia; H. Gabrielse, Geological Survey of Canada, Vancouver, British Columbia.

Working Group 3: Geodynamics of the Alpine-Mediterranean Region

Chairman: H. Berckhemer, Institut fur Meteorologie und Geophysik der Universitat, Feldbergstrasse 47, 6 - Frankfurt a.M., FRG.

Working Group 4: Geodynamics of Continental and Oceanic Rifts

Chairman: G. Palmason, National Energy Authority, Laugavegur 116, Reykjavik, Iceland
Canadian member: F. Aumento, Department of Geology, Dalhousie University, Halifax, N.S.

Working Group 5: Properties and Processes in the Earth's Interior

Chairman: O.L. Anderson, Institute of Geophysics and Planetary Physics, University of California, Los Angeles, California 90024, U.S.A.
Canadian members: W.S. Fyfe, Department of Geology, University of Western Ontario, London, Ontario; M.G. Rochester, Department of Physics, Memorial University of Newfoundland, St. John's, Newfoundland

Working Group 6: Geodynamics of the Himalayan - Indonesian Region

Chairman: H. Narain, National Geophysical Research Institute, Hyderabad, India

Working Group 7: Dynamics of Plate Interiors

Chairman: R.I. Walcott, Geophysics Division, D.S.I.R., Wellington, New Zealand
Canadian member: D.I. Gough, Institute of Earth and Planetary Physics, University of Alberta, Edmonton, Alberta

Working Group 8: Connections between Oceanic and Continental Structures

Chairman: M.H.P. Bott, Department of Geological Sciences, University of Durham, Durham, U.K.
Canadian member: C. Keen, Atlantic Geoscience Centre, Bedford Institute, Dartmouth, N.S.

Working Group 9: History and Interactions of Tectonic, Metamorphic and Magmatic Processes

Chairman: V.V. Beloussov, Soviet Geophysical Committee, Molodezhnaya 3, Moscow B-296, USSR
Canadian members: R.L. Armstrong, Department of Geological Sciences, University of British Columbia, Vancouver, B.C.; N. Rast, Department of Geology, University of New Brunswick, Fredericton, N.B.

Working Group 10: Global Syntheses and Paleoreconstruction

Chairman: D.A. Valencio, Dept. de Ciencias Geologicas, Ciudad Universitaria, Universidade de Buenos Aires, Buenos Aires, Argentina

The President of ICG is A.L. Hales of the Research School of Earth Sciences, Australian National University, Canberra, Australia; the Secretary-General is R.D. Russell of the Department of Geophysics, University of British Columbia, Vancouver, B.C.

2. Canadian Contributions to the Geodynamics Project

Approximately 50 countries have established National Committees or Correspondents and are involved in the Geodynamics Project. The Canadian Subcommittee for Geodynamics, reporting to the Canadian National Committee for the International Union of Geodesy and Geophysics and to the National Advisory Committee on Research in the Geological Sciences, coordinates Canadian participation to the Project. To focus and to briefly survey the Canadian contributions, the Subcommittee has published three reports. The most recent one (Third Report by the Canadian Geodynamics Subcommittee, Ottawa, March 1975) reviews the present status and future orientation of the Canadian program for geodynamics. It outlines the Canadian effort within the framework of five main areas of research:

(1) Global dynamics - including studies of rotational dynamics, the gravity and magnetic fields, and core dynamics;

(2) Short-term motions and deep-seated causes of motion - including studies of earth tides, postglacial uplift, precursory phenomena of earthquakes, recent seismicity, and rheology and dynamics of the lithosphere and upper mantle;

(3) Crustal evolution - analysis of tectonic and compositional evolution of the lithosphere based on comparative studies of the record of Archean, Proterozoic and Phanerozoic rocks, including the role of lithosphere plate motions, geochemical evolution, and the nature and significance of variations in physical and chemical properties of minerals and mineral assemblages from the crust and upper mantle;

(4) Phanerozoic fold belts and their adjacent oceans - determination of the volcanic, sedimentary, and metamorphic history, time-space relationships, and geotectonic implications of the Appalachian, Cordilleran and Innuitian fold belts and their adjacent ocean basins; and

(5) Canadian Shield - determination of the nature and tectonic significance of the principal subdivisions of the Canadian Shield.

The Third Report is available upon request from G. Ranalli, Secretary, Canadian Subcommittee for Geodynamics, Department of Geology, Carleton University, Ottawa, Ontario, K1S 5B6.

Several important events have taken place during 1974/75. The Geodynamics Subcommittee has sponsored a Symposium on the Grenville Province in Ottawa (February 1974), the highlights of which have been published in Geoscience Canada and Geotimes. Working Groups 1 and 2 have convened a geodynamics symposium at the 13th Pacific Science Congress in Vancouver (August 1975). More recently, the Geodynamics Subcommittee has organized a Symposium in Ottawa on "The Hudsonian Orogeny and Plate Tectonics" (March 1976).

On the international front, the Inter-Union Commission on Geodynamics held its annual meeting concurrently with the 16th General Assembly of the International Union of Geodesy and Geophysics in Grenoble, August-September 1975. This meeting was particularly important because it marked the mid-term of the Geodynamics Project (running from 1971 to 1979). Participating countries were asked to present mid-term reports on activities and future developments related to geodynamics. The Third Report by the Canadian Geodynamics Subcommittee was the official Canadian submission to the ICG. At the same meeting the Commission elected a Canadian, R.D. Russell of the University of British Columbia, to the position of Secretary-General.

VIII EXPLORATION GEOPHYSICS

Compiled by: G.F. West

1. Introduction

This section attempts to provide a listing of non-confidential research in exploration geophysics in Canada completed or in progress during 1975. The function of the report is to provide those interested with information about current research projects which have not yet reached the publication stage. It is not to provide statistical data on the amount of work going on. The report is definitely not comprehensive as all submissions are voluntary. Virtually no research in petroleum geophysics by industry is reported here. However, the reporting of University and Federal Government projects is reasonably complete. Mining geophysical R and D is reported by several manufacturing and service companies, but not by exploration companies.

The definition of research vis-a-vis development on the one hand and exploration on the other is very fuzzy. The editor has deleted or shortened some submissions about new instruments, where the material will be included in P.J. Hood's annual review in Canadian Mining Journal. It has been customary to list new public geophysical surveys of an exploration nature such as are done by the Department of Energy, Mines and Resources. However, there are increasing numbers of surveys being done by provincial bodies and only a few are listed here.

2. University Research

(a) University of British Columbia *(R.M. Clowes, Department of Geophysics and Astronomy)*

R.A. Wiggins (now at Western Geophysical Company, Houston) and personnel of Western Geophysical have completed a study of the use of the general linear inverse method for automated residual statics analysis.

When estimating near-surface time anomalies it is commonly assumed that apparent seismic reflection times are comprised of the sum of "surface-consistent" source and receiver static terms, "sub-surface-consistent" structure and residual NMO terms, and random noise. Use of

these assumptions leads to a set of linear equations whose solution-parameters consist of spatially varying statics, NMO, and structural terms that best match (in a least-squares sense) the redundant travel-time observations from multifold seismic data. DCP travel-time data are insufficient to allow a completely determinate solution; consequently, conventional direct methods of solution are not applicable.

Guided by the general linear-inverse methodology, we treat the problem using the Gauss-Seidel iteration procedure. In this approach, both the observed travel-time data and solution parameters are "spectrally decomposed" analogously to the ordinary Fourier frequency-decomposition of time series. The component statics solutions are almost sinusoidal along the profile direction, and are characterized by specific spatial wavelengths. A property of this decomposition is that, given a gross estimate of the uncertainty (standard deviation) in the observations, we can assess the accuracy of the statics solution as a function of wavelength. In particular, statics corrections having spatial wavelengths much shorter than a cable-length have relatively small uncertainties whereas long-wavelength corrections have much larger standard deviations and are thus poorly determined.

By combining the linear inverse analysis with the Gauss-Seidel iterative approach we can know in advance how many iterations are required to obtain a given reduction of the statics error as a function of wavelength. Errors in shorter-wavelength corrections converge rapidly to zero while longer-wavelength corrections converge slowly or not at all. However, because those longer-wavelength corrections can be estimated only with large uncertainty, it is desirable to exclude them from the statics solution by (1) limiting the number of iteration cycles, (2) introducing a "white noise" component in the least-squares formulation, or (3) pre-conditioning the travel-time observations.

Application of these combined tools yields demonstrable improvement in both synthetic and field-data sections and affords deeper understanding of the nature of the residual statics problem.

L.R. Lines and T.J. Ulrych are proceeding with a determination of various seismic deconvolution operators by estimating a seismic source wavelet and subsequently designing an appropriate inverse filter which converts the wavelet to a spike. Seismic wavelets and deconvolution operators must be estimated in a time-adaptive sense due to the non-stationarity of the seismic trace. The wavelet estimation methods considered in this study use either the assumption of a minimum phase wavelet and a random reflectivity function or the assumption that the wavelet cepstrum is readily separable from the cepstrum of the seismic trace. The former assumption is required in using the Wilbert transform and Wiener-Levinson wavelet estimations, whereas the latter assumption is used in homomorphic deconvolution. These wavelet estimates can be used in the design of multichannel Wiener and Kalman deconvolution operators. Multichannel usage of homomorphic deconvolution can also be implemented through various types of cepstral stacking.

In the designing of time adaptive deconvolution filters, the autocorrelation function can be used to monitor the nonstationarity of the seismic trace. The estimation of the autocorrelation function, which is necessary in the computation of least-squares inverse filters, can be performed in an optimum fashion by using the maximum entropy method. Although the first few lobes of an autocorrelation function calculated in this manner do not significantly differ from conventional estimates, the calculation of a continuously time-adapting filter, as suggested by Riley and Borg (1972), requir-s the maximum entropy approach. The performance of various wavelet estimators and inverse filters is being compared for real and synthetic seismic data.

K.D. Aldridge is applying dynamic programming techniques to find optimum reward policies in decision making associated with geophysical prospecting. The principle of dynamic programming can be summarized by the statement that the best way to proceed in any situation is independent of how the present situation developed. For illustration this principle has been applied to the following geophysical action timing problem. A known number of prospects will be presented over some period of time. At the presentation of each prospect a decision must be made to drill the prospect or continue on to prospects of unknown merit. If a probability distribution for the merit of prospects is assumed our model provides a simple decision criterion: if the merit of the prospect at hand is greater than some value provided by the model, the prospect is drilled, otherwise it is better to continue to the next prospect.

(b) **University of Calgary** *(K. Duckworth, Geology Department)*

Projects under investigation in 1975

(i) Comparison of electrode arrays

This involved an examination of the performance of a wide selection of electrode arrays. A joint investigation of resistivity and induced polarization responses was undertaken using a scale model approach. The work has been described in "Evaluation of Some of the Electrode Arrays Used in Induced Polarization and Resistivity Surveying for their Relative Responses, an M.Sc. Thesis by A.S. Saydam, April (1975).

(ii) Electromagnetic Depth Sounding

Development of a depth sounding technique using source orientation as the sounding variable was carried to the stage of field tests. The technique was tested in Saskatchewan and Northern Australia.

(iii) Structural Investigations in Severe Terrain. An investigation of the limitations of the Gravity Method

A detailed gravity survey of an area on the front range of the Rocky Mountains was performed with a view to evaluating the ability of this type of survey to provide structural information where severe topographic noise is encountered.

(c) **Université Laval** *(M.K. Seguin)*

Spectrométrie des rayons gammas:

M.K. Séguin a mis au point une technique relativement simple du traitement digitalisé de données de spectrométrie aéro-et héliportées des rayons gammas. En collaboration avec M.A. Côté (ingénieur physicien) et A. Grenon (étudiant en maîtrise), on a mis au point un système de traduction de la version analogique à une version digitale des données acquises sur ruban magnétique standard à 9 pistes. Les réductions effectuées sur les données radiométriques observées comprennent l'extraction du mouvement propre, les variations dues à l'altitude de vol, l'effet d'absorption dans l'air, les variations climatiques (surtout le degré d'humidité) et les variations de la composition du mort-terrain. 3 programmes mathématiques de pré-traitement et 5 programmes de traitement proprement dit des données permettent d'obtenir, par affichage numérique, 6 ou 8 traces à la sortie, à savoir l'altitude de vol, le nombre de comptes de radiations totales, de radiations dues au potassium (K), au thorium (Th) et à l'uranium (U). Les rapports Th/K, U/K et U/Th sont alors calculés et un système de filtrage numérique adéquat (convolution) permet un adoucissement nécessaire et adéquat des profils obtenus. Quelque 14,000 Km linéaires de levés aéroradiométriques d'un secteur de la Gaspésie et de la région des monts Otish ont été traités avec un ordinateur IBM 370/158 de la manière décrite plus haut. La production de cette grande masse de données a donné lieu à une amélioration constante et une optimisation finale du processus de traitement alors en cours.

(d) **McGill University** *(Department of Mining and Metallurgy)*

The following projects were current during 1975:

(a) Etude des parametres affectant l'impédance électrique des certaines métaux et minéraux *(Roger Lambert)*

The impedance of various metals and minerals, including graphite, was measured in the frequency domain (0.001-1000 Hz) both in the laboratory and field. A new model was developed, based on electrochemical parameters and taking into account the measuring electrode arrangement and resistivity of the host medium as well as the target parameters, which replaces the Warburg (ionic diffusion) impedance model.

(b) Homomorphic deconvolution of seismic data to obtain crustal attenuation-dispersion response *(Stephan Mercure and O.G. Jensen)*

The high-pass portion of the complex cepstrum obtained by the common homomorphic transformation (Z-transform, logarithm, inverse Z-transform) of seismograms has been shown to contain a convolution of the undistorted crustal layer attenuation-dispersion functions. Recognition and deconvolution of such functions should provide an additional geological parameter, formation Q, useful to the interpretation of sedimentary domains. A pilot analysis of marine seismic data obtained over the Laurentian Core south of eastern Newfoundland have shown that the technique is promising.

(c) Geological mapping in the St. Lawrence Lowlands *(David Williams)*

Geophysical methods, including VLF, tellurics and magnetics, have been combined with geology to outline the complex fault system in the Ottawa and St. Lawrence valley sediments. Considerable new and modified geological structures have been postulated. A possible control of the Monteregian intrusives may be indicated and the association of sedimentary type base metal deposits with the structure considered.

(d) Radon emanation technique of uranium exploration *(N.M. Soonawala)*

Field data were collected from granite intrusives and quartzite-volcanic zones in Quebec, Saskatchewan and Labrador. A diffusion column was constructed to determine the emanation concentration over different sources and a computer program developed to solve the radon diffusion equation by iteration for different source geometries.

(e) Laboratory modelling *(Jacques Liard)*

A complete bench model system has been constructed for scaled magnetic and electromagnetic anomalies simulating complete regions or isolated targets. A gravity anomaly simulator, using light-reflecting surfaces and moving photocells, is near completion. The model system is already in use for laboratory instruction and graduate research.

(f) Geophysical interpretation of Bay of Fundy - Gulf of Maine region *(Russell Parrott)*

Data has been compiled for various sources to provide $1/10^6$ base maps of magnetic and gravity data of this area. Regional interpretation of these data has been completed and models, modified from previous interpretations, have been checked by computer.

(g) Wave-tilt EM applications to permafrost exploration *(Brian Powell and O.G. Jensen)*

Analysis has now been completed of the results of the wave-tilt EM measurements obtained by the GSC during the winter and summer of 1973 over permafrost in the Fort Simpson area of the Mackenzie River Valley. Using traditional geophysical methods and drilling for control, it has been demonstrated that accurate estimates of the depth to the top of permafrost layer as well as a measure of the resistivity contrast between the permafrost and soil overburden can be obtained. A permafrost index has been obtained which appears to correlate better than any other geophysical measure with permafrost occurrence. The wave-tilt method has been found especially promising in delineation of permafrost occurrence in the discontinuous zones, particularly in view of the rapidity of coverage possible using the EM16-R type instrument.

(h) Analysis of high-sensitivity aeromagnetic data *(Dennis Teskey)*

A study of high-sensitivity aeromagnetic data by various digital processes is being carried out with a view to increasing the depth range. The Kirkland Lake survey area, where other controls are available, is being used for initial studies.

(i) Survey technique for mapping bedrock *(W.M. Telford)*

Preliminary tests have been made to develop a fast yield technique for mapping bedrock topography employing a combination of VLF, telluric, magnetotelluric and resistivity methods.

(j) Well logging in mineral holes *(W.M. Telford, Alex Becker, Jean Roy et al.)*

In a joint program with Ecole Polytechnique, sponsored by the Dept. Richesses Naturelles, Québec, through MERI, multiple geophysical measurements - SP, resistivity, IP and tellurics have been carried out downhole in selected mineralized areas (mainly base metals) at Lingwick, P.Q. and Sudbury, Ont. Additional techniques - EM, magnetics, radio-activity are to be added to the logging suite.

(e) Ecole Polytechnique *(Department of Mineral Engineering)*

The following projects were current during 1974-75:

i) Geophysical Prospecting in Diamond Drill Holes *(C.W. Faessler, J. Roy, D. Doucet)*

A number of field tests with our equipment for electrical and IP downhole measurements were undertaken on behalf of the G.S.C. and M.R.N.Q. The equipment performed satisfactorily up to the maximum depth tested which was of the order of 2000'. The results of the trials will in due course be published by the sponsors of the program.

ii) Multifrequency EM Mapping *(A. Becker, C. St-Hillaire)*

It appears that carefully collected airborne multifrequency electromagnetic data can be interpreted to obtain overburden thickness and conductivity parameters. The results relating to the interpretation of some five miles of TRIDEM AEM data compare favourably with those obtained with the seismic method. This has been described in the M.Sc.A. Thesis of C. St-Hillaire, "Cartographie Electromagnétique Aéroportée."

iii) Inductive measurement of electrical conductivity *(A. Becker, R. Bazinet)*

A simple apparatus for the measurement of resistance change of a coil upon sample insertion proved quite satisfactory for the measurement of the electrical conductivity of sulphide minerals. The audio frequency measurements can serve as an aid to the interpretation of field EM data. A description of this work is in the M.Sc.A. Thesis of R. Bazinet, Mesure Inductive de la conductivité électrique des roches.

iv) Magneto-telluric measurements *(Pham Van Ngoc, D. Boyer, M. Chouteau, D. Lefebvre)*

This program of research carried out in collaboration with AMOK and MNRQ encompassed data collection, analysis and interpretation in Saskatchewan and Quebec. There is no doubt that the method can be successfully applied to structural mapping.

(f) University of Toronto *(Department of Physics)*

i) Magnetometric resistivity (MMR) studies *(R.N. Edwards)*

The electrical prospecting method, known as the Magnetometric Resistivity (MMR) method, is based on the measurement of the low level (about 100 milligamma), low frequency (1-5 Hz) magnetic fields associated with non-inductive current flow in the ground. The horizontal component of the magnetic field is measured along profiles which are at right angles to a baseline joining two widely separated current electrodes.

Edwards and Howell (1976, in press, Geophysics) describe a field test of the method conducted in the south-western United States. A steep, faulted contact between basement rocks of differing resistivity, covered by 500 m of volcanics and sediments, was mapped.

Theoretically, vertical MMR anomalies may be computed analytically for a number of structures. Edwards (1975) and Lee have assembled solutions to the quarter space, the thick and thin dike, the dipping dike, the half cylinder (trench), the half sphere (bedrock depression) and Stefanescu's α-medium. Mr. Lee's work appears in an M.Sc. Thesis entitled "On the computational aspects of MMR and its application to the mapping of a sink" (1975).

ii) Seismoelectric effect

Fernandez-Tomé (Studies on the seismoelectric effect, M.Sc. Thesis, Toronto, 1975) reports that a new mathematical theory has been developed to explain the seismoelectric effect. The phenomenon has received little attention in the literature since its discovery by Ivanov in 1939. The theory relates electrokinetics and seismic wave propagation in porous media. Use is made of Biot's theory on seismic propagation in porous media. It is shown that the following factors influence the measured voltages in the ground when a seismic wave passes by:

1. the degree of ionization of the pore saturant
2. the amplitude of the seismic disturbance
3. the frequency content of the disturbance, especially when the inelasticity of the skeletal frame is taken into account
4. the porosity of the media involved

The final expression for the potential agrees well with experimental results.

iii) EM Systems *(Y. Lamontagne and G.F. West)*

A wide-band, time-domain, ground EM system has been developed. The design objective is to obtain, with a practicable portable field instrument, precise broad spectrum EM data in a form which can facilitate quantitative interpretation. The transmitter consists of a precisely triangular, low-frequency, current waveform in a large horizontal loop. The receiver is a coil and sampler-averager which measures the time-derivative of the magnetic field at several binary related time delays after the transition time of the primary waveform. The receiver maps the field of the transmitter in the region being prospected. The initial system (UTEM I) employed 8 measuring channels and a 30 Hz base frequency. A new version (UTEM II) is under construction as a joint project with Geonics Ltd. It has 10 measuring channels, a variable base frequency and a complete digital data recording system.

Field surveys with UTEM I have demonstrated the practicality of the instrument system and the interpretational value of broadband data. The EM response of the bedrock conductors surveyed exhibited three types of response: at very short delay times, the response was primarily one of current gathering from overburden or a halo zone; at intermediate delays, it was a simple inductive response and at very long times, there were anomalous effects due to induced polarization or magnetic induction.

This project is being continued for two years with support from a consortium of companies. Details of this work are given by Y. Lamontagne, 1975, "Application of Wide-band, Time-domain, EM measurements in Mineral Exploration", Ph.D. Thesis, University of Toronto.

(g) University of Western Ontario *(A.E. Beck, Department of Geophysics)*

i) Time series analysis *(Mereu)*

A new deconvolution and wave shaping time-domain digital filter was designed which is capable of molding any given wavelet "exactly" into any desired waveform. This filter differs from other time-domain inverse filters in that (a) no equations are solved, (b) no Z transform polynomials are divided, (c) it can produce an error-free output with a "finite" number of weights. Its design is carried out entirely in the time-domain by a series of successive convolution operations which begin with the original digitized values of wavelet t be deconvolved. These operations have the effect of slipping sets of zeros in between the data points to produce a sequence of widely spaced spikes. The filter is then truncated and normalized, such that its output contains only one spike of unit amplitude. The final step of the wave-shaping design is carried out by convolving the spiking filter with the desired output. Minimum, maximum and mixed delay wavelets may be handled with equal ease. Since the input parameters needed to design this filter are identical to those needed to design the Weiner filter, and since the desired output can be of any shape, the filter has wide applications to problems involving signal contraction, enhancement and prediction.

The following projects are also underway:

ii) Use of radiometric exploration methods as an exploration tool (L.W. Matthews, A.E. Beck)

iii) Gamma ray spectral techniques in exploration methods (M. Yusof, A. Hayatsu)

iv) Geophysical investigation of a possible extension of the Muskox intrusion (J.A. McCance, A.E. Beck)

v) Use of the finite element method in exploration seismology (F.K. Maxwell, L. Mansinha)

3. Government Research

(a) Department of Energy, Mines and Resources - *Geological Survey of Canada, Ottawa, Ontario*

i) Terrain Geophysics Program (L.S. Collett)

Due to a reorganization in the Resource Geophysics and Geochemistry Division in 1975, the Terrain Geophysics Program now comprises one of the three programs in the R.G.G. Division. The Terrain Geophysics Program essentially consists of the Electrical and Seismic Method Sections. The head of the TGP is Mr. L.S. Collett, who also remains head of the Electrical Methods, and Dr. J.A. Hunter has been made head of the Seismic Methods. The purpose of the reorganization is to meet the mission requirements of the division as they relate to planning, budgeting, management and administration of projects.

Electrical Methods

1. *Assessing Airborne Electromagnetic Systems Applied to Overburden Mapping*
Tridem System (Scintrex)

To test the concept of a variable-frequency EM system for mapping purposes, a contract was arranged in 1974 with Scintrex Ltd. to fly the Tridem System in the Hawkesbury and Timmins areas. The system records the in-phase and out-of-phase components of the secondary magnetic fields of 500, 2000 and 8000 Hz. Dr. A. Becker, Mineral Exploration Research Institute, Montreal, has been contracted to interpret the data over the Hawkesbury test site. The Timmins data is being interpreted by Drs. A.K. Sinha and A.P. Annan, GSC.

Quadrem System (McPhar)

Arrangements have been made with McPhar Instrument Corporation to fly the five frequency Quadrem EM System over test sites at Hawkesbury, Breckenridge and Cavendish. The system records the out-of-phase magnetic components of 95, 285, 855, 2565 and 7695 Hz. A contract has been awarded to Dr. M.K. Ghosh, Geoprobe Ltd., to assess the performance of the Quadrem System and to interpret the data for the three test sites.

2. *Permafrost Geophysics*

Dr. W.J. Scott carried out IP and VLF measurements at Fort Simpson and Involuted Hill (Tuktoyaktuk) test sites to evaluate the response levels from ice-bonded clays.

In marine permafrost investigations, Dr. Scott developed a preliminary version of a marine resistivity system based on digital recording of resistivity data and incorporating a navigational system. The system was used in field trials to map sub-bottom resistivity variations in a lake on the Tuktoyaktuk Peninsula. Further development is planned for the system.

Radar sounding at Tuktoyaktuk (PCSP base) and Involuted Hill were carried out in April, 1975, by Dr. A.P. Annan, J.L. Davis and Dr. W.J. Scott. The pulse system was supplied by Geophysical Survey Systems Inc., Burlington, Mass. Reflection and wide

angle reflection and refraction techniques were employed. Radar investigations will be carried out in the Creswell Bay area, Somerset Island, along the Eastern Arctic pipeline route in April, 1976.

3. Borehole Exploration

A review of borehole geophysics applied to metallic mineral prospecting was published during 1975 (GSC Paper 75-31). Mr. A.V. Dyck with the cooperation of industry (Amax, Canex Placer, Cominco and Noranda) continued borehole measurements using IP, EM and magnetics in the Sudbury and Bathurst areas during 1975. Also some experimental multifrequency EM and VLF techniques were assessed during the year.

4. Resource Evaluation

During the summer of 1975, Dr. W.J. Scott surveyed three sulphides deposits in the N.W.T. with a wide range of electrical techniques, including SP, IP and VLF resistivity. The purpose of the study was to assess the influence of permafrost on geophysical responses and to follow-up geochemical anomalies.

5. Soil Moisture Investigations

A study of the feasibility of determining soil moisture content in the top two metres of soil is being carried out at the GSC in cooperation with CCRS and Agriculture Canada. The relationship between soil moisture and dielectric constant is being verified in laboratory and field measurements for various soil types. Dr. J.L. Davis has developed a wide-band TDR (Time Domain Reflectometer) system (10 MHz-1 GHz) for measuring dielectric constant in coaxial tube and balanced parallel transmission lines (in situ). Dr. I.J. Katsube is measuring the electrical characteristics of soils in the laboratory. Dr. A.P. Annan and J.L. Davis are applying radar techniques in this study. If the relationship between soil moisture and dielectric constant is significant, the development of a non-contacting system will be the next phase of the study. The influence of soil moisture on gamma ray attenuation effects is also being investigated.

6. Geophysical Test Sites

A number of investigations have been carried out to select appropriate sites for calibrating and testing the performance of various types of geophysical equipment.

7. Laboratory Investigations on Electrical Properties of Soils and Rocks (T.J. Katsube)

Laboratory Facilities

An automatic electrical rock property measuring system, which is controlled by a mini-computer, has been developed for measurements at frequencies from 10^{-2} to 10^{-6} Hz. The capabilities for the 10^{6} - 10^{7} Hz range is under construction at present. Graphic display of Cole-Cole diagrams accompany the system. A new data analysis technique which is based on a "Three Electrical Polarization Mechanism" model (Katsube, 1975), and which makes use of 9 parameters, is being used to analyse and characterize the rock samples which have been measured.

Applications to Mineral Exploration

Electrical properties of rocks depend upon the type of water used and how they were saturated when being prepared for measurement. Basic studies on the standardization of the measurement procedures is being carried out on request by industry. More than 70 serpentinite samples have been measured and are being analysed at present, mainly on request by industry and universities. Recent studies have indicated a possibility of differentiating the grain size of conductive minerals in rocks. This subject is being pursued in view of seeing a major development in IP differentiation of sulphide minerals.

Applications to Engineering Geophysics

More than 120 measurements have been carried out on more than 40 permafrost samples, and presently the data is being analysed. Studies on sand to clay rich soils is being carried out to clarify the electrical mechanisms involving the moisture content. This study is being carried out to aid in determining an optimum electromagnetic system for remote sensing of soil moisture. On request from the University of Quebec, electrical measurements on serpentinite and acidic rocks have been carried out to determine whether porosity, permeability, resistance to heat and radioactive damage in rocks can be measured by electrical methods. This information is required for selecting radioactive waste disposal sites.

8. Applied Theoretical EM Studies

Airborne EM Studies

The effects of altitude of the aircraft and displacement currents on airborne E-Phase anomalies were studied theoretically using homogeneous and layered models. A paper "Effect of altitude and displacement currents to plane wave EM fields" was presented at the 45th Annual SEG Conference at Denver, Colorado (October 12-16, 1975) and is currently under publication in Geophysics.

Ground EM Studies

Determination of sea-ice thickness: field testing to determine the usefulness of two e.m. instruments, Geonics EM-15 and Apex double-dipole system for determining sea-ice thickness was undertaken in the spring of 1975 over the frozen Kugmallit Bay near Tuktoyaktuk, N.W.T. The instruments were used in the differential mode with two coil configurations. The results are quite encouraging.

EM sounding of permafrost: studies on multifrequency e.m. sounding of permafrost terrains using the mutual coupling of two small loops were completed in 1975. One paper, "Determination of ground constants of permafrost terrains by an electromagnetic method", is to be published in the March, 1976, issue of Canadian Journal of Earth Sciences.

9. Satellite Weather Receiver

In cooperation with the Polar Continental Shelf Project (G.D. Hobson), Mr. S. Washkurak has been developing a satellite weather receiver to obtain hard copies of weather information to aid airborne and ship survey work in the Arctic. Portable stations were set up at Tuktoyaktuk and Resolute Bay during the summer, 1975. This weather information, since it is received in real time, is proving to be a real economic benefit to planning local survey logistics on a daily basis. Improvements to the equipment are still being made. During 1976, it is planned to put one of these receiver stations at the base camp for the Skyvan gamma spectrometer operations.

ii) Regional Geophysics Program *(P.J. Hood)*

An annual review of trends and developments in mining geophysics was published in the Canadian Mining Journal for the eleventh year in succession by P.J. Hood. The review for 1974 contained tabulations of airborne geophysical systems offered for contract surveys, commercially-available drillhole logging and induced polarization equipment.

1. Aeromagnetic Surveys

A total of 191 aeromagnetic maps were published by the Geological Survey of Canada during 1975. Of these, 96 were 1:25,000, 86 were one-mile, and nine were 1:250,000 aeromagnetic maps. The total line mileage of aeromagnetic survey flown in Canada from 1947 to the end of 1975 is 4,654,410 line miles, of which 146,544 line miles were flown during 1975, and this has resulted in the magnetic survey coverage for Canada shown in Figure 1. Also included in Figure 1, is the shipborne coverage which resulted from the survey operations of the Canadian Hydrographic Serv.

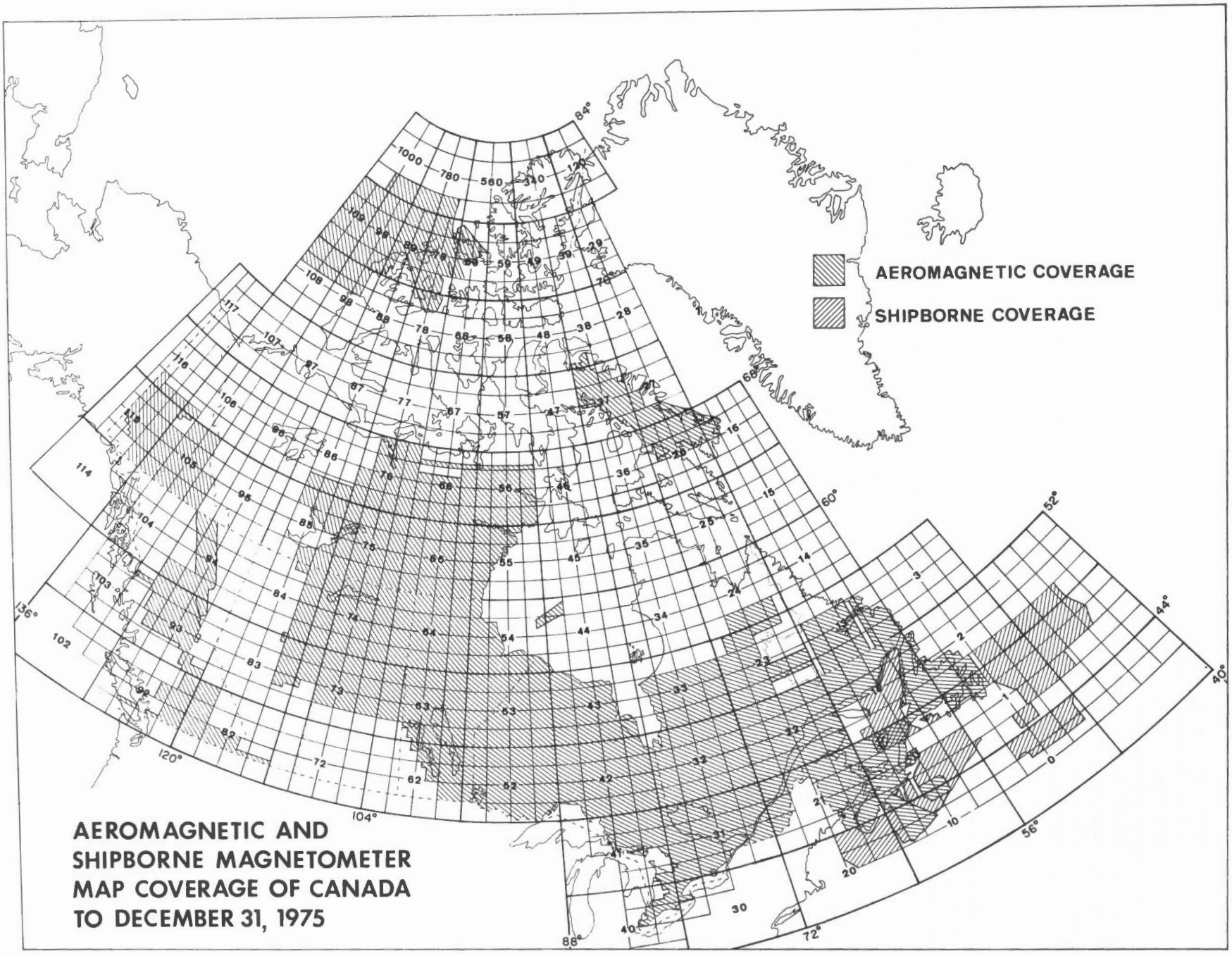


Figure 1. Aeromagnetic and shipborne magnetometer map coverage of Canada to December 31, 1975.

2. *Aeromagnetic Interpretation - Appalachia (P.H. McGrath)*

P.H. McGrath has devised computer programs to produce calculated vertical gradient and residual total field maps of the Bathurst, N.B., high resolution aeromagnetic survey flow in 1972 by GSC Beechcraft aircraft. The resultant processed maps will be put on open file. The ground magnetic investigation of the Roberts Arm area, Newfoundland, begun in 1974 was completed in 1975.

3. *High Resolution Aeromagnetic Survey Project*

The inboard vertical gradiometer system installed on the GSC Beechcraft aircraft by a group headed by P. Sawatsky was extensively test flown during the early part of 1975 in order to improve the compensation figure of merit as much as possible and to debug the system. Two vertical gradient surveys have now been carried out in the vicinity of Ottawa to obtain experimental results for evaluation by L.J. Kornick. The first survey was carried out in the White Lake area some 40 miles west of Ottawa and the second survey covered the Carleton Place map sheet (31F/1). From an analysis of the results it is readily apparent that there is a great deal more detailed information contained in the vertical gradient compared to the total field data. The results obtained to date also illustrate well the fact that vertical gradient anomalies are always narrower than the concomitant total field anomalies, and this important property results in a much better resolution of individual rock formations by the vertical gradient map.

4. *Ocean Aeromagnetics*

The cooperative aeromagnetic project with the National Aeronautical Establishment was continued during 1975 and survey operations were carried out in the high Arctic during the period April 1-12, 1975. The North Star aircraft of the National Aeronautical Establishment which is equipped with an inboard digital-recording cesium magnetometer system was used as the survey platform.

There were several objectives for the field operation in the high Arctic. The first objective was to carry out an aeromagnetic reconnaissance of the continental shelf of northern Ellesmere and Nansen Sound to ascertain whether a substantial thickness of sediments exists in those areas which would make them of interest for petroleum exploration. A second objective was to obtain magnetic survey evidence to evaluate the hypothesis that the Alpha Cordillera is part of the global mid-oceanic ridge system. In addition, the 1975 operation was an exercise which would provide experience to those involved in the logistical requirements for further airborne surveys in the Arctic Ocean using the new Convair 580 aircraft of the National Aeronautical Establishment, which is the replacement for the North Star aircraft. The results of earlier work in the Davis Strait and adjacent areas was published in Memoir 4 of the ISPG (Hood and Bower, 1975).

5. *ERTS Imagery Evaluation (V.R. Slaney)*

This project in addition to building up a file of usable ERTS imagery of Canada is being carried out to assess the geological applications of ERTS imagery, and provide advice and assistance in its use.

6. *Seismic - Arctic Continental Shelf and Continental Margin (A. Overton)*

This project is carried out in cooperation with the Earth Physics Branch and the Institute of Sedimentary and Petroleum Geology to define the regional and structural geology of the coastal and continental shelf regions of Arctic Canada.

iii) Seismic Methods

The main thrust of the use of seismic methods during 1975 has been applied to the Arctic in on-shore and off-shore environments in aid of exploration and engineering problems. Current research being carried out at the Geological Survey of Canada is listed as follows:

1. Mapping permafrost in the Beaufort Sea (H.A. MauAuly, J.A. Hunter, G.D. Hobson)

Several oil companies have made available to the GSC over 8000 line miles of seismic data for this study. From this data, a sub-bottom map of the thickness of sediments to the top of the permafrost has been compiled. Continuous permafrost and areas completely free of permafrost have been mapped. Interpretations of this data have been checked by refraction profiles and drill holes.

2. Thickness of permafrost in the Beaufort Sea (K.G. Neave)

The thickness of permafrost beneath the shelf of the southern Beaufort Sea has been investigated. High velocity seismic refraction events interpreted from the front-ends of industry reflection records have been correlated with frozen ground of high ice content. Because the ice-bonded layer offshore is relatively thin, strong attenuation of the seismic refracted energy occurs. The frozen layer thickness can be estimated from the attenuation rates. The exponential decay of refractor amplitude resulting from shear-wave radiation into the surrounding medium is governed by the shear-wave velocity in the surrounding medium as well as the layer thickness. Thickness estimates of the high velocity layer in offshore shelf areas vary between 10 and 40 metres. This work is supported by the Polar Continental Shelf Project.

3. Borehole seismic techniques (J.A. Hunter)

Field experiments to measure compressional and shear wave velocities to identify earth materials were conducted in exploration oil and gas wells in the Mackenzie Delta. The objective of the experiment is to identify the presence of gas hydrates beneath the base of permafrost. Close cooperation is maintained with the Geothermal Methods Section, Earth Physics Branch, to measure the thermal temperatures in these wells.

A three-component down-hole geophone system utilizing digital enhancement and non-explosive sources have been designed for shallow drill holes in permafrost and in surficial materials.

4. Sulphide mineral detection (J.A. Hunter and A. Overton)

Investigations using seismic velocity techniques to determine the structure of surface outcrop of ore bodies in permafrost have been conducted in the N.W.T. by J.A. Hunter.

Seismic techniques have been investigated by A. Overton for massive sulphide deposits in Bartouille Tp. and Levy Tp. in Quebec. A modified fan shooting technique was employed to measure the acoustic properties of the host rock and the sulphide orebody.

iv) Radiation Methods *(K.A. Richardson)*

Much of the activity of the Radiation Methods Section has been related to the Federal-Provincial Uranium Reconnaissance Program, either directly, as airborne gamma-ray spectrometry surveys, or as closely related follow-up activities.

The following activities were carried on in 1975:

1. Federal-Provincial Airborne Gamma-Ray Spectrometry Surveys (K.A. Richardson)

Airborne gamma-ray spectrometry surveys using the GSC Skyvan system, were flown in:

Saskatchewan	N.T.S. 64E, 64L, 74A, 74F, 74G, 74H
Manitoba	N.T.S. 64F, 64J, 64K, 64N, 64O
Ontario	N.T.S. 31F, 52G, 52J

These surveys were flown with 5 km line spacing, and results will be released as Open Files comprising 7 contour maps, (Total Count, K, eU, eTh, eU/eTh, eTH/K) and stacked profiles at a scale of 1:250,000.

Results of 1974 airborne gamma-ray spectrometry surveys were released in eight GSC Open Files during 1975.

O.F. 242	Wollaston Lake, Saskatchewan, 64L, SE$\frac{1}{4}$
257	Northern Saskatchewan, 64M, 74N, O, P
258	Hatchet Lake, Saskatchewan, Part of 64L
259	Black Lake, Saskatchewan, Part of 64M
262	Blind River, Ontario, 41J
264	Ottawa-Arnprior, Ontario, Part of 31F
269	Prince Edward Island, 11L
270	St. George's Basin and Burin Peninsula, Nfld., Parts of 1M and 12B
271	Havre St. Pierre, Quebec, 12L

2. *Contract Airborne Gamma-Ray Spectrometry Surveys (J.M. Carson)*

A Contract airborne gamma-ray spectrometry survey of approximately 1,000,000 km^2 area (400,000 mi^2) was flown in the Northwest Territories. East-west survey lines at a spacing of 15' of latitude (27 km) will be used to produce profile maps of total count, radio-element concentration, and ratios, for the area from 60° to 66°N, 112°W to Hudson Bay; and 66° to 68°N, 116°W to Foxe Basin.

3. *Ground Gamma-Ray Spectrometry (B.W. Charbonneau)*

Ground investigations in areas of earlier airborne gamma-ray spectrometer surveys, were made in the area of uraniferous granitic rocks in the northern part of the Blind River map sheet (N.T.S. 41J), western edge of the Ottawa-St. Lawrence Lowlands (N.T.S. 31F), and the northwestern edge of the Precambrian Shield in the N.W.T.

4. *Gamma-Ray Spectrometric Borehole Logging (P.G. Killeen)*

Tests were carried out in the Ottawa, Bancroft, Elliot Lake, and Sudbury areas to evaluate two commercial portable borehole gamma-ray spectrometer systems during the summer of 1975. This led to the development of specifications for state-of-the-art borehole spectrometry equipment to be used in borehole geophysical research related to uranium exploration. In conjunction with this research model holes will be constructed at Ottawa for calibration of borehole spectrometers.

5. *Gamma-Ray Spectrometry Laboratory (P.G. Killeen)*

The GSC gamma-ray spectrometry lab is presently undergoing modifications to interface the equipment to a minicomputer. When completed the computer will handle an automated NaI(Tl) counting system for routine K, U, and Th analyses, in addition to a GE(Li) detector system for research purposes.

(b) Ministry of Natural Resources, Geological Branch, Ontario Division of Mines

As an aid to regional development and to stimulate exploration, an airborne electromagnetic survey (INPUT) was flown on contract in a 350 square mile area near Matachewan, in the district of Timiskaming. Approximately 2700 line miles were flown at a line spacing of 1/8 of a mile. A total of 377 individual E.M. intercepts were recorded of which 14.3% were 6 channel, 16.2%, 5 channel, 23.1%, 4 channel, 21.7%, 3 channel and 24.7% were 2 channel responses. The maps (P.1014 to 1022) were released in April, 1975.

In the Cretaceous Basin of the James Bay Lowlands, a ground seismic and resistivity survey was carried out, on contract, as part of a program to assess the fossil fuel potential of Lowlands. During the period February 2 to March 5, 1975, a 18 man crew completed 45 line miles of refraction seismic and 50 stations of resistivity soundings, spaced at one mile intervals. The results of the survey were released in August, 1975 (Utard, 1975).

A reconnaissance airborne gamma-ray spectrometer survey was flown in the Ignace-Sioux Lookout area in 1975 as part of the Federal Provincial Uranium Reconnaissance Program in conjunction with the Geological Survey of Canada. The survey was designed to provide information for exploration and assessment of Uranium potential and the results will be released in 1976.

4. Industry Research

(a) Barringer Research Limited

Development of Cotran Airborne EM System

A broadband time domain airborne EM system is under development using digital signal processing. A pulse waveform is transmitted and is received on orthogonal wideband receiving coils mounted in a stinger. The received signal is digitized and coherently added in a mini-computer and the signal is dumped two times per second on magnetic tape. Classification of conductive anomalies is carried out by a pattern recognition technique in a computer. The system is the subject of issued and pending patents and is expected to go into test survey during the summer of 1976. The equipment has been designed for use in conjunction with an airborne geochemical system known as AIRTRACE and it is planned to operate it at low altitudes, without the use of a towed bird.

(b) Canadian Thin Films Ltd.

A major program within the company has been the development of an ultra sensitive "SQUID" magnetometer. The Superconducting Quantum Interference Detector (SQUID) magnetometer is a cryogenic device operating at liquid helium temperature (4.2°K). The magnetic response of the device is very closely associated with the magnetic flux quantum ϕ_0 ($\phi_0 = 2.07 \times 10^{-7}$ gauss-cm^2).

The CTF SQUID Magnetometer consists of five principal parts: (1) the superconducting field coil(s); (2) the SQUID sensor; (3) an R.F. Bias Module; (4) an Interface Module; and (5) a Flux Lock Module. An example of two parallel systems is pictured in Figure 1.

Functionally the superconducting field coil couples the magnetic field to the SQUID sensor. Through variations in the coil geometry the unit can function either as a component magnetomter or as a component gradiometer.

The CTF SQUID Sensor is a solid niobium differential device employing a uniquely developed weak link (Dayem Bridge) of single crystal Niobium Diselenide. For shielding and packaging considerations the unit is hermetically sealed within a superconducting cylinder with provisions for R.F. and field coil coupling.

The CTF Bias Module provides the R.F. biasing and initial signal processing for the magnetometer. It consists of a crystal stabilizable R.F. oscillator voltage tunable over the range 15-40 MHz; a voltage controlled R.F. current source with a dynamic range in excess of 50 db; a low noise R.F. amplifier; a prefiltered detector; and a 200 kHz post filtered amplifier for line driving.

The SQUID Interface Module provides the power for the Bias Module; control voltages for the R.F. frequency and amplitude level (including sweep modes for system alignment); and a range of reference audio frequencies from 30 Hz to 10 kHz.

The Flux Lock Module is an analog lock-in detector which linearizes the periodic magnetic response to a resolution of $\phi_0/2000$. In addition the unit includes a range of low pass filters (0-1 Hz, 0-10 Hz, 0-100 Hz, 0-1 kHz and 0-200 kHz); D.C. offset; range switching; automatic overrange reset (with provision for up/down counting) and a $3\frac{1}{2}$ digit

DVM display.

The overall system noise (S/N = 1; bandwidth 0-10 kHz) for an effective flux transformer gain of unity is 2 x 10^{-9} gauss (rms)/$(Hz)^{\frac{1}{2}}$. The dynamic range within a quantum reset is 66 db and the slew rate, at maximum sensitivity, is of the order of 1 gauss/sec.

With a superconducting flux transformer, flat response, zero noise gains of from 10-100 are possible depending on field coil geometry and coupling efficiency. Accordingly there is a proportional increase in field resolution and an inversely proportional decrease in slew rate.

With an appropriately designed flux transformer the unit can be configured as a component magnetometer with a sensitivity potential of 10^{-11}-10^{-12} gauss and a dynamic range of 10^{8}.

Gradiometers have unique advantages over magnetometers; increased resolution and insensitivity to diurnal and secular variations. In addition to these benefits a SQUID gradiometer has the unique capability of being configured within a single package over a very short baseline (10-20 cm) with a realizable sensitivity of $10^{-5}\gamma$/foot. In addition, the component features of a SQUID gradiometer allow for the full determination of the magnetic gradient tensor (for which there are 5 independent terms). This full tensor information provides for greater analytical leverage in data analysis. Specifically, as a subset, the measurement of three appropriately chosen components of the gradient tensor can be used to construct a component of the gradient of the total field, thus providing a link with presently flown gradient systems (P. Hood; Mineral Exploration, Trends & Developments in 1974; Canadian Mining Journal 93, 1 (1975)).

(c) Crone Geophysics Ltd.

The Ground Pulse EM (PEM) method capabilities are being expanded from the small loop, both coils moving system, to the large loop turam type system and borehole applications. All methods incorporate the same basic transmitting and measuring instruments. Pulse EM units in 1976 will be operating in Canada, U.S.A., Finland, Poland, South Africa, Sultanate of Oman and Australia.

A Borehole Pulse EM is being constructed for the Department of Energy, Mines and Resources with depth capabilities of 1,000 meters. Model test studies of this method and equipment have been completed by Dennis Woods of Queens University. These studies show that borehole surveys not only detect hidden conductors up to 100 meters from the borehole but also help determine the size, shape, conductivity and position of a body that is intersected by the hole. Further model test studies are proposed to be carried out by Frank Hiebert of the University of Calgary.

Papers covering the development and field usage of the Pulse EM method were presented at the AIME in New York, February 1975 and at GEOLOGORAZVEOKA, Moscow,November 1975.

A hydrostatic elevation difference meter system for gravity survey purposes was developed in 1975. Elevations can be obtained along uncut lines to an accuracy of 10 cm at a survey rate of 0.8 km per hour.

(d) Geonics Ltd.

During 1975 Geonics Limited continued to emphasize the development of new geophysical instruments employing electromagnetic principles.

Under contract with Hudson Bay Mining & Smelting the Beechcraft inphase/quadrature phase towed-bird electromagnetic system was expanded to 2 frequencies viz 380 and 1225 hertz. This system, which is flown with a transmitter-coil/receiver-coil spacing of 225 feet (70 meters) produces a noise level at both frequencies of approximately 100 ppm peak to peak. The low noise level, combined with the large inter-coil spacing produces excellent depth penetration. The use of two frequencies, with both inphase and quadrature phase information at each frequency, is proving useful in establishing a target priority rating based on conductivity-thickness product, particularly in regions of conductive

overburden.

Geonics Limited has reached an agreement with the University of Toronto whereby Geonics Limited will manufacture and sell the UTEM Time Domain Electromagnetic System developed by G.F. West and Y. Lamontagne. This instrument has been specifically designed through extensive theoretical and physical modelling experiments to differentiate between unwanted surficial responses and suspected bedrock conductors of various sizes and shapes.

The UTEM system will be commercially available in mid 1976.

Finally Geonics Limited will also enter the market in early 1976 with a helicopter-towed rigid-boom electromagnetic system. The boom, of length 20 feet, is constructed from recently available materials which, coupled with an improved towing harness, should result in substantially improved system noise levels. Initially available in a single frequency version, updating of the system to multi-frequency capability is anticipated to take place in late 1976.

(e) Huntec (70) Ltd.

In 1975, Huntec's Hydrosonde Deeptow Seismic (DTS) System was extensively used on the Nova Scotian and Labrador shelves, and in the Davis Strait for sediment studies, geological reconnaissance, and target selection for surficial bedrock seabed drilling. During this phase, high resolution sub-bottom data were acquired over 6000 line kilometers, at speeds to 8 knots and sea swells to 7 meters.

Following the initial trials of the DTS System in 1974, an attitude sensor/heave compensation system was installed in the tow fish to enable continuous monitoring and recording of pitch, roll, acceleration, velocity, heave and pressure. The compensation network adjusts the source firing instant to compensate for fish heave due to ship motion. The resulting profiles are effectively decoupled from the obscuring effects of heavy seas.

During the 1975 field work, much of the field data was recorded on magnetic tape for offline processing. Current research with these data is directed to remote and automatic classification of the material properties of the sea floor and underlying strata.

(f) Scintrex Limited

Scintrex research personnel were active in the following research projects during 1975.

1. Neutron-Prompt Gamma grade analysis of coarse material being conveyed on moving belts, e.g., for iron, copper, nickel.

2. Development of new combined time and frequency domain induced polarization transmitters.

3. Development of new gamma ray spectrometers for uranium exploration purposes.

4. Development of techniques using computers for automatic quantitative interpretation of multi-frequency Tridem airborne electromagnetic data to determine the electrical characteristics of horizontally stratified overburden.

(g) Soquem Ltd.

Soquem has developed a software programmable IP receiver based on a microprocessor. The unit uses an analogue to digital converter operating at 16 Hz and obtains the IP measurement by executing an analysis program on the data. The initial instruments have been programmed to work with a time-domain transmitter unit and to display Vp, chargeability and error estimates to the operator. Additional programs are being developed for time-domain analyses, etc.

(h) Varian Associates of Canada Ltd.

A new portable Cesium Magnetometer is currently being developed. It will be approximately the same size and weight of currently available Portable Proton Magnetometers but will have the following advantages; Sensitivity will be 0.1 gamma, it will be continuous reading, audio output as well as digital display, and optional analog and digital outputs. This new instrument should be introduced by April/76. Initially it will be packaged for land use only but we intend to eventually produce an underwater version.

5. Canadian Mining Geophysical Industry: Sales and Services in 1975 *(Peter Hood)*

The Canadian companies which offer airborne and ground geophysical services for manufacture mining geophysical equipment were canvassed for their 1975 sales statistics; 22 companies responded (compared to 19 in 1974) which was almost a 100% response, so it is felt that the figures presented in this report reasonably reflect the present level of activity in the Canadian mining geophysical industry.

The following three tables (Tables 1, 2, and 3) give the sales figures in millions of dollars for 1973, 1974 and 1975 respectively for the three main areas of activity, namely aerial survey, ground survey and instrument sales and services. The figures in parentheses are percentages expressed with respect to the combined total. The numbers given in the tables have also been plotted in two graphs (Figs. 1 and 2) for each of the years 1973, 1974 and 1975.

Several conclusions can be drawn from Tables 1, 2 and 3 and from Figures 1 and 2, as follows:

1. The revenue of Canadian geophysical contractors and instrument manufacturers has improved considerably over the three-year period 1973-75 from 18 to 25.9 million dollars, which is a 43.9% increase.

2. The improvement is due to a much improved revenue from aerial surveys and instrument sales both of which have improved by 62% over the three-year period. Aerial surveys now provide 61.8% of all revenue received by the companies canvassed compared to 56.7% in 1973.

3. However, the most noticeable improvement can be attributed to an improvement in foreign sales. The revenue from aerial surveys overseas has more than doubled, and instrument sales overseas improved by 77% from 1973 to 1975. Thus foreign sales now provide 61% of the revenue of the companies canvassed compared to 52.8% in 1973.

4. In comparison, contracted ground geophysical surveys have declined both in absolute and relative importance, especially when the effect of the recent double-digit inflation is taken into account. Ground surveying is essentially a 2 million dollar business in Canada although there are a number of small domestic operators who were not canvassed which would augment the statistics quoted. The cost of ground surveys carried out by the mining companies themselves is also not included.

Table 1: 1973 Sales Figures for Canadian Geophysical Companies (Collected by Dr. H.O. Seigel)

ACTIVITY	DOMESTIC	FOREIGN	TOTAL
	$M	$M	$M
Aerial Survey	5.4 (30.0%)	4.8 (26.7%)	10.2 (56.7%)
Ground Survey	1.2 (6.7%)	2.1 (11.7%)	3.3 (18.3%)
Instrument Sales & Rentals	1.9 (10.6%)	2.6 (14.4%)	4.5 (25.0%)
TOTALS	8.5 (47.2%)	9.5 (52.8%)	18.0 (100%)

Table 2: 1974 Sales Figures for Canadian Geophysical Companies

ACTIVITY	DOMESTIC	FOREIGN	TOTAL
	$M	$M	$M
Aerial Survey	6.5 (30.5%)	6.5 (30.5%)	13.0 (61.0%)
Ground Survey	0.9 (4.3%)	1.5 (17.0%)	2.4 (11.3%)
Instrument Sales & Rentals	1.9 (8.9%)	4.0 (18.8%)	5.9 (27.7%)
TOTALS	9.3 (43.7%)	12.0 (66.3%)	21.3 (100%)

Table 3: 1975 Sales Figures for Canadian Geophysical Companies

ACTIVITY	DOMESTIC	FOREIGN	TOTAL
	$M	$M	$M
Aerial Survey	6.0 (23.2%)	10.5 (40.6%)	16.5 (63.8%)
Ground Survey	1.4 (5.3%)	0.7 (2.8%)	2.1 (8.1%)
Instrument Sales & Rentals	2.7 (10.5%)	4.6 (17.6%)	7.3 (28.1%)
TOTALS	10.1 (39%)	15.8 (61%)	25.9 (100%)

Because airborne geophysical surveys bring in the largest percentage of the revenue for Canadian contractors, the contractors were requested to provide a breakdown of their statistics in the three categories - aeromagnetic, combined airborne electromagnetic (AEM)/aeromagnetic and combined airborne radiometric/aeromagnetic. Table 4 summarizes the 1975 statistics for airborne geophysical surveys carried out by Canadian contractors. The following conclusions may be reached from Table 4, as follows:

1. All three categories are equally important activities to Canadian contractors with combined airborne electromagnetic/aeromagnetic having a slight overall edge (37.6%).

2. Aeromagnetic and combined airborne radiometric/aeromagnetic surveys provide the greater part of the overseas business which itself provides 63.6% of the revenue to Canadian contractors.

3. In contrast, combined airborne electromagnetic/aeromagnetic surveys provide 60% of the domestic business; 58% of combined AEM/Mag work is carried out in Canada itself. Thus one would infer that the airborne electromagnetic technique still has greater acceptance by mining companies etc. in Canada than by their equivalent organizations overseas.

To conclude, it is apparent that the previous observed trend towards an increasing proportio of business for the Canadian geophysical survey industry going overseas was maintained in 1975. Aerial surveys are the most important activity overseas, and airborne magnetic and radiometric surveys presently provide the greater part (62.4%) of the revenue for this activity.

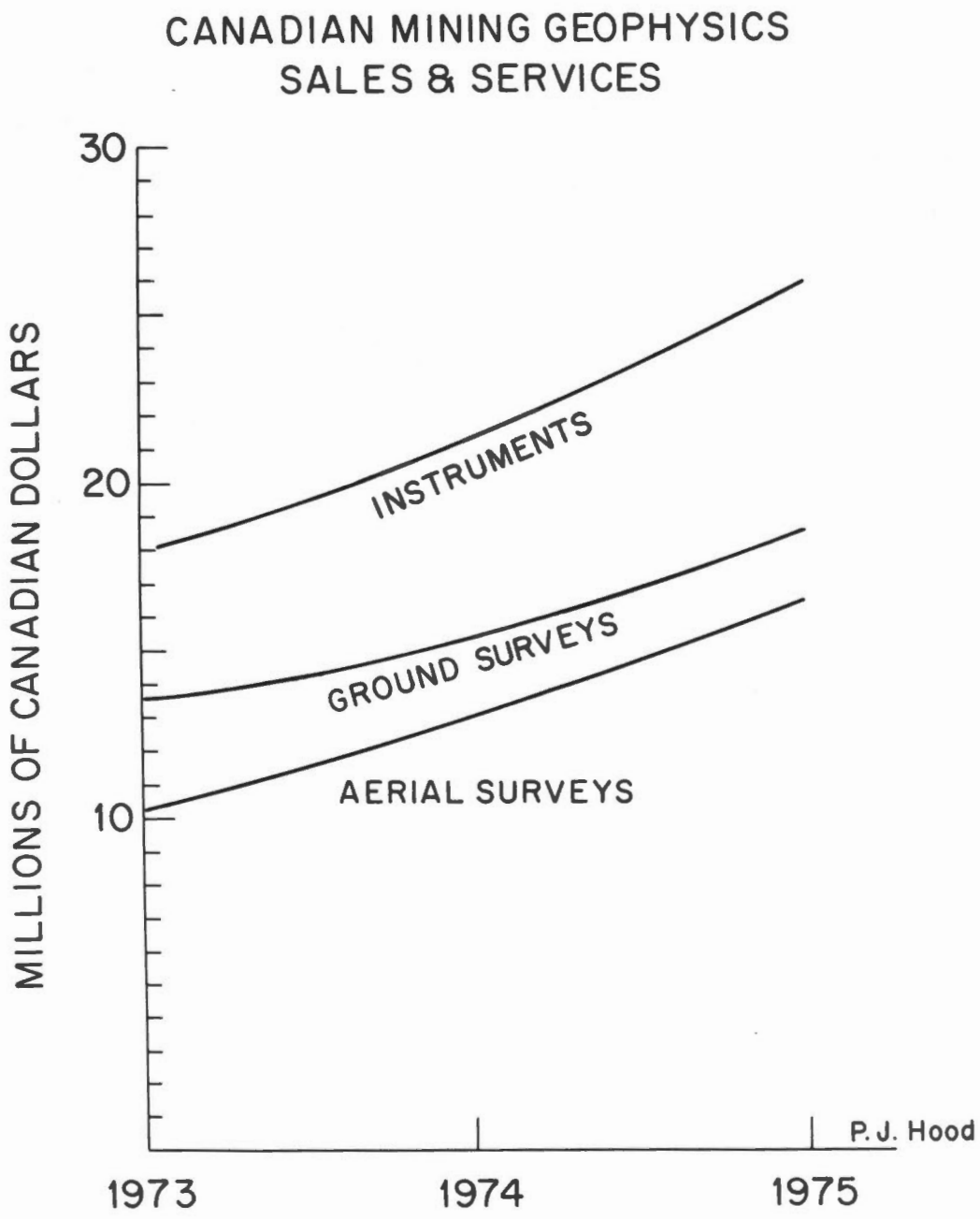


Figure 1. Revenue for Canadian geophysical companies by activity for 1973-1975.

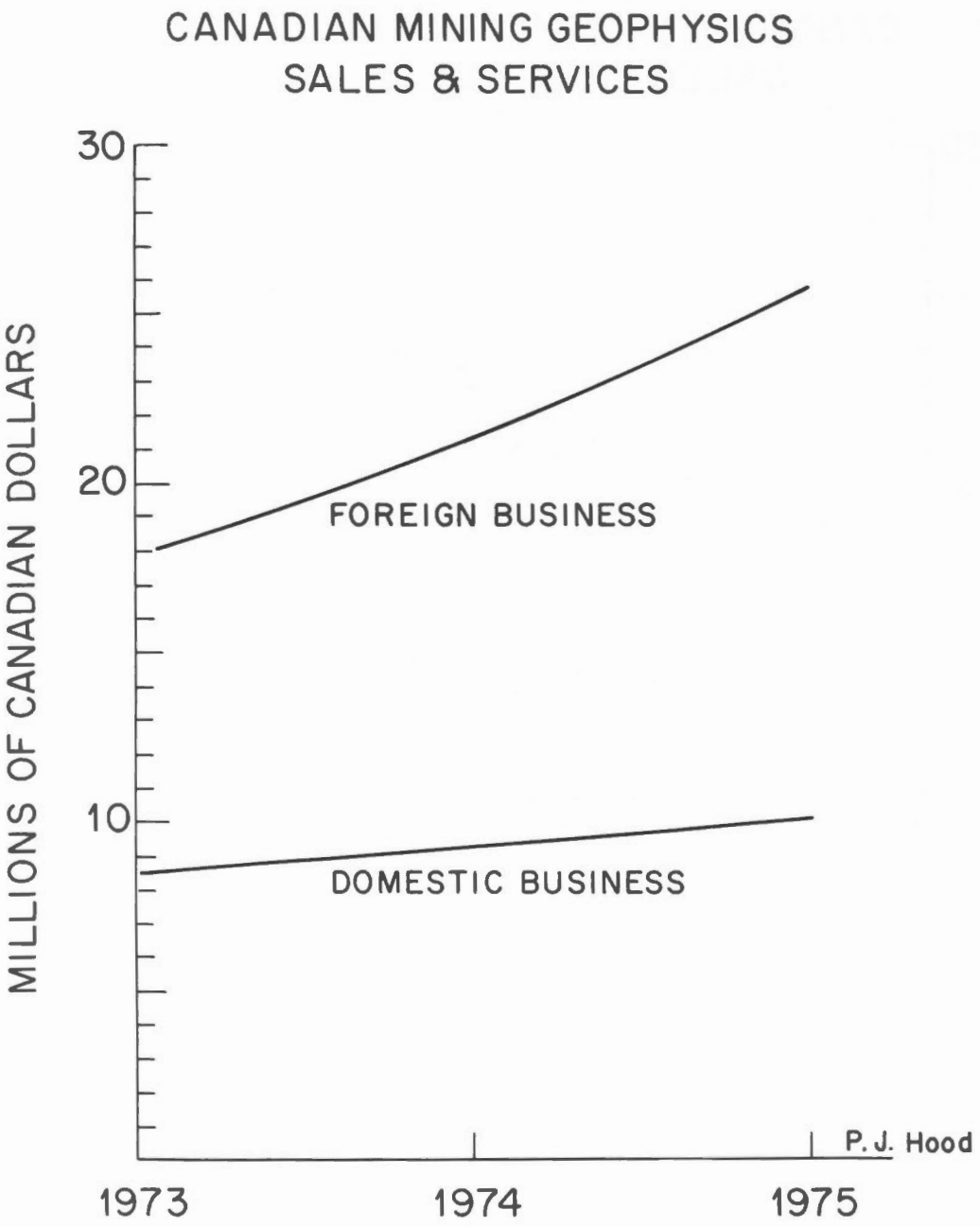


Figure 2. Domestic and Foreign revenue for Canadian geophysical companies for 1973-1975.

Table 4: Statistics for airborne geophysical surveys carried out by Canadian geophysical contractors in 1975.

ACTIVITY	DOMESTIC		FOREIGN		TOTALS		
	Line Miles	$M	Line Miles	$M	Line Miles	$M	
Aeromag	122,559	1.0	320,688	4.3	443,247	5.3	(32.1%)
Combined AEM/Mag	133,956	3.6	85,543	2.6	219,499	6.2	(37.6%)
Combined AR/Mag	108,654	1.4	361,265	3.6	469,919	5.0	(30.3%)
TOTAL	365,169	6.0 (36.4%)	767,496	10.5 (63.6%)	1,132,665	16.5 (100%)	

6. Bibliography

1. Annan, A.P., Davis, J.L. and Scott, W.J. Impulse radar profiling in permafrost, Geol. Surv. Can., Paper 75-1C, 343-351, 1975.

2. Annan, A.P., Davis, J.L. and Scott, W.J. Impulse radar wide angle reflection and refraction sounding in permafrost, Geol. Surv. Can., Paper 75-1C, 335-341, 1975.

3. Cameron, G.W. and Hood, P.J. Residual aeromagnetic anomalies associated with the Meguma Group of Nova Scotia and their relationship to gold mineralization, Geol. Surv. Can., Paper 75-1C, 197-211, 1975.

4. Carson, J.M., Hunter, J.A. and Lewis, C.P. Marine seismic refraction profiling Kay Point, Yukon Territory, GSC Paper 75-1B, 9-12, 1975.

5. Caulfield, D.D., Liron, A., Lewis, C.F.M. and Hunter, J.A. Preliminary test results of the "Banges" Through-Ice Sub-Bottom Acoustic Profiling System at Tuktoyaktuk, N.W.T.: GSC Paper 76-1A, 1976.

6. Charbonneau, B.W. and McGrath, P.H. Cavendish geophysical test range, Ontario: ground magnetic surveys; Geol. Surv. Can., Paper 75-1C, 187-190, 1975.

7. Charbonneau, B.W., Jonasson, I.R. and Ford, K.L. Cu-U mineralization in the March Formation Paleozoic Rocks of the Ottawa-St. Lawrence Lowlands, Geol. Surv. Can., Paper 75-1A, 229-233, 1975.

8. Collett, L.S. Geophysical parameters of permafrost: National Research Council, Canada, Technical Memorandum No. 113, 1-16, 1974.

9. Collett, L.S. Symposium on permafrost geophysics: Geoscience Canada, 2, no. 1, 51-54, 1975.

10. Darnley, A.G., Cameron, E.M. and Richardson, K.A. The Federal-Provincial Uranium Reconnaissance Program; in Uranium Exploration '75, Geol. Surv. Can., Paper 75-26, 49-71, 1975.

11. Davis, J.L. Relative permittivity measurements of a sand and a clay soil in situ, Geol. Surv. Can., Paper 75-1C, 361-365, 1975.

12. Davis, J.L. and Chudobiak, W.J. In-situ meter for measuring relative permittivity of soils, Geol. Surv. Can., Paper 75-1A, 75-79, 1975.

13. Demura, G.V., Ku, C.C., Telford, W.M. and Becker, Alex. Some statistical methods for detecting weak geophysical anomalies from a noisy background, Soc. Expl. Geophys. 45th Annual Meeting, Denver, Oct. 1975.

14. Duckworth, K. Electromagnetic depth sounding using a source orientation mode, Geophys. Prospecting, 23, no. 1, 139-155, 1975.

15. Dyck, A.V., Becker, A. and Collett, L.S. INPUT AEM Results from Project Pioneer, Manitoba, Can. J. Earth Sci., 12, no. 6, 971-981, 1975.

16. Dyck, A.V. Borehole logging (electrical), Geol. Surv. Can., Paper 75-1A, 81-82, 1975.

17. Dyck, A.V. (editor) Borehole geophysics applied to metallic mineral prospecting: A Review, Geol. Surv. Can., Paper 75-31, 67, 1975.

18. Dyck, A.V., Becker, A. and Collett, L.S. INPUT AEM results from Project Pioneer, Manitoba, Can. J. Earth Sciences, 12, no. 6, 971-981, 1975.

19. Edwards, R.N. The MMR Method, Paper No. 75-L-82, AIME, Salt Lake City, 1975.

20. Gagne, R.M. and Hunter, J.A. Hammer seismic studies of surficial materials, Banks Island, Ellesmere Island and Boothia Peninsula, N.W.T., Geol. Surv. Can., Paper 75-1B, 13-18, 1975.

21. Gauvreau, C. and Katsube, T.J. Automation in electrical rock property measurements, Geol. Surv. Can., Paper 75-1A, 83-86, 1975.

22. Hobson, G.D. and Overton, A. Seismic refraction - Sverdrup Basin, Geol. Surv. Can., Paper 75-1A, 88, 1975.

23. Holroyd, M.T. The extension of the ADAM (Aeromagnetic Data Automatic Mapping) system to include the application of two-dimensional digital filters to grid data, Geol. Surv. Can., Paper 75-1A, 109-110, 1975.

24. Hood, P.J. Book review of "Geomagnetism in Marine Geology", V. Vacquier, Elsevier, Amsterdam, 1972, 195 p., Tectonophysics, 22, 197, 1974.

25. Hood, P.J. Mineral exploration: trends and developments in 1974, Can. Min. J., 96, no. 2, 191-229, 1975.

26. Hood, P.J. Cavendish geophysical test range, Ontario (NTS 31 D/16W); historical background, Geol. Surv. Can., Paper 75-1C, 175-177, 1975.

27. Hood, P.J. Residual magnetic anomaly maps for Eastern Canada and Guyana, Zmuda Memorial Conference on Geomagnetic Field Models, Colorado Springs, March 24-25, Abstract published in EOS, 56, no. 8, 544, 1975.

28. Hood, P.J. Sawatzky, P., Kornik, L.J., McGrath, P.H. and Holroyd, M.T. An inboard digital-recording aeromagnetic gradiometer system; a progress report, Paper GM-11, 45th Ann. SEG Meeting, Denver, October 12-16, 1975.

29. Hood, P.J. EMR's new geophysical tool, GEOS, Fall issue, 18-20, 1975.

30. Hood, P.J. The GSC aeromagnetic gradiometer - a new mapping tool for mineral exploration, Northern Miner, 61, no. 37, A1, A20-21, 1975.

31. Hood, P.J. and Bower, M.E. Northern Baffin Bay: Low-level aeromagnetic profiles obtained in 1974, Geol. Surv. Can. Paper 75-1, pt. A., 89-93, 1975.

32. Hood, P.J. and Bower, M.E. Aeromagnetic reconnaissance of Davis Strait and adjacent areas, in Proc. Canada's Continental Margins and Offshore Petroleum Exploration, Calgary, Sept. 29-Oct. 2, 1974, Memoir 4, ISPG, 433-451, 1975.

33. Hood, P.J. and Dyck, A.V. Magnetic drillhole measurements in mineral exploration, in Borehole geophysics applied to metallic mineral prospecting - a review (A.V. Dyck, Ed.), Geol. Surv. Can., Paper 75-31, 35-38, 1975.

34. Hood, P.J., McGrath, P.H. and Kornik, L.J. Evaluation of derived vertical gradient results in the Timmins area, Ontario, Geol. Surv. Can., Paper 75-1, pt. A, 111-115, 1975.

35. Hunter, J.A. Borehole geophysical methods in permafrost; in Borehole geophysics applied to metallic mineral prospecting, a review by A.V. Dyck (Editor), Can. Geol. Surv. Paper 75-31, 67, 1975.

36. Hunter, J.A. and Godfrey, R.J. A shallow marine refraction survey, Cunningham Inlet, Somerset Island, N.W.T., Geol. Surv. Can., Paper 75-1B, 19-22, 1975.

37. Hunter, J.A. and Veillette, J. Borehole density logging in permafrost, Tuktoyaktuk, N.W.T Geol. Surv. Can., Paper 76-1A, 1976.

38. Judge, A.S., Hunter, J.A., Good, R.L., Cowan, J. and Robb, G. Thermistor cable installation in permafrost materials with a water jet drilling method, Geol. Surv. Can., Paper 76-1A, 1976.

39. Judge, A.S., MacAulay, H.A. and Hunter, J.A. Anomalous shallow seismic velocities in Mackenzie Bay, N.W.T., Geol. Surv. Can., Paper 76-1A, 1976.

40. Katsube, T.J. The electrical polarization mechanism model for moist rocks, Geol. Surv. Can., Paper 75-1C, 353-360, 1975.

41. Katsube, T.J. Electrical parameter conversion table, Geol. Surv. Can., Paper 75-1A, 99-100, 1975.

42. Katsube, T.J. The critical frequency and its effect on EM propagation, Geol. Surv. Can., Paper 75-1A, 101-105, 1975.

43. Katsube, T.J. Frequency range for mineral differentiation by IP methods, Geol. Surv. Can. Paper 75-1A, 95-98, 1975.

44. Killeen, P.G. and Carmichael, C.M. Radioactive disequilibrium determinations Part I: Determination of radioactive disequilibrium in uranium ores by alpha-spectrometry, Geol. Surv. Can., Paper 75-38, 1975.

45. Kornik, L.J. Ground magnetometer survey in the Agricola Lake area, District of Mackenzie, Geol. Surv. Can., Paper 75-1A, 214-217, 1975.

46. Kornik, L.J., McGrath, P.H., Holroyd, M.T. and Hood, P.J. Evaluation of high resolution aeromagnetic survey data over a test range in the Timmins area, Ontario, Geol. Surv. Can., Paper 75-1B, 23-38, 1975.

47. McGrath, P.H. A two-dimensional first vertical derivative operator, Geol. Surv. Can., Paper 75-1A, 107-108, 1975.

48. McGrath, P.H. and Cameron, G.W. Ground magnetic survey, Roberts Arm, Newfoundland, Geol. Surv. Can., Paper 75-1A, 117-119, 1975.

49. McGrath, P.H. and Hood, P.J. Reply to authors to discussion by M. Al-Chalabi on the paper "An automatic least-squares multimodel method for magnetic interpretation", Geophysics, April 1973, Geophysics, 39, no. 5, 693-694, 1974.

50. McLaren, P., Scott, W.J. and Hunter, J.A. The implications of geophysical studies on the permafrost regime and surficial geology, Melville Island and Byam Channel, N.W.T., Geol. Surv. Can., Paper 75-1B, 39-45, 1975.

51. O.D.M. Airborne electromagnetic and total intensity magnetic survey, district of Timiskaming: Ontario Division of Mines, Prelim. Maps P. 1014 to 1022, Geophys. Ser., 1975.

52. Overton, A. A seismic investigation near Flin Flon, Manitoba, Geol. Surv. Can., Paper 75-1A, 121-128, 1975.

53. Overton, A. Borehole seismic methods; in Borehole geophysics applied to metallic mineral prospecting by A.V. Dyck (Editor), Geol. Surv. Can., Paper 75-31, 3-12, 1975.

54. Ready, E. and Hood, P.J. Contract aeromagnetic surveys (1974) progress report, Geol. Surv. Can., Paper 75-1, Part A, 129-132, 1975.

55. Richardson, K.A., Darnley, A.G. and Charbonneau, B.W. Airborne Gamma-Ray Measurements Over the Canadian Shield, Proceedings, the Natural Radiation Environment II, 681-704, 1975.

56. Richardson, K.A., Killeen, P.G. and Charbonneau, B.W. Results of a reconnaissance type airborne gamma-ray spectrometer survey of the Blind River - Elliot Lake Area, Ontario 41J, Geol. Surv. Can., Paper 75-1A, 133-135, 1975.

57. Sawatzky, P. and Hood, P.J. Fabrication of an inboard digital-recording vertical gradiometer system for aeromagnetic surveying, a progress report, Geol. Surv. Can., Paper 75-1, pt. A, 139-140, 1975.

58. Scott, W.J. Preliminary experiments in marine resistivity near Tuktoyaktuk, District of Mackenzie, Geol. Surv. Can. Paper 75-1A, 141-145, 1975.

59. Scott, W.J. VLF resistivity (radiohm) survey, Agricola Lake area, District of Mackenzie, Geol. Surv. Can., Paper 75-1A, 223-225, 1975.

60. Scott, W.J., Campbell, K.J. and Orange, A.S. EM pulse survey method in permafrost, National Research Council, Canada, Technical Memorandum No. 113, 92-96, 1974.

61. Scott, W.J. and Hunter, J.A. Seismic and electrical methods in permafrost detection, National Research Council, Canada, Technical Memorandum No. 113, 48-49, 1974.

62. Seguin, M.K. The use of geophysical-statistical methods in predicting dimensions, shapes, tonnages, and grades of metamorphic iron formations of the Carol Lake District, Labrador, Newfoundland, AIME Trans., 256, 112-121, 1974.

63. Seigel, H.O. and Nargowalla, S. Nuclear logging system obtains 'bulk samples' from small boreholes, E & MJ, August 1975.

64. Sellman, P.V., McNeill, J.D. and Scott, W.J. Airborne E-phase resistivity surveys of permafrost, National Research Council, Canada, Technical Memorandum, No. 113, 67-71, 1974.

65. Sinha, A.K. Altitude dependence of plane wave e.m. fields, Geol. Surv. Can., Paper 75-1A, 147-148, 1975.

66. Sinha, A.K. Electromagnetic sounding over layered permafrost terrain, Geol. Surv. Can., Paper 75-1A, 149-151, 1975.

67. Slaney, V.R. Colour photography in the Beechey Lake belt, District of Mackenzie, Geol. Surv. Can., Paper 75-1A, 226, 1975.

68. Soonawala, N.M., and Telford, W.M. Diffusion of Radon 222 and interpretation techniques for emanometer data, Soc. Expl. Geophys. 45th Ann. Meeting, Denver, Oct. 1975.

69. Utard, M. Report on refraction seismic and resistivity surveys in the James Bay Lowlands Cretaceous Basin for the Ontario Ministry of Natural Resources, Division of Mines, Geological Branch, Ontario Division of Mines OFR 5148, pt. 2, 47 p., 1 fig., 6 plates, 10 charts, 1975.

70. Yu, T-R., and Telford, W.M. Rayleigh wave dispersion technique for geoexploration with special reference to permafrost, Can. Soc. of Petr. Geol. and Expl. Geophys. Joint Convention, Calgary, May 1975.

IX. GLACIER RESEARCH

Compiled by: C.S.L. Ommanney

1. Introduction

In 1975 the Subcommittee on Glaciers that had ceased to exist once the Associate Committee on Geodesy and Geophysics was disbanded was reformed under the Associate Committee on Hydrology. It will sponsor a meeting in Ottawa, in 1978, on 'The Ice-Rock Interface: Beds of Glaciers and Ice Sheets'. G.K.C. Clarke is the Chairman.

Also in 1975, an Advisory Committee on Glaciological and Alpine Nomenclature was set up to advise the Canadian Permanent Committee on Geographical Names. Priority will be given initially to establishing guidelines for the delineation of glacier features, on the usage of specific glaciological terms and to the preparation of a list of glacier names. C.S.L. Ommanney is the Chairman.

2. Energy, Mines and Resources

(a) Geological Survey of Canada, Ottawa

(i) *Glacier Fluctuations: Eastern Arctic Canada and Northwest Greenland (W. Blake, Jr.).* During the 1974 cruise of the C.S.S. Hudson many glacierized areas along the ship's route were photographed: Northumberland Ø, Smith Sound, Pim Island, the S coast of Buchanan Bay in Kane Basin, the E and S coasts of Devon Island, the NW corner of Bylot Island and the N coasts of Borden and Brodeur peninsulas. Photos were also taken of the Greenland Ice Cap margin near Camp TUTO, previously visited in 1954. In 1975 numerous glaciers in eastern Axel Heiberg Island and near Yelverton Pass (N. Ellesmere Is.) and the small ice caps near Muskox and Baad fiords (S. Ellesmere Is.) were photographed from the air.

(ii) *Neoglacial Events, Kluane National Park, Y.T. (V.N. Rampton).* Debris-covered glaciers, ice-cored moraines, rock glaciers and lateral moraines were examined in 1974. It seems that the Neoglaciation here was limited to the last 2800 years. Most glaciers were expanding around 2800 years B.P., from 1050-1250 and during the last 450 years. Synchronous advances of many glaciers appear to have occurred from 200-250, 120-150, 40-70 and from 25 years B.P. to the present. Lakes formed five or six times through damming of the Alsek River by the Lowell Glacier.

(b) Polar Continental Shelf Project (R.M. Koerner)

(i) *Meighen Island.* The 1973-74 annual mass balance was -5 g/cm^2 and the winter 1974-75 balance was 10 g/cm^2.

(ii) *Melville Island.* The 1973-74 annual mass balance on the southern ice cap was -18 g/cm^2 and the 1974-75 winter balance 17 g/cm^2.

(iii) *Devon Island.* The annual mass balance on the NW side of the Devon Island Ice cap for 1973-74 was -8 g/cm^2 with a winter balance for 1974-75 of 8.6 g/cm^2. The NW side strain net at 1300 m was remeasured to determine long term mass balance. A profile across the Sverdrup Glacier at 300 m was levelled for comparison with similar surveys in 1961 and 1971.

Analysis continues on particulate content, chemistry and crystallography of 3 cores taken at 1800 m in 1971, 1972 and 1973. The first has revealed annual layers but the record is discontinuous due to random particle fallout during some periods. Crystal sizes show a gradual increase to about 15 m depth but irregular variations below that. A strong c-axis orientation develops from 150-200 m depth but does not strengthen below that. Pollen samples were collected for analysis by Dr. Lichti-Federovich on this and the Meighen, Melville, Axel Heiberg and Ellesmere island ice caps.

(iv) *Bylot Island.* A 13 m core taken on the ice field at 1800 m showed a surprisingly shallow firn cover of 6 m and a 12 m temperature of -8°C. Both facts indicate unexpectedly high melting in this area.

3. Environment Canada

(a) Applied Hydrology Division (I.A. Reid, J.O.G. Charbonneau)

(i) *Glacier Surveys, Western Canada.* Reports and maps of the surveys of the Bugaboo, Nadahini, Sentinel, Sphinx, and Kokanee glaciers (B.C.) and the Athabasca and Saskatchewan glaciers (Alberta) from 1970-1975 are in various stages of preparation and printing. The Alberta glaciers were resurveyed in 1975. The Bugaboo Glacier is advancing, all others surveyed are retreating.

(b) Glaciology Division (O.H. Løken, Chief)

(i) *Glacier Inventory of Canada (C.S.L. Ommanney).* On Ellesmere Island glaciers have been identified and indexed in 80% of the basins and some 17 maps compiled for the Glacier Atlas; only the area north of Greely Fiord/Lake Hazen remains. Recent photos of the Coast Mts have been obtained from Austin Post for the archives. Some 1700 references are now included in the main bibliography. Bibliographies on rock glaciers and on Canadian glacier studies since 1960 are almost complete. A comprehensive list of glacier names has been compiled. The glacier inventory of the St. Elias Range, being carried out by the Arctic Institute of North America, will be completed by April 1976.

(ii) *Aerial Photography (K.C. Arnold, D.M. Christian, D.A. Sherstone, A.C.D. Terroux).* With Polar Continental Shelf Project support, 110 air photo hours were flown over the Mackenzie River and Queen Elizabeth Islands. Breakup was studied along the lower Liard and Mackenzie rivers and excellent coverage obtained of ice jams. In the High Arctic coverage of the following glaciers was obtained - South Cape Fiord, Jakeman, Ekblaw, Leffert, Eugenie, in Makinson Inlet, d'Iberville, Otto Fiord, Mokka, Thompson, White, Iceberg, Cape Stallworthy central ice cap, Canon Fiord, Parrish, Sven Hedin, Benedict and Stygge. Niche glaciers and semi-permanent snow patches near Simmonds Bay and several ice-dammed lakes on Ellesmere Island were also photographed. Ground control is not usually available. Flight charts and photos are available from the National Air Photo Library. Stakes, that can be read from the air, are being developed.

(iii) *Calving Glacier Studies, Ellesmere Island (G. Holdsworth).* Leffert and d'Iberville glaciers, with discharges of 7 x 10^6 m^3/a and 1.5 x 10^8 m^3/a respectively, are being used to study calving processes and ice/sea water interaction. Terminal ice thicknesses are in the order of 60-100 m. The North Water party, under the direction of Dr. F. Müller, visited Leffert Glacier several times to determine the intensity of melt and the mass balance.

(iv) *Barnes Ice Cap Surge Study, Baffin Island (G. Holdsworth).* The 35 stakes, 300-1000 m apart, along a 25 km flow line in the surge portion of the South Dome were resurveyed. The traverse incorporates two large strain nets, and one on the divide. D. Classen (University of Victoria) sank three strings of 7 thermistors each to depths of 88, 120 and 200 m (20 m short of bedrock). Near the margin the basal ice temperature is about 1°C lower than pressure melting but in the deepest hole is at pressure melting 20 m above bedrock. Mass balance measurements are being continued along this and the northern lines.

(v) *Mount Logan, Yukon Territory (G. Holdsworth).* Control points were established around the NW col area (5400 m) for a 1:10,000 scale map and as a reference for movement and strain measurements. A 15.8 m snow/firn core is being analysed for tritium and O^{18}. The 10 m temperature of -28.9°C corroborates stratigraphic evidence that the site is within the dry snow facies; recent accumulation rates are 1.3-1.5 m/a of snow. Radio echo sounding at 600 MHz yielded a probable snow/firn depth of 120 m at the Arctic Institute camp, 700 m from the col. Evaluation of the drill site and a 1977 drilling operation continues.

(vi) *Tweedsmuir Glacier, British Columbia (G. Holdsworth).* Final terrestrial photos were taken in August and map compilation is progressing. Parts of the land-based margin show the effects of wasting though further up-glacier slight thickening may still be continuing. The Alsek River margin is still cliffed but about the same as last year; the two-year surge is essentially over.

(vii) *Glacier Slide, Meager Creek, B.C. (O. Mokievsky-Zubok).* A brief investigation was made of the Capricorn and Job glaciers from which an estimated 2 x 10^9kg of ice were contributed to a fatal ice and debris slide of over 91 x 10^9kg that covered 5 km over an elevation range of 1200 m.

(viii) *Glacier Mass Balances: Eastern Cordillera (G.J. Young), Western Cordillera (O. Mokievsky-Zubok).* Measurement of winter and summer balances continued on Ram, Peyto, Woolsey, Place and Sentinel glaciers. Specific net balances were -0.62, -0.57, +0.36, -0.24 and +0.88 m H_2O respectively. From Sentinel measurements were extended to Helm and Warren glaciers and to others from Peyto.

A system for mapping mass balance data is now operational and has been used in the preparation of the summary data reports on the IHD glaciers *(G.J. Young).*

At Sentinel and Sphinx glaciers the bottom topography of Garibaldi Lake was studied for sublacustrine ridges to determine the maximum extent of alpine glaciation *(O. Mokievsky-Zubok).*

(ix) *Hydrochemical Model of Glacier Meltwaters (O. Mokievsky-Zubok).* In cooperation with *J. Zeman*, of the Water Quality Branch, the hydrochemistry of the Sentinel basin is being investigated to determine the characteristics of various glacier meltwaters and develop a regional classification.

4. National Defence

(a) Defence Research Board, Ottawa (H. Serson)

(i) *Northern Ellesmere Island.* The Ward Hunt Ice Shelf and Ice Rise ablation networks were remeasured and the stakes on the small ice cap north of St. Patrick Bay. All areas indicate a net loss for the 1974-75 season: -205, -140 and -124 mm H_2O respectively. On September 29 the equilibrium line on Per Ardua Glacier was at 936 m, the highest since measurements started in 1964 when it was 750 m.

5. Karl E. Ricker Ltd., Vancouver

(i) *Yukon Resource Atlas (with F.F. Slaney & Co. Ltd.).* An Atlas at a scale of 1:250,000 is being prepared for the Department of Indian Affairs and Northern Development. Studies of glacier and snow physics, chemistry and climatology will be included in a Hydrology Section with full reference to available information.

(ii) *Inventory of Glaciers Suitable for Summer Ski Resort Development, Pemberton Area, Coast Mts., B.C. (with Howard Paish & Assoc. Ltd.).* Available glacier and climate data have been gathered to determine the physical suitability of some sites near Pemberton for year-round ski facilities.

(iii) *Tchaikazan Valley Glaciers, Coast Mts., B.C.* Rates of glacier retreat from 1951-75 were established for the Tchaikazan and Friendly glaciers and the condition of the Hourglass, Pathetic, Monmouth and Miserable glaciers noted. Moraine positions were plotted from aerial photographs and crude estimates made of the rate of retreat from ca. 1900-1951. Results have been compared to retreat curves for the Canadian Rockies and Garibaldi Park. Cairns marking the 1975 snout positions of the Tchaikazan and Friendly glaciers and notes, in waterproof cannisters, have been left for others to repeat the survey.

(iv) *Wedgemount Glacier and Lake, Coast Mts., B.C. (with W. Tupper, BCIT).* Moraines and related features are being mapped in Wedgemount Creek basin. Historical photos of Wedgemount Glacier and Lake, since 1927, are being used to study rates of recession and the growth of the ice marginal lake. Computerized photogrammetric contouring from the photo sequence is being used to calculate volumetric rates of glacier wastage and estimate the future health of parts of the glacier. Glacier retreat from 1951-75 was ca. 13 m/a. A 1:5000 scale map has been made.

6. University of British Columbia, Vancouver

(a) Department of Geophysics and Astronomy (G.K.C. Clarke)

(i) *Radio Echo Sounding Yukon Glaciers (with B.B. Narod).* Airborne radar surveys were made on a number of surge-type glaciers in the St. Elias Mts as a field test of the prototype UBC 840 MHz sounder. Best results were obtained over Klutlan Glacier (up to 550 m depth) and sounding over Kluane Lake yielded encouraging results. The radar transparency of lakes is largely dependent on the free ion concentration and this lake may be exceptionally transparent.

(ii) *Steele Glacier, Yukon Territory (with T. Ahern, S.G. Collins).* Near-surface ice and water samples were collected from boreholes for O^{18} analysis. A single 110 m hole at a new site was instrumented with thermistors. The network of tetrapods, established in 1974, was resurveyed giving post surge ice motion ranging from 0.61-10.45 m/a depending on the site; annual ablation ranged from 1.57-2.77 m/a.

(iii) *Rusty Glacier, Yukon Territory.* Three radioglaciology experiments were carried out - (a) an attempt to measure in situ the electromagnetic birefringence of glacier ice, to sense the state of stresses within the glacier, (b) studies of the depolarization of waves reflected from the rough glacier bed, and (c) studies of the fading patterns and statistical properties of radar echoes from the bed. These last two may lead to remote sensing of bed roughness.

(b) Department of Geology (W.H. Mathews)

(i) *Berendon Glacier (with G.J. Young, Glaciology Division).* Buried accumulation markers were relocated by sextant observations and electromagnetic detectors. Ablation was measured on the south Berendon Glacier and a set of signals painted on the valley walls to facilitate future surveys to be based on angles measured from the stakes themselves.

7. University of Colorado, Boulder, Colorado, U.S.A.

(a) Institute of Arctic and Alpine Research (J.T. Andrews)

(i) *Glaciation Levels (with G.H. Miller, C. Wright).* A map of glaciation levels in the Northern Hemisphere has been compiled.

(ii) *Neoglacial Snow Cover and Glacier Inception, Baffin Island (with C. Wright, L.D. Williams).* Areas of retarded lichen growth or kill have been plotted from LANDSAT-1 imagery and the data used to construct paleoglaciation levels for the area N of Barnes Ice Cap; the level averaged 300 m lower than present. The neoglacial snow cover can be matched by lowering summer temperature 1-1.5°C, by decreasing solar radiation 5% or by increasing accumulation by a factor of two. M.A. Mahaffy's three-dimensional numerical ice flow model has been used to examine the rate of glacierization.

(iii) *Rate of Cirque Glacier Erosion, Baffin Island (L. Anderson).* Rates of erosion at ten cirque glaciers near the head of Pangnirtung Fiord are approximately 50 mm/1000a.

8. McGill University, Montreal, and E.T.H., Zürich, Switzerland

(a) Department of Geography (F. Müller)

(i) *Laika Glacier, Coburg Island.* The mass balance was determined using standard and photogrammetric techniques. A mass loss was observed in the lower part and a slight gain in the upper part. The accumulation area is all within the superimposed ice zone.

(ii) *Axel Heiberg Island.* The englacial temperature regime of White Glacier is being studied to provide input data for a two-dimensional thermodynamic model of a subpolar valley glacier. The modified Kasser, Röthlisberger and Iken drill achieved drilling rates of 25-50 m/h. Due to heavy summer snowfalls the equilibrium line was low. Glacier structures (crevasses, foliations and shear planes) were mapped by Dr. M. Hambrey and the relationship between the structures, glacier movement and strain magnitude studied.

9. McMaster University, Hamilton

(a) Department of Geography (S.B. McCann)

(i) *Hydrological Investigations in South-Central Ellesmere Island (with M-K Woo, J.G. Cogley, C.K. Ballantyne, S.P. Blachut).* Studies centred on the hydrologic regime of two principal rivers draining from the ice cap into Vendom Fiord and the drainage behaviour of a series of ice marginal lakes that contribute to these rivers.

10. Memorial University of Newfoundland, St. John's

(a) Department of Geography (R.J. Rogerson)

(i) *Berendon Glacier Debris Systems (with N. Eyles).* Extensive debris sampling was carried out on the glacier with debris sites, such as extraglacial avalanche-swept bedrock walls and subglacial cavities, being given special emphasis. Sequential development can be delineated. Preliminary results indicate the passivity of ice transport in generating debris characteristics for all but subglacial loads. The importance of rock wall processes is emphasized. Cationic denudation rates were estimated. Those bedrock areas contributing daughter debris products have been better defined. Recent recession has been fitted into the northwestern North American chronology.

11. University of Minnesota, Minneapolis, U.S.A.

(a) Department of Geology and Geophysics (R. LeB. Hooke)

(i) *Barnes Ice Cap, Baffin Island.* A 52 m hole, 1 km from the ice margin, was drilled and cased; the ice is about 115 m thick here. After penetrating over 10 m of dirty ice drilling stopped at 52 m due to excessive sediment accumulation. Temperature and deformation measurements were made. The bottom 30 m were in unusually fine grained (25 crystal/cm^2) white ice of Pleistocene age and suggested a high rate of deformation. The temperature gradient in a 110 m hole, 17 km S of the first, is consistently two-thirds that at comparable heights above the bed at the 52 m and another hole, both the same distance from the margin. Preliminary K analyses of bedrock samples suggest higher radioactive heat production in the area of the hole with the steeper basal gradient but recent local thinning of the ice could also explain the differences in gradient.

12. University of Ottawa, Ottawa

(a) Department of Geography and Regional Planning (P.G. Johnson)

(i) *Moraine Glaciers and Rock Glaciers, Yukon Territory.* Drainage tracing experiments were tried on rock and moraine glaciers of Grizzly Creek to obtain data on their internal structure. It appears that ice and sediment are being added to these landforms today. Under low flow conditions no resurgencies occur on most of them implying accretion of the ice surface. On moraine glaciers all the sediment load is deposited inside as it does not appear in the resurgent streams.

(ii) *Ablation in Ice-Cored Moraines, Grizzly Creek, Yukon Territory.* Rates of ablation were 5-10 times greater than in 1974 but average climatic conditions showed little difference between the two seasons. One contributing factor might have been a 9-day warm spell but even during the 20-day cold spell ablation rates were still twice those of 1974.

(iii) *Hydrology of a Glacier-Fed Stream, Grizzly Creek, Yukon Territory.* The stream regime was dominated by basin snowmelt and glacier meltwater; the former contributing the greatest work potential to the stream. High discharge from the glacier occurred during a period when drainage changed from a predominantly lateral system to a subglacial one with resurgence under hydrostatic pressure at the glacier snout.

13. University of Toronto, Toronto

(a) Department of Physics (J.R. Rossiter)

(i) *Scattering of Radio Frequencies in Glaciers.* Radio interferometry soundings, at frequencies from 1-32 MHz, have been made on the Athabasca Glacier (Alberta) and the Juneau Icefield (Alaska). The data from both sites are dominated by random scattering at and above 8 MHz (20 m wavelength in ice). Analogue scale model experiments and theoretical studies are being made to elucidate the nature of the scattering mechanisms. Preliminary results indicate that dielectric contrasts must be quite large to cause significant volume scattering. Scattering from the ice-bedrock surface is only important if the typical roughness height is above about 0.3 wavelengths.

14. Canadian Exploration Group, Peterborough

(a) Director (J.S. Marsh)

(i) *Mt. Sir Sandford Area, Selkirk Mts, B.C.* The Sir Sandford and Silvertip glaciers were surveyed and a 1:10,500 scale map produced by the Canadian Exploration Group. A chain survey of the Haworth Glacier snout was completed. Comparison with Howard Palmer's 1911 survey shows the Sir Sandford has retreated about 1.3 km; 18.1 m/a from 1911-1961 and 30.4 from 1961-1975. There is no evidence for

any advance comparable to the Illecillewaet Glacier. Microclimate studies included testing a model for the onset of a glacier wind, measurement of temperature and wind profiles across the Haworth Valley and Glacier and temperature transects of the Silvertip and Palmer Creek valleys.

15. BIBLIOGRAPHY: GLACIER STUDIES

The following abbreviations are used:

IAHS 104 = Proceedings of the Moscow Symposium on Snow and Ice, August 1971, International Association of Hydrological Sciences Publication No. 104, International Union of Geodesy and Geophysics.

IRRP 4 = Icefield Ranges Research Project Scientific Results Volume 4, American Geographical Society and Arctic Institute of North America, 385 pp.

1. Andrews, J.T., Funder, S., Hjort, C. and Imbrie, J. Comparison of the glacial chronology of eastern Baffin Island, East Greenland, and the Camp Century accumulation record. Geology, Vol. 2, No. 7, 355-358, 1974.

2. Andrews, J.T. and Jacobs, J.D. University of Colorado 1973 field season in eastern Baffin Island. Arctic, Vol. 27, No. 3, 243-244, 1974.

3. Andrews, J.T. and Mahaffy, M.A. Rate of growth of the Laurentide Ice Sheet based on a three-dimensional numerical ice flow model. Geological Society of America Abstracts, Vol. 7, 977-978, 1975.

4. Andrews, J.T. et al. The Laurentide Ice Sheet: problems of the mode and speed of inception. In Proceedings of the WMO/IMAP Symposium on "Long-term climatic fluctuations", Norwich, 18-23 Aug. 1975, WMO No. 421, Geneva, Switzerland, 87-94, 1975.

5. Barre, K. de la and Williams, A. The Icefield Ranges Research Project, 1974. Arctic, Vol. 28, No. 1, 82-84, 1975.

6. Barry, R.G., Andrews, J.T. and Mahaffy, M.A. Continental ice sheets: conditions for growth. Science, Vol. 190, 5 December, 979-981, 1975.

7. Bell, W. Surging glacier - lonesome solitude on the cap of the beautiful Tweedsmuir Glacier moving to create a new lake. North, Vol. 21, No. 1, 2-5, 1974.

8. Bradley, R.S. Equilibrium-line altitudes, mass balance and July freezing-level heights in the Canadian High Arctic. Journal of Glaciology, Vol. 14, No. 71, 267-274, 1975.

9. Carrara, P.E. The ice-cored moraines of Akudnirmuit Glacier, Cumberland Peninsula, Baffin Island, N.W.T., Canada. Arctic and Alpine Research, Vol. 7, No. 1, 61-67, 1975.

10. Clarke, G.K.C. Surging glacier studies. Canadian Alpine Journal, Vol. 58, 38, 1975.

11. Clarke, G.K.C. and Goodman, R. Radio echo sounding and ice-temperature measurements in a surge-type glacier. Journal of Glaciology, Vol. 14, No. 70, 71-78, 1975.

12. Collins, S.G. Survey of the Rusty Glacier area, Yukon Territory, 1967-1970. IRRP 4, 259-272, 1974.

13. Derikx, L. The heat balance and associated runoff from an experimental site on a glacier tongue. IAHS 104, 59-96, 1975.

14. Dozier, J. Channel adjustments in supraglacial streams. IRRP 4, 189-205, 1974.

15. Driscoll, F.G. Meltout rates of ice-cored moraines. Geological Society of America Abstracts with Programs, 1974 Annual Meetings, Vol. 6, No. 7, 715-716, 1974.

16. Foessel, D.G. An analysis of the temperature distribution over the Peyto Glacier, Alberta. M.Sc. Thesis, Department of Geography, Guelph University, Ontario, 137 pp., 1974.

17. Geist, V. On life in the sight of glaciers. Nature Canada, Vol. 4, No. 3, 10-16, 1975.

18. Goodman, R.H. Radio echo sounding on temperature glaciers. Journal of Glaciology, Vol. 14, No. 70, 57-69, 1975.

19. Goodman, R.H., Clarke, G.K.C., Jarvis, G.T., Collins, S.G. and Metcalfe, R. Radio soundings on Trapridge Glacier, Yukon Territory, Canada. Journal of Glaciology, Vol. 14, No. 70, 79-84, 1975.

20. Guigné, J.Y. Glacio-hydrological mass balance study of the Cathedral Massif glacier system, 1975, Atlin, British Columbia, Canada. Mimeo report, Foundation for Glacier and Environmental Research, Juneau Icefield Research Program, 69 pp., 1975.

21. Harrington, R. The fantasy of Tarr Inlet as a new Yukon port. Canadian Geographical Journal, Vol. 91, No. 5, 12-17, 1975.

22. Hattersley-Smith, G. North of Latitude Eighty: the Defence Research Board in Ellesmere Island. Defence Research Board, Defence Research Establishment Ottawa, Information Canada, Cat. No. DR3-1774, 121 pp., 1974.

23. Hattersley-Smith, G. Present arctic ice cover. In Arctic and Alpine Environments, J.D. Ives and R.G. Barry (Editors), Methuen, 195-223, 1974.

24. Hobson, G.D. and Jobin, C. A seismic investigation - Peyto Glacier, Banff National Park and Woolsey Glacier, Mount Revelstoke National Park. Geoexploration, Vol. 13, No. 2, 117-127, 1975.

25. Holdsworth, G. Deformation and flow of Barnes Ice Cap, Baffin Island. Inland Waters Directorate Scientific Series No. 52, Environment Canada, Ottawa, 19 pp., 1975.

26. Holdsworth, G. Ice flow measurements of d'Iberville Glacier, Ellesmere Island, N.W.T. Unpublished report, Glaciology Division, Environment Canada, Ottawa, 14 pp., 1975.

27. Holdsworth, G. Instruments and Methods - Measurement of small strain-rates over short time periods. Journal of Glaciology, Vol. 14, No. 71, 317-324, 1975.

28. Holdsworth, G. and Traetteberg, A. Deformation of an arctic ice island. In Proceedings of the 2nd International Conference on Port and Ocean Engineering under Arctic Conditions, Reykajavik, Iceland, 419-440, 1974.

29. Iken, A. Velocity fluctuations of an arctic valley glacier, a study of the White Glacier, Axel Heiberg Island Research Reports, Glaciology No. 5, McGill University, Montreal, 115 pp., 1974.

30. Ives, J.D. Glaciers of Baffin Island. The Beaver, Outfit 306, No. 1, 32-39, 1975.

31. Ives, J.D., Andrews, J.T. and Barry, R.G. Growth and decay of the Laurentide Ice Sheet and comparison with Fenno-Scandinavia. Naturwissenschaften, Vol. 62, 118-125, 1975.

32. Jarvis, G.T. and Clarke, G.K.C. The thermal regime of Trapridge Glacier and its relevance to glacier surging. Journal of Glaciology, Vol. 14, No. 71, 235-250, 1975.

33. Johnson, P.G. Glacier load variations, west lobe Kaskawulsh Glacier terminus, Yukon Territory. Geoscope, Department of Geography, University of Ottawa, Vol. 5, No. 1, 63-76, 1974.

34. Johnson, P.G. The morphological effects of surges of the Donjek Glacier, St. Elias Mountains. IRRP 4, 253-258, 1974.

35. Johnson, P.G. Mass movement processes in Metalline Creek, southwest Yukon Territory. Arctic, Vol. 28, No. 2, 130-139, 1975.

36. Kenting Earth Sciences Ltd. The ice cometh. Survey, Kenting Earth Sciences Ltd., Ottawa, Vol. 5, No. 2, 2, 1974.

37. Krouse, H.R. Stable isotopes in the study of snow and ice resources. In, Advanced Concepts and Techniques in the Study of Snow and Ice Resources, an Interdisciplinary Symposium, Monterey, California, December 2-6, 1973, National Academy of Sciences, Washington, D.C., 651-660, 1974.

38. Kucera, R.E. Secrets of the Athabasca Glacier. B.C. Outdoors, Vol. 31, No. 2, 53-57, 1975.

39. Labelle, J.C. Snow studies at high elevations, Mt. Logan, Yukon. IRRP 4, 211-218, 1974.

40. Lichti-Federovich, S. Pollen analysis of surface snow from the Devon Island Ice Cap. In, Report of Activities, Part A, April to October 1974, Geological Survey of Canada Paper 75-1, Part A, 197-199, 1975.

41. Lichti-Federovich, S. Pollen analysis of ice core samples from the Devon Island Ice Cap. In, Report of Activities, Part A, April to October 197 , Geological Survey of Canada Paper 75-1, Part A, 441-444, 1975.

42. Lichti-Federovich, S. Pollen analysis of surface snow from five Canadian Arctic ice Caps. In, Report of Activities, Part B, Geological Survey of Canada Paper 75-1, Part B, 135-137, 1975.

43. Loijens, H.S. Streamflow formation in the Mistaya River basin, Rocky Mountains, Canada. Proceedings of the Western Snow Conference, 42nd Annual Meeting, Anchorage, Alaska, 86-95, 1974.

44. Marcus, M.G. A note on snow accumulation and climatic trends in the Icefield Ranges, 1969-1970. IRRP 4, 219-223, 1974.

45. McMechan, R.D. A study of Berendon Glacier new Stewart, British Columbia: recent history, variations and flow rates. B.Sc. thesis, Department of Geology, University of British Columbia, 154 pp., 1975.

46. Miller, G.H., Bradley, R.S. and Andrews, J.T. The glaciation level and lowest equilibrium line altitude in the high Canadian Arctic: maps and climatic interpretation. Arctic and Alpine Research, Vol. 7, No. 2, 155-168, 1975.

47. Miller, M.M. and Anderson, J.H. Alaskan Glacier Commemorative Project, Phase IV: Pleistocene-Holocene sequences in the Alaska-Canada Boundary Ranges. National Geographic Society Research Reports 1967, National Geographic Society, Washington, D.C., 197-223, 1974.

48. Müller, F., Blatter, H., Braithwaite, R., Ito, H., Kappenberger, G., Ohmura, A., Schroff, K., Stauffer, B. and Weiss, J. North Water Project: progress report 1 April to 29 September 1974. Unpublished progress report in fulfillment of Contract No. OSX4-0098, Marine Sciences Directorate, Environment Canada, Ottawa, 62 pp., 1974.

49. Müller, F., Blatter, H., Braithwaite, R., Ito, H., Kappenberger, G., Ohmura, A., Schroff, K. and Züst, A. North Water Project: progress report 1 October 1974 to 30 September 1975. Unpublished progress report in fulfillment of Contract No. OSX4-0098, Government of Canada, Contract No. GV-40404A1, U.S. National Science Foundation and Contract No. 2.383.70, Schweiz. Nationalfonds zur Förderung der wissenschaftlichen Forschung, 149 pp., 1975.

50. Müller, F., Ohmura, A. and Braithwaite, R. Research study of the glacio-climatology of the North Water polynya in northern Baffin Bay. Unpublished report on North Water Project field activities April 1, 1973 to March 31, 1974, Environment Canada Contract No. OSP3-0403, 58 pp., 1974.

51. Munro, D.S. Energy exchange on a melting glacier. Ph.D. Thesis, Department of Geography, McMaster University, 182 pp., 1975.

52. Narod, B.B. Ultra high frequency radio echo sounding of glaciers. M.Sc. Thesis, University of British Columbia, 1975.

53. O'Neil, R.A. and Jones, S.J.J. Radio depth sounding on Barnes Ice Cap. Journal of Glaciology, Vol. 15, No. 73, Symposium on Remote Sensing in Glaciology, Cambridge, September 1974, Abstract, 458-459, 1975.

54. Osborn, G.D. Advancing rock glaciers in the Lake Louise area, Banff National Park, Alberta. Canadian Journal of Earth Sciences, Vol. 12, No. 6, 1060-1062, 1975.

55. Østrem, G. Present alpine ice cover. In, Arctic and Alpine Environments, J.D. Ives and R.G. Barry (Editors), Methuen, 225-250, 1974.

56. Østrem, G. ERTS data in glaciology - an effort to monitor glacier mass balance from satellite imagery. Journal of Glaciology, Vol. 15, No. 73, Symposium on Remote Sensing in Glaciology, Cambridge, September 1974, 403-415, 1975.

57. Parker, G. Meandering of supraglacial melt streams. Water Resources Research, Vol. 11, No. 4, 551-552, 1975.

58. Reid, I.A. and Charbonneau, J.O.G. Glacier surveys in British Columbia - 1970. Inland Waters Directorate Report Series No. 32, Environment Canada, Ottawa, 23 pp. and 5 maps, 1975.

59. Simmons, M. Glacier inventory. In, The Mirrored Spectrum, Vol. 2, Ministry of State for Science and Technology, Information Canada ST31-2/1974-2, 88-94, 1974.

60. Simmons, M. Inventaire de nos glaciers. In, Réalisations patentes et latentes, Vol. 2, Ministère d'Etat, Science et Technologie, Information Canada ST-31-2/1974-2F, 100-107, 1974.

61. Stengle, T.R., Lichtenberg, J.J. and Houston, C.S. Sampling of glacial snow for pesticide analysis: the high plateau glacier of Mt. Logan. IRRP 4, 225-226, 1974.

62. Stupavsky, M. and Gravenor, C.P. Water release from the base of active glaciers. Bulletin of the Geological Society of America, Vol. 85, No. 3, 433-436, 1974.

63. Taylor, B. The energy balance climate of Meighen Ice Cap, N.W.T. Ph.D. Thesis, Department of Meteorology, McGill University, Vol. I, 66 pp., Vol. II, 102 pp., 1974.

64. Tupper, W.A. Peyto Glacier map sheet. Canadian Alpine Journal, Vol. 57, 58, 1974.

65. Vivian, R. Recherches galciologiques au Yukon (Canada). Annales de Géographie, Vol. 84, No. 464, 505-507, 1975.

66. Weaver, R.L. "Boas" Glacier (Baffin Island, N.W.T., Canada) mass balance for the five budget years 1969 to 1974. Arctic and Alpine Research, Vol. 7, No. 3, 279-284, 1975.

67. Whytock, J.K. An inventory of the perennial ice masses on Coburg Island, N.W.T.: a case study of glacier inventory research techniques. M.A. Thesis, Department of Geography, Carleton University, Ottawa, 181 pp., 1974.

68. Williams, L.D. The variation of corrie elevation and equilibrium line altitude with aspect in eastern Baffin Island, N.W.T., Canada. Arctic and Alpine Research, Vol. 7, No. 2, 169-181, 1975.

69. Williams, P.J. Field course in glacial hydrology. Geoscience Canada, Vol. 1, No. 4, 39-42, 1974.

70. Wood, W.A. The Icefield Ranges Research Project, 1967. National Geographic Society Research Reports 1967, National Geographic Society, Washington, D.C., 307-311, 1974.

71. Young, G.J. Glacier mass-balance and terrain shape: a methodological study. Ph.D. Thesis, Department of Geography, McGill University, Montreal, 320 pp., 1974.

72. Young, G.J. Accumulation and ablation patterns as functions of the surface geometry of a glacier. IAHS 104, 134-138, 1975.

73. Zubok, O.M. Half decade study of mass balance at Sentinel Glacier, B.C., Canada. IAHS 104, 202-207, 1975.

74. Environment Canada. Peyto Glacier, Banff National Park. Map scale 1:10,000, Inland Waters Directorate, Glaciology Division, Department of the Environment, I.W.D. 1010, 1975. (Bilingual Edition).

75. Environment Canada. Tweedsmuir Glacier, British Columbia. Map scale 1:50,000, Inland Waters Directorate, Glaciology Division, Department of the Environment, July 1974. (Bilingual Edition).

X MATHEMATICAL GEOPHYSICS

Compiled by: E. Hyland
I.E.P.P.

The Division of Mathematical Geophysics of C.G.U. has begun the process of bringing workers in the application of mathematical geophysics into closer contact in Canada. The subject is such that distinctions from other geophysical disciplines are somewhat arbitrary but the probability that the same mathematical methods may be of value in several disciplines suggests that mathematical geophysics should be independent of the more traditional geophysical disciplines. At the 1975 congress of the CAP there was a 2 day symposium on mathematical geophysics which was both well attended and showed the breadth and vitality of the activity in Canada. Future meetings of the C.G.U. will include more such symposia.

As an indication of Canadian activity in 1975, at the University of Alberta mathematical geophysics involved model studies of geodynamics, seismic risk under artificial lakes, lateral heterogeneity and the construction of synthetic seismograms. For more detail please see the section on seismology. At Memorial University in Newfoundland mathematical geophysics of core dynamics is studied extensively. The activity at Memorial University is reported under the headings Physics of the Earth's Interior and Geodesy. At the University of Toronto work continues on the study of wave propagation in heterogeneous media. For more details see the section on seismology. At York University Smylie and coworkers are active in the application of mathematical methods to geophysics.

A variational approach is being used to estimate eigen-frequencies of oscillation of stably stratified core models. The method employs piecewise cubic Hermite splines as approximating functions resulting in a quadratic eigenvalue problem for banded matrices. Instrumental development for the observation of core modes by detection of variation of gravity has proceeded in parallel to the theoretical work. Observatory data at the 10^{-11} g value is now being collected at the Montreal site.

Recalculation of the dissipation of tidal energy in the earth's mantle including the higher harmonies of the deformation field arising from the ocean response is being carried out. Early results indicate that mantle dissipation is a factor of 2 or 3 times larger than previously thought.

Application of the maximum entropy method to two dimensional problems is being investigated. Algorithms are being developed for high resolution filtering and spectral analysis of satellite data from the Canada Centre for Remote Sensing.

The geophysical research group at York has participated in experiments with Canadian radio astronomers acquiring trans-Atlantic base-line data at 2.8 cm wavelength since 1973. All the video-tape data from the 1973 experiments has now been successfully correlated. Extensive software development including a computer model of the interferometer and all known motions of the antenna relative to inertial space as well as aberration and proper motion of the source has now been completed. The inversion of the March, May and June 1973 data has yielded geodetic ties to England accurate to ±150 cm formal error for all 3 experiments.

At the University of Alberta Takashima and Aldridge have studied the stability of a horizontal layer of dielectric fluid under the simultaneous action of a vertical D C electric field and a vertical temperature gradient. They found that when the electrical conductivity is assumed to be a quadratic function of temperature the electric field can exhibit a strongly destabilizing effect on the fluid layer and the numerical results coincide with existing experimental results in order of magnitude. This problem is interesting from a geophysical standpoint because the electric field can provide the driving force in laboratory models of thermal convection in the earth's core. Further details can be found in the Geomagnetism section of this report.

Available by mail from:

Printing and Publishing
Supply and Services Canada,
Ottawa, Canada K1A 0S9

Earth Physics Branch,
Energy, Mines and Resources Canada,
1 Observatory Crescent,
Ottawa, Canada K1A 0Y3

and at Canadian Government Bookstores:

HALIFAX
1683 Barrington Street

MONTREAL
640 St. Catherine Street West

OTTAWA
171 Slater Street

TORONTO
221 Yonge Street

WINNIPEG
393 Portage Avenue

VANCOUVER
800 Granville Street

or through your bookseller

Catalogue No. M74-37/28

Price: Canada: $2.00
Other countries: $2.40

Price subject to change without notice