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# CANADIAN GEOPHYSICAL BULLETIN

# BULLETIN CANADIEN DE GÉOPHYSIQUE

## Volume 32

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# CANADIAN GEOPHYSICAL BULLETIN

# BULLETIN CANADIEN DE GÉOPHYSIQUE

## Volume 32

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**December/décembre 1979**
**Ottawa, Canada**

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# INTRODUCTION

The Canadian Geophysical Bulletin is an annual report of geophysical research and development in industry, government and universities in Canada. Its main purpose is to inform geophysicists in Canada and abroad of projects, developments and publications in their own and related areas. At the same time it provides an overview for those outside the earth science disciplines, of the extent and directions of scientific research activity in this subject in Canada. Since 1974 the Bulletin has been published under the authority of the Canadian National Committee for the International Union of Geodesy and Geophysics.

The Mining Geophysics chapter, which was one of three new chapters introduced last year, is now expanded and it is expected that the Petroleum and Engineering chapters will also grow in the next few years to reflect the great importance of these areas. This year's Bulletin contains no Volcanology chapter as the format of that contribution is being modified to better serve the geoscience community. The Aeronomy section was compiled from material kindly provided by the Space Research Facilities Branch, but unfortunately contains a very incomplete bibliography.

Once again the editor wishes to thank his colleagues who have cooperated so readily in supplying the information which makes up the Bulletin, and in particular the compilers of the chapters for the time and effort which they have spent in collecting and organising the material included herein. It is also a pleasure to acknowledge the assistance of Ms. M.S. Bradfield and Ms. J. Breton in preparing the typescript.

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

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M.E. Evans
Editor

# INTRODUCTION

Le Bulletin canadien de géophysique est un rapport annuel des recherches et des développements géophysiques dans l'industrie, le gouvernement et les universités au Canada. Le but principal du Bulletin est d'informer les géophysiciens au Canada et à l'étranger des projets, des développements et des publications dans leurs propres disciplines en plus que les disciplines connexes. Pour ceux hors des disciplines des sciences de la terre, il fournit un exposé des étendues et des directions de la recherche scientifique à ce sujet au Canada. Depuis 1974, le Bulletin est publié sous la direction du Comité National du Canada de l'Union Géodésique et Géophysique Internationale.

Le chapitre sur l'exploitation minière, un des trois nouveaux chapitres présentés l'an dernier, a été augmenté et l'on envisage le développement des sections sur le pétrole et l'ingénierie, en raison de l'importance de ces domaines. Cette année, le Bulletin ne contient aucun chapitre sur la volcanologie, puisqu'on modifie actuellement la façon de présenter ce sujet, afin de mieux servir les géoscientifiques. La section sur l'aéronomie, rédigée à partir de matériel fourni par la Direction des installations de recherches spatiales, ne contient qu'une bibliographie très incomplète.

Encore, le rédacteur désire rendre un témoignage reconnaissant à ces collègues pour leurs coopérations en fournissant l'information nécessaire à la composition du Bulletin et en particulier aux compilateurs des chapitres pour le temps et effort dépensé à la collection et à l'organisation du matériel ci-inclus. Nous tenons aussi à remercier Md. M.S. Bradfield et Md. J. Breton pour la préparation des documents pour fins d'impression.

Le bulletin est publié et distribué aux lecteurs au Canada et à l'étranger par la Direction de la physique du globe du Ministère de l'Energie, des Mines et des Ressources à la demande du Comité National du Canada de l'Union Géodésique et Géophysique Internationale et le Conseil Canadien des Sciences de la Terre. Les demandes pour obtenir des exemplaires individuels et des éditions précédentes doivrent être acheminées au:

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M.E. Evans
Rédacteur en chef

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# I (A) GEODESY

Compiled by: D. E. Wells

1. Geodetic Survey of Canada
2. National Research Council, Division of Physics
3. Bedford Institute of Oceanography
4. Canadian Hydrographic Service
5. Université Laval
6. University of New Brunswick
7. York University
8. Bibliography

## 1. Geodetic Survey of Canada

### (a) Horizontal Positioning

Primary and secondary horizontal control was established using satellite Doppler, conventional methods and the Inertial Survey System, thus providing increased density in both urban and sparsely populated areas.

Eighty-four satellite Doppler positions were observed as follows: Newfoundland (12), Quebec (14), Ontario (22), Manitoba (3), Hudson Bay (6) and Arctic Islands (27).

In urban centres forty-two 1st order and twenty-one 2nd order horizontal control points were provided by triangulation/trilateration. One new precise calibration baseline was measured at Scarborough, Ont. four others were re-measured bringing to 19 the total now located at various major urban centres. Forty-nine astronomic determinations (13 Laplace and 36 deflection) were made in various locations to support field operations and research.

The Inertial Survey System was employed extensively in the prairie provinces for secondary control surveying. The transportation mode was by helicopter. This combination produced 17,870 km of traversing and covered an area of 156,000 $km^2$. Mapping control for 172 map sheets was provided.

### (b) Vertical Positioning

Primary vertical control totalling 5290 km of levelling was completed in 1979. Of this total, new levelling accounted for 1515 km and relevelling of existing lines, 3775 km. Relevelling of tidal gauges on the St. Lawrence Seaway, east of Kingston, provided further data on their stability.

Vertical control for mapping was established by altimeter traverses. This was concentrated in Manitoba (5700 km), Northern B.C. (2800 km), and the Arctic Islands (600 km). A further 4500 km of vertical control traversing in Quebec was completed by Ground Elevation Meter (GEM), and a combination of GEM and spirit levelling was used in Eastern Ontario to furnish vertical mapping control.

### (c) Data Processing and Banking

Development of the automated computer-based data file continued. Positional data for approximately 127,000 stations have now been automated.

Preparation for participation in the new 1983 North American Datum (NAD83) adjustment of North American horizontal networks is continuing. Primary network data was prepared for a preliminary test adjustment to be computed in 1980 when the new datum is defined. The basic primary horizontal framework has been completed and is ready for adjustment on reasonably short notice. New densification work is added each year to the framework file. At present the primary horizontal framework consists of 5,800 terrestrial network stations and 425 satellite Doppler stations, 170 of which are known as the basic satellite framework. Of these, 120 coincide with the terrestrial network stations.

Evaluation of secondary networks is continuing. Geodetic Survey assumes responsibility for approximately 32,000 secondary and 52,000 lower order stations. About half of these secondary surveys have now been evaluated. One block of approximately 2,000 stations mainly in the Yukon has been adjusted using computer programme GANET. Close co-operation with provincial survey agencies is being maintained to exchange data in connection with the integration of secondary and lower-order networks to the NAD83 adjustment.

Automation of the Vertical Reference System was continued in 1979. The trans-Canada line and several other loops have now been automated.

Relevelling of the Primary Vertical network continued at an accelerated pace to bring many old level lines up to date.

(d) Research Activities

Investigations related to datum for the 1983 Redefinition of North American Horizontal Geodetic Networks was pursued, and astronomical longitude orientation differences between Canadian and U.S. observations were the object of a detailed investigation. The mathematical mapping of horizontal network distortions was investigated using complex variables and least squares estimation techniques in order to evaluate lower order geodetic coordinate displacements due to datum changes.

Research related to the 1987 Redefinition of North American Vertical Geodetic Networks was contracted out to the University of New Brunswick. The overall status of this redefinition project is described in Lachapelle, 1979a, d; Lachapelle & Whalen, 1979.

Several topics related to the earth's gravity field were investigated. Gravimetric geoid undulations were compared with Doppler derived undulations at 120 North American stations in order to assess the accuracy of both solutions and obtain an estimate for the semi-major axis of the mean earth ellipsoid. Deflections of the vertical in the Rocky Mountains were evaluated with an accuracy of $2''.0$ to $2''.5$ using a combination of topographic-isostatic and astrogeodetic data. Local characteristics of the gravity anomaly covariance function using Canadian gravity data were investigated. A method to predict gravity anomalies in mountainous areas using the correlation between heights and gravity anomalies and a least squares prediction method was developed. The departure of the vertical reference system used to calculate free-air gravity anomalies of the Canadian National Gravity Data Base from a single equipotential surface was investigated.

Many aspects of inertial positioning were investigated. A computer program was developed for covariance analysis studies of local level inertial survey systems in order to study the various error mechanisms and improve filter design. The combination of inertial and satellite Doppler positioning data was continued. Other research was contracted out to the University of New Brunswick.

In the field of satellite positioning, investigations of the external accuracy of semi-short arc Doppler surveys carried out during the past few years were made, based on reoccupations of stations previously positioned using precise satellite ephemerides and comparisons with positions derived by U.S. NGS geoceivers. A field program for testing of satellite Doppler receiving equipment was designed and carried out; in connection with this, long line tests were conducted in cooperation with The Ohio State University between Ottawa and Columbus using ten receivers simultaneously. Another performance test of receivers was completed, and this, together with other investigations described above, was used to assemble guidelines and specifications for satellite Doppler surveys which are to be published in 1980. Some of the above experimental test data will be processed with the original and new versions of the GEODOP software in order to analyse the significance of recent GEODOP modifications.

Various technological research studies were conducted. Studies of the Mekometer stability, invar levelling rod calibration and the stability of the national baseline were carried out. The development of the Automatic Transit Detector (ATD), a microcomputerized transit instrument for geodetic astronomy, was continued. The study of new procedures and techniques for precise levelling was initiated. Field experience with the Lambert "Twin" tower for geodetic measurements carried out during past years was documented in Swanson, 1979.

A Geodetic Survey plan for geodetic research and development in the 1980's was developed.

2. National Research Council, Division of Physics

(a) Photogrammetric Research Section

Research has been continued in the field of refraction and its application in geodesy and photogrammetry.

(b) 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 UT1. The first leap second occurred at the end of June 1972, and subsequently at the end of December each year.

The value of DUT1, which is the difference between UT1 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 V-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 DUT1 and leap seconds, several weeks in advance.

The NRC CsV primary cesium standard of time and frequency has been operating continuously since May 1, 1975, and has demonstrated accuracy and stability of 1-2 microseconds per year. Three new primary cesium standards, CsV1 A, B and C, have been built, and will improve further the reliability and stability of the NRC time scale.

In July 1978 two-way satellite time transfers began between NRC and Observatoire de Paris using the Symphonie satellite, and between NRC/NBS and NRC/USNO using the Hermes satellites. These experiments have shown that precision of a few nanoseconds can be attained in comparing times, and that the frequencies of the time scales can be compared internationally to $1 \times 10^{-14}$.

3. Bedford Institute of Oceanography (Canadian Hydrographic Service and Metrology Division)

(a) Integrated Navigation

The BIONAV integrated navigation system was used operationally on "Hudson" from mid-1979 onwards. User response indicates it has achieved its design goals of reliability, ease of operation and versatility. BIONAV was also used to position the main and satellite camps on the LOREX operation. BIONAV integrates passive ranging LORAN-C, satellite navigation, ships log and gyro compass, with the capability of accepting Decca, Omega and Mini-ranger inputs. Outputs include magnetic tape, video monitor, link to another computer, etc. Work will continue to extend and adapt BIONAV to other inputs and outputs, and to meeting specific users' needs.

(b) Phase Prediction and Performance of LORAN-C

Analysis of last year's LORAN-C calibration in nearshore waters shows smooth results with a variability of about $\pm 0.2 \mu s$ (equivalent to about $\pm 60$ m). As $0.2 \mu s$ roughly represents the combined stability of the chain and a receiver, land-path error calibration is shown to match the other aspects of system performance. The results are being incorporated in the charts. Further experimental work is being done close inshore, and the ability of theory to predict land-path error over a complex coastline is being tested.

(c) Tides

Work on vertical tidal measurement and analysis is being concentrated on the continental margins, and particularly the Labrador Sea. A small part of the effort is to be directed to the deep ocean. Work is being done under contract with respect to the development of a sophisticated acoustic telemetry link to transmit tidal data from a bottom mounted pressure gauge to a remote site. This work is at present in the design stage.

(d) Hydrographic Development

Tests on high-speed towing of sidescan sonar showed that sufficient quality for hydrographic work can be achieved when speed is increased from the usual 5 kts to 12 kts. A comparison of plotters for producing hydrographic field sheets is underway, looking at the speed, accuracy, quality, etc. A number of programs have been developed to solve survey and navigation problems, projections, etc., in Fortran and for the H.P. 9815 and TI 59 calculators.

4. Canadian Hydrographic Service

(a) Tides, Currents and Water Levels Division

The Tides, Currents and Water Levels Division sponsors a network of water level gauging stations along the shores of Canada's coastal and inland navigable waters. The accumulation of long and continuous time series of water level data at these stations contributes to studies of sea level variations and vertical crustal movements, as well as to the establishment and control of vertical datums for levelling networks. Off-shore tidal information is also being gathered by moored deep-sea pressure gauges. The CHS continues to operate the IHO Tidal Constituent Bank through the facilities of the Marine Environmental Data Service.

(b) Nautical Geodesy Section

The Nautical Geodesy Section completed submitting all CHS horizontal survey control to the Geodetic data bank, thereby completing a task begun in 1978. A data file was established containing an up-to-date listing of all fixed aids, providing the latest positions and characteristics as well as a complete historical record for each individual aid. An adjustment programme was continued in preparation for the NAD 1983 redefinition. Cape Breton Island and the eastern shore of Nova Scotia were the areas that received immediate attention. Nautical Geodesy participated in several calibration exercises, assisting in collecting and analyzing the data, and providing parameters for the navigational charts.

5. Université Laval

Le project sur l'application du nivellement géométrique pour l'évaluation des variations à long terme de l'inclinaison de la croûte terrestre à l'Observatoire géophysique de Charlevoix a été complété. La méthode d'observation qui a été développée permet de définir la position relative de repères avec une précision de l'ordre du microradian. Les mesures se poursuivront à l'Observatoire de Charlevoix avec cette méthode et une analyse comparative sera faite avec les résultats obtenus à l'aide des inclinomètres localisés dans une voûte sur le même site. Une analyse de l'influence de la réfraction sur les observations de nivellement est également en cours.

Une étude du potentiel des gyrocompas suspendus a été amorcée en vue d'en permettre une utilisation plus étendue en géodésie. Une théorie originale du gyrocompas suspendu a été développée et les résultats permettent d'envisager des procédures de mesures améliorées, de meilleures méthodes de réduction des observations et l'obtention d'une précision accrue dans la détermination de l'azimut astronomique.

Un programme de recherche sur différents problémes reliés à l'application de la méthode de positionnement Doppler est en cours. Un premier project a pour but de définir les paramètres d'intégration des données Doppler au systéme géodésique officiel du Québec et d'analyser différents systèmes de traitement des données Doppler. Un autre project a été amorcé, en collaboration avec l'Observatoire Royale de Belgique et la Division de la Physique du Globe, E.M.R., en vue d'analyser l'évaluation dans le temps des coordonnées de trois stations permanentes (Bruxelles - Ottawa - Mizusawa).

6. University of New Brunswick

Research continued on problems related to the redefinition of vertical networks in Canada. The authors present their proposals on many of the problems associated with the redefinition, based on recent theoretical developments and experiments in the areas of residual atmospheric refraction; earth tides and ocean loading; vertical crustal movements: uniquely defined height systems incorporating observed gravity data; the influence of physical effects on mean sea level as a datum; and new approaches to weight estimation and statistical dependence in levelling. The significance of these developments and results is treated in the context of the main successive stages of redefinition: (a) raw data reduction, including newly formulated corrections and rejection criteria; (b) conversion of "instrumental" elevation differences to uniquely defined height differences; (c) introduction of an appropriate vertical datum and the role of sea level data and possible extra-terrestrial control; and (d) some aspects of network adjustment and analysis, including weight estimation and the treatment of vertical dynamics. Research was also carried out on the proper inclusion of sea level data in the forthcoming readjustment of the North American vertical geodetic networks. A review of errors in precise geodetic levelling was reported in Anderson, 1979a.

An investigation on the theoretical level of correlation in levelling was carried out in which the construction of covariance models and investigation of error propagation was treated. In Vanicek, Castle and Balazs (1979) work is reported on: an investigation of a datum for vertical movements, a formulation of the effect of correlation in levelling on the accuracy of vertical crustal movement determinations, formulation of gravity requirements for levelling and a rigorous proof that any height system based on actual gravity closes.

Work was carried out over the past three years at UNB, in cooperation with the Earth Physics Branch, on the compilation of a map of vertical crustal movements; this work has been summarized in several publications.

Research continued on the use of inertial measuring units in geodesy and surveying. A review of mathematical and statistical models is given in Schwarz (1979a) and investigations on the analytical form of the transition matrix for local-level systems are presented in Wong and Schwarz (1979). The error propagation in inertial positioning has been examined and a full variance-covariance matrix for the determined stations derived. A simulation program for local-level systems has been developed by Adams (1979) and a covariance analysis program by Wilkinson (1979). Studies of the vertical deflection determinations and extensive tests to determine the accuracy and precision of inertial positioning have been carried out.

Empirical investigations of the covariance function of the gravity anomalies are presented in Schwarz and Lachapelle (1979) for most of the Canadian mainland and coastal areas. Improperly posed problems which play a role in the downward continuation of gravity are reviewed in Schwarz (1979d) and their relation to least-squares collocation methods is discussed in Rummel et al (1979).

Research has been initiated at U.N.B. to determine whether the GEOS-3 altimetry can add to our knowledge of geoid in Northern Canada. GEOS-3 satellite radar altimeter data available for Hudson Bay and the Northwestern Atlantic region were collected from September to December 1976 from telemetry station at Caribou, Maine. To date (September 1979) from a total of about 600 passes of data acquired by this station, 238 passes have been received, processed and stored in the data base maintained at U.N.B. The computation of an altimeter derived sea surface of Hudson Bay is being carried out. Comparison with detailed geoids derived from astro-gravimetric data supplemented by selected satellite data (e.g. Doppler derived geoid heights) will follow. Editing and merging of the available data have been performed, and analytical tidal models have been developed and used to correct the data for the tidal effect. A regional adjustment of a network of about 100 Altimetry Arcs is currently underway.

A detailed geoid is being computed for the area 52° N to 70°N and 70°W to 100°W from observed gravity data, Doppler satellite data, GEM 10 spherical harmonic coefficients of the Earth's gravity field and astrogeodetic deflections of the vertical. The development of the software required is very nearly complete.

A systematic list of effects and corrections to geodetic quantities due to the earth's body tides and ocean loading has been compiled in Vanicek (1979a).

Research is being carried out to extend the Vanicek method of Least Squares Spectral Analysis to incorporate a covariance function of the observed time series.

Results of research on the application of tensor apparatus and commutative diagrams to linear parametric least squares is reported in Vanicek (1979b).

A summary of research done in modelling recent vertical movements in Southern California utilizing scattered geodetic relevelings and tide-gauge records is given in Vanicek, Elliott and Castle (1979).

## 7. York University

Research is continuing at York University on the applications of long baseline interferometry (LBI) to geodesy and geodynamics.

We have recently completed an LBI-Doppler satellite validation program using a three element interferometer composed of antennae at Lake Traverse, Ontario, Canada, Big Pine California, USA, and Chilbolton, England. At each of these sites Doppler receivers were set up within 100m of the LBI antenna simultaneously with the acquisition of the LBI data.

Results of this work indicate that after correcting the Doppler data for a revised value of GM and for the effect of the displacement of the satellite antenna phase centre from the satellite centre of mass there remains a scale bias between the IAU-BIH coordinate frame and the Doppler NSWC 9Z-2 coordinate frame of 0.48 $\pm$ 0.05 PPM and a difference in longitude origin of $0\overset{''}{.}87 \pm 0\overset{''}{.}01$. In addition the interferometer coordinates were rotated in declination relative to the Doppler coordinates by $0\overset{''}{.}05 \pm 0\overset{''}{.}01$.

Accurate coordinates for seven extra-galactic compact radio sources were obtained, the errors in right ascension being of the order of $\pm\ 0\overset{''}{.}002$ and in declination of the order of $\pm\ 0\overset{''}{.}03$.

Work is continuing in conjunction with J.L. Yen of the University of Toronto, J.A. Galt of Dominion Astrophysical Radio Observatory at Penticton, B.C. and the Herzberg Institute of Astrophysics on a satellite phase linked interferometer for Earth rotation studies. This program makes use of the new ANIK-B communications satellite.

Work will also commence in 1980 in conjunction with J.L. Yen at the University of Toronto and the Herzberg Institute of Astrophysics on a Canadian version of a wide band group delay measurement program for precision geodesy. It is expected that the system being developed will be superior to the MIT/GSFC Mk I system and ultimately competitive with the new Mk III system being deployed in the U.S. and elsewhere.

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# I (B) GRAVITY

Compiled by: R.A. Gibb


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   (b) Gravity Data Base
   (c) Gravity Map Production
   (d) Gravity Surveys
   (e) Gravity Interpretation and Related Studies
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4. Nova Scotia Research Foundation Corporation
5. Ontario Geological Survey - Ministry of Natural Resources
6. Dalhousie University
7. University of New Brunswick (Department of Geology)
8. University of New Brunswick (Department of Survey Engineering)
9. Laval University
10. McGill University
11. University of Manitoba
12. Canadian Society of Exploration Geophysicists
13. Bibliography


## 1. Introduction

This report has been compiled from information provided by various sources believed to be the principal contributors to gravity investigations in Canada. A report on the activities in the field of geodynamics carried out by the Earth Physics Branch has been included in this summary of activities.

## 2. Earth Physics Branch

### (a) Gravity Standards

In an attempt to detect second and higher order components in the calibration correction function of LaCoste and Romberg gravimeters an experiment was carried out jointly with three Italian and one U.S. agency whereby twelve gravimeters were observed in ladder sequence over twelve absolute stations between Catania, Italy and Hammerfest, Norway.

In preparation for the readjustment of the National Gravity Net in 1980 to meet future requirements for high precision geodetic and possible secular variation studies, the reobservation of the first order net comprising some 60 stations and their related excentres began early this year. The work will be carried out partially under contract and is scheduled for completion in mid-1980.

The maintenance service for IGSN71 and the Latin American Network (LAGSN77) continued but at a somewhat reduced level from previous years.

### (b) Gravity Data Base

The National Gravity Data Base, now largely converted to operation under System 2000, continues to be a stable and effective means for storage and distribution of digital gravity data. Some 400 retrievals were processed during the past year for both internal and external users.

In collaboration with the Geodetic Survey of Canada an investigation was undertaken of the absolute accuracy of the vertical reference datum used to determine the heights of gravity stations in older surveys.

(c) Gravity Map Production

Three new open file gravity maps were released during the year. Details describing the type of map (Bouguer and/or free-air), map scale, and location can be found in the bibliography.

(d) Gravity Surveys

During 1979 more than 3000 new static gravity stations were occupied over the Canadian mainland and offshore areas and about 19,000 line kilometres of dynamic gravimeter profiling were logged off the east and west coasts of Canada and in the Arctic Ocean.

(i) Western Canada

In the Rocky Mountains south of latitude 53°N, 325 new gravity stations were observed during the second year of a three year contract. The experience gained by the contractor, in the first year of the contract, in the use of a helicopter mounted inertial survey system, to determine latitude, longitude and elevation of gravity observation points, was reflected in a significant improvement in data quality during the 1979 survey.

During a contracted survey, in support of a requirement of the Geodetic Survey, Surveys and Mapping Branch, Department of Energy,
Mines and Resources, about 1600 gravity stations were observed along precise geodetic level lines in British Columbia, Alberta, and the Yukon. The survey was carried out in two areas. In the Yukon, about 750 gravity stations were observed at 1 km intervals along the Dempster and 60-mile highways; in Alberta - British Columbia, more than 800 gravity stations were observed at 1 km intervals between Lethbridge, Alberta and Osoyoos, British Columbia, following highway route No. 3.

More than 4600 line kilometres of gravity profiling were completed during a 19 day cruise on board the CSS PARIZEAU in October/November in Hecate Strait east of the Queen Charlotte Islands. Profile separation was 5-10 km.

(ii) Arctic Ocean

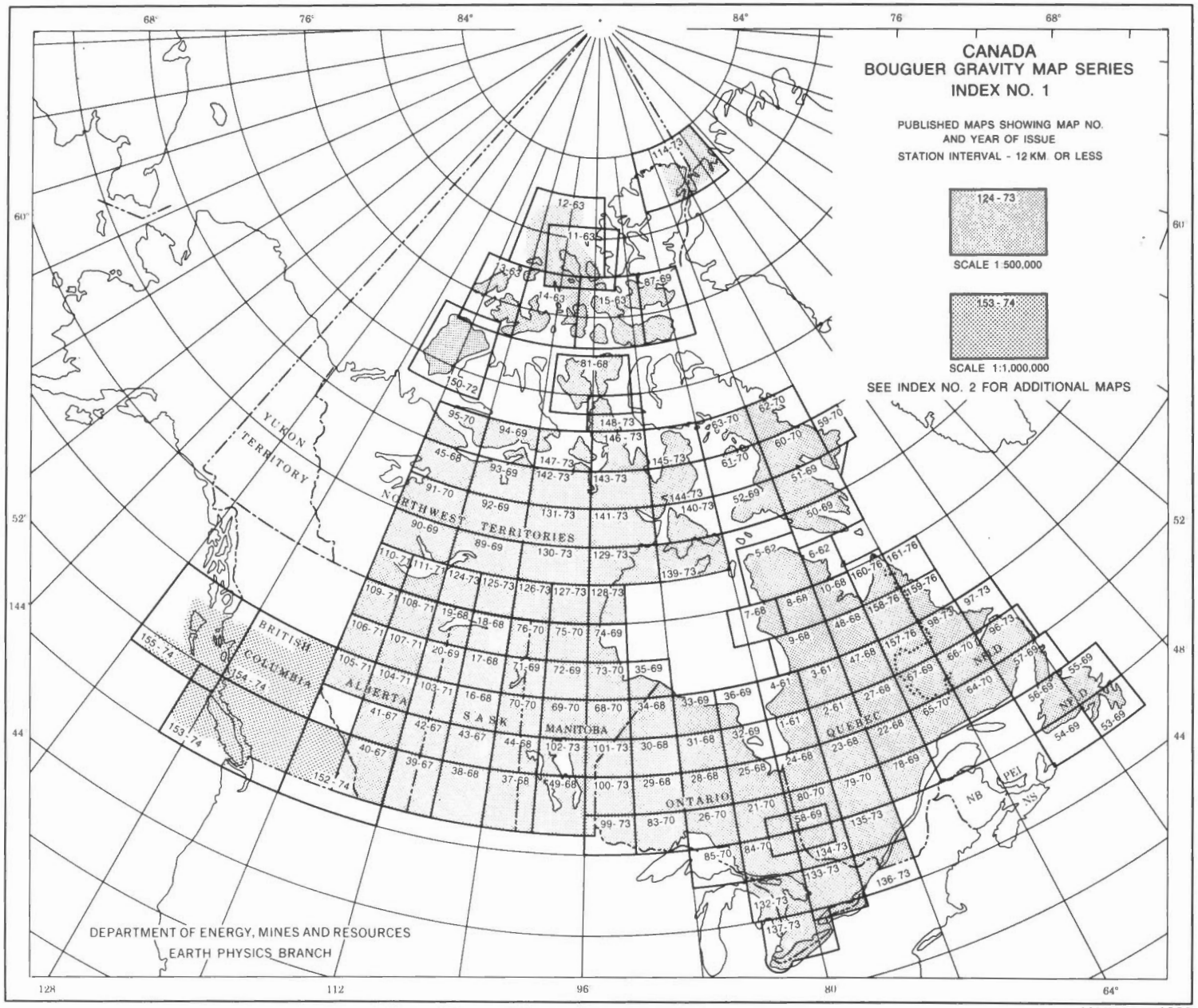
About 700 gravity stations were observed in April and May in the vicinity of the geographical north pole as part of the Lomonosov Ridge Experiment (LOREX 79). More than 250 of these stations were observed on the frozen ocean surface using helicopter transportation. Station spacing averaged 6 km. In addition more than 400 line kilometres of gravity profiling were observed using instrumentation installed at three ice island campsites, which drifted across the Lomonosov Ridge. Station density along the profiles varied from 1 - 5 km.

(iii) Hudson Bay

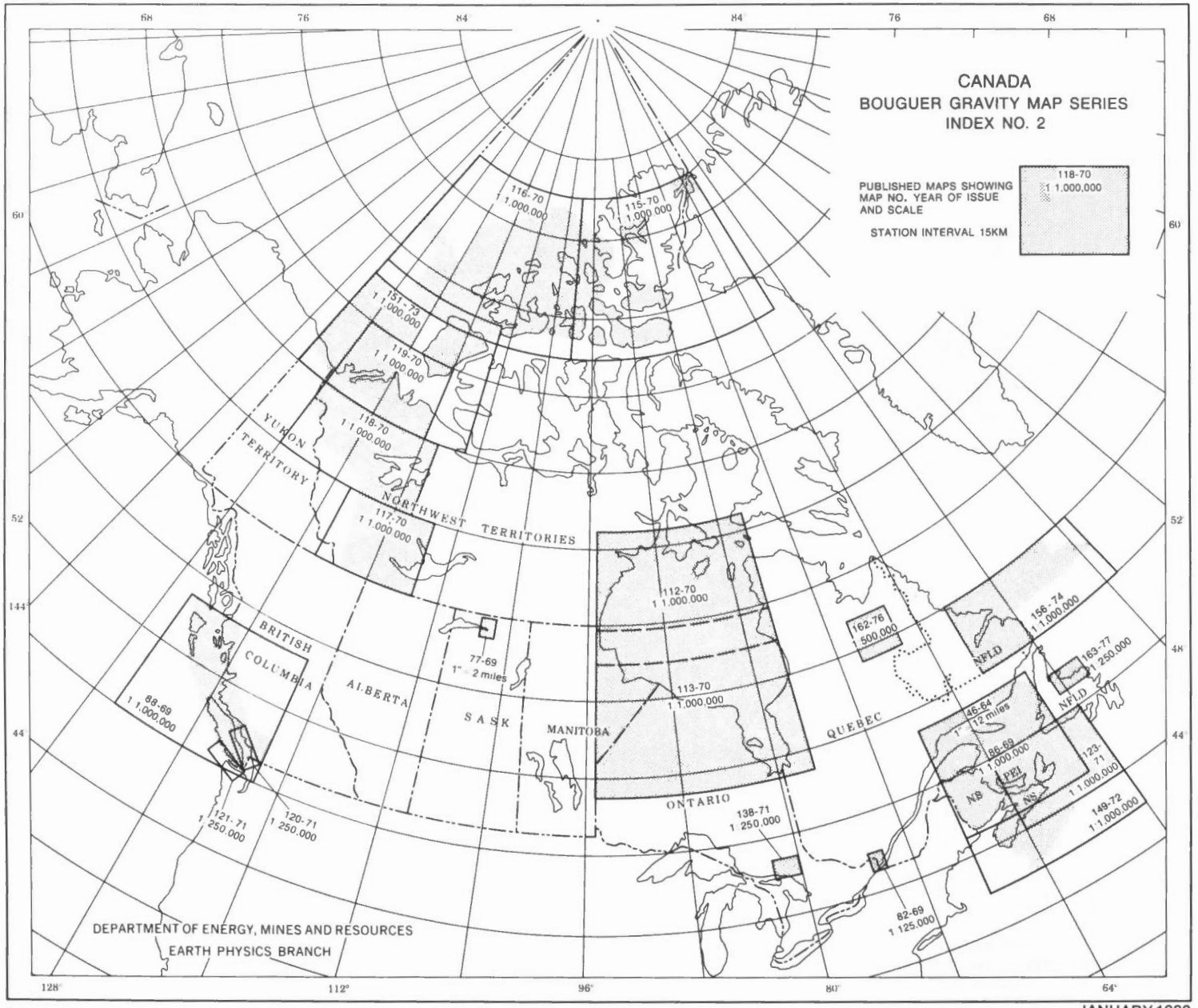
A survey on the frozen surface of Hudson Bay between the Ottawa Islands and the mainland was completed by contract. 429 stations were observed.

(iv) Eastern Canada

A six week cruise aboard CSS BAFFIN in cooperation with the Atlantic Geoscience Centre was completed over part of the Scotian shelf located about 550 km southeast of Halifax. About 14,000 line




JANUARY 1980

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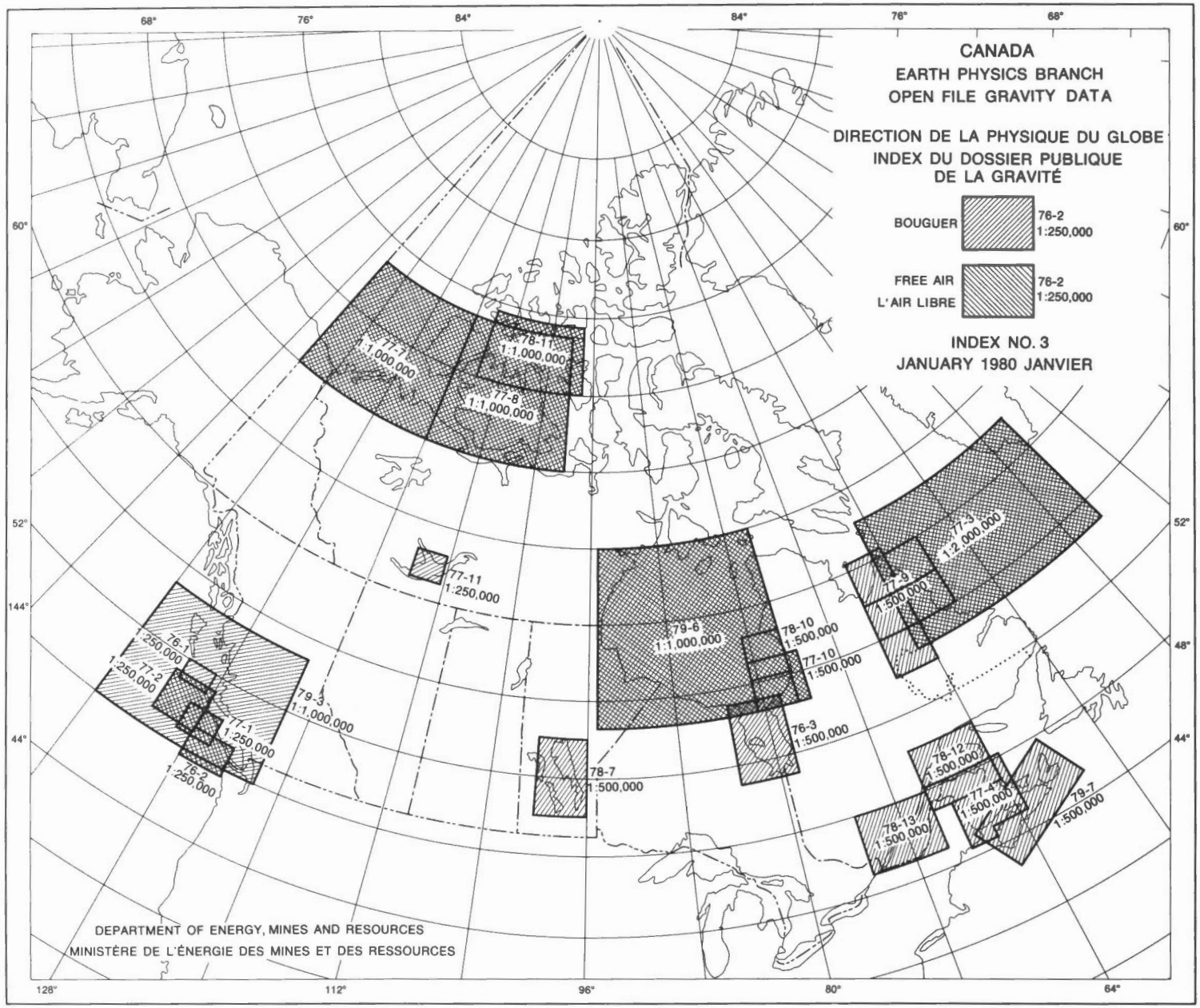
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MINISTÈRE DE L'ÉNERGIE DES MINES ET DES RESSOURCES
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kilometres of gravity profiling were collected. Profile separation averaged about 40 km.

(e) Gravity Interpretation and Related Studies

(i) Western Canada

Juan de Fuca Plate Map

A full colour shaded bathymetric and topographic relief map of the area of the Juan de Fuca plate and its zone of interaction with the North American continent at a scale of 1:2,000,000 was published. The map is available in a set with black-white contour only and grid only versions at the same scale.

Dellwood Knolls

Interpretative work on the Dellwood Knolls has been completed. The complex migration of the Explorer Ridge north-westwards coupled with the initiation of Dellwood Knolls spreading in older crust seems to be part of the triple junction development pattern which has controlled recent structure in the Winona Basin - Tuzo Wilson Knolls area over the last 4 m.y.

Gorda Plate

Application of the magnetic anomaly analysis techniques used previously in the Explorer Plate and Nootka Fault areas to the Gorda Plate off southern Oregon suggests that an active right-lateral fracture zone may exist within the plate and that convergence in the area immediately north of Cape Mendocino stopped at about 1.5 Ma b.p.

Queen Charlotte Fault and Winona Basin

Interpretation of gravity data over the Queen Charlotte Fault Zone has confirmed the existence of up to 5 km of sedimentary material beneath the terrace and suggests the existence of a sliver of older crust lying between the two boundary scarps. Interpretation of gravity data over the Winona Basin in conjunction with a detailed study of seismic profiling data agrees with the 5 km sediment thicknesses suggested by seismic reflection data but disagrees with the thicker crustal section interpreted previously from refraction data.

Geodynamics of Juan de Fuca Plate

A major review of the geodynamics of the Juan de Fuca plate was prepared by a number of authors from Pacific Geoscience Centre, UBC and some U.S. institutions. This review forms the Final Report of the Juan de Fuca Plate Study Group of Working Group II of the Geodynamics Project and will be published in the Final Report volume by AGU. The review summarizes the developments in the understanding of the geodynamics of the Juan de Fuca plate since 1971 and includes a bibliography selected to give key entry points into the accumulated literature.

(ii) Arctic Canada

Arctic Ocean (Tectonics)

An updated summary of Arctic Basin structure and tectonic evolution has been prepared which incorporates several new polar studies completed over the past year. In this report evidence is

presented to suggest that the Fletcher abyssal plain, which lies between the Alpha and Lomonosov ridges, may have been produced by seafloor spreading and, further, that the Alpha Ridge may be a fragment of continental crust.

A second report focuses on the polar continental margin of North America and reviews geophysical and geological data collected along this zone. This information is used to assess some major features of present margin structure and dynamics. Geological and crustal seismic data are then combined to reconstruct the probable sequence of Phanerozoic tectonics that affected the region of the polar boundary both before and after its inception.

Arctic Ocean (Gravity)

Preliminary interpretation of LOREX 79 data shows a free air high of up to 120 mgal over the ridge crest and flanking gravity lows between 0 and -35 mgal about 40 km on either side of the crestal zone. The minimums are less pronounced than expected and may indicate that the ridge does not have a very large low density root.

Sverdrup Basin

An analysis of gravity and seismic data (shallow and deep) along two detailed lines across the western Sverdrup Basin indicates that the Sverdrup Basin, an overlying successor basin, is about as thick as the Franklinian Geosyncline, that sediments are regionally isostatically compensated by a mantle antiroot, and that the thickness of the crystalline crust varies inversely with the overlying sediments.

(iii) Eastern Canada

Northern Appalachians

A gravity-magnetic study (in collaboration with Concordia University) of the Sutton Gravity High, located southeast of Montreal and immediately northwest of Sherbrooke, suggests that the anomaly can be explained by a thick volcanic pile which crops out in a discontinuous belt along the axis of the Sutton Mountain Anticlinorium where it is known as the Tibbit Hill Greenstone.

(iv) Canadian Shield

Eastern Churchill Province

A series of regional gravity anomalies in the eastern Churchill province of the Canadian Shield, running parallel to the structural boundaries with the Superior and Nain provinces, has been ascribed to major fault-bounded crustal blocks. The occurrence of these blocks to the east of what has earlier been interpreted as the site of an ancient subduction zone and eventual continental collision (Labrador Trough), and several common geological features, has suggested that the region has a geological analogue in the central Andes of Peru.

Eastern Hudson Bay

Recent marine gravity surveys in eastern Hudson Bay (1976-79) show that the distinctive linear gravity pattern of paired positive and negative anomalies associated with the Cape Smith foldbelt of northern Ungava extends southward into Hudson Bay to the

Belcher Islands. Interpretation of five gravity profiles across the Cape Smith and Belcher foldbelts suggests that the Churchill crust is thicker and denser than the Superior. The boundary between the two contrasting crustal blocks (interpreted as a collisional suture) can be traced southward from Cape Smith.

Gravitationally Induced Stresses at Structural Boundaries

Prominent gravity anomalies consisting of paired positive-negative belts occur in Canada at structural boundaries between Precambrian geological provinces. The associated anomalous masses produce what are termed gravitationally induced stresses. These stresses may contribute to the failure of rocks along pre-existing faults, or other zones of weakness. Studies suggest that failure at shallow depths in the crust is likely to occur in the region outlined by the negative gravity anomaly whereas failure deeper within the crust and upper mantle may occur beneath the positive anomaly.

Yellowknife Density Study

In 1977 and 1979 gravity measurements were made in two goldmine shafts sunk in the Archean Yellowknife greenstone belt, to determine the in situ densities of basic volcanic rocks of the Kam Formation, Yellowknife Supergroup. Densities were computed from the gravity results with appropriate corrections for surface terrain and underground voids such as shafts, drifts and stopes.

Extension of Yellowknife Greenstone Belt into Great Slave Lake

The results of a gravity survey carried out on the frozen surface of Great Slave Lake suggest that the Yellowknife greenstone belt extends offshore for some 12 km and then swings southeast along the North Arm of the lake for a further 60 km. A three-dimensional model of the greenstone belt was derived from the gravity anomalies.

Northern Saskatchewan

A gravity survey has been undertaken in the Wollaston-Waterbury Lakes area bounded by latitudes 58° 08'N, 58° 22'N and longitudes 102° 30'W, 104° 15'W to test the feasibility of the gravity method for locating uranium deposits. The survey forms part of a larger geophysical, geological and geochemical program sponsored by the Nuclear Energy Agency and International Atomic Energy Agency (NEA/IAEA). About 240 gravity stations were observed by the Earth Physics Branch at a 2 km station interval to map the regional field and 134 rock samples were collected for density analysis. Asamera Oil and Gas Corporation Limited has provided 2500 previously established gravity stations at 1 km station intervals for use in the study and Numac Oil and Gas Company Limited has provided 1000 previously established gravity stations on a 200 x 400 ft grid over part of Midwest Lake for future detailed studies.

(v) Gravity Interpretation Methods

A 2-D program for gravity interpretation developed previously has been updated by the addition of a plot package, which allows the user to plot cross-section, terrain, observed gravity, calculated gravity, and residual gravity at specified scales in a variety of combinations. By the proper choice of scales for horizontal and vertical distances, plots ready for publication can be produced.

The program for 3-D gravity interpretation previously developed in the Division has been updated to provide a printer plot of gridded values and to format the output for automatic contouring by GPCP.

(f) Dynamic Gravimetry Research

A second test to determine the capability of the LaCoste and Romberg inertial platform to measure positions on solid surfaces has been completed with the following results (one sigma):

| | |
|---|---|
| Elevation | 120 cm |
| Horizontal position | 20 m |
| Gravity | 0.3 mgal |

A third test to extend the results to helicopter operations is planned.

(g) Geodynamics

(i) Precise Gravimetry

Semi-annual resurveys of precise gravity networks in seismically active areas of Charlevoix, Québec and Vancouver Island, B.C. continued through 1979. Temporal variations in gravity of the order of 200-300 $nm/s^2$ (20-30$\mu$gals) are observed at Charlevoix. Comparisons of these gravity data with tilt and seismic travel time data have revealed some interesting correlations. A preliminary physical model for crustal deformation at Charlevoix is emerging from these studies. Gravity variations of the same order are observed on Vancouver Island. These variations can be modelled in terms of the attraction effect of lake-level variations.

Calibration tests on LaCoste and Romberg model D gravimeters are continuing. The objective of these tests is to explain systematic discrepancies observed from time to time when comparing results from different instruments.

(ii) Measurement of Crustal Tilt and Strain

Two crustal deformation observation sites were operated during 1979 at Charlevoix, Québec. Observations of tilt, strain and borehole water-levels were made at the main site. Tilt and borehole water levels were also observed at a second site 8 km away. Observed seasonal and transient variations in tilt and strain at the main site can be explained in terms of deformations of the observation vault under the influence of surface temperature variations and episodes of flooding or by strains induced in the local rock formations due to heavy rainfall. No transient events that could not be explained by either high rainfall ($>$ 1 inch per day) or melting episodes have yet been observed at the two sites in Charlevoix. Longer term trends in tilt observed at the main observatory correlate with gravity variations detected in the vicinity and suggest the presence of ongoing crustal deformation. It is too early to relate these phenomena to the seismicity of the area. Coseismic offsets were observed in tilt, strain and water levels at the time of the August 19/79 M = 5.1 earthquake. The sense and amplitudes of the offsets indicate that they are dominated by the distorting effects of local rock structure. Work has continued at the Pacific Geoscience Centre, Sidney, B.C. on the design and construction of a hydrostatic tiltmeter system for detection of long term tilt.

(iii) Vertical Crustal Movements

A vertical crustal movement map of Canada has been compiled by the University of New Brunswick and the Earth Physics Branch. Trends in water levels from over one hundred tide gauge stations have been combined with data from a file of relevelled segments from across the country. Surface fitting to the data for each of several regions has now been combined into a single national map.

(iv) Polar Motion Studies

The earth's rotation, polar motion and crustal plate dynamics continued to be monitored at the two polar motion observatories located near Ottawa, Ontario and Calgary, Alberta. Doppler observations of navigational and geophysical satellites are carried out by two TRANET stations; their operation has been fully automated by means of a distributed network of three mini-computers which facilitates unattended data acquisition, verification and real-time communication to the DMAHTC Satellite Polar Monitoring Center.

Optical astronomical observations are carried out by automated PZT instruments. The photographic plates are evaluated daily and the results transmitted weekly to BIH and monthly to IPMS. The annual summary report on the PZT time and latitude observations in 1977 has been published in the Geodynamics Series Bulletin No. 70.

A geophysical long baseline interferometry (LBI) system is being developed in cooperation with York University and operational tests have been conducted between ARO and DRAO using ANIK-B communication satellite to monitor relative local oscillator phase. This radio technique using extragalactic sources is potentially superior to the optical astronomical and satellite Doppler methods since it combines high precision, sensitivity and long term stability.

Analysis and comparison of the routine and experimental observations of the earth's rotation and polar motion is used to improve data reduction models, reference standards and observation techniques. All available PZT observations at Ottawa (1956-78) and Calgary (1968-78) have been completely reprocessed in a uniform system to analyse reduction model parameters and variations in the earth's rotation in the last two decades. The satellite Doppler reduction software has been improved to refine satellite orbit and pole position determinations.

Preparations for active participation in Project Merit campaigns in 1980 and 1983/84 have taken place and a possible involvement in the development of GPS geodetic and geodynamic applications has been investigated.

3. Atlantic Geoscience Centre

Gravity data for six natural resource map areas covering southern Saglek Bank and the adjacent Labrador Sea were released as part of GSC Open File No. 607. A compilation of Labrador Sea gravity data at a scale of 1:2,000,000 has been released as GSC Open File No. 627. A compilation of gravity data for the Appalachians has been released in a small scale draft compilation as GSC Open File No. 615. The published version should be out early in 1980.

Three north-south gravity tie lines were run through the Labrador Sea using an Askania Gss-2 gravity meter on the CSS Hudson; a total of 4,000 line kilometres of gravity data were collected. These data will be combined with the existing agency gravity coverage of the Labrador Sea and all data will be adjusted using programs provided by the Gravity and Geodynamics Division, Earth Physics Branch. A LaCoste and Romberg sea gravity meter was used on CSS Baffin for a multiparameter survey of the Scotian margin. Gravity data were collected on a series of lines running perpendicular to the margin. The line spacing was 38 km and the lines extend from the seaward edge of the shelf to the 5,000 m depth contour. A total of 14,000 line kilometres of gravity data was collected.

A new gravity meter control chassis has been built for the Askania Gss-2 and was used on the Hudson cruise. A microprocessor based cross-coupling computer is in the process of development for this meter.

4. Nova Scotia Research Foundation Corporation

Preliminary contouring of gravity data over the Sydney coalfield in southeast Cape Breton Island has revealed a positive gravity anomaly near Sydney which coincides with a prominent magnetic anomaly. Other prominent gravity highs occur in the Louisburg-Scatarie Island area, Sydney Forks area and the Fourchu Bay area. These anomalies may represent shallowing of the basement rocks, or changes in basement rock type, or both. Negative gravity anomalies are centred on the landward side of Gabarus Bay, Leitches Creek and Glace Bay areas. A linear, northwest-southeast trending gravity gradient extends from the northeast side of Gabarus Bay to the North Sydney area. It is disrupted by east-northeast to northeasterly trending gravity gradients which may represent structural features in the basement rocks. This work was supported by a Research Agreement with the Earth Physics Branch.

Commercial activities include gravity surveys for oil companies in the Atlantic Provinces, the sale of gravity data from Nova Scotia to an oil company, and a gravity survey in northern Saskatchewan for a mineral exploration company.

5. Ontario Geological Survey - Ministry of Natural Resources

. A systematic gravity data collection and interpretation program was instigated in 1974 by the Ontario Geological Survey (OGS). The aim of this program is to improve the gravity station coverage in Ontario and to aid in defining the deeper structural characteristics of the Canadian Shield. This will in turn give a better understanding of the evolution of the Canadian Shield, especially the metavolcanic belts and their associated mineral deposits.

As part of this continuing program, an OGS field party with fixed-wing aircraft and helicopter support established over 1700 gravity stations in the Gowganda-Shining Tree-Gogama area during the summer of 1979. This area of approximately 6100 $km^2$ is bounded by latitudes 47° 20'N and 47° 55'N and longitudes 80° 30'W and 81° 45'W and is an extension to the west of the northern portion of the area surveyed in 1977 and 1978. In addition 200 gravity stations were established in the Round Lake Batholith area to enable further study of this structure. The average station distribution over the area was approximately 1 gravity station per 4 to 6 $km^2$. The survey area covers parts of both the Superior and Southern provinces. 950 density measurements have been made on rock samples collected from the area.

Analysis of the data collected on earlier OGS gravity surveys over several Early Precambrian metavolcanic-metasedimentary belts and a wide corridor in northwestern Ontario extending across the Berens, Uchi, English River and Wabigoon subprovinces of the Superior Province is complete. Results of these studies will be published in various journals in the near future and

will also appear in an OGS Open File Report. The Bouguer gravity maps resulting from the Temagami area survey of 1977 will be published early in 1980.

6. Dalhousie University

The isostatic response function appropriate to a large part of the Canadian Shield has been computed from two-dimensional Fourier transforms of gravity and elevation data. An unexpected result is that the response function is directionally dependent; this may indicate the presence of bimodal, small-scale convection in the upper mantle. The isostatic response, when considered as a function of the modulus of wave number only, has been inverted to obtain a density-depth profile in the lithosphere under the assumption that the lithosphere may be regarded as a thin elastic plate. The best fitting model gives a depth of compensation for the surface topography of about 13 km. Either a large part of the gravity anomaly field arises from density variations that are less deep than the Mohorovicic discontinuity or a more complicated model is necessary. This study was supported by a Research Agreement with the Earth Physics Branch and will continue in 1980.

7. University of New Brunswick (Department of Geology)

A project to evaluate the application of horizontal gradient measurements of gravity to salt exploration has been started by the Department of Geology. 102 gradient arrays were measured over a known salt deposit in New Brunswick and gradient magnitudes with a range of 4 to 273 Eotvos units were obtained. There is a good correlation of gradient direction with the gradients inferred from the map of the known Bouguer gravity low over the salt structure. The gradient 'noise' effects of topography and near surface changes in geology are also being studied by computer modelling.

8. University of New Brunswick (Department of Survey Engineering)

An investigation on how a dedicated gravity satellite might add to geodetic terrestrial gravity needs in terms of more gravity data, in what form and with what accuracy resulted in the conclusion that essentially nothing would be added.

A report was compiled on the vertical crustal movements (terrestrial techniques) session of the GEOP-9 conference (Vanicek, 1979).

Work is continuing on gravity tilt observations and corresponding analysis.

9. Laval University

Two gravity investigations were undertaken at Laval this year:

1) Subsurface geological modelling of gravity data from the Shickshock mountains in the northern Gaspé area was undertaken. The early results of the gravity interpretation indicate that the crystalline basement is involved in the upthrusting of the Appalachian domain.

2) A detailed gravimetric survey was carried out over the Maquereau Group (dome?) in the Chandler-Port-Daniel area, southern Gaspé peninsula. A preliminary study indicates the presence of a 20 mgal or more Bouguer anomaly over this structure. Some 170 gravity measurements were made over the structure. It is planned to conduct a quantitative interpretation of the reduced data and to obtain a geological model from both ground magnetic and gravimetric data.

## 10. McGill University

The McGill 3-component ultra-long period seismograph which comprises three Linton-designed gravity meters is now being temporarily installed on the McGill campus in order to accomplish its complete calibration and an analysis of its spurious response to temperature, atmospheric pressure and geomagnetic field variations. Temperature control of the acceleration sensors to within $10^{-3}$°C has been achieved and it appears that this level of control is sufficient to maintain mechanical drift to below 1 $\mu$gal/day. The electronic systems have also been realigned and calibrated and the subsequent analysis of their effects on the measurement of acceleration has shown that they should not contribute an equivalent rms noise and drift level exceeding 0.2 $\mu$gal with periods greater than 1 hour. In the normal-mode band, the electronic noise should contribute less than 0.01 $\mu$gal rms.

The eventual installation of this seismograph at a good site within the Montreal region will complement a similar system being developed by the group at York University. The major geophysical research activity supported by these installations includes studies of the mechanical motions of the body of the earth in the normal-mode and sub-seismic bands and studies of the tidal deformations with particular emphasis on the diurnal resonance.

## 11. University of Manitoba

Two interpretation studies were completed in 1979. The first was a study of the Lac du Bonnet pluton, Manitoba carried out on contract for Atomic Energy of Canada Limited. The second was an interpretation of a gravity survey of the Aulneau batholith, northwestern Ontario. The preferred interpretation suggests a thickness of about 10 km for the batholith which is interpreted as overlying denser rocks.

## 12. Canadian Society of Exploration Geophysicists

The companies listed below reported gravity activities in 1979.

| Company | Area | Crew Months |
|---|---|---|
| Canadian Occidental | Alberta | 1 |
| Petro Canada | N.W.T. | 3 |
| Wilshire Oil of Canada Ltd. | B.C. | 2 |

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Open File of the Earth Physics Branch No. 79-6. Bouguer Anomaly and Free Air Maps of Hudson Bay, Area: Latitude 54°30' - 64°00', Longitude 77°00' - 95°00', 1979.

Open File of the Earth Physics Branch No. 79-7. Bouguer Anomaly Map of the Province of Nova Scotia, 1979.

# II SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR

Compiled by: E.R. Kanasewich

1. Canadian Seismograph Stations
2. Canadian Seismicity - Earth Physics Branch and Pacific Geoscience Centre
3. Earth Physics Branch, Ottawa
4. Pacific Geoscience Centre
5. University of Alberta
6. University of British Columbia
7. University of Manitoba
8. McGill University
9. University of Saskatchewan
10. University of Toronto
11. University of Western Ontario
12. Memorial University
13. Bibliography

## 1. Canadian Seismograph Stations

The seismograph facilities administered by the Earth Physics Branch of the Department of Energy, Mines and Resources, Ottawa and several Canadian Universities are listed in Table 1.

The following changes were made to the Eastern Telemetered Network (ECTN):

On April 26, 1978, OTT at Ottawa, Ontario was closed and replaced by Gentilly, P.Q. (GNT). On January 26, 1979, OTT was added to the ECTN system with digital recording only, and no paper monitors. On February 15, 1979, RHO, at Fitzroy Harbour, Ontario, latitude 45.45°N, longitude 76.22°W, and elevation 72 m, was added to supersede the regional station at Chats Falls. On October 26, 1979, both short and long-period digital data (a total of 6 seismic channels) became available at GAC, Glen Almond, P.Q. GAC is a borehole seismograph station with telemetry to Ottawa. On February 27, 1979, LCQ at La Grande, P.Q. was replaced by LDQ. On November 1, 1979, LAQ and LBQ at La Grande, P.Q. were discontinued. They have been superseded by the single telemetered station, LDQ.

All standard and some regional 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, Colorado 80302, which answers international requests for Canadian seismograms. The annual publication 'Canadian Seismograph Operations' summarizes information on those seismograph installations operated by or for the Division of Seismology and Geothermal Studies, Earth Physics Branch. This report also gives the characteristics of the various systems and describes the format and availability of the recorded data.

Table 1 Canadian Seismograph Stations (December 13, 1979)

| | STATION CODE | STATION | LATITUDE N | LONGITUDE W | COMMENT |
|---|---|---|---|---|---|
| | | Standard Stations (Energy, Mines and Resources) | | | |
| 1. | ALE | Alert, N.W.T. | 82.48 | 62.40 | |
| 2. | EDM | Edmonton, Alta. | 53.22 | 113.35 | University of Alberta |
| 3. | FCC | Fort Churchill, Man. | 58.76 | 94.09 | |
| 4. | FFC | Flin Flon, Man. | 54.73 | 101.98 | |
| 5. | FRB | Frobisher Bay, N.W.T. | 63.75 | 68.55 | |
| 6. | FSJ | Fort St. James, B.C. | 54.43 | 124.25 | Closed April 17, 1979 |
| 7. | INK | Inuvik, N.W.T. | 68.29 | 133.50 | |
| 8. | LHC | Thunder Bay, Ont. | 48.42 | 89.27 | |
| 9. | MBC | Mould Bay, N.W.T. | 76.24 | 119.36 | |
| 10. | MNT | Montréal, P.Q. | 45.50 | 73.62 | |
| 11. | OTT | Ottawa, Ont. | 45.39 | 75.72 | |
| 12. | PGC | Sydney, B.C. | 48.65 | 123.45 | |
| 13. | PHC | Port Hardy, B.C. | 50.71 | 127.43 | |
| 14. | PNT | Penticton, B.C. | 49.32 | 119.62 | |
| 15. | RES | Resolute, N.W.T. | 74.69 | 94.90 | |
| 16. | SCH | Schefferville, P.Q. | 54.82 | 66.78 | |
| 17. | SES | Suffield, Alta. | 50.40 | 111.04 | |
| 18. | STJ | St. John's, Nfld. | 47.57 | 52.73 | |
| 19. | YKC | Yellowknife, N.W.T. | 62.48 | 114.47 | |
| | | Regional Stations (Energy, Mines and Resources) | | | |
| 20. | BLC | Baker Lake, N.W.T. | 64.32 | 96.02 | |
| 21. | BMS | Minton, Sask. | 49.21 | 104.79 | |
| 22. | CFO | Chats Falls, Ont. | 45.47 | 76.23 | Closed Feb. 16, 1979 |
| 23. | CHQ | Charlesbourg, P.Q. | 46.89 | 71.30 | |
| 24. | DLY | Dezadeash Lake, Y.T. | 60.37 | 137.06 | |
| 25. | EFO | Effingham, Ont. | 43.09 | 79.31 | Commenced July 7, 1979 |
| 26. | FSB | Fort St. James, B.C. | 54.48 | 124.33 | Commenced April 30, 1979 |
| 27. | GDR | Gold River, B.C. | 49.78 | 126.05 | Moved August 5, 1978 |
| 28. | HAL | Halifax, N.S. | 44.63 | 63.60 | |
| 29. | IGL | Igloolik, N.W.T. | 69.38 | 81.81 | |
| 30. | KEY | Kluane Lake, Y.T. | 61.05 | 138.50 | Closed until spring 1980 |
| 30a. | KEY | Silver City, Y.T. | 61.03 | 138.41 | Commenced Dec. 5, 1979 |
| 31. | KRY | Koidern River, Y.T. | 61.97 | 140.41 | |
| 32. | LGQ | La Grande, P.Q. | 53.69 | 77.73 | |
| 33. | LMQ | La Malbaie, P.Q. | 47.55 | 70.33 | |
| 34. | MCE | Mica Creek, B.C. | 52.01 | 118.56 | Resumed operation April 27, 1979 |
| 35. | PBQ | Poste-de-la-Baleine, P.Q. | 55.28 | 77.74 | Single SPZ from October 15, 1979 |
| 36. | POQ | La Pocatière, P.Q. | 47.36 | 70.04 | |
| 37. | PWM | Pinawa, Man. | 50.19 | 96.04 | |
| 38. | QCQ | Québec City, P.Q. | 46.78 | 71.28 | |
| 39. | SIC | Sept-Iles, P.Q. | 50.19 | 66.74 | |
| 40. | SKB | Skidegate, B.C. | 53.25 | 132.00 | |
| 41. | SUD | Sudbury, Ont. | 46.47 | 80.97 | |
| 42. | UNB | Fredericton, N.B. | 45.95 | 66.63 | |
| 43. | WHC | Whitehorse, Yukon | 60.74 | 135.10 | |
| 44. | WNR | Windsor, Ont. | 42.26 | 83.11 | Closed April 30, 1979 |

Table 1 (continued)

| | STATION CODE | STATION | LATITUDE N | LONGITUDE W | COMMENT |
|---|---|---|---|---|---|
| | Eastern Canadian Telemetered Network (ECTN) (Digital recording, Single Component) (Energy, Mines and Resources) | | | | |
| 45. | FHO | Fitzroy Harbour, Ont. | 45.45 | 176.22 | Replaced CFO on Feb. 15, 1979 |
| 46. | GAC | Glen Almond, P.Q. | 45.70 | 75.47 | 6 channel buried seismograph |
| 47. | GNT | Gentilly, P.Q. | 46.36 | 72.37 | |
| 48. | LAQ | La Grande, P.Q. | 53.82 | 77.02 | Closed Nov. 1, 1979 |
| 49. | LBQ | La Grande, P.Q. | 53.54 | 77.35 | Closed Nov. 1, 1979 |
| 50. | LCQ | La Grande, P.Q. | 53.54 | 76.97 | Replaced by LDQ |
| 51. | LDQ | La Grande, P.Q. | 53.54 | 76.97 | Replaces LCQ Feb. 27, 1979 |
| 52. | MIQ | Maniwaki, P.Q. | 46.37 | 75.97 | |
| 53. | MNQ | Manicougan, P.Q. | 50.53 | 68.78 | |
| 54. | MNT | Montréal, P.Q. | 45.50 | 73.62 | |
| 55. | OTT | Ottawa, Ont. | 45.39 | 75.72 | Commenced Jan. 26, 1979 |
| | Western Canadian Telemetered Network (WCTN) (Digital Recording, Single Component) (Energy, Mines and Resources) | | | | |
| 56. | ALB | Port Alberni, B.C. | 49.27 | 124.82 | |
| 57. | HYC | Haney, B.C. | 49.26 | 122.57 | |
| 58. | PGC | Sydney, B.C. | 48.65 | 123.45 | |
| 59. | PIB | Pender Island, B.C. | 48.82 | 123.32 | |
| | Yellowknife Array,N.W.T.<br>18 elements of short-period vertical recording (Analog Telemetry)<br>3 elements of long-period vertical recording | | | | |
| 60. | YKA | Yellowknife Array | 62.493 | 114.605 | Centre |
| | Special Stations | | | | |
| 61. | | Charlevoix Array, La Pocatière, P.Q. | 47.55 | 70.33 | A seven-element telemetered array recording on analog tape. Commenced operation Aug. 30, 1977. |

Table 1 (Continued)

| | STATION CODE | STATION | LATITUDE N | LONGITUDE W | COMMENT |
|---|---|---|---|---|---|
| | | Mica Dam, B.C. Telemetered Array (Analog Single Component) | | | |
| | | (University of British Columbia) | | | |
| 62. | DPR | Downie Peak Ridge | 51.575 | 118.196 | |
| 63. | GST | Gold Stream | 51.660 | 118.685 | |
| 64. | DAI | Mt. Dainard, B.C. | 52.1986 | 118.3845 | |
| 65. | TAB | Tabernacle Mtn., B.C. | 51.7512 | 117.7617 | |
| 66. | THO | Mt. Thompson, B.C. | 52.6892 | 119.1208 | |
| 67. | SPR | Mt. Spring-Rice | 52.015 | 117.256 | |
| 68. | EPM | Eagle Pass Mtn. | 51.063 | 118.540 | |
| 69. | SLE | Sale | 51.167 | 118.134 | |
| | | (University of Manitoba) | | | |
| 70. | | Star Lake, Whiteshell Provincial Park, Manitoba (one-short-period cluster of Willmores and one vertical long-period on analog tape) | | | |
| | | Seismic array on FM analog tape (University of Western Ontario) | | | |
| 71. | LND | London | 43.040 | 81.183 | |
| 72. | DLA | Delaware | 42.858 | 81.390 | |
| 73. | ELF | Elginfield | 43.193 | 81.315 | |
| | | (University of Alberta) | | | |
| 2. | EDM | Edmonton - 3 components of the standard short-period station are recorded digitally at 18 times per second as 14 bit words. 3 components of the standard long-period station are recorded digitally 3 times per second. | | | |
| 74. | ELD | Ethyl Lake Duckett Farm Cold Lake | 54.536 | 110.332 | Closed June 17, 1979 |
| | | (Memorial University) | | | |
| 75. | CBK | Corner Brook, Nfld. | 48.92 | 57.97 | Single-component short-period station |
| | | (University of Saskatchewan) | | | |
| 76. | | Saskatoon, Sask. | 52.1916 | 106.3835 | Digital recording short-period station in process of installation |
| 77. | PKP | Parker's Pond, Nfld. | 47.5859 | 52.7834 | Short period vertical telemetered station |

## 2. Canadian Seismicity - Earth Physics Branch, Ottawa (EPB), and Pacific Geoscience Centre, Sidney, B.C. (PGC)

### (a) Canadian Earthquakes

#### (i) Preliminary summaries, Catalogues and Earthquakes of 1979

The EPB prepares and distributes to interested organizations preliminary bi-monthly summaries of all Canadian earthquakes approximately 7 months in arrears. Currently, the months of May-June 1979 are being analysed, and the summary will be distributed in January, 1980. The purpose of the lists is to provide interested organizations with a complete (but not final) picture of Canadian data on all Canadian earthquakes to be included in the International Seismological Centre's world-wide bulletins.

Those organizations interested in receiving such bimonthly summaries of Canadian earthquakes should contact the Division of Seismology and Geothermal Studies, Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, K1A 0Y3.

EPB continues to monitor the telex data on earthquakes sent daily by the operators of the Canadian Seismograph Network for rapid detection and location of larger Canadian earthquakes. Present procedures allow the detection and location of earthquakes of magnitude 4 or greater anywhere in Canada within two weeks of their occurrence. Canadian earthquakes that are widely felt or otherwise generate public interest are also analysed as soon as possible, usually within 48 hours of their occurrence.

The 1977 Canadian Earthquake Catalogue has now been published in bilingual format and a copy may be obtained from the Earth Physics Branch for a charge of $3. The 1978 Catalogue is in the final stages of preparation and will be available in 1980.

The largest earthquake in or near Canada during 1979 occurred on February 28 in the St. Elias Mountains of southeastern Alaska with a tentative magnitude ($M_S$) of 7.2. The tremor was felt to distances of 800 km in southern Alaska, the Yukon and northwestern British Columbia, and caused minor damage in several Yukon communities. Earthquakes of magnitude 5 occurred west of Vancouver Island on March 13 and 14, south of the Queen Charlotte Islands on June 21, near the Boothia Peninsula on June 24, in the southern Mackenzie Mountains on July 11, and in the Charlevoix Region of Québec on August 19. The last of these tremors was widely felt in southern Québec and Maine, but did not cause any significant damage.

#### (ii) Special Studies

Eastern Canada

The data from the seven-element seismological array deployed around the Charlevoix region, Québec, were routinely analyzed during 1979 by F.M. Anglin (EPB). A sufficient number of hypocentres have now been derived for this zone of microactivity to define its northwest boundary as two offset planes of seismicity dipping 76° to the south east and striking parallel to the north shore of the St. Lawrence River. An event of magnitude 5.1 occurred on August 19, 1979, in the north eastern section of this zone. From a fault plane analysis of this event, one plane was found to be parallel to the northwest boundary of the microactivity. All of the microactivity is still located in the Precambrian.

Microearthquakes associated with the filling of the La Grande 2 reservoir, Québec, are being studied by EPB staff as a cooperative project with Société d'Energy de la Baie James. Activity started on December 27, 1978 and by October 18, 1979, 122 events of $M_L < 1.0$ had been located in a zone approximately 10 x 10 km immediately upstream from the dam site. The three-element array around the reservoir was reconfigured in February 1979 by replacing the element most distant from the active zone by one on the north west boundary of the activity. As of October 1979, the activity was sporadic, with one event every two or three weeks. Most of the activity occurred during January to March 1979 with another small burst of activity in May when the rate of filling of the reservoir increased. Since October 1979 the area has been monitored by the station nearest the active area.

A.E. Stevens (EPB) has compiled the early history and instrumentation at all permanent Canadian seismograph stations established before 1955 in eastern and central Canada. The stations with their year of installation are: Toronto (1897), Ottawa (1906), Saint Boniface (1910), Halifax (1915), Saskatoon (1915), Ste-Anne-de-la-Pocatière (1925), Shawinigan Falls (1927), Seven Falls (1927), and Kirkland Lake (1939). All but Ottawa and Halifax are now closed. A relatively recent station at La Pocatière (1972) is very close to the original Ste-Anne site. Instrument changes are also tabulated for six American stations - Cambridge (1908), Fordham (1910), Weston (1930), East Machias (1932), Harvard (1933) and Williamstown (1937). This instrumental history will facilitate re-assessments of the older Canadian earthquakes, which are required in seismic risk evaluations.

Western Canada

R.B. Horner, C.A. Crosby and J.P.S. Mercure (EPB), in a joint project with Foothills Pipe Lines (South Yukon) Ltd., conducted a microearthquake survey in the Kluane Lake region of the Southwestern Yukon Territory between September 7 and October 7, 1979. Using six portable short-period visually-recording seismographs centered around a 40 km segment of the Shakwak fault, activity at a rate of about one event per day with magnitudes of approximately $M_L=1$ and less was observed. In this area it appeared that there were no events to the northeast of the fault. The earthquakes seemed to be more or less randomly scattered through a broad fracture zone, about 15 km wide, bounded by the Shakwak fault on the northeast and a line parallel to the Duke River on the southwest. The focal depths were predominantly upper crustal. A preliminary composite P-nodal solution indicated predominantly left-lateral strike-slip motion on faults striking west to northwest or north to northeast. The mapped faults in this area trend approximately northwest.

R.B. Horner and C. A. Crosby (EPB) are continuing their analysis of low-level seismicity in the southwestern Yukon Territory in another joint venture with Foothills Pipe Lines. Events down to about magnitude 2 appear to occur in two distinct, well-separated zones that correlate with two major fault systems: the Fairweather-Yakutat along the coast of southeast Alaska and the Denali that runs through Alaska, the southwest Yukon, northwest B.C. and Chatham Strait to connect with the Fairweather off the coast of southeast Alaska. One feature emerging from the pattern of low-level seismicity is a connection, not along Chatham Strait but further west through Glacier Bay. The seismicity appears to turn away from the Denali system near 60°N, 137°W. There is no evident geologic correlation. H.S. Hasegawa (EPB) is examining fault

mechanisms for some of the larger events in the southwest Yukon, and P.W. Basham (EPB) is determining recurrence rates for the purpose of seismic risk estimation.

J.C. Lahr, C.D. Stephens (U.S. Geological Survey), H.S. Hasegawa (EPB) and J. Boatwright (Lamont-Doherty) have completed an assessment of the extent to which the seismic gap between Icy Bay and Yakutat Inlet in southeastern Alaska has been filled by the magnitude 7.2 St. Elias, Alaska, earthquake of 28 February, 1979. The results indicate that the eastern part has been filled by this earthquake, though the western part has yet to be filled. Hasegawa, Lahr and Stephens have also completed a study of the focal parameters of this earthquake. The results indicate a shallow angle thrust fault in an interplate environment.

C.W. Stover, B.G. Reagor (U.S. Geological Survey) and R.J. Wetmiller (EPB) have completed a study of the felt area of the St. Elias earthquake and past large tremors in the same region. The St. Elias earthquake was felt over an area of about 500,000 $km^2$ of Alaska, the Yukon Territory and Northern British Columbia. The maximum intensity was VII in Alaska and VI in Canada. Minor damage was observed in Canada at Bayshore (south of Kluane Lake), Beaver Creek, Burwash Landing, Destruction Bay, Haines Junction and Whitehorse, all in the Yukon. The total felt area of the St. Elias tremor is comparable to the felt area of other large tremors in the region, notably the much larger magnitude 8 events of 1899 and 1900.

G.C. Rogers (PGC) has compiled maps in the Juan de Fuca map series of seismicity, fault plane solutions, and seismograph stations. Rogers is also undertaking a re-examination of the earthquake catalogue for western Canada. So far, revisions have been made to about one third of the entries prior to 1960.

R.J. Wetmiller (EPB) is continuing a study of small earthquakes near Rocky Mountain House, Alberta. The area about 50 km southwest of Rocky Mountain House has been the site of more than 100 earthquakes of magnitude 4 or less since 1976. The area produces both natural gas and petroleum but location accuracy on the earthquakes is insufficient to correlate with particular production areas. The rate of earthquake activity for 1976-77 correlates well with the rate of oil production from one of the area's fields. No fluid injection schemes are being operated at the fields involved. A field survey of the area is being planned for the late summer of 1980.

R.D. Hyndman and G.C. Rogers (PGC) with R.M. Ellis (University of British Columbia) have examined the microseismicity of the Queen Charlotte fault zone by a temporary array of ocean bottom seismographs and land stations on the Queen Charlotte Islands. The events recorded all occurred on the steep bathymetric scarp just off the coast of the islands. It may be possible to deduce from the data whether the fault zone exhibits purely strike slip motion or has a component of underthrusting as suggested by plate models.

(b) Strong Motion, Seismic Risk and Earthquake Engineering

EPB personnel have continued their work on the Canadian Standards Association Technical Committee on Seismic Qualification of CANDU Nuclear Power Plants and on the Canadian National Committee for Earthquake Engineering. The Branch continues to provide advice to the Atomic Energy Control Board, to the provincial power utility companies and to other agencies on seismological monitoring and seismic risk assessment.

Research directed toward new seismic risk maps for Canada has continued at EPB and PGC. H.S. Hasegawa, P.W. Basham and M.J. Berry (EPB) are developing new strong ground motion attenuation relations based on western United States strong motion data and both eastern and western Canada intensity data. The assessment of zones of earthquake occurrence in western Canada, integrating historical seismicity with current understanding of seismogenetic processes, has been completed by PGC staff. Basham and D.H. Weichert (PGC) are developing zones of earthquake occurrence and associated magnitude recurrence relations for the whole country and adjacent regions. Weichert is developing the seismic risk analysis program that will be applied to map ground motion parameters throughout Canada at a variety of risk levels, and has derived maximum likelihood estimators for the seismicity parameters based on different periods of observation for different magnitude intervals.

M.J. Berry and H.S. Hasegawa (EPB) have completed a review of the risks posed by earthquakes, natural or induced, to the disposal of toxic wastes by burial or fluid injection into the crust.

D.H. Weichert and W.G. Milne (PGC) have completed processing and assembling of all western Canadian strong motion records from 1965 to 1976.

Requests from the engineering and consulting community for site specific seismic risk estimates in terms of peak horizontal ground acceleration, usually with a 0.01 per annum probability, continue to be received in previous numbers. Estimates for this purpose are made by the Milne-Davenport method, using the straight line representation of the unlimited extreme value distribution of historical events.

The first strong motion record obtained in eastern Canada was recorded in Tadoussac, by an instrument operated by the National Research Council Noise and Vibration Group. Peak horizontal acceleration at 55 km was 0.01g. A copy of the film record was made available to the Earth Physics Branch by H. Rainer.

## 3. Earth Physics Branch

### I Seismology and Physics of the Earth's Interior

#### (a) Lithospheric studies

The following three paragraphs describe progress made by EPB staff in the study of a seismically active area in eastern Canada.

As the continuing part of the Earth Physics Branch Program to search for changes in seismic velocities in a seismically active area, further calibration shots were set off during 1979 by G. Buchbinder in the La Malbaie region, Québec, and recorded by EPB staff using up to 12 instruments. In June, two shots were set off on the north shore and one on the south shore of the St. Lawrence River. One shot on each shore was also set off in September. Long and short-term changes in travel time continue to occur.

Results of the combined reflection and refraction survey within the Charlevoix crater, Québec, were reported by J. A. Lyons in the 1978 Bulletin. The unreversed profiles obtained from Thetford Mines blasts, timed and analysed by D.A. Forsyth, suggest a comparable deep structure beneath the north and south shores with average crustal velocities of 6.8 and 6.7 km/s respectively. A minor mid-crustal discontinuity is suggested and Moho depth is estimated at 42-43 km. The 6.2 km/s upper crustal velocity found for the crater and immediate area is low compared to 6.4 - 6.5 km/s found for the eastern shield in general. Structural

lineations from satellite imagery suggest a larger area of impact disruption than previously recognized which may partly explain the microearthquake activity as well as the lower crustal velocity in the crater area.

Dans le but de vérifier si le facteur d'atténuation Q varie temporellement dans une zone séismiquement active, S. Mercure a entrepris une étude de l'atténuation des ondes P dans la région de la Malbaie. Ayant recours à toutes les données provenant des nombreux tirs de calibration effectués par la Direction de la physique du globe dans cette région, on a évalué une relation empirique entre d'abord l'amplitude de l'onde et la distance et ensuite entre l'amplitude et la charge utilisée. D'autre part, afin de déterminer la valeur approximative de Q apparent, on utilise deux méthodes. La première fait appel au rapport spectral et permet d'obtenir directement la valeur de Q apparent pour 2 parcours donnés. La seconde nécessite l'emploi de la technique de déconvolution homomorphique qui libère la fonction d'atténuation-dispersion de la fonction-source. Or la forme de la fonction d'atténuation-dispersion dépend du facteur Q apparent. Il en résulte la possibilité de cerner indirectement la valeur de Q apparent.

A.G. Green has conducted a multi-coverage seismic reflection survey across the faulted contact of the Thompson nickel belt with the Churchill province in northern Manitoba. The seismic data have been used as follows: (a) to delineate the location of the faulted contact in a region covered by surficial sediments using P-wave velocities and S-wave attenuation, and (b) to map several very prominent deep crustal reflections (two-way travel times of 5 to 7 seconds).

J.A. Mair has completed the interpretation of several refraction profiles obtained during EMR's - 'LOREX' program, near the North Pole, between March and June, 1979. The seismic data indicate that, in this area, the Lomonosov Ridge is made up of mainly oceanic rocks. A thin veneer of sedimentary material possibly of continental origin, overlies a root made up of oceanic material, with a maximum thickness of about 27 km beneath the ocean floor. The adjacent basins (Makarov and Amundsen) have very different crustal structures. The Makarov with a crustal thickness of 12 km may be the result of back-arc spreading by the Alpha Ridge. The Amundsen with a crustal thickness of 16 km is probably the result of spreading by the Nansen-Gakkel ridge contemporaneous with the opening of Baffin Bay and the North Atlantic.

J.A. Mair, D.A. Forsyth and F. Anderson participated in a refraction survey of the Churchill-Superior Boundary in Saskatchewan during August 1979. This project was a continuation of the cooperative efforts by a group of Canadian universities and EPB (COCRUST) to obtain large-scale refraction data and multi-fold reflection data in areas of economic or tectonic interest. The data collected will be available to all interested groups or individuals by March 1980 as an EPB Open File, and extends the data base, recorded by this consortium in 1977.

EPB staff have continued the interpretation of seismological and related data as part of the joint EMR - Atomic Energy of Canada Limited (AECL) program on the investigation of potential sites for the disposal of radioactive waste. The following three paragraphs describe progress made in this area.

J.A. Mair has contracted and supervised two field experiments, evaluating the Mini-Sosie technique (high-resolution seismic reflection) as a means of detecting fracture-shear zones within granite batholiths. A very coherent, high amplitude reflection has been detected at 300 to 600 m depths, in the Lac du Bonnet batholith near Pinawa, Manitoba.

C. Wright, M. Johnston and C.P. Lam interpreted two seismic reflection profiles recorded at Chalk River in 1977 as a series of overlapping reversed refraction profiles. These profiles were about 2 km in length, running from northwest to southeast (profile A) and from northeast to southwest (profile B). Profile A yielded P velocities between 4.5 and 5.6 km/s for the uppermost region of the gneiss - monzonite rock body, with the velocities below 5.0 km/s confined to narrow zones at the ends. These velocities are significantly lower than those reported by Lam and Wright in the 1978 Bulletin over a similar path, but using recording at hydrophones placed in a borehole. The P velocities for profile B exceed 6.2 km/s over a distance of about 250 m at the northeastern end of the profile, and are attributed to propagation through gabbro. Further south, the velocities are close to 5.5 km/s, as expected for weathered gneiss or quartz monzonite. No clear correlation with surface geology is evident for the velocities of either profile, though the lowest velocities appear to be correlated with lithological changes that may be associated with extensive fracturing.

An experiment to test a modified weight drop device as a source of shear wave energy was undertaken by EPB staff at Chalk River in October. Recording was undertaken first using hydrophones in a borehole, and secondly along two surface profiles using alternate horizontal and vertical-component strings of geophones.

(b) Seismological Instrumentation

Instrumentation of the borehole seismometer at Glen Almond, Québec, has been completed, and nine channels of digital data are now being radio-telemetered to Ottawa. Short-period data are produced at 30 samples per second, while long-period data and three extra channels that provide information on station operating conditions are produced at 1, and 1/60 samples per second respectively. Selected short-period events, and all long-period data are archived.

The Eastern Canada telemetered network is being considerably expanded through cooperative agreements with a number of outside agencies, including Société d'Energie de la Baie James, the U.S. Nuclear Regulatory Commission, Atomic Energy of Canada Limited and Ontario Hydro. To facilitate this expansion, equipment is being developed to transmit data from one to four outstations over a single radio-link. Each station will produce 60 data samples per second with a minimum resolution of 8 bits and a dynamic range of 108 db. Nine outstations are being assembled for installation in the coming year. Site selection and transmission path evaluation are in progress.

Work has also progressed on expanding the software required to accommodate the additional stations. The ECTN system can now process sixteen channels of data with the event detector algorithm operating on any ten of them.

Extensive efforts are being made to streamline the data management facility of the division. Among the planned improvements are the following:

- the system will provide a means for the interactive capture, editing and analysis of all earthquake data,
- a seismologist with only an elementary knowledge of the system should be able to use it effectively,
- all time series data will be converted into a standard format,
- a common archival procedure will be used for all data regardless of source.

As part of a federal program for the transfer of technology to industry (COPI), a project funded by the National Research Council to develop the 'MK2 Backpak' was successfully completed and twelve units were subsequently built. In the "timed" mode of operation the instrument can record three channels of data at up to 120 samples per second. A 12-bit analog to digital converter combined with four - step gain-ranging provides a dynamic range of 108 db with a minimum resolution of 8 bits. At present the detection algorithm used in the "event-triggered" mode can process 60 samples per second. However, adding a hardware multiply-divide facility should improve the trigger mode performance. Facilities for playback in either digital or analog format are built in. Total package weight is 16 kg.

## II Physics of the Earth's Interior

### (a) Heat flow and heat production

Data gathering activities have continued mainly in the Arctic and Cordilleran regions. Measurements of temperature have been made in holes in the Howe Sound, Okanagan and Foothills areas of the Cordillera, in the southern Yukon, MacKenzie Delta, the Arctic Islands, and in the Canadian Shield. Many of these measurements were made in conjunction with programs of research into geothermal energy, permafrost or underground waste disposal. The collection of samples for laboratory measurement of heat production have accompanied temperature measurements in many areas.

The series of regional analyses of geothermal data has continued with a completed study of the Maritime Provinces, by A.M. Jessop and A.S. Judge, in cooperation with R.D. Hyndman (PGC) and D.S. Rankin (Nova Scotia Research Foundation), both formerly of Dalhousie University.

Temperature data from oil well records of the Prairie Provinces are being collected and analysed by J. Majorowicz. The large amount of data available permits a statistical evaluation of temperature and temperature gradient patterns in several sections of the sedimentary column, and it is hoped that a heat flow contour map will be produced that will permit interpretation in terms of known tectonic and petrological features of the Precambrian basement.

Utilizing a newly designed high precision light weight thermal gradiometer probe, A. Judge and V. Allen measured, as part of the LOREX-79 project near the North Pole, the heat flow through the ocean bottom sediments in the Makarov and Fram Basins and over the Lomonosov Ridge. The results for the 42 sites are being analysed in terms of the tectonic history, crustal structure, sedimetation history, stability of ocean bottom water temperatures and topographic relief in the region.

### (b) Geothermal Energy

The study of the geothermal energy potential of the Regina area has continued with the drilling of a production well on the campus of the University of Regina during the winter of 1979. This project was managed by the University and funded by the Earth Physics Branch. The well was drilled to basement, at a depth of 2208 m, and was then terminated at 2214 m. The Winnipeg formation was found to have a net thickness of 30.2 m with a permeability value of 462 md. The Deadwood formation showed a net thickness of 80.4 m and a permeability of 331 md. Reliable temperature measurements are not yet available, but results a few degrees below predicted values are indicated. Salinity levels are about 120,000 ppm. Further tests, including pumping and hydrofracturing were done in the summer of 1979, but detailed results are not yet available. All results so far indicate that the well is potentially a successful producer of hot water for space heating.

Work at Meager Mountain has been continued by B.C. Hydro with partial funding and technical advice from EMR. Drilling during the summer and autumn of 1979 has demonstrated the existence of high temperatures at shallow depths beneath the south side of the volcanic complex. The highest temperature detected so far is 202°C at a depth of 367 m.

(c) Permafrost Studies

The Geothermal group has continued with the acquisition and preservation of Arctic drillholes for deep temperature observation in northern Canada. Results reveal permafrost thickness of up to 700 m both in the Mackenzie Delta and the high Arctic. An analysis of calculated equilibrium conditions in these wells has commenced revealing a range of subsurface temperatures ranging from below 0°C to +20°C at 500 m depth. Preliminary determinations of heat flux are high, commonly greater than 80 $mWm^{-2}$, but this is believed largely due to perturbations caused by past climates. The results are being analysed to determine the palaeoclimatic implications.

Offshore permafrost drilling investigations of the Beaufort Sea sediments conducted to depths of 60 m during the years 1976 and 1978 have been published. The results of 34 holes reveal a fairly simple geological and thermal picture in the western offshore Mackenzie Delta and highly complex series of inter-relationships to the north of Richards Island. Ground temperatures to depths of 60 m have been measured at Alert, N.W.T., for the past year, in cooperation with the National Research Council and the Department of National Defence. One year of data has been collected and published revealing the complex relationships between slope aspect, weather patterns, snow cover and permafrost ground temperatures. Under Energy Research and Development funding, contract investigations into the behaviour of soil moisture in cold regions as it affects industrial development have continued. Studies have included the evaluation of Time Domain Reflectometry (TDR) to determine, non-destructively, the unfrozen water contents of frozen soils, a rate study of heave processes and ice segregation behind a freezing front, and a study of isotopic redistribution of oxygen and hydrogen due to permafrost formation and changes in climate. The TDR technique appears to hold considerable promise for geotechnical evaluation of permafrost conditions, and field deployable systems are now being developed by Carleton University.

Equipment development has continued and has resulted in a sixteen-channel multisensor digital data acquisition system with a resolution of 1 part in $10^4$, and the capacity to record on quarter-inch magnetic tape for two years at two hour intervals. Testing of the prototypes is currently underway, although a prototype instrument with higher data acquisition rate was successfully deployed in a thermal gradiometer mode during the 'LOREX' expedition. Standard field bridges are being upgraded with newly developed null detectors using light emitting diodes rather than a meter movement.

(d) Tectonophysics

D.A. Forsyth has completed a first look at the relationship between seismicity and the geological and geophysical features of the the western Québec seismic zone. Results show that while the majority of epicentres are located within or near the Grenville metasedimentary belt, the largest historical events fall within the Palaeozoic rift zone outlined by the Ottawa river. A group of epicentres along the northwest edge of the metasedimentary belt occurs in a region of major northeast trending magnetic and gravity anomalies. The seismicity also correlates with gradient zones around two prominent anomalies in the smoothed Bouguer

gravity field. A similar correlation with the free air gravity field has been observed in Arctic and Eastern Canada. The pattern of aeromagnetic anomalies and drainage channels indicate that the Central Metasedimentary Belt continues beneath the Palaeozoic sediments to Lake Ontario. The strike of magnetic, gravity and drainage features north of the lake is parallel to structural features mapped to the south. Geological data and geophysical trends indicate that a cataclastic zone is continuous along most of the eastern border of the metasediment belt. Prominent aeromagnetic and gravity trends and some cataclastic evidence characterize the western border.

In connection with the joint EMR-Atomic Energy of Canada Limited (AECL) radiocative waste disposal program, C. Wright and K. Langley have used the crack theory of O'Connell and Budiansky to estimate the crack and saturation parameters of crystalline rocks from both field and laboratory measurements of seismic velocities. The results emphasize the importance of being able to measure reliable S wave velocities.

C. Wright and D.C. Kamineni (Geological Survey of Canada) have investigated the degree of correlation between various sets of seismic velocity and density data derived from borehole samples from Chalk River. The results have been interpreted in terms of the relative contributions of mineralogical variations, crack parameters and observational errors. Methods of estimating crack-free P and S wave velocities of crystalline rocks were also studied, because these velocities are required when applying crack theories to the interpretation of laboratory or field measurements of seismic velocities.

## 4. Pacific Geoscience Centre

### I Seismology

#### (a) Lithospheric Studies

G. McMechan has been using modelling techniques to study the appearance of and information contained in the 3.5 KHz seismic sounding west of Vancouver Island. In collaboration with R.G. Currie (Geological Survey of Canada), the physical nature of shallow formations is being compared with drill hole data in the region. McMechan, currently on leave at Stanford University, is continuing this study and related problems associated with modelling the near field, or surface formations.

R.D. Hyndman, with R.M. Clowes, R. Ellis and D. Au (University of British Columbia), has carried out a detailed refraction experiment across the Queen Charlotte fault zone using explosives and a large airgun as sources, and ocean bottom seismographs, sonobuoys and land stations as receivers.

### II Physics of the Earth'S Interior

#### (a) Heat Flow and Heat Production

E.E. Davis has made a large number of new marine heat flow measurements in the Winona Basin off northern Vancouver Island. The heat flow is nearly constant after a large correction is applied for the thermal effect of high sedimentation rate that varies across the basin. The result suggests that all of the basin has the same quite young age.

R.D. Hyndman and E.E. Davis with J.A. Wright (Memorial University, Newfoundland) have completed a study of the design and use of a multipenetration marine geothermal heat probe with digital acoustic telemetry. The probe has been used extensively for heat flow measurements in the deep sea and in the deep inlets. The in-situ thermal

conductivity technique has been studied through analytic and numerical models and through laboratory and field calibration. The estimated measurement accuracy is better than 5%.

R.D. Hyndman, J.A. Wright and M. Burgess (EPB) have made a series of marine geothermal heat flow measurements on the Queen Charlotte fault zone. The heat flow decreases markedly from the deep sea toward the coast. The data suggest that the plateau half way down the continental slope is underlain by a sliver of relatively old oceanic crust.

(b) Tectonophysics

R.D. Hyndman is studying the average rates of fault motion of the transform faults of western Canada based on the observed historical seismicity and empirical earthquake magnitude-seismic moment relations. The rates are in general agreement with those from sea floor magnetic anomalies and plate tectonic models, indicating that the observed seismicity probably is representative of heat for millions of years and giving support to the current plate model.

R.D. Hyndman, R.P. Riddihough and G.C. Rogers have undertaken detailed marine geophysical studies over the southern end of the Queen Charlotte fault zone and the Tuzo Wilson seamounts. The data suggest that the seamounts are in fact a short spreading centre and that the present active Queen Charlotte fault zone lies very close to the coast of the Queen Charlotte Islands. A deep filled trough with up to 7 km of consolidated sediments lies just off the islands.

5. University of Alberta

I Seismology

(a) Theoretical Studies

Dr. F. Hron and his graduate students continued in their efforts to develop a complete package of the computation of synthetic seismograms for real geological structures. They were using their own modifications of asymptotic ray theory as the theoretical basis for the numerical computations. Special attention was given to the problems associated with seismic wave propagation in anisotropic, laterally inhomogeneous media displaying various degrees of anelasticity. Their programs based on numerically constructed partial ray expansions were checked against the results produced by Dr. Mikhailenko's programs employing the so-called Mikhailenko-Alekseev method for the solution of wave equations. This method, which combines the method of separation of variables with finite differences, has gained enormous popularity among the scientists in the oil industry and academic institutions since it can be applied to a wide class of different geological structures (anelastic media, porous media or media with arbitrary anisotropy). Drs. B. Mikhailenko and F. Hron have also been investigating the non-geometric features of seismic waves and the numerical means of their modelling.

Dr. P.F. Daley and Dr. F. Hron modified asymptotic ray theory for application to homogeneous parallel transversely isotropic layers to provide a theoretical basis for the development of computer programs for synthetic seismogram computation. It was found that even a moderate degree of elliptical anisotropy results in easily noticeable changes both in the temporal and dynamic properties of seismic body waves. A recent increase in the popularity of the vibroseis technique in the oil industry has resulted in the revival of interest in the properties of horizontally polarized shear waves. Since very frequently hydrocarbon bearing structures are located in geological structures with very thin layers that display elliptical anisotropy for SH waves of long enough

wavelength, Daley and Hron initiated development of two independent methods, namely, the Ray Series Method and The Method of Integral Transforms applied directly to the equation of motion for the medium displaying ellipsoidal anisotropy for SH waves. Because both theories agreed rather well in all regions outside the interference zone, where the Ray Method is not applicable, a hybrid technique has been developed for the computation of synthetic seismograms. This technique maintains the speed of asymptotic ray theory, providing physically justified results inside the interference zone. In this manner a very fast and efficient technique for the computation of synthetic SH sections for regions of keen economic interest has been developed.

Dr. L.W. Marks and Dr. F. Hron continued their investigations of seismic waves in laterally inhomogeneous media. They found, however, that before the programs for the computation of synthetic seismograms for generally inhomogeneous media could be developed, a rather extensive theoretical investigation had to be undertaken so that all necessary modifications of asymptotic ray theory could be carried out. This involved, among others, ray amplitude computation in the vicinity of caustics, where asymptotic ray theory cannot be used. The traditional method of ray amplitude evaluation, with the help of Airy function Ai, could not be used due to a rather significant loss of accuracy occurring when two interfering rays of both travel time branches have distinctly different amplitudes after travelling through different parts of the medium. The new solution overcomes this difficulty by expressing the ray amplitude as a linear combination of Airy functions Ai and Bi or by a similar combination of appropriate Hankel functions. The second major problem was related to a suitable mathematical description of an inhomogeneous medium. Since in many cases we are dealing with vertically inhomogeneous layered structures, a special computer program was used for this case. It incorporates an automatic ray generation scheme according to which all rays, regardless of the number of reflections or conversions, are assembled into groups of kinematically and dynamically equivalent waves, thereby making the synthetic seismogram computation extremely efficient. In the computer program, the arbitrary velocity depth function $v=v(z)$ is first decomposed into individual monotonically varying parts. Then the inverse dependence $z=z(v)$ is approximated inside of each of these regions with a natural spline $z=a+bv+cv^2+dv^3$, with a, b, c, and d being the spline coefficients found numerically. As a result of this approximation, analytic expressions are available for all the kinematic characteristics (range, travel time and geometrical spreading) that are necessary for synthetic seismogram computation and the otherwise costly numerical integration can be avoided. When dealing with generally inhomogeneous layers separated by curved interfaces a different method must be used. In such a program the medium is split into small blocks of different velocity gradients and the interfaces are approximated by the second order polynomials allowing analytical computation of ray paths that are necessary for the ray shooting procedure. In such a way synthetic seismograms are computed efficiently with reasonable accuracy. This is also due to the new formulae, for geometrical spreading in generally inhomogeneous layered structures separated by curved boundaries, which were obtained as a result of the joint research of Drs. V. Cerveny and F. Hron.

Dr. E.S. Krebes and Dr. F. Hron continued their studies of seismic waves in anelastic media. The linear theory of viscoelasticity has been used to model anelastic of real media. Calculations of various physical quantities, such as energy flux and dissipation of seismic plane waves propagating in a viscoelastic medium, have been carried out. As the calculations are based on the energy conservation equation derived from first principles and independent of the type of viscoelasticity, they represent an improvement over previous methods for such media. Results of computer modelling indicate that energy partitioning plays a crucial

role in the determination of dynamic characteristics of seismic waves. Thus if serious inaccuracies in the computation of synthetic seismograms are to be avoided, appropriate reflection and transmission coefficients for anelastic media must be used. They differ significantly from those corresponding to elastic media, with deviation increasing as Q decreases. Synthetic seismograms for teleseismic body waves and for spherically divergent seismic waves were computed. In both programs automatic ray generation has been used. The results for perfect elasticity are obtained by setting Q = OO in each layer. The seismograms for the anelastic layers exhibit amplitude attenuation and waveform spreading seen on actual field records. The program can play an important role in a better understanding of seismic wave propagation in such highly dissipative media as tar sands. This is necessary if the quality and accuracy of the interpretation and seismic exploration techniques presently in use are to be improved.

Dr. L.W. Marks and Dr. F. Hron also studied the accuracy of the zeroth order approximation of asymptotic ray theory by developing a new computational technique for the numerical evaluation of next higher terms in the ray series. Their numerical results will be compared with those obtained by Dr. Mikhailenko's programs.

During the past 12 months, Dr. Mat Yedlin has continued to work on problems of anisotropic wave propagation, culminating in a paper on turning points of elastic waves in anisotropic media. Two other subjects of interest, which have been pursued to successful termination, are the geometrical construction of the asymptotic expansion of Green's function in an anisotropic, elastic medium and the evaluation of singular integrals arising in ray seismology. Dr. Yedlin spent three months in Scotland with Dr. S. Crampin at the Institute of Geological Sciences in Edinburgh. During that time, a project was initiated on generalized ray tracing in arbitrary anisotropic media, including evaluation of the Jacobian to compute ray tube cross-section. This project is now a subject of ongoing research. It is hoped that some of the results contained therein will be compared with finite difference techniques. The subject of finite difference methods has also been a focus of interest for Dr. Yedlin, and as such, he has completed a comprehensive set of notes on existing numerical finite difference methods. Current directions of interest involve the investigation of diffraction, and how it may be modelled. Another related subject of investigation has been the study of dispersive waves. The results of finite difference methods for the solution of such problems have been compared to closed-form analytic calculations. So far, the results are in close agreement with extensions of the methods being pursued at the present time. An exciting possibility is the comparison of Dr. Hron's ray method of solution with the finite difference equations which model dispersion.

Ray methods are being used by D.C. Ganley and E.R. Kanasewich at both vertical and non-vertical incidence with the inclusion of attenuation and dispersion. Y.C. Athias is developing finite difference techniques for modelling the forward problem of P and S wave propagation in an inhomogeneous medium.

Dr. M. Hron and Dr. M. Razavy have shown that the J-fraction expansion formulation of the inverse problem of wave propagation yields accurate and stable results for one-dimensional systems. This suggests the possibility of an extension of this method to three-dimensional problems where the inhomogeneous medium is spherically symmetric. In this case the time of arrival of a wave as a function of the ray parameter can be used to determine the wave velocity as a function of the radial distance. Assuming a medium of finite extent, the logarithmic derivative of the wave amplitude at the boundary can be expressed as an infinite continued fraction with the ray parameter as the variable. A

finite continued fraction will result, if one starts with Calogero's equation for the phase function, changes it to a particular form of Riccati equation by a homographic transformation, and then replaces the derivatives by finite-differences. By terminating the first expansion, or using the second expansion the phase shift will be given as the ratio of two polynomials. In this representation the variable wave velocity in different layers can be obtained directly in terms of the coefficients of the two polynomials, where these polynomials are determined from the empirical results by Thiele's reciprocal-difference method.

(b) Experimental Seismology

Crustal refraction and reflection recordings were made in Manitoba and Saskatchewan as a part of the program of the Consortium for Crustal Reconnaissance using Seismic Techniques (CO-CRUST). Participants were from the Earth Physics Branch (D.E.M.R.) and the Universities of Alberta, British Columbia, Manitoba, Saskatchewan, Toronto and Western Ontario. From the University of Alberta Dr. E.R. Kanasewich and Dr. G.L. Cumming are involved together with Gary D. Mann and Zbigniew Kazmierczak. Refraction arrivals were recorded across the Churchill geological province initiating a program which will tie the crustal work in Manitoba to our own studies near Swift Current, Saskatchewan.

The use of shear waves in shallow seismic mapping is being advanced on both the experimental field level by E.R. Kanasewich and the theoretical level with the development of synthetic seismograms by Dr. F. Abramovici.

The spectral ratio method for measuring absorption and dispersion from seismic data has been examined by D.C. Ganley and E.R. Kanasewich. Corrections for frequency dependent losses due to reflections and transmissions have been shown to be an important step in the process. The first data were from a sedimentary basin in the Beaufort Sea. Measured Q values were $43 \pm 2$ for a depth interval 549 to 1193 meters and $67 \pm 6$ for a depth interval 945 to 1311 meters. The estimate of Q is obtained from a fitted least-squares line. Despite the high level of noise introduced in the field, imperfections in the air gun source function upon repeated shootings and noise introduced in digitizing photographic analog recordings, the value of attenuation is well constrained over thicknesses of about 0.5 to 1 km. A dispersion curve was obtained successfully from this same data by unwrapping the phase curve.

Dr. E. Nyland working with colleagues in Mexico at the Instituto de Investigaciones en Matematicas Applicadas y en Sistemas at Universidad Nacional Autonoma de Mexico assisted at the birth of a new digital seismic telemetry network. The RESMAC network became operational two weeks before the largest earthquake of 1978 occurred in the State of Oaxaca (November 29, 1978, $M_S$=7.8). He was on leave from the University of Alberta at the time and working as a Visiting Professor at UNAM. Presently he and Cecilio Rebollar are analysing spectra of aftershocks of this event as recorded on the RESMAC system.

Two geodetic networks have been installed in southern Mexico, near the Caribbean-North American plate boundary. These networks were built and will be monitored in collaboration with staff of the Instituto de Ingeneria of UNAM. They are expected to provide very useful data on geodynamics of plates near an unstable triple junction (CARIB-NOAM-COCOS). The observing points use concrete pillars and forced centering equipment of a new design.

Nyland and Lamoreaux are continuing analysis of the Russion pattern-recognition techniques as they apply to earthquake catalogues. Both the bursts of seismicity and the sigma tests appear to work well in an area of Central America near Guatemala. In Mexico and Panama they do not work or are at best inconclusive. The reason for these differences lies in an assumption about the nature of a tectonic regime which is intrinsic in the Russian approach, but has hitherto not been perceived.

It is by now well accepted that under certain conditions plate collisions can cause plastic deformation of plates. Margrave and Nyland are exploring the relationship between aseismic ridge-continental plate collisions and continental deformation. At least in the case of the Nazca Ridge there is good evidence that such a collision also can cause extensive plate deformation. The case of the Tehuantepec Ridge is more complex for it may well be a relic fracture zone which lacks the strength to deform continents.

An event-detecting cassette digital-recording system is being developed by M.D. Burke, L. Ramsdell and E.R. Kanasewich. Initial tests appear promising and the detection system incorporated in the microprocessor is able to discriminate quite well between many types of events and micro-seismic or cultural noise.

Dr. Jones and Dr. J.S. Rogers of the Low Temperature Group in the Department of Physics have constructed six Stacey-type mercury tiltmeters to be used for measuring Earth tides and local tilts. Two instruments have been operated continuously during the summer of 1979 at the Leduc Observatory. A further six instruments are under construction. The tiltmeters will be used for measurements in Western Canada.

An array of three short-period vertical seismometers, recording in digital format on magnetic tape was operated continuously from December 1978 to June 1979. Over 500 local events of very low magnitude were recorded. About a sixth of these were due to military activities. The remainder have not been identified as to source but the phase velocities and azimuths have been determined. Further studies will be necessary in this area with its concentrated heavy oil recovery projects.

## II Physics of the Earth's Interior

A study of stress in Western Canada has been made by D.I. Gough and J.S. Bell. Many oil-wells in Alberta are non-circular as a result of spalling in their walls. Such break-outs occur over a wide depth range covering the stratigraphic column from Devonian through Cretaceous, and in siltstones, sandstones, limestones, dolomites and one shale. The azimuths of greatest elongation are given by modern four-arm dipmeter logs, and are tightly grouped in a northwest-southeast direction. They are unrelated to dip of the strata. We advance the hypothesis that the spalling is caused by concentration of stress at the walls of the holes, in a general stress field having large, unequal horizontal principal stresses. The observed break-out orientations would require the larger horizontal principal stress to be directed northeast-southeast, at right angles to the Rocky Mountain fold axes. As a normal stress field ($\sigma_1$ vertical) would give horizontal stresses too small to produce break-outs at depths of a few hundred meters, it is believed that $\sigma_1$ is horizontal and NE-SW. Hydraulic fracturing data support our hypothesis. In the Pembina area of western Alberta there is evidence that water pressure applied in oil-wells produces vertical fractures NE-SW. If these form normal to $\sigma_3$, the implied stress orientation gives $\sigma_1$ in agreement with that inferred from the oil-well break-outs. Steam injection near Cold Lake in east central Alberta gives similarly oriented vertical fractures. There is thus strong evidence that $\sigma_1$ is consistently northeast-southwest throughout the Alberta Plains. The data from

oil-well break-outs do not discriminate between a thrust-type stress field ($\sigma_3$ vertical) and a strike-slip field ($\sigma_2$ vertical) but the hydraulic fractures suggest the latter. The stress field proposed could be related to present tractions on the plate, to postglacial rebound of Hudson Bay, to residual stresses from the Laramide folding of the Rockies, or to some combination of these. If our hypothesis is validated it may lead to determinations of stress orientations in many sedimentary basins which have been drilled for hydrocarbons, where the four-arm dipmeter has been used in logging the wells.

Dr. T.J.T. Spanos has completed the construction of a physical description of immiscible displacement in a porous medium which includes a theory of viscous fingering. A perturbation analysis has been applied to this theory to examine the stability of the flood front during immiscible displacement. Characteristic numbers result from this analysis which specify the onset of instability and the minimum width a viscous finger may attain. A generalization of the equations of immiscible displacement includes inertia and the use of these terms in describing the initial conditions, breakthrough conditions and the rate of finger growth in an unstable displacement. Dr. Spanos is constructing a general stability analysis for an inhomogeneous porous medium and is investigating the importance of inertia to the stability.

## 6. University of British Columbia

### I Seismology

D. Au and R.M. Clowes are continuing the interpretation of an extensive set of marine seismic data obtained from 3 ocean bottom seismometers (OB's) deployed around the Nootka fault zone, the narrow region along which relative movement between Explorer and Juan de Fuca plates is taking place. A total of 150 explosive charges, supplemented by a 16 litre air gun to 15 km distance, were shot along 3 profiles through the array. The analysis of travel times and amplitude information on corrected record sections show considerable complexity in the crustal structure.

S. Levy and R.M. Clowes have prepared a paper entitled "Phase-Only Processing and its Applications in Seismology". The phase-only component of a seismic trace provides an estimate of the earth's impulse response function if a zero-phase or near-zero phase wavelet is assumed. As well, an appropriate zero-phase wavelet can be estimated from a given seismic trace by a simple procedure. A number of examples with synthetic data demonstrate the viability of the method. Its application to real data is exemplified by the removal of bubble pulse oscillations from a set of marine reflection data recorded using explosive charges. Because the basic procedure involves only Fourier transformations, phase-only processing is an extremely economical technique for both deconvolution and wavelet estimation.

S. Levy and R.M. Clowes have prepared a manuscript providing a new approach, based on generalized linear inverse (GLI) theory, to the solution of the debubbling problem associated with marine seismic data. They show that estimation of either the wavelet or the impulse response from a seismic trace can be formulated as a GLI problem. This parametric approach enables the accuracy of the solution to be controlled such that it is consistent with the observational errors and/or known noise levels. The complete debubbling procedure can be described in four steps: (1) apply minimum entropy deconvolution to obtain a first approximation to the earth's response function; (2) use this trace and the observed data as input to the GLI procedure to compute a basic wavelet; (3) use the results of steps 1 and 2 to construct the compound source wavelet; and (4) use the latter and the observed data as input to

the GLI method to obtain a debubbled, deconvolved seismogram. The applicability of the new approach (which is computationally expensive) is illustrated with a set of synthetic seismic traces and a set of field seismograms.

R.M. Ellis, R.M. Clowes, D. Au and K. Whittal participated in a combined seismicity refraction experiment with the Pacific Geoscience Centre on the Queen Charlotte Fault zone. Five land and four ocean bottom seismographs were deployed. Two profiles, one in deep water parallel to the coast and a reversed line across Moresby Island were shot with explosives and additional profiles recorded on the OBS's to provide information on the upper oceanic crust. Approximately 25 local earthquakes were recorded by the array.

A 6 station telemetered digital seismic network has been planned by R.D. Meldrum and R.M. Ellis for installation in the Lower Mainland - Vancouver Island region in early 1980. The data for this array will be integrated with that of the Earth Physics Branch and used to study the movement of the lithospheric plates, delineate active fault zones, and determine regional crustal structure.

G.C. Rogers continues to study the seismotectonics of Canada's west coast. Epicentres of all earthquakes greater than magnitude 4 prior to 1965 have been re-examined. Thus far about 200 location and magnitude changes have been made to this data set. In the Queen Charlotte region revised parameters indicate not all earthquakes occur offshore along the Queen Charlotte fault but some occur on the land mass of the Queen Charlotte Islands. In the southern Vancouver Island region earthquakes in the subducted plate seem continuous from southern Puget Sound to 49°N.

R.M. Ellis has continued operation of the seismic array about the Mica reservoir and the region of the Revelstoke reservoir at which filling will take place in 1983. In the past year, seismicity has been at a low level. A summary study of the monitoring operation for the period 1973-78 is now near completion.

## 7. University of Manitoba

### I Seismology

A.G. Green completed the interpretation of a seismic reflection survey in the Kisseynew subprovince and the boundary zone between the Churchill and Superior provinces of the Canadian shield, in the vicinity of Thompson, Manitoba and interpretation of COCRUST seismic reflection data over the Superior province and the boundary zone in the vicinity of Brandon, Manitoba.

W. Delandro and W. Moon started detailed interpretation of 1977 COCRUST refraction seismic data obtained in the vicinity of Brandon, Manitoba. In this research the modelling by theoretical synthetic seismograms and systematic inversion methods will be applied besides the conventional technique. A. Aming and W. Moon are also planning to interpret, in detail, the 1979 COCRUST refraction seismic data over Virden, Manitoba with the same technique.

A.G. Green and others have completed the interpretation of two crustal reflection surveys in northwestern Ontario. Prominent reflections were used to map the crust-mantle boundary, two near-horizontal intra-crustal discontinuities and a major near-vertical fault. The most shallow intra-crustal discontinuity, at 16 km depth, was observed to be continuous beneath the Aulnear granite batholith and the adjacent greenstone belt. A composite seismo-gravity interpretation of this region has been completed in collaboration with W.C. Brisbin.

A.G. Green and others have conducted gravity, magnetic and seismic surveys across the Superior-Churchill boundary zone in southern Canada. Preliminary interpretations from these surveys have been completed, and further data processing and synthetic seismogram analysis of the seismic data are currently underway. Early results suggest that the crust thickens from 41 km beneath the Superior province to 46 km beneath the Churchill province.

W. Moon is continuing the study of diffraction and scattering by circular objects using new methods developed by C.H. Chapman (1979).

## 8. McGill University

### I Seismology

R. Leskinen has recently completed a thesis which, in a tutorial style, compares the results of spectral analyses and deconvolutions of seismic data which is modelled as moving average (MA), autoregressive (AR) or mixed (ARMA) processes. This study has shown that while the apparent spectral resolution depends strongly upon the data model assumption, an accurate spectral representation can only be economically achieved if the assumed data model corresponds to the actual generating process. It has been found that extensions of the autocorrelation functional estimates based upon the ARMA data model can provide for even greater apparent spectral resolution than is available under an AR model-based extension which corresponds to the maximum entropy spectral estimates. Deconvolutions of both synthetic and real seismic data have demonstrated that ARMA deconvolution filters comprising only a very few coefficients can achieve as much resolution of a seismic reflection series as is available using much longer AR and MA deconvolution filters. However, the difficulty and computational expense involved in obtaining the required ARMA filters would seem to limit their immediate acceptability in large-scale seismic processing.

Following the recent completion of his thesis concerning the theory of multi-channel autoregressive data modelling and the development of a Burg-like recursion algorithm, P. Tyraskis has revised his computer programs which compute the multi-channel prediction-error system and the derived maximum entropy multi-spectral estimates in order to make them more efficient. These revised programs have already been applied in a study of 4-channel magneto-telluric data by R. Mathur. Work is now being directed toward extending the Wiggins method for filling gaps in data series with statiscally consistent estimates to allow for multi-channel data series showing interchannel coherency. These procedures should find an early application in the editing of data gaps derived from the McGill 3-component ultra-long period seismograph.

O.G. Jensen is continuing a development of the theory of seismic motions generated in the mechanical interaction of the earth with the possible temporally varying strains in the background geometry of space which could be caused by General Relativistic gravitational waves. In cooperation with W.H. Cannon, who has recently obtained the general equation of motion describing gravitational wave-forced motions in an elastic continuum, an analysis of the response of a real layered crust lying in a gravitational field is now underway with a view to providing a prediction of the actual characteristics of seismic motions that would be generated by possible gravitational waves in the 1 Hz band.

The McGill ultra-long period seismograph is now being calibrated and its noise and drift characteristics are being studied before it is eventually deployed at a site yet to be chosen. Further details are given in the Chapter entitled Geodesy and Gravity.

## 9. University of Saskatchewan

### I Seismology

Z. Hajnal and B. Reilkoff coordinated the 1979 CO-CRUST (Consortium for Crustal Reconnaissance using Seismic Techniques) crustal seismic experiment in the area of the Nelson Trend in southwestern Manitoba and southeastern Saskatchewan. The program included a forty km. twelve-fold reflection survey over the contact of the Superior Province and the transition zone. The Universities of Alberta and Manitoba provided field crew support for this part of the program.

The second phase of the program consisted of three three-hundred km. refraction profiles. The instrumentation and the field crews were supplied by the Seismological Division of E.M.R. and University of Western Ontario. Two lines were located in a north-south direction. One was in the transition zone between the Churchill and Superior Provinces, the other in the Churchill Province. The third line represented a westernly extension of the 1977 profile. Digital processing of both sets of data is in progress.

Z. Hajnal and M.R. Stauffer continued their investigations of seismic characteristics of Precambrian outcrops in the Flin Flon region. It was discovered that all rock types in the region have a low velocity upper layer associated with them. Logging investigations revealed that this zone has high frequency attenuation characteristics.

As part of the high resolution seismic investigation in the Athabasca basin, Z. Hajnal and B. Reilkoff are experimenting with a new multi-channel coherency technique to recognize reflected events in low signal to noise ratio environment. For the solution of major static problems a processing technique, built on the Hibert transform of the data, is adopted. This process provided a signifcant improvement in the segment of the data analyzed so far.

A six channel short period permanent siesmograph station is being installed approximately 16 km. east of Saskatoon. The data are continuously transmitted from the site to the laboratory and recorded digitally on paper.

### II Physics of the Earth's Interior

G. West and J.C. Mareschal have reported the results of a study of early Precambrian tectonics, invoking the heating and weakening of a radioactive crust blanketed by denser volcanic flows. A finite-element numerical model has been used to trace the downwarping of the weakened, gravitationally unstable crust. The model explains many of the features of greenstone belts in the Shield.

Glacial isostasy: the global model for the predicton of relative sea level changes following deglaciation has been further expanded (Peltier and Wu) to include the temporal behaviour of the associated free air gravity anomaly. When the sea level and gravity data are jointly inverted for mantle viscosity the constraint on lower mantle viscosity is much improved, and the favoured number is found to be of order 1 Pa.s (10 Poise) beneath the transition region. This number has also been obtained independently (Peltier and Sabadini) by inverting the secular part of the ILS polar motion curve assuming that the observed real polar wander is deglaciation induced.

Mantle convection: laboratory experiments on the properties of convection with internal heat generation have been completed (de la Cruz) and effects due to the temperature dependence of viscosity observed.

Related theoretical work (Sharpe and Peltier) has included the calculation (using Galerkin methods) of steady finite amplitude solutions for this geophysically important geometry and the use of the empirical heat transfer relation in parameterized convection models (Sharpe and Peltier) of the Earth's thermal history. Other work has focussed on the linear stability of the boundary layers embedded in the large scale circulation (Yuen and Peltier) and the discovery, using finite difference numerical models, of a new theory for the observed flattening of sea flow bathymetry away from the $t^{-1/2}$ behaviour predicted by boundary layer theory (Jarvis and Peltier).

Mantle rheology: work on postglacial rebound has firmly established that the linear visco-elastic Maxwell model provides an excellent approximation to the rheology of the mantle for long timescale processes. The viscosity obtained by using this model to invert the data is just that required in the convection hypothesis of continental drift. This model may be usefully extended to cover short timescale processes using the Burger's body framework, with the new parameters constrained by observations of the Q's of the elastic gravitational normal modes (Yuen and Peltier), the period of the Chandler wobble, and other processes in the short timescale end of the geodynamic spectrum.

## 10. University of Toronto

### I Seismology

An interpretation study of crustal scale seismic refraction recordings of mine blasts gathered in the Sturgeon Lake area of N. W. Ontario over several years has been completed by R. Young for his Ph.D. thesis, under the supervision of G.F. West. The study has made extensive use of new synthetic seismogram modelling techniques devised by Chapman. The data indicate a crustal structure with the M discontinuity at about 40 km. The lower crust has a positive velocity gradient and a complicated transition into the mantle. The mantle velocity appears to rise to about 8.5 km/s at a depth of about 50 km. The upper and mid-crustal structure varies laterally. To the north, the p velocity is constant at 6.0 km $s^{-1}$ to a depth of about 20 km where a rapid transition to higher velocity is observed. To the south, a high (6.3 km $s^{-1}$) velocity cap overlies 6.0 km $s^{-1}$ and the rise in velocity below 20 km is gradual.

In recent years, C.H. Chapman has developed a new method for computing synthetic seismograms. A very useful approximation to this method, the WKBJ seismogram, has been fully developed. A versatile computer program has been written to compute WKBJ seismograms; it has been widely distributed and is used by many institutes. Results have been compared with those from reflectivity, full-wave theory and Cagniard programs and in most cases give equivalent results at a fraction of the cost. In particular, the method can be proved to be equivalent to geometrical ray theory (GRT) when the latter is valid, but to remain applicable on direct and reversed branches of travel-time curves, at caustics, critical points and for partial and total reflections from interfaces, head waves and Fresnel diffractions. Four projects using WKBJ seismograms are in progress.

WKBJ seismograms are a high frequency approximation, although they are a significant improvement on GRT. C.H. Chapman has developed new theoretical methods to cover two long-period corrections: the effect of the spherical geometry, and long-period partial reflections from velocity gradients. The new method is ideal to cover propagation in a spherical model as it leads to an exact solution, whereas previous techniques had used asymptotic expansions. To describe partial reflections from a velocity gradient, a new technique using the Langer approximation in an

iterative solution (rather than an asymptotic expansion) had to be developed. Theoretical development is complete and numerical computations for realistic models is proceeding. The technique is ideal for answering the question - to what extent can we distinguish an interface from a velocity gradient?

Together with Dr. J.A. Orcutt of Scripp's Institute of Oceanography, C.H. Chapman is developing an inversion technique for oceanic refraction data. Initially the method is being tested using data from the 1959 Fanfare cruise of the Scripp's Institute. These data had been previously interpreted by trial-and-error using reflectivity synthetics. Using this solution, it has been established that WKBJ seismograms are sufficiently accurate to model the data. Partial derivatives are easily computed for WKBJ seismograms and, for sufficiently low frequencies, the problem is always pseudo-linear. The inversion is solved as a least-squares problem, using a combination of the generalized inverse and the damped least-squares (Marquardt) methods in the frequency domain.

The WKBJ seismogram is being extended to models with lateral variations by C.H. Chapman. The WKBJ seismogram consists of an integral of the plane-wave impulsive responses of the medium. In laterally inhomogeneous media, the plane waves are propagated using asymptotic ray theory. The method is valid if the source and receiver are in simple regions even if caustics, etc., form at the receiver when the plane waves are combined. To expedite tracing the plane waves, the model is approximated by linear functions in each triangle of a grid. This method was developed by Hron and Marks (University of Alberta) and is very efficient because analytic solutions can be used in each triangle. In the WKBJ seismogram, the (small) caustics formed by the gradient discontinuities are not troublesome as they are smoothed automatically. Development of the computer programs is almost complete.

C.H. Chapman is extending the WKBJ seismogram program to include the effects of attenuation and/or tunnelling, or for computations near the source. In each case, the plane-wave impulse response of the model, which in the WKBJ seismogram is a delta function, is replaced by a broader pulse. Therefore all 3 problems can be handled in a very similar fashion. Modification of the computer program has just begun. Great emphasis is being placed on efficiency and simplicity, as the present program, which is in wide usage, is so fast and easy to use.

## 11. University of Western Ontario

### I Seismology

The complexity of P waves is a function of both the source signature and the characteristics of the media through which the wave has travelled. When the ray path passes through a homogeneous earth, the energy arriving at a seismic array will be relatively coherent with the signal complexity depending mainly on the source function. When the signal encounters both lateral and vertical inhomogeneities along its path, much of its energy is scattered and arrives at the array as incoherent energy. Various methods of measuring the signal complexity of the coda based on signal coherence are being investigated in order to determine which is best in revealing the nature of the transmission media.

By using array records from earthquakes located at various distances and depths, a study is being made by S.B. Ojo and R.F. Mereu to determine how coherency varies with ray path. Preliminary results show that the region of the upper mantle above the 400 km discontinuity is much more complex or heterogeneous than deeper regions. This heterogeneity may be a result of the interaction of the lithospheric plate with the asthenosphere.

When a plane P wave travels through a medium in which small changes in seismic velocities occur at random, the wave becomes attenuated as some of its energy becomes scattered and converted into other modes. In practice the scattered energy forms the coda of the P waves. Since a theoretical analysis of this problem is exceedingly difficult, the feasibility of employing a finite difference approach to the problem is being investigated.

The University of Western Ontario seismic array near London, Ontario continued to operate under the direction of R.F. Mereu and T. Yapp during the past year. As a result of a small earthquake which was detected between Woodstock and Kitchener, plans are underway to add more stations to the array so that the low level seismicity of that region may be studied in more detail. The structure of the upper crust in S.W. Ontario is also being studied with portable stations using area quarry blasts as sources.

Work continued by J. Brunet, R.F. Mereu and B. Price on the development of a new portable seismic recorder. The system features a low power RCA 1802 microprocessor for programmed timing and control.

During the summer of 1979, R.F. Mereu and S.B. Ojo participated with the University of Saskatchewan and the Department of Energy, Mines and Resources in a major seismic refraction experiment to study the structure of the Superior-Churchill geological boundary in Manitoba and Saskatchewan. Three refraction lines approximately 280 km in length were recorded. In this experiment the U.W.O. recorded 80 seismograms with 8 portable refraction instruments. Analysis of the data is at present underway.

The theory of elastic surface waves travelling circumferentially on a solid cylinder in a vacuum was developed by Sezawa (1927). This has now been extended by F.K. Maxwell and L. Mansinha to include three other cases. The period equations for (1) surface waves on a cylindrical cavity in an elastic medium, (2) Stoneley waves on a cylinder immersed in a liquid and (3) a liquid filled cavity are all derived from the same basic equations by interchanging Bessel and Hankel functions. Of these only the waves travelling around a solid cylinder in a vacuum exhibit no attenuation in the azimuthal direction. In the other three cases the surface waves appear to be transformed into body waves when the local velocity of the surface waves exceeds some critical value.

Since topographic features such as oceanic trenches and mountain ranges extend for long distances in one direction they can be approximated by a sequence of segments of cylindrical surfaces. It is assumed that over these short segments the seismic wave will behave as though it were propagating on a surface of constant, local, curvature. Then the dispersion and attenuation of the boundary waves over any arbitrary continental or suboceanic topographic feature may be determined. The ratio of the wavelength of the surface wave to some parameter defining the width of the feature determines both dispersion and attenuation.

Valleys and hills on continental crust act as high pass filters. Wavelengths much shorter than the width of the feature are unchanged in amplitude. The travel time increases consistently with decrease in frequency. Underwater topographic features show a much greater attenuation of the higher frequencies. However all frequencies are attenuated much more severely than would be the case for a similar structure on the continent.

The vast increase in the number of recorded seismic events has led I.F. Jones and L. Mansinha to search, once again, for possible temporal

and spatial periodicities. Fourier analysis of the global data set from 1918 to 1975 has failed to show any signifacnt peaks above the noise level. By breaking up the data set into natural spatial regions a rough sort of periodicity is seen in several regions. Work is underway to test if these periodicities are real and related in some manner to local plate motion. The anlysis has been made difficult by the inhomogeneity of the data set, i.e., the increase in the number of recorded events which does not reflect a corresponding increase in seismic activity. We have not yet evolved a completely satisfactory method of correcting for the inhomogeneity.

## II Physics of the Earth's Interior

A study by S.P. Fodemesi and A. E. Beck to examine the stimulation of heat transfer by convection in the needle probe thermal conductivity technique continues. We now find evidence of the onset of convection, using typical experimental conditions, in cases where the axial heater is oriented vertically as well as in the cases when it is oriented horizontally; as expected, convection is more easily induced for the horizontal case.

Our principal objectives now are (1) to find simple criteria which would enable a researcher to detect the presence of significant convection transfer from the needle probe temperature-time curve alone, and (2) to find a physically based theoretical mechanism which explains the results sufficiently well that appropriate corrections can be put in when convection transfer takes place.

Work by A.E. Beck continues on developing the recording system, the principal aim being to record the information digitally on a battery operated portable tape recorder with simultaneous, or slightly delayed, output for a monitor analogue record.

One interesting development has been the reinterpretation of a number of logs previously run in the University of Western Ontario borehole. The basic data have already been published but many of the minor "wiggles" which had been interpreted as noise turn out to be real signal of minor variations in the thermal resistance of thin layers. It now appears that we can detect changes of 0.1 mKm over distances of less than a meter in cased boreholes. In addition, work has started on wavelength filtering of the record to separate temperature gradient changes that are spatially dependent (due to lithology) from those that are temporally dependent. This means that the precision continuous logging technique may be used to detect very small water flows in and across the borehole, a matter of considerable importance for waste disposal projects.

The disturbance to subsurface temperatures due to the annual temperature change is well damped out at depths greater than 20 meters. However, in many boreholes there are obvious signs of longer period surface temperature changes with the disturbances extending to depths of well over 100 meters. With the continuous recording of temperatures and temperature gradients to a high precision it may now be possible to obtain the temperature-time function at the surface, back to a few thousand years ago, from the detailed thermal logs. Work has started on this aspect by removing the short wavelength temperature gradient variations and comparing them with the thermal resistivity measurements made on core, i.e., the effects of structure are removed and a temperature-time function from the remainder is produced.

Measurements by R. Facer, a visiting professor from the University of Wollongong, Australia, of heat generation and thermal conductivity of rocks (mainly granitic) which form part of the basement to the

coal-bearing Sydney Basin have been completed. The investigation was carried out to assess the possible effect of heat generation variations on coal rank within the basin. Heat generation is slightly higher than "average" for such rocks.

An investigation by R. Facer and A. E. Beck has been commenced to determine the heat generation, thermal conductivity and heat flow of the Sydney Basin. By combining the data thus obtained with other geophysical (including gravity, magnetic and seismic) and geological data it is hoped to develop a thermal model for the basin. As this is an important coal-producing region such a model should assist in understanding variations of coal rank within the basin.

K, Th and U are the main contributors to the generation of heat (by radioactive decay) in rocks. However, the geochemical behavior of Th and U during metamorphism is very poorly understood. Accordingly an investigation by R. Facer has been commenced on Australian and Canadian igneous and sedimentary rocks to assess the behaviour of K, Th and U (and other elements) in response to varying degrees of regional and thermal metamorphism. Because of the low levels of Th and U in most rocks, initial work on the Canadian rocks will concentrate on granite rocks from the Grenville Province and the Sudbury area.

The possible relationship between heat generation, seismic velocity and specific gravity of rocks (especially igneous rocks) is being assessed by R. Facer and H. Schloessin. This suggested relationship (based on recent research by Rybach in Switzerland) is being further assessed by a study of electrical properties.

High pressure reaction rate studies by N.S. Brar and H. Schloessin show that the calcite/aragonite and quartz/coesite transitions change from slow to fast transformation rates over very narrow temperature intervals, varying from about 40 to 120 K depending on pressure and the direction of the transformation. Rate constants K and exponents n, obtained for single and polycrystals, agree well with Avrami's and Cahn's nucleation and growth theories. Transformed volume fractions y(t) at time t, determined by X-ray diffraction, are generally in accordance with y(t)=1-exp(-Kt) with n close to 4 for nucleation and close to 1 for growth. K(s) varies from 10 at low p,T to 10 at high p,T values and is thus found to be many orders of magnitude greater than the lower bound of values required for convection and transformation to be compatible within the earth. Lower bounds to typical nuclei sizes y and finiteness of the total volume 6, cause deviations from the simple growth law during the early and late transition stages. Optical microscopy of etched and/or stained samples and X-ray diffraction topography give direct evidence of preferred nucleation at lattice imperfections and defects. They point to the significance of inhomogeneity stresses and stress concentrators influencing transformations and confirm observations by Grady et al. on transformation in shock compression.

The thermal conductivity of a Brazilian basalt was measured by E. Barker, A.E. Beck and H. Schloessin by means of the cylindrical rod method (Carslaw and Jaeger, 1959). At pressures between 2.53 and 5.60 GPa and temperatures between 346 and 563 K the conductivity varies between 1.85 and 1.42 WmK. The pressure coefficient in WmK GPa, is 6.8 x 10 at 346 K, and 2.6 x 10 at 569 K. The temperature coefficient in WmK is 1.7 x 10 at 2.53 GPa and 1.06 x 10 at 5.28 GPa.

The lattice conductivity of Carolina dunite, in WmK, varies between 6.01 at 300 K and 5.6 GPa to 2.96 at 600 K and 1.95 GPa. The pressure coefficient, in WmK GPa, decreases from 1.9 x 10 at 300 K to 1.04 x 10 at 600 K, The temperature coefficient, in WmK, increases from 7.9 x 10 at 1.95 GPa to 9.1 x 10 at 5.6 GPa. The increasing temperature coefficient

appears to be influenced by a radiative conductivity contribution as is borne out by deviations from linear 1/T plots and comparison with earlier results due to Lubimova and Kingery.

Size frequency distribution studies of vesicles were carried out by H. Schloessin and E. Barker on core samples of oceanic basalts from Leg 37 of D.S.D.P. with maximum sub-bottom depth of 517 m. Point counts of the vesicles in seven size categories were made using X-ray absorption topographs. Discoveries include a direct correlation of radius with frequency and a minimum in the total number of vesicles per core sample at intermediate depths. Two explanations for the latter finding involve saturation of the melt with gases and vapours. Supersaturation of the magma with dissolved gases and vapours occurs most probably only at the top and bottom of the magma column arising from below the ridge axis. Under the supposition of this column model the size distribution reflects either (a) the steady state velocity distribution of the bubbles in the rising column if the solidus meets the ocean floor or (b) in-situ freezing of bubbles, preferentially accumulating near the centre of the column (where the solubility is lowest), if the solidus lies well below the ocean floor. Owing to the high specific heats of the vapour gas content of vesicles and their high mobility relative to the ascent velocity of the magma as a whole, considerable amounts of heat, not usually accounted for, are thus transported by means of effervescence.

P-wave velocity measurements, both on the laboratory bench and in the 200-ton cubic press, are underway by H. Schloessin and E. Barker. PZT-transducers are used as transmitters and receivers with various modes of coupling. The simple time-of-flight method works most satisfactorily. Input and transmitted pulse are recorded and measured on a two-channel digital oscilloscope. Without graphical interpolation the time resolution at present is 0.5 sec giving velocity determinations with a resolution of at best +0.02 Km/s. Attenuation measurements, in small samples, give reliable results which are directly applicable to absorption, only for single crystals. In polycrystalline samples more complicated effects are caused by grain boundary scattering.

D.C. electrical conductivity measurements (in 010 direction) of triglycine sulphate were made through the Curie point and pressures between 20 and 60 kbar by H. Schloessin and E. Barker. The Curie temperature increases by 0.2 K GPa and shows pronounced temperature hysteresis. Discontinuous changes in pressure at the transition increase with pressure by 0.001 GPa. The activation energy for the conduction in the FE-phase decreases from 0.30 to 0.28 eV, that for the PE-phase increases from 0.55 to 0.76 eV. The corresponding activation volumes, obtained from E/P, are -1.2 and +13.5 cm mole. Increases in the conductivity due to aging exhibit a critical aging temperature and amount to more than one order of magnitude; conductivity is restored on cooling. X-ray diffraction through the FE-PE transition shows irregular variations of Bragg reflections which may be related to jumps in domain motion similar to those causing Barkhausen jumps during field switching.

Melting and pre-melting phenomena in chemically inhomogeneous materials are being investigated by H. Schloessin. General interest is strong and debates continue on this rather controversial topic. The question of characterization and determination of partial melt fractions by electrical conductivity measurements has been pursued further. In most minerals the conductivity mechanisms are mixtures of mostly intrinsic, rarely intrinsic, electronic and ionic conductivities. Melting and processes prior to melting involve significant changes in conductivity mechanism, i.e., change in type of charger carrier, number of carriers, mobility and lifetimes. In olivine and basalts pressure increases the conductivity below melting and decreases it above melting. Changes in free energy with pressure give activation volumes which can be

related to compressibility and Gruneisen exponent below and above melting. Pre-melting and premonitory conductivity effects can best be explained in terms of boundary layer conductivity models for large-angle grain boundaries.

## 12. Memorial University

### I Seismology

Field work by I.C.F. Stewart in Central Newfoundland is being carried out with 2 analog seismographs and 2 digital Microcorders. Quarry blasts at Baie Verte are monitored for refraction studies, and teleseismic events are also recorded to enable P-wave residuals to be correlated with crustal structure. A new fixed seismograph station PKP employing telemetry is being established near St. John's as an additional reference for times recorded at the field stations. Processing of field data recorded since 1977 is continuing.

Measurement of seismic velocity and porosity at in situ pressures in well cores is being commenced, in conjunction with J.A. Wright and R.Gagnon. Samples are from sedimentary structures of economic interest from offshore eastern Canada.

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# III GEOMAGNETISM

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   (h) University of Western Ontario
   (i) University of Toronto (Physics)
   (j) University of Windsor
6. Bibliography

## 1. Geomagnetic Surveys, Charts, and Compilations

### (a) Atlantic Geoscience Centre

Detailed magnetic data collected since 1974 over Saglek Bank and adjacent Labrador Sea were compiled in the form of six Natural Resource Maps and released as part of Geological Survey of Canada Open File 607. Each map covers 1° of latitude and 2° of longitude at a scale of 1:250,000.

A compilation incorporating all existing magnetic data in the Labrador Sea has been completed on a scale of 1:2,000,000. The map was released as part of Geological Survey of Canada Open File 627.

Small scale compilation of published and unpublished magnetic anomaly (and Bouguer gravity anomaly) data for the Appalachian orogen were released as part of Geological Survey of Canada Open File 615. This publication also includes a description of the major magnetic lineations within the Appalachians and the associated tectonic features. These compilations were made in preparation for a 1:1 million scale compilation of magnetic anomaly (and gravity) data to be compatible in area, scale, and projection with William's Tectonic-lithofacies Map of the Appalachian orogen.

A total of 14,000 km of magnetic (together with gravity and bathymetry) data was collected off Nova Scotia coast as part of the multiparameter survey in cooperation with Canadian Hydrographic Services. The data were collected on lines running perpendicular to the margin at a spacing of 38 km. The lines extended from the edge of the shelf to water depth of 5,000 m.

(b) Earth Physics Branch

(i) Magnetic Repeat Station Survey

As part of a continuing study of magnetic secular variation, eight repeat stations were occupied by contract in Ontario and Quebec during May and June. A digitally-recording fluxgate magnetometer provided a record, for a minimum of 30 hours at each station, of variations in the magnetic declination (D), the horizontal component (H) and the vertical component (Z). Auxiliary analog chart recorders provided a visible record. Absolute measurements of declination (D), inclination (I) and total intensity (F) provided baseline control.

In October eight more stations, from Nova Scotia to British Columbia, were occupied to begin a new schedule of secular variation surveys. The number of repeat stations has been reduced from 112 to 58, the recording period is lengthened to 3 or 4 days and the stations will be occupied in the autumn if possible.

Seven of the 16 stations occupied in 1979 form part of a worldwide ground support network for the MAGSAT (magnetic survey satellite) project. These stations (Essex, Frobisher Bay, Goose Bay, Halifax, Saskatoon, Sept Iles and Whitehorse) will be reoccupied at two-year intervals over the next 6 years. (E. Dawson and L.R. Newitt).

(ii) Magnetic total intensity data, uncorrected for transient variations, from Hudson Bay ship-towed magnetometer surveys 1975, 1976, 1977, and 1978 have been processed and plotted. Transient variation corrections have been applied to the surveys 1975 to 1977, but because control station data have only recently become available the corrections for survey 1978 have not yet been determined. It is expected that this will be completed by mid-1980. (R.L. Coles and G.V. Haines)

2. Interpretation of Magnetic Surveys

(a) Atlantic Geoscience Centre

Magnetic data collected from multiparameter survey off Nova Scotia during 1979 and from other cruises were used to determine the magnetic heading correction for CSS Baffin. For a magnetometer towed 600 ft. behind the ship, the heading correction is given by

$$- 6.6 \cos^2 H + 11 \cos H + 18$$

where H is the heading of the ship with respect to the magnetic north.

(b) Earth Physics Branch

(i) Magnetic Repeat Stations Surveys

Recent secular variation (SV) measurements indicate that the geomagnetic field in Canada is still being influenced by the large SV impulse which affected a large part of the northern hemisphere in the early 1970's. The rate of change in D has doubled in western Canada since that time. While H is still increasing over most of Canada, parts of western Canada now show a significant decrease. The isoporic focus of H, which, in 1975, was located in the Atlantic Ocean, a few hundred km SE of Nova Scotia, now appears to be located in southern Quebec. It has diminished in intensity from 100 nT to 80 nT per year. Z is now decreasing over most of Canada ranging from -10 nT per year at Resolute Bay to -120 nT per year at Ottawa. (E. Dawson and L.R. Newitt).

(ii) Magsat

The Division of Geomagnetism is participating in the analysis and interpretation of data from the MAGSAT satellite, as part of NASA's Resource Observation Program. The satellite is now in orbit with initial apogee 561 km and perigee 352 km. The MAGSAT Project will provide data: (1) for accurately describing the earth's main magnetic field both for charting and mapping applications and for investigations into the nature of the field sources: (2) mapping, on a global basis, fields caused by sources in the earth's lithosphere. A knowledge of these latter fields will contribute to our understanding of large-scale variations in the characteristics of the crust and uppermost mantle, and will be relevant for future planning of resource exploration strategy. The Division of Geomagnetism is incorporating data from its magnetic observatories and variation stations into the analysis of the MAGSAT data, in order to reduce the effects of ionospheric and magnetospheric fields. MAGSAT data on solid earth fields will be combined with the Division's extensive airborne vector magnetometer data set over Canada in the interpretation phase of the Project. (R.L. Coles, G.V. Hines, G. Jansen van Beek, E. Dawson, J.K. Walker).

(iii) Airborne Magnetic Survey 1976

Reduction of data is completed for the three component airborne magnetic survey of central and eastern Quebec, Davis Strait, the Atlantic provinces, and adjacent areas of the Atlantic Ocean. The survey was carried out in late 1976, at an average altitude of 4.6 km and average flight line spacing of 74 km. The data were averaged over 30 seconds of time, or approximately 3.5 km of flight track. The International Geomagnetic Reference Field was removed from these averages, and the resulting residuals plotted as profiles. (G.V. Haines and W. Hannaford).

(iv) LOREX

During the LOREX 79 expedition to the Arctic Ocean to study the Lomonosov Ridge, two total field proton precession gradiometers were operated at ice-stations SNOWSNAKE and ICEMEN. At each station, one sensor was positioned 1 metre above the ice surface, and the second sensor was held at 140 metres below the surface. Data from SNOWSNAKE confirm the existence of a positive anomaly over the western flank of the Ridge near the North Pole, and show a corresponding gradient anomaly. The data are contaminated by a signal of period about 5 hrs, possibly related to ocean currents and tides. Further investigations are still underway. Unfortunately, problems developed at ICEMEN, and only data from the top sensor were recovered. (R.L. Coles and P.A. Camfield).

(c) Université Laval - Department of Geology

A detailed ground magnetic survey was carried out by M.K.-Seguin and students on the Maquereau group structure in the Chandler-Port-Daniel area, southern Gaspé peninsula. A preliminary study indicates the presence of slight unusual anomalies around this structure. A quantitative interpretation is planned to obtain a geological model from magnetic and gravimetric data.

(d) University of Manitoba - Department of Earth Sciences

D.H. Hall has been designated an investigator for NASA for the MAGSAT program. He and T. Millar are developing magnetic models for Precambrian provinces and sub-provinces in the Churchill-Superior

boundary region and will be searching the MAGSAT data for signatures of these features.

Dr. D.H. Hall, T. Millar, and K. Mok have completed an interpretation of the Questor aeromagnetic survey sheets in the Lynn Lake area that were released in 1976 and 1977 by the Manitoba Mines Branch. The interpretation includes qualitative catalogues of magnetic signatures of rock units, a ground susceptibility and remanent magnetization survey and quantitative modeling of anomalies, and the development of computer methods for display and storage of the data which are in digital form.

A.G. Green, G.L. Cumming, and D. Cedarwell examined the magnetic signatures of the Churchill-Superior boundary zone by qualitative interpretation of aeromagnetic and upward continued ground magnetic maps.

3. Magnetic Observatories and Instruments

(a) Earth Physics Branch

A prototype of the new Automatic Observatory System (AMOS Mk III) has been completed and is under test at the Blackburn Magnetic Laboratory.

A full description of the Canadian Magnetic Observatory network and of the data available from this network is given in the 1978 Geophysical Bulletin. Copies of magnetograms and raw or edited digital data may be obtained on a cost-recoverable basis from the Division of Geomagnetism, Earth Physics Branch, Ottawa K1A 0Y3.

Twenty-seven-day forecasts of Geomagnetic Activity are issued on request every three weeks by the Ottawa Magnetic Observatory. Beginning in 1979, short-term magnetic activity predictions up-dated twice a week and recorded in English and French, were available via telephone from May 22 to September 30. Details of other services available from the Division of Geomagnetism are listed in the Catalogue of Services for the Division of Geomagnetism.

An instrument to measure the vertical gradient of the geomagnetic field was designed for use on an ice island. Three were built for the LOREX expedition; two for deployment and one spare. The gradiometer employs two proton precession magnetometers. One sensor is located above the ice and the other is suspended in the sea water on a 1000-foot cable. The system is controlled by a microprocessor which also reads clock time and the two intensities, computes the gradient and outputs this information onto an analog recorder and digital cassette.

A portable, microprocessor-controlled data logger for recording data from analog field instruments onto digital cassettes was designed and two prototype units were tested on field trips in the Yukon, Ontario, and B.C. The instrument features 12-bit resolution, number of input channels selectable from 1 to 8, scan interval selectable from 1 second to 10 minutes, and alias filter characteristics automatically programmed to match the scan interval. It also maintains and records real time including date. The level of input on each channel can be presented on a digital display. Memory may be expanded to provide signal processing capability. As a result of field tests some hardware improvements are being implemented.

(b) University of Alberta - Institute of Earth and Planetary Physics

Sixteen new Gough-Reitzel magnetometers have been completed and tested. In addition, the 25 original magnetometers have been greatly improved in the design of many optical parts. A new camera-drive stepping motor with worm-gear drive has been fitted to all 41

magnetometers, and entirely new electronic systems have been installed in all. The new system is controlled by the Texas Instruments Data Chron quartz clock/calculator.

Dr. Alabi carried through much of the optical work, assembly and testing of the magnetometers, excluding the electronics, before he returned to Nigeria at the end of February. The electronic boards were completed, tested and installed during the summer. Eight magnetometers are the property of the University of Ife and are now in Nigeria. The University of Alberta set now numbers 33. (D.I. Gough, N. Riebeek, M.D. Burke, A.O. Alabi, M. Paulson, V. Wynnychuk, B. Telder, C. Wighton).

## 4. Electromagnetic Induction in the Earth

### (a) Earth Physics Branch

#### (i) Time Dependence of Magnetotelluric Parameters and its Association with Seismicity

Magnetotelluric (MT) fields continued to be recorded at three stations near the centre of seismicity in a tectonically active region in Charlevoix County on the north shore of the St. Lawrence River. An additional reference station in Parc des Laurentides and the station near Baie-St-Paul have consistently provided stable impedance estimates, while interesting and apparently significant variations have been observed during the year at stations near Mont des Eboulements and further east at St. Fidèle. A magnitude 3.1 earthquake occurred on March 23/79 10 km southwest of St. Fidèle and this event was preceded by measured impedance changes. On Aug. 19/79 a magnitude 5.1 event occurred in the St. Lawrence River to the southwest of St. Fidèle, but in this instance prior impedance changes at the station were small and probably insignificant. A clear correspondence between time-dependent electrical properties in the crust and local seismicity has not yet been found in this area. (R.D. Kurtz, E.R. Niblett)

#### (ii) An anomalous Electrical Resistivity Zone near Ste-Mathilde, Quebec.

A limited region of very low electrical resistivity at shallow depths in the earth's crust has been located near the village of Ste-Mathilde, Quebec. In cooperation with École Polytechnique of Montreal and the Geological Survey of Canada, estimates of the depth and areal extent of the anomalous zone have been made by magnetotelluric, audio-magnetotelluric and Schlumberger DC resistivity observations. One-dimensional modelling techniques indicate that the upper part of the conducting body lies at depths between 250 and 1000 m and that it is a few kilometers thick. This anomaly is associasted with very large attenuation of the telluric field and apparent resistivities which lie well below 1 $\Omega$m. (R.D. Kurtz, E.R. Niblett).

#### (iii) Lomonosov Ridge Expedition: Magnetovariational and Magnetotelluric Studies near the North Pole

During Project LOREX in April and May 1979, magnetotelluric stations were established at each of the three manned drifting camps and operated for a period of six weeks. Fluxgate magnetometers were deployed to sense the magnetic variations. Telluric potentials just below the ice-sea water interface were detected using Ag-AgCl electrodes at 250-300 m separations; after band-or low-pass filtering, these and the magnetic signals were sampled at one-minute

intervals by dual digital cassette recorders. Faster sampling (5s intervals) was also maintained during a six-day drift traverse across the Ridge. In spite of the near loss of equipment in newly-opened leads in the ice pack, excellent data were collected. Magnetic vertical-field response arrows, from transfer functions in the period range 5-60 min, point away from the Ridge, suggesting that it is more resistive than the ocean water. Apparent resistivities in the period range 200-4000s are greater by a factor of 3-5 over the Ridge (water depth 1000m) than over the deep (4000 m) ocean basins on either side. Hence it seems unlikely that the Ridge has a hot (electrically conducting) core. A preliminary two-layer interpretation of the apparent resistivity curves yields a lack of conducting sediments on the Ridge but an appreciable thickness in the basins. This finding is in accord with the shallow seismic results from the Project. (Camfield, Drury, Kurtz, Niblett).

(iv) Crustal electrical resistivity studies

Using laboratory data on the electrical resistivity of oceanic basalts and gabbros at simulated in situ conditions, electrical resistivity models of the ocean crust have been constructed. Assuming that the crust is saturated with seawater to the base of layer 3, it is shown that the mean crustal resistivity varies between approximately 400 and 600$\Omega$, depending on the type of crustal structure model used.

The ocean crust models may have a bearing on continental crust geomagnetic induction anomalies. Several such anomalies occur either parallel to present continental margins or over postulated aulacogens, where the low observed crustal resistivities do not correlate with abnormally high heat flow. This implies a close association between the site of anomalies and former plate boundaries, areas where old oceanic crust might be buried in the continental crust. A resistivity model of buried ocean crust can explain features of several shallow continental anomalies, such as eastern North America, and the Alert anomaly on Ellesmere Island. (M.J. Drury and E. R. Niblett).

(v) Geomagnetic variation sounding of the asthenosphere beneath the Juan de Fuca Ridge

Two ocean bottom magnetometers were deployed in June 1978 at sites on either side of the Juan de Fuca Ridge, 20 and 40 kilometers from the crest, near latitude 47°N. The twelve days of data, recorded simultaneously at the two sites, have been used to determine the electrical conductivity structure beneath the region. The vertical field variations at both stations are of very low amplitude in the period range .28 to 8 hours, with no detectable phase reversal across the ridge. Resistivity models which fit the data are characterized by a comparatively resistive crust and upper lithosphere overlying a low resistivity zone, 5 to 20 m, between depths of 55 and 75 km which in turn appears to be underlain by a slightly higher resistivity section. The published conductivity profile from magnetotelluric data on 72 Ma ocean in the North Central Pacific has similar characteristics to the 1 Ma old conductivity structure near the Juan de Fuca Ridge, but with the low resistivity layer at depths of 140 to 220 km. The increase in depth to this zone with increasing lithospheric age is in general agreement with plate tectonic concepts. (L.K. Law, J.P. Greenhouse).

(vi) Investigation of Volcanic Areas in the Cascades

Further geomagnetic variation measurements have been made across the Cascade volcanic belt in central Washington state, in cooperation with the geophysical group at the University of Washington (J. Booker). The data from these more closely spaced stations, located along the previous profile, have confirmed the presence of a major N-S geomagnetic variation anomaly coincident with the Cascade volcanics. The location of the axis of the anomaly, now known within 10 km, is in a region directly south of Mt. Rainier. Previous work in the Canadian Cordillera has shown the conductive zone does not extend as far north as British Columbia. Data are currently being obtained at sites between the original profile and the Canadian border to determine the northern extent of the anomaly and its related tectonic implications. (D.R. Auld, L.K. Law).

(vii) Geomagnetic Depth Sounding in Northern Yukon - Mackenzie Delta Region

At nine locations in July, 1975, transistorized 3-component magnetometers have measured the variations of the Earth's geomagnetic field in the Northern Yukon - Mackenzie Delta region. The profile of stations is close and parallel to the 70 degree north geomagnetic latitude. Station separation is about 50 km for a total profile length of 400 km. Induction arrows and Z/H energy density ratios are now available. A large spatial variation along the profile of the normalized Z and D components and reversals of the Parkinson's arrows suggest an internal concentration of electric currents beneath the profile. These currents are believed to flow in a sediment filled trough (Blow Trough) located between Barn and Richardson Mountains. Models of the bouguer gravity anomaly and the published geology for this region indicate about 5 km sediment in the trough. The internal electric currents flow in a direction almost normal to that of the overhead auroral electrojet. Therefore these internal currents have been induced elsewhere (Arctic Ocean) and are channelled through the flyschoid deposits in the Blow Trough. (Jon M. DeLaurier).

(viii) Geomagnetic variations at sites across the Leach and San Juan Faults, Vancouver Island

Field recordings have been obtained in the fall of 1979 at two sites on either side of these faults which are located in southern Vancouver Island. Station separation was about 7 km across the Leach fault and about 12 km across the San Juan fault. Visual examination of the 3-component magnetic recordings indicates that no significant ($>$2 nT) amplitude differences could be detected between similar station components. Also these magnetic components were not different from those recorded at the Victoria magnetic observatory about 22 km to the east. Consequently, the magnetic variations for periods of 60 s to 7200 s suggest that internal electric currents, if present, are uniformly distributed beneath these stations. The surficial geology is far from uniform however. The steeply-dipping Leach River slates occur between these two faults. Massive volcanics occur to the north (andesites, dacites) and to the south (basalts). Any internal electric currents are not concentrated by the slates nor by the faults. (Jon M. DeLaurier).

(b) University of Alberta - Institute of Earth and Planetary Physics

(i) Array study in South Africa (J.H. de Beer, D.I. Gough, J.S.V. van Zijl)

Dr. de Beer visited us for a month in April-May, and brought with him the edited and Fourier-transformed data acquired by the array in 1977 and processed under his direction in Pretoria. He and Dr. Gough have completed and submitted two papers, abstracts of which follow. Further work continues.

The Southern Cape Conductive Belt

A magnetometer array study in 1971 led to the discovery of a zone of electrically conductive material in the crust or upper mantle, elongated east-west and located beneath the Cape-Karroo Basin of South Africa. In 1977 a second array study was made, with 53 magnetometers distributed over the tip of Africa south of 30°S. This array recorded magnetic storms and substorms which provided signals of good amplitude in the period range 24 min to 158 min and of various polarizations. Magnetograms for three time sequences have been used in location of the edges of the conductive region. Sets of maps of Fourier transform amplitudes and phases, at periods for which the events supply adequate energy, show anomalies related to currents flowing in three conductive structures. These are the continental-edge structures off the south-east and west coasts, and an intracontinental conductive strip running approximately east-west from coast to coast. The use of several magnetic variation events, with various phase differences between X and Y components, has proven highly effective in isolating the intracontinental conductor from the continental edge (including oceanic) induction effects. The former is named the Southern Cape Conductive Belt and has been well mapped from the Fourier transform maps and the magnetograms. Anomalous fields, normalized to the horizontal field at a station within the craton, are used to locate the induced currents where they cross three profiles, and to yield maximum depth estimates between 46 and 52 km. The Southern Cape Conductive Belt is thus in the crust or uppermost mantle. It correlates closely with a static magnetic anomaly, whose source must lie above the Curie isotherm and so no deeper than 38 km. The Conductive Belt is strongly related to geochronologic provinces and lies outside the edge of the Namaqua-Natal Mobile Belt which forms the edge of the craton. Heat flow data indicate that the Conductive Belt is probably not thermally related. It is provisionally associated with an accumulation of oceanic crustal rocks, containing hydrated minerals such as serpentine, in either a Proterozoic zone of subduction or a marginal sea of Proterozoic Gondwanaland.

Source-field bias in geomagnetic transfer functions

A magnetometer array study in 1971 discovered the Southern Cape Conductive Belt beneath the Karroo Basin and Cape Folded Mountains of South Africa. A second array in 1977 has mapped this Conductive Belt in some detail, by means of anomalies in maps of Fourier transform amplitudes and phases. Transfer functions from horizontal to vertical components were calculated from data recorded by each array, and used to map induction vectors. The in-phase induction vectors from the 1971 array are in good agreement with the current locations shown by the Fourier transform anomaly maps. The 1977 array data give induction vectors which agree with neither those of 1971, nor the anomaly maps. After other possible sources of systematic error had been eliminated, it has been shown that the problem arises from source-field bias introduced by

cross-correlation between the horizontal components of the normal field. Two tests have been worked out, for the selection of events for calculation of valid transfer functions. Errors from source-field bias could be important in work with small numbers of magnetometers, in which anomalies cannot be mapped from simultaneous observations of events by a large array.

(ii) Magnetotellurics and Micropulsations (D. Rankin)

A continuing statistical analysis of data from the University of Alberta Geophysical Observatory is used to study the nature of the micropulsation field as well as induction in the crust and upper mantle. In addition methods of interpretation and noise reduction in the magnetotelluric method are studied.

Field programs to study crustal structure are regularly carried out and new instrumentation is being developed with a view to extending the techniques to the exploration of the shallow crust.

D. C. resistivity measurements are also being carried out to support the interpretation of near surface effects.

Ongoing studies are being carried out on the precambrian boundaries beneath the sediments in southern Saskatchewan and Manitoba. Other projects on geothermal anomalies and tar sands studies are active.

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

The perturbation of uniform and nonuniform electro-magnetic fields by two-dimensional and three-dimensional electrical conductivity anomalies is being investigated by Dr. Jones using numerical techniques. The three-dimensional iterative electromagnetic induction program is being further developed and methods to improve its performance are being investigated. Also, programs for the calculation of perturbation and induction arrows associated with three-dimensional models are being improved. The electromagnetic response of a subducting slab, in which the electrical conductivity is derived from the thermal regime obtained from the heat flow modelling work, is being studied.

(c) University of Toronto - Geophysics Laboratory (R.C. Bailey, R.N. Edwards, G.D. Garland, Enrique Gomez and Hendryk Urbanski)

(i) Long-Period Geomagnetic Sounding of Eastern North America

The long-period sounding project has been continued by extension of the studied region northward into Ontario. Geomagnetic variations of periods several minutes to several hours were measured for several weeks at each of six locations between North Bay and Toronto. Geomagnetic transfer functions computed for these locations reveal that only the sites near Lakes Ontario and Erie are dominated by the lower crustal Appalachian conductivity anomaly. North of this, sites are dominated by the effects of a new conductor, perhaps corresponding to the Michigan basin. These new results also make clear that the transfer functions at these latitudes are not dominated by source effects. Computer modeling of the conductivity structure of the Appalachian and Michigan basins is currently in progress.

(ii) Controlled-Source Geoelectrical studies in the sedimentary basin of Southern Ontario

The geology of the Paleozoic sedimentary basin of Southern Ontario consists of a sequence of interbedded shales and limestones with some evaporites and occasional major Silurian reef structures. The latter, which occur typically at depths of about one kilometer, are known sources of hydrocarbons. Six electromagnetic sounding experiments were conducted in the basin in order to determine its electrical properties. The same sites were later reoccupied to complement the electromagnetic data with resistivity measurements. The knowledge of the electrical properties of the basin was used to design a local experiment to detect the presence of a known reef by electrical methods. The Corey reef, a pinnacle water-filled reef, which was selected for the experiment is located in Lambton County. Preliminary analysis of the data show that in fact the reef structure was detected by the electrical method. A wide band (0.03 Hz to 15 kHz) electromagnetic system using a pseudo-noise source was used in the field experiments.

(iii) Short Period Geomagnetic Variations in the Sudbury Basin

Short period (4 sec to 300 sec) geomgnetic and electric field variations have now been measured at 23 locations in and near the Sudbury Basin, with the intent of investigating the suitability of such data for examining the conductivity structure of local conductivity anomalies. Approximately 1100 hours of data were collected this year with three portable geomagnetic observatories. Some of these data were collected with a simultaneous array configuration to permit gradient sounding of the resistive crust of the shield. Analysis is currently underway to determine the temporal and spatial variability of the various geomagnetic transfer functions and the extent of their correlation with local conductivity structure.

(d) University of Victoria - Department of Physics (H.W. Dosso, W. Nienaber, R. Chan, G. Heard)

A scaled model of Vancouver Island and the surrounding region was constructed and detailed model measurements for both the E and H polarizations for a uniform horizontal source field have been carried out. The analogue model results were compared with magnetotelluric measurements from field stations at various locations on Vancouver Island and the mainland. The model results were also compared with finite difference numerical calculations. These studies were carried out in collaboration with Dr. L.K. Law (Earth Physics Branch, Department of Energy, Mines and Resources, Victoria), Dr. F.W. Jones (University of Alberta, Edmonton), and Dr. V. Ramaswamy (Dehra Dun, India).

The effect of the contour of a continental coastline, in the form of bays and capes, for a near-by island has been examined using analogue model methods. The analogue model measurements were compared with field measurements at two stations in a bay at Port Renfrew on Vancouver Island. The contour of the coastline was found to play an important role in determining the behaviour of the coast effect.

In collaboration with Dr. V.R. Hutton (Edinburgh) a model study of the British Isles region has been carried out. The analogue model results are being compared with available field station results. In collaboration with Dr. J.A. Wright (Memorial University), Dr. J.P. Greenhouse (University of Waterloo) and Dr. R.C. Bailey (Toronto), a laboratory analogue model of the eastern coast of Canada was constructed and detailed measurements completed. The results again are being

compared with field station measurements for that region. The model results will be used to produce contour plots of field components and ratios. The contour plots will provide reference values for the region, and differences between these reference values and field station values should be indicative of subsurface inhomogeneities and anomalies.

In collaboration with Dr. J.P. Lokken (Defence Research Establishment Pacific) a model study and a field station study of the coast effect in an Arctic bay is underway. The field station studies will include electric and magnetic field measurements at the surface of the ocean using the ice as a platform.

## 5. Paleomagnetism, Rock Magnetism and Tectonomagnetism

### (a) Earth Physics Branch

#### (i) Precambrian Program

Several papers have been published (or are in press) on studies of different rock units: four units from the Coronation Geosyncline, three units from the Belcher Islands volcanics and intrusives, the St. Urbain Anorthosite, a contact between Nipissing diabase and Gowganda argillites, the Seal Lake Group volcanics and sills and the Sudbury Irruptive. These studies indicate that interpretations of Precambrian data can be ambiguous. This is illustrated in a review of data using a graphical approach with the suggestion that we may be dealing with a limited and biased data-base. Work is therefore continuing to extend this data-base. Soon to be published is a study of multi-component magnetizations of the Little Dal Group of the Mackenie Mountains while the Katherine Group and the Tsezotene Formation and Sills of the same region are under investigation. Also under study are the Cameron Bay Group, the Hornby Bay and Port Radium Sills of the Coronation Geosyncline, rocks from the Brock Inlier and dikes from the Mealy Mountain Complex.

#### (ii) Appalachians Program

Results from three rock units of Newfoundland, the Botwood Formation, the Mount Peyton intrusives and the Notre Dame Bay Lamprophyre dikes, and three from New Brunswick, the Mascarene Group intrusives and the St. George and St. Stephen Plutons, have been published. The results indicate that the Paleozoic APWP and/or the tectonics of the Appalachians are extremely complex. Several more units are under investigation: the Mascarene Group sediments, Silurian redbeds of the Arisaig regions, the Coldbrook Formation, Silurian redbeds from Antigonish Cambrian diabases, the Moncton Group and the Chaleur Bay Group, all from New Brunswick and Nova Scotia with the Chaleur Bay extending into Quebec. In addition, results from dikes and volcanics of the Buckingham and the Bellefeuille area (Quebec) should be published soon. Other Paleozoic units being studied are sediments from Somerset Island, Prince of Wales Island and central Sahara.

#### (iii) Cordillera Program

Results from the Takla Group, the Hazelton Group, the Axelgold Intrusion and the Karmutzen Formation should be published shortly. The results lead to the suggestion that the Stikine block and Wrangellia were formed considerably to the south of their present positions relative to cratonic North America. To test the hypothesis, more recent rock units were sampled during the summer.

(iv) Technical and Analytical Program

A continuous low-high temperature magnetometer is being developed. The instrument will permit one to study and chart the magnetic characteristics of a specimen during treatment. This method has a marked advantage over the step-wise treatment for the detection of any chemical changes. Our Schonstedt SSM1 is now equipped with an Anisotropy of Susceptibility kit and has been used extensively for the Radwaste Program.

(v) Interpretation and Map Program

Much effort has been devoted toward the updating of the paleomagnetic data catalogues with the purpose of issuing catalogues in a new format in the near future. Those data have been condensed in review papers accompanied with maps and describing scenarios such as the Evolution of Pangea and drift of the major continental blocks.

(b) Geological Survey of Canada

The following projects are being carried out generally in cooperation with field geologists from the GSC:

(i) Borden Basin Sediments and basaltic flows (Paleozoic) and cross-cutting dikes on Baffin Island. Stable and consistent magnetization in the sediments and lavas show a number of reversals. Magneto-stratigraphic correlation will be attempted between Baffin, Somerset, and Prince of Wales Islands.

(ii) Work on a small collection of Tertiary basalt of Padloping Island (Labrador) is completed and self-reversal of remanent magnetization of similar rocks from Cape Dyer collected by Prof. E. Deutsch has been demonstrated.

(iii) Work on a large collection of samples from Lac St. Jean (Quebec) anorthosite and associated rock is essentially completed and the results appear to be similar to results of other studies on Grenville anorthosites.

(iv) The results for a large collection of Proterozoic basalts, red beds and andesites from Richmond Gulf and the Manitounuk Islands (Quebec and NWT) show a consistent SE - up direction of magnetization with a rather large spread in declination.

(v) Proterozoic red beds were collected near LaGrande 4 (Quebec) and show stable remanence with NE to E up direction (compare to Richmond Gulf, Manitounuk Islands).

(vi) Experimental work is to start on a collection from basaltic flows from the Ottawa and Sleeper Islands (NWT) in Hudson Bay. The results are to be compared to those from Richmond Gulf - Manitounuk Islands, LaGrande 4, and Cape Smith.

(vii) Amount of uplift of the Shield since about 2 Ma is being evaluated using a new technique on dike contacts in the Sudbury-Timmins area. Reasonably consistent results have been obtained for two contact zones of Abitibi dike (age 2100 Ma) and a different result is given by two profiles across a Sudbury dike (1300 Ma).

(c) University of Alberta

(i) Precambrian Formations (M.E. Evans, G.S. Hoye)

Seventy-three stratigraphically ordered sites have now been sampled in the Burnside River (N=45, composite section ~430 m) and Peacock Hills (N=28, composite section ~80 m) Formations of the Bathurst Inlet area. Magnetic measurements on the Burnside River Formation samples are complete, but ony preliminary data are available for the overlying Peacock Hills Formation. The response of the samples to routine step-wise thermal demagnetization is variable and some samples yield no stable remanence vectors. However, the majority of sites yield statistically significasnt mean directions and these define two groups of opposing polarity. Southerly directions predominate in the lower half of the sequence, but the upper part exhibits both polarities. This supports, but does not prove, a correlation between the Burnside River Formation and the Akaitcho River Formation of the Great Slave Lake area some 500 km to the SW. Such correlations have potential for elucidating the evolution of major tectonic features such as the Coronation Geosyncline, and it is hoped that the details currently emerging from the upper part of the sequence will further strengthen such correlation.

(ii) Cretaceous Magnetostratigraphy (M.E. Evans)

This work involves the active collaboration of Drs. J.F. Lerbekmo and H.A. Baadsgaard of the Geology Department, University of Alberta. A paper has been published summarizing paleomagnetic and radiometric investigations carried out in the Red Deer River Valley.

Sampling has now been extended laterally in an attempt to recognise marine magnetic anomalies on a regional basis. To this end preliminary collections have been made in Montana and North Dakota, and the corresponding laboratory work is currently in progress.

(iii) Quaternary and Late Tertiary Formations (M.E. Evans, G.S. Hoye)

While on study leave at the Geophysics Department, University of Edinburgh, Dr. Evans collaborated with Professor K.M. Creer and Dr. P.W. Readman in a project involving a suite of samples obtained from two very long accurately oriented cores (>100 m) from the coastal plain of west central Italy. Preliminary results show that polarity reversals are present and that the cores extend back into the Gauss Epoch. The reversal stratigraphy is not unequivocal, however, as the sediments involved carry only a weak and rather unstable remanence, with the consequence that reversed material often carries a substantial normal overprint. Nevertheless an interpretation involving the sequence Brunhes Epoch - Matuyama Epoch - Gauss Epoch is consistent with paleontological evidence. Detailed sub-sampling has been aimed at elucidating long period secular variation. On the basis of the preliminary data, a segment of one of the cores was selected for detailed study. Smooth oscillations in declination and inclination were found. These have periodicities of the order of $10^5$ years if the Brunhes/Matuyama boundary has been correctly identified, and sedimentation has been essentially continuous up to relatively recent times. The results thus provide much-needed data on the nature of very long period secular variation and the vexing problem of dipole wobble. This project is continuing with parallel studies on several other long cores from the same locality.

Paleomagnetic investigations of 50 separate cooling units from Level Mountain (a continental shield volcano in northwestern B.C. of uppermost Tertiary and Quaternary age) have been completed. The overall mean direction yields a paleopole at 256E, 85N. This pole lends no support to the eccentric dipole model of Wilson - in fact the pole itself is slightly "near-sided", not "far-sided" as that model predicts. Stratigraphically, the sequence comprises several polarity zones, and with the aid of a few key radiometric dates, currently being processed, these should lead to improved understanding of the evolution of volcanism in this area. This study is part of a larger project being carried out by Dr. C.M. Scarfe and Mr. T.S. Hamilton of the Geology Department involving the petrology, geochemistry, and history of Level Mountain.

The study of sediments from the Olympia Interglacial of British Columbia is continuing. Since the Mono Lake, California, site is only 10° from our B.C. site the absence of the geomagnetic excursion recorded in California poses a serious problem. A model involving a small magnetic dipole in the outer core has been used recently to account for the Mono Lake observations, but this predicts a very large effect in southern B.C. The available radiocarbon dates just permit a situation in which there is no temporal overlap at the two sites, and leads to the expectation that the Mono Lake Excursion lies above our sampled section. We therefore plan to extend sampling upward, with the prospect of verifying at least one of the many proposed "excursions" which abound in the current literature.

(iv) Archeomagnetism (G.S. Hoye)

Following the initial work of 1978, an extensive collection of archeological and related materials has been made in Southern Italy. One hundred and seventy oriented samples were taken from a total of eleven baked features (kiln, hearth or oven) at ten archeological sites. The number of samples collected depended on the size and state of preservation of the feature (and of the curator of the site) and ranged between 5 and 66 per feature. The associated archeological dates cover the interval from the eighth century B.C. to the fourth century A.D. (approximately one dated feature per century). Two undated kilns were sampled with the intention of deriving an archeomagnetic date, rather than using the known age to construct the curve of secular variation.

A modern kiln last used in 1960 was sampled in detail. It is hoped that measurements will shed light on the debated influence of kiln shape and disposition on the measured remanence direction.

The lavas of 9 different eruptions of Mount Vesuvius were sampled at 20 sites. The dates of these eruptions cover the complete range (1631-1944) of historically recorded events resulting in lava flows.

The only other recorded event before 1631 is the archetypal Plinian eruption of 79 A.D. Specimens of the ensuing hot mud flow which engulfed Herculaneum were collected at the townsite. Initial measurements on this material show that it retains a stable (depositional?) remanence which yields an archeomagnetic field direction of D=352°, I=57°, k=212, $\alpha_{95}$=2°. The measurements made to date on material from the kiln on the site of the excavation by the University of Alberta at San Giovanni di Ruoti give a direction of magnetisation of D=347°, I=58°, k=234, $\alpha_{95}$=3°. This direction is indistinguishable from that for Herculaneum and suggests that the kiln fell out of use late in the first century A.D. The meager archeological data for the kiln do not contradict this conclusion.

(v) Rock Magnetism (M.E. Evans, G.S. Hoye)

While on study leave at the University of Edinburgh Dr. Evans worked with Drs. P.W. Readman and P. Tucker on depositional remanence in synthetic sediments. By arranging for the ambient field to change direction relative to the sample while deposition is in progress, it is possible to assess the remanence acquisition as a function of time. Subsequent alternating field (AF) demagnetization studies reveal that the earlier remanence is associated with the magnetically softer grains. This is consistent with a simple model in which the smaller (= magnetically harder?) particles retain mobility in the interstitial cavities after the larger, softer grains have been mechanically locked in position. This work is aimed at elucidating the acquisition of depositional remanence, but if these early findings are substantiated and can be shown to apply to natural samples, they have important implications since AF cleaning is usually assumed to remove the later magnetizations and thus isolate the so-called primary direction of magnetization.

Chemical remanence (CRM) in red beds is also being investigated in the laboratory. Hematite-bearing sandstone analogues are being synthesized by dehydrating goethite on a porous, granular pyrex base. Measurable CRMs have been produced, and these are currently being investigated by means of acid leaching to see if the known components can be separated.

To facilitate chemical leaching of our relatively impervious Precambrian red bed collections a corrosion-resistant high-pressure cell has been designed and construction is nearing completion. The cell, which accepts standard 1" cylindrical rock specimens, applies a triaxial retaining load hydraulically, and will allow acid at pressures up to 40 MPa to be used.

(d) Dalhousie University - Department of Geology

(i) Iceland

Completion of sampling and measurement for paleomagnetic purposes of a 3 km crustal section in eastern Iceland has shown that the uppermost 2.5 km is uniformly normally magnetized and represents a minimum thickness for upper crust of sea floor spreading anomaly 5 age in the area. Such a great thickness was not anticipated, but may be explained in terms of high volcanic productivity in the proximity of the central volcano, Thingmuti. The lowermost 500 m of the crustal section contains sections of flows of both normal and reverse polarity. Since the former are associasted with zones of dense dike intrusion, with the dikes also being of normal polarity, extensive hydrothermal remagnetization is suspected. At this deep crustal level in Iceland the occurrence of polyphase magnetizations, as seen in the Canadian Shield, seems probable. Identification of changes in magnetic properties with crustal depth is presently underway (J. Hall, C. Walls, W. Kay, L. Hall and workers at other Universities).

(ii) Mid-Atlantic Ridge

The first trials of a modified version of the Bedford Institute electric bottom drill in an area of oceanic crust were successfully carried out during September 1979. Basalt and/or limestone was recovered at each of ten drill stations on seamounts to the west of Flores, Azores (P.J.C. Ryall and others).

(iii) Bermuda

Paleo and rock magnetic data from our 800 m Bermuda drill core, which had been accumulated over the period 1973 to 1977, finally yielded an overall explanation for the complex magnetic picture. The results are now interpreted in terms of widespread additional stable magnetization in Cretaceous MORB basalts produced by hydrothermal alteration during a Tertiary diking event: in a paper to appear in CJES early in 1980 we suggest that such additional stable magnetization may form the source of the linear magnetic anomaly patterns of the ocean basins (P. Rice, J. Hall, J. Peckenham).

(iv) Structural Interpretation

A new departure in the use of the paleomagnetization of ocean floor basalts is in structural interpretations. Paleomagnetism used alone allows minimum rotations to be estimated; combined with segregation vesicle measurement actual values of rotation can be obtained. Nancy Gruver is making excellent progress with these combined techniques and has shown that sections of oceanic basalts up to 100 m in thickness in DSDP drillholes in the North Atlantic are often highly tectonically disturbed and are sometimes overturned.

(v) Hungary

Continued collaboration with the Hungarian Geological Institute led to the detailed paleomagnetic study of a second >1 km drillcore from the Hungarian Basin. The second core showed much of the polarity detail seen in the first core, implying that the detail represents original field behaviour, and not sedimentological or accidental sample inversion. Among many features of the field that are apparent for the first time are the oscillatory, distributed nature of reversals and the relative abundance of periods of mixed polarity (H.B.S. Cooke, W. Kay, J. Hall and others).

(e) Université Laval - Department of Geology

A palaeomagnetic study of the Saint-Sébastien-Ste-Cécile Devonian granitic stock and the associated Siluro-Devonian metasedimentary units and hornfels. The laboratory work on the granite (including both AF and thermal demagnetization) is complete. In the case of the sediments and hornfels, the laboratory studies undertaken by M.K. Seguin and R. Pinault is underway.

A second palaeomagnetic study of the Upper Cambrian Postdam formation was undertaken by M.K. Seguin and P. Arnal. The NRM, magnetic susceptibilities and Q ratios are already measured and thermal demagnetization studies have been initiated.

M.K. Seguin and K.V. Rao (partly supported by Physics Department, Memorial University of Newfoundland) have initiated Paleozoic Paleomagnetic studies of the Avalon zone in Cape Breton Island, Nova Scotia. They have collected about 220 oriented hand samples in the summer 1979 from the following rock units:

- Late Hadrynian Fourchu volcanics (12 sites).
- Late Hadrynian (560-580 my) granites (10 sites).
- Early Cambrian red sandstones from Morrison River Formation (10 sites).
- Middle Cambrian Bourinot Group volcanics (2 sites).
- Devonian (350 my) granites (10 sites).

In New Brunswick in cooperation with D. Venugopal (New Brunswick Dept. of Natural Resources, Fredericton), they have also collected about 40 diabase samples (8 sites) from the 180 my old Caraquet Dike which extends from Northern New Brunswick to Main.

(f) University of Manitoba - Department of Earth Sciences

Dr. D.H. Hall and Sheraz Khan are working on the palaeomagnetism of pre-Sickle gabbro intrusives in the Lynn Lake area. Preliminary indications suggest that these bodies are suitable for palaeomagnetic work.

The measurement of magnetic properties of surface samples in various sub-provinces of the Shield in Manitoba and northwestern Ontario is continuing.

(g) University of Toronto - Department of Geophysics

(i) A paleomagnetic study of the diabase dikes in the vicinity of the Kapuskasing structural zone. (Ernst, R. and Halls, H.D.).

More than 30 diabase dikes have been paleomagnetically sampled in the vicinity of the Kapuskasing Structural Zone (KSZ). The purpose of the project is to test, through detailed analysis of multicomponent remanent magnetization, the possibility of large scale rotations and uplift which on geological evidence appear to be associated with the KSZ. In particular diabase dike patterns show systematic changes of up to 30° in strike across the zone. Providing that dike swarms are correlative between the regions to the east and west of the KSZ it should be possible to test for differential rotation using paleomagnetic means.

Preliminary results from the survey show that all dikes on the west side of the KSZ show coherent stable remanence components which will be compared with those reported by various workers from the eastern side (eg. Fahrig and Larochelle 1965, Strangway 1961, Schutts 1979).

(ii) A study of shock remanent magnetization associated with meteorite impact craters. (Halls, H.C.).

A remanent magnetization caused by shock pressures above 20 kb is present in the impacted rocks of the Slate Islands, and decreases in intensity away from the impact point. Whether such a paleomagnetic halo is a common feature of impact craters is to be tested. Two sampling programs, one from the Gosses Bluff crater in Australia, the other from the Lonar Crater in Central India, have been made and measurements are underway.

(iii) Paleomagnetism of Keweenawan rocks. (In cooperation with University of Western Ontario.) (Halls, H.C., Palmer, H.D., and Pesonen, L.T.).

Detailed paleomagnetic measurements on volcanic pebbles from Keweenawan conglomerates show evidence of a partial magnetic overprint. The effect is particularly noticeable on the Keweenaw Peninsula (KP) where there is in addition an increase in the degree of resetting in a westward direction along a 40 km strike length within the Copper Harbor Conglomerate. There is a strong inverse correlation between the magnetization intensity of individual pebbles and their degree of magnetic resetting. This relation indicates that the overprint is due to chemical alteration.

A similar study in lava flows interbedded with the conglomerate shows the same phenomenon, and also that the apparent stability of remanent magnetization is not necessarily an indicator of a primary or early-formed component.

(h) The University of Western Ontario - Department of Geophysics

During the summer of 1979 field work in the Port Stanley Till - Maumee Silt was completed. Two collections were made from Proterozoic successions in the northern part of the continent. One of these collections is from sedimentary rocks and basalts of the Tindir Group exposed in the Alaska-Yukon border region. The second collection was obtained from Proterozoic rocks exposed in the Fury and Hecla Strait region of Baffin Island. Sandra White participated in both these field excursions and paleomagnetic study of the material obtained will form the basis of her M.Sc. research.

(i) University of Toronto - Department of Physics

(i) Magnetic Properties and Paleointensities of Oceanic Layer 2 Basalts from near the Mid-Atlantic Ridge. (M.E. Bailey, D.J. Dunlop).

A detailed study of the rock magnetic properties of a large collection of basalts from Deep Sea Drilling Project Legs 37 and 45 has been completed. Samples have been subjected to Curie temperature determinations, hysteresis measurements, alternating-field demagnetization and acid leaching experiments. The results demonstrate that within-site variations in the observed magnetic properties can be attributed solely to changes in magnetic domain structure resulting from low-temperature oxidation of titanomagnetite. Variations in the observed magnetic properties between sites of approximately the same age result from real differences in the average grain size of the initial titanomagnetites.

Paleointensity determinations were made on 20 samples from Legs 37 and 45 using the conventional Thellier method. Low paleointensity values (0.15 $\pm$ .05 Oe) were obtained from fresh unoxidized material, while higher values (up to 0.7 Oe) were obtained from oxidized samples. Low paleointensities are correlated with an ability to acquire a strong viscous remanence and are therefore believed to be unreliable. The higher paleointensity values obtained from samples which have undergone partial low-temperature oxidation are believed to be reliable. These values indicate that the intensity of the earth's magnetic field between 3.5 and 15 my (the range of ages covered by legs 37 and 45) was not significantly different from the present-day field.

(ii) Magnetism of Layers 2B, 3 and 4 of the Oceanic Crust and the Source of Linear Magnetic Anomalies. (D.J. Dunlop, M. Prévot, Université de Paris).

Drs. Dunlop and Prévot have completed a study of tectonically-emplaced mafic and ultramafic intrusive rocks drilled during Legs 30, 37 and 45 of the Deep Sea Drilling Project (DSDP). Magnetite, rather than titanomagnetite, is the principal magnetic mineral in all samples. In the layer-2B gabbros of Leg 30, the magnetite is a product of deuteric oxidation. In the shallower layer-3 cumulate gabbros of Leg 37, the magnetite is an alteration product of plagioclase and pyroxenes. In the deeper Leg 37 cumulate gabbros and peridotites and Leg 45 layer-4 (upper-mantle) lherzolites, the magnetite is a byproduct of serpentinization of

olivine. Whatever the source of the magnetite, it is clear that the deeper layers of the oceanic crust are a potent source of remanent magnetization, particularly if serpentinization extends to several km depths. The source of 'magnetic stripe' anomalies over the oceans is not simply a surface veneer of highly magnetic basalts, but extends to the Moho and possibly into the upper mantle.

(iii) Archeomagnetism (D.J. Dunlop, M.B. Zinn).

Archeomagnetic measurements on a 19th century pottery kiln near Jordan, Ontario are consistent with the date of 1841-1843 suggested by archeological evidence for the last firing of the kiln. Magnetic declinations agree with the 1840's geomagnetic declination recorded at the Toronto magnetic observatory and not with the present geomagnetic declination. However, inclinations are, on average, 4° shallower than either 1845 or 1979 field inclinations, an effect that seems to be due to self-demagnetization in the strongly magnetic kiln floor. Reliable paleointensities were determined on 27 brick specimens by the modified Thellier double-heating method. The 1840's field was 1.17 $\pm$ 0.09 times as intense as the present-day field.

(iv) Grenville Province Paleomagnetism. (D.J. Dunlop, K. Argyle, M.O. McWilliams, Stanford University).

Drs. Dunlop and McWilliams have begun a "Grenville transverse" across the Grenville Front near Temagami, Ontario extending 20-40 miles north and south of the Front. Nipissing diabase sills and both preorogenic and synorogenic dikes in the Superior Province and supposedly correlative intrusions in the Grenville Province have been sampled. Thermal studies are being done at Toronto and alternating field studies at Stanford. The object is to test the "thermochron model" of orogenic overprinting by calibrasting progressively weaker Grenvillian magnetic overprints north of the Front, as well as possible surviving pre-Grenvillian magnetization at and south of the Front.

The Cordova gabbro, located in the lowest-grade part of the Hastings Basin near Madoc, Ontario exhibits a novel "C" component of magnetization in 15 samples from 8 sites, in addition to the usual "A" and "B" components. The C magnetization could be as old as -1.2 Ga, the $^{40}Ar/^{49}Ar$ hornblende age of the nearby, higher-grade Thanet gabbro. The C direction is consistent with -1.2 Ga results for North America only after 90° clockwise rotation about a local Eulerian pole. The C magnetization could therefore record divergence of the Grenville and Superior Provinces ca. -1.2 Ga, the closing of the intervening ocean between -1.2 and -1.05 Ga being the cause of the Grenvillian orogeny. Alternatively, the C magnetization may be a Silurian-Ordovician overprint.

(v) Paleomagnetism and Magnetic Overprinting in Archean Rocks of the Wabigoon, Quetico and Shebandowan Subprovinces. (D.J. Dunlop, C.J. Hale).

Further sampling in the summer of 1979 has brought to eleven the number of sites in the Poohbah Lake alkaline complex showing clear magnetic overprints acquired at the time of the Kenoran orogeny (ca. -2.6 Ga). A contact test on baked Couchiching sediments intruded by the Poohbah complex reveals the same overprint at high demagnetization levels.

Some samples of large WNW-trending olivine diabase dikes near Wabigoon, Ontario show a characteristic Mackenzie-age (-1.25 Ga) magnetization. This is the first evidence of Mackenzie dikes in this part of the western Superior Province. It also favours the view that similar magnetization components in the Wabigoon gabbro, Gulliver greenstone and Ignace gneiss of the Wabigoon subprovince are Mackenzie overprints and not primary Archean magnetizations.

(vi) Paleomagnetism and Magnetic Overprinting in Archean Rocks of the Abitibi Subprovince. (L.D. Schutts, D.J. Dunlop).

Mr. Schutts has taken specimens throughout the Aphebian-Archean geological column in the Abitibi sub-province of the Canadian Shield in order to investigate the magnetic effects of both contact and regional heating in the area. Paleomagnetic results from the older Archean units imply the existence of a reasonably uniform characteristic remanence which post-dates initial formation and concomitant or subsequent structural deformation. Thermally and chemically reset moments due to the intrusion of late Archean Matachewan diabase dikes, Aphebian Abitibi diabase dikes and a possible Hudsonian age regional heating have also been found. Intrusion resetting occurs both near and, quite frequently, well away from surficial intrusive expression. Determination of sample hysteresis properties at various temperatures is planned, in order to compare theoretical with actual secondary moment acquisition.

(vii) Archean Paleofield Intensity and Test of Metamorphic Overprinting Equations. (C.J. Hale, D.J. Dunlop).

Geomagnetic paleointensity during the Archean is the subject of a two-part investigation by Christopher Hale. The well accepted Thellier experiment has been performed on samples from the Abitibi subprovince of the Canadian shield. Earlier reports have been confirmed that the strength of the geomagnetic field at the time of emplacement of the Matachewan dykes (-2.65 Ga) was comparable to the present day intensity. Similar experiments performed on Archean basalts and gabbros into which these dykes are intruded have been less successful and younger Abitibi dyke samples have shown erratic behavior. A vacuum furnace has been built in the lab, as it is hoped that its use will minimize the chemical degradation resulting in erratic behavior.

Preliminary measurements of diabase samples from the early Archean Komati formation (South Africa) have shown that they possess strong, stable remanence and this, coupled with their low metamorphic grade, makes them prime candidates for paleointensity measurements. Thellier determinations will be made in the near future.

(viii) Fine-Particle Rock Magnetism. (D.J. Dunlop, L.D. Schutts).

David Dunlop has been analysing the viscous (time-dependent) acquisition and zero-field decay of remanent magnetization in magnetite particles spanning the single-domain (SD), pseudo-single-domain (PSD) and multidomain (MD) size ranges. The smallest size fraction is 0.03-0.10$\mu$m; the largest is of order 100 $\mu$m. At temperatures varying from 20° to 500°C, viscous acquisition and decay curves are approximately linear with the logarithm of time at the lowest and highest temperatures, but significantly non-linear in log(t) for intermediate temperatures. Simple theories predicting log(t) behaviour are therefore inadequate. Viscous effects are very strong in SD grains near superparamagnetic size and relatively strong also in PSD grams 10-15$\mu$m in size, presumably due to domain-wall activation.

Dr. Dunlop has also tested Neel's predictions about the dependence of magnetic blocking temperature ($T_B$) on applied field (H) for SD and MD particles. Data on the coercive force of magnetite particles as a function of temperature has been transformed to the equivalent dependence of $T_B$ on H. For the most part, an SD-type thermal-fluctuation-field equation gives the better fit to data, both SD and MD, than a purely MD, domain-wall-motion equation. However, for very small fields, the MD equation works better. These results are the reverse of those expected; the MD model should work for large fields, while the SD model takes over for very small fields.

Larry Schutts has incorporated a spherical distribution of grain easy axes into the basic energy equations for an assemblage of single domain-like grains. The resultant super-paramagnetic and TRM induction curves are in much closer agreement with various published experimental results than curves based on an aligned grain assumption. The results also demonstrate that particle interactions, which were invoked in earlier theories of TRM induction, actually play a minor role.

(j) University of Windsor

(i) D.R.A. Symons, M. Stupavsky and C.P. Gravenor

An experimental study to determine the degree of paleomagnetic remanence resetting resulting from shock and sediment deformation during sediment sampling has been completed and a paper has been submitted for publication. The degree of remanence shock resetting in natural lacustrine and glacial sediments varies considerably. The remanence of moist lacustrine silt may be nearly completely reset by subjecting the silt to a few cycles of shock in which the shock amplitude is equivalent to dropping the specimen from a height of one meter. In contrast, there is no measurable remanence resetting in dry clayey sediment during equivalent shock treatment. In moist sediments, the shock causes the sediment viscosity to momentarily decrease to sufficiently low values to enable some magnetic carriers to re-align in the ambient magnetic field.

(ii) C.P. Gravenor, M. Stupavsky and D.T.A. Symons

A paleomagnetic study of the Late Precambrian Gaskiers Tillite, Newfoundland has been completed. Remanence stability tests indicate the tillite remanence is only marginally stable. A coherent tillite magnetization is isolated after storage in 'zero' magnetic field for a week and AF demagnetization at low fields. A conglomerate test on boulders in the tillite shows that this magnetization is an overprinted metamorphic remanence that, after tilt correction, gives a GVP at $\sim$550 Ma on the APW curve for the Early Paleozoic and Late Hadrynian of North America.

(iii) D.T.A. Symons, M. Stupavsky and D. Walley

Paleomagnetic studies of Precambrian Algoman type iron formations (IF) are continuing. Two completed IF studies at the Sherman Mine, Temagami, and the Moose Mountain Mine, Capreol, show that these IF have very similar magnetic properties. The measured magnetic parameters (NRM remanence, anisotropy of magnetic susceptibility) and the observed IF geometry explain nearly completely the observed aeromagnetic and ground magnetic anomalies. AF, thermal and chemical demagnetization isolate, in both IF, two well-defined prefolding remanence components that give VGP at $\sim$2.5 Ga and 2.8 Ga on the Archean APW curve.

(iv) D.T.A. Symons, H.I. Hutcheson and M. Stupavsky

H.I. Hutcheson has obtained the first successful test of the dike contact paleomagnetic method for paleogeobarometric determination.

(v) E.J. Schwarz, D.T.A. Symons, K.L. Buchan and M. Stupavsky

Paleogeothermometry study of the feeder dike contacts in the Columbia Plateau lavas has been submitted for publication. The observed very narrow heated contact zone in the host lavas has been interpreted as evidence for geothermal convection in the groundwater layer at time of intrusion.

(vi) D.T.A. Symons

Paleomagnetic studies on the West coast diorite complex on the western shoreline of Vancouver Island in the Insular Belt of the Cordilleras in B.C. have begun.

(vii) J. Foster and D.T.A. Symons

A study on the paleomagnetism of plutons on the western end of the Monteregian Intrusives has been completed. The resulting polarity pattern evidence constrains the duration of the Monteregian event to a time period between 123 and 116 Ma and lends some support to the hypothesis that it is a relict plume.

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# IV ISOTOPE STUDIES AND GEOCHRONOLOGY

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4. University of Calgary - Departments of Physics, Geology and Biology
5. Carleton University - Departments of Geology and Physics
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13. Bibliography

## 1. University of Alberta - Department of Physics

(G.L. Cumming, J. Gray, P. Thompson, S.J. Song, A. Sasaki)

### (a) Mass Spectrometer Instrumentation

We have begun major modifications of one of the 12" radius solid source mass spectrometers, with a view to eventual automation. The first step involves digitally controlled turn-on of the filament up to a preset current or a preset temperature, since reproducibility of isotope ratio measurements appears to depend in some degree on the heating history of the sample. Some preliminary design work is underway on flight tube modification in order to incorporate the latest fashion of double focussing into this instrument. Control and data processing will be carried out by a TI990/10 mini-computer which will be installed by year end.

We recently incorporated an HP97S calculator into the measuring system of the MM602 H/D instrument.

### (b) Radiogenic Isotope Studies

Several Pb isotope projects are either in press (Mexican Pb deposits) or nearing completion. An extensive suite of ore and rock leads from the Pueblo Viejo gold mine in the Dominican Republic indicates that it is unlikely that the ore Pb (trace Pb in iron sulphides) can have been derived from the host rocks, but rather that the rock Pb is distinctly more radiogenic in both 207 Pb and 206 Pb and thus may be contaminated, perhaps by sedimentary Pb, while the ore is much closer to what would be expected for conformable leads.

Work on Pb in sulphides from the mines of the Thompson nickel belt is essentially complete. The isotopic composition of the Pb is extremely variable, but with only one or two interesting exceptions, all samples are colinear indicating a model Pb/Pb age for these deposits of about 2250 M.Y., intermediate between Kenoran and Hudsonian orogenies. Some controversy exists concerning the time of emplacement of these nickel ores which these isotope measurements may resolve.

A study of rock Pb from the Seton volcanics is completed and will be submitted for publication soon. An excellent Pb/Pb isochron was obtained and the age of about 1800 M.Y. agrees well with previous Rb/Sr measurements on the same rocks.

A study of ore Pb from several small nickeliferous sulphide bodies in the Ivrea zone of northern Italy was carried out in cooperation with V. Koeppel at ETH Zurich. This area is one in which possible upper mantle material outcrops, presumably as a consequence of the extreme deformations associated with the collision of Africa with Europe. There are some small but interesting variations in Pb isotope ratios which may be related to the different sources - lower crust or upper mantle - for these ores. Further studies of the Pb composition in the host rocks of the ores are underway.

(c) Stable Isotope Studies

A project involving carbon isotope ratios of Alberta oil sand material has recently been completed in collaboration with the Hydrocarbon Research Centre. Results obtained from Athabasca bitumen, asphaltene and maltene are very similar to the corresponding ratios obtained from Cold Lake deposits suggesting that the Athabasca and Cold Lake Reservoirs have similar histories.

Stable isotope ratios of peat taken from a 3.5 m frozen core from Fort Simpson, N.W.T. have recently been measured by C. Chatwin of the Department of Geology. Prior $^{18}O$ analysis of the living plants, representing all the major peat-forming plants at the site showed them to have the same $^{18}O$ composition so that analysis was carried out on cellulose extracted from bulk peat. The peat was dated by the $^{14}C$ technique. Preliminary results for the period 400 years BP to 10,380 years BP have been obtained. A maximum variation in $\delta^{18}O$ of 3.25°/00 is found with a relatively cool period 10,000 to 7,000 years BP and a general warming at about 5,500 years BP, the temperatures throughout being apparently less than present day temperatures. Further detailed studies are continuing in this field.

$^{18}O/^{16}O$ analyses of cellulose extracted from tree ring material and peat moss from various regions in North America have been carried out.

The least squares equation defining the tree data is $\delta^{18}O = 0.54\ t_{ann} + 22.9$°/oo (SMOW). The equivalent equation for peat samples is $\delta^{18}O = 0.52\ t_{ann} + 20.2$°/oo. These data are compared with $\delta^{18}O$ values for aquatic plants taken from the literature. The slopes of these three groups of data are essentially identical while the intercepts vary by a range of about 6.7°/oo. These results support the contention that the oxygen composition of celluose in biological systems is recording the oxygen composition of precipitation and hence mean annual temperature.

2. Bedford Institute of Oceanography - Chemical Oceanography Division, Atlantic Oceanographic Laboratory (F.C. Tan and P. M. Strain)

(a) Stable Isotope Studies in the Eastern Arctic

The distribution of sea-ice meltwater and meteoric water in the Eastern Canadian Arctic has been studied by oxygen isotope techniques. Sea-ice-melt concentrations $>$15% were found at several locations in central Baffin Bay. Distinguishable sea-ice melt is confined to the upper 50 m in open water and to the upper 150 m in more confined areas. A paper describing these results and their significance, together with a discussion of the use of oxygen isotopes for the detection of brines and for examining the potential sources of Baffin Bay Bottom Water, is currently in press.

The carbon isotope ratio analysis of the organic matter collected in vertical plankton tows from the Eastern Arctic has recently begun. These data, together with previously measured total dissolved $CO_2$, particulate and sedimentary organic carbon isotope ratios, will be examined for information on carbon cycling in an Arctic environment.

(b) Stable Isotope Studies in Nearshore Environments

With a view toward using carbon isotope ratios to further understand the sources, pathways and behaviour of organic carbon in the nearshore environment, we participated in an August, 1979, cruise to the Gulf of St. Lawrence and St. Lawrence Estuary. There are two principal goals of this program: i) an examination of the relationship between plankton and total particulate organic carbon isotope ratios and ii) a study of organic carbon in the turbidity zone of the upper St. Lawrence Estuary.

(c) Mass Spectrometer Improvements

Changes made to our Nuclide isotope ratio mass spectrometer over the past year have significantly extended our analytical capabilities. The installation of a small sample inlet system makes possible the analysis of foraminiferal calcite and particulate organic carbon from areas of low concentration. The simultaneous conversion to a triple collector almost halves analysis time, thereby facilitating the analysis of small samples and increasing the total number of samples that can be run.

(d) Planktonic Fractionation of Carbon

Mr. Ulrich Lobsiger, a Ph.D. student in the Oceanography Department at Dalhousie University, is currently using the isotope ratio mass spectrometer at BIO in his study of carbon cycling in laboratory plankton cultures, a part of his thesis research.

3a. University of British Columbia
Department of Geological Sciences (R.L. Armstrong)

(a) Age Determinations - Coast Plutonic Complex

R. Parrish is continuing his Ph.D. thesis work using fission track dating to determine uplift and cooling history of the Coast Plutonic Complex. The first results for Mount Logan and the Tkope River Batholith in the Saint Elias Mountains indicate late Cenozoic uplift at rates of 0.5 to 0.3 mm/a, respectively.

A traverse to collect samples for Rb-Sr work was made across the batholith near Alice Arm by K. Scott. Initial Sr results were completed for the Bella Coola traverse (R. Parrish) and other localities scattered in the southern Coast Mountains (G. Woodsworth, Geological Survey). A few suites have yielded whole rock isochrons.

P. Shore and D. Whitford have completed U-Pb zircon dates for two Cretaceous plutons in the Howe Sound area near Vancouver.

L. Werner added 5 K-Ar dates to his data collection for the Coast Plutonic Complex southwest of Atlin Lake and should finish writing his Masters thesis soon.

P. van der Heyden completed his second field season studying the Gamsby Group and related rocks on the eastern side of the Plutonic Complex east of Kitimat for a Masters thesis. Chemistry and geochronometry will follow.

Bridge River schists and cherts have been collected by Jim Monger for Rb-Sr and $^{87}Sr/^{86}Sr$ analyses for comparison with other sediment suites.

K-Ar dating of post-Cretaceous mafic intrusive rocks of the Vancouver area is in progress to provide time control for G.S.C. paleomagnetic tests of microplate displacements across the Fraser fault system (J. Monger, Geological Survey and E. Irving, Earth Physics).

(b) Age Determinations - Intermontane Belt

C. Godwin has finished data collecting on his traverse project in the Intermontane Belt east of Terrace. This study includes numerous K-Ar dates and measurements of Sr isotopic composition. Initial observations include anomalous radiogenic Sr in Coast Mountains plutons, low initial ratios ($<0.704$) in Mesozoic Intermontane Belt plutons but distinctly higher initial ratios ($>.704$) for the Eocene plutons of the same area.

L. Thorstad is writing her thesis which includes an isochron for Upper Triassic Kutcho volcanics in the Cry Lake area of northern B.C.

(c) Age Determinations -Insular Belt

New Rb-Sr analyses of Sicker Volcanic rocks have been completed. A suite of Leech River Schist samples (from L. Fairchild, University of Washington) awaits Sr isotopic analyses. K-Ar and Rb-Sr analyses for igneous blocks in a Miocene melange collected offshore Vancouver Island by C.J. Yorath in a submersible vehicle have shown these to be mafic Mesozoic basement and a mid-Miocene felsic volcanic rock and not ocean floor fragments.

(d) Age Determinations - Omineca Belt

R. Parrish is writing up his field and lab studies of the Nemo Lakes area on the north side of the Valhalla dome. W.H. Mathews continues his study of Eocene resetting of K-Ar dates in Shuswap rocks. New samples have been collected to find the precise limits of the reset terrane.

A suite of Trail-Castlegar gneiss samples, collected by P. Simony (University of Calgary), is waiting for Sr isotopic analysis.

The Sr and Ar dating of a suite of Frenchmans Cap Dome and Clachnacudainn salient rocks, collected by R. Brown (Carleton University), is complete. Core rocks are 2.1 Ga old and Eocene mineral-date resetting is extensive.

P. Read (Geological Survey), has collected core and mantling gneisses further south for further Sr studies. For comparison, several Broadview and Milford Formation samples are being analyzed for Rb-Sr and $^{87}Sr/^{86}Sr$. Purcell Sr data exist but we need to add Windermere samples to our study.

D. Whitford will be dating nepheline syenite of the Jordan River area by U-Pb zircon. A large amount of zircon has been recovered from that rock. Zircon dating of core gneiss is also planned.

Jane Leroux has completed one summer's mapping and <u>in situ</u> gamma-spectrometer heat-generation measurements in the Coryell batholith north of Grand Forks, B.C. Lab work for this Masters thesis will begin soon.

Sr and Zircon dating of Eagle Bay Formation metavolcanic rocks (for P. Read, Geological Survey, and V. Preto, B. C. Mines Ministry). Initial Sr data suggest an age of 300-400 Ma.

(e) Age Determinations - Cascade Mountains

A large suite of Darrington Phyllite samples is in progress for Rb-Sr and $^{87}Sr/^{86}Sr$ analyses. Sr and Ar dates will be determined for muscovite-bearing amphibolite near Groat Mountain where a separate blueschist block gives ~220Ma K-Ar dates.

A whole rock isochron date of 34 ± 3 Ma for the Index batholith, including highly mineralized rocks, was provided for R. Zamboras( Western Washington University), Sr analyses of Nooksack sediments for J. Sondergaard (W.W.U.) Sr analyses of Chilliwack sediments for B. Christiansen (W.W.U.) and Sr and Ar dates for blueschists and phyllites near Mount Watson for R. Haugerud (W.W.U.).

A good Rb-Sr isochron of 45 ± 1 Ma for late orthogneiss dikes of the Skagit Gneiss complex (collected by P. Misch, University of Washington and J. Engels) indicates that the metamorphic history there in the high-temperature core of the Cascades is longer and more complex than previously inferred. Further work on the Skagit - Cascade River metamorphic units is planned.

(f) U-Pb Dating

Our zircon lab is now operational with early total operating blanks of 1 to 6 nanograms. Several zircon suites are in progress; two have been completed so far.

(g) Lead Isotopic Studies

Seventy analyses of galena from mineralized areas in the Selwyn Fold Belt and MacKenzie Fold Belt and eighty of galena from mineral deposits in B.C. have been completed and work on samples from B.C., Yukon, N.W.T., and Alaska is continuing (B. Ryan, C. I. Godwin, A. J. Sinclair and R. D. Russell and W. F. Slawson of the Geophysics Department).

3b. Department of Geophysics and Astronomy (R.D. Russell, W.F. Slawson, T.K. Ahern, R.D. Meldrum, B.D. Ryan, P. Whaite)

Complete automation of the oxygen isotope mass spectrometer has just been completed by T. K. Ahern. The system is controlled by an Interdata Model 74 minicomputer, a Motorola 6802 microprocessor and several intelligent hardware controllers. The operator need only optimize the mass spectrometer in the morning and mount carbon dioxide samples on an automated inlet system when prompted by the microprocessor. The system maintains optimization and is capable of analyzing samples at a rate of six per hour with a precision of 0.04%. Peter Whaite has been developing an automated sample preparation facility for carbon dioxide samples from water for oxygen isotopic analysis. This is intended to interface with the automated sample line mentioned above.

R. Ahern and T. Ahern have analyzed about 200 samples from the Steele Glacier, Yukon Territory. The results clearly provide isotopic evidence of the last four surges of the Steele as well as providing information as to the surface variations of the oxygen isotope ratio.

Russell has continued his interests in the early history of the earth as evidenced by isotopic measurements. A review paper, presented at the Tuzo Wilson Symposium in May, 1979, provided a subjective integration of evidence from lead, strontium, samarium, helium and argon isotopic ratios. Application of geophysical inverse theory, in cooperation with D.W. Oldenburg, has been investigated. The technique provides useful information about the resolution and uniqueness of lead isotopic models.

Since July, while on leave at the University of Western Australia, Russell has been developing a microprocessor based facility for the automatic analysis of isotopes of the rare gases in meteorites and terrestrial samples.

W.F. Slawson and B.D Ryan have revived the Shasta (California) lead isotope project. We have resampled several of the abandoned mines and rerun all the samples. The analytical results are much superior to our previous attempts. A good linear relationship between $^{206}Pb/^{204}Pb$ vs $^{207}Pb/^{204}Pb$ is now evident. Surprisingly, we see no obvious isotopic difference between East and West Shasta although the mineralization horizons are respectively Triassic and Devonian in age.

Radon emanation studies by W.F. Slawson now confirm a seasonal pattern and a lack of correlation with tidal effects. The monitoring of emanation from Geological Survey of Canada uranium test pads has not revealed a significant difference between the uranium rich pad and the blank pad.

In order to attempt to determine whether enhanced radon outgassing occurs prior to rock failure a field project has been started in cooperation with Cominco Ltd. at the Sullivan Mine, Kimberley, B.C. Four test sites have been established over active and inactive mining areas. The project has been in operation for only three months with no clearly defined pattern observed.

4. University of Calgary
Departments of Physics, Geology and Biology (H.R. Krouse, C.J. Bland, J.A. Case, F.A. Campbell, A.A. Levinson, E. Laishley)

(a) Instrumental

Recently a high resolution gas chromatograph VG Organic 70-70 mass spectrometer was installed in the laboratory. It is providing additional information for interpreting isotopic data in the studies of natural gas accumulations and the oil sands.

In isotope ratio mass spectrometry, a Dynabyte microprocessor has been used successfully for aspects of instrument operation and data handling.

In the atmospheric sampling programme, a nine high-volume sampler array has been constructed on a trailer. Eight samplers respond to selected wind directions, while the ninth operates when winds are below a set velocity. To date, sulphur isotope data on $SO_2$ and particulates have been obtained on samples collected by this array. Other elements will be studied isotopically.

(b) Stable Isotope Studies

(i) Medicine Hat Gas Field - (H.R. Krouse and R. Nodwell) An 18 month study has just been completed in which carbon isotope analyses were carried out on gas chromatographically separated gases from 64 gas wells, oil, coal, and carbonates. Sulphur isotope analyses were carried out on $SO_4^{2-}$ in formation waters and pyrites. With increasing depth, $\delta^{13}C$ values for methane increased from -70°/oo to -45°/oo P.D.B. coinciding with the $C_1/(C_1+C_2)$ ratio decreasing from 0.99 to 0.85. This signifies the bacteriogenic production of methane in the shallower environments and the transition to thermally generated gas in deeper strata. Vitrinite reflectance and illite crystallinity determinations revealed trends with depth consistent with the isotopic data. $\delta^{34}S$ values of pyrites were quite negative (down to -30°/oo) signifying formation during bacteriogenic sulphate reduction. The isotopic data for

the gas are explainable in terms of maturation and generally do not require mixing phenomena as previously reported with limited data by other workers.

(ii) $^{34}S/^{32}S$ Ratios in Oil Sand Components - (R. Roche and G. Ritchie, Dept. of Chemistry, U. of C. and H.R. Krouse). Asphaltenes extracted from Athabasca Oil Sand materials were thermally decomposed with linear temperature increase. Released $H_2S$ had $\delta^{34}S$ values near +6°/oo at lower temperatures. At higher temperatures, there was an abrupt decrease in $\delta^{34}S$ to near 0°/oo. This trend is opposite to what is expected thermodynamically. Hence, one interpretation is that the sulphur in these extracts was introduced during two geological events and did not equilibrate isotopically. heavy oils and oil sands from other deposits are being examined in the same manner to further elucidate this phenomenon.

(iii) Microbiological Isotope Fractionation - (H.R. Krouse, E. Laishley and others). Work continued with $SO_3^{2-}$ reduction by C. pasteurianum as part of the Ph.D. project of Miss G. Harrison. The reduction of $S^{2-}$ production in the presence of $SeO_3^{2-}$ was found to involve inhibition of $S_3O_6^{2-}$ and $S_2O_3^{2-}$ decomposition in the pathway. Despite these inhibitions, the overall sulphur isotope fractionation for $H_2S$ product was not changed but the isotopic release pattern was compressed along the $H_2S$ product axis with increasing $[SeO_3^{2-}]$. Thus $SeO_3^{2-}$ did not alter the isotopic selectivity of rate controlling steps in the conversion.

(iv) Ore Deposits - Zn-Pb-$BaSO_4$ Deposits, Red Dog Creek and Drenchwater Creek Areas, Alaska (I. Lange, Univ. of Montana, H.R. Krouse). Sulphur and oxygen isotope compositions of barites in these volcanogenic deposits suggest that they were probably derived from seawater sulphate ($\delta^{34}S$, 14.2 to 17.3°/oo, $\delta^{18}O$ + 12.8 to 14.1°/oo SMOW). $\delta^{34}S$ values for sphalerite and galena are similar in vein and stratiform occurrences ranging from -1.5 to +2.5 and -7.2 to -3.5°/oo respectively and yielding S-isotope thermometry temperatures between 230 and 270°C. Pyrite is not in isotopic equilibrium with the PbS and ZnS being isotopically lighter and parogenetically earliest.

(v) Continuing Stable Isotope Projects
- (a) Kidney Stones (A.A. Levinson, D. Piggot, and H.R. Krouse)
- (b) Coal in western Canada (H.R. Krouse)
- (c) Geohydrology, South of Great Slave Lake (A. Weyer, Environment Canada, H.R. Krouse)
- (d) $^{34}S/^{32}S$ ratios in the atmosphere (J. Case and H.R. Krouse)

(vi) Terrestrial Radioactivity - (C.J. Bland and A.A. Levinson). Radionuclides from the decay of U and Th are measured by $\alpha$ and $\gamma$ ray spectrometry. Major research efforts have been devoted to improving methods for identifying radionuclides released in the mining of uranium particularly $^{226}Ra$ and $^{210}Pb$. A novel method of preparing thin sources using Mn impregnated plastic has been published. In addition the use of desk minicomputers for the pulse height analysis of counts from several surface barrier detectors has enabled us to overcome the problem of long counting times.

Measurements have been carried out to determine the degree of radioactive disequilibrium between $^{214}Bi$ and U. This aspect is relevant to exploration techniques using $\gamma$ ray spectrometers.

5. Carleton University
Departments of Geology and Physics (K. Bell, J. Blenkinsop, T.J.S. Cole, D.P. Menagh)

(a) Geochronology and Isotopic Studies

Grenville province, southeastern Ontario and western Quebec (with A. Davidson, GSC)

We have been trying to define the ages of the various suites of 'granite' rocks present in the region. Results to date suggest that most plutons were intruded between roughly 1200 and 1000 m.y. ago, a finding consistent with those of other studies within the area. The isochrons obtained in general show a scatter of points slightly in excess of experimental error, and that, coupled with fairly limited spreads in Rb-Sr ratios for most sample suites, may make it difficult to resolve age differences between the suites of plutonic rocks. However, initial ratio studies seem to indicate two distinct suites, one with $^{87}Sr/^{86}Sr$ ratio about 0.7017, the other with a value about 0.7065.

Canadian Shield, northern Sakatchewan (with personnel of the Saskatchewan Geological Survey)

Our program of dating rock suites from the different domains of the Precambrian of Saskatchewan is continuing. We have so far obtained errorchrons of about 2600 m.y. on intrusions thought to be Archaean in age from the Wollaston domain. We have also indicated an event of about 1720 m.y. on a granitic intrusion from the Virgin River domain. In addition, we have obtained an age of about 1500 m.y. from the Harriot Lake enderbite (Kisseynew domain), a value which may reflect uplift and cooling. The agreement between this figure and U-Pb ages reported on uranium-bearing minerals from the Northwest Territories is interesting.

Alkalic complexes of Ontario (with D.H. Watkinson, Carleton, and R.P. Sage, Ontario Department of Mines).

Of the isochrons obtained from the alkalic complexes of Ontario, most have given ages of about 1100 m.y., though the Spanish River complex, previously dated (K-Ar) at about 1500 m.y., gave an age of about 1800 m.y. An errorchron on the Sturgeon Lake syenitic complex suggests an age of about 2500 m.y. Our results support the findings of an earlier K-Ar study concerning grouping of the ages of the complexes, so we have more recently concentrated on the information given by initial $^{87}Sr/^{86}Sr$ ratios. The initial ratios for the older complexes, and the carbonatitic members of the 1100 m.y. group, fall near the mantle development line, while those members of the younger group (lacking carbonatite) fall significantly above the line, a finding which could be explained in terms of mantle heterogeneity.

Mount Peyton batholith, Newfoundland (with D.F. Strong, Memorial University of Newfoundland)

Additional work on the bimodal Mount Peyton batholith has confirmed our previously published age of about 390 m.y., based on samples from the granitic part of the pluton. Further analyses on the gabbroic part, and on a suite of hybrid rock types within the complex, suggest that the gabbroic rocks are not comagmatic with either the hybrid or granitic rocks, and that the hybrid rocks could possibly have been produced by mixing of gabbroic and granitic magmas. In addition, the initial $^{87}Sr/^{86}Sr$ for the isochron indicates the granitic magma may have been produced by either anatexis or by partial melting or a source terrane that is not the upper mantle.

(b) Instrumentation

Our new 15 cm mass spectrometer became operational in the latter part of last year, and has since produced over 70 high precision (better than 0.01% at the two sigma level) isotopic analyses. Notable features of the machine include fast pump-down, and the capability of making rapid measurements of ion-beam intensities by employing an electron multiplier, and a magnet supply that can be quickly switched from peak to peak. We are using a Commodore PET personal computer for control of the mass spectrometer and for data acquisition. The PET was chosen in part because it has a partial implementation of the IEEE 488 interfacing standard thus greatly simplifying the job of interfacing it with the other components of the mass spectrometer.

6. Dalhousie University
Department of Physics and Geology (P.H. Reynolds)

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

(i) Ages of paleomagnetic poles. Biotites and hornblendes from various rock units from the island of Newfoundland are being dated by the $^{40}/^{39}$stepwise outgassing method. These rock units (for example, diabase dikes from the Wesleyville area and the Mount Peyton granite-gabbro complex) are generally characterized by more than one stable remanence direction. Initial results suggest that the earliest phases of the Mount Peyton complex may be up to 40 Ma older than the late phases. These data can be used to estimate the rate of apparent polar wander in Silurian-Devonian times (with P. Lapointe, Earth Physics Branch, G.S. Murthy, Memorial University and Honours student, W. Morgan).

(ii) Metamorphic and intrusive events in southwest Nova Scotia. Our paper summarizing results of over 40 K-Ar and $^{40}Ar/^{39}Ar$ analyses of micas from the granitic phases will soon be submitted for publication. Current studies are concentrating on the metamorphic rocks, investigating, among other things, the effect of variable silt contents on the $^{40}/^{39}$ gas release patterns (with G.K. Muecke, M. Zentilli, D.B. Clarke and Honours student, M. Savell).

(iii) The timing of intrusive-metamorphic events in the Zagros and Makran zones (Iran) and the Indus suture zone (Pakistan-India). Results of the Iranian study will soon be published (Nature, in press, with S. J. Haynes, Brock University). A first paper on the Indus zone is in preparation (with M.E. Brookfield, Guelph University); the work continues on a second set of samples collected by Brookfield.

(b) Stable Isotope Studies

We now have our Micromass 602D mass spectrometer installed. We expect to have, in the near future, a small sample (down to 0.1 mg) carbonate preparation system on-line to the mass spectrometer. Initial projects will include:

(i) the correlation of marine sediment cores using oxygen isotope abundances;

(ii) a study of O, C and S isotope abundances in the Gay's River (N.S.) deposit (with S. Akande, graduate student).

7. University of Manitoba
Department of Earth Sciences (G.S. Clark)

(a) Churchill-Superior boundary - Fox River area, northeastern Manitoba (with R.F.J. Scoates): The Fox River belt consists of mafic volcanic rocks interlayered with sedimentary rocks and differentiated intrusions. Previously, the rocks in the belt were inferred to be post-Archean on the basis of lithological and structural features. Rb/Sr ages from mafic volcanics and a metasedimentary unit have established a late Aphebian age for the belt. It has also been shown that the belt occupies the Churchill-Superior boundary zone since felsic orthogneisses to the south yield a Rb/Sr age of 2670 m.y. and a "Kisseynew-type" paragneiss north of the belt was dated at 1740 m.y.

(b) Lynn Lake greenstone belt, northwestern Manitoba: Whole-rock Rb/Sr ages have been determined for several lithological units within this Proterozoic greenstone belt. Ages have been obtained for two pre-Sickle Group granitic plutons, a post-Sickle granitic body, two Wasekwan Group volcanic units and an arkosic metasedimentary unit of the Sickle Group. The Wasekwan Group consists of metavolcanic rocks with metasedimentary rocks subordinate. Stratigraphically, these are the oldest rocks in the volcanic belt. These are overlain unconformably by the Sickle (sedimentary) Group. The ages range from 1940 m.y. (for a pre-Sickle and post-Wasekwan) granodiorite-tonalite body to 1760 m.y. for a Sickle meta-arkose. The Wasekwan volcanic rocks give ages intermediate to these and probably reflect recrystallization ages. All evidence points to a late Aphebian age for the evolution of the greenstone belt and the Rb/Sr results do not support a derivation of any of the lithological units from preexisting Archean Rocks.

(c) Age of orthogneiss basement, northwestern Ontario and southeastern Manitoba (with L.D. Ayres and R. Bald): A deformed and recrystallized (amphibolite facies) trondhjemite to granodiorite orthogneiss forms an easterly trending strip, up to 1.2 km wide, along the northern boundary of the Lake of the Woods greenstone belt. It has been traced for about 15 km from West Hawk Lake, in Manitoba, to Winnetka Lake in Ontario. The gneiss yields an isochron age of 2950 m.y. Based on isotopic age and degree of deformation and recrystallization, the orthogneiss is interpreted to be basement to the adjacent metavolcanic sequence of the greenstone belt.

(d) Regional Rb/Sr investigation in the Churchill Province, northern Manitoba: Rb/Sr age studies in the Churchill Province of Manitoba have been confined chiefly to certain greenstone belts and the Churchill-Superior boundary. The present program extends the Rb/Sr studies to areas within the Churchill Province where bedrock exposures are sparse and isotopic ages are needed to assist in identifying rocks of possible Archean age and to help delineate age relationships between possible Archean basement and younger intrusions and paragneiss.

8a. McMaster University
Department of Chemistry (C.E. Rees and H. G. Thode)

Carbon and sulphur isotope ratios in banded iron formations are being used to characterize depositional conditions and provide information on the possible role of living organisms in the early Precambrian.

Measurements of the four stable sulphur isotopes in meteorites and lunar samples are being continued in order to investigate the isotopic homogeneity of the early solar system and the history of the lunar regolith.

Studies are continuing of the isotope ratios and concentrations of various sulphur compounds in sediments, petroleum, oil bearing rocks and other materials. The information obtained is used to follow the details of such processes as sediment diagenesis, the formation, maturation and migration of oil, and the movement of sulphur between the various geochemical reservoirs.

8b) Department of Geology (R.H. McNutt and H.P. Schwarcz)

(a) Stable Isotope Geochemistry of Speleothems (H.P. Schwarcz)

We have continued to study the oxygen and carbon isotopic compositions of speleothems, calcium carbonate deposits formed in caves, in order to obtain paleoclimatic information about the last 350 Ka. Through the past year we have identified deposits which were formed in isotopic equilibrium and obtained records of secular isotopic variation in speleothems from Indiana, Kentucky, Missouri, British Columbia, and England. The records in the last two areas have been shown to represent distinct changes from glacial to interglacial climate, as recognized by pronounced shifts in the $^{18}O$ content, correlated with similar climatic events identified in deep-sea sediments.

(b) Fluid Inclusions in Speleothems (H.P. Schwarcz)

Complementary to the above research, we have been extracting droplets of water trapped as inclusions in speleothems and analysing their O and H isotopic composition. The oxygen isotopic composition has now been successfully obtained on a number of samples and will permit us to identify trends in paleotemperature directly. Hydrogen isotopic compositions of both fluid inclusions and drip waters in modern caves are being studied to test whether these waters display the same O-H isotopic correlation as do meteoric waters.

(c) Radiometric Dating of Travertines (H.P. Schwarcz)

We have been continuing our program of $^{230}Th/^{234}U$ - dating of chemically precipitated fresh-water carbonates from Pleistocene deposits, partly to supply a time base for the paleoclimate work described above, and partly to obtain absolute ages for archaeological and paleontological sites in the Old World (Britain, France, Israel, etc.) Absolute ages for a number of important archaeological sites have been obtained.

(d) Stable Isotope Studies of Gold-bearing Archean Rocks (H.P. Schwarcz and J.H. Crocket)

We have been analysing carbon and oxygen isotopic compositions of carbonates associated with gold deposits at Timmins, Ontario, as a means of determining the source of the anomalously large amounts of carbon (as carbonate) present in these rocks. Initial results show that it will be necessary to obtain a complete stable isotopic profile of these rocks in order to define the temperature of deposition and thus to identify the bulk composition of the fluids responsible for introduction of the carbon. We are proceeding to analyse oxygen and hydrogen isotopes in silicates and oxide phases as well.

(e) Medical Stable Isotope Research (H.P. Schwarcz)

In collaboration with C. Toews of the McMaster Faculty of Health Sciences we have been using stable isotope tracers to monitor the rate of production of glucose in newborn infants suffering from glucose deficiency. The stable isotope tracer methods are also being applied to problems of drug compliance, and weight-gain in infants.

(f) D/H Ratio Mass Spectrometer (H.P. Schwarcz)

A new mass spectrometer has been commissioned for the purpose of analysis of H isotope ratios. It is equipped with a direct water input system through an on-line uranium furnace. Isotope ratio output is obtained directly through an on-line computer terminal. A precision of 0.6% has been obtained on routine water analyses. The ion detection system utilizes operational amplifiers as proposed by R.D. Russell.

(g) Grenville Studies (L.Heaman, R.H. McNutt and D.M. Shaw)

The Rb-Sr whole rock study of rocks from Chandos Township is nearing completion. The oldest rocks (Apsley Gneiss) consist primarily of metavolcanics with an age ca 1400Ma. The massive flows within this unit have remained closed-systems during metamorphism.

Two intrusive units, the Tallon Lake Sill and the Loon Lake Pluton, have ages of 1220Ma and 1060Ma ($\lambda = 1.42 \times 10^{-11}\ yr^{-1}$) respectively, and agree with previously established periods of igneous activity within the Grenville.

(h) Archean Studies (G. Beakhouse and R.H. McNutt)

An area of the English River Gneiss Belt north of Kenora and Vermillon Bay in N. W. Ontario is being investigated by the Rb-Sr whole rock method. An age of 2630Ma ($\lambda = 1.42 \times 10^{-11}\ yr^{-1}$) has been obtained on the Redditt granodiorite. The Trout Lake diorite and older (3000Ma?) gneissic unit are under study. U-Pb zircon work will be done on these same units.

(i) South American Studies
Bolivia - (R.H. McNutt with A.H. Clark and R. Robertson, Queen's University)

We are investigating W and Sn bearing granites of two distinct ages, i.e., ca 200Ma and 20Ma. Trace element data (LIL and REE) suggest differences in source region and/or crystallization history for each group. Preliminary $^{87}Sr/^{86}Sr$ data indicate that both have identical ratio ($\sim$.708) suggesting that the source region for both is similar. More isotopic work is being done.

Chile-Argentina (F.J. Longstaffe, University of Alberta; R.H. McNutt; and A.H. Clark, Queen's University)

Mineral oxygen isotope values are being determined on the same suite of samples that have Sr and Pb data (McNutt et al 1975, 1979). Our whole rock $^{18}O/^{16}O$ data suggest a lower crust or mantle origin for these Andean rocks.

Pampean Ranges, Argentina (L. Heaman and R.H. McNutt with C. W. Rapela, University of La Plata, Argentina)

Rb/Sr whole rock ages from four major batholiths in the Pampean Ranges indicate a period of igneous activity between 400-500Ma (425Ma; 437Ma; 447Ma and 475Ma)

An older age was also obtained for one of the batholiths (549Ma). This suggests that segments of this unit may represent remnants of the Brazilian Orogenic Cycle (600-700Ma).

One batholith gave an age of 350Ma, in agreement with published K-A ages (316-410Ma) and supports a carboniferous igneous event.

9. Université de Montréal
Département de Géology (Christopher Brooks)

(a) Rapport entre les zones Paléoseismiques, le Volcanisme Archéen, et la Métallogénèse Ancienne (avec Michel Boily)

La variation des constituants chimiques des roches volcaniques produite dans un milieu "arc volcanique", a été étudiée par de nombreux auteurs. Il a déjà été démontré (réf.) que la relation entre le contenu du Sr des laves et la profondeur de la zone séismique (zone de Benioff) au dessous d'un volcan était linéaire, c'est-à-dire que le contenu du Sr augmente en fonction de la profondeur de la zone.

Notre projet de recherche a pour but de réunir les données de Sr des basaltes de l'Abitibi, d'établir une carte géochimique du Sr et par conséquent une carte de la profondeur des zones palaeoséismiques. A partir de ces cartes, on va tenter de répondre aux questions suivantes: (i) Les complexes volcaniques archéens représentent-ils les équivalents précambriens des arcs modernes ou bien s'agit-il d'un volcanisme particulier à l'époque? (ii) Peut-on relier les centres volcaniques et la minéralisation avec les zones de subduction?

(b) Géochimie et Géochronologie des Roches Métavolcaniques de la Ceinture Michipicoten, Ontario (avec S.R. Hart et T. E. Krog)

La répartition interne des roches volcaniques de la ceinture de Michipicoten a été étudiée pour déterminer si les divisions correspondent à une chemostratigraphie et s'il y a une différence en âge entre la série inférieure et la série supérieure. La ceinture a commencé avec une série calco-alkaline à la base suivie de deux séries tholeiitiques. Les komatiites sont exclusivement restreintes aux séries tholeiitiques.

A l'aide des techniques Rb-Sr et U-Pb, on veut démontrer que la ceinture a été formée dans un court intervalle de temps, il y a 2730 m.a.

(c) Migration des Isotopes dans les Roches Felsiques et Mafiques due à l'altération sous-marine et au Métamorphisme Régional

Ce projet est la poursuite d'une évaluation des isochrones Rb/Sr trouvées dans les roches archéennes. Dans ce projet-ci, les isochrones des roches de la région de Chibougamau on été étudiées en référence à un âge U-Pb du zircon. La différence obtenue entre l'âge Rb-Sr et U-Pb s'explique par le degré de migration des éléments pendant les événements qui ont eu lieu après la cristallisation des roches.

(d) Le Développement du Bouclier Canadien et son Rapport avec les autres Régions Précambriennes

Cette recherche est la base de toute recherche en géologie isotopique à l'Université de Montréal. Son principal objectif est la chronologie radiométrique des anciennes roches ignées et métamorphiques du Québec et la corrélation de leurs âges absolus et de leurs compositions géochimiques. Ceci est essentiel pour tous les aspects de la géologie du bouclier du Québec, qu'ils soient académiques ou économiques.

(e) Pétrogénèse des Tholéiites Mésozoiques de l'Hémisphère Sud

L'étude des isotopes du Sr, O, Nd et Pb, dans les tholeiites de Tasmanie suggère que ces roches ne sont pas contaminées par la croûte continentale. Le rapport isotopique élevé en Sr est donc une propriété du manteau. Le manteau serait donc plus hétérogène que prévu. La poursuite de cette étude éclaircira peut-être cette question.

(f) Géochronologie et Géochimie des Roches Granulitiques, Ceinture Pilwitonei, Manitoba (avec Robert Charbonneau)

Cette étude dans une région près d'un front orogénique (ceinture Thompson) démontre que le métamorphisme granulitique avait lieu il y a 2600 m.a. et que, par conséquent, il n'est pas le résultat de l'orogénèse Hudsonien. Les roches de la ceinture Pilwitonei ont un âge d'au moins 3000 m.a.

(g) Systématique des Systèmes Rb/Sr et Sm/Nd dans les Tholéiites Continentales: Implication pour l'Évolution Chimique du Manteau Sub-Continental (avec Clément Gariepy)

Les systèmes isotopiques tels que Rb/Sr, Sm/Nd ou Pb/Pb peuvent être utilisés pour étudier la composition chimique du manteau. En effet, dans un magma basaltique, la proportion des isotopes d'un élément dépend directement de leur proportion dans le manteau qui a produit ce magma. Ainsi, les analyses isotopiques faites au cours des dernières années démontrent que le manteau n'est pas de composition chimique uniforme.

Le but de ce projet est d'étudier, à l'aide des systèmes Rb/Sr et Sm/Nd, les changements de composition chimique du manteau avec le temps. Pour ce faire, nous avons choisi des échantillons d'un même type de roche, les tholéiites continentales, provenant de massifs ayant des âges variant entre 1,800 et 35 millions d'années. La première étape du projet sera d'établir si ces suites magmatiques ont assimilé des matériaux de la croûte sialique, modifiant ainsi leur composition isotopique originale, et la seconde sera d'étudier les changements chimiques survenus dans le manteau depuis 1,800 millions d'années.

(h) Implantation au Québec, de la Méthode Uranium-Plomb de Datation en Utilisant le Mineral Zircon (avec Gilles Gauthier)

Connaître et surtout comprendre la distribution, les interrelations et l'origine des roches anciennes du Québec est un prérequis essentiel au bon développement des richesses naturelles (métaux de base, uranium, etc., etc.) En utilisant le minéral zircon, on peut obtenir, par la méthode de datation U/Pb, le maximum d'informations géologiques et géochronologiques.

Nous menons présentement une étude géochronologique du Massif de Duxbury dans la région Eastmain, Province de Québec, à l'aide de cette méthode de datation. Elle est faite en collaboration avec Tom Krogh du "Royal Ontario Museum".

(i) Evolution Géochimique du Manteau Terrestre dans le Bouclier Canadien (avec N. Machado et S.R. Hart)

L'évolution du manteau terrestre peut être étudiée à l'aide de la géochimie des roches volcaniques mafiques et ultramafiques d'âges différents.

L'homogénéité locale du manteau peut être abordée par l'étude géochimique d'une région géographiquement limitée.

Bien que la plupart des roches précambriennes soient métamorphisées et/ou altérées, il arrive que les clinopyroxènes gardent leurs caractéristiques primaires. L'analyse des isotopes du Sr et du Nd ainsi que de certains éléments hygromagmatophyles (K, Rb, Cs, Ba, Zr, Hf, Lantanides) de ces minéraux permettra d'évaluer les variations de composition du manteau terrestre dans le temps pour une région déterminée, soit la ceinture de l'Abitibi et ses environs.

Les résultats préliminaires de l'analyse du rapport isotopique $^{87}Sr/^{86}Sr$ dans des clinopyroxènes provenant des komatiites du Canton de Munro et des pyroxénites du filon-couche de Dundanolad semblent indiquer une hétérogénéité du manteau terrestre de l'ordre de 0.00003-0.00004 dans la région. D'autres clinopyroxènes provenant des régions de Rouyn-Noranda, Matagami et Chibougamau sont en train d'être analysées.

(j) Géochimie des Isotopes dans les Collines Montérégiennes (avec N. Machado, C. Gariepy et J. Ludden)

Les collines Montérégiennes sont une série d'intrusions alcalines différenciées mises en place durant le Crétacé. En général, on s'accorde pour expliquer les variations chimiques et pétrographiques observées dans les roches mafiques de ces intrusions pour les processus de cristallisation fractionnée et/ou par différents degrés de fusion partielle du manteau. Il y a toutefois désaccord sur l'origine des roches intermédiaires et felsiques. Certains auteurs proposent que ces roches soient le résultat de l'assimilation de matériaux de la croûte par le magma basique alors que les résultats de l'analyse des oligoéléments et des rapports $(^{87}Sr/^{86}SR)_0$ suggèrent plutôt l'absence d'assimilation.

Cette recherche a trois objectifs:

- datation précise des intrusions majeures par les méthodes Rb/Sr et/ou Sm/Nd;
- établir le rôle de l'assimilation dans la genèse des magmas intermédiaires et felsiques en comparant la composition isotopique de xéno-cristaux d'origine profonde avec celle de phases minéralogiques plus tardives;
- évaluer l'homogénéité chimique du manteau source de ces magmas.

10. University of Toronto
Department of Physics (R.M. Farquhar and I.R. Fletcher)

The first stage of a continuing study of variations in the lead isotope ratios in minerals and rocks in the Grenville geological province was completed during 1979. Dr. I. R. Fletcher received his Ph.D. on completion of his study of $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ in Zn-Pb mineral deposits in the Central Metasedimentary Belt. The least radiogenic leads in his data set give lead model ages which agree well with ages of sedimentation determined by conventioanl radiometric dating methods. More radiogenic leads from volcanogenic sulphide deposits and quartz veins have model "ages" which range down to values several hundred Ma less than the age generally accepted for the end of the Grenville orogeny; evidently successive episodes of sulphide mineralization and/or metamorphic additions of radiogenic lead have given rise to apparently younger sulphide deposits. These sulphides have all been derived from a region within the earth depleted (relative to average crustal rocks) in U and Th. This suggests a mantle origin for the least radiogenic leads in the Central Metasedimentary Belt. Lead at Balmat, New York is exceptional, being apparently a mixture of a mantle-derived component with lead of crustal origin. Dr. Fletcher also made an extensive series of measurements on lead from phanerozoic-age vein and replacement deposits. These show the usual anomalous lead isotope characteristics of Mississippi Valley type deposits; the isotope distributions observed are consistent with their derivation from Grenville basement.

The existence of an extensive Grenville lead isotope data base has made it possible to identify the source of some of the galenas occasionally found in prehistoric Indian grave-sites (ca 500-1000 B.C.) in Ontario.

Most of these have come from the Rossie, New York, area, although one group of samples is from the Upper Mississippi Valley, over 1100 km away. These prehistoric Indian mineral "collections" give us unique sets of samples from outcrops which have now presumably been mined out by operations in historic time.

11. University of Waterloo
Department of Earth Science (P. Fritz)

(a) Isotopic Geochemistry of Ground waters in Low Permeability Rocks

This project is directly related to Canadian and international efforts to study clays, shales and crystalline rocks for their hydrogeologic characteristics and to see which of these materials can be used for the long-term containment of toxic and/or radioactive materials. Apart from the traditional hydrologic and geochemical tasks, we worked with stable isotopes, $^{3}H$, $^{14}C$, the uranium decay series and rare gases to determine age and origin of any water encountered. Study areas are in Canada (Ontario and Manitoba) and Sweden (Stripa granite).

(b) Isotopic Geochemistry-Geothermometry of Meager Creek, B.C., Geothermal Area

$^{18}O$, $^{3}H$, $^{2}H$, $^{13}C$ and $^{34}S$ analyses were done on waters and rocks to define the subsurface history of these waters and to contribute to the evaluation of these reservoirs as potential steam/hot water sources for power generation.

(c) Fresh Water Carbonate Sedimente (with J. Turner)

We are attempting to find an explanation for the observation that some lakes show a "hard-water" effect and others do not. "Hard-water" effects lower the $^{14}C$ contents of the precipitate and thus make marls unsuitable material for $^{14}C$ dating.

(d) Paleoclimate Studies

We now have a new core from the U.K. under investigation. We will analyze fresh-water shells and, possibly, organic matter for their stable isotope contents and are specifically interested in the magnitude of isotope shifts associated with major climatic events.

12. University of Windsor
Department of Geology (A. Turek and P. Smith)

Geochronology of the Gamitagama area, 40 km south of Wawa has been completed. Whole rock Rb-Sr and zircon U-Pb ages range from 2570 Ma to 2715 Ma for this Precambrian terrain. This study is now being expanded to the adjacent greenstone belt at Wawa. Sampling and analytical work has started and both Rb-Sr and U-Pb ages will be measured. Published K-Ar ages for the Wawa area range from 800 Ma to 2500 Ma. However, with the possible exception of Proterozoic dykes the rest of the rocks should be Archean in age. In this study emphasis is being placed on the determination of the age limits of the greenstones in order to correlate with other belts in northwestern Ontario.

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# V METEOROLOGY AND ATMOSPHERIC SCIENCE

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## 1. Introduction

The incessant inflationary pressures on the Canadian economy have made cutbacks in governmental and institutional spending a fact of life. In spite of these restraints atmospheric research activities during 1979 continued at a high level, as indicated by the following reports. Research programs must now be socio-economically relevant to obtain the optimum return on the monies invested. Thus studies of wind and solar radiation as sources of energy have been given high priority as the effects of the worldwide shortage of non-renewable resources become more aggravating.

At the same time, widespread research is being carried out to model and measure the environmental impact of hazardous pollutants arising from industrial activities. Ironically these activities include the exploitation and development of such non-renewable resources as the Tar Sands. Major studies of the medium and long-range transport of pollutants are focusing on the deleterious effects of acid rain and sulphur deposition on the biosphere, in particular Canada's Precambrian lakes with their resident fish populations. Numerous local studies of air pollution are being made in large urban centres. All of these efforts should persist and grow rapidly during the next decade.

The Canadian Meteorological and Oceanographic Society held its Thirteenth Annual Congress at the University of Victoria from May 30 to June 1, 1979. Increasing participation of meteorologists and oceanographers in mutual and parallel studies was reflected in the Congress theme, "Dynamic Similarities of Oceans and Stmospheres".

The Society prizes for 1978 were awarded to: Christopher Garrett, President's Prize: John D. Reid, Dr. Andrew Thomson Prize in Applied Meteorology; Bruce McArthur, Graduate Student Prize; A group of forecaster

meteorologists at the Quebec Forecast Office at Ville St-Laurent, Rube Hornstein Prize in Operational Meteorology. Citations were also awarded to: Tim Padmore, Science Editor of the Vancouver Sun, for the high level of his scientific reporting; and The Canadian Arctic Resources Committee, for their role as a concerned independent body in promoting environmental improvements and in developing environmental ethics in the Canadian North.

The CMOS showed steady growth with the formation of two new Centres (Rimouski and Vancouver Island) and two new Chapters (New Brunswick and Newfoundland). Each province now has at least one local branch located in a major city to represent Society concerns about the Canadian environment.

2. University of British Columbia - Department of Geography

(a) Energy Balance of an Urban Air Volume and the Dynamics of the Mixed Layer.

Analysis of data from a 30-m tower, surface observations, minisonde ascents and acoustic radar observations has resulted in a number of conclusions about the interactions between the urban surface and the overlying atmosphere. The important role of latent heat exchange has been confirmed, stressing the significance of urban irrigation and advection of sensible heat within the urban area. Measured wind spectra have been used to estimate diffusion coefficients as a function of travel time, resulting in a long-awaited independent evaluation of these coefficients.

Comparisons between observed and calculated development of the mixed layer during the day showed anomalous behaviour after mid-morning. Agreement has been improved by incorporating the effects of sea-breeze flow in the model. Smaller than anticipated depths of the mixed layer were observed during the day.

(b) Physical Model Illustrating Urban and Rural Cooling Rates

In the rural mode a simple physical scale model showed good agreement with Brunt's model of nocturnal cooling. Comparison of the rural situation with six different urban geometries (thermal admittance being held constant) showed the importance of the sky view factor for long-wave radiative loss, implying a potential for energy conservation in cities by simple considerations of geometry. The magnitude and temporal variations of the model "heat islands" also showed good agreement with full-scale observations.

(c) Measurement and Modelling of Short-wave Irradiance for Inclined Surfaces

This programme is continuing with the observational data set which illustrates the significant impact of slope orientation on the frequency distribution of the incident radiation. The extensive data set also shows the need to include in any numerical model the anisotropy of the diffuse radiation received from the sky hemisphere. The diffuse sky radiation distribution has been monitored using a combined radiometric/photographic technique.

(d) Mesoscale Variability of Short-wave Radiation

An observation programme involving 13 measurement sites within and adjacent to Vancouver has illustrated the considerable spatial variability of solar radiation in an area of large topographic variations and the consequent lack of representativeness of the usual single observation of solar radiation. Attempts to characterize this variability using satellite data are underway, the work drawing on the

results of an earlier study which used satellite data to estimate radiant energy exchanges at the ocean surface during GATE.

(e) Cloud Mapping Using an Infrared Radiance Contrast Technique

This study, now complete, showed that the technique had only limited utility, even though it could replicate manually observed cloud amounts and photographically determined cloud distributions. However, the operational requirements and the difficulty in determining a clear-sky background radiance make the technique inappropriate for routine observations.

(f) Anomalies in the 50-kPa Geopotential Height Patterns

Geopotential heights of the 50-kPa constant pressure surface at the 1977 NMC grid point locations for the Northern Hemisphere are being used to determine persistent (5-day average) anomalies. The temporal and spatial characteristics of these anomaly centres are being studied. This study should make a significant contribution to our knowledge of atmospheric clocking and other features of quasi-stationary long waves.

3. University of Alberta - Department of Geography, Meteorology Division

(a) Urban Valley Air Pollution Studies

Analyses of 13 experiments involving simultaneous measurements of carbon monoxide concentration, winds, and temperatures in the North Saskatchewan River valley in Edmonton during 1977 and 1978 are described in a final technical report to be published by the Research Secretariat of Alberta Environment. These studies revealed some of the complexities of the micrometeorology of a small urban valley and showed that motor vehicle pollutant concentrations in the valley occasionally exceed those observed in the central business district despite relatively low source strengths. A mathematical model was developed to evaluate the roles of decreasing wind speeds and decreasing vertical mixing as contributors to late evening maxima in carbon monoxide concentrations above the valley downtown. Additional experiments are planned and attempts will be made to model transport and diffusion in the valley.

(b) Aircraft Icing (E.P. Lozowski and M. Oleskiw)

The model of airfoil icing continues to be developed. The aerodynamics component has been completed and tested and the thermodynamics component will soon be ready.

(c) Finite-Element NWP (E.P. Lozowski and T. Goos)

The finite-element method of solution is being applied to a spectrally-truncated, two-layer, baroclinic channel model. Comparisons are being made with both the spectral and analytic solutions in order to test the sensitivity of the finite-element method to the model parameters.

(d) Dry Ice Sublimation (E.P. Lozowski and R. Kochtubajda)

The sublimation of dry ice particles in clear air and in cloud is being studied both theoretically and experimentally.

(e) Hailpad Networks (E.P. Lozowski)

Errors of hailpads and hailpad networks are being investigated using Monte Carlo simulation.

(f) Synoptic-Scale Studies

B. Greaves, using NOAA-5 data, has extended B. Green's work on thermal patterns observed over Banks Island and the Beaufort Sea. His study focuses on detection of the Arctic sea-breeze, and on development of small cyclonic systems in the zones of thermal gradients found in summer along the coastlines of the Western Arctic.

In a related project now completed, R. Cross investigated the surface temperature distribution of the Beaufort Sea in summer. His studies revealed a complex temperature regime involving ice movement, surface currents, and upwelling, as well as the effects of strong insolation on ice melt and surface warming. Temperatures over multi-year pack ice are generally below 0°C and quite uniform, but are 1 to 2°C higher, and more variable over first-year ice. Over multi-year ice, temperature gradients of 1.0-1.5°C per degree of latitude separate ice concentrations greater than 6/10 from concentrations less than 6/10; the locus of maximum gradient separates open water from ice concentrations greater than 1/10. The ability to detect such ice/water boundaries depends on the capacity to discriminate between slight differences in the infrared radiation temperatures. Mr. Cross has successfully obtained such resolution by objective methods supported by stringent statistical criteria.

R. Hopkinson and E.R. Reinelt have employed NOAA-4 imagery to investigate the cloud patterns associated with various objectively-defined synoptic weather types occurring in Alberta and British Columbia. Visible-range and infrared images are used to estimate the height distributions of all significant cloud masses. The correlation of cloud systems with specific surface weather types in Alberta and British Columbia was found to be of a lower order than expected, apparently because of the pronounced effect of the Western Cordillera on the low-level circulation.

J. Broszkowski completed an M.Sc. thesis on the application of empirical orthogonal functions to climatological analysis and data storage. Ten years of monthly mean temperatures from Western Canada were used to produce eigenpatterns and periodograms of the temperature field. He also applied the method successfully to 500-mb contour patterns for the purpose of detecting errors efficiently in large data sets. However, the analysis of Alberta precipitation data for the summer months produced, as expected, only disappointing results.

M. Dupilka has almost completed an investigation on the origin and mechanism of mountain-associated waves. The data used were observations made in 1972-74 at Edson, Alberta, during the course of a joint project with the Washington State University and the University of Idaho.

## 4. Alberta Oil Sands Environmental Research Program

The Alberta Oil Sands Environmental Research Program continued into the fifth year of its initial five-year period of operation. Research has been directed to providing information which will permit orderly development of the oil sands without undue environmental damage. At the end of March 1980 AOSERP will merge into the Research Management Division of Alberta Environment.

Description of the baseline state of the AOSERP Study Area continued with the operation of meteorological and air quality data collection networks and a tall tower. The characteristics of plume behaviour and associated air quality factors were examined in a series of field studies. The primary focus of research work has been on developing a series of air quality models for the Study Area. Several scientific reports relating to meteorology and air quality were published by the Program in 1979 and are listed in the bibliography.

## 5. Alberta Environment

A computer model was developed for predicting individual risk as a function of distance from a sour gas pipeline. The model takes into account such factors as: transient release rate, sonic jet expansion, plume rise, surface roughness, mean wind speed, mean wind direction, atmospheric turbulence, source-dominated turbulence, indoor-outdoor concentration relationships, concentration fluctuations, and time of day.

Environmental sulphur research is a continuing high priority topic with the air system research programs. An inventory of industrial sulphur emissions for Alberta 1974-1978 was published. Two projects on the use of stable sulphur isotopes for environmental monitoring were completed.

Consultation with the Province of Saskatchewan has been initiated to investigate the possible medium range transport of air pollutants from Alberta to Saskatchewan.

## 6. Research Council of Alberta - Atmospheric Sciences Division

### (a) Introduction

The main research activity, funded by the Alberta Weather Modification Board (AWMB) was again focused on convective storms to resolve the mechanisms of hailstorms and to determine the feasibility of modifying them beneficially. Since 1979 was the concluding year of the five-year Alberta Hail Project, a comprehensive report on the research performed during that period was presented to the AWMB. The report, in 4 volumes, entitled "Research, Operations and Evaluation in the Alberta Hail Project (1974 - 1978)", is now a public document available from the Research Council of Alberta. Substantial effort was also devoted to the application of weather radar to the operational measurement of areal rainfall. Finally, a modest program of environmental research dealt with pollutants in precipitation and the measurement and identification of airborne particulates in and around Edmonton and in central Alberta.

### (b) Storm Environment Program

The objective of the Storm Environment Program is to understand the formation and decay processes of hailstorms. To achieve this, wind, temperature and moisture must be measured at several atmospheric levels where thunderstorms thrive throughout their lifecycles. The Rocky Mountain House Area Genesis Study (RAGS) program was mounted in 1978 and pursued in 1979 to meet this goal. A physical model of weather events leading to hailstorm formation in the Alberta foothills was partially confirmed.

A study of a large funnel cloud which occurred very close to Penhold in 1976 was completed. Although menacing in appearance, the funnel had a maximum wind speed of only 15 m/s while moving horizontally at 2 m/s.

### (c) Cloud Physics and Modelling Program

For several years, one activity of the Cloud Modelling Program has been to study the use of simple numerical cloud models for statistically evaluating a hail suppression project. The role of these models is to provide a measure of the natural ability of storms to produce hail. Some measures or "predictors" have been found, e.g., the maximum parcel energy of the storm, the predicted maximum hail size of the storm, and the height of the in-cloud freezing level. In addition, regression models have been derived, for both seeded and not-seeded storms, for numerous response variables (i.e., actual measures of the storm hailfall). No difference attributable to cloud seeding has been found, but this may be

due to the very crude measurements used in the calculations which result in large margins of error. The calculations of the predictors are being improved by an objective method of defining the cloud base of a storm, an important parameter previously estimated subjectively.

Development of a numerical model of the growth of hail embryos is continuing. Preliminary calculations with a set of measured initial cloud droplet spectra, updraft speeds and liquid water contents suggest that droplets which have grown to a 200-m diameter while rising from cloud base during a 6-min period could have concentrations of $1L^{-1}$ at the -10°C level. The model is being improved by adding drop nucleation and breakup processes. Another numerical model has been derived for calculating the rate of sublimation of dry ice as a function of temperature and altitude.

A highlight of the Cloud Physics program was the field project conducted from 6 to 26 July, 1979. The University of Wyoming Queen Air made numerous penetrations in the new growth zone of Alberta hailstorms. A hail chase vehicle, was directed into these storm areas and obtained timed, sequential hail samples from three major storms penetrated by the aircraft. Preliminary results from the aircraft measurements are as follows: hundreds of ice crystals per litre can be made in supercooled clouds by dry ice at temperatures below zero, and by silver iodide at temperatures below -7°C; "Possible Seeding Signatures", defined as ice crystal concentrations greater than $10L^{-1}$ in the inflow and/or up-wind regions of seeded hailstorms, have been detected in most small and medium sized hailstorms, but rarely in large, well-organized storms. The common dynamic features of the latter are abundant buoyancy aloft, strong updrafts, copious supercooled water, negative thermal buoyancy at cloud base and their occurrence in "warm atmospheres" just north of a weak surface front.

(d) Radar Studies Program

The Radar Studies Program comprises pure and applied research, technology development and transfer, operational applications in weather and water management, and joint programs and consulting. In 1979, the principal component of the Radar Studies Program was the areal measurement of rain, snow, and hail at the ground. The main result is that measurements of areal rainfall by weather radar are far superior to estimates by conventional surface raingauge networks. Polarization and multi-wave length radar research (using more than one radar) has continued in conjunction with additional computations of the scattering characteristics of precipitation, particularly large oblate spheroids. Further interpretation of the data collected from rainstorms and hailstorms, suggest that remote measurement of hailstone size, large snowflakes and raindrops would be feasible.

Since voluminous data are collected by weather radar during short time periods, considerable effort has been expended on developing a radar-computer technology to record, process and display the data. They can now be displayed, in real time or post facto, on contoured slanted plan position maps, constant altitude plan position maps and vertical cross-sections of reflectivity, and on maps of maximum echo tops, rainfall rates or total accumulation of rainfall. These accomplishments are best seen in the context of extensive program and system structures which will provide a sound basis for rapid software development and a means of transferring the current hardware and software technology to industry for marketing to other weather radar agencies.

The Radar Studies Program continued to provide operational support to the Alberta Weather Modification Board for cloud-seeding in central Alberta, and participated in a pilot program and studies of the

operational use of weather radars in hydrology, hail and crop insurance schemes and forest fire programs.

(e) Data Processing Program

The Data Processing Program provides computer support for data collection, processing, display, and analysis. The PDP-11/34 minicomputer in Penhold collected and displayed in real-time simultaneous data received from the C-band and S-band radars and from project aircraft.

A major ongoing project on the PDP 11/50 minicomputer in Edmonton is development of an interactive graphics facility, to provide an efficient, device-independent system for high-level application programs. All terminals within the Division are now supported, and the software is being considered for use by other computer systems within Council. A graphics terminal capable of overlaying multiple, independent data sets in full colour has been added.

Another ongoing project in conjunction with the Chemistry Division uses the link between their PDP-11/40 and the PDP-11/50 to develop and evaluate software for inter-computer communication and resource sharing. Based on experience with this system, a link to the PDP-11/34 in Penhold is being planned.

(f) Hailfall and Rainfall Studies Program

The aim of the Hailfall and Rainfall Studies Program is to examine fine-scale variations in surface hailfall and rainfall, with the ultimate goal of determining their usefulness in better understanding hail formation mechanisms and in evaluating hail suppression experiments. For hailfall, estimates of crop damage are correlated with the physical characteristics of the hailstones, while for rainfall variations in the daily total precipitation are examined for seeded and non-seeded storms.

Analysis of ten hailstorms from 1974 to 1977 showed that the horizontal component of the impact energy density can increase by 50 to 210 percent, depending on hailstone size, for accompanying wind speeds of 13.4 m/s. Hail-crop losses in these storms for barley crops grown in chernozems and prairie soils were stratified into three stages of maturity: percentage crop damage increases with an increase in the total impact energy density for each, and is greater for the milk and soft dough stages than for the medium-hard dough stage.

Analysis of the 1974 - 1978 hailpad data showed that at least two questions needed further study: the various scales of hailfall on the surface; and the relationship between ground and radar measurements of hail intensity. During 1979, four hailpad networks of increasing sampling densities were established surrounding Rimbey. Network "A" had 188 pads within a 1750 $km^2$ area and contained a second network "B" (442 pads in a 215 $km^2$ area) which also incorporated network "C1" (45 pads in a 2.56 $km^2$ area). Two micro-dense networks, MD1 and MD2, were also established with 40 and 39 pads, respectively, each in an area of 0.64 $km^2$; the latter networks recorded hailfall point frequencies of 5 and 6, respectively, confirming the high frequency of hailstorms in this area.

From 1974 to 1978, several questions were examined about the effects on rainfall resulting from the cloud seeding activities to supress hail. Data from a network of about 500 stations in the Alberta Hail Project area (33,000 $km^2$), showed on the average that, for the northern portion, about 50 percent of the total summer precipitation falls on days when seeding could be carried out, while for the southern portion, 42 percent. This percentage can drop to 25 percent in any year when, e.g.,

an unseeded cold low pressure system passes through the project area. The effect of seeding on summer rainfall could then only result from the response of some of the total summer rain events. For example, an increase of 10% could only be obtained from say 50% rather than all of the total summer rainfall. These results are much lower than had been anticipated.

(g) Evaluation Studies Program

The Evaluation Studies Program supports statistical design and evaluation of experiments in weather modification and other fields. To evaluate the hail suppression test of the Alberta Hail Project various measures and comparisons, set by the AWMB and used in this study, were examined. The results are contained in volume IV of the final report to the AWMB and are generally inconclusive. The difficulties in obtaining sensitive measures were more serious than those of finding appropriate statistical techniques. Much more effort in evaluation measure design is required.

The average rainfall in the Alberta Hail Project area during the historical period was compared with that in surroundings, used as a control area and a covariate. There was significant difference in average rainfall.

A project is underway to devise a mathematical integration technique for designing evaluation measures, and also forms part of a Monte-Carlo experiment for hail suppression simulation. Efforts are mainly directed toward determining meaningful values of the parameters used for the integration technique, but this is difficult because the detailed data required on hailfall characteristics and hailswath structures are lacking.

The more important applications of multivariate techniques to weather modification evaluation are being investigated, including use of principal components analysis and factor analysis to reduce the number of predictor variables in multiple linear regression models.

Climatic modelling using time-series techniques are being examined in both the frequency and time domain, since it is important for historical comparisons of seeded and non-seeded periods in the eveluation of weather modification.

(h) Atmospheric Chemistry

Several atmospheric chemistry projects are jointly carried out with the Chemistry Division. The major effort conducted under contract with Alberta Environment was devoted to studying the chemical composition of atmospheric particulate at a site in Edmonton. The prime objective was to document and explain the daily and seasonal variations in the particulate. Total suspended particulate (TSP) was sampled daily for three 28-day periods between November 1978, and August 1979; size fractionated samples were collected on two occasions during each sampling period. The particulate was analyzed for 32 chemical species. Results will be presented early in 1980. Rain and snow samples collected in Edmonton and Central Alberta were analysed for 23 inorganic chemical species. Sequential rain samples were also collected in Edmonton during July and August 1979, the particulate sampling site. Processing and analysis of data from this program should be completed by mid 1980.

An on-going analytical methods development program supports these activities. Evaluation of filter technique for measuring ambient atmospheric concentrations of sulfur dioxide and sulfate showed that concentrations of 1 ppb of sulfur dioxide and 0.7$\mu$g $m^{-3}$ of sulfate could be routinely determined in 24-h air samples.

7. University of Calgary - Department of Physics - Atmospheric Physics Group

Absorption spectra of $NO_2$ in the stratosphere are being obtained with a ground-based spectrometer. Results from a study of the stratospheric $NO_2$ carried out at Lauder, N.Z. (45°S) during January and February have been published in the Canadian Journal of Physics.

Some results from a study of Calgary ambient aerosol have been published in Atmospheric Environment and others will appear in a spring issue of the Canadian Journal of Physics. Integrating nephelometer and spectronephelometer instruments were used to relate aerosol size distributions with visual range. Aerosol mass loading was monitored by means of cascade impactors.

A two-year study of pollution and visibility situations in the Calgary urban atmosphere has been completed and a report submitted to Alberta Environment.

Development of a standard ruby lidar system is continuing. It will be operated simultaneously with the Department's acoustic sounder system to study local urban pollution patterns during Chinook and temperature inversion events.

The high-power acoustic sounder system located at a small airport near Calgary has been used to measure wind and turbulence profiles up to an altitude of several thousand feet.

8. Western Research & Development

During 1979, Western Research & Development supplied meteorological consulting services to a wide range of clients in the private and public sectors. The consultations covered a wide range of topics including urban air pollution, cooling pond fog generation, arctic climatology and deposition of sulphur dioxide. Major studies included modelling the sulphur dioxide deposition from sulphur extraction plant plumes, prediction of future air quality levels in Calgary, evaluation of hazards associated with a proposed Liquid Natural Gas facility, assessment of NO to $NO_2$ conversion rates in plumes originating from large compressor stations, and evaluation of building downdraft effects.

9. Intera Environmental Consultants Limited

A study funded by the AOSERP Research Secretariat has been undertaken in cooperation with the University of Calgary to measure and chemically analyse particulates present over Calgary. Hailstorm studies assumed an operational status during 1979.

10. Agriculture Canada - Swift Current Research Station

(a) Introduction

The Swift Current Research Station is the designated centre of expertise in Agrometeorology for the Western Region of Agriculture Canada's Research Branch. Meteorological research in support of Western Agriculture is pursued on an interdisciplinary basis. Generally, Agrometeorology and related research work can be categorized under four headings: Environmental Studies, Crop-Environment Modelling, Energy-Climate Relationships, and other related research. Work is carried out under the Meteorological and Climatic Indices Program which has a 1982 Establishment Goal to: derive selected meteorological and climatic indices that can be easily utilized by producers in their decision-making; and acquire more detailed information to maximize returns on weather sensitive agricultural operations, including the use of wind and solar energy.

(b) Environmental Studies

A new data-logging system consisting of a PDP 11/10 mini-computer and Hewlett Packard cross-bar scanner and digital voltmeter was installed in 1977, and automatically records up to 300 channels of information on magnetic tape. Wind (speed and direction), temperature (profiles in the soil and above the crop) and radiation (photosynthetic, net and total incoming) instruments, heat flux plates and a four-foot diameter strain gauge lysimeter are connected to the system. In association with data from 16 manometric lysimeters, studies are being conducted on the energy balance and comparative growth response of Manitou and Pitic spring wheats.

A similar study of the energy balance and water use of Russian wild rye was started in 1979.

A simulated dryland growth-room study was completed in 1978 on the interactions of nitrogen fertility, temperature and moisture stress with growth dynamics, grain yield, protein content and N distribution of Manitou spring wheat. This provided much needed information about environmental effects on growth characteristics.

(c) Crop-Environment Modelling

Swift Current was the official Canadian representative in an international experiment organized by the World Meteorological Organization. The WMO Working Group for the Acquisition of Wheat Weather Data consisted of eight member countries having 11 experimental sites throughout the wheat growing areas of the world. A common variety of wheat, Siete Cerros, was grown at these sites for 4 years, using two planting dates and two levels of fertility. A complete set of meteorological and phenological data was kept, as well as crop dry weights, yield and protein content. Data from all sites have been compiled on computer magnetic tape and are being analysed and used for developing computer simulations of wheat growth and yield.

A new WMO Working Group has been established for Crop Weather Modelling. As a member of the Group, Swift Current is developing a statistical and a dynamic model of wheat growth using the data from WMO, and field and growth-room studies.

(d) Energy-Climate Relationships

Studies on the application of solar and wind power to agriculture are being conducted. Three solar collectors were built in 1978 and tested for use as grain driers and heaters for livestock shelters. The collectors were of a simple owner fabricated design and could be made from materials obtained from inventory. Two years of research demonstrated that wheat can be dried from 20% moisture content to 14% in 19 days. The collectors have a payback time of 4 years if used to dry grain, and 2 years if used to supplement heat for livestock shelters.

A 27.5 m high vertical axis wind turbine was erected at the Research Station as a cooperative project with the Saskatchewan Power Corporation, National Research Council and Agriculture Canada. Turbine performance is being monitored relative to climatic factors to assess the practicality of wind power on the Canadian Prairies.

(e) Related Research

Other climate-related research is carried out mainly under the Irrigation, Drainage and Desalination Program, which includes important projects to investigate use of sewage effluent for irrigation;

maintenance of irrigation ditches; runoff and water quality from small agricultural watersheds; control of seepage from farm-sized reservoirs; irrigation scheduling for alfalfa; snow management with grass barriers; reclamation and control of saline seeps; and moisture recharge and conservation in dryland farming.

11. Saskatchewan Research Council

Atmospheric sciences studies were conducted in areas of micrometeorology and acid rain.

Work started on the design, construction, and operation of a micrometeorological system for Canada Department of Agriculture in Regina. The purpose of the project is to study how fast and how much of the herbicide chemicals, once incorporated in the soils, are lost to the air over the period of a growing season. The flux of herbicide vapor emanating from a treated field can be calculated from the vertical gradient of concentration, along with the atmospheric turbulent diffusivity coefficients which are to be determined by both the aerodynamic and energy balance techniques. Whenever one method breaks down (e.g., the aerodynamic method during light wind) the other can be used quite effectively. Six levels of instrumentation are required to a maximum height of two metres. All data collected in the field are to be stored on a tape cassette and interfaced with existing computer facilities to derive values of the chemical mass fluxes directly.

The increasing impact of acid rains on the ecology of Northern Saskatchewan is developing into a program requiring increasing research. Levels of sulphur in snow deposits, rain and aerosols indicate that there is little impact at present. However, because of the rather impressive industrial scenario unfolding in the Athabasca Oil Sands region of Alberta, continual monitoring must be conducted within the environment. Lakes and streams in the unbuffered Precambrian Shield areas of Saskatchewan are particularly sensitive to increasing acidity effects.

Atmospheric science services were offered to provincial industries. A general survey program was completed on stack emission from potash industry operations. Results from each mine site were quite variable, thus reflecting the variability of the pollution control equipment.

Research programs are just getting underway to study short-and long-term impacts of uranium in Saskatchewan upon the environment. Preliminary monitoring of site, environmental heavy metal and radioactivity is being undertaken. Special studies will be devoted to uranium tailings ponds; primary goals are to minimize any deleterious effects for future generations.

12. University of Windsor

(a) Department of Geography

Ongoing studies are being made of the climatology of Essex Region and the climatology and hydrology of southern Baffin Island. Operation of the precipitation gauge network is continuing in cooperation with the Essex Region Conservation Authority.

(b) Department of Physics

Measurement of fundamental parameters relevant to minor atmospheric species is continuing. Particular attention is being paid to development of new techniques for pollution sampling and detection. These include laser 2-photon absorption and spectroscopy with thin films.

13. University of Waterloo - Environmental Fluid Mechanics Group

Two studies of large-scale weather prediction have been carried out. One was on normal mode initialization for primitive equations models, and a method has been proposed for application to models with surface friction. The other study dealt with the rate of change of available potential energy during east-coast cyclogenesis, and used data produced by an 8-level primitive equations model simulating actual cases.

A one-layer mesoscale wind model has been applied to Lancaster Sound and Metropolitan Toronto; in the latter application, lake-breeze cases with varying boundary-layer height were examined. A variational approach to diagnosing winds in the vicinity of a radiosonde station has been designed. A 2-dimensional non-hydrostatic model is being set up to study winds and temperatures in the vertical plane.

Work has also been done on simple methods of computing downward long-wave and solar radiation fluxes at the earth's surface.

Further development and testing of a 2-dimensional (vertical plane) hydrostatic planetary boundary-layer (P.B.L.) model has been completed. This model was modified and results were tested against data gathered at a tar sands plant; it was quite successful in predicting the essential features of the observed wind and temperature fields some six hours in advance. Work is progressing on inclusion of a second-order closure turbulence model into a P.B.L. model.

Considerable time was spent on developing a model for atmospheric diffusion that would incorporate the effects of cross-wind shear, which is assumed to cause enhanced relative diffusion, as well as distortion of the plume cross-sectional shape. This distortion can result in a skewed ground-level distribution of contaminants and a very significant reduction in the magnitude of the concentrations. The work on cross-wind shear effects on plume dispersion is now complete.

The Syncrude data have been analysed further for the study of buoyant plume behaviour.

14. McMaster University - Department of Geography

(a) Energy Budget Studies (Wayne R. Rouse)

Continuing program in energy-budget studies in the low Arctic tundra. Continuous measurements of component fluxes of the radiation budget, soil heat flux, soil temperature and evaporation for forested and non-forested permafrost terrain during snow-melt, thaw, mid-summer, freeze-back and early winter.

(b) Radiation Studies (John A. Davies)

1. Determination of aerosol effects on radiation using aircraft measurements of radiation fluxes and airborne particles.

2. Assessment of numerical solutions to the radiative transfer equation with respect to tropical clouds.

15. University of Toronto

(a) Department of Physics - Meteorology

Ion Studies: Experiments on gas-to-particle reactions continue. Nucleation of ammonium chloride was studied, and the catalytic effect of ions was determined - negative ions are most efficient for this

reaction. Sulfur dioxide and water vapour produce nucleation only when ions are present: in this case ions of both signs are approximately equally efficient. Surprisingly, oxygen does not enter the nucleation reaction. Mass spectroscopic experiments have started, in order to obtain information about the mechanism of ion-induced nucleation.

Systematic investigation of the field-induced ion evaporation from liquid surfaces at atmospheric pressures continues. The influence of molecular structure and of concentration has been studied; experiments suggest that the process may have value as a new analytical tool.

A set of experimental studies was completed on the field-controlled ion capture by ice crystals in a unipolar atmosphere, a process relevant to the formation of shielding layers in thunderclouds.

Glacial isostasy and climatic change: Both heavily parameterized energy-balance models and general circulation models are being employed to investigate the direct and indirect causes and effects of glaciation-deglaciation upon atmospheric climate. Direct effects include ice-albedo feedback; indirect effects include forced variations in the orbital dynamics of the planet resulting from glacial isostasy and the internal dynamics of the cryosphere.

Atomospheric waves and turbulence: The linear and non-linear dynamics of both internal and Rossby waves are being investigated, paying particular attention to critical level effects. Some specific applications were made to mountain waves and downslope windstorms, Kelvin-Helmholtz waves and turbulence, the vertical propagation of Rossby waves and Stratospheric Sudden Warning.

Geophysical fluid dynamics: Numerical models have been constructed for various phenomena associated with mantle convection and continental drift. A major discovery is a mechanism for the explanation of the flattening of ocean floor topography away from the $t^{1/2}$ law of boundary-layer theory, which allows the heat source concentration in the planetary mantle to be directly inferred. A boundary-layer instability mechanism has also been proposed for explaining intraplate volcanism - an example of which is provided by the Hawaiian Islands.

Boundary - Layer Processes: Dynamic processes responsible for the horizontal eddy transport of vertical vorticity by cumulus convection have been studied by Dr. H. R. Cho and his students. This transport has been found to be very important for the dynamics of tropical disturbances. Using GATE A/B-scale aerological data, the transport effects have been identified, and they agree quantitatively very well with predictions made according to the theoretical analyses.

Forest fires: Atmospheric dynamic processes which may cause fast spread of forest fires are being studied: these include the associated mesoscale circulations which may cause fires to blow up, and the synoptic-scale conditions which may favour such mesoscale circulations to develop.

Upper Atmosphere Water Vapour: The concentration of $H_2O$ in the middle atmosphere is being studied using data from the Stratospheric and Mesospheric Sounder onboard the NIMBUS G satellite. Thermal emission in the far infrared is used for stratospheric concentrations; resonant scattering of sunlight in the 2.7-$\mu$m band, for mesospheric concentrations. Calculations of expected emissions and interpretation of observed signals are being made at the University of Toronto using calibrated satellite data supplied by the University of Oxford, England.

Cloud Physics: Numerical experiments have been started on time-dependent evolution models for rainshafts. If reduced to steady-state situations they agree with earlier List-Gillespie type results.

Previous drop collision/breakup experiments were carried out at laboratory pressures. However, the pressure drop with height in the atmosphere may well alter the influence of the "third" body participating in a collision of two drops, namely the air. First experiments can now be reported on the breakup at 50 kPa.

Icing experiments with cylinders showed that the sponginess of the deposits depended considerably on rotation rates. Thus, interpretations of hailstone history which are based on structures are becoming just dreams. It was further demonstrated that hailstones are excellent instantaneous converters of cloud water into rain.

(b) Institute for Environmental Studies

Atmospheric research is an integral part of the activities of the Institute, which seeks to build bridges between disciplines and university departments. For example, one of the programme themes at the Institute is "Climate and Society". The major activities during 1979 relating to this theme were:

- Professors F.K. Hare and R.E. Munn presented overview papers at the World Climate Conference (Geneva, February, 1979).

- Professors F.K. Hare, I. Burton, R.E. Munn and G.R. Williams participated in an Institute/AES/SCOPE Workshop and prepared the subsequent report: "Climate-Society Interfaces".

- Professors F.K. Hare and R.E. Munn presented papers and chaired Working Groups at the AES Worship or Energy/Carbon/Dioxide Issues and Impacts (Toronto, August 1979).

- Professor Hare is Chairman of the AES Climate Planning Board while Professor Munn is a member of the Climate Advisory Committee.

- Mr. K. Higuchi has begun doctoral studies, to develop design criteria for monitoring the global and regional biogeochemical cycles of carbon, a topic relevant to the problem of greenhouse warming of the atmosphere.

Dr. Munn continues to coordinate the activities of the Institute in the design of environmental monitoring systems. A special study has just been funded by WHO to examine the air pollution exposures of populations, and to determine the relevance of standard outdoor air quality monitoring stations for health studies. This work is to be undertaken in collaboration with the Medical Faculties at Toronto and McMaster Universities, and the Ontario Ministry of the Environment.

The Institute has a major interest in long-range transport and the impacts of acid rains on aquatic and terrestrial ecosystems. Profs. H. Harvey and R.E. Munn are members of the AES Scientific Advisory Committee on LRTAP.

16. Ontario Ministry of the Environment - Air Resources Branch

(a) Air Quality and Meteorology Section

Development of a model to predict short-term pollutant concentrations caused by elevated sources during convective conditions has been completed. The model has been validated with data collected during field studies in Maryland and in the Sudbury area.

Preliminary results from a long-term, long-range statistical model have been obtained. $SO_2$ and $SO_4$ concentrations have been estimated for a grid covering the northeastern United States and Canada.

Research has been conducted on estimating the expected deviation between model predicted concentrations and time-averaged measurements. This work is important for model validation and for "predicting" concentrations for supplementary emission control.

The response of idealized biological systems to pollutants has been modelled using a simple linear absorption-detoxification assumption. The model has been applied to the response of COHb concentrations in human blood to ambient CO concentrations.

Large-scale weather influences on nitrate in suspended particulate matter in Southern Ontario were studied, including assessment of the contribution of long-range transport of nitrates to the ambient levels.

(b) Special Studies Unit

Studies of plume diffusion in a convective boundary layer were made for the tall stack at Sudbury, Ontario. Related work included development of a mixed layer climatology for the area.

The impact of Sudbury smelting activities and long-range transport on local wet and dry atmospheric deposition of acids, sulphates and trace metals was investigated.

Studies of the Nanticoke area included: field measurements of atmospheric turbulence and pollutant dispersion in a lakeshore environment; and impact of Nanticoke industrial activities and long-range transport.

17. Acres Consulting Services Limited

Results were published for an extensive literature survey of empirical atmospheric deposition parameters: deposition velocities of particles and gases, surface resistance to gaseous deposition, scavenging coefficients of particles, scavenging (washout) ratios, and scavenging coefficients of gases.

An in-depth review of literature was prepared for Alberta Oil Sands Environmental Research Program on pollution deposition processes of both gases and particulates in precipitation (scavenging) and non-precipitation (dry) conditions. The report included recommendations on the hypotheses, algorithms or models considered to be the most suitable for incorporation into a pollutant transport and diffusion model to be selected later. Field monitoring programs were also reviewed. A program was designed to provide data for calibrating the models recommended as suitable for the AOSERP study area.

18. Trent University - Department of Geography

Several projects continued on the study of: ice and snow-cover on Peterborough-area lakes; snowfall and snow-cover in the Peterborough area; and land and lake snow-cover in Northern Quebec/Labrador.

19. Communications Research Centre

The detailed study of the precipitation climatology of Canada, as described in the 1978 Bulletin, has continued during 1979. A comprehensive report discussing various statistical aspects of the occurrence of moderate and intense rainfall in all regions of the country has been published.

20. National Aeronautical Establishment - Flight Research Laboratory

Atmospheric turbulence, a governing factor in aircraft design and in many problems encountered in operations, is the subject of continuing theoretical study and experiment. A thoroughly instrumented T-33 aircraft is the principal means for obtaining turbulence measurements aimed at understanding, modelling, and predicting these disturbances. This aircraft has been used in a number of national and international projects to measure atmospheric turbulence generated by various sources including severe convective storms, mountain waves, boundary-layer flow, wind shear in jet streams, and vortex wakes from transport aircraft. Recently (1974-1978) it served as the seeding aircraft in a cloud physics experiment designed to assess the feasibility of stimulating precipitation from towering cumulus clouds for forest-fire suppression. This was conducted in cooperation with the Cloud Physics Research Division of the Atmospheric Environment Service. The NAE Twin Otter used as the command aircraft in this experiment has been extensively instrumented to make microphysical measurements of cloud particles and precipitation as well as to record the dynamical properties of the air motion within the cloud. It was flown on repeated penetrations of both seeded and unseeded control clouds to determine their natural characteristics and to evaluate their potential for rainfall enhancement as a result of treatment with dry ice or silver iodide. A third aircraft, a Beech 18, was flown below the selected clouds to monitor cloud-base conditions and measure the rate of fall of any resulting precipitation. Reports and papers listed in the bibliography for 1979 were products of this experiment.

During 1979 the NAE and the AES were invited to participate in the High Plains Cooperative Experiment (HIPLEX) at Miles City, Montana. This is an annual 3-month study to investigate the precipitation formation process and seeding potential in convective clouds over the plains. The NAE Twin Otter and 7 scientific and support staff participated in this experiment in July. The Twin Otter served as the cloud-base aircraft to measure the precipitation, microphysics, and turbulence beneath cumulus clouds also being studied by the University of Wyoming King-Air and the CIC Lear Jet. To assess whether HIPLEX results may be directly transferable to the Canadian environment, penetrations were flown through the tops of other convective clouds to determine to what extent the microphysics of Montana clouds are similar to those of Canadian clouds previously studied.

21. McGill University

(a) Department of Meteorology

Analytical and numerical research on long planetary waves was continued including investigation of the role of the critical layer in such waves.

The role of sideband "noise" in the resonant growth of topographically forced Rossby waves is also being studied. One suggestion arising from this work is that the long-wave amplification occurring in sudden stratospheric warming events is most probable when the pre-existing flow is approximately zonal.

A numerical model for the transfer of solar radiation through the atmosphere has been developed that is suitable for use in a 3-dimensional global climate model. This model has the advantage over others in

allowing for interactions with the atmospheric aerosol. It is being used to study the effects of haze on the solar radiation budget of the Arctic. A more highly parameterized solar radiation model is also being developed.

Modelling studies are being made to determine the role of giant nuclei in the initiation of the warm rain process.

The shape of snowflake size distribution growing by deposition and aggregation has been calculated by means of a numerical model - to a good approximation a negative exponential shape is maintained.

Research on the numerical simulation of convective clouds in three dimensions continued; the effects of wind shear, water load, and evaporation on the development of moderate-sized cumulus were computed.

The statistical properties of radar echoes on date 261 of GATE were analysed to obtain a unique data set for comparison with modelled results.

A simple ice-phase microphysical parameterization scheme was introduced into the model and a study of the effect of AgI seeding on the dynamics and microphysics of convective clouds is underway.

Work on using a random heating function in the initialization of the cloud model has begun; the effect of wind shear on the scale of cumulus convection will be investigated.

A 13-GHz passive radiometer with fixed antenna has been colocated with the McGill weather radar to compare radar data with the microwave emission from clouds and rain.

Work has continued on the application of radar data to the analysis and design of microwave communication systems.

The McGill energy-budget models have been extended and improved and used in studies of the physical characteristics of various local climates and in studies of climate impact. Since the models can be applied to any climatic and geographic region they have been used for studies of areas as different and remote as the East Africa source region of the Nile and the coast of James Bay.

The water flow in the White Nile was examined to see how it would respond to various changes of surface characteristics (e.g., building of storage dams, draining of swamps, denudation of vegetation cover, improved water-holding capacity of the soil). The creation of open water in an otherwise ice-covered area near the mouth of a river was studied to see how it affected coastal fog and cloud in the James Bay region.

(b) Macdonald Campus - Department of Agricultural Chemistry and Physics

The projects described in the 1978 Canadian Geophysicasl Bulletin are continuing.

22. Université de Sherbrooke

Recherches en cours

- Le climat des Cantons de l'Est. J.J. Boisvert. Recherche sous tous les aspects de la climatologie régionale.

- Étude de l'interaction rayonnement émis/rayonnement réfléchi pour l'inertie thermique. F. Bonn et M. Bernier

- Étude de l'inertie thermique de la biomasse. F. Bonn et A. Barcados.

- Étude des inversions de températures par thermographie, application aux gelées nocturnes. F. Bonn, J.J. Boisvert, J. Lévesque.

- Étude des variations climatiques dans les Cantons de l'Est. G. Bousquet et J.J. Boisvert.

23. Ministére des Richesses Naturelles du Québec - Service de la Meteorologie

(a) Le Programme de Connaissances intégrées (P.C.I.) a été poursuivi sur le bassin de la rivière L'Assomption et entrepris sur le bassin de la rivière Du Nord. L'étude du bassin de la Yamaska a été publiée. Les sujets particuliers traités dans ces études on été décrits dans le B.C.G. de l'année 1978.

(b) Dans le cadre de la rationalisation du réseau météorologique du Québec, l'étude d'homogénéité des séries chronologiques de données nivométriques et thermométriques est parachevée, celle portant sur les pluies a été publiée au cours de l'année 1979.

(c) On est à compléter la mise au point et les tests d'un systéme de traitement automatique des données obtenues des pluviographes F & P.

(d) Le Service de la Météorologie a entrepris en 1979 un programme à long terme dans le domaine des énergies nouvelles (solaire et éolienne):

1- en énergie solaire, des projets spécifiques porteront sur:

- l'inventaire des données en énergie solaire au Québec et la constitution d'une banque informatique de ces données.

- les statistiques de l'énergie solaire spécialement adaptées aux besoins des utilisateurs dans le domaine.

- l'amélioration des réseaux de mesure en énergie solaire.

- la simulation du rayonnement solaire par modèle numérique et par méthode statistique.

- la climatologie de l'énergie solaire et sa cartographie.

2- en énergie éolienne, les principaux projets consisteront à:

- monter une banque de données anémométriques pertinentes aux besoins généraux en énergie éolienne au Québec.

- présenter des statistiques relatives au potentiel éolien, spécialement adaptées aux besoins des utilisateurs dans le domaine.

- présenter la cartographie du potentiel éolien québécois à l'échelle mensuelle et annuelle.

- améliorer les réseaux de mesure du vent.

(e) On poursuit le développement de méthodes d'extraction et de traitement de divers types de diagrammes par digimétre: ainsi un systéme de traitement des pluviogrammes est maintenant opérationnel et on élabore présentement un système d'extraction d'anémogrammes et d'actinogrammes.

(f) On termine un projet de révision de toutes les données mensuelles archivées au Service de la Météorologie en vue de les préparer à être microfilmées.

(g) On élabore actuellement un systéme de mise en banque informatique et de validation des données transmises en temps quasi réel via le satellite GOES.

(h) On a commencé un travail d'inventaire en vue de la fusion éventuelle de deux banques de données mensuelles, soit une banque constituée des sommaires mensuels archivés et une autre formée à partir des données quotidiennes déjà archivées sur support informatique.

(i) Un projet d'étude de micro-climat urbain a été entrepris: la premiére étape a consisté en une campagne intensive de relevés en vue de détecter l'ilôt de chaleur à Québec en été.

(j) Le programme de prévisions hydrométéorologiques en période de fonte printanière s'est poursuivi en 1979 et sera développé davantage pour la saison prochaine.

(k) Enfin, le programme de prévisions météorologiques reliées à la thermographie aéroportée des pertes de chaleur a été temporairement suspendu en 1979 et sera possiblement repris plus tard.

24. Université du Québec à Chicoutimi - Centre de Recherche du Moyen-Nord

(a) Programme

L'objet des recherches entreprises touche les aspects du climat dans le Moyen Nord et ses influences sur la technologie employée dans ces régions. Conséquemment, les recherches portent sur des sujets reliés au givrage des lignes de transport d'énergie, aux modèles climatiques, aux microclimats artificiels, aux précipitations orographiques, à l'énergie interne des lacs et des rivières et à la chimie des terpènes.

(b) Projets

1. Recherches relatives au givrage des lignes de transport d'énergie

- Adhésion de la glace sur les conducteurs ou sur d'autres structures
- Étude de la microstructure du givre et du verglas
- Construction d'une soufflerie réfrigérée avec formation de gouttelettes surfondues
- Les arcs électriques sur les isolateurs en présence de givre et de verglas
- Génération de chaleur dans les conducteurs
- Vibration des conducteurs
- Étude de la croissance d'un manchon de glace sur un conducteur
- L'influence du champ électrique sur les propriétés mécaniques de la glace (électro-congélation)

2. Recherches en chimie des terpènes d'origine forestiére

- Les terpènes émis par la forêt et la photochimie atmosphérique
- L'influence des facteurs d'environnement sur la qualité et la quantité de la production terpènique forestiére

3. Les cultures abritées dans le Moyen Nord

4. Étude de la physique des lacs

- La physique des lacs du Moyen Nord québécois sur l'ensemble du cycle estival
- Modèles de prédiction de l'énergie des lacs et généralisation de ceux-ci

5. Stations météorologiques du Moyen Nord

- Station météorologique du Pavillon des Sciences
- Inversion de température dans le Haut-Saguenay

25. Atmospheric Environment Service

(a) Meteorological Services Research Branch

(i) General Program

The Meteorological Services Research Branch supports AES operational systems for the observation and prediction of weather elements and other weather-department environmental parameters. Emphasis is on applied research although more fundamental aspects receive attention when necessary. Advances in remote sensing (especially from weather satellites), computerization in the forecasting function, and automation of the observational system have received much attention of late. The research programs of the Branch are organized in the following areas:

Large-scale dynamic prediction in numerical atmospheric modelling and development of atmospheric prediction 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 weather-dependent environmental phonemena such as atmospheric pollution, wind-waves and ice at sea or on inland waters;

Aerospace Meteorology embracing aeronautical meteorology; the meteorology of weather effects on man's activities and structures; and remote sensing, including reception, processing and dissemination of meteorological satellite data;

Design of integrated systems for the use of computers in forecasting, from recognition of all data including the latest, through large-scale NWP, through more regional and local processes to the final forecast products.

(ii) Detailed Studies

In addition to considerable effort expended on improving the parameterization of physical effects in the operational spectral model, a number of integrations were made with the succeeding version of the model using finite elements in the vertical instead of finite differences.

Improved boundary specifications for the limited-area finite-difference primitive equations model eliminated previous problems arising from unstable corner points and non-conservation of mass. Frequent integrations were made with both 5- and 10-level versions.

Development continued on the three-dimensional variable mesh finite-element primitive equations model. Vectorization of key program segments reduced computation time by 40%. Revisions to data transfer techniques and the use of packing further reduced running time and improved memory utiliation, permitting the model to be integrated at higher resolutions. Integrations were obtained with grid lengths as short as 127 km.

A system for continuously updating the covariance statistics was tested and then incorporated into the operational optimum interpolation data-assimilation scheme. Stastistics are computed for every 10° latitude band. Separate statistics for land and sea would be desirable but not enough ship observations are available.

A new version of the spectral model output program was completed. Storage of model output in isobaric coordinates on the model Gaussian grid rather than as spectral coefficients on sigma surfaces reduced user access time for forecast fields by about 80%.

Several global integrations with the operational spectral model were made from a set of July 1974 analyses obtained from NCAR. Runs were made with and without detailed analyses prepared at Florida State University for the tropical Atlantic.

A sequence of experiments on the predictability of a spectral non-divergent barotropic model was carried out, yielding interesting results about the effects of: surface drag; diffusion schemes; simulated baroclinic forcing terms; model truncation; observational errors in short and/or long waves; and the earth's rotation.

Five-day forecasts were made with the GARP basic data set using several different models in both global and hemispheric configurations as part of an international model comparison experiment.

The Beaufort Sea Winter Ice Experiment, a joint government-industry activity, was initiated. A comprehensive data acquisition phase was completed in which routine meteorological data were collected and collated, a field program was carried out to obtain oceanographic and ice information, buoys were deployed on the ice for sensing meteorological and oceanographic parameters and transmitting data in real time, aircraft ice reconnaissance surveys were made to obtain ice information by means of SAR, SLAR, laser and infrared scatterometer equipment, and helicopters were utilized to obtain visual and film records of ice characteristics. This activity was primarily to obtain a data base for developing local and regional scale ice-prediction models, but also to test advanced remote-sensing and data transmission equipment for supporting marine operations in Arctic winter ice conditions.

Special applications of the Small Area Model for predicting surface winds were developed and one was incorporated into the Canadian contribution to a project of the International Energy Agency.

Increased effort was again directed to developing procedures for empirical-physical prediction of weather parameters. The data base became large enough so that a set of climatological aids could be generated for selected locations throughout Canada, and statistical procedures could be applied on physically-significant meteorological and geophysical parameters for predicting probability of precipitation.

Several R & D projects were undertaken jointly by Meteorological Services Research Branch and Regional Weather Centres: operational test of an isentropic analysis procedure; implementation of a polynomial interpolation procedure at Halifax for analysis of selected meteorological parameters; devising and testing of a freezing spray forecasting procedure at Gander and Halifax. Joint activities continued on devising a model to predict snow squalls induced by water bodies, studying the probability of precipitation

with applications to agriculture, and predicting areas likely to experience severe convective storms.

A comprehensive evaluation of a K-profile version of a planetary boundary-layer prediction model was initiated. A higher-order 3-dimensional turbulence model was tested with some numerical instability appearing after about 250 time steps.

Simple advection and extrapolation schemes for short-range forecasting of selected meteorological parameters were developed and tested. Initial test results for sea-level pressure indicate the procedures have promise, especially in the first 12 h of the forecast period.

A program was planned to enhance and extend sea-state service provided by the Atmospheric Environment Service.

The Satellite Data Laboratory operates read-out facilities for both United States operational environmental satellite systems, the NOAA polar orbiting satellite and the GOES geostationary satellites. All data received are processed digitally and enhanced before being retransmitted to operational ice and weather forecast offices in Canada. The systems also provide a limited amount of data for archiving on computer compatible tapes or for transmitting via direct computer-to-computer links for research and development purposes.

The Aerospace Meteorology Division carries out a program of research and development to improve the use of satellite data in AES operations. Via R & D contracts with McGill University and Goodwood Data Systems the Division is developing a system to investigate methods of combining weather radar and satellite data to identify precipitation over large areas in real time. Essentially the radar data are used as groundtruth for the satellite data to determine the relationship between precipitation and satellite-derived radiances. This relationship is then used to provide estimates of precipitation outside the range of the radar. In addition to analysis of precipitation, temporal extrapolation will be used to compute 2-, 4- and 6-h forecasts of the motions of precipitation areas.

In a cooperative program with Transport Canada the Division has contracted with MacDonald Dettwiler and Associates to develop precision mapping and radiance analysis software as a prerequisite for producing a system to provide computer-assisted extraction of ice information from NOAA satellite data.

Other research programs include investigation of the potential AES applications of data from the SEASAT type of sensors and use of satellite sounding data.

Research in the area which has come to be known as Wind Engineering is also being carried out. Measurements on the wind and turbulence structure in the planetary boundary layer are made over various types of terrain for application to problems such as the wind loading of buildings, bridges and other structures, transmission line oscillation and the handling and response of small aircraft. The flow in the planetary boundary layer is being simulated in the AES Wind Tunnel to assess the capabilities of the wind tunnel for this type of study. Some recent reports on these activities are listed in the bibliography.

(b) Atmospheric Processes Research Branch

(i) Experimental Studies Division

Experimental and theoretical studies of the stratosphere and ozone layer are continuing to assess the depletion of the ozone layer by chlorofluoromethanes.

In February a STRATOPROBE/York University payload was flown at CFB Cold Lake, Alberta in support of the "ground truth" program for the LIMS, SAMS and SBUV Experiments on the NIMBUS VII satellite. The Balloon measurements included $HNO_3$, $NO_2$, $O_3$, $H_2O$ and $CH_4$.

As part of a joint program with the CSIRO and FAA, in March and April, two AES experiments were flown in Alice Springs and one in Mildura, Australia, viz., the $NO_2$ spectrophotometer and the $HNO_3$ radiometer. The objective was to obtain background stratospheric profiles of nitrogen constituents in the Southern Hemisphere. Two additional flights of these experiments were made at Mildura, Australia in October.

Ground-based remote-sensing measurements of $NO_2$ have been obtained in conjunction with the STRATOPROBE balloon flights. Resulting from advances in monitoring ozone, an effect of $SO_2$ pollution on the Dobson ozone instrument has been detected; column amounts of $SO_2$ are now being routinely monitored at Downsview.

Daily surface-based measurements of total atmospheric ozone using the Dobson ozone spectrophotometers continue at Edmonton, Goose, Churchill, Resolute and Toronto. The vertical ozone profiles from the surface to 30 km are measured by balloon sounding with electrochemical sondes each Wednesday at the first four of these stations. At Edmonton and Resolute the ECC ozonesonde replaced the Brewer Mast ozonesonde (which was the standard program instrument since its inception). A solar cycle variation is indicated in the total ozone data.

Observational testing of the new Brewer ozone spectrophotometer for network use has been completed. Several extensive intercomparisons were carried out at Wallops Island, Virginia, Boulder, Colorado and Palestine, Texas. To promote this Canadian-designed and manufactured instrument for WMO and world use, COPI funding has been obtained to incorporate final modifications before manufacturing it as a reliable field instrument.

The constituent data sets from the STRATOPROBE flights are being theoretically simulated in collaboration with York University. Comparisons indicate that hydroxyl densities in the 18 to 30-km region are smaller than current models predict. The consequences of low hydroxyl densities on ozone depletion by CFM's have been evaluated with a scenario model. The projected depletions of ozone by freons at the 1973 usage rate are about a factor of three smaller than those predicted by models with current photochemistry; injections of $NO_x$ from high altitude aircraft could cause significant ozone depletions.

(ii) Cloud Physics Research Division

Radar Meteorology - Considerable emphasis was placed on development of the radar system, 5-dimensional data processing and remote digital transmission before providing full radar service in the Toronto area from the research radar facility to meet all the

needs of many active internal and external users in real-time, i.e., forecasting, public information, hydrometeorology and research. Studies continue on Z-R climatology, rainfall measurement and variations in raindrop distribution. A system to digitize radar data from a USSR radar and provide magnetic tape records for the PEP/WMO experiment in Spain was completed.

Cloud Microphysics/Weather Modification - During June 1979, the AES and NRC signed a Memorandum of Understanding with the U.S. Bureau of Reclamation (BOR) regarding Canada/U.S. cooperation in the High Plains Cooperative Program (HIPLEX) of BOR. HIPLEX is designed to find methods of increasing growing season precipitation on the High Plains. During July 1979, 5 AES and 7 NRC personnel, an NRC Twin Otter aircraft instrumented for cloud physics research, and data analysis computer systems were stationed in Miles City, Montana. Useful data were subsequently collected and Canada's involvement in HIPLEX was beneficial to both Canadian and U.S. scientists.

(c) Air Quality and Inter-Environmental Research Branch

(i) Long-Range Transport of Air Pollutants (LRTAP)

LRTAP and related acidic precipitation has developed into one of the most serious environmental problems that Canada faces today. The problem is inter-governmental and international in nature, and as a result, in an effort to eliminate duplication and to enhance cooperation, steps were taken to strengthen federal/provincial, private sector, and international interfaces.

The primary AES contribution to the LRTAP scientific program was concentrated in the areas of:

(a) atmospheric transport and deposition - in particular, transboundary sulphur fluxes; seasonal and annual deposition fields in eastern Canada; and relative contributions from Canadian and U.S. pollution sources. Supporting research was also conducted on nitrogen oxide measurements which are expected to become increasingly important during the next decade.

(b) calibrated watersheds. Four watersheds have been selected for study - Kejimkujik Park, Montmorency Forest, the Algoma region, and the Kenora basin. Information has been documented on the in-lake synergistic reactions to acidification.

In addition to these research activities, a scientific program management secretariat was established, responsible, as a focal point, for coordinating the various elements of the federal LRTAP Program in the Department of the Environment.

(ii) Environmental Monitoring

The Canadian Network for sampling Precipitation (CANSAP) operated during 1979. About half of the collectors were upgraded to new design standards in an effort to improve their catch efficiency and reliability. The remaining instruments will be upgraded during 1980. Four new sampling sites were added (Revelstoke, B.C., Kejimkujik, N.S., Dorset, Ont., and a station in the Experimental Lakes Area of Ontario near Kenora) while three sampling programs were relocated (Wawa to Kapuskasing; Windsor to Harrow CDA Research Station; Fort Simpson to Hay River). By December 1979 there were 54 stations in the network.

A joint sampling program was undertaken in cooperation with the Ontario Ministry of Environment to ensure that results from their APOS (Acidic Precipitation in Ontario Study) network would be comparable with those from CANSAP. Plans were completed with the National Atmospheric Deposition Program to start a joint sampling program at selected sites in Canada and the United States in the spring of 1980. An intercomparison of samplers at Pennsylvannia State University was terminated in May 1979 and the results are being analysed.

A change to monthly-composite sampling was planned for January 1980 to improve sample quality. The first two years' operation of CANSAP was assessed and several areas of the program were identified which require attention to ensure the continued scientific validity of the program.

As part of the WMO background environmental monitoring program, atmospheric $CO_2$ concentrations were measured at three Canadian sites. In cooperation with the Institute of Ocean Sciences a number of Pacific coast locations are being evaluated to determine a sampling site to replace Ocean Station "Papa".

(iii) Great Lakes Water Quality Agreement (GLWQA) Program

The 1978 Canada-U.S. Great Lakes Water Quality Agreement identifies programs and measures required to come to grips with the impact of airborne pollutants upon the Great Lakes and their drainage basin. The measures include identification of pollutant sources, their relative contributions, and more accurate definition of pollutant deposition rates.

Since September, the Branch has been supporting the GLWQA Program through two separate research programs. The first involves development of appropriate methodology for monitoring particulate dry deposition over snow, water and ice surfaces. Equipment for generating tagged, monodisperse aerosols is being constructed and tested for application in field studies of uptake by artificial collector. The second project is designed to estimate the atmospheric input of certain nutrients, heavy metals and organic contaminants to the Great Lakes and to examine the relative importance of various sources through a comprehensive simulation modelling effort. As the first step in this research, relevant emission inventories and parameterizations of physical and chemical dispersion processes are being surveyed.

(iv) Criteria and Standards

The Branch provides scientific and technical support to the Federal/Provincial Subcommittee on Air Pollution through its Subcommittees on Air Quality Objectives and on Air Quality Indices. For the Objectives Subcommittee, computer-based data management and display techniques were developed and tested for preparing criteria documents, a criteria digest for $NO_2$ was prepared and studies were started on deriving criteria for pollutant mixtures. A review of the health effects of carbon monoxide was also prepared; no justification could be found to make changes to the present objectives.

For the Indices Subcommittee revisions were completed on guideline documents for short-term and for annual air quality indices.

A Panel on Particulate Matter Effects on Atmospheric Processes was organized to prepare input to the Air Subcommittee of the NRC Associate Committee on Scientific Criteria for Environmental Quality.

(v) Environmental Impact Assessment (EIA)

The Branch contributes to the Departmental EIA program through the review of the air quality aspects of EIA's, and through the development of systems to transfer EIA-related technology to other AES components, other government agencies, and the private sector.

In direct support of other agencies, an EIA of a uranium refinery in Corman Park, Sask., was carried out for EPS and a review of airport pollution models was completed for MOT and ICAO.

Impact assessment research focused on air pollution potential in Canada and on development of numerical models for assessing air quality impact under specific situations. In the former case, joint-frequency distributions of mixing depth parameters were prepared for Canada and these were analysed to delineate regional patterns. The applicability of the mixing depth concept to the Canadian Arctic is being evaluated as well as the stability of mixing depth statistics as a function of record length. Modelling activities included (a) development of a Maritime Episode Model (MEM) and three Climatological Air Models (CLAM) for eventual application to an Atlantic Regional study of air quality in cooperation with the Province of New Brunswick, (b) development of a Gaussian puff model for short-range dispersion studies of instantaneous point sources of radionuclides, (c) development of a mixed-layer model which provides a seasonal or annual cumulative frequency distribution of hourly and 24-hourly average pollutant concentrations based on the joint frequency distribution of daily maximum mixed-layer heights and wind speeds, and (d) intercomparison of the EPA CRSTER and RAM dispersion models. In addition, a routine is being developed to test how the effectiveness of an air quality monitor depends on its location relative to the source being investigated. Also, trajectory analysis is being used to interpret differences in the chemical composition of precipitation, as monitored throughout Ontario in cooperation with Ontario Hydro.

Technology transfer was effected in several ways. Week-long courses on Air Pollution Meteorology were presented both in Ottawa and Toronto and the complete set of accompanying lecture notes was published. About fifty representatives from AES Regional and Downsview Offices attended a four-day Workshop on Air Pollution Meteorology and Environmental Assessment whose proceedings were published. Work continued on developing user manuals and placing short-term air quality models for point and area sources on a time-shared computer for access by users outside the Branch.

(vi) Canadian Arctic Air Pollution Program (CAAPP)

In recent years, widespread particulate pollution in the Arctic originating from emissions in mid-latitude regions of Europe and eastern North America has been observed. Because of the environmental and climatological implications of polluting the polar cap, the governments of Norway, Denmark, the United States and Canada are cooperating in a joint study of suspended particulate matter north of 60°N. The CAAPP is the Canadian component of this joint study and its objectives are to (a) determine the temporal and spatial variations in composition and concentration of trace substances in Canadian Arctic air, (b) determine major pathways of pollutants into and within the Arctic and (c) develop a predictive

capability to assess the impact on Arctic air quality of increased emissions to the atmosphere both inside and outside the Arctic region.

The CAAPP is composed of three major projects. In the first, high-volume particulate samplers at Mould Bay and Igloolik collect weekly samples for subsequent analysis of major ions and heavy metals; integrating nephelometers also measure particulate backscatter which is highly correlated with atmospheric sulphates. In 1980 measurements will also be made at Alert. The second project is a pollutant deposition study in which snow is regularly collected from nine sites in the Canadian Arctic and subsequently analysed for major ions and pH. The third is derivation of a seasonal climatology of air trajectories to determine the dominant pathways of air pollutants into the Arctic.

(vii) Nanticoke Environmental Study

The Nanticoke Environmental Study was a major field study carried out in June, 1978, in cooperation with AES Ontario Region, Ontario Hydro and the Ontario Ministry of the Environment to investigate shoreline effects on air pollutant concentrations in the vicinity of a lakeside thermal generating station. The follow-up work is now virtually complete with 12 project data reports prepared and four scientific papers to be submitted to journals early in the new year. The Study has produced comprehensive and valuable documentation on ground-level pollution enhancement caused by shoreline fumigation.

(viii) Environmental Contaminants

The Branch contributes to the Federal Environmental Contaminants Program established under The Environmental Contaminants Act (1976). Research has been initiated to investigate the behaviour of atmospheric inorganic and organic contaminants interacting with the biosphere. Specific objectives are:

(a) Determination of existing loading and pathways of problem substances in the environment through research and monitoring, including modelling activites:

(b) Interpretation of the significance of problem substances in the environment, through research on their biological effects.

The inorganic contaminants receiving particular attention are a number of metals which upon entry to aquatic and terrestrial ecosystems build up residues which have long-term effects on the environment and human health. The organic contaminants occur in a multitude of forms including the polycyclic hydrocarbons such as polychlorinated biphenyls (PCB's) hexachlorobenzene, and benzo (a) pyrene, many of which are carcinogenic.

One on-going research activity in direct support of this departmental program is aimed at a better understanding of the atmospheric pathways of mercury and its compounds. At present, very little information is available regarding the dispersion, transport, chemical transformation, and removal mechanisms of the thousands of tons of mercury introduced into the atmosphere annually on a global basis by a variety of natural and anthropogenic sources. Moreover, to make meaningful measurements of atmospheric mercury concentrations, particularly of background levels, suitable sampling techniques and highly sensitive and accurate analytical methods must

be developed. Two commercial mercury monitors were tested and evaluated under laboratory conditions to determine their sensitivity, reliability, performance, and operational characteristics. During the summer months they were also assessed under field conditions at two different sites. Deficiencies in the instruments have been identified and are being remedied. Organic compounds in the atmosphere also received attention. A contract was let to Dr. F. Harasek of the University of Waterloo to assist AES staff in developing and testing a vapour phase trapping technique for monitoring organic contaminants in air. When completed AES will have the capability of sampling and measuring very low levels of specific contaminants in the atmosphere (i.e., 1 to 10 $mg/m^3$). Assessment has continued on a gas chromatograph's capability for separating and identifying organic chlorine compounds.

(ix) Spruce Budworm Project

This is a cooperative project with the Maritime Forest Research Centre (MFRC), the Canadian Climate Centre and AES Atlantic Region. Data from 1976 to 1978 were analysed, indicating that sea-breeze fronts were the principal source of non-synoptic mesoscale convergence lines effective for producing line-concentrations of moths. A non-dimensional sea-breeze index was developed that was 85% successful in separating sea-breeze from non-sea breeze days, if days with synoptic fronts or off-water flows were excluded. A prediction equation for maximum inland penetration of sea-breeze fronts was also developed (correlation coefficient: 0.78; standard error: 17.5 km). From 1973 to 1976 the MFRC in New Brunswick about 100 km inland detected concentrated lines of moths on five evenings at sites. Using the criterion that a sea-breeze front that penetrated 80 km or more would result in a line of moths observable by entomological radar, four out of the five events were successfully predicted while the other was over-predicted.

(x) Modelling and Numerical Studies

(a) Developmental work continued on a Monte Carlo model for transport and dispersion of air pollutants. The model was adapted to investigate the long-range drift of forest pesticide spray.

(b) Boundary-Layer Flow in Complex Terrain
A model of the far wake region of flow behind a small hill or other obstacle in the planetary boundary layer was developed and used to study net increases in total drag on the earth's surface caused by isolated topographic features.

(c) Wind Power Studies
Wakes behind wind turbines have been modelled to estimate the reductions in available power caused by wake interactions. Preparatory studies have been undertaken to set up a field experiment, to be conducted as part of the international Energy Agency programme of Research and Development on Wind Energy Conversion Systems (WECS).

(d) Three-dimensional Mesoscale Model of the Planetary Boundary Layer
Improvements have been made to the physics and numerical formulations of the model. Experiments for variable roughness or topography are being conducted with encouraging results.

(e) Boundary-Layer Parameters

(i) The evaluation of boundry-layer parameters based on limited profile data was continued. Application has been extended to analysis of several well-known field experiments.

(ii) To provide a priori information for the Polynya Experiment, a numerical model is being developed to estimate flux parameters over the fetch of an Arctic open lead.

(xi) Field Experiments and Data Analysis

(a) New Tethersonde and the Pinawa project
A prototype for a new tethersonde was completed and successfully tested. The new design allows for up to 10 channels of meteorological data to be sampled at 10 $H_z$ and transmitted at 403 $MH_z$ for on-line recording and analysis. Intercomparisons are being completed on the data recorded during the Pinawa Experiment by the old and new sondes and the tower instruments.

(b) Marine Meteorology

(i) The quality of VLF upper-air wind data processed at 5-mb intervals has been assessed by comparison with the radar wind data.

(ii) The albedos of water surfaces were estimated from hourly values of global reflected solar radiation obtained from Ocean Weather Ship Quadra during GATE. The albedo values were studied as a function of solar elevation angle and sky condition.

(c) Polynya Heat-Budget Experiment
The second year of a three-year Polynya Study was undertaken in cooperation with the Frozen Sea Research Group of Ocean and Aquatic Sciences (Department of Fisheries and Oceans). Preliminary results indicate that temperature decreases rapidly from the surface to 0.5 m within the first 20 to 30 m of open water fetch.

(d) Acoustic Sounder
The highlight of this year's field experiments occurred in Boulder, Colorado, where the Acoustic Sounder was used in WMO-CIMO intercomparisons of low-level sounding systems. Such intercomparisons provide an excellent opportunity to examine all aspects of calibrating a remote-sensing system.

(d) Canadian Climate Centre

(i) Introduction

The Canadian Climate Centre (CCC) is a focus for climate activities in Canada, relating to research, data management, information services, applications, impacts, monitoring and prediction. A Canadian Climate Program is being developed to improve our understanding of climate, and should provide services designed to alleviate any concerns about climatic variation, and to optimize its potential benefits. Other government departments, universities and the private sector

have been encouraged to participate actively in the Climate Program.

During its first full year of existence the CCC has:

- answered 14,000 requests for information from its publications and microfiche, microfilm and digital archives

- established a Data Management Division to modernize and automate the climate input system and make efficient use of the newly reformatted digital archive

- started a weekly bulletin Climatic Perspectives to monitor developing climate situations of socio-economic importance in Canada

- negotiated and supervised outside contracts to define data on wind and solar energy potential, needed by the Candian Energy Program

- supervised advanced stages of the AES/CIDA Flood Forecast Project in Columbia, South America

- developed techniques for mapping snow cover and lake temperatures from satellite data

- demonstrated the advanced state of the AES General Circulation Climate model

- provided numerical, quantitative assessments of the $NO_x$ and fluorocarbon effects on ozone, and of the $CO_2$ - climate relationship

- convened several meetings of the Climate Advisory Committee and planned for the initial meeting of the Climate Planning Board and official opening of the Centre of June 12th, 1979

- organized Worshops on $CO_2$ and Agriculture

- participated in the planning for WMO's World Climate Conference and World Climate Program

(ii) Data Management Division

A revision was made in the METSTAT chart showing the locations of synoptic and hourly observing stations in Canada.

During 1979 the numbers of climatological stations in most categories continued to decrease, however, the number of automatic stations increased: this trend should persist through the 1980's.

The backlogs in the quality assurance and processing of climatological data have been reduced; a start on processing data from the automatic stations has been made.

(iii) Climatological Services Division

Demand for climatological services continued to grow during 1979: data were supplied for more than 14,000 requests for climatological information; and specialized services were provided for more than 300 projects requiring data from the AES digital archive. More that 600 pages of historical data were published in

Number of Climatological Stations in Canada

| | | | |
|---|---|---|---|
| Principal climatological | 312 | Soil temperature | 68 |
| Ordinary climatological | 2250 | Evaporation | 138 |
| Synoptic | 234 | Bright sunshine | 307 |
| Hourly weather (24-h) | 158 | Upper air | 35 |
| Daily extremes of temperature | 2054 | Automatic stations | 39 |
| Daily precipitation | 2459 | Radiation | 53 |
| Rate of rainfall | 496 | | |

regular periodicals during 1979, and close to 350,000 frames of climatic data were placed on microfilm/microfiche during the year.

A document describing CCC plans for the 1951-80 normals and long-term climatological data abstracts was circulated to Canadian users for comment; a systems design for preparing these comprehensive data sets was completed. The quarterly periodical, Daily Soil Temperature Data, is now prepared by photocomposition technique.

Where feasible, conversion data in the National Digital Archive of climatological data were converted to metric units. At the same time, a new format was introduced to make the archive more easily used by such popular program languages as COBOL and FORTRAN. Organization of the archive is chronological by climatological element and station. Report generating programs are being developed to provide quick access to the digital data via computer analyses which display data and statistics. Specially designed programs were also prepared for specific customers on several occasions for processing the digital archive data. Frequent requests for archival copy and analyses are received from government agencies, universities and the private sector. All services are cost recoverable.

(iv) Hydrometeorology Division

The Division had a major role in organizing the WMO Workshop on the application of World Weather Watch to Operational Hydrology.

Activities previously reported under Hydrometeorological and Environmental Impact Research are now within the Hydrometeorology Division. Projects continued on the spatial analysis of meteorological parameters, particularly temperature and precipitation; the influence of land cover on snow cover characteristics; and snowfall-snowpack measurements. The latter includes: measurement of snowfall in low precipitation regions (Prairies, Arctic); significance of trace amounts; water equivalent of fresh snowfall at climate stations; development of Nipher-type shields for recording gauges; and metrication and standardization of snow samplers. An experiment on the use of active microwave imagery for assessing snow cover conditions was carried out. Results from the Nanticoke Environmental Study - Surface Fluxes Program - were analysed in detail. A study of lake evaporation of Lake Okanagan has been started which involves measurement of actual lake evaporation using several micrometeorological techniques to calibrate a mass-transfer equation.

There was much activity on the frequency analysis of precipitation. Development of procedures to map short duration (5 min - 24 h) rainfall statistics for Canada are well underway, a program to calculate long duration (1 - 10 days) rainfall frequency statistics from standard archive data was completed; and return-period analysis of areal precipitation (100 to 10,000 mi) was carried out for several Canadian regions using "Storm Rainfall in Canada" as a data base. A computerized orographic model based on one recommended by WMO was completed for determining probable maximum precipitation. Five SCEPTRE radars are recording quantitative data on magnetic tape; many tapes were analysed for storm precipitation accumulation and for seasonal precipitation accumulation occurring during the 1978 drought in southern Ontario. Development work continued on analysis of snow cover using satellite data.

Further development work continued on: a program to process and map weekly national water-budget components in near real-time; a technique to estimate temperature trends and precipitation occurrence over longer time scales, for the purpose of providing meteorological input to hydrologic models. Two studies were completed on: estimations of lake evaporation in northern latitudes; and estimating the breakup date of river ice in the Saint John Basin.

Climatological studies of East Coast locations were made for the Ship Safety Branch of the Canadian Coast Guard in support of their evaluation of terminals for the transport of liquified natural gas from Melville Island in the Canadian Arctic. The effectiveness of meteorological drifting buoys deployed on Hudson Bay, and other types of meteorological buoys moored in Lake Ontario was studied. The utility and accuracy of wave heights obtained from SEASAT A radar altimeter data was examined as a part of the SURSAT program. Computer programs to extract and display satellite infrared water-surface temperatures were being modified to use NOAA-6 and TIROS-N data. Although the programs were developed for the Great Lakes, analyses have been performed for Lake Winnipeg, the Bay of Fundy and Hudson Bay near Churchill.

(v) Applications and Impacts Division

Arctic Section concentrated on offshore weather conditions relevant to oil and gas exploration and shipping. Northwestern Baffin Bay and Lancaster Sound were given particular attention, the former to determine effects on proposed drilling, the latter to determine the best uses for the area. Wind and temperature throughout Arctic waterways were being assessed as factors affecting the strength of ship hulls.

Work on solar and wind energy required further extension of a data base to include both radiation and meteorological parameters. This data base is tailored to supply information needed for designing solar collectors. Studies included evaluation of satellite data as a means of estimating solar radiation received at the earth's surface, preparation of a reference book on solar radiation models, collection of data on the low-level wind and temperature structure of the atmosphere, and of normalization of wind data to an anemometer height of 10 m.

In physical climatology, studies were completed on the recreational bioclimate of Nahanni National Park, the National Capital Region, and on climatonomic relations in the Toronto area. Literature was reviewed to discover better ways of integrating

climatological data into biophysical land assessments. One application was for a proposed resource inventory in the Yukon Territory. An impacts program, beginning with an assessment of drought in the Prairies and in Canada was initiated. A project was also started to produce a series of concise climatologies of Canadian cities for broad public use.

Climatological applications to agriculture and forestry included production of a Handbook on Agricultural and Forest Meteorology with work completed on a second volume and just begun on a third. A climatological study of blocking situations in the Northern Hemisphere during 1945-1977 was submitted for publication and is undergoing revision. Work continued on determination of soil characteristics from samples taken near the AES soil-temperature observing sites so that the National Soil Temperature Archive may have wider application and be interpreted better.

Biometeorological studies included; cooperative work with the Maritimes Forest Research Centre on the wind flow patterns which determine spruce budworm moth dispersal in New Brunswick; assessment of meteorological factors associated with severe damage to white bean crops in southern Ontario; and evapotranspiration measurements with a lysimeter near Toronto.

(vi) Monitoring and Prediction Division

The predictability of monthly and seasonal temperature anomalies in the atmosphere is being investigated through analysis of time-lagged correlations of atmospheric circulation parameters. Two approaches are being used: (1) modelling of time series with autoregressive integrated moving average (ARIMA) models, and (2) modelling of the dominant components of the large-scale circulation with multivariate regression models.

Time-series model identification and forecasting based on the Box-Jenkins ARIMA procedures has been applied to the monthly mean anomalies of the 500-1000 mb thickness over the Northern Hemisphere, to spherical harmonic coefficients of the thickness, and to surface temperatures for Canadian stations. The results are presented in the form of analyses of the reduction of residual variance arising from series fitting and the significant lags in the autocorrelation function. Forecasts of the 500-1000 mb monthly mean thickness anomalies are being produced on an experimental basis.

Multivariate regressions are being developed with canonical correlation analysis applied to the dominant components of the 500 mb geopotential fields. The components consist of functions which are Fourier decompositions in the east-west direction and empirical orthogonal functions in the north-south direction.

(vii) Numerical Modelling Division

The AES spectral atmospheric general circulation model (GCM) has been extensively improved, and can be used with more than the previous five vertical levels and with either rhomboidal or triangular truncation in the horizontal. The surface energy balance, boundary terms, and radiation processes have been improved considerably. The model will be "frozen" in this form to permit impact studies and sensitivity experiments to be performed. A doctoral student from the University of Toronto is studying interactive cloud parameterization using the GCM.

A two-level GCM is also being developed. This simpler model requires less computer time than the multi-level model and as a result, longer term integrations are possible. A January simulation has been made and is being analysed. Simulations over several annual cycles are planned.

Modelling experiments continued with the two-dimensional radiative-photochemical dynamical model of the stratosphere to determine the possible impact of fluorocarbons, increased atmospheric carbon dioxide, and solar ultra-violet flux variations associated with the eleven-year solar cycle on stratospheric ozone distribution, temperature and zonal wind structure. Radiative-convective-photo-chemical time-dependent models of the atmosphere (from the surface to 60 km) were developed and allow self-consistent calculation of the odd oxygen, hydrogen, and nitrogen families and temperature structure. These models are designed for application to the anthropogenic climate change problem.

The AES general circulation diagnostic package is nearing its final form. It has been designed for maximum generality and utility. Besides basic general circulation statistics, it can produce the zonal and time averaged budgets of mass, angular momentum, heat, moisture, kinetic energy, and available potential energy. A three-dimensional time averaged budget capability will be added. Most of the above diagnostics and the routines for enstrophy are available in terms of zonal wave number and spherical harmonics.

The diagnostic package has been applied to the output of the GCMs extensively and to the objective analysis from the Canadian Meteorological Centre as well as to the level III-a data from the Global Weather Experiment. Extensive diagnostic studies of the level III-b data are planned. Other applications include studies on the energy budgets of standing and transient waves, and in the wavenumber domain, studies on energy time behaviour, baroclinicity, and energy/enstrophy fluxes and dissipation.

(e) Central Services Directorate

Ice Branch

Regular data acquisition and ice forecasting services continued at normal annual levels in support of marine activities in Canada's ice-covered waters; highlights involved acquisition of a mini-computer for forecasting applications and participation in special projects such as SURSAT and the Winter Ice Experiment in the Beaufort Sea (WIEBS). Aerial reconnaissance activities remained the same at approximately 2600 hours of chartered aircraft flying; Side Looking Airborne Radar in one aircraft provided an invaluable capability for all-weather and wintertime Arctic reconnaissance. Satellite data increased with the addition of the TIROS-N satellite to the NOAA series, and with the expansion of data received from Prince Albert from a seasonal to an annual basis. The new mini-computer in the forecasting centre permits gradual introduction of digital forecasting techniques and ice modelling, ultimately leading to better and more timely forecasts. During the fall an experiment was undertaken to test Gulf of St. Lawrence freeze-up models, using air-droppable thermographs as an oceanographic data source rather than a more costly ship cruise. If the model proves adequate, annual cruises in the Gulf will be cancelled. Climatological activities continued to concentrate on analysis of laser profiler data for ice topographical statistics, publication of ice atlases and consulation to the marine industry.

(f) Field Services Directorate

The field Services Directorate is the operational arm of the Atmospheric Environment Service responsible for routine operation of the Canadian weather forecasting system. Accordingly, its resources are primarily directed to:

(a) operation of an extensive network of stations dedicated to observing surface and upper-air meteorological conditions,
(b) operation of several offices dedicated to analysing and forecasting meteorological data,
(c) operation of a network of offices for serving the public through the provision of meteorological information and services, and
(d) supervision of the communication system required to link all components in this widespread network.

Field Services Directorate is supported directly and indirectly by the research activities of various other AES units. Studies, carried out within the Directorate, which aim at improving operations and products might more properly be termed development. A few examples are: devising statistical and dynamical methods of predicting weather elements from the more abstract fields of standard numerical weather prediction: developing a computer-facsimile interface and enhancement curves for VISSR photographs suitable for regional needs; and preparing various Environmental Impact Statements.

26. Canadian Forestry Service

(a) Maritimes Forest Research Centre

A cooperative study of the dispersion of spruce budworm moths by the MFRC, the Atmospheric Environment Service and the University of New Brunswick has been ongoing since 1973. Coordinated use of radar, specially-instrumented aircraft and observations from platforms extending above the forest canopy has established the massive scale and regularity of evening take-off flights in July and subsequent nocturnal dispersion at altitudes of several hundred metres. A model is being constructed to predict the occurrence and behaviour of sea-breeze fronts and their effect on moth dispersion.

(b) Northern Forest Research Centre

The NFRC has had a research program in the area of forest climatology for many years. Recent and current research programs can be summarized as follows.

(i) Climatic Zonation for the Forested Areas of the Prairie Provinces

Daily temperature and precipitation data for May to September for the years 1961-1970 from over 300 stations were used with location factors to develop a matrix of 22 independent variables as input for factor analysis. A hierarchical profile grouping procedure was applied to the factor scores to delineate stations having similar summer climatic regimes. Discriminant analysis was used to test the significance of the groups, to establish the degree of stability within and between groups, and to position the boundaries between groups.

(ii) Climate of Clear-cut Forested Areas in the Hinton Area

Seven summers and one winter of climatological data were collected within a radius of about 50 km of Hinton. Each summer

40-50 locations were sampled (in all about 115 sites), mainly on clear-cut areas, although a few stations were operated within forest stands. All stations were equipped to measure temperature, humidity, and precipitation; a sample of these, to measure wind, radiation, evaporation, soil temperature, and soil moisture. Data from the 7 years have been extracted, and summaries of the different parameters have been produced for many of the years.

(iii) Effect of Microclimate of Clear-cut Areas on Pine and Spruce Seedling Growth

Air and soil temperature data were collected from transects on four areas for 3 years. Extraction and analysis of some of the microclimate data is complete.

(iv) Climatic Fluctuations and Forest Biomass Productivity

A new study is being initiated to use the period of climatological records from the boreal forest zone and proxy data to establish the history of climatic variations and relate this to forest biomass productivity.

(v) Biogeoclimatic Ecosystem Classification of the Province of Alberta

Microclimatic data along with vegetational and soil characteristics were used to provisionally ascertain biogeoclimatic zones. Additional derived climatic parameters, involving summer-only data are now being employed via statistical analysis to characterize each zone by its most significant climatic parameters.

(vi) Fire Behaviour and Management Systems

Data from climatic stations are being used in developing tables of fire spread and intensity for important classes of fuel in four forest types near Slave Lake. A climate station was also operated in Jasper National Park in conjunction with a prescribed fire study. Work also continues on improving the fire weather index.

(vii) Vegetation Manipulation - Hydrogeologic Modelling

A new watershed model is being developed, using an existing model (PROSPER) and a new snowmelt model, to simulate generated runoff. Data input requirements include daily values of solar radiation, temperature, relative humidity and precipitation.

(viii) Small Forest Opening and Snow Accumulation and Evaporation Study

Base-line data on temperature, humidity, wind and snow have been gathered for the James River study of varying size forest openings.

(c) Pacific Forest Research Centre

At the PFRC work continues on adapting numerical wind models to forestry problems such as budworm dispersal and smoke management. Field experiments are carried out to provide some of the data base for the modelling studies. Investigations are also being made on climate series and topographic variations in climate in relation to pest populations and forest fire problems. A modest amount of instrument development is carried out so as to be cognizant of current technology and to be capable of recommending meteorological instrumentation which can suit forestry needs.

(d) Petawawa National Forestry Institute

The past year has been one of moving and reorganizing. The program at PNFI includes wrapping up programs that were underway in Ottawa and starting new research. The major thrust over the next few years will be on modelling winds over rough forested terrain and testing the wind model using field observations.

(i) Blowdown

Interaction between a tornado and the rough terrain north of Ottawa has been inferred from the pattern of damage to trees. The terrain was shown to have had a marked effect on the intensity and motion of the Masson tornado.

(ii) Remote Weather Station for Use in Forestry

A remote weather station communicating with the GOES satellite via a Labarge DCP was established at Casselman, Ont. in cooperation with personnel of the Inland Waters Directorate of the Department of the Environment. A second station using a Bristol DCP is planned for the spring of 1980. The Hermes Electronics Ltd. station is still under construction but not completed.

(iii) Forest Wind

The major meteorological goal during the next five years will be prediction of wind over rough forested terrain. The first phase of the study will be a comparison of the wind estimated from synoptic weather maps with the wind derived by objective analysis from observations at surrounding stations. Subsequent phases will include the following:

- Modelling the wind for terrain and roughness;
- Modelling separated flow phenomena;
- Modelling trunk space winds;
- Modelling fire generated winds;
- Modelling fire whirls and fire runs.

Anemometers on nine 32-m masts will be used to test validity of the model.

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# VI OCEANOGRAPHY

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1. Memorial University
2. Dalhousie University
3. Bedford Institute of Oceanography
4. Université du Québec à Rimouski
5. INRS-Océanologie
6. Pêches et Océans, Région du Québec
7. GIROQ
8. McGill University
9. Ocean and Aquatic Sciences, Central Region
10. National Water Research Institute
11. Fisheries and Oceans, Ottawa
12. University of British Columbia
13. Royal Roads Military College
14. Institute of Ocean Sciences, Sidney, B.C.
15. Bibliography

## 1. Memorial University

### (a) Centre for Cold Ocean Resources Engineering

Ice continued to be the major focus of research at the Centre for Cold Ocean Resources Engineering, with concentration on the properties, detection and behaviour of sea ice and icebergs, and the implications for offshore development. Using the Arctic and East Coast oceans as its primary laboratories, C-CORE has recently been:

- using time lapse radar to study the movement patterns of sea ice around offshore structures, and the interactions between structure and ice, particularly pressure ridges, and also investigating measurement systems and test structures;
- investigating the bearing capacity of sea ice to failure;
- continuing development of an ice strain measuring system;
- developing an operational impulse radar system and associated interpretation techniques to characterize and estimate the thickness and strength of sea ice from airborne platforms;
- studying the interaction of oil and ice in an actual spill situation;
- investigating rates and processes of iceberg scouring on the Labrador shelf seabed;
- developing numerical modeling techniques for the prediction of sea ice and iceberg movement for site-specific applications.

### (b) Department of Physics

The Department of Physics initiated in 1979 a program of study leading to an M.Sc. in Physical Oceanography. Memorial has recently established the Newfoundland Institute of Cold Ocean Science in the Faculty of Science. The purpose of the Institute is to provide for the coordination and promotion of scientific knowledge and other studies related to the development and exploitation of the cold oceans of importance to Newfoundland and Labrador. Research is concentrated in the following areas:

- Elastic properties of natural ice (Kiefte, Clouter, Denner and Gamon).
- Ice dynamics in the Labrador Current, modelling and experimental (Denner).
- Modelling of the ocean dynamics of the Labrador Current and of the Grand Banks (Helbig).
- Acoustical noise generation by ice/wave interaction (Denner).

- The physical limnology and dynamics of large lakes in Newfoundland (Denner, Weir, Wright).

2. Dalhousie University: Department of Oceanography

(a) Chemical Oceanography

Three major lines of research were followed in the past year. R. Cooke and B. Johnson have studied reactions resulting from the formation of particulate matter by the contraction of bubbles under pressure and the variables involved in the size distribution of bubbles. R. Cooke, P. Kepkay, D. Plasse, and M. Lowings have studied the interaction of sea water with sediments, and the effects of organic matter on these reactions. The effects of microbial activity on near-shore sediments and the kinetics of the carbonate system have been areas of particular interest.

R. Moore, R. Gershey and others have completed the construction and testing of a photo-oxidative dissolved organic carbon analyzer. This apparatus should be sturdy enough to be used at sea, and should become a standard technique for such analyses. Moore is also continuing his interest in the distribution of trace metals, particularly the transition elements, in sea water. In this area of research, he is working with P. Stoffyn on early diagenesis of clay minerals in porewaters. R. Moore also took part in the LOREX expedition to the Arctic where he and M. Lowings investigated nutrient and radioactive Cs and Sr distributions in the water column under the ice.

P. Wangersky spent the academic year on sabbatical, during which he worked on the development of the Turbidostat, an apparatus for the cultivation of phytoplankton at constant population density. With this apparatus, he could maintain diatom cultures in log phase for periods up to four months. He also developed a Monte Carlo model for the growth of phytoplankton communities in a regime where nutrients arrived randomly in time and space. In such a regime, phytoplankton patchiness is the rule rather than the exception, and physical mechanisms must be involved to explain any homogeneities.

M. Gagnon is nearing the completion of his Ph.D. thesis project on the distribution of surface-active materials in estuaries; U. Lobsiger is investigating the variables involved in carbon isotope discrimination in phytoplankton; J. Painchaud has finished the experimental work on an M. Sc. thesis on the effects of particulate matter on microbial regeneration of nutrients; B. Gershey has completed and tested his apparatus for the concentration and collection of surface-active materials from the upper layers of the water column; and B. Whitehouse is initiating a thesis project on the early diagenesis of petroleum hydrocarbons in the sediment.

(b) Physical Oceanography

C. Garrett and B. Toulany completed their development of a variable depth Green's function which was then convolved with shelf-edge currents from Greenberg's numerical model of the Gulf of Maine/Bay of Fundy system. The results explain the substantial variations in the phase of $M_2$ observed along the edge of the continental shelf and have implications for the sampling strategy in other locations.

J. Loder has found that a large part of the anticyclonic gyre around Georges Bank is due to tidal rectification. A fully non-linear semi-analytical theory predicts near-Eulerian currents about twice as big as the mean Lagrangian current.

K. Drinkwater completed a program of field measuresments in St. Georges Bay with a number of current meter and thermistor chain moorings. Work is underway on a 2-layer baroclinic model to investigate the observed gyre in the bay and the apparent surface inflows which leads to a deep warm surface mixed layer.

Flow through the Strait of Belle Isle is under investigation. C. Garrett and B. Petrie (BIO) have re-examined current meter and sea level data obtained by BIO in 1963, and find that cross-strait geostrophy holds well. This opens up the possibility of monitoring surface flow through the strait using tide guages. In fact permanent tide guages have been installed on opposite sides of the Strait since 1969, so that the variability of the flow can be described. A strong winter inflow is evident. Garrett and Toulany are investigating the driving mechanisms. They find that large scale meteorological forcing dominated down to frequencies of about 1/2 cycle/month, but other factors must be important at still lower frequencies.

D. Huntley collaborated with members of the Geology Department at the University of South Carolina in a study of the role of waves and currents in a typical large ebb-dominated tidal inlet. The observations suggest relatively little wave driving of mean flows near the inlet mouth, but there are indications that this might become important for particular wave incident directions. Huntley also collaborated with scientists at the Shore Processes Laboratory, Scripps Institution of Oceanography, La Jolla, California, in a study of nearshore long period wavemotion, using data from a multisensor array placed offshore from Torrey Pines Beach, California. Analysis of current records clearly shows the presence of long period low mode edge waves, both standing and progressive alongshore, but significant energy at long periods is also non-resonantly forced by incident wave groups.

Measurements of waves and currents over a nearshore sand bar system in the Gulf of St. Lawrence have shown the vital part that long-period (T=30s) wave motion plays during storm conditions. Drift velocities associated with the long period waves have magnitudes similar to velocities of the incident wave driven longshore currents and are probably responsible for maintaining the bar system.

T. Bowen is studying waves on beaches which involves infragravity waves, waves and cusps, and beach equilibrium. R. Holman completed his Ph.D. thesis looking at the infragravity observations and their theoretical background in terms of forcing by the incident waves. The waves and cusps work has been extended in collaboration with B. Guza to show that as beach cusps grow they perturb the dispersion relation of the edge wave that produces them. The development of idealised equilibrium models based on Bagnold's ideas lead to some rather better predictions than those of the nullpoint models. These ideas are being extended by using the observed currents on a beach as input to the model.

T. Bowen is also studying the dynamics of the body of a turbidity current. M. Stacey is investigating the development of a turbidity current for his Ph.D. thesis research. At present, he is focusing his interest on the time development of a uniform (downslope) current. The problem of the effect of the suspension on the dynamics in terms of the Richardson Number is also being investigated.

## 3. Bedford Institute of Oceanography, Dartmouth, N.S.

### (a) Ocean Circulation

Mooring experiments at 50°W and 40°W are part of a continuing program to map the mean and quasi-geostrophic eddy velocity fields in the

North Atlantic. This program was begun in conjunction with the USA-USSR Polymode program and continues in close co-operation with Woods Hole Oceanographic Institution. The completed 50°W moorings provide the first long-term set of measurements from a coherent array at the mean position of the Gulf Stream Axis. The new array will provide long-term measurements further to the east in the Gulf Stream decay region.

The Hamilton Bank array is a continuation of the Labrador Sea program of 1976-1978 and is designed to provide estimates of possible seaward and year to year variations of the flow in the Labrador Current. This program is plagued with high mooring losses. Earlier losses were ascribed to iceberg scouring. This years losses may have been due to corrosion or perhaps fishing effort.

The Flemish Cap experiment was designed to determine the factors determining year-class variations of the Flemish Cap cod stocks. The physical oceanographic component was designed to test a hypothesis that local circulation on Flemish Cap tends to hold the eggs and larvae on the Cap and that this circulation is stronger or weaker from year to year. Surface drifters placed on the Cap at various times this year have all left it within several weeks indicating that such a circulation, if it exists at all, is weak. These drifters are currently being tracked across the Atlantic and are presently nearing the European coast.

This year, small-scale field programs were carried out to determine the heat and humidity flux from an Arctic polynia in winter, and also to determine the small-scale structure in the upper ocean and its variation in response to changing weather conditions. Analysis work continues on earlier studies of similar experiments designed to study oceanic microstructure and its variation in time and also earlier studies on $CO_2$ transfer between ocean and atmosphere. The ocean microstructure group carried out the first deployment of a new and smaller instrument to measure small-scale temperature, salinity and velocity gradients.

This year the theoretical studies group carried out a project to study the problem of how to set up the open ocean boundary condition for estuary models. Further work was done on three-dimensional tidal current models and also models to predict the response of coastal water levels to atmospheric forcing. Properties of various instabilities of the flowing rotating annulus were investigated both analytically and numerically and work on the large-scale numerical model of the Labrador Sea and Baffin Bay system continued.

(b) Coastal Oceanography

A study of the northwestern Gulf of St. Lawrence started in 1978 has continued with the aim of investigating the relationship between fresh water input into that area and the dynamics of water movement. A sharp density front has been found across the channel about 50 km east of Pointe des Monts which is continued to the Gaspe coast along the outer edge of the Gaspe current. There is evidence of an area of upwelling beneath the frontal zone and an implication that river discharge by causing the front and the upwelling may have a strong influence on biological productivity. Field observation of the deeper motion in the Laurentian channel is continuing; five current meters have been installed for one year and we plan to continue the installation for another year.

Analysis of the Shelf Break dynamics experiment is complete. It has revealed several interesting seasonal and low frequency features of shelf break circulation. An 18 month study of circulation of the southwestern Scotian shelf in the vicinity of Cape Sable has commenced. We hope to investigate seasonal current flow, to assess the role of low frequency circulation and tidal mixing and to investigate centrifugal upwelling.

We are attempting to provide a time series of bottom temperature variation on the Newfoundland - Labrador shelf. Two bottom pressure and temperature gauges have been installed in the Avalon Channel and on Nain Bank. We hope to use the pressure data complemented by hydrographic (CTD) surveys to estimate alongshore geostrophic transport. Analysis of the Baffin Bay Labrador Shelf water mass is continuing using historical data on surface salinity and temperature, ice formation and fresh water run-off. Seasonal variations in fresh water input appear to cause significant changes in salinity distribution and thus the seasonal mass field.

Work on wave climate studies is continuing, and a coastal wave climate study for the nearshore regions and marginal seas of the Canadian Atlantic seaboard is being implemented. Annual significant wave heights have been determined for the Gulf of St. Lawrence, Bay of Fundy, Scotian Shelf, Newfoundland Shelf and Labrador. We hope to extend this coastal wave climate study to a three year wave climate.

We have studied the behaviour of suspended particulate matter from several different regions including St. John Estuary and Belle Isle Strait. Floculation experiments are also underway in the laboratory. The numerical model of the Bay of Fundy - Gulf of Maine is being used to study suspended sediment transport in Minas Basin and will be used to study sedimentation in Chignecto Bay and bottom sediment movement.

(c) Ocean Technology

Equipment is being acquired and assembled into systems for the measurement of physical (conductivity, temperature, dissolved oxygen, etc.) and biological (chlorophyll, zooplankton, light attenuance, etc.) parameters in the ocean. Attention is being given to the dynamics of CTD cables and instrument packages and shipboard handling systems for this equipment. Studies of corrosion problems and motion of current meter moorings are underway.

The Division is concerned with bottom sampling techniques including modifications and improvements to an electrically-powered hard rock coring drill to extend its ability to sample a wider range of rock types and its depth of operation, and provision of an acoustic positioning system aboard ship to improve site selection and relocation capabilities. Work is continuing in collaboration with the Canadian Hydrographic Service to produce an integrated navigation system for Institute ships based upon Loran-C and satellite navigation equipment. Data from the GEOS-3 satellite is being analyzed to determine geoid shape in eastern Canada and data from the Lomonosov Ridge Experiment is being analyzed. This experience will lead to implementation of improved high Arctic navigation methods at sea. Research is also underway on acoustic positioning methods in the solution of oceanographic and geological problems such as measurement of vertical current profiles.

(d) Chemical Oceanography

Studies of the behaviour and fluxes of metals in estuaries of the St. Lawrence Basin have continued with increased emphasis upon conditions during seasons of low river flow. Particular attention has been paid to the remobilization of manganese from nearshore sediments and its importance in the supply of manganese to the deep ocean. Studies of the recent geochronology of Saguenay Fjord sediments have revealed close relationships between the distributions of Pb-210, Cs-137 and the history of both storm events and anthropogenic mercury injections to the fjord. The fate of particulate organic material of terrigenous origin, discharged to coastal waters, has also been studied using stable isotope ratio and carbon/nitrogen analysis techniques. An international

intercalibration experiment for trace metals in seawater was conducted for the International Council for the Exploration of the Sea (ICES).

Research related to marine pollution questions has been largely concentrated in the eastern Canadian Arctic. Surveys of the incidence of petroleum hydrocarbons in sediments and water in the vicinity of oil seeps have been used as a method of determining the location and intensities of such natural hydrocarbon releases. Gas chromatography/mass spectrometry analyses of organic material in sediments in these areas show the presence of components of crude petroleum, biogenic hydrocarbons and possibly the products of high temperature combustion that have been widely disseminated through long distance atmospheric transport. Considerable effort was also devoted to surveys of the distribution of petroleum hydrocarbons on the Scotian Shelf following the accidental release of oil from the tanker KURDISTAN.

Studies of the marine geochemistry of a variety of substances have continued with the eastern Canadian Arctic and Baffin Bay receiving the greatest attention. Profiles of O-18/O-16 ratio and salinity in the waters of Baffin Bay and Lancaster, Jones and Smith Sounds have been used to define the extent of sea-ice meltwater penetration and to estimate the annual turnover of sea-ice. Helium isotope and tritium distributions, measured as part of a collaborative program with McMaster University, indicate that ice-cover restricts surface water mixing and significantly reduces air/sea exchanges in northern waters. Preliminary nutrient, tritium and helium isotope data from central Baffin Bay show that bottom water, which contains both excess silicate and helium-4, has a fairly long ($\gtrsim$100 yr) residence time. A budget for trace metals in Baffin Bay has been constructed and will be subsequently refined for dealing with the fluxes of other chemical constituents. Marine chemical research in other areas includes investigations of the vertical transport and mixing of radionuclides in sediments underlying the western boundary undercurrent on the Newfoundland Slope and the study of vertical transport processes of metals in deep ocean waters.

Increasing interest is being devoted to the exchange of chemicals at the freshwater and atmospheric ocean boundaries. A two-year survey of metal discharges in dissolved and suspended form from the St. Lawrence River has been completed and the results examined in the context of metal fluxes in global river runoff. A further field experiment for the measurement of carbon dioxide gas exchange across the air/sea interface has been conducted using the eddy-correlation technique.

Baseline measurements of radionuclides and their stable analogues have been made in the water and sediments of the Bay of Fundy. Reviews of the physical oceanography and marine biology in the area have been conducted in order to identify radionuclide transport mechanisms and potential sites of radionuclide accumulation that require to be considered in future surveillance monitoring.

4. Université du Québec à Rimouski: Département d'océanographie

On distingue deux grands programmes de recherches:

(a) Ce programme comprend des études à long terme de la circulation de l'estuaire maritime du Saint-Laurent (M. El-Sabh et T.S. Murty) qui se sont plus récemment portées sur un examen théorique des courants transversaux à la radiale de Rimouski et sur un échantillonnage de cinq stations océanographiques occupées près de Matane et de Ste-Luce. Une étude en modèle numérique des mouvements des eaux induits par les vents et la marée dans le bas estuaire du Saint-Laurent (M. El-Sabh, L. Levesque et T. Murty) a donné des résultats qui correspondent bien qualitativement avec les observations. Une étude du courant de Gaspé (J.

Benoit et M. El-Sabh), basée sur des mesures de courant au large de Matane, est en cours, menée en coopération avec C.L. Tang, de l'Institut Bedford. Un travail sur la variabilité des données océanographiques (Y. Gratton) a porté sur l'étude du phénomène de Hurst en océanographie. Un modèle bi-dimensionel pour simuler le mouvement et la dispersion d'une nappe d'huile (F. Aubin, T.S. Murty et M. El-Sabh) a été calibré avec des déversements expérimentaux effectués au large de l'Ile-Verte.

(b) Ce programme de recherche inclut messieurs J. Lebel, N. Silverberg, B. Sundby et leurs étudiants et vise à comprendre et quantifier les processus géochimiques et les flux à travers les interfaces eau-sédiment et eau douce-eau de mer. Parmi les études en cours, nous citons: le comportement global du manganèse et du fer dans le système du Saint-Laurent; des mesures des flux des substances dissoutes et solides à travers l'interface eau-sédiment, incluant des mesures des vitesses de sédimentation; l'influence des organismes benthiques sur la géochimie du sédiment; la géochimie du bore, du soufre et des métaux de transition; des relations entre l'alcalinité, le pH et la salinité incluant l'usage de l'alcalinité comme indicateur de mélange; des facteurs contrôlants responsables de la composition chimique de la matière en suspension dans la zone de turbidité de l'Estuaire; et des réactions chimiques dans l'intervalle 0 - 1°/oo salinité.

5. Institut National de la Recherche Scientifique: Océanologie, Rimouski

Le programme de recherche en sédimentologie littorale est présentement moins développé mais connaîtra une expansion considérable l'an prochain. Au niveau de la recherche fondamentale deux projets étaient en cours en 1978-79; l'un portait sur la sédimentation dans le port de Gros-Cacouna et l'autre sur la dynamique des sédiments littoraux dans la région de Trois-Pistoles. La recherche commanditée en 1978-79 a été centrée sur le projet de développement d'un port de mer à Cap-du-Dauphin, pour le transport du sel éventuellement miné aux Iles-de-la-Madeleine. Les travaux ont porté sur l'étude du transport littoral des sédiments, le mouvement des courants de surface et la mesure de la houle dans la région de Cap-du-Dauphin et de la Pointe-de-l'Est.

Sur le plan technologique un déclencheur électronique pour prendre plusieurs échantillons à des profondeurs prédéterminées a été complété au cours de l'année. Ce nouvel appareil océanographique fera l'objet d'une demande de brevet.

6. Pêches et Océans: Région du Québec, Québec

Les travaux de ce laboratoire sont orientés surtout vers les pêches et la biologie marine. Il s'y poursuit également un programme de chimie marine, sous la direction de J. Piuze. Ce programme met l'accent sur des problèmes de pollution marine et comprend une étude d'échanges de polluants (surtout de métaux traces) entre l'estuaire et le Golfe du Saint-Laurent, étude menée en collaboration avec des chercheurs de l'INRS Océanologie (V. Koutitonsky, D. Cossa). Un bilan de la situation du mercure dans les écosystèmes du Saguenay, ainsi qu'un projet d'utilisation de la moule bleue comme indicateur de pollution sont aussi en cours, en collaboration avec l'INRS Océanologie. Une étude générale à long terme des métaux traces dans l'estuaire et le golfe du Saint-Laurent s'est déjà penchée sur la distribution du mercure et projète l'étude de celle de l'arsenic et du sélénium. En collaboration avec C.S. Wong (IOS, Pat Bay) et K. Kremling (Meereskunde, Kiel, RFA) J. Piuze a aussi étudié les effets catalytiques posibles du cadmium et du cuivre sur l'oxydation du manganèse dans des structures fermées telles qu'utilisées par CEPEX.

Des échantillonages de température, salinité, sels nutritifs et chlorophylle ont été répétés mensuellement depuis un an à un réseau de 30 stations dans l'estuaire maritime du Saint-Laurent, sous la direction de J.C. Therriault, qui a aussi participé aux études de circulation entre le Saguenay

et le Saint-Laurent en collaboration avec R.G. Ingram (McGill) et G. Seibert (BIO). Des études plus intensives de la variabilité spatiale de la production primaire et secondaire et des facteurs physiques et chimiques qui pourraient les influencer sont aussi en cours à un réseau plus serré de stations près de la Pointe au Père.

7. GIROQ - Groupe Interuniversitaire de Recherches Océanographiques du Québec

Le GIROQ regroupe des chercheurs des universités Laval, McGill et de Montréal. En 1979, les activités du GIROQ en sciences physiques se sont déroulées dans le cadre des études menées dans l'estuaire du Saint-Laurent et dans les baies de James et d'Hudson.

Estuaire du Saint-Laurent

- Analyse de la variabilité à long terme des caractéristiques des masses d'eau et de la circulation dans l'Estuaire maritime, principalement à la tête du chenal Laurentien, à proximité de l'embouchure du Saguenay. (R.G. Ingram, McGill)
- Etude des échanges quantitatifs entre l'Estuaire et le Saguenay. (Pêches et Océans Canada en collaboration avec R.G. Ingram, McGill)
- Etude de la variabilité de la circulation hydrodynamique dans l'Estuaire moyen supérieur. (Y. Ouellet et C. Trump, Laval)
- Détermination de la circulation résiduelle à différentes profondeurs dans l'Estuaire moyen inférieur, en relation avec le transport des larves de poissons. (C. Anderson et R.G. Ingram, McGill)
- Développement d'un système de mesures pour l'étude de la couche suprabenthique dans l'estuaire du Saint-Laurent. (B. d'Anglejan et R.G. Ingram, McGill)
- Etude des mécanismes de transport de sédiments dans la couche suprabenthique dans l'Estuaire moyen. (J.-P. Savard et B. d'Anglejan, McGill)
- Etude des interactions entre le polychète Pista maculata et son substrat sédimentaire dans l'Estuaire moyen. (J. Daignault et B. d'Anglejan, McGill)

Baie de James

- Etude des caractéristiques des masses d'eau et de la circulation dans l'estuaire de la rivière Eastmain et à son embouchure dans la baie de James et effets de la réduction des débits d'eau douce. (R.G. Ingram, McGill)
- Etude du régime sédimentaire de l'estuaire de la baie de Rupert. (B. d'Anglejan, McGill)

Baie d'Hudson

- Etude de la circulation et des caractéristiques des masses d'eau du détroit de Manitounuk et des embouchures de la Grande rivière de la Baleine et de la Baleine (Sud-est de la baie d'Hudson). (R.G. Ingram, McGill)

8. McGill University: Marine Sciences Centre

(a) Physical oceanography

The Ice Research Project group participated in a two-month interdisciplinary project on drifting ice near the geographic north pole in spring 1979 (LOREX). Emphasis was placed on continuous STD and current meter profiling at frequent intervals over the observation period. Satellite positioning was used to determine the station movement. Analysis of these data is presently underway (Pounder, Peltola and Stalinski).

Following the long term current meter mooring program in the maritime part of the estuary (Tadoussac to Manicouagan) in 1978 and the following winter, emphasis was shifted to the middle estuary in 1979. A three month field program between Cap-aux-Oies and Tadoussac was successfully completed in association with a larval fish study of the same region. (C. Anderson, R.G. Ingram).

A joint program of research in the Saguenay fjord with BIO and Pêches et Océans Canada (Quebec City) was completed in early October of 1979. The work included current meter moorings, STD profiling at drifting and fixed stations, and biological and chemical sampling (R.G. Ingram).

A month of observations was taken in early fall of 1979, to be used in describing the plume characteristics, salt intrusion and tidal circulation of the estuary of the Eastmain River.

(b) Marine Geology: B. d'Anglejan

Le travail effectué en 1979 a été concentré sur la mise au point d'un système benthique autonome intégrant des données continues de vitesse, turbidité, température, salinité, marnage sur des périodes de temps prolongées et compatible avec l'échantillonnage de la matière particulaire épibenthique. Le développement de cet équipement a requis l'adaptation d'un transmissiomètre pour qu'il enregistre sur bande magnétique. Le système a été calibré et essayé au cours de trois croisières. La première, dans le Golfe du Saint-Laurent, a démontré la très grande sensibilité du transmissiomètre, capable d'enregistrer dans la colonne d'eau des variations inférieures à 1 mg/litre, dans la couche néphéloïde à 300 mètres de profondeur. Les autres, dans l'estuaire moyen, ont fourni des enregistrements continus de turbidité sur des périodes de 13 heurs et 26 heures.

Des travaux additionnels de courantométrie et d'échantillonnage de la matière en suspension ont été effectués dans la région de l'estuaire faisant face à la baie de Sainte-Anne. Cette baie, agissant comme réservoir temporaire des matériaux sédimentaires introduits par le fleuve Saint-Laurent, on a étudié les échanges de matière en suspension avec l'estuaire moyen. Les résultats de cette étude ont été présentés à la 5th Estuarine Research Federation Conference et sont en voie de publication.

Des études de bioturbation et de recyclage de matière particulaire (carbone, azote, matière minérale) ont été effectuées en laboratoire (John Daignault) sur des échantillons de polychaete detritivores (Pista Maculata) prélevés sur les Bancs de Kamouraska. On s'est appliqué à examiner les taux de recyclage pour différentes concentrations de nourriture disponible.

9. Ocean and Aquatic Sciences: Central Region, Burlington, Ontario

(a) Physical Oceanography

Studies are being carried out in Hudson and James Bays to assess the effect on the marine environment of fresh-water regulation brought about by ongoing and planned hydroelectric development in the surrounding watershed. In February, 1979, a field survey was carried out in James Bay off the La Grande River to measure a no flow condition during filling of the LG-2 reservoir, and off the Great Whale River to obtain preliminary measurements of the dynamics of a freshwater plume under an ice cover. Freshwater volume content, interfacial slopes, and gradient Richardson Numbers were calculated from the Great Whale data. Estimates of heat and salt content for the summer and winter periods in both Hudson

and James Bay were made from data collected in previous years. These computed storage terms were then checked against estimates of heat and salt fluxes into the system and good agreement was achieved. In the study of Chesterfield Inlet, a narrow, energetic, well-mixed estuary, one-dimensional stochastic-deterministic numerical models were developed for the dispersion of salt and nutrients. Through analysis of field data collected in the summer of 1978, good correlations were obtained between such physical parameters as longitudinal dispersion coefficient, bulk estuarine Richardson number, trap volume/channel volume ratio, and biomass distribution.

Further north in the Arctic Archipelgo, a physical oceanographic field program, operating from the Panarctic Oil Ltd. drilling rig, Whitefish, was carried out in the central Sverdrup basin. In addition to the current meter data from this program, which was directed at measuring water mass movement into the basin, data collected by industry is being analysed to provide a better understanding of the circulation in this basin.

In the south, work continued on the production of data reports for the middle estuary of the St. Lawrence river. A technique was developed to decompose the density and velocity fields into barotropic and baroclinic components, and it was found that the middle estuary has energy densities approximately 150-200 times as large as the energy densities of the Scotian Shelf.

In the Bay of Quinte, on Lake Ontario, work was nearly completed on the study of the hydrodynamics of the bay, including the barotropic and baroclinic free oscillations, the storm related exchange flow, and the two-layered flow regime.

(b) Shore Property Studies

Stage-related erosion profile data has been collected over the past seven years to develop a more precise understanding of erosion processes on the Great Lakes system and to estimate set-back requirements for development. All the 162 erosion stations were monitored this summer and the data have been compiled into histograms of annual bluff changes. Site specific studies were undertaken to assess the impact of structures and proposed developments including Long Point, Fifty Mile Point, Point Pelee and Port Burwell.

10. National Water Research Institute

(a) Burlington

Physical limnology research at the National Water Research Institute concentrates on four areas:

- physical limnology of large lake systems with particular emphasis aimed at better quantitative understanding of physical processes and the application of this knowledge in developing hydrodynamic and transport numerical models.
- physical limnology of special lake systems such as fjords and reservoirs.
- studies on coastal and shore dynamics to investigate nearshore waves, currents, diffusion, sediment movements, and shore development.
- studies of air/water interaction including the generation, propagation, and dissipation of wind-waves, and interfacial momentum, mass and heat transfer.

(b) Western and Northern Region, Winnipeg, Manitoba

Research studies include nutrient loading models and their effect on productivity, and limnocorral nutrient-addition experiments in the lakes of the Qu'Appelle and Pembina River Basins, of southern Saskatchewan and Manitoba respectively (R.J. Allan); benthic fauna and paleolimnology of culturally contaminated prairie lakes (W.F. Warwick); research into mixing and sediment resuspension by wind in large and small shallow prairie lakes (B.C. Kenney); mercury pollution of the Wabigoon-English River-Lake System of northwestern Ontario, and smelter heavy-metal contamination of a river-lake system at Flin Flon, Manitoba (T.A. Jackson); studies of phosphorus bioavailability in various lakes and reservoirs of the Churchill-Nelson diversion system (T.A. Jackson).

(c) Pacific and Yukon Branch, West Vancouver, B.C.

The research activities of this western branch of the NWRI continue to focus on the study of the large, deep, mountain-valley lakes of southern British Columbia. Studies of the dynamics of lake systems are conducted by P. Hamblin and E. Carmack; sedimentary aspects of limnological problems are treated by C. Pharo. Interests in water properties and circulation of the Antarctic Ocean continue, in a collaboration between E. Carmack and P. Killworth, of Cambridge University.

## 11. Fisheries and Oceans, Ottawa, Marine Sciences and Information Directorate

The Directorate provides a national function for Ocean and Aquatic Sciences (OAS) in terms of staff support for OAS science program activities, a headquarters coordination and representation function, a national data service and a national scientific information and publication facility.

The Ocean and Aquatic Science Affairs Branch provides staff support and a national focus for:

- international activities such as the London Dumping Convention, Intergovernmental Oceanographic Commission, NATO Science Committee, and bilateral agreements pertaining to marine sciences;
- environmental assessments such as Lancaster Sound, marine pollution aspects of the Canada Shipping Act, Arctic marine transportation; offshore oil and gas regulations, etc.;
- marine science coordination such as the departmental science subvention program, post doctorate fellowships program, Canadian Climate Program remote sensing activities, environmental contaminants, etc.;
- marine technology such as the Unsolicited Proposal Program of DSS, the COPI program, the managmeent and coordination of the Canadian Ocean Data System, etc.

The Marine Environmental Data Service (MEDS) is a branch of this Directorate. MEDS processes and archives physical oceanographic data when collected in Canadian waters. Data sets included in MEDS archives are Nansen bottle observed data, bathythermograph (XBT and MBT), tides and water levels and the waverider buoy data. The research interest of the staff is mostly to develop new data quality checking techniques and new data products from its archives.

An investigation was undertaken to search for the possible distortion of the tide by the presence of a fast ice cover in the Canadian Arctic. The technique of geophysical inverse theory was used to make calculations of the absolute geostrophic transport through the sides of the Bonavista Triangle. This triangle is an ICNAF section and was sampled about forty times in the spring and summer for sixteen consecutive years beginning in 1948. Many staff

members participate in the daily processing of oceanographic data collected by the FGGE drifting buoy data in the southern ocean. Some immediate products of this experiment, available through MEDS, are buoy tracks, sea-surface temperature contour plots and anomalies contour plots computed from the climatological data.

## 12. University of British Columbia: Department of Oceanography

### (a) Physical Oceanography

Studies of the physical oceanography of the Strait of Georgia and the behaviour of the Fraser River plume have been continued. S. Pond has developed a system to profile salinity, temperature and speed shear in the upper 10 m, which runs continuously and provides a profile every 20 seconds. It will be used in conjunction with drogue tracking in the plume and perhaps in Howe Sound to study the overall flow. Three automatic, internally recording, profiling current meter/CTD systems (cyclosondes) have been obtained and will be deployed in the Strait and in some of the B.C. fiords. W.J. Emery has instrumented two B.C. ferries running between the mainland and Vancouver Island to measure continuously temperature and salinity from the sea water intake. Wind observations are being collected from coastal stations and it is planned to install an anemometer on a navigation buoy in the Strait. In addition, a two-year series of monthly cruises is planned in the Strait in order to sample (by CTD) the upper water structure along and between the ferry routes. These observations, together with LANDSAT images of the area, which clearly show the distribution of the silt-laden Fraser plume, will provide an understanding of how wind, tidal currents and river discharge combine to control the distribution of Fraser River water in the Strait of Georgia.

A.E. Hay is studying the dissemination of tailings from a copper mine in Rupert Inlet under R.W. Burling. Some new techniques to sample suspended solids, analysis of particle size and for quantitative analysis of echo-sounding data have been devised and observations of turbidity currents and sediment profiles near and on the bottom have been obtained. L.W. Davidson completed his study of the physical oceanography of Burrard Inlet and Indian Arm, with R.W. Burling, early in the year. The observations show the trend of physical events during 18 months of 1974/5, and include an interesting prolonged replacement of deep water in Indian Arm extending through four months.

R.W. Burling is continuing work on the distribution of carbon dioxide in the ocean with the aim of developing improved ways to model the balance of $CO_2$ between the ocean and atmosphere.

W. Large, working under S. Pond and R.W. Burling, completed his Ph.D. on fluxes of momentum and sensible heat at high wind speeds. The behaviour of the drag coefficient has been established for winds up to about 25 m $sec^{-1}$ and extrapolates to agree with hurricane values obtained elsewhere. He is currently working on JASIN data which will provide moisture flux information, as well as more sensible heat flux results. R. Marsden should complete his Ph.D. on methods of modifying bulk aerodynamic parameterizations for estimating fluxes from climatological or synoptic meteorological data, early next year.

L.A. Mysak and P.H. LeBlond have developed a theory of very long period (several months) trench waves and it has been successfully tested (with W.J. Emery) using sea level observations along the Japan-Kuril and the Peru trenches. A theoretical study of the wind generation of thermal anomalies in the Northeast Pacific has recently been completed (A.J. Willmott and L.A. Mysak). In particular the model is able to simulate the presence of the frequently observed thermal feature off Sitka, Alaska. A theory of nonlinear shelf wave interactions has been developed

and applied to the Oregon shelf by W.W. Hsieh and L.A. Mysak. Also, a major review of recent advances in shelf wave dynamics, which will appear in the February 1980 issue of Reviews of Geophysics and Space Physics, has been completed by L.A. Mysak. E.R. Johnson and L.A. Mysak completed their analytical study of barotropic and baroclinic instabilities of coastal currents. Some of their results have been used to help interpret the presence of certain satellite-sensed thermal features off Vancouver Island (W.J. Emery and L.A. Mysak). G. Mertz and L.A. Mysak have been investigating various mechanisms that might account for the observed low-frequency current fluctuations in the source region of the Somali current (4°S).

W.J. Emery, in collaboration with C. Ebbesmeyer (Seattle), completed a study of six XBT multi-ship swathes to identify open ocean 'eddies' by their three-dimensional structure. This was compared to the number of features that would be identified as 'bumps' in a temperature section; about half the 'bumps' could be classified as closed circulation features. Work designed to develop objective criteria for identifying mesoscale 'eddies' from single XBT sections has continued. Fitting gaussian bumps to the eddies holds promise for future quantification of eddies.

Thermal sections across the Antarctic Circumpolar Current have been collected over a 2-year period (W.J. Emery). A total of 1500 casts from 20 sections have been taken in each austral summer. These sections, together with simultaneous surface meteorological measurements, provide a unique opportunity to improve the analysis of the heat budget of the Southern Ocean from widely spread sections at infrequent time intervals.

J. Dewar, with W.J. Emery, is carrying out computations of dynamic height maps from temperature observations for his M.Sc. thesis. As an outgrowth of this project, an atlas of mean ST and SZ curves will be produced for the North Pacific and North Atlantic as one of the Johns Hopkins monograph series.

W.J. Emery is also analyzing the three-dimensional spectra of surface winds and temperature with a Ph.D. student at Texas A and M University. A description of the generation potential of sea surface temperature at Rossby wave scales has been completed.

T.R. Osborn is continuing his research on ocean turbulence, particularly the measurement and interpretation of small-scale fluctuations of velocity shears. Measurements have been made in the Pacific Equatorial Undercurrent with W.R. Crawford and over the shelf slope off Vancouver Island with R.G. Lueck. Measurements are also being made in the North Pacific Subtropical Front north of Hawaii with R.G. Lueck as part of the FRONTS experiment. A new family of profiling vehicles is being developed to support this work. CAMEL II has been successfully field tested and is being used in the FRONTS experiment. CAMEL III is being developed and will feature internal data recording and will have a greater depth capability (3000 metres). An expendable small-scale velocity profiler is also being developed; it will permit dense profiling in both spatial and temporal domains and deployment in rough weather.

(b) Chemical Oceanography

Studies on the geochemistry of heavy metals in marine waters and sediments are being conducted in several areas along the B.C. coast by E.V. Grill. In the pelagic zone, sediments and bottom waters from Juan de Fuca and Explorer Ridges, two active spreading centres that lie just off the west coast of Vancouver Island, are being studied (with R.L. Chase and J.W. Murray) for evidence that metal-rich deposits occur there

comparable to those found in recent years at spreading centres in the Red Sea and to the south on the East Pacific Rise. The data available so far indicate that the trace metal content of the sediments generally is below that of average Pacific pelagic clay; however, hydrothermal mineral deposits have also been found in the study area that presumably were formed as a result of geological processes that produce metalliferous deposits. In the coastal zone, analyses are being made on sediments from the Strait of Georgia to determine the extent to which gold is being concentrated in placer deposits off the Fraser River mouth. Also, a study (with S. deMora) is being made to determine how the different forms of manganese present in Fraser River water are affected by mixing with seawater in the estuarine zone, and whether manganese-oxide coatings that potentially act as adsorbents of other more toxic heavy metals are formed or dissolved.

R.J. Anderson continued his research on the secondary metabolites produced by marine invertebrates and marine phytoplankton. Three new peptide alkaloids, celenamide A, B and C were isolated from the burrowing sponge Cliona celata. A new family of lipids, farnesic acid glycerides, were isolated from a dorid nudibranch, Archidoris odhner. New members of the steroidal peroxide family have been found in local nudibranches and a local sea whip. Our phytoplankton research has resulted in the isolation of 1-(2,6,6-trimethyl-4-hydroxy cyclohexenyl)-1,3-butanedione from the culture filtrates of the dinoflagellate Prorocentrum minimum. This metabolite possesses anti-bacterial and trace metal chelating properties.

(c) Geological Oceanography

The Pacific Ocean Minerals Project (R.L. Chase and E.V. Grill), initiated in 1977 to search for evidence of hydrothermal processes in the northeastern Pacific Ocean, mounted a three-week cruise jointly with personnel from the Pacific Geoscience Centre. A bathymetric and CSP survey was undertaken of Northeastern Explorer Deep, a rift valley at the northern end of Explorer Ridge. The valley has 200 m of sediment overlying basalt and 15 cores of the upper 1-2 m of this sediment were raised. A study of their sedimentary structures, minerals and major and trace element chemistry is underway. This valley was thought to be a recently abandoned spreading centre between Explorer and Pacific plates, but dredging of fresh basalt from a hill near its southwestern end indicates recent volcanism. Although our 1977 study shows that the locus of most active spreading along this plate boundary follows an en echelon sequence of rifts (Northwestern Explorer Deeps) to the north, minor tectonic disturbances may have continued up to the present in the southeastern deep.

13. Royal Roads Military College - Coastal Marine Science Laboratory

(a) Water Mass Studies

Circulation and Modelling of Estuaries and Harbours - D.P. Krauel

The project is concerned with circulation and mixing in coastal and estuarine waters generally near the College, such as Esquimalt Harbour and Lagoon and Royal Roads Anchorage. Fairly extensive time series have been obtained from these local areas and a stochastic model has been developed for dispersion in Royal Roads Anchorage and numerical models are under development for Esquimalt Harbour Lagoon. The physical oceanography of the Miramichi Estuary, New Brunswick including temperatures, salinities, tides, currents, circulation, mixing, flushing, and wave climate has been investigated in detail using observed data and a numerical model which simulated the wind and freshwater runoff effects on the circulation. Flushing times have been calculated and a general circulation model developed for the Bras d'Or Lakes, Nova Scotia. A

detailed study of coastal erosion in the vicinity of CFB Comox has been completed with the aid of a computer model and historical aerial photographs. Software for an information archiving and retrieval system based on a Hewlett Packard 9825A calculator has been developed along with other software for data analysis and presentation.

Numerical Modelling Problems - F. Milinazzo et al.

Work continues in close collaboration with R.F. Henry of IOS Patricia Bay on problems of modelling tidal effects in coastal waters. Particular attention is being given to the influence of Kelvin waves.

Trace Metal Concentrations in Coastal Waters in the Vicinity of Victoria - M.R. Barr and W.C. Horning

The IL351 Atomic Absorption Spectrometer with Flameless atomization has been used for the direct measurement of iron in sea water down to concentrations of $5 \times 10^{-2}$ parts per million without chemical concentration. Work on other metals, where chemical pretreatment is required, awaits the completion of new "clean lab" facilities.

(b) Sea Bottom Studies

Sea Bottom Studies - Acoustics - H.J. Duffus et al.

Using an ORE 3-7 kHz sub-bottom profiler and a Wesmar 105 kHz side scan sonar on the 30-foot research launch "Tayut", reconnaissance surveys have been made of nine harbours or bays in the vicinity of Royal Roads. Accurate positioning has been greatly facilitated by the recent acquisition of a Del Norte MS06 Trisponder system. Many interesting sub-bottom structures have been found, some of which are suspected to contain gas. Current work is concentrating on a more detailed examination of Sooke Basin.

Plans are well along to obtain and analyze deep cores and gas samples from a few of the sub-bottom structures, with the assistance of the Pacific Geoscience Center and Institute of Oceanography Patricia Bay.

Magnetic Interpretation in a Coastal Zone - W.T. MacFarlane and J.M. Gilliland

Plans are well developed, in collaboration with the Pacific Geoscience Center Patricia Bay, to conduct a detailed magnetic survey of Royal Roads Anchorage. One interesting aspect is the possibility that the Leach River fault, a major tectonic discontinuity, may extend seaward under the sediments of Esquimalt Lagoon and Royal Roads Anchorage and may be detectable by magnetic measurements.

(c) Sea Surface Studies

Remote Sensing and Surveillance - Murray Press et al.

Satellite imagery has been used, through the cooperation of the Canada Center for Remote Sensing, to trace the extension of the Fraser River Plume into Juan de Fuca Strait. Attempts to obtain sea state and surface movement data by lapse rate photography of the Ministry of Transport ship control radar display, have been held up by equipment delays. Wave measuring equipment is being installed off the College to study wave climate and longshore sediment transport. The Institute of Ocean Sciences Patricia Bay is cooperating in these studies.

## 14. Institute of Ocean Sciences, Sidney, B.C.

### (a) Arctic Studies - Frozen Sea Research Group

Analysis of oceanographic data collected in the channels of the Canadian Arctic Archipelago was completed. The work on the definition of salinity carried out under the auspices of SCOR Working Group No. 10 has been completed and a final report was presented at the I.U.G.G. Assembly in Canberra, Australia, November 1979. An oceanographic study of Bridport Inlet, Melville Island was carried out in support of Petro Canada plans for a LNG terminal. Work on the physics of deep oilwell blowouts was completed in conjunction with Dr. P.R. Bishnoi, University of Calgary. The formation of gas hydrates was demonstrated and the behavior of rising hydrate-covered gas bubbles from simulated depths of 900 m to the ocean surface studied. The release of dissolved gas from oil droplets rising from similar depths was also studied. A theoretical study was made of the behaviour of oil and gas mixtures trapped under ice, in conjunction with Dr. D.E. Thornton, E.P.S., Edmonton. Development has commenced of a sonic system for current meter orientation in Arctic areas close to the North magnetic pole where the conventional compass direction reference technique is unreliable.

### (b) Coastal Oceanography

A study of the oceanographic features of the Continental Shelf off the west coast of Vancouver Island was begun in early 1979. Measurements of current speed and direction, temperature salinity and dissolved oxygen are being made with moored instrument arrays at four sites, together with periodic monitor cruises. Analysis of the data is just commencing. One interesting occurrence was the development, and subsequent collapse, of a hydrographic event that led to very low (0.7 ml/l) dissolved oxygen concentrations in a major fishing ground.

A measurement program in Alberni Inlet was also begun in early 1979. The data obtained, combined with those taken concurrently on the shelf, will be used to examine circulation phenomena in this fjord system, and to investigate the role of coastal upwelling in the deep water renewal process. Preliminary examination of the data has shown a more dynamic behaviour than anticipated. For example, water property changes, apparently originating on the Shelf, can be propagated throughout the system on a time scale of a few days. Similar advection of Shelf water seems to be responsible for changes in the late summer structure in the inner basin of Alberni Inlet which were originally attributed to diffusive processes.

The study of the circulation in Knight Inlet continued through 1979, providing further insight into the interactions between the tidal flow and the sill. A gated-Doppler acoustic system is being developed to examine the spatial structure of flow over the sill in considerable detail.

### (c) Remote Sensing

A program of airborne water colour measurement using the 256 channel silicon diode spectrometer has demonstrated the possibility of using this technique for rapid chlorophyll surveys. In 1979 such surveys were conducted in the Mediterranean, in B.C. coastal waters and in the Canadian Arctic as part of the joint Canada France Ocean Optics Experiment. (CFOX). Studies of satellite data have included use of images from Landsat, NOAA and synchronous satellites for studying atmospheric and sea surface features, and use of the GEOS-3 satellite radar altimeter for measuring wave height.

Data from the SEASAT A oceanographic satellite has been used in an internal wave experiment (SIWEX) which included participation of DREP and the Canadian SURSAT project. SEASAT A data was used also in a joint U.S. Canadian project on the tail of the Grand Banks June 1978 and May 1979 in which airborne and satellite observing techniques were applied to the study of the oceanography of this area.

(d) Numerical Modelling

Two- and three-layer hydrostatic models of internal hydraulic jumps were developed and applied successfully in simulating observed behaviour in Babine Lake and Knight Inlet. A new objective tsunami magnitude scale based on potential energy was defined. Numerical tests were carried out on improved methods for simulating open boundaries in tsunami, tidal and storm surge models.

Developments in the Georgia/Juan de Fuca Straits project included study of high resolution local area models driven by boundary values taken from the overall model. Large scale eddies predicted by a fine scale model have been confirmed by observations and a Tidal Current atlas is in preparation.

(e) Offshore Oceanography

Support to the First GARP Global Experiment was maintained; Dr. Garrett's secondment to the International Drifting Buoy Program Centre in Toulouse terminated in August but analysis of buoy data is continuing. I.O.S. oceanographic personnel aboard the PARIZEAU participated in the FGGE Tropical Wind Observing Ship Program in January and February 1979.

Collection of STD data at Station P and along line P was continued from the Weatherships and climatological analyses of the data were carried out with particular attention being given to persistent fronts along line P. A year-long pilot study of the current system west of Vancouver Island on the continental shelf and immediately offshore is in progress, using moored current meters, shipboard observations, infrared satellite images and drifting buoys. Work has continued on tidal motion in Johnstone Strait, including study of internal tides, and a complete analysis of historical mean sea level data for the B.C. coast is in hand.

Participation in ADS (Anomaly Dynamics Study) continued, and further work was done on the study of processes responsible for modification of the upper ocean on time scales of days and space scales of a few kilometres.

(f) Ocean Mixing

Effort in the ocean mixing program has been concentrated on analysis of data obtained in Knight Inlet in November 1978. Turbulence sensors mounted on the PISCES IV submersible were driven through the highly turbulent nonlinear internal wave train which is formed over the inner sill as the tide changes to flood and subsequently propagates up-inlet. These are the first field measurements of all three components of the turbulent velocity field at dissipation scales. Results indicate that in the most strongly turbulent region at the leading edge of the wave train, the velocity field approaches isotropy in this scale range. Preparations are under way for an investigation of the mixing processes occuring at the base and the lateral boundaries of the Fraser River plume during freshet.

(g) Tides and Currents Section

Current and current shear measurements were taken in the Pacific on six transects of the equator, in order to define the limits of the equatorial undercurrent. On the same cruise a free fall microstructure instrument was deployed 45 times to measure microstructure shears and temperature gradients. Analysis of the data is being carried out.

Field measurements in the Fraser River were carried out in order to incorporate the behaviour of the salt wedge into a working numerical model of the river. Preliminary field work in the Skeena River directed toward the development of a numerical model were carried out.

(h) Ocean Chemistry

The on-going research in Ocean Chemistry is concentrated in several areas such as the marine carbon cycle, marine hydrocarbons, trace metals and controlled experiments to understand processes in the ocean. Application of basic marine chemical knowledge to environmental problems, such as mine tailings disposal, oil pollution, ocean dumping and environmental contaminant transfer, is also stressed.

In Marine Carbon Cycle, the major emphasis is on time-series measurements of $CO_2$ over the ocean, with manning of the Canadian Weather Station P (50°N 145°W) in the tenth year of documenting the atmospheric $CO_2$ increase. Other $CO_2$ stations on west coast lighthouses were set up as part of the weathership replacement effort. Ship of opportunity on the Canada Maru to collect air samples across the Pacific is also utilized. Other oceanic measurements included participation in the GARP experiment cruise, FGGE, in the equatorial Pacific to study air-sea $CO_2$ exchange. In order to understand the global carbon cycle, a more critical scrutiny of the $CO_2$ contribution from wood burning was made, indicating that this contribution would amount to 15% of the fossil fuel $CO_2$ input.

In Trace Metals Study, an ultra-clean room was in operation with ability to detect low levels of lead in sea water. A NATO intercalibration was carried out between Ocean Chemistry, the Institut fur Meereskunde at Kiel and Department of Oceanography at Liverpool University for trace metals using CEPEX enclosure of 65,000 liters of seawater. Another CEPEX experiment was conducted for studying the environmental pathways and toxicity of tetraethyl lead in the marine environment. Ocean dumping studies of release of trace metals from dredge-spoils and of chemical variability statistical analysis of samples prescribed under the Ocean Dumping Act were carried out.

In Hydrocarbons, the main effort was placed on a Kitimat baseline environmental study by contract, with analysis of polyaromatic hydrocarbons in the sediments, organisms and seawater. A CEPEX experiment was conducted to understand the pathways of PCBs in the marine environment. Baseline tar distribution on beaches at Triangle Island was also scrutinised in connection with tanker traffic in the area off northern Vancouver Island.

In Coastal Pollution, joint programs with EPS were carried out on environmental effects of mine tailings, with studies of sediment samples, pore waters, arsenic methylation and bio-uptake by M. edulis. The investigations were mainly in the area of Rupert, Holberg and Quatsino Inlets. Studies on the sewage outfalls in the vicinity of Victoria were initiated.

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# VII GLACIER STUDIES

Compiled by C.S.L. Ommanney

1. Energy, Mines and Resources Canada
2. Environment Canada
3. Karl E. Ricker Ltd., Vancouver, B.C.
4. Universiy of British Columbia
5. McGill University and E.T.H., Zurich
6. McMaster University
7. University of Minnesota
8. University of Ottawa
9. Simon Fraser University
10. University of Toronto, Erindale College
11. University of Wisconsin
12. Bibliography

## 1. Energy, Mines and Resources Canada

### (a) Geological Survey of Canada

(i) Bylot Island (R.N.W. Dilabio and W.W. Shilts) - Laboratory analysis of till and debris samples from glaciers and moraines in SW Bylot Is. indicate that (1) the different grain size fractions of debris have different provenances; (2) englacial debris includes debris derived from the glacier bed; (3) the finest debris from the hinterland is diluted in a regular way in the down-ice direction, and (4) the lithology of glacial debris can be used to characterize drainage basins of individual glaciers and their tributaries.

(ii) McArthur Range, Y.T. (O.L.Hughes) - A debris-covered glacier with ice exposed in a large collapse pit was examined briefly.

(iii) Cathedral Glacier, B.C. (L.E. Jackson, Jr.) - Debris flows generated by a jokulhlaup from Cathedral Glacier were investigated.

### (b) Polar Continental Shelf Project (W.S.B. Paterson, R. M. Koerner & D. A. Fisher)

(i) Ellesmere Island, N.W.T. - A 138 m borehole was drilled to bedrock at the crest of the Agassiz Icefield. Dirt layers found in the lowest few metres suggest that the basal ice was at the melting point at some stage in the past. This is surprising because the present basal temperature is -22°C and there were no dirt layers in the 1977 core about 1.5 km down slope. There are also major differences in oxygen isotope profiles in the two cores. Laboratory analysis of the 1977 core is continuing with emphasis on microparticle concentration, trace elements, and the detection of volcanic eruptions by measurement of electrical conductivity. Without an accurate map, a complete mass balance of the Icefield was not possible. However, measurements show that melting on the irregular surface of a western glacier is an order of magnitude higher than on the smooth surface of a glacier that drains the NE side of the Icefield. A Bristol University expedition (M.E.R. Walford, M. Harper and R. Berry) to the Agassiz Icefield was succesful in developing some new field techniques for phase-sensitive radio-echo sounding. It seems that this can be used for recognizing and analyzing some reflection situations and distinguishing between grossly different geomorphological regimes.

(ii) Meighen Island, N.W.T. - routine mass balance measurements were carried out.

(iii) Devon Island, N.W.T. - The mass balance of the northwest side of the Devon Island Ice Cap was -99 kg/m$^2$ for 1976-77 and +27 kg/m$^2$ for 1977-78.

(iv) Queen Elizabeth Islands, N.W.T. - Bea Alt, under contract, is continuing investigations of the synoptic meteorology of years with extreme conditions during the period of record (the last 20 years). Analysis of the 'warm' summers, those in which the mass balance of the ice caps is strongly negative, showed that contraction of the 500 mb polar vortex, or a shift of it toward the Soviet side of the Arctic Ocean results in universally warm conditions in the Queen Elizabeth Islands. Differences within the region can be explained by the position and shape of the vortex. The cold summers are now being studied; the situation seems to be more complex than in the warm summers.

2. Environment Canada

(a) Water Survey of Canada, W.R.B. (I. A. Reid and J.O.G. Charbonneau)

Glacier Surveys, Alberta - The Saskatchewan and Athabasca glaciers were resurveyed by terrestrial photogrammetry. Maps and reports from these and previous surveys are in preparation.

(b) Snow and Ice Division, N.H.R.I. (D.K. MacKay)

(i) Glacier Inventory (C.S.L. Ommanney and M.M. Strome) - The Glacier National Park study continued. A further 24 basins with 1191 glaciers were added to the Yukon inventory (S.G. Collins). All published Glacier Atlas of Canada maps are now available in French.

(ii) Penny Ice Cap, N.W.T. (G. Holdsworth) - A reconnaissance ice core site survey was carried out on the Penny Ice Cap, Baffin Island (67°15'N, 64°55'W; Elev. 2000 m). A 20 m core was retrieved which covers the last 30 years. About 42% of the core is ice, with a marked decrease in ice content since 1954 (maximum). The core was dated using $\delta^{18}O$ and tritium plots. The average isotopic temperature is -18°C, whereas the measured borehole temperature between 10 and 20 m is close to -14°C. Ice depth at the site (near the divide) is 550-600 m. Additional radio-echo sounding was done by P. Gudmandsen. Reference poles, in a strain array, were inserted and a cache left for future medium depth core drilling planned for 1981-82. An electromechanical drill, based on a Rufli-Rand design, has been constructed and tested in Ottawa.

(iii) Donjek Glacier ice-dammed lake, Y.T. (G.J. Young and M. Perchanok) - A reconstruction of the glacial lake chronology for the Donjek Glacier terminus area is well underway.

(iv) Iskut River glaciers, B.C. (O. Mokievsky-Zubok) - Three glaciers (106 km$^2$), representing an ice coverage of 67% and 23% in two watersheds draining into the Iskut River, have been chosen for a study of the impact of glacier variation and runoff on a proposed reservoir. "Andrei", "Yuri" and "Alexander" glaciers had negative balances of -0.64, -0.57 and -0.50 m$H_2O$, respectively.

(v) Mass balances, Coast Mts, B.C. (O. Mokievsky-Zubok - Measurements of winter and summer balances, meteorological variables and meltwater flow continued on Sentinel and Place glaciers. Mass balance only was determined for Helm Glacier. Specific net balances were -1.72, -1.98 and -2.71, respectively.

(vi) Bridge River glaciers, B.C. (O. Mokievsky-Zubok and S. Fogarasi) - Studies continued in order to determine the effect of glaciers on basin runoff and to evaluate the seasonal and operational forecast models for a downstream reservoir (J.R. Gordon, BC Hydro). A Data Collection Platform (DCP) was used for continuous monitoring of hydrological and meteorological variables. Bridge, "Sykora" and "Zavisha" glaciers had balances of -1.1, -1.1 and -0.69 m $H_2O$, respectively.

(vii) Flood Glacier jökulhlaup, B.C. (O. Mokievsky-Zubok) - Lakes dammed by the Flood and "Natavas" glaciers flash-flooded the tributaries of the Iskut and Stikine rivers. The lakes and sites were investigated before and after the discharges and some measurements were taken.

(viii) Sentinel Glacier, B.C. (S. Fogarasi and O. Mokievsky-Zubok) - Daily total direct and diffuse radiation was calculated on a 250 m grid and the sum compared with measured global radiation values. Initial surface albedo was estimated, its daily variation calculated by Petzold's method, and inferences made with respect to the magnitude of attenuation coefficients. Net radiation values were calculated, plotted, and their impact on hydrologic processes examined.

(ix) Peyto Glacier, Alta. (G.J. Young) - The basic monitoring of mass balance (-0.81 m $H_2O$), meteorology and hydrology continued. A detailed water chemistry and sedimentation study was undertaken (D.N. Collins): snowpack density investigations continued (J. Edworthy) and an investigation of glacier winds undertaken (C.E. Banfield and A. Stenning).

(x) Simulation of alpine runoff (J.M. Power and G.J. Young) - Extensive modelling of runoff from the Peyto Glacier catchment used an adaptation of the UBC hydrologic forecasting model for glacierized watersheds. This model is also being used on the glacierized Goldstream River basin (Columbia River). The program to monitor the hydrology and climatology of non- and glacierized catchments in Yoho National Park continues.

3. Karl E. Ricker Ltd., Vancouver, B.C.

Upper Clendenning Creek, Lake and glaciers, B.C. - Studies of the glaciers draining into Clendenning Creek show many to be advancing, while one other large valley glacier is now slowly retreating at the expense of an enlarged terminal lake. "Surf Glacier", at the head of the valley, is overriding "Wave Glacier". Cairns have been placed on the latter to monitor changes and tree ring and lichen measurements made on a recessional sequence of five moraines. The region is covered more or less by 10 sets of aerial photography dating from 1940 to 1979. The advance and retreat of the glaciers will be determined using 1947/48 as the datum. The results will appear in the 1980 Canadian Alpine Journal.

Snowcap Lake and Glacier, B.C. (with W.A. Tupper as of 1980) - a simplified geomorphic and glacier history of the area has been developed and published in the Canadian Alpine Journal. The glaciers of interest are now being plotted from the various years of aerial photography and changes in areal extent will be calculated over the coming year.

Wedgemount Lake and Glacier, B.C. (with W.A. Tupper) - Extreme ablation, following a dry and warm summer, exposed many old firn lines, stripped the glacier of the 1979 snowpack up to 2200 m level and gave rise to a much siltier lake with higher levels. 1979 saw the establishment of two velocity profiles, the extension of the survey net, rephotography and mapping of the

snout, moraines and trimlines. A 1:10,000 scale map of the entire glacier-basin will be available in 1980. The N side of the snout retreated 10 m while the S side advanced 5 m. Observations on a newly developing ice front lake were taken in the next valley north of Wedgemount where a paternoster sequence of lakes have appeared since the climax advance around the turn of the century.

4. University of British Columbia - Department of Geophysics and Astronomy

(i) Ice-dammed lakes, Y.T. (G.K.C. Clarke) - A time-lapse film was made of the 9-11 July 1979 drainage of Hazard Lake. After the outburst flood, a levelling survey of the empty basin was carried out and a detailed bathymetric map prepared. Down-hole seismometers have been emplaced in the Steele Glacier ice dam so that seismicity accompanying future jökulhlaups can be recorded. A study of the paleohydrology of Recent Lake Alsek is being continued.

5. McGill University, Montreal and E.T.H., Zürich - Departments of Geography

(i) North Water region, N.W.T. (F. Müller and K.Schroff) - Mass balance measurements were made on the "Laika Glacier and Ice Cap" (Coburg Island) and on Leffert and an unnamed glacier on Ellesmere Island.

(ii) Axel Heiberg Island, N.W.T. (F. Müller) - Separate winter and summer balance measurements were made on White and Baby glaciers. Data from earlier years, back to 1959/60, have been compiled and analyzed for publication. On White Glacier, an improved drill successfully reached bedrock in the accumulation area. Two holes were drilled there, one at the equilibrium line, and two more in the tongue close to the glacier edge; all reached bottom between 80 and 350 m. There are now a total of 22 thermistor sites along the longitudinal profile.

6. McMaster University - Department of Geography

Eidsbotn Fiord, Devon Island, N.W.T. (P. Marsh and M.K. Woo) - A runoff model for high arctic basins is being developed. It incorporates data from glacierized and nival basins studied near Eidsbotn Fiord.

7. University of Minnesota - Department of Geology and Geophysics

Barnes Ice Cap, Baffin Island, N.W.T. (R. LeB. Hooke) - A hole was drilled to 316 m at the top of the South Dome and cores were extracted at depth intervals of about 25 m. With increasing depth C-axis fabrics in the core change from weakly oriented near the surface to distinct two maximum fabrics indicative of pure shear, and thence to small circle fabrics reflecting uniaxial compression. Previous holes were resurveyed for deformation and temperature. In hole T020 hole-parallel strain rates are approximately independent of depth over the top 100 m, or roughly one-third of the glacier thickness and the temperature profile has been affected by a surface cooling event of about 2.5°C some 40 years ago. This is attributed to a climatic warming resulting in the formation of superimposed ice which restricts the penetration of percolating melt-water thus decreasing the importance of this heat source in the near surface ice.

A laboratory test of various theories of sliding of temperate glaciers is being initiated. A block of ice about 20 x 45 cm, under a normal force of 30,000 lbs, will be forced over an irregular bed by a shear force of 3000 lbs.

8. University of Ottawa - Department of Geography

Glacier and rock glacier hydrology (P.G. Johnson) - Hydrological regimes encountered in the Yukon fluctuated very widely with large hydrograph responses to small climatic variations and precipitation events. Routing of flow was difficult due to complex subsurface conditions, dilution and absence of resurgences (especially with rock glaciers). Water chemistry studies offer promise of a better definition of routing and water sources with some distinct trace element patterns emerging.

9. Simon Fraser University - Department of Geography

Mount Assiniboine rock glacier, B.C. (B. Sagar and B.M. Yarnal) - Analysis of the nature and distribution of sediments and plant cover of a complex rock glacier-like feature suggest that the present configuration is the result of an early Holocene event and three separate periods of Neoglacial activity. The two oldest stages of development were rock glacier in character, while the remains of the two more recent events are glacial.

10. University of Toronto, Erindale College - Department of Geography

Peyto Glacier radiation, Alta. (D.S. Munro) - A model of the net shortwave radiation distribution in a glacierized basin has been devised. It estimates global radiation from sunshine records, and distributes the values according to slope and aspect. Values of surface reflectance are applied to the incoming radiation to estimate net shortwave radiation. Provision is made for snowline migration.

11. University of Wisconsin, River Falls - Department of Plant and Earth Sciences

Barnes Ice Cap, Baffin Island, N.W.T. (R.W. Baker) - Creep tests in simple shear were continued on samples of natural ice collected from the surface and within the wedge of deformed-superimposed ice at the margin of the Barnes Ice Cap. Twenty-four specimens have been tested, in the field and laboratory, to study the combined effects of crystal size and fabric on creep rate. Results show that for samples with similar fabrics, creep rate increases in proportion to the 2.3 power of the grain size, d, for d=1.7 to 7.3 mm ($\dot{\gamma} \propto d^{2.3}$). For samples with similar grain sizes, creep rate increases in proportion to the 1.5 power of the fabric intensity, fi, (as determined by the number of points in 1% of the area of an equal-area stereographic projection) for fi=8 to 40% ($\dot{\gamma} \propto fi^{1.5}$). The latter results are being analyzed using Kamb's method of statistically evaluating fabric diagrams.

About 180 kg of glacier ice, taken from the field in 1979, are being tested in a university cold laboratory. Priority is being given to testing samples with multiple-maxima fabrics in simple shear and samples with isotropic fabrics in multiaxial stress - simple shear with simultaneous uniaxial compression. The multiaxial tests should provide information on the relationship of the third invariant of the deviatoric-stress tensor to creep rate.

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# VIII HYDROLOGY

Compiled by: Dr. I.C. Brown

1. Introduction
2. National
3. Provincial
   (a) Newfoundland
   (b) Prince Edward Island
   (c) Nova Scotia
   (d) New Brunswick
   (e) Québec
   (f) Ontario
   (g) Manitoba
   (h) Saskatchewan
   (i) Alberta
   (j) British Columbia

## 1. Introduction

Continuing restraints on research funding resulted in more short term applied studies aimed at providing answers to immediate management and operational problems. More studies were directed to the use of models and of remotely sensed data to extend data coverage without extensive field data collection. While reporting of hydrological activity improved in 1979 it is still not as complete as desirable and consequently coverage may appear rather uneven. Hydrological activity in Glacier Studies is reported in the section on that subject and hydrometeorological studies are reported under Meteorology and Atmospheric Science.

## 2. National

The Canadian Hydrology Symposium: 79 - Cold Climate Hydrology was held in Vancouver in May and the proceedings, including the special session on the Resistance to Flow of Ice Covered Rivers, are available from NRCC publications. The Association committee on Hydrology completed its report on the status of hydrology education and its study of national research priorities in hydology. Both have been published in its newsletter Hydrological Events. The hydrological research priorities are reviewed every three years and this second round showed very little change from the first, indicating both the long term nature of hydrological research and the difficulty in getting research findings applied operationally.

Agriculture Canada undertakes and supports such hydrologic research in the near surface zone as drainage, desalinization and return flows from irrigated lands. Agrometeorology research includes improving water use efficiency, crop yield prediction from soil-water and weather data, and modelling of water use by crops. The soil resource inventory program includes research in soil-water processes, and studies of the impact of shallow groundwater processes on soil properties and uses. An improved approach for characterizing the soil-water regime is under development for use in the soil resource inventory program. Studies on nutrient runoff from farm land is receiving increased support.

The National Water Research Institute (NWRI) has a wide ranging research program in water resources and only the hydrological aspects of this are reported below. Modelling programs involved lake and river processes including wave prediction, sediment transport, water quality, simulation of effluent discharges and of urban runoff using both ground and remotely sensed data.

A wide variety of studies were undertaken in Lake Erie including studies of exchange processes in the coastal area and with the open lake and those

affecting the supply of dissolved oxygen to the central basin hypolimnion, the thermocline structure, and paleoenvironmental studies covering 100-300 years. The vertical circulation, thermal structure and the effect of flood control and dams on Kootenay Lake was investigated. Studies were done of the sensitivity of aquatic regimes to airborne pollutants, acidification, 2,4-D and the sources, seasonal variation, transport and degradation of a wide range of toxic contaminants. River processes under study include ice jamming criteria, dynamics of frazil ice, rehabilitation of hypertrophic river-lake systems and detoxification of mercury and heavy metal polluted rivers. Development continued in the digital image analysis of satellite data related to water quality in the Great Lakes using the Nimbus and coastal zone colour scanner backed up by an extensive field program in western Lake Ontario, and in the application of lake optics to water quality evaluation and the development of software to support a digital colour analysis system.

The National Hydrological Research Institute's (NHRI) research program is closely coordinated with that of the NWRI and the highlights of the NHRI program follow: Hydrological modelling is being developed for use in studying stream flow, peak flows, flood or drought frequency and evapotranspiration. Hydrological studies of groundwater dynamics, the effects of open pit mining and dewatering, hot springs, groundwater aspects of northern hydrology and groundwater contamination with trace elements including radionuclides from radioactive waste disposal are being undertaken in many areas of Canada. The ice hydrology program involved studies of snow and ice dynamics including spring runoff, ice breakup, mountain hydrology, influence of aufeis and ground ice on stream channels, glacier mass balance and paleoclimatology studies using glaciers. Permafrost studies concentrated on the geothermal effects near arctic streams. Remote sensing of snow water equivalent using gamma-ray techniques continued to be studied and data retransmission techniques were developed and refined.

3. Provincial

(a) Newfoundland

The province is developing a comprehensive "Water Use Management Plan" that includes collection of basic hydrologic data and hydrologic research and involves gradual expansion of existing hydrometric, water quality and climatological networks. Hydrological investigation of community water supply areas continued in different hydrological regions to quantitatively evaluate the precipitation - water yield relationship and its seasonal distribution and to develop design criteria. The urban hydrological study in Waterford River Basin continued to examine changes in the hydrological regime of the basin including the type and magnitude of chemical and biological pollution of surface and groundwaters. Modelling of these processes is under study to attempt to develop planning and management criteria for all water management aspects of urban development. The processes involved in the production and migration of leachates in relation to hydrogeologic characteristics of the area and climatic variables were investigated at a sanitary landfill site near Terra Nova. Several other water disposal sites were monitored to determine their effect on surface and groundwater pollution. Memorial University initiated some research on the hydrology of peat lands with special emphasis on soil moisture movement.

(b) Prince Edward Island

The Water Resources Branch of the P.E.I. Department of the Environment improved its monitoring programs for surface and groundwater quality and quantity and is developing a comprehensive and dynamic groundwater well data storage and retrieval system with the assistance of the Computer Services Centre of the P.E.I. Department of Finance. An investigation into Road Salt Contamination of Wells on P.E.I. was

undertaken as a result of complaints blaming road salt piles and road salting procedures for contaminating wells. Six localities with different characteristics are being closely monitored and a final report is expected by Spring 1981. As part of a Provincial Contingency Plan, and following extensive field work, a site was selected and a comprehensive hydrogeologic study started to determine its acceptability for disposal of oily debris in case of an oil-spill at sea off the coast of P.E.I. A final report is scheduled for December 1980.

(c) Nova Scotia

Studies continued for the Bras d'Or Watershed and the unique hydrological characteristics due to its connection to the sea. The contamination of wells by arsenic released during rock weathering continued to be a problem and studies were concentrated in the Shubenacadie Basin.

Dalhousie University led a cooperative program of study of the effects of atmospheric precipitation on lake waters, particularly the problem of acidification. Work is mainly in Kejimkujik Lake.

Nova Scotia Technical College continued its study of urban storm water quantity and quality in a small catchment in Halifax and of the appropriate model to use.

(d) New Brunswick

An extensive hydrological modelling exercise on the complex Saint John River estuary was completed for the purpose of preparing flood risk maps and improved flood forecasts. Calibration of the upstream flow forecast model is nearly complete and the program for snow cover mapping by satellite continues to improve.

An international workshop was held in October on the World Meteorological Organization's World Weather Watch Saint John River Basin Forecasting Project. Participants came from several countries in South America, from Europe and the Far East as well as North America to consider how the experience of such cross-border cooperation can be applied elsewhere.

The University of New Brunswick's study of the effects of clear cutting on the Nashwaak Experimental Watershed was in its first post-cut year and the results of the effects are beginning to come in. This study was initiated in 1970 on three small watersheds, calibration for the watershed to be clearcut took place in 1978-79.

Detailed field measurements of channel geometry have been made on a reach of the Nashwaak River near Fredericton, New Brunswick. Observations of the winter ice regime were made. Measurements were made to determine resistance to flow under ice cover. These results are to be compared with the results predicted by various empircial equations.

(e) Québec

At Laval University research continues into forest hydrology and into methodology for correcting LANDSAT images for the effects of topography, sun elevation and the angle of view of the satellite so as to permit better vegetation classification and more accurate measurement of albedo and improve the quality of data entered into hydrological models and used in the classification of lakes and water quality and sediment transport studies such as that done in Rupert Bay for the Society of the Development of James Bay.

The University of Sherbrooke conducted research in thermography, particularly in regard to the study of soil moisture.

The "Stormy Weather Group" at McGill University continued its radar precipitation research to provide quantitative precipitation forecasts for 4 to 6 hours that will assist in runoff forecasts. Using these data McGill is cooperating with Ecole Polytechnique on an urban runoff study and with INRS Eau for larger basins. In the latter case radar precipitation data and satellite data are being used in the CEQUEAU hydrological model. Also the retreat of snowline in the spring obtained from LANDSAT and NOAA satellite images is being compared with that simulated by the model and this work shows possibilities of application to various meteorological parameters which would result in a change in emphasis in data networks.

(f) Ontario

The Water Resources Branch of the Ontario Ministry of the Environment continued its studies on snow distribution and melt and the resulting runoff in a number of basins. This was supported by an Ontario Centre for Remote Sensing (OCRS) development study to provide flood forecast models with timely and accurate snow cover estimates. Historical and current snow depletion curves will be used as input to the snowmelt component of a hydrologic model for watersheds. OCRS in conjunction with the Geological Survey of Canada, Environment Canada and the Ontario Ministry of Natural Resources is involved in further work on the feasibility of using the Geological Survey of Canada gamma-ray spectrophotometer for improved area weighted measurements of water content in snow and ice. This information will be used to improve flood forecast estimates.

Groundwater pollution studies concentrated on radio-active waste migration and the migration of leachate from landfill sites. The feasibility of using remote sensing techniques for the mapping and detection of leaching from landfill sites is under study.

The Water Resources Branch studied waterborne thermal plumes from generating stations in the Great Lakes. Weekly synoptic flights, conducted under the auspices of the OCRS, over the Pickering A Nuclear Generating Station on Lake Ontario provided information on the nature and extent of winter thermal plumes which are poorly understood. Plumes were mapped on the basis of a network of inshore/offshore transects flown at low altitude using an infrared radiometer supplemented by an extensive array of in-situ thermal recorders, current meters and boat sampling. Plumes were also studied by digital analysis of airborne infrared linescanner data.

OCRS completed a study outlining a methodology for the delineation and mapping of Cladophora extent in the coastal zones of lakes using conventional multispectral vertical aerial photography and interpretation techniques. The OCRS also completed the development of an infrared mapping technique for the detection of surface groundwater discharge.

The University of Waterloo investigated the use of aerial photography to determine the direction and aerial extent of suspended solids plumes under various synoptic conditions off Centre Creek in the Nanticoke Region of the eastern basin of Lake Erie. Low altitude oblique multispectral aerial photography was used and supported by simultaneous ground sampling. Another study involved the development of methods to determine heat storage of small Pre-Cambrian shield lakes using digital infrared linescanner data. The test site included three small lakes and a section of the Ottawa River adjacent to the Chalk River Nuclear Laboratory. One component of the study involved the detection of groundwater input to lakes.

At Queen's University research concentrated on modelling techniques. Real-time streamflow forecasting research included calibration and appraisal of the two versions of the National Weather Service River Forecast System for two basins in Canada. Stochastic forecasting models were being considered for short-term forecasting. These are time series models of the Box-Jenkins type, and transfer function-noise models which allow for weather forecasts and hold more promise than time series models.

In the area of flood frequency analysis, distribution fitting techniques for the log Pearson Type 3 distribution have shown, via Monte Carlo simulation techniques, that for hydrological purposes the method of moments is a superior fitting technique to others including maximum likelihood.

A distributed event model was developed which is both conceptually appealing and physically realistic. This model has great advantages over lumped models when considering very inhomogeneous urbanizing or typical natural basins in northern Canada. Work was done on an existing even model, HYMO, both on the hydrological components and the user/program interface. The new version, called QUEEN'S HYMO, has as options to the original HYMO, improved procedures for soil moisture accounting, hydrograph generation and reservoir routing and is bilingual in terms of units (both SI and IS).

A cornfield in the South Nation River Basin has been instrumented and a drainage model has been developed to provide simulated flows for comparison with observed flows. This drainage sub-model will be incorporated into a basin model so that the impact of drainage on flooding, low flows, etc. can be determined.

(g) Manitoba

The Universtity of Manitoba continued its study of pollution caused by runoff from agricultural lands and the application of modelling techniques for predicting the nutrient loads from small watersheds and assessing the effectiveness of various strategies for minimizing this type of pollution.

(h) Saskatchewan

The Saskatchewan Department of the Environment is co-operating with the University of Saskatchewan and with U.S. officials on projects designed to lead to improved forecasts of spring runoff peaks and volumes. The programme, begun in the Wascana Creek basin, involves the use of comprehensive snow survey data based on land use units in conjunction with remote sensing techniques. These data are intended to become input to a Sacramento model. Calibration of this model is under way.

The impact of agricultural drainage on flood peak potentials continues to be of major concern in Saskatchewan. The Department of the Environment has completed, or has under way, impact-of-drainage studies for the Quill Lakes, the Upper Assiniboine, and Qu'Appelle drainage basins. The Qu'Appelle work also includes an analysis of the effect of various suggested conveyance options.

The Saskatchewan Research Council continued research into the use of airborne photography and thermal IR to monitor potash mines and tailings ponds. The program is used to identify changes in vegetation and groundwater problems. Digital IR tapes were used to quantitatively measure the groundwater flowing into the tailings pond of a particular mine. The University of Saskatchewan (Civil Engineering) used a small

aircraft as a photographic platform for the investigation of feedlot pollution. The Canadian Wildlife Service working with Saskatchewan Wetlands Committee and the National Wetlands Committee continued to use aerial photographic remote sensing techniques to develop both wetlands classification and an hierarchical habitat mapping system.

NOAA-5 digital tapes and LANDSAT archives were used in experimentation with soil moisture and groundwater detection by the Saskatchewan Research Council and in a large percentage of its environmental and geological programs. The Saskatchewan Research Council is actively engaged in producing sensors and electronic packages for hydrological users of Data Collection Platforms. New sensors have been developed for internal monitoring of the DCP's: battery monitoring, solar panel charging rate and on-site communication using the DCP. Monitoring packages for averaging, maximum and minimum values and integration are being investigated. Computer graphics have been used for the production of monthly information.

(i) Alberta

The Alberta Department of the Environment is developing a complex water balance model for the South Saskatchewan River basin, in Alberta, to be used in assessing the impact of alternative water management schemes; and used a complex one-dimensional hydrodynamic model to study the hydraulic characteristics of the rivers and channels which control the levels of Lake Athabasca to evaluate existing structures and their effect on the lake. Data were collected on the physical characteristics and the behaviour of ice jams and studies of the regime relationships for irrigation canals in southern Alberta were conducted.

The first phase of a 5 year program to measure the rate of sedimentation in Lesser Slave Lake was completed in 1979 with collection of baseline topographic information over selected areas using the HYDAC 200 depth sounding and positioning system. Suspended sediment from the rivers contributing to the sedimentation of these delta areas is being monitored during the 5 year period and the hydrographic survey will be repeated in 1984.

The Department is introducing 30 GOES data collection platforms to its hydrometric network over the next five years to satisfy the requirements for river forecasting.

(j) British Columbia

Studies continue involving the application of natural isotope techniques to hydrological aspects of groundwater occurring in fractured crystalline bedrock in coastal areas and on surficial deposits of the southern interior of the province. Also, work continues on the analyses of rainfall distribution in mountaineous terrain which in turn will be used to estimate runoff characteristics for input to forest folios and for water supply and road culvert design. At Simon Fraser University, a second year's continuous monitoring of precipitation and runoff in a forested, an urbanizing and an urban watershed in Surrey was completed.

At the University of Victoria, a computer programme was developed to map human and natural hazards/risks as a composite dollar value: an application will be in flood zone appraisal. Dissolution of hydrocarbons in water was also studied.

In UBC Faculty of Forestry in-stream regulation of water chemistry was studied by addition of N and P to a small stream and in chamber experiments; decreases in concentration are correlated with periphyton biomass. Streamflow and water chemistry continues to be monitored on

watersheds clearcut and slashburned in 1973-74. The treatment phase was started on the Jamieson Creek experimental basin in Greater Vancouver Municipal Watershed with the initiation of forest harvesting. Effect of slash burning on water repellency of soil forms a special study.

In UBC Geography, evapotranspiration from cities, its role in urban energy balance and implications for urban water management continued to be studied. Investigations are continuing of permafrost growth on drained lake bottoms in the western arctic: ground ice development, ice and subpermafrost groundwater chemistry, pore water pressures and water movement. Pingos, ice wedges and active layer processes are under long term observation. Observations continue at Miller Creek, an alpine experimental basin in the southern Coast Mountains, with emphasis on snowmelt, water balance and water chemistry. A study of runoff regime in British Columbia from long runoff records revealed that an abrupt, geographically variable increase in runoff occurred around 1950.

The links between conceptual models of hillslope hydrology and stochastic properties of streamflow were studied. A practical outcome may be spacetime tradeoffs in precipitation-runoff data networks. The annual subglacial drainage of Hazard Lake, Yukon Territory, is being monitored by UBC Geophysics to provide data for research to develop a simulation model to predict peak discharge from glacier outburst floods.

The Civil Engineering Department studied short term streamflow forecasting of snowmelt runoff in mountainous catchments, including glacial and rain components; hydrological data network design and representativeness of point data in terms of basin wide response; optimal operation of water resource systems; use of satellite imagery to determine aerial distribution and intensity of precipitation; basic mechanisms of sediment bedload transport; and the development of a microprocessor hydrologic instrument.

B.C. Hydro conducted snowcover mapping during the freshet period by aircraft over 35 basins supplemented by imagery from weather satellites over 3 basins to provide input to runoff simulation models for short term forecasting. Since snow depth and water content cannot be determined on an aerial basis and hydrometeorological networks are sparse in this mountainous region studies continue on various methods of improving the data base and of expanding networks by retransmission of data from data collection platforms via GOES satellite.

# IX ENGINEERING GEOPHYSICS

Compiled by: P. Hoekstra

The relatively strong position of engineering geophysics in Canada was evident at the 1979 Annual Meeting of the Association of Engineering Geologists held in Chicago in October, 1979. Of the six papers presented in engineering geophysics three contributions were from Canada. A. C. Brown of the B.C. Department of Highways reviewed their routine use of geophysics. Seismic refraction and electrical resistivity surveys with magnetic induction methods are now used by the Highway Department to locate test holes and interpolate subsurface information between holes in most of their exploration programs. Mr. Brown presented impressive evidence of the cost savings from reduction in number of test holes by the Department from the use of resistivity surveys in exploration for borrow sources. Mr. McNeill of Geonics Ltd., Toronto discussed the theory of magnetic induction conductivity measurements and the substantial simplification in interpretative techniques that result from proper selection of frequency, antenna separation, and orientation in their instrumentation.

Engineering geophysics also appears to have become an accepted method in routine exploration programs, along Arctic pipe lines, for granular material inventories in areas of resource development, for mapping overburden type and depth in areas of oilsands mining.

Research and development in the use of high frequency electromagnetic sounding methods was continued at the Electrical Method Section of the GSC in Ottawa. Evaluations were made of the potential use of radar sounding for identifying changes in conditions ahead of tunneling for in-situ recovery of heavy oil.

The National Research Council commissioned Hardy Associates (1978) Ltd. to document the research needs in permafrost engineering in Canada. The document that was issued reached the conclusion about the state of permafrost engineering geophysics that many suitable techniques for surface geophysics are presently available for mapping permafrost. However, the writers of the report found a lack of education in engineering geophysics in the curriculum of the geotechnical engineer. The document also recommended development of geophysical methods for determining ice content of ground from the surface and in boreholes.

# X MINING GEOPHYSICS

Compiled by: Norman R. Paterson

A. Industry

1. Phoenix Geophysics Limited, Toronto
2. Instrumentation GDD Inc., Sainte-Foy, Quebec
3. EG & G Exploranium, Toronto
4. Scintrex Limited, Toronto
5. Sander Geophysics, Ottawa
6. Geoterrex Limited, Ottawa
7. EDA Instruments Inc., Toronto
8. Geophysics G.P.R. International, Montreal
9. Shell Canada Resources Limited, Calgary
10. McPhar Geophysics, Toronto
11. DIGHEM Limited, Toronto
12. Sonotek Limited, Toronto
13. Magnetics and Radiometrics Division, Questor Surveys Limited (formerly Northway Survey Corportion)
14. Barringer Research Limited, Toronto

B. Government

15. Geophysics/Geochemistry Section, Ontario Geological Survey, Ministry of Natural Resources
16. Resource Geophysics & Geochemistry Division, Geological Survey of Canada

C. University

17. Geophysics Laboratory, Department of Physics, University of Toronto
18. Department of Geophysics, University of Western Ontario
19. Department of Geophysics & Astronomy, University of British Columbia
20. IREM-MERI and Ecole Polytechnique, Montreal
21. Department of Geology, University of Laval
22. Department of Geology, University of Windsor
23. Department of Geological Sciences, Queen's University
24. Department of Geology and Geophysics, University of Calgary
25. Department of Mining & Metallurgical Engineering, McGill University
26. Department of Geology, Carleton University
27. Department of Geology, University of Toronto
28. Institute of Earth and Planetary Physics, University of Alberta

Compiler's Comments:

A total of 28 organizations reported activity in exploration geophysics research in 1979. With the exception of some service organizations the reporting appears to be fairly complete.

The following summaries duplicate in some respects the annual review by P.J. Hood in the Canadian Mining Journal, but the writer has tried to emphasize methodology or technique as distinct from haradware.

In general there appears to have been a substantial increase in exploration-oriented research in Canada, with no evidence of any levelling off in the near future. Organizations do not appear to be experiencing any significant shortage of research funds, but several have reported a lack of suitable staff (both in Industry and at the graduate student level in University). Petroleum companies continue to hire most geophysics graduates and there is considerable pressure on mining exploration organizations to attract geophysicists of suitable calibre.

## A. Industry

### 1. Phoenix Geophysics Limited, Toronto

A number of instrumental developments were carried out, mainly in the fields of IP and MT/AMT. Emphasis was on the application of microprocessors to IP and AMT receivers.

Field testing spectral IP equipment was carried out, including its application to petroleum exploration.

Theoretical and laboratory IP studies of the metallic-ionic interface and synthetic mineralized rocks continued.

### 2. Instrumentation GDD Inc., Sainte-Foy, Quebec

This company has developed two miniature sensors that can detect conductive material at a depth of 4-18 inches. The BEEP BOOT is worn in the operators boot and can sense a conductive boulder at a depth of about 4 inches. The BEEP CANE operates more like a mine detector and has a penetration of about 18 inches.

A depth of exploration of 6 feet for metallic objects and mineralized boulders is claimed for the EMVU (Electromagnetic Vehicle Unit) which consists of an EM transmitter and a bank of receivers mounted in a "sulky" towed by a vehicle.

The inventor, Edwin Gaucher, hopes that these devices will lead prospectors to new base metal deposits by the tracing of mineralized boulders.

### 3. EG & G Exploranium, Toronto

Most of the research of this organization is done in the United States. The Canadian group developed a small, rugged and versatile threshold scintillometer with four-digit LCD display. A relatively large (4.5 cu. in.) detector, audio alarm system and accommodation for an external crystal are other features of the instrument.

### 4. Scintrex Limited, Toronto

Scintrex is one of the more active research organizations in Canada with a full time R & D staff of 45 workers and a gross annual budget of about $1.1 million.

During 1979 development projects were under-way in the fields of induced polarization, airborne, ground and borehole EM, radiometric borehole logging and electro-optical analytical devices.

In the latter two categories progress has been made in the quantitative determination of mineral content, in-situ, for a broad range of elements. The radiometric logger is intended to give quantitative estimates of U content to very high grades. Electro-optical methods, including laser-induced fluorescence and Zeeman modulated AA spectroscopy will be used for in-field analyses of U. Sn, W, Mo, Au, Ag, Cu, Pb, Zn, Ni, Hg, etc.

Work is also in progress toward the determination of radiogenic stable lead isotopes by AA spectrometry.

### 5. Sander Geophysics, Ottawa

Work is continuing in the use of crystal-controlled clock synchronized ground magnetic stations in the levelling of aeromagnetic data. During 1979 tests were made of a Litton Systems LTN-51 inertial navigation system in the preparation of high resolution magnetometer maps.

Further improvements were made on the Sander VLF-EMII system, particularly with regard to corrections for aircraft movements and the display and interpretation of the data.

6. Geoterrex Limited, Ottawa

Geoterrex is involved with Amax, Exxon and the University of California, Berkeley, in the development of a helicopter-borne superconducting, single coil electromagnetic prospecting device. The system utilizes a 3m superconducting single coil operating at 40 Hz. A conventional Geonics EM-30 EM system will be mounted coaxially within the SCEM coil. The combination will offer deep penetration for conductive bodies and discrimination as to source conductivity and depth. The system is expected to be operational in late 1980.

The company is participating with Barringer Research and Aquitaine in the development of the COTRAN system originally invented by Barringer. The system utilizes a transmitted square wave pulse. The received signals are co-added and compared by computer with signatures characteristic of pre-selected conductor types. The method is expected to be commercially available in 1980.

7. EDA Instruments Inc., Toronto

The company is developing a new series of ground portable spectrometers and scintillometers featuring added convenience and sensitivity.

A recording base station proton magnetometer with 0.1 gamma accuracy has been developed for magnetic observatory applications.

The company is continuing its involvement with E, M & R in the development of the AMOS II microcomputer controlled "automatic magnetic observatory system".

8. Geophysics G.P.R. International, Montreal

The company has carried out experimental high resolution seismic reflection work in a variety of applications. In the Athabasca Basin the problem has been to define boundaries between media of low velocity contrast. Blasting configurations, charge sizes etc. have been found to be critical.

A combination of reflection and refraction techniques is being used in the evaluation of both industrial mineral and metallic mineral deposits.

Other work is being done on problems of an engineering nature such as the detection of underground cavities.

9. Shell Canada Resources Limited, Calgary

Shell Canada, in cooperation with Royal Dutch Shell, have developed a 3-D EM modelling program which is currently being used to study system design parameters both for the evaluation of existing EM systems and for determining the feasibility of developing new airborne EM apparatus. Tank model experiments are being done to verify the numerical results.

Field research is being done in the Athabasca Basin to test the application of a variety of geophysical methods to deep sounding.

The company is funding applied research in mining geophysics at several institutions across Canada.

10. McPhar Geophysics, Toronto

The company completed the development of the RD-500 computerized borehole radiometric logging system. Sponsored by EM&R, the development was carried out under the direction of P. Killeen, J. Conaway and A. Bristow. The real-time processed data provides continuous analogue records of ppm uranium over narrow wall intervals, as well as cumulative grade. Simultaneous hard copy and magnetic tape records can be made of 8 unprocessed channels.

McPhar is developing additional borehole probes to measure such parameters as temperature, resistivity, VLF, etc. Each probe will have an associated plug-in module for the data logging console.

11. DIGHEM Limited, Toronto

DIGHEM continued to improve its helicopter EM facility, with particular emphasis on airborne resistivity mapping. Research studies were conducted for AECL at Chalk River and Pinawa to assess the application of airborne EM/VLF to the evaluation of terrain for waste disposal purposes.

12. Sonotek Limited, Toronto

The company continued its development of computer-controlled geophysical data acquisition systems. The IGSS 2 comprises a data acquisition system with built-in magnetometer and spectrometer. Its on-board computer performs functions for which separate, dedicated sensor electronics are normally required. The LSI-II processor allows immediate in-flight analysis and graphic display of data.

13. Magnetics and Radiometrics Division, Questor Surveys Limited (formerly Northway Survey Corporation), Toronto

The company continued testing and improving computer processing techniques for "de-corrugating" airborne geophysical data. The method selectively suppresses long wavelength components in the flight line direction, with very little effect on the high-frequency signals. The process is able to treat magnetic data recorded during active diurnal conditions and gamma ray spectrometric data with inadequate background correction.

A real-time computer correction process for removing atmospheric, cosmic and aircraft background effects from the wanted geologic signals is being field tested.

14. Barringer Research Limited, Toronto

A successful series of test flights were conducted using the new COTRAN airborne EM system in a fixed wing, towed bird mode. The fully digital system operates at a fundamental frequency of 90 Hz. and combines real time and post flight digital processing techniques. Deeper penetration and better target discrimination may be possible with the system which is expected to be in commercial operation early in 1980.

Further testing of the SURTRACE technique was conducted in 1979, including a program carried out in conjunction with the Ontario Geological Survey in forested Precambrian Shield areas. The application of the system to rapid geochemical surveys in semi-arid terrain was demonstrated on a 3500 line km survey carried out in South West Africa.

Further testing and development, in conjunction with the USGS, demonstrated the application of the AIRTRACE system as a technique for hydrocarbon exploration.

B. Government

15. Geophysics/Geochemistry Section, Ontario Geological Survey, Ministry of Natural Resources

Apart from routine airborne and ground geophysical surveys of various types, the Geophysics/Geochemistry Section undertook two projects in the area of applied research.

Following intensive gravity field work in northwestern Ontario, interpretation studies were carried out on two Archean greenstone belts. Various methods of regional-residual filtering were employed and eight two-dimensional gravity models were computed. Geophysical and geological constraints were varied widely in an attempt to reconcile a maximum 500m vertical extent of a portion of the Birch-Uchi volcano-sedimentary belt with the 11,000m measured stratigraphic thickness.

A program of multi-frequency airborne EM was conducted over the southern and eastern parts of the Cretaceous basin, James Bay Lowlands. The survey technique was designed on the basis of results of a previous research project carried out over the Onakawana lignite field situated between Cochrane and Moosonee, Ontario. The study represents the first large scale attempt to use multi-frequency data in the audio frequency range for terrain mapping.

16. Resource Geophysics & Geochemistry Division, Geological Survey of Canada

(a) Resource Radioactivity Subdivision

A. A. Richardson reports that the Uranium Reconnaissance Program has now covered almost 2 million km and that publication is underway. Follow-up and interpretation is being carried out in eastern Ontario and Baffin Island, NWT. Ground-airborne rock classification correlations are being done in the Yellowknife area, and uranium disequilibium studies are being undertaken to confirm the usefulness of gamma-ray spectrometry for measuring the uranium content of Precambrian Shield rocks.

A new generation microprocessor-based portable spectral logging system, built under contract by McPhar Geophysics, is currently being evaluated. Other borehole research includes studies of the effects of borehole and formation parameters on the gamma-ray spectral log. The effects of dipping zones, borehole diameter, fluid content, casing, rock density and pore fluid content are being studied. A low noise, high precision temperature logging tool with downhole signal digitization has been developed and is currently being tested.

(b) Regional Geophysics Program

P. J. Hood has edited an 827-page volume entitled "Geophysics and Geochemistry in the Search for Metallic Ores". The volume, which is the Proceedings of Exploration 77, a conference held in Ottawa in October 1977, contains 40 papers covering the field of exploration and evaluation of mineral deposits using geophysical and geochemical techniques.

The aeromagnetic survey of Canada continues, with a total of 309 aeromagnetic maps being published during 1979. Total survey coverage in Canada from 1947 to the end of 1979 is now 7,956,067 line km. Work is underway to produce 1:1,000,000 scale digital aeromagnetic composite maps; NTS sheet 75 has been compiled.

High resolution aeromagnetic surveys, including vertical gradient measurements, were flown in Ontario and Saskatchewan, for a total of 16,000 line km. Vertical gradient measurements have contributed to research studies by AECL at Chalk River and Atikokan, Ontario.

(c) Terrain Geophysics Subdivision

Testing and evaluation were carried out of the Huntec MkIV IP system, a borehole VLF receiver developed by MERI, Montreal, and a marine resistivity system designed and constructed by W. J. Scott.

A. K. Sinha made an evaluation of the effects of topography and misorientation on a multi-frequency EM system.

A. V. Dyck developed a computer modelling procedure for the EM response of a sphere and a plate to a borehole time domain EM system.

## C. University

### 17. Geophysics Laboratory, Physics Department, University of Toronto

This Department continued to lead Canadian universities in applied geophysics research, with five faculty members and at least 15 graduate students active in exploration geophysics.

By far the largest effort is currently in the field of EM prospecting, which is under the direction of G. F. West and has the support of both Ontario Geoscience Research and NSERC grants. A. Dyck, T. Eadie, S. Holladay, J. Macnae, A. Tejero, C. Villegas, Y. Lamontagne and J. C. Mareschal are all involved on this program. The purpose of the program is to use computer and analog scale modelling methods to improve the capabilities of EM mineral prospecting methods. In particular, the methods should be able to search more deeply and discriminate better between prospective targets and geological noise. The research is divided into three categories:

(1) creating the modelling facilities;
(2) using the facilities to study various EM prospecting problems and devise interpretation methods to solve them; and
(3) studying typical field cases in detail to verify the proposed interpretation methods.

At this stage of the project a number of achievements are reported:

(1) A major facility for analog scale model studies has been established, with facilities for both frequency and time domain modelling. The system has microcomputer control and data logging.

(2) A very flexible and economic set of programs for computer modelling plate-like and sphere-like conductors is now operating on the Department of Physics VAX computer. An instruction manual for use of the program will soon be available to Industry users who can either operate the computer in the lab or connect to it by telephone.

(3) T. Eadie produced a set of interpretation nomograms for determining the electrical parameters of the overburden, using the standard horizontal loop system (Slingram). C. Villegas made a comprehensive study of the horizontal loop EM response to step-like, ridge-like and valley-like features in a conductive overburden.

(4) J. Macnae completed an extensive compilation of various geophysical surveys made on the Cavendish Township test site. He also carried out new wideband surveys there with the UTEM and MAXMIN systems.

(5) A. Dyck compiled a catalogue of type curves for borehole surveys with the Crone PEM system. He intends to continue research on this method at the Geological Survey of Canada.

R. N. Edwards and E. Gomez-Trevino carried out studies in the Paleozoic sedimentary basin of southern Ontario with a wideband (0.03 Hz to 15 kHz) EM system, developed by the Department. A direct current is reversed through a long wire bipole transmitter in a pseudo-random binary sequence. A sensitive one-component fluxgate magnetometer is used to monitor temporal changes in the magnetic field at the recorder site.

R. N. Edwards and H. Urbanski continued development of the geomagnetic depth sounding (GDS) technique to investigate the very deep structure of base metal mineral deposits. Existing appratus was modified to record geomagnetic variations in the period band 2 seconds to 5 minutes.

J. D. Redman, J. S. Holladay, C. Horne and D. W. Strangway continued audio frequency magneto-telluric (AMT) studies over test sites for water, permafrost and nuclear waste disposal. Design work has been completed on a microprocessor-based AMT tensor system, permitting on-site processing of individual transients and resolution into the tensor components. It is expected that this system will be in operation in 1980.

MT studies were carried out by D. W. Strangway and J. D. Redman in the Blind River-Elliott Lake area and in northern Saskatchewan over thick sections of highly resistive Proterozoic sediments.

All of the AMT and MT studies were done with the financial assistance of E, M & R.

J. Wong and D. W. Strangway worked on the development of an electrochemical model for the IP effect. This work, also supported by E, M & R, includes both laboratory and field measurements, as well as analytical studies.

An NSERC strategic grant has enabled G. F. West, R. N. Edwards, R. C. Bailey and G. D. Garland to carry out work on electrical methods of exploration for petroleum, uranium, coal and geothermal energy. Several of the studies conducted under this program are integrated with work reported on above. The progress of the work has been considerably enhanced by the acquisition of several terminals for accessing the Physics Department's new VAX-11/78- computer. M. Bloore, a computer science graduate, has been involved in both hardware and software development in connection with this project.

R. C. Bailey, with support from E, M & R has applied inverse theory and factor analysis to the problem of optimally determining radio-element concentration from airborne gamma-ray spectrometry.

B. Dickson and R. C. Bailey, with support from NSERC, are working on the development of automated computer methods for the detection of artificial radionucleides on the ground by airborne gamma-ray spectroscopy.

18. Department of Geophysics, University of Western Ontario

Four research studies were aimed specifically at mineral exploration problems.

A theoretical study was conducted by L. Mansinha for the interpretation of resistivity sounding data in which the kernel function is computed by convolving the apparent resistivity measurements with a forward filter. The method has been tested on synthetic two-layer curves.

Mansinha, Mwenifumbo and Maxwell carried out field and laborastory studies of mise-a-la-masse resistivity, using the Cavendish test site as model. Complex resistivity measurements were made in the laboratory of drill core samples from the same test range.

A study was made by C. J. Irvine and A. E. Beck of the potential of radioactive lead-210 as an indicator of uranium-238 of which it is a daughter product. While results on soil samples from southern B.C. compare favourably with other exploration and physical property data, the long counting time (about one day) required for the lead-210 analysis is at present a limitation to the commercial application of the method.

Paleomagnetic and heat flow studies continued at the Department and both theoretical and field experiments were conducted in seismology and seismicity.

19. Department of Geophysics & Astronomy, University of British Columbia

B. F. Jose and R. M. Ellis have investigated the piezoelectric effect in quartz-rich rock both in the laboratory and the natural environment. Initial investigations indicate that piezoelectric signals can be observed for source-target distances as large as 55m and electrode-target distances to 20m.

Field experiments were carried out by G. Mitchell and R. D. Russell to search for non-linearities in electrical ground responses. Limits have been set below those previously reported. Current work emphasizes instrumentation.

Work is in progress on the development of apparatus incorporating adaptive filters for multi-frequency IP measurements.

Inversion techniques are being applied to controlled source (horizontal current loop) EM data by Peter Fullagar and D. W. Oldenburg.

20. IREM-MERI and Ecole Polytechnique, Montreal

Work has continued on downhole VLF EM, emphasizing mechanical aspects such as microprocessor winch controller, signal conditioner and display unit.

Software is being developed for the SWP-1 microprocessor controlled IP receiver.

A data transfer system is being developed to communicate borehole X-ray fluorescence results to a large central computer. The communication will be made through a floppy disc medium with the help of a terminal unit. A large data bank is planned.

The above projects are being carried out under the direction of Marcel St.-Amant with the financial support of SOQUEM.

Research in methods of MT prospecting are continuing under the direction of Pham Van Ngoc and Alex Becker in the Department of Applied Geophysics, Ecole Polytechnique.

New AMT equipment is being built that will give the ratio E/H at 12 frequencies in the range 1-2,000 Hz. Existing MT equipment simultaneously records 4 channels in the 0.001-1,000 Hz frequency range.

A microprocessor MT unit has been designed and will be tested in 1980 that will record nine field components simultaneously at frequencies in the range 0.006-8 kHz on digital tape.

Theoretical studies in MT are being carried out by Michel Chouteau on the behaviour of MT fields incident on three-dimensional structures. The work is being correlated with the results of field studies.

21. Department of Geology, University of Laval

A one-dimensional spectral analysis has been carried out by M.K. Seguin and J. Sénéchal of aeromagnetic data from the Gaspé and Gulf of St. Lawrence regions.

Work is continuing in the development of an on-line interactive processing system for rapid and accurate interpretation of gravimetric data.

Permafrost geophysical studies have been carried out in the Schefferville iron ore mining district.

22. Department of Geology, University of Windsor

The research work of this department is in the field of paleomagnetism and has been reported on under the heading of Geomagnetism and Aeronomy elsewhere in the Bulletin.

One project is directed toward mineral exploration and is being financed under the Ontario Geoscience Research Grant program. It is a study of D.T.A. Symons, M. Stupavsky and D. Walley of the magnetic properties of iron formation from various Ontario iron mines (to date the Sherman and Moose Mountain mines) in order to:

(1) provide information to assist in the quantitative interpretation of magnetometer data over similar deposits; and

(2) lead indirectly to a better understanding of the genesis of certain Ontario iron ore deposits.

23. Department of Geological Sciences, Queen's University

D. V. Woods is reactivating the analogue borehole pulse EM system used in earlier (1974) scale modelling work. The system will be applied to research on time domain EM systems in both borehole and surface modes.

24. Department of Geology and Geophysics, University of Calgary

K. Duckworth and J. R. Panenka have developed a high resolution airborne gamma ray spectrometer featuring real time data processing and new detector techniques which permit reduced detector volume.

Analogue EM scale modelling is being directed by K. Duckworth and A. Boys at the development of new techniques for deep exploration.

A Huntec Mk IV IP receiver is being used in the field and the lab to study the effect of temperature on IP response. The work, by K. Duckworth and A. Kay, includes surveys over known mineral occurrences in Arctic areas.

25. Department of Mining and Metallurgical Engineering, McGill University

A study was conducted by R. Mathur and W. R. Telford to determine the feasibility of making useful measurements of phase difference between the E and perpendicular H components of MT fields in situ. After encouraging field results an instrument is being designed that will operate in the 1-1000 Hz range.

P. LaFleche and O.G. Jensen conducted field experiments in the measurement of wave impedance at 60 kHz to supplement standard VLF surveys. The WWVB signal from Fort Collins, Colorado was of sufficient strength to permit measurements over 6 ohm-m ground near Montreal.

J. Roy used newly designed borehole VLF equipment with microprocessor based data conversion system to compare surface and subsurface VLF fields in the Sudbury and Rouyn areas.

26. Department of Geology, Carleton University, Ottawa

J. W. Card and Keith Bell continued the development of methods for the collection of radon decay products, as a substitute for other alpha-particle detectors commonly used in uranium exploration. This research, financed under the Ontario Geoscience Research Grant program, has demonstrated the usefulness of metal and plastic collectors, both charged and uncharged, in the detection of weak radon anomalies in several test areas.

The method can be applied both in-situ, by suspending collectors in holes in the soil and, in the laboratory, using soil samples. Simplicity and low operating costs are factors in favour of the method.

27. Department of Geology, University of Toronto

Geophysical studies in this Department are under the direction of D.W. Strangway who holds a cross-appointment with the Department of Physics. Work in MT, AMT, IP etc. has already been reported on above.

A. M. Tasillo, J. Bambrick and S. Letros carried out studies of the magnetic properties of the Blake River volcanics under an Ontario Geoscience Research Grant. This work also involved the interpretation of high resolution aeromagnetic data and the development of new analytical interpretation techniques. J. Geissman joined the group in 1979 and carried out work on the collection and analysis of more than 1,000 oriented samples of Archean volcanics in the Timmins-Kirkland Lake area. The rocks include calc-alkalines, magnesium-rich tholeiites and iron-rich tholeiites. The magnetic property data are being used to establish the base levels for equivalent susceptibility maps derived from the aeromagnetic data.

The program is aimed at establishing relationships between magnetic properties and the petrology and metamorphic/tectonic history of rocks. It is hoped that the study will also result in a better understanding of the applications and limitations of aeromagnetics in geologic mapping.

28. Institute of Earth and Planetary Physics, University of Alberta

Geophysicists of the Institute of Earth and Planetary Physics, University of Alberta, are active in electromagnetic research of several types. These studies are directed mainly to investigation of the crust and upper mantle on a large scale. Electromagnetic methods are of prime importance in mining geophysics, however. Part of the work at IEPP is already applied to the search for sources of geothermal energy, and applications to mineral exploration are in prospect.

A group led by D.I. Gough uses large two-dimensional magnetometer arrays to map highly-conductive structures in the crust and upper mantle. Some of the conductive regions so discovered are related to anomalously high temperatures in the upper mantle, with partial melting and an obvious relation to geothermal sources. Regions of this kind were first discovered by magnetometer arrays in the western United States, beneath the Basin and Range Province, Southern Rocky Mountains and Wasatch Front. Extensive secondary exploration, by electromagnetic, seismic and geothermal methods, has followed. In Canada partial melting in the upper mantle is present west of the Rocky Mountain front, but the partial melt zone is thinner than in the U.S.A. Gough's group is continuing work with magnetometer arrays, both on the large scale (one array covering an area like that of Alberta) to study the subduction-related structures, and with smaller-scale arrays for detailed study of geothermal prospects. Elsewhere, other magnetometer array studies have discovered and mapped a major fracture zone in the basement linking the Wollaston Domain of Saskatchewan to the Black Hills of South Dakota and the northern end of the Southern Rockies in Wyoming. This fracture zone may have significant relation to mineralization, and a mining company in the United

States is interested in the possibility of a detailed array study of Wyoming. Dr. Gough's group has pioneered the magnetometer array as a geophysical technique, and groups in five other countries have built themselves sets of magnetometers after his design and are making magnetometer array studies of large structures related to plate tectonics. The use of the technique in mineral search is largely a matter of scale of the array. Once discovered by an array, structures can be studied using another array with reduced spacing between the magnetometers, or by magnetotelluric or other electromagnetic methods. Dr. F. W. Jones and Dr. L. H. Lam are using numerical modelling techniques to calculate the perturbation of natural electromagnetic fields by two and three dimensional electrical conductivity anomalies. Transfer functions and related perturbation and induction arrows are being calculated and their use for estimating the depth and spatial extent of such anomalies is being investigated.

# XI PETROLEUM GEOPHYSICS

Compiled By: A. E. Wren

1. Introduction
2. Field Acquisition
3. Shear Waves
4. Processing
5. Modeling
6. Migration
7. Other Research

## 1. Introduction

The level of geophysical activity in 1979 reached record crew levels in the early part of the year, tapered off in the summer but recovered in the fall, and the January, 1980 crew total is a new record 120.

The continued activity is a reflection of the oil industry momentum in Canada within the framework of escalating World and Canadian oil prices, the indications of a resumption of natural gas exports to the United States and a continuation of the Alberta Government exploratory incentive credit programmes.

Exploration Highlights of the year include the indicated successes of Dome Petroleum in the Beaufort Sea and the Petro-Can-Chevron-Mobil-Texaco group successes on the East Coast, particularly the Hibernia discovery. In both cases these are geophysical successes.

1979 was a year of geophysical consolidation rather than one of innovation and breakthrough although there are strong indications of "sleeping giants" awaiting a breakthrough. These include 3-D techniques and shear waves in combination with Vertical Seismic Profiling (V.S.P.).

In general terms the overall emphasis is maintaining the shift to higher resolution and wavelet processing as pre-conditioners for inversion of the seismic trace into a pseudo-acoustic impedance log. Seismic stratigraphy in both the macro - and micro - sense is well established. In this area interactive modeling has seen rapid acceptance, providing a focal point for both geologists and geophysicists.

## 2. Field Acquisition

In traditional seismic field recording procedures there have been certain basic parameters that were varied in generating optimal field record quality. These include near and far trace offset, the seismometer array, the charge size and depth, the shot-hole array, the multiplicity (or fold), the sample rate and the recording filter(s).

With present day recording capability - 1,000 channels, instantaneous floating point amplifiers and the ability to involve any geometry - great care must be taken to optimise the field parameters. Also, since reflection attributes are now as important as reflection times, the effect of recording parameters on reflections must be considered. Field parameters must therefore be designed around known characteristics of target geological formations, with coherent noise better handled in the computer.

While source and receiver arrays have traditionally been used as spatial filters for the reduction of horizontally propagated noise, they also should be examined in terms of high frequency signal distortion.

Field data monitoring with a microcomputer in the recording truck now provides an immediate analysis of source and receiver arrays, frequency analysis and noise spreads. Software is available to handle statics and normal move - out and generate a new stack section.

In sign - bit recording only the sign (±) bit of the geophone output is recorded. Therefore there is only one bit per sample. This approach is now well established in areas of very poor S/N ratio. High redundancy will also provide proper amplitude recovery.

Mini seismic sources such as Mini-Sosie are now accepted for shallow high resolution exploration. A recent innovation is the use of a standard 8 gauge industrial shotgun which has provided a bandwidth of 25 - 200 Hz in shallow work.

In the marine environment new streamer modifications include modules in the cable which house the IFP amplification and analog to digital conversion, reducing the number of active analog pairs in any part of the cable to 14. The number of channels is now commonly 192 and 480. This provides improved high frequency and better resolution of the shallow section.

Recent Canadian Foothills seismic was done by having the recording system in an aircraft maintaining a high altitude over the general recording area. This radio - telemetry of multichannel data contributed to high daily production rates and data with substantial noise reduction.

3. Shear Waves

There is a new surge of interest in shear wave techniques although the basic problem remains the generation of shear waves. Various methods are available including shear - wave vibrators and horizontal hammers with specially designed shear wave seismometers. In this environment the normally recorded compressional (P) wave becomes undesirable noise.

The main attraction of the shear wave method is that in combination with P - wave data it will provide information on lithology, rock properties and the possible delineation of saturation and fluid types.

4. Processing

Modern interpretation of seismic data relies less on mapping of key horizons and aims more at detailed analysis of geological invironments. This requires appropriate field parameters, increased bandwidth and amplitude reliability. Stratigraphic exploration, wavelet processing and inversion have generated the need for alternate deconvolution methods.

The conventional model of the seismic trace is that it can be decomposed into a wavelet and a spike series. Wavelet processing involves the estimation, extraction and shaping of seismic wavelets. Pre-stack wavelet processing usually involves shaping the source wavelet into a stable form and also making the effective waveshape the same when using data recorded with different equipment at different times. Post-stack wavelet processing is directed at extracting and compressing the seismic wavelet to produce wide - band signal sections. The data may then be used for detailed interpretation and in the generation of synthetic acoustic impedance logs. Wavelet processing provides maximum resolution zero - phase sections.

5. Modeling

Interactive modeling is now firmly established as an interpretive tool. The time response for any geological depth model may be generated by using asymptotic ray series solutions to the elastic wave equation.

Important processing parameters such as stacking and migration velocities can be determined. The approach is partaicularly appropriate for subtle stratigraphic traps. Seismic modeling, zero - phase processing and high resolution have all combined to facilitate the search for stratigraphic traps.

The seismic interpretation of structures usually involves the identifying and mapping of marker reflections. However, forward (direct) modeling has shown that it is very difficult to map the complex reflections images that arise from geological structures. Inverse modeling by ray techniques offers the potential of computing a structure in the depth domain where it is relatively easy to evaluate a structural target.

## 6. Migration

Conventional source and receiver arrays have little directional effect. Far stronger directional effects can be simulated through a combination of successive field stations as in plane wave methods.

Wave equation migration was introduced by Claerbout by means of a finite difference algorithm. There are many recent improvements. Schneider has presented an alternative approach to wave equation migration involving Kirchoff summation. The non-recursive nature of this approach makes the method less suitable for lateral variations in the propagation velocity of the subsurface. Stold and Gazdag introduced migration in the wavenumber - frequency domain. This method is fast and elegant but not suitable for inhomogeneous media. It is a natural extension of conventional summation type techniques. In summation migration, a dipping reflector is shifted from its point of tangency with a diffraction hyperbola to the apex of that hyperbola. In F-K domain migration, the seismic section is first transformed from the time - space (T-X) domain into the F-K domain via a 2-D Fourier transform. This transformation automatically defines and isolates discrete dip components. Each point in the F-K plane can be assigned a dip value. When a discrete dip is known, the point of tangency of this dip with a diffraction hyperbola can be calculated exactly. Migration then consists of shifting this dip from its point of tangency to the apex of the diffraction hyperbola.

The object of migration is to focus seismic events, place them in their correct position and remove amplitude distortion. The migration technique must be capable of accounting for both vertical and lateral changes in propagational velocity.

## 7. Other Research

Numerous other topics may be briefly grouped under this general heading. They include 3-D acquisition and processing techniques; the conversion of electrical logs to pseudo - velocity logs; research into statistical and structural pattern recognition; research into better deconvolution and wavelet estimation; continued research in rock properties and their seismic response; statics; the effects of pore fluids in seismic attenuation and velocity.