Energy, Mines and Resources Canada
Earth Physics Branch

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

CANADIAN GEOPHYSICAL BULLETIN

BULLETIN CANADIEN DE GÉOPHYSIQUE

Volume 31

December/décembre 1978
Ottawa, Canada

CANADIAN GEOPHYSICAL BULLETIN/BULLETIN CANADIEN DE GÉOPHYSIQUE • Vol. 31 Dec. 1978

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Volume 31

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

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

December/décembre 1978
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 sequence of chapters has been modified this year to provide a more rational grouping of related topics. The Exploration Geophysics chapter has been discontinued in its earlier format, being replaced by three new chapters on Engineering, Mining and Petroleum Geophysics respectively. These new chapters are, of necessity, quite short this year, but growth commensurate with the great importance of these areas is envisaged.

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 again this year of Ms. M.S. Bradfield, Ms. T.L. Harris and Ms. J. Wagner 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 (Volumes 29 and 30) should request these from:

Publications
Earth Physics Branch
Department of Energy, Mines
and Resources
1 Observatory Crescent
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There is no charge for the Bulletin, but the Canadian National Committee appreciates receiving similar national or international reports in exchange.

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.

La suite des chapitres a été changée pour cette année avec l'intention de fournir un groupement plus logique des sujets alliés. Le chapitre d'exploration géophysique a été discontinué dans son format précédent étant remplacé par trois nouveaux chapitres sur l'ingénierie, l'exploitation minière et géophysique d'exploration des pétroles respectivement. Ces chapitres sont, de nécessité, très courts cette année, mais on envisage leurs développements en même mesure que la grande importance de ces disciplines.

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, Md. T.L. Harris, et Md. J. Wagner 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 (volumes 29 et 30) doivrent être acheminées au:

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Direction de la physique du globe
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1 Place de l'Observatoire
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Le bulletin est offert à titre gratuit, mais le Comité National du Canada apprécierait recevoir en retour, des rapports semblables des sources nationales ou internationales.

M.E. Evans
Rédacteur en chef

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ISBN: 0-662-50383-X

ISSN: 0068-8819

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ISSN: 0068-8819

I(A) GEODESY

Compiled by: D.E. Wells

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1. Geodetic Survey of Canada

(a) Horizontal Positioning

Primary and lower-order geodetic coordinates were determined or reobserved at some 1415 stations using either conventional methods (trilateration and traversing) (203 stations), satellite Doppler positioning (98 stations) and positioning by inertial methods (1114 stations). Astronomical observations for Laplace and/or deflection of the vertical were carried out at 31 stations.

A trilateration survey to increase the density of horizontal control in the greater Edmonton area was completed. The first-order triangulation network in the vicinity of Prince George, B.C., was strengthened to provide control for provincial surveys. Six stations in the first-order triangulation network near La Malbaie, Québec, were reoccupied as part of a study of crustal movement across the St. Lawrence River. The inspection and renovation of some 100 primary stations in Prince Edward Island, New Brunswick, Nova Scotia and Québec were carried out. Some 3500 km (about 170 stations) of conventional second-order traversing in the area north of latitude 64° and west of the Mackenzie River were completed. Scale control for the Yukon-Alaska boundary triangulation network north of latitude 65° was provided by measuring 7 distances in that network. Satellite Doppler positioning was carried out in Yukon (9 stations), British Columbia (7 stations), Saskatchewan (28 stations), Manitoba (2 stations), Québec (19 stations), Baffin Island (25 stations), Coats, Mansel and Walrus Islands (4 stations) and along the Canada - U.S. border (3 stations reobserved). Positioning by inertial techniques was carried out in Québec (76 stations), Northern Ontario (159 stations), Saskatchewan and Alberta (826 stations) and Manitoba (53 stations). Inertial techniques were also used to provide horizontal control on the Columbia Icefield, B.C., in connection with a project financed by Fisheries and Environment Canada and Indian and Northern Affairs Departments.

Mekometer baselines used to calibrate distance measuring survey instruments were remeasured to check the stability of piers in Moncton, N.B., Mississauga, Ont., Winnipeg, Man., Saskatoon, Sask., Calgary, Alta., and Victoria, B.C. Some 31 Laplace and/or astrogeodetic deflection stations were observed or reobserved in Québec, Ontario, Manitoba, Alberta, British Columbia, North West Territories and Yukon.

(b) Vertical Positioning

Over 2975 km of new first-order levelling and 3080 km of first-order re-levelling were completed. Lower-order vertical control for mapping was established in many areas using spirit levelling, conventional altimetry and the Ground Elevation Meter (GEM) system. The following first-order levelling projects were carried out during the year: a 315 km line from Wrong Lake to Hole River to Berens River area, Manitoba; 490 km of lines

in the Brantford-London-Chatham and Wingham-Atwood-Mitchell-Goderich areas of Ontario; a 20 km line re-levelled twice during the year in Inuvik, N.W.T., to monitor the behaviour of various types of benchmarks in permafrost; a 630 km line re-levelled along the Alaska highway from Whitehorse, Yukon, to Tetlin Junction, Alaska; gravity measurements were carried out along the Alaska Highway in cooperation with the Earth Physics Branch; a 650 km line along the Dempster Highway from Dawson, Yukon, to Arctic Red River, N.W.T.; 160 km and 40 km special-order levelling lines from Port Alberni to Tofino and in Strathcona Park respectively, B.C.; a 100 km line from Campbell River to Kelsey Bay, B.C.; 300 km of lines in the Edmonton network; a 400 km line from Edmonton to Calgary; 370 km of lines in the Regina area; a 180 km line from North Battleford to Saskatoon; a 110 km line from Noranda to the Ontario border, Québec; a 150 km line from Sorel to La Prairie, Québec; a 150 km line from Ste-Anne-des Monts to New Richmond, Québec; 20 km of line in the East Richmond and North Troy, Vermont, area to tie to the U.S. network; a 160 km line from Mont Joli to Matapedia, Québec; a 160 km line from Campbellton to St. Leonard, New Brunswick; 800 km of lines relevelled in the Moncton-Fredericton-Plaster Rock area, New Brunswick.

Lower order spirit levelling was carried out in Saskatchewan and Southern Alberta for vertical control at 47 and 40 ISS control points. Conventional altimetric traversing was carried out in Northern Ontario (2600 km), Northern Manitoba (3500 km) and Baker Lake area, N.W.T. (3000 km). Ground Elevation Meter measurements were performed in Québec and New Brunswick.

(c) Data Processing and Banking

Preparation for the readjustment of North American horizontal geodetic networks was continued (McLellan 1978). The analysis of the October 1977 test adjustment on a geocentric system was completed (Beattie et al. 1978). Further adjustment and analysis of the satellite Doppler network was carried out (Boal and Kouba 1978). The processing of ISS and satellite Doppler data was continued (Boal and Junkins 1978). The development and documentation of processing programs ISSPOS, GANET and GDLSAT were completed.

The secondary networks integration project was continued (McLellan et al. 1978). Recent estimates indicate that Geodetic Survey will be responsible for the readjustment of approximately 80,000 secondary and lower-order points out of a total of 215,000 for the whole of Canada.

The assembly of geodetic data for the data bank was continued (Gareau 1978). Some 114,000 stations are now on the data bank and 89% of these have been audited and are available for distribution. The inventory of lower order networks was continued.

(d) Research Activities

Problems associated with datum for the NAD1983 Redefinition were reviewed following results from the October 1977 test adjustment of Canadian horizontal geodetic networks (Kouba 1978). Geodetic Survey is working closely with the U.S. National Geodetic Survey in this matter and a preliminary joint report is under preparation. The study of inertial reference systems and their applications in geodesy and geodynamics was continued (Blais 1978a). Research into the estimation of geoid undulations and deviations of the vertical using a combination of satellite dynamic (geopotential coefficients), surface gravity and astrogeodetic data was pursued (Lachapelle 1978a; Lachapelle and Tscherning 1978). In connection with this, 1^{o} X 1^{o} mean free air gravity anomalies were evaluated using surface gravity data and mean topographic elevations of blocks of various sizes (Lachapelle 1978b). The

estimation of deviations of the vertical in the Rocky Mountains using a method based on a combination of topographic-isostatic deviations and geopotential coefficients has been initiated. GEODOP doppler reduction software was tested and compared with the U.S. National Geodetic Survey software (Kouba and Hothem 1978). Results indicated that, under similar conditions, the programs give identical results within 20 cm (1σ). An analysis of static tests on the Inertial Survey System carried out by Geodetic Survey was conducted by the Department of Surveying Engineering of the University of New Brunswick in order to gain a better understanding and to improve the accuracy of the system. Geodetic Survey participated in four VLBI-Doppler experiments between Canadian, U.S. and British radio observatories. Results are likely to contribute to the definition of the NAD1983 datum. The error analysis of geodetic and photogrammetric least squares adjustments was pursued and results are reported in Blais (1978b). The Geodetic Survey Study Group on the redefinition of the vertical reference system pursued its work. A major part of the research arising from this redefinition was contracted out. A critical study of field procedures was carried out through contract. The status of the redefinition of the vertical reference system is described in Lachapelle (1978c). The automation of the data of Geodetic Survey's 100,000 km of first-order levelling lines has been initiated and is expected to be complete within five years. The direct recording of field observations in an automated form is being investigated.

The system for handling Doppler and ISS field data was improved by the addition of hardware and the development of related software. The new system enables Satellite Doppler field data recorded on digital cassettes or paper tape to be majority voted and entered on 9-track magnetic tape for further processing on a larger computer. Similarly, ISS observed data can be quickly transferred to magnetic tape for final processing on a large machine. Specifications for station establishment by ISS were developed. The investigation of benchmarks in permafrost was continued; analysis of data at Inuvik indicates that wooden piles provide the most stable benchmarks. Development of an automatic transit detector was undertaken to improve accuracy and reliability of astronomic observations. Practical methods to observe second-order astronomical azimuths in the north were investigated. In connection with this, a special prism attachable to a DKM3-A theodolite for sun observations was investigated. The monitoring of the precise National Baseline, Ottawa, was continued by the use of invar tapes and the Mekometer. A movement of approximately 3 millimeters of one pier over the past 4 years has been confirmed. A study of the stability of the Mekometer was also carried out.

2. National Research Council, Divison 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 B-27, and is identical for the three CHU frequencies 3,330 kHz,

7,335 kHz and 14,670 kHz. A series of bulletins TF-B- announce relevant changes, such as 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, CsVI 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 1×10^{-14}.

3. Bedford Institute of Oceanography

(a) Integrated Navigation

Development of production versions of the BIONAV integrated navigation system was completed. BIONAV has been used with passive ranging LORAN-C, satellite navigation, ship's log and gyrocompass, and the Mini-ranger, DECCA and Omega radio positioning systems. BIONAV output options include moving head disk, floppy disk, magnetic tape, tape cassette, tape cartridge, paper tape, and hard copy terminal and video monitor display. BIONAV was installed on CSS PARIZEAU in November and will be installed on CSS HUDSON early in 1979.

(b) Phase Prediction and Performance of LORAN-C

Loran-C phase measurements have been made on land at surveyed points, and at sea positioned by Miniranger (20 m accuracy) or satellite navigation (150 m accuracy), over a large area of the Maritime provinces and their continental shelf. Field analysis showed ± 0.1 μs repeatablility on land. Variations in phase with the type of land along the propagation path are in the process of being analyzed.

4. Canadian Hydrographic Service

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.

5. Université Laval

Des mesures par nivellement géométrique se sont poursuivies à l'Observatoire géophysique de Charlevoix dans le but de développer une méthode de surface pour évaluer les variations à long terme de l'inclinaison de la croûte terrestre. Les mesures ont été faites mensuellement sur un ensemble de huit repères ancrés dans le roc et disposés sur un cercle de vingt mètres de rayon. La méthode d'observation qui a été dévelopée a permis de définir la position relative des repères avec une précision de l'ordre du microradian. L'analyse des variations d'altitude en fonction du temps a été faite à partir d'un modèle mathématique (sinusoide caractéristique) basé sur l'hypothèse que le site d'observation se comporte comme un panneau rigide. Ce modèle explique assez bien les variations à court terme mais on devra poursuivre les mesures

pour l'analyse des variations d'inclinaison à moyen et à long terme (Gagnon et al., 1978). Une analyse comparative sera entreprise en 1979 avec les résultats obtenus par la division de Physique du globe, EMR, à l'aide d'un inclinomètre localisé dans une voûte sur le même site.

Une étude des propriétés géométriques fondamentales des ellipsoides confocaux à trois axes et leur application à la géodésie utilisant la géométrie différentielle et l'algèbre tensorielle est en voie de réalisation (Mazaachi, 1978). Cette étude traite du calcul des paramètres fondamentaux de courbure et identifie les principaux systèmes de coordonées utilisables. Pour chaque système de coordonnés, les lois de transformation sont décrites et une attention particulière est donnée au système géodésique parallèle.

Le projet sur la modification et l'amélioration du mode de prise de mesure et l'automatisation du calcul et de l'analyse de la mesure de la ligne de base de l'Université Laval a été complété. Le chainage de grande précision de cette ligne de base peut maintenant être effectué par section indépendante de 48 mètres. La fréquence de vérification a pu être ainsi augmentée et la longueur de la base a pu être établie avec une précision de $1/10^6$.

Le projet sur l'élaboration d'une méthode de calibrage rapide et précise des rubans d'acier ou d'invar a été complété (Jobin et Van Chestein, 1978). Des montages spéciaux ont été installés en permanence au laboratoire de métrologie. La réduction des mesures et l'analyse de la précision ont été automatisées et sont effectuées à partir d'un terminal APL. Les rubans peuvent être calibrés très rapidement avec une précision de l'ordre de 10 micromètres.

6. University of New Brunswick

Research continued on the use of inertial systems for geodesy and surveying. Special emphasis was given to the study of errors in the data acquisition process and their correlations. This resulted in a number of stationary tests performed in collaboration with the Geodetic Survey of Canada and in a comprehensive computer simulation for local-level and space-stabilized systems. Gyro drifts, accelerometer biases, quantizer errors, heading sensitivity, and the effects of Kalman filtering were among the phenomena investigated either by system tests or by simulation studies. The determination of deflections of the vertical by inertial systems has been analysed and results indicate that systematic errors are introduced by the Kalman filtering procedure. Alternative mathematical models are under study.

Numerical methods related to the determination of the earth's gravity field received some attention. The use of least-squares collocation models in physical geodesy is discussed in Schwarz (1978). The application of regularization techniques for improperly posed geodetic problems was also investigated.

A thorough investigation of discrepancies between old and new primary geodetic levelling in Canada has commenced. Practical aspects include recomputations using more rigorous models for gravitational, refraction, earth tide and ocean loading corrections. Simultaneously, a review of theoretical developments in weight estimation have been presented. Considerable progress has been reported in determination of Canadian crustal movements based on investigations of sea level variations.

Work continued on the design and analysis of geodetic networks using interactive computer graphics (Nickerson et al. 1978). The sequential algorithms used in the software have been expanded to allow greater flexibility of data entry/removal (Nickerson 1978). The use of this tool in the mathematical maintenance of geodetic networks also received some attention.

Research has been carried out into the testing for outliers in observations and in the assessment of unkown parameters. A link has been established not only between univariate and multivariate testing for outliers but also between testing in observation space and testing in parameter space (Krakiwsky 1978).

A cooperative research project has just been completed involving the Department of Surveying Engineering, University of New Brunswick, and the Surveys and Mapping Branch of the Province of Manitoba in which all geodetic information in the Province has been catalogued and assessed. It was found that there is over 100 million 1978 dollars worth of such data that need to integrated into one homogeneous system.

7. York University

Research at York University is continuing in the application of long baseline interferometry (LBI) to geodesy and geodynamics (Cannon 1978, Cannon et al. 1979). A number of simultaneous LBI-satellite Doppler observing sessions were carried out beginning in May 1977 to investigate the differences in scale and orientation of the coordinate systems involved. LBI observations were conducted with a three element interferometer composed of antennae at Lake Traverse, Ontario, Big Pine, California and Chilboton, England. At each of these sites, satellite Doppler receivers were set up within about 100 m of the LBI antenna. Preliminary results from the first observing session indicate a difference in scale between the LBI coordinate system and the NSWC 9Z-2 coordinate system used for the satellite Doppler reductions of 0.5 +/-0.1 PPM. The difference in orientation of the zero meridians of the two coordinate systems was found to be +0.97" +/-0.01".

A pilot project to use LBI to make high accuracy measurements of earth rotation parameters is now underway. The major innovation setting this system apart from other similar efforts is the inclusion of a scheme to accurately monitor local oscillator drifts using two way transmissions through the Anik B communications satellite. The purpose of this innovation is to eliminate the troublesome possibility of mistakenly interpreting oscillator drifts as real geophysical effects.

8. Canadian Petroleum Association - Surveying and Mapping Committee

(a) Surveying and Mapping

Surveying and mapping conducted for the petroleum industry has been oriented over the past year towards specific application projects. Inertial systems and doppler satellite receivers have been used far more extensively on industry related projects. In mid 1978 Shell Canada Resources Ltd. acquired two high precision Inertial Survey Systems (ISS) from Ferranti in Scotland. In late 1978 those systems were successfully used to establish positions in Alberta, British Columbia and Quebec. The co-ordinates obtained from these systems have been used in providing the ground control for 1:20,000 mapping. Extensive calibration tests are conducted on a E-W and N-S baseline established for that purpose near Calgary, as a means to refine and develop further system capability. An accuracy of one metre (1 sigma) is now achievable, however improved results should be available in the near future.

(b) Data Base Systems

Considerable work has been done by industry in developing data base systems together with interactive graphics. Several systems now in place offer a smooth data flow from storage to map retrieval.

(c) Arctic Island Ice Movement Studies

Doppler satellite systems are now extensively used to detect ice movements of one metre or more on a daily basis, during the winter season. Fourteen such unmanned ice shelters were deployed throughout the Arctic Islands during 1978. Each station can operate unattended for several weeks and the data collected can be retrieved without visitation by the utilization of an interrogation device that dumps the positional data upon an aircraft passing within line of sight of the station. This operation is carried out by Shell Canada Resources Ltd. under contract to Panarctic Oils Ltd.

(d) Research Activities

Considerable inhouse software development is being carried out by Shell associated with inertial systems and doppler satellite techniques. In December Shell successfully mounted the GEODOP program upon an HP 2100 computer with 256k words of memory. This system is now operational and can produce high precision results during the actual field operation.

Industry is also participating on several study groups regarding transmission of digital data by satellite.

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1(B) GRAVITY

Compiled by: J.G. Tanner

1. Introduction

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

2. Earth Physics Branch

(a) Gravity Standards

The National Gravity Net has undergone major editing during the past year based on data and information acquired during the inspection surveys carried out between 1973 and 1978. As a result some 2200 obsolete or destroyed control stations have been deleted from the data base. The revised net now consists of control stations about 90% of which have printed descriptions available through the Gravity Data Centre. The 1978 field inspection contract involved updating and extension of the network in northern Alberta, British Columbia, the southern Yukon and the southwestern portion of the district of Mackenzie.

International activities in gravity standardization included assistance to the Instituto di Miniere e Geofisica Applicata, Trieste in the adjustment of the national gravity net for Italy and the adjustment of a regional vertical motion net in the Fruili earthquake region. The Latin American Gravity Standardization Net 1977 (LAGSN77) compiled and adjusted by the Earth Physics Branch was reviewed by the World Gravity Standards Working Group and endorsed as an international reference standard at the September 1978 meeting of the International Gravity Commission. Activities related to the maintenance of IGSN71 included the completion of compilation and printing of updated station descriptions from material received from some 40 countries over the past two years.

Studies in the theory and analysis of error distributions carried out in the last two years in collaboration with a scientist of the National Research Council were published in two papers.

(b) Gravity Data Base

The conversion of the Gravity Anomaly File to System 2000 has been completed and the new system put in production in June 1978. Although operating costs remain about the same as with the earlier in-house data management system, reduced software maintenance has resulted in a saving of several man-months of programmer time.

A new file known as the Digital Terrain File has been added to the National Gravity Data Base. This file, which is designed to provide data for the computation of regional terrain corrections in mountainous areas presently consists of some 400,000 elevation picks on a 1 km grid in southern British columbia.

(c) Gravity Map Production

Six new open file gravity maps and one new map in the gravity map series were released during the year. Details concerning type of map (Bouguer and/or free-air), map scale and location can be found in the biliography.

(d) Gravity Surveys

More than 5100 new static gravity stations were occupied in 1978 over the Canadian mainland and off-shore areas and more than 36,000 line kilometres of shipborne gravimeter profiling were logged in Hudson Bay and in the west coast offshore area.

(i) *British Columbia, Alberta, Yukon*

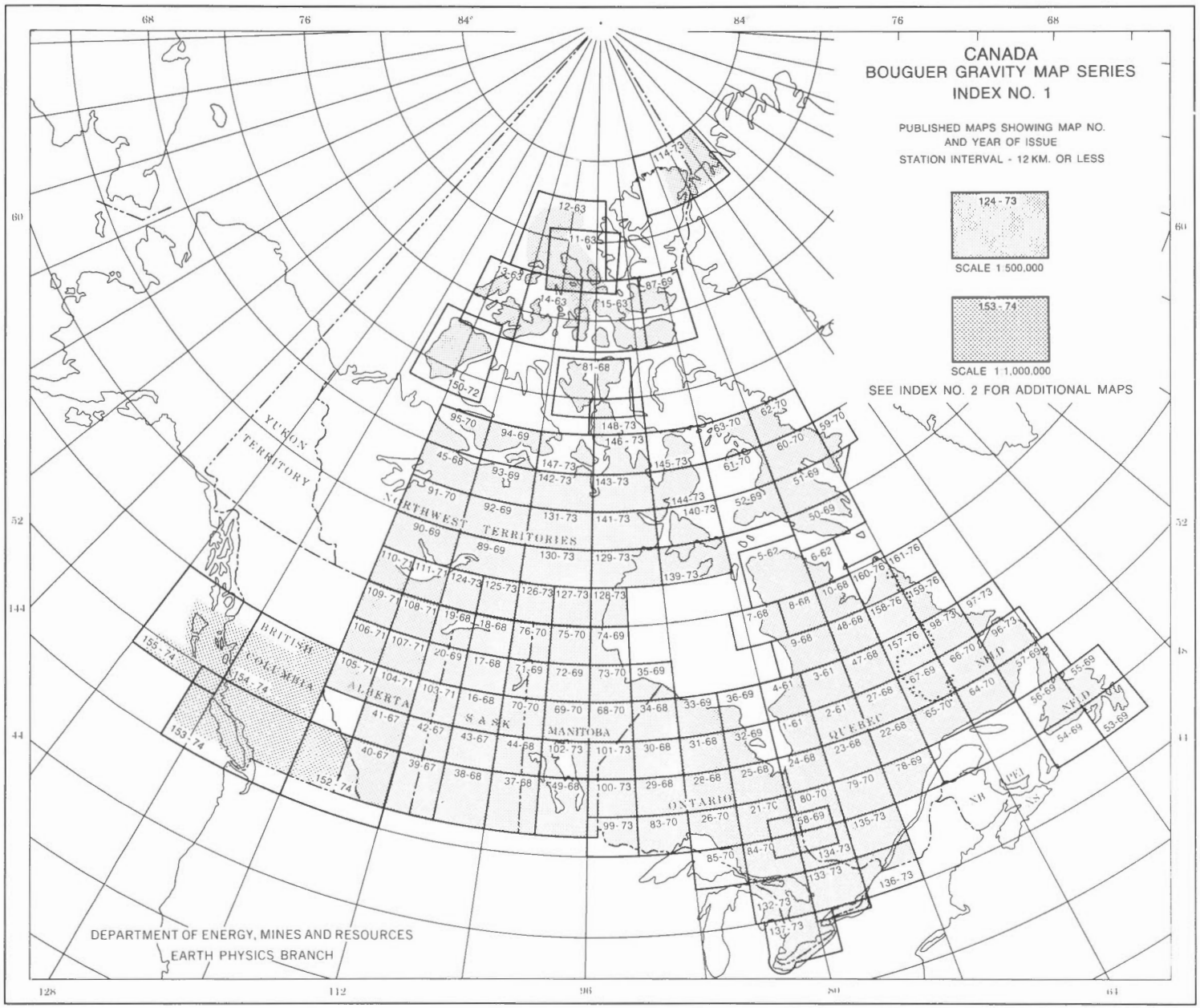
In July and August approximately 15,000 line kilometres of shipborne gravimeter measurements were carried out in an area west of the Queen Charlotte Islands and in the adjacent area of Dixon Entrance. The cruise was carried out in co-operation with the Canadian Hydrographic Service, Department of Fisheries and Environment. Average line spacing was 6-10 km.

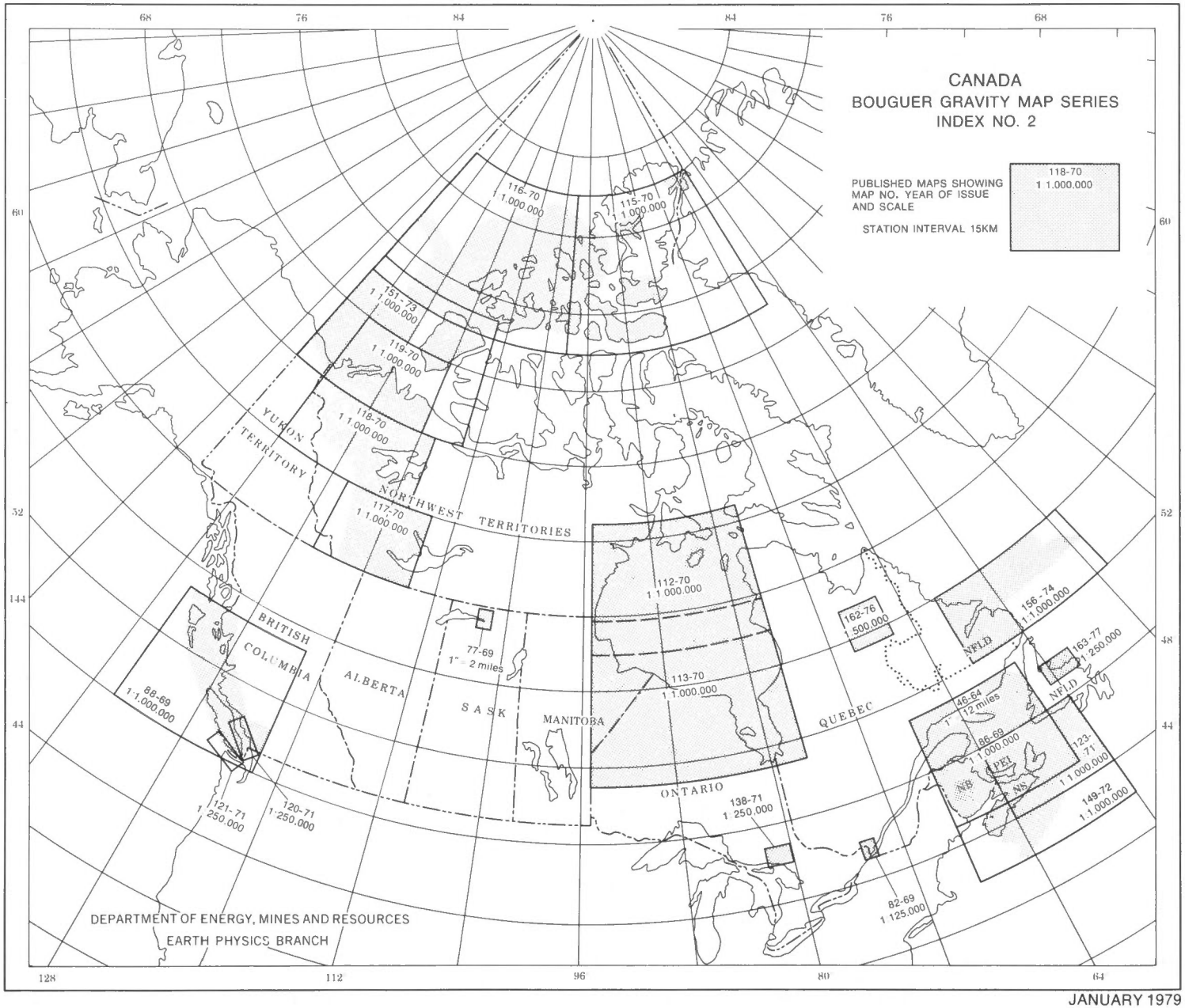
Approximately 300 new gravity stations were observed in the Rocky Mountains during the first year of a three year contract. The prime objective of this survey was to complete the 12 km station spacing for an area between latitudes 49° and 51° and longitudes 114° and 120°. A point of interest in this survey was the use of a helicopter-mounted inertial survey system to determine the latitude, longitude and elevation of gravity observation points.

In support of a requirement for the Geodetic Survey, Surveys and Mapping Branch, EMR, more than 1400 gravity observations were made by contract at precise level bench marks and associated precise elevation points along the Alaska Highway between Fort Nelson, British Columbia and the Alaska-Yukon boundary. Station spacing along the route was 1-3 km.

(ii) *Northwest Territories*

A helicopter-supported survey of the eastern half of Viscount Melville Sound observed more than 1200 gravity stations on the ice. Average station spacing was 6 km.


CANADA
BOUGUER GRAVITY MAP SERIES
INDEX NO. 1
PUBLISHED MAPS SHOWING MAP NO.
AND YEAR OF ISSUE
STATION INTERVAL - 12 KM. OR LESS
124-73
SCALE 1:500,000
153-74
SCALE 1:1,000,000
SEE INDEX NO. 2 FOR ADDITIONAL MAPS
YUKON TERRITORY
NORTHWEST TERRITORIES
BRITISH COLUMBIA
ALBERTA
SASK
MANITOBA
ONTARIO
QUEBEC
NFLD
DEPARTMENT OF ENERGY, MINES AND RESOURCES
EARTH PHYSICS BRANCH
JANUARY 1979



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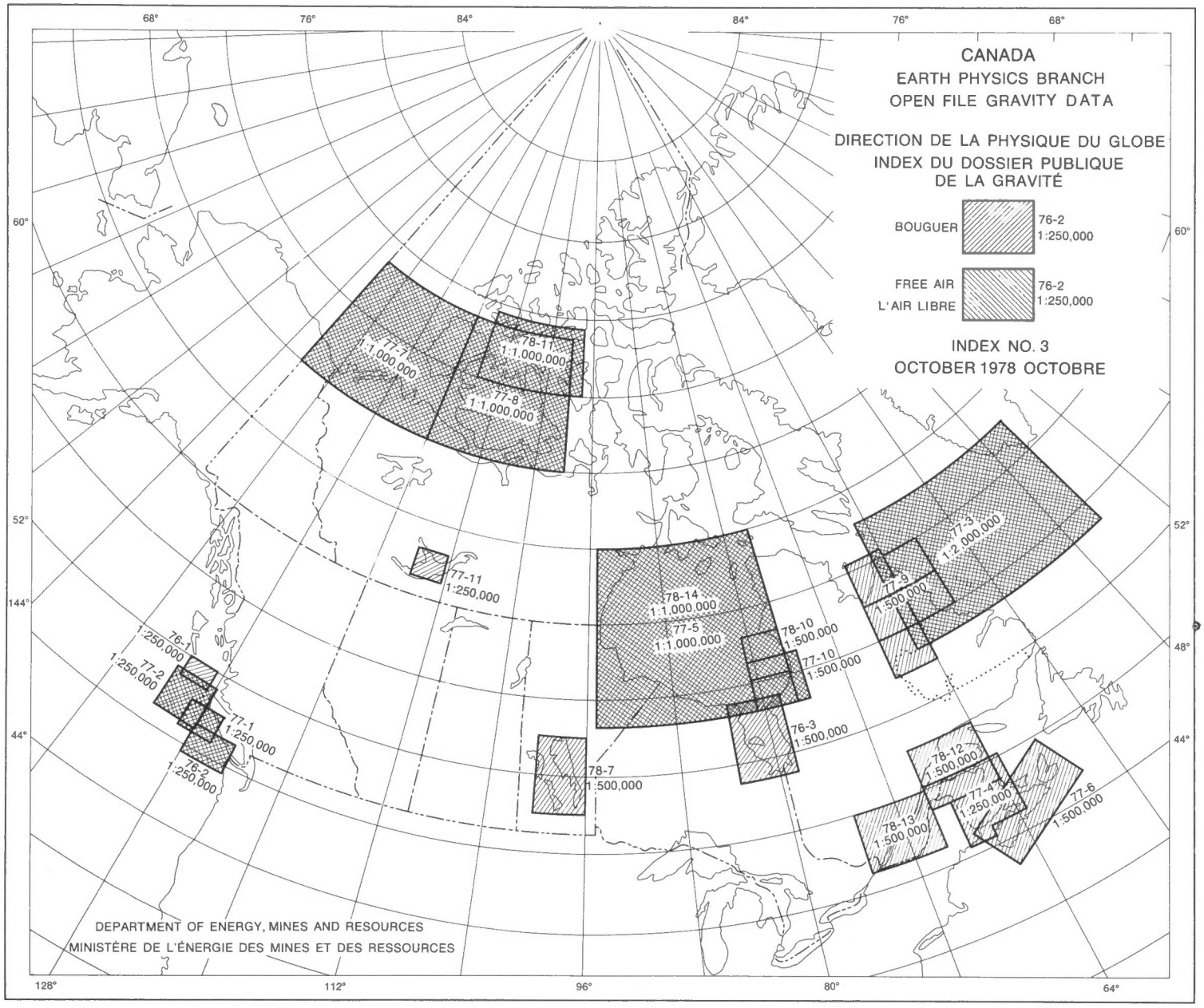
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OPEN FILE GRAVITY DATA
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INDEX DU DOSSIER PUBLIQUE
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BOUGUER
76-2
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DEPARTMENT OF ENERGY, MINES AND RESOURCES
MINISTÈRE DE L'ÉNERGIE DES MINES ET DES RESSOURCES

(iii) *Hudson Bay*

A 68-day cruise in Hudson Bay by the CSS Narwhal completed more than 21,000 line-kilometres of gravity profiling. This cruise completes that portion of the regional reconnaissance gravity survey of Hudson Bay to be done using shipborne instrumentation. The overall line density is now generally closer than 10 km, except in areas of the littoral zone where further surveys on the ice will be needed to complete gravity coverage of the entire bay.

A co-operative survey involving the Canadian Hydrographic Service and the Ministry of Transport produced approximately 1200 stations at 6 km intervals on the frozen surface of Hudson Bay, north and east of the Belcher Islands. Helicopters were used to provide transportation.

(iv) *Manitoba*

A contracted survey of Lake Winnipeg using helicopter transportation during February and March completed nearly 700 gravity observations throughout the full length of the Lake. Stations were located at 6 km intervals.

(v) *Nova Scotia*

A three week car-supported survey in August saw the completion of 6 km regional gravity coverage of Nova Scotia. About 270 new gravity observations were made.

(e) Gravity Interpretation Studies

In 1978 gravity and related studies were carried out in five main areas as follows:

(i) *Sedimentary and Ocean Basins, Arctic Canada*

Arctic Ocean (Tectonics)

A special Earth Physics Branch study of Arctic geophysical data has been published. This new volume, "Arctic Geophysical Review", first reviews the history of geophysical measurements made in Arctic regions. It then reconstructs the development of the Arctic Basin using these measurements and the major tectonic relationships as constraints. The 108 page review is divided into nine subjects: bathymetry, seismicity, heat flow, magnetotellurics, geomagnetism, gravity, crustal structure, topography of the Alpha Ridge and the evolution of the Arctic Basin. The summary combines and correlates the collected geophysical information and offers an analysis of Arctic Basin structure and morphology. Included are four large 1:7,500,000 maps of the north polar regions that show bathymetry, seismicity, observed/predicted free-air gravity and residual free-air gravity north of 60°N.

Arctic Ocean (Bathymetry)

A further discussion of the detailed bathymetry of the Arctic Ocean north of 85°N latitude has been completed. This manuscript has been written as a result of criticism of an ealier publication on the same subject.

Sverdrup Basin

Two detailed gravity profiles with station intervals of about 1.5 km (one about 500 km long along the axis of the basin and the other about 200 km long across the northwest flank of the basin) are being analysed in conjunction with deep and shallow seismic refraction data taken in 1972, 1973 and 1974. Preliminary studies show both short and long wavelength anomalies; the former are related to igneous intrusions and evaporite diapirs and the latter appear to be related to deep-seated causes such as the variation in thickness of the Sverdrup Basin, the Franklinian Geosyncline and the crust. Larg, massive, deep-seated igneous intrusions within and below the Franklinian Geosyncline (Paleozoic) sediments may also contribute to the regional anomalies. Panarctic's Drake Point well (D-68) drilled over 150 m of granodiorite within the Paleozoic sediments below about 4500 m.

Bonnet Plume Basin, Yukon Territory

Preliminary studies of the gravity data (consisting of 100 stations observed in an east-west direction across the centre of the basin and 108 stations provided by industry for the west side of the basin) indicate an eastward, gently-dipping (about 1°) basin consisting of a Tertiary-Cretaceous formation up to 760 m thick, flanked by major faults with throws of 5.4 km on the west side and 760 m on the east side. The eastern side is flanked by outcropping Precambrian basement which in turn is flanked on the east side by a major buried fault with a throw of about 4.1 km. To the west and east of the Bonnet Plume Basin complex, which during the early Paleozoic was the locale of an intermittent seaway between the Selwyn Basin in the south and the Richardson Trough in the north, there are inward-dipping Paleozoic basins (6.2 km and 4.1 km thick, respectively) with an irregular basement topography, probably resulting from normal faulting which has produced displacements in the basement of up to one kilometre.

Theoretical Sedimentary Basin Studies

In a joint study with Dalhousie University, it was demonstrated that regional isostatic adjustment (elastic or viscoelastic flexure of the lithosphere) to the load that fills the trough of a large (50 to 100 km wide) graben will produce a surface depression that extends far beyond the boundaries of the load. It was shown that sediment infilling of this depression, independent of the loading rate within the graben trough, can lead to the development of a major sedimentary basin as the regional adjustment mechanism approaches isotatic equilibrium.

(ii) *Foldbelts and Collision Orogenies*

Southern Appalachians

A positive-negative pair of Bouguer gravity anomalies can be traced along the length of the Southern Appalachians. Profiles across the pair are very similar to gravity profiles observed at structural boundaries in the Canadian Shield that have been interpreted to arise from the juxtaposition of two blocks of continental crust of different mean density and thickness in relative isostatic equilibrium. The boundary between the blocks is thought to represent a suture between collided protocontinents. The similarity in the gravity signatures across the Southern Appalachians and Precambrian boundaries suggest that similar plate tectonic processes have operated throughout Proterozoic and Phanerozoic time. By

analogy with the Precambrian, where the polarity of subduction may be determined by comparing radiometric age dates across structural boundaries (younger ages indicate the reactivated craton under which subduction has taken place), it is inferred that subduction associated with continent-continent collision in the Southern Appalachians has been directed southeastwards.

Slave-Churchill Structural Boundary

The analogue model of plane indentation was applied to the proposed collision of the Slave craton and the western Churchill craton. The model successfully predicts several large scale deformational features of the collision zone including the sense of movement of large-scale strike-slip faults, the occurrence of crustal thickening in the Churchill craton and the regional fault pattern.

(iii) *Studies of Anorthosite Massifs*

Lac Fournier Anorthosite Massif, Quebec

A large positive gravity anomaly with an amplitude of over 60 mgal coincides with the eastern part of the Lac Fournier Anorthosite Massif located about 200 km northeast of Sept Iles in the Grenville Province. A more mafic-rich phase of anorthosite than found elsewhere in the complex is present in the anomalous region and, with the evidence of the gravity data, is interpreted to represent the upper levels of a differentiated magma body. The body, interpreted to be gabbroic in composition, has been modelled in three dimensions and comprises an uppermost thin funnel shape some 5 km thick underlain by two roots extending to around 12 km.

(iv) *Gravity Surveys Over Possible Impact Structures*

An interpretation of the gravity field over the circular depression within Skeleton Lake, Ontario has been completed. A circular Bouguer anomaly of -3.3 ± 0.7 mgal (-33 ± 7 $\mu m.s^{-2}$) over the depression was separated from the complex regional gravity field. Taken in conjunction with aeromagnetic and geologic data, the anomaly is interpreted as due to a partly eroded 3.6 km diameter impact crater of Paleozoic age.

A gravity survey was conducted in July, 1978, at the Triassic Lake St. Martin structure near Gypsumville, Manitoba. Preliminary analysis of the data indicates a distinct negative anomaly over the 24 km diameter circular structure which is attributed to hypervelocity impact on the basis of earlier studies of shock metamorphism.

An interpretation of the -9.5 mgal (-95 $\mu m.s^{-2}$) negative anomaly over the shock-metamorphosed Haughton structure, Devon Island, has been included in a B.Sc. Thesis of the University of Western Ontario.

(v) *Gravity Reduction and Interpretation Methods*

The method of least-squares was employed to derive a recurrence relation to determine the coefficients for a polynomial approximation to calculate theoretical gravity for the Geodetic Reference System 1967. Results using this more general approximation were compared with those obtained earlier by telescoping the Taylor series expansion of the theoretical gravity formula with satisfactory results.

One method of determining the depths of sources of anomalies in the Earth's gravity field is to plot log $((2n+1)\sigma_n)$ versus n where σ_n is the n^{th} term in the amplitude spectrum of the Earth's gravitational potential. This procedure assumes that the amplitude spectrum of the anomalous density variations does not vary with n. Such an assumption may not apply to the Earth and in the case of the Earth's equivalent rock topography, which is at the surface, the above mentioned procedure gives a depth estimate of a few hundred kilometres.

Non-linear optimization methods and iterative procedures using matrix inversion techniques may be used to determine the minimum density contrast value for which a homogeneous body will accurately reproduce an observed gravity anomaly. In the case of negative anomalies, the result can often be used to determine whether the causative body is a sedimentary basin or a low-density granite batholith. If the minimum density contrast value is large, the anomaly source is probably a sedimentary basin; if it is small, the source could be either a sedimentary basin or a granite batholith. The minimum density contrast method has been successfully tested on the Cheshire Basin and the Weardale granite in England.

(f) Dynamic Gravimetry

Investigations in dynamic gravimetry have centred around the evaluation of the LaCoste and Romberg air/sea gravimeter as an inertial survey system (ISS) to provide simultaneous observations of horizontal position, elevation and gravity. Two series of tests were carried out and preliminary results indicate that accuracies in elevation of about one metre can be achieved when the gravimeter is operated in the ISS mode. ISS operating constraints include: a) nearly straight-line traverses; b) a stop for zero-velocity updates at five minute intervals; c) mission times not exceeding 2 hours; and d) known positions at the beginning and end of each mission. Other research includes the development of techniques to compute statistically optimal cross-coupling corrections for marine applications.

(g) Geodynamics

(i) *Precise Gravimetry*

The mean standard error of ties in Canadian precise gravity networks is 15-20 nm/s^2. Inter-instrument comparisons and other tests show, however, that a more realistic estimate of accuracy for the Lacoste and Romberg model D gravimeter is 30-40 nm/s^2. This accuracy can only be maintained over the long term where uncertainties in gravimeter calibration curves are minimized by resetting to the same dial reading on the resurveys. A further deterioration in accuracy to 40-50 nm/s^2 occurs where reliance is placed on presently available D meter calibration curves. Despite the present accuracy limitation significant time variations in gravity of 100-150 nm/s^2 are seen in semi-annual resurveys of precise gravity networks in the seismically active areas of Charlevoix, Quebec and Vancouver Island, British Columbia. These results will be compared with first-order levelling in an attempt to understand their tectonic significance.

Further experience has been obtained in the measurement and interpretation of the vertical gradient of gravity. A new tripod for gradient measurements was designed and constructed. Gradient measurements in the Chalk River test area are being compared with seismic and magnetic data.

(ii) *Measurement of Crustal Tilt and Strain*

Observations of tilt and strain in an underground vault at Charlevoix, 130 km northeast of Quebec City, are continuing. Several tilt/strain events have been recorded previous to local earthquakes. To study the spatial coherence of these events, a second vault, 8 km from the main vault, has now been instrumented. In addition to transient events, changes in tidal tilt admittances have also been observed but these are difficult to interpret because of the apparent variation in noise levels at tidal frequencies. A 50 m depth well has been drilled and instrumented at the main site for the purpose of verifying the transient events and tidal admittance changes observed at the surface. Preliminary tests showing a clear tidal signal in the water level in the well indicate that the well should be a sensitive monitor of the volume strains expected to accompany the surface phenomena under study. Long-term tilts are monitored by monthly relevelling of a 40 m diameter bench-mark array. One year of observations shows random variations from month to month of 2-3 μ-radians. No convincing trends have yet been observed.

(iii) *Vertical Crustal Movements*

A vertical crustal movement map of Canada compiled by the Earth Physics Branch and the University of New Brunswick is nearing completion. The trends in water levels from 136 tide gauge stations have been determined. Programs have been developed to analyse, edit and display these data as well as data from the file of relevelled segments that have been gathered from all available Canadian sources.

A study of crustal deflection due to the loading of the LG-2 reservoir (James Bay) has been initiated. A six-station 50 km-long profile of precise gravity stations was surveyed by the Earth Physics Branch and a 15 km section of the first-order level line was resurveyed by the Geodetic Survey of Canada prior to the start of filling in December 1978. An expected vertical deflection of about 8 cm at the dam will be measured by a resurvey of the gravity and level lines when filling of the reservoir is complete in 1980.

(iv) *Measurement of Ocean and Ice Dynamics*

The anomalously large tilts of the pack-ice measured on the Beaufort Sea during the AIDJEX project have been duplicated in a laboratory experiment involving a model of wind-induced tilt. Earlier problems with boundary layer effects have now been overcome.

(v) *Polar Motion Studies*

Astronomical (PZT) and satellite Doppler monitoring of polar motion and earth's rotation continued during 1978 at geodynamic observatories near Ottawa and Calgary. The PZT observations have been contributed regularly to the international time (BIH) and polar motion (IPMS) services. The satellite Doppler data have been transmitted to the DMATHC Polar Monitoring Service.

The geoceiver operation at the Calgary station was discontinued at the end of October and replaced by a TRANET station which has been modified to facilitate fully automated computer controlled satellite tracking. The real-time data processing and communication mini-computer network has been upgraded to handle power failures and parallel TRANET tracking and remote control of both terminals.

A general computer program for PZT data reduction has been developed and all the Ottawa PZT observations between 1956 and 1977 have been re-reduced in a uniform system; the data set is being analysed.

VLBI and satellite Doppler results have been compared in 5 separate experiments between three radio observatories: ARO (Ontario), CFS (England) and OVRO (California). Improvements in Doppler reduction software including satellite orbit refinements have been studied to increase accuracy of satellite positioning and pole determination.

Under contract to York University a development of LBI system for precise monitoring of the earth's rate of rotation has commenced in 1978.

3. Atlantic Geoscience Centre

Gravity data covering 12 Natural Resource Map areas northeast of Newfoundland have been released as part of Geological Survey of Canada Open File 525. Each map covers 1^{o} of latitude by 2^{o} of longitude at a scale of 1:250,000. Free-air and Bouguer anomalies are presented in contour and posted form.

Gravity data for 6 Natural Resource Map areas covering southern Saglek Bank and the adjacent Labrador Sea have been contoured and will be released on Open File shortly.

A total of 7278 km of gravity data were collected in the Labrador Sea using two Askania Gss-2 sea gravity meters. This completes the multiparameter survey coverage of the Labrador Sea, except for some lines in the vicinity of Cape Chidley.

C.S.S. HUDSON completed two tie lines extending from Davis Strait to the Strait of Belle Isle. During 1979 three tie lines will be run to provide additional connections between the 6 cruises that contain most of the multiparameter data collected in the Labrador Sea.

Compilation of the Labrador Sea gravity data at a scale of 1:2,000,000 has been completed. The free-air anomaly map shows a low extending along much of the extinct spreading centre. In general, in deep water, to the west the anomalies are negative (-20 to 0 mgal) while to the east they are positive (0 to 20 mgal). The belt of positive anomalies along the shelf edge is more prominent on the Labrador margin than on the Greenland margin. This asymmetry may be caused by a difference either in the sediment thickness on the two margins or in the deep crustal structure. Seismic refraction data will be collected across the Greenland margin in 1979 to test these hypothesese.

C.S.S. HUDSON collected 2500 km of gravity data in Baffin Bay with an Askania Gss-2 sea meter. The gravity coverage of Baffin Bay at a line spacing of 50 km or less is now complete. An updated version of the gravity map of Baffin Bay at a scale of 1:2,000,000 is being compiled.

Average free-air anomalies for 1^{o} by 1^{o} squares have been computed for the Gulf of St. Lawrence, the Scotian Shelf, the Grand Banks, and the Labrador Sea. These data have been used to examine the relationship between free-air anomalies and water depth for older oceanic crust.

An additional 5700 km of gravity data were collected northeast of Newfoundland to complete the mapping of that area. These data will extend the gravity coverage of Notre Dame Bay published in the Earth Physics Branch Gravity Map Series No. 163 and help define the offshore extent of the ophiolitic units that are exposed along the shores of the Bay. Detailed

coverage was also obtained off northern Newfoundland where the apparent source of the Hare Bay allochthon is marked by a major gravity and magnetic anomaly. Interpretation of the data in this location will be assisted by the interpretation of a seismic refraction program carried out over the suspected structure.

A compilation is underway of all the gravity (and magnetic) data for the Appalachians which will be compatible with the Tectonic-Lithofacies map of the Appalachians (Memorial University Map No. 1). It is hoped to publish this 1:1,000,000 gravity compilation late in 1979, but a smaller scale draft compilation should be available as an open file early in 1979. It is apparent that the major gravity gradient along the western edge of the Appalachian system is a prominent indicator of that edge even where it is covered, either by transported units as in the southern United States or by water as in the area of eastern Canada. The compilation and its interpretation will be an objective of the Caledonian/Appalachian Orogen project (Project 27) of the International Geological Correlation Programme, and should be extended to cover European areas later in 1979.

The replacement of the Askania sea gravity meters used on the multi-parameter surveys is being considered. The new meter must be capable of collecting usable data during manoeuvering to avoid ice. An investigation of the Bell BGM-3 gravity system is being carried out to see if this meter would meet the AGC requirements.

The electronics for the Gss-2 sea gravity meter used on C.S.S. HUDSON are being replaced. A new meter control box and cross-coupling computer will be built both of which will be used during the 1979 field season. The integrated navigation system being developed at BIO (BIONAV) will mean that cross-coupling and platform errors, and not navigation errors will be the limiting factor when collecting gravity data in rough weather.

4. Nova Scotia Research Foundation Corporation

Gravity data in southeast Cape Breton Island, over the Sydney coalfield, is being updated and reprocessed using the 1967 International Gravity Formula and the 1970 gravity base network. Interpretation will commence when the Bouguer gravity contour maps are completed. The work is funded by a Department of Energy, Mines and Resources Research Agreement.

Commercial activities included gravimeter rental, gravity data reduction and interpretation of gravity anomalies in the Atlantic Provinces for evaporite exploration. A detailed gravity grid was measured in Nova Scotia in the search for barite deposits.

5. Ontario Ministry of Natural Resources

A systematic gravity data collection and interpretation program was instigated in 1974 by the Ontario Division of Mines. 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, detailed gravity surveys were conducted during 1975 and 1976 in the Birch-Uchi-Confederation Lakes area and the Red Lake area respectively. During 1978, staff of the Geophysics/ Geochemistry Section carried out a gravity interpretation study based on gravity data collected during these surveys. Over 5100 Bouguer values and 2550 rock densities are being used to interpret the 21,300 km^2 area which is centred on these two prominent metavolcanic-metisedimentary belts. Spectral analysis and two dimensional modelling have been completed and an open file report is expected to be released by March 1979.

Data reduction and compilation were completed on the field data collected during the Temagami area survey of 1977. Further analysis of this data will soon be undertaken.

No gravity field work was carried out in 1978.

6. New Brunswick Department of Natural Resources

Gravity readings have been made at about 2500 stations in various parts of the Carboniferous Basin of New Brunswick in 1978. The main purpose of this gravity survey is to assist in the regional evaluation of evaporite deposits. In addition, gravity readings have been taken along a seismic reconnaissance line shot across the Carboniferous Basin this summer. The interpretation of this data, combined with the seismic results, should provide a better understanding of the structural features of this region.

7. University of Saskatchewan

Gravity investigations were limited to a survey carried out over a solution-collapse structure in central Saskatchewan as part of the undergraduate field school. A short publication on the interpretation of the data by the students is available through the university.

8. McGill University

The McGill group has recently taken delivery of 3 gravity meters of novel design developed by J.A. Linton, York University. The instruments employ a quartz fibre in torsion to support the central plate of a 3-plate AC voltage divider. The suspension is temperature compensated through a system of zero-friction, zero-hysteresis levers. Temperature control to within $\pm 10^{-3}$°C should maintain the mechanical drift to an equivalent 1 µgal/day. Using heterodyned lock-in amplifiers and an AC reference standard source, electronic noise and drift should not degrade the inherent stability and sensitivity provided by the mechanical sensors.

In the initial configuration in the McGill installation, one unit will be operated as a true gravity meter while two units will be operated as tilt meters. Through careful site selection it is hoped that the horizontal instruments will provide useful seismic signals in the normal-mode band. Sharp filters are employed to remove tidal and secular tilts.

The major geophysical research areas supported by the McGill and York installations comprises studies of the extremely long period seismic motions of the Earth in the normal-model and sub-normal-mode bands. Coincidentally high quality data should be available to encourage studies of tidal deformations with particular interest to be directed towards resonance at diurnal periods.

9. University of Manitoba

Field work for a gravity profile study of the Lac du Bonnet Batholith was completed during the summer of 1978. Two hundred and thirty gravity stations, with an average spacing of 0.5 km, were established along a profile which followed the course of Manitoba Hwys. 11 and 406 from Elma to Pine Falls, and is approximately orthogonal to the long dimension of the batholith. The specific gravities of the major rock units along the profile were determined from 300 measurements of rock samples. All observational data have been reduced to Bouguer anomaly values and interpretation of the anomalies using two-dimensional analysis is proceeding.

Although the batholith is, in general, characterized by a Bouguer anomaly low, the gravitational effects at both contacts are somewhat over-ridden by the effects of other masses such as a high density intrusion south of the Lac

du Bonnet body and another high density body just south of the northern contact.

Interpretation will be completed early in 1979.

10. Université Laval

This year a group of students in geophysics are compiling a gravity map of the Appalachians of Québec. This will be presented in its final form as a coloured map indicating gravity zoning. A corresponding aeromagnetic map is also being prepared. Combining the gravity and magnetic data with the geological information, the group will try to explain and interpret the geological setting at depth, first on a regional scale and second, where sufficient information is available, on a local or detailed scale. This interpretation is of a semi-quantitative nature only at present. We are also working on a crustal model of Ecuador in collaboration with Dr. Tomas Feininger of our Department.

11. University of Alberta

A two-dimensional fast Fourier technique for inverting gravity and magnetic data has been developed. This is an extension of the algorithm previously developed by Parker. This multi-layer inversion scheme requires an initial starting model from a seismically determined model and allows for lateral variations of density and thickness.

12. Canadian Society of Exploration Geophysicists

Activity by companies of the petroleum industry is given in the table below.

Area	Gravity Crew months	Gravity with Seismic Crew Crew months
Northern Saskatchwan	2	-
Manitoba	1	1
Central Alberta	7	-
Northeast Alberta	5	½
Alberta & B.C. Foothills	18	1
N.W.T.	-	1
Yukon (mining)	1	-
TOTAL	34	3½

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Open File of the Earth Physics Branch No. 78-11. Gravity Data Viscount Melville Sound, N.W.T. Latitude: 72°00'-75°00'; Longitude: 98°00'-116°00'.

Open File of the Earth Physics Branch No. 78-12. Gravity Data Gaspé Peninsula, P.Q. Latitude: 47°00'-50°00'; Longitude: 64°00'-69°30'.

Open File of the Earth Physics Branch No. 78-13. Gravity Data Eastern Townships, P.Q. Latitude: 45°00'-48°00'; Longitude: 69°30'-75°00'.

Open File of the Earth Physics Branch No. 78-14. Gravity Data Hudson Bay, N.W.T. Latitude: 54°30'-64°00'; Longitude: 77°00'-95°00'.

II SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR

Compiled by: E.R. Kanasewich

1. Canadian Seismograph Stations

The seismograph facilities administered by the Earth Physics Branch of the Department of Energy, Mines and Resources, Ottawa are listed in Table 1. The standard seismograph station at Victoria, British Columbia, was closed on March 29 and commenced operating (on helicorders) on July 10 at the Pacific Geoscience Centre. Seven new regional stations were commissioned. One of these, Skidegate, British Columbia, (SKB) began operating on October 20, replacing Sandspit (SSQ) which was closed on March 17. Station WNR at Windsor, Ontario, commenced March 8 and replaced the six-element array. The station at Gold River, British Columbia, GDR, began operating April 28, but was moved on August 4 to a better location less than one kilometre away. Three regional stations were installed in the Yukon Territory at Kluane Lake (KEY), Koidern River (KRY) and Dezadeash Lake (DLY), as a joint venture with Foothills Pipe Lines (South Yukon) Limited; they commenced operation on August 26, August 29, and September 3, respectively. Another regional station was also established at Pinawa, Manitoba, (PWM) on October 6, as part of the joint program with Atomic Energy of Canada Limited (AECL).

Progress continued on the Glen Almond, Québec, (GAC) borehole seismograph station telemetry to Ottawa. Analogue helicorder recording commenced during the year and digital recording will commence in 1979. The arrays at Yellowknife and Charlevoix, Québec, and the telemetered digital networks ECTN and WCTN have operated routinely during the year. A new station was added to the ECTN at Gentilly, Québec, (GNT) in February 1978 as part of a cooperative program with Hydro-Québec. Three further stations were added in October (LAQ, LBQ and LCQ) in the region of the new reservoir LG2 on the La Grande River, Québec, in cooperation with the Société d'Energie de la Baie James.

All standard and some regional station seismograms are microfilmed in Ottawa by the Canadian Government Public Archives, and copies of the 35 mm microfilm are deposited with the U.S. Department of Commerce, NOAA, EDS Solid Earth Data Division in Boulder, Colorado 80302, which answers 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, 1978)

	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	
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	Sidney, B.C.	48.65	123.45	Commenced, July 10, 1978
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.	VIC	Victoria, B.C.	48.52	123.42	Closed, March 29, 1978
20.	YKC	Yellowknife, N.W.T.	62.48	114.47	
		Regional Stations (Energy, Mines and Resources)			
21.	BLC	Baker Lake, N.W.T.	64.32	96.02	
22.	BMS	Minton, Sask.	49.21	104.79	
23.	CFO	Chats Falls, Ont.	45.47	76.23	
24.	CHQ	Charlesbourg, P.Q.	46.89	71.30	
25.	DLY	Dezadeash Lake, Y.T.	60.37	137.06	Commenced, Sept. 3, 1978
26.	GDR	Gold River, B.C.	49.78	126.04	Commenced, April 28, 1978
	GDR	Gold River, B.C.	49.78	126.05	Moved, August 5, 1978
27.	HAL	Halifax, N.S.	44.63	63.60	
28.	IGL	Igloolik, N.W.T.	69.38	81.81	
29.	KEY	Kluane Lake, Y.T.	61.05	138.50	Commenced, August 26, 1978
30.	KRY	Koidern River, Y.T.	61.97	140.41	Commenced, August 29, 1978
31.	LGQ	La Grande, P.Q.	53.69	77.73	
32.	LMQ	La Malbaie, P.Q.	47.55	70.33	
33.	MCE	Mica Creek, B.C.	52.01	118.56	
34.	PBQ	Poste-de-la-Baleine, P.Q.	55.28	77.74	
35.	POQ	La Pocatière, P.Q.	47.36	70.04	
36.	PWM	Pinawa, Man.	50.19	96.04	Commenced, Oct. 6, 1978
37.	QCQ	Québec City, P.Q.	46.78	71.28	
38.	SIC	Sept-Iles, P.Q.	50.19	66.74	
39.	SKB	Skidegate, B.C.	53.25	132.00	Commenced, Oct. 20, 1978
40.	SSQ	Sandspit, B.C.	53.25	131.82	Closed, March 17, 1978
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	Commenced, March 8, 1978

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.	GAC	Glen Almond, P.Q.	45.70	75.47	
46.	GNT	Gentilly, P.Q.	46.36	72.37	Commenced, April 24, 1978
47.	LAQ	La Grande, P.Q.	53.82	77.02	Commenced, Oct. 12, 1978
48.	LBQ	La Grande, P.Q.	53.54	77.35	Commenced, Oct. 12, 1978
49.	LCQ	La Grande, P.Q.	53.54	76.97	Commenced, Oct. 12, 1978
50.	MIQ	Maniwaki, P.Q.	46.37	75.97	
51.	MNQ	Manicouagan, P.Q.	50.53	68.78	
52.	MNT	Montréal, P.Q.	45.50	73.62	
53.	OTT	Ottawa, Ont.	45.39	75.72	
		Western Canadian Telemetered Network (WCTN) (Digital Recording, Single Component) (Energy, Mines and Resources)			
54.	ALB	Port Alberni, B.C.	49.27	124.82	
55.	HYC	Haney, B.C.	49.26	122.57	
56.	PGC	Sidney, B.C.	48.65	123.45	Commenced, March 18, 1978
57.	PIB	Pender Island, B.C.	48.82	123.32	
58.	VIC	Victoria, B.C.	48.52	123.42	Closed, March 14, 1978
		Yellowknife Array, N.W.T. 18 elements of short-period vertical recording (Analog Telemetry) 3 elements of long-period vertical recording			
59.	YKA	Yellowknife array	62.493	114.605	Centre
		Special Stations			
60.		Charlevoix Array, La Pocatière, P.Q.	47.55	70.33	A seven-element telemetered array recording on analog tape. Commenced operation, August 30, 1977.
61.		Windsor, Ont.	42.26	83.10	A six-element array, recording on analog tape in the Canadian Rock Salt Co. Mine. Closed, March 7, 1978.

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)			
		(University of Western Ontario)			
		Seismic array on FM analog tape			
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 at 3 times per second			
74.	ELD	Ethyl Lake Duckett Farm, Cold Lake	54.536	110.332	Commenced Dec. 16, 1978 3 vertical components in a 500' array.
		(Memorial University)			
75.	CBK	Corner Brook, Nfld.	48.92	57.97	Single-component short-period 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 the Earthquakes of 1978*

The EPB prepares and distributes to interested organizations preliminary bi-monthly summaries of all Canadian earthquakes approximately 6-9 months in arrears. Currently, the months of May-June 1978 are being analysed, and the summary will be distributed in January, 1979. The purpose of the lists is to provide interested organizations with a complete (but not final) picture of Canadian earthquakes in as short a time span as possible, and to allow 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 the larger Canadian earthquakes. Present procedures allow the detection and location of earthquakes of magnitudes 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 1976 Canadian Earthquake Catalogue is now published and a copy may be obtained from the Earth Physics Branch for a charge of $3. The 1977 Catalogue is in the final stages of preparation and will be available in 1979.

For 1978, the following provisional information is available. The largest earthquake in or near Canada occurred on June 11 just west of Vancouver Island with magnitude (M_S) of 6.4. Earthquakes with magnitudes greater than 4.5 occurred on the Queen Charlotte Islands on January 13 and July 11, on northern Vancouver Island near Cape Cook on June 2, June 3 and July 25, in east-central British Columbia near McNaughton Lake on May 14 and in the Prince Gustaf Adolf Sea in the Queen Elizabeth Islands on February 5. The largest earthquake in eastern Canada in 1978 occurred on February 18 near St-Donat, Québec, north of Montréal with a magnitude (m_N) of 4.1. No damage has been reported in Canada this year from any earthquake. The Cape Cook earthquakes of June 2 and July 25 and the St-Donat earthquake in February were all felt to distances of 100-200 km, and had a maximum intensity of V(MM) in the epicentral region.

A minor tremor reported in the area south of Windsor, Ontario on September 5 was the result of an industrial explosion in southern Detroit. No micro-earthquake activity has been detected in the Windsor area by the seismographs operated there by EPB throughout the year.

Residents of Cornwall and other eastern Ontario communities reported hearing frequent cracking sounds in late December 1977 and January 1978. Investigations from EPB showed that these were not earthquakes as some had feared, but ice cracks in the thick ice coatings left over from two unusually heavy rain storms experienced in December and January. The phenomenon disappeared as more normal winter weather conditions returned to the area in February.

Residents of Shelburne County, Nova Scotia, experienced frequent sonic booms from the British Airways and Air France Concorde flights into and out of the eastern U.S., starting in November 1977. Earthquakes were again initially thought to be the cause, but EPB investigators were quickly able to identify the Concorde as the most likely cause. The Concorde flight tracks off Nova Scotia were shifted away from the coast in late February at the request of the Ministry of Transport (MOT), and this, coupled with the end of winter atmospheric conditions along the east coast, served to greatly reduce their intensity; the booms heard in Shelburne County, however, were not eliminated. The on-going MOT investigations indicate that the Concorde is indeed responsible for the majority of the booms reported in Shelburne County, while a small percentage appear to be caused by other supersonic aircraft operating off the east coast.

(ii) *Special Studies*

Eastern Canada

Using the data from the seven-element array deployed around the Charlevoix region, Québec, F.M. Anglin (EPB) has derived a set of hypocentres which define an aseismic 'wedge' under the St. Lawrence River in the region of the Charlevoix impact structure. The zone of microactivity is found to be confined to a band enclosed by the river and a section of the north shore with all the hypocentres in the Precambrian material.

G. Buchbinder and F.M. Anglin (EPB) continue to advise the Société d'Energie de la Baie James concerning the seismic monitoring in the area of the La Grande 2 reservoir. In addition to the regional station LGQ, three telemetered stations have been installed around the future reservoir. They began operating in October and the reservoir started filling on November 27. Starting in the latter part of December, no natural or induced seismicity has been observed.

R.B. Horner, R.J. Wetmiller and H.S. Hasegawa (EPB) have completed a study of the St-Donat, Québec, earthquake sequence of February 18-23, 1978. The main shock of magnitude (m_N) 4.1 was felt over an area of about 70,000 km^2 in western Québec, eastern Ontario and northern New York State, with a maximum intensity of V in the St-Donat region. Two small aftershocks ($M_L \simeq 1$) were detected during a three-day field survey following the main shock. These were followed by an event of magnitude (m_N) 3.4 on February 23, felt mildly in the epicentral region. Main shock and aftershock activity occurred within a small active volume at a depth of 7 km with an estimated uncertainty of 1 km on all three hypocentral parameters. The main shock seismic moment was calculated to be 0.8×10^{22} dyne-cm. A well constrained P-nodal solution indicated almost pure thrust motion on a plane striking N20°W and dipping 40°NE or 50°SW. The deviatoric compression axis was nearly horizontal in a SSW direction. Similar results from the 1975 Maniwaki, Québec, earthquake suggest that a uniform stress condition exists throughout western Québec. A systematic change in focal depths across this zone, from shallow (upper-crustal) depths north of Montreal to deeper (mid-crustal) depths north of Ottawa, is suggested by available data.

Western Canada

In response to the recent decision to construct a natural gas pipeline down the Alaska Highway, R.B. Horner, H.S. Hasegawa and P.W. Basham (EPB) have commenced a study of the seismicity of the southwestern Yukon and adjacent regions of British Columbia and southeastern Alaska. The seismicity can be clearly confined to two

major fault systems. The Fairweather system, terminating in the Yakutat Bay region, has experienced magnitude (M_S) 7 or greater earthquakes about once every 15 years since 1899. The onshore Denali fault system has experienced no earthquakes of magnitude 7 or greater in the same time period, but has experienced magnitude 6 events with an average return period of about 15 years. The region between these two systems is active at lower magnitudes, but the region to the northeast, between the Shakwak and Tintina faults appears aseismic to the present seismograph network. Two preliminary P-nodal solutions suggest that pre-existing faults may be reacting to the apparently high rate of vertical uplift in the region. In a joint venture with Foothills Pipe Lines Ltd., a low-level monitoring program has been initiated. Three short-period vertical seismographs installed along the Alaska and Haines highways in late August, 1978, appear to have lowered the location capability in the region to about magnitude 2. During their first six weeks of operation, a relatively higher rate of micro-activity was observed near the south end of Kluane Lake. The seismicity patterns are similar to those previously suggested by the larger magnitude events.

R.D. Hyndman and G.C. Rogers (PGC) have completed a study of microearthquakes on the Juan de Fuca - Explorer ridge system located by three temporary arrays of ocean-bottom seismometers. The events appear to be restricted to the main plate boundaries as defined by other marine geophysical data. The data provide information on the velocity structure and Poisson's ratio in the oceanic upper mantle of the region.

The tectonic origin of earthquake generation in western Canada is being studied by R.D. Hyndman, R.P. Riddihough, G.C. Rogers, D.H. Weichert and W.G. Milne (PGC). In southwestern Canada most earthquakes appear to be in response to the convergence of the Juan de Fuca and Explorer plates with the margin. In northwestern British Columbia and the southwestern Yukon, most events are in response to the strike-slip motion between the Pacific and American plates.

G.C. Rogers (PGC), R.M. Ellis (University of British Columbia) and H.S. Hasegawa (EPB) have jointly completed a study of the focal parameters of the Valemount, British Columbia, earthquake of May 14, 1978. The results indicate a low stress drop and thrust faulting mechanism at a shallow (upper crustal) depth.

Arctic Canada

A seismicity survey was conducted on northern Baffin Island between September 8 and October 7, 1978, using portable short-period visually-recording seismographs at three locations along the east coast. A.E. Stevens (EPB) operated one vertical and one horizontal component instrument at Pond Inlet, J.S. Mercure (EPB) operated similar instrumentation at Clyde River, and Petro-Canada personnel operated a single vertical seismograph at a temporary camp at Cape Adair. Since station spacing was 200 km, little information on focal depth is anticipated.

About 100 small earthquakes were recorded in 29 days, the majority originating from northern Baffin Island between Pond Inlet and Cape Adair. The frequency and epicentral regions are consistent with those expected from previous activity revealed by the Canadian Seismograph Network since the early 1960's. The purpose of the field survey was to delineate the seismic areas more accurately and to examine possible correlations with geologic features. Data are being exchanged with the Atlantic Geoscience Centre and the Danish Geodetic

Institute, both of whom operated temporary stations in northern Baffin Bay and in western Greenland, respectively. Data analysis is continuing.

(b) Strong Motion, Seismic Risk and Earthquake Engineering

EPB personnel have continued their work on the Canadian Standards Association Technical Committee N289 on Seismic Qualification of CANDU Nuclear Power Plants. Four of the five standards in this series will be issued for trial use in early 1979. 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 for nuclear power plant siting. A similar project is being planned within the joint AECL/Ontario Hydro/EMR program for geological disposal of radioactive wastes.

Much of the EPB research effort in seismic risk in the past year has been devoted to methods and techniques to be applied in derivation of the next version of the seismic zoning map of Canada. H.S. Hasegawa (EPB), W.G. Milne (PGC) and M.J. Berry (EPB) have been reviewing the relevance, and methods of derivation, of various strong ground motion parameters and their attenuation coefficients in eastern and western Canada. P.W. Basham (EPB) and D.H. Weichert (PGC) have been assessing zones of earthquake occurrence throughout the country, methods of seismic risk analysis and the sensitivities of risk estimates to seismicity model parameters.

G. McMechan (PGC) has written a computer program for prediction of seismic activity with an error predictor operator. This approach provides predictions of the overall level of activity plus predictions of the temporal relations between the expected events. The method has been applied to data for the Feng-Wei region of northern China and western North America. The results are encouraging.

Routine processing of Canadian strong motion records has been reviewed by W.G. Milne, D.H. Weichert and G.C. Rogers (all PGC). The records from the 1976 Pender Island earthquake have been processed and will be published together with all previous Canadian strong motion records. Recorded peak accelerations from this 1976 event range up to about 0.05 g.

G.C. Rogers (PGC) has documented cases of soil failure during the 1946 magnitude 7.3 British Columbia earthquake. Slumping and liquefication were common and caused a significant proportion of the earthquake related damage. Liquefaction occurred up to a distance of 100 km from the epicentre.

G.C. Rogers continues to supervise the development of the strong motion seismograph network in western Canada. At the end of 1978 there were 52 accelerographs and 73 seismoscopes deployed in Canada.

The study of methods of quantifying the estimates of seismic risk has been continued at PGC by D.H. Weichert and W.G. Milne. A comparison has been made of the methods currently in use, and it is concluded that provided zones of seismic activity can be reliably defined, the Cornell approach provides a more robust solution than either the extreme value method, or the average amplitude method. A second study has shown that the choice of parameters or data for the risk solutions, such as the length of the data set, or the attenuation curves used, provides a range of acceleration values for the 0.01 annual probability of exceedence at one site. The Cornell approach to seismic risk analysis has been programmed at PGC to provide data for a contour map of peak horizontal ground acceleration.

3. Atlantic Geoscience Centre

I Seismology

(a) Seismic Refraction Studies with Ocean Bottom Seismometers

The Atlantic Geoscience Centre engaged in several seismic refraction experiments with ocean bottom seismometers (OBS). In the Orphan Basin, northeast of Newfoundland, refraction studies initiated in 1977 were completed. Good reversed lines are now available in that area, showing that thinned out continental crust, underlain by "normal" mantle exhibiting velocities of about 8 km s^{-1}, occupies both Flemish Pass and Orphan Basin. There does not appear to be a simple relationship between crustal extension and the amount of crustal thinning in these areas. Good shear wave velocities were measured for some of the sedimentary layers and for the main crustal layer.

On the shelf northeast of Newfoundland, short reversed refraction lines over offshore extensions of ophiolite suites were carried out to determine their seismic properties. These lines have yet to be analysed.

Two refraction lines were obtained near the Nova Scotian margin; one near the edge of the shelf over continental crust and one near the foot of the slope, over the oldest identifiable oceanic crust. The line on the shelf passed over the sites of several deep exploratory wells for which sonic logs are available, and it should be possible to correlate seismic P and S velocities with sediment types. Comparisons will be made betweeen the continental line and the oceanic line to look for characteristics which distinguish between continental and oceanic crust.

The feasibility of using an ocean bottom seismometer through the ice of the Arctic basin was demonstrated on project CANBARX - Canada Basin Acoustic Reverberation Experiment. This international project took place 250 km north of Alaska in the Canada Basin in 3700 m water depth. A near surface hydrophone array and an OBS were used to record acoustic and seismic signals from explosive charges detonated near the camp and to ranges of 75 km. Moho and other refractors were recorded. The OBS was a regular OBS stripped of its floats and release mechanism, and lowered to the bottom on a lightweight 'Kevlar' cable. Quiet recording for 12 hour periods was easily achieved.

(b) Baffin Bay Seismicity

The seismicity of northern Baffin Bay and Baffin Island was studied in a joint project. The Earth Physics Branch had portable seismographs on Baffin Island at Pond Inlet, Clyde River and Cape Adair; the Danish Geodetic Survey operated a station at Upernavik, West Greenland; and AGC had three OBS's deployed in Baffin Bay. The OBS's were located on a 100 km sided triangle 150 km east of the Baffin Island coast. Two 1000 lb explosions detonated near the OBS's were well recorded on Baffin Island but not in Greenland. The OBS's clearly recorded a magnitude 3 event, 200 km distant at Buchan Inlet. Numerous smaller events are evident, analysis of which is just beginning.

(c) Lithospheric Studies

Examination of PP-P travel time residuals (with I. Stewart, Memorial University) have shown that there is a region of slow seismic velocities in the upper 100 km of the mantle beneath the Fogo Seamounts, south of the Grand Banks. Interpretation of all geophysical data within the region suggests that a hot spot or plug of high temperature mantle material may have occupied the area during the Cretaceous, producing the volcanic seamounts. The anomalous travel-time residuals may be caused by residual

high temperatures, leading to a low velocity region beneath the region. The PP-P travel times may be useful in locating the remnants of other "hot spots", now extinct.

Seismic refraction data collected on the Reykjanes Ridge with the OBS's as part of the International Reykjanes Ridge Seismic Project is being analysed using a variety of computational methods. Both conventional and extremal inversion techniques have been applied to the travel-time data to obtain velocity-depth curves. The layered model obtained from conventional methods fits within the bounds derived from the extremal inversion, but it is evident that a model composed of velocity gradients would fit the data equally well. The layered velocity model exhibits velocities typical of layer 2, layer 3a and layer 3b, underlain by the Moho at a depth of 15 km (velocity 8.3 km s^{-1}) which suggests that anomalously low mantle velocities are not present beneath this section of the ridge crest. Further travel-time inversion and comparison with synthetic seismograms is necessary to confirm the model.

'Seabed' is a 5 year research project to provide remote sensing of the geotechnical properties of marine sediments. A deep-towed, broad-band, high resolution seismic source with a highly repeatable output pulse is employed. As part of the engineering and signal processing research program, the following developments are underway:

- Adaptive time variable gain unit for deconvolution of the return signal.
- Acoustic reflectivity module, with microprocessor, for estimation of reflectivity of sea floor interface.

The success rate of the 'Seabed' pattern classification scheme in the identification of surficial geological units on the Scotian Shelf is approximately 76% (with the remaining problems being in discrimination between two different sand units and a gravel unit).

II Physics of the Earth's Interior

(a) Tectonophysics

Studies of the subsidence of the shelves off Nova Scotia and Labrador, using biostratigraphic data from deep exploratory wells, have shown that the early subsidence history follows a linear $t^{1/2}$ relationship, similar to the depth-age curves for the cooling and thickening oceanic lithosphere. These results suggest that the fundamental cause of subsidence can be attributed to geothermal processes, as in the case of the oceanic plate. The subsidence curves were then used in conjunction with the cooling plate model to determine the temperature-time history of the sediments deposited on the subsiding and cooling plate, and thus to predict the organic maturation properties of the sediments. The predicted values, when compared with values of organic metamorphism measured from material collected in the wells, were good.

Work is continuing on comparisons of geophysical and geological structural trends on the shelves off Eastern Canada, Europe and Africa. Refined pre-rift reconstructions of the positions of the North American, European, Iberian and African plates have been obtained. These fits are sometimes in conflict with geophysical data showing the position of the ocean-continent boundary, and further work is needed to resolve this problem.

4. A. Earth Physics Branch

I Seismology

(a) Lithospheric Studies

As 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 by G. Buchbinder in the La Malbaie region and recorded by up to 11 instruments. In May and August, one shot on each side of the St. Lawrence River was set off. Changes in travel time of up to 47 ms have now been observed with respect to the start of the experiment in 1974. Two shots were set off on the North Shore in November, coinciding with a maximum and a minimum of the vertical component of the solid earth tide; no significant changes in travel time were observed. Thus, the vertical component of the solid earth tide does not introduce changes in travel time.

A synthesis of seismic refraction data with other geophysical data for the Sverdrup Basin by D.A. Forsyth shows major features that correlate well with the regional geology. Record sections show little coherent secondary energy compared with those from other areas of Canada. Properly normalized sections reveal a significant loss of amplitude and coherence of first arrival energy on traversing a major northeast-trending structure between Melville and Lougheed Islands. The upper mantle Pn phase propagates strongly beneath the structure. Aeromagnetic data show a major series of dykes or minor graben as the likely cause of the scattering and attenuation of seismic energy. Focal depths of earthquake swarm activity corroborate the suggestion that the structures extend to near-mantle depths. The age dates available suggest that fracture or dyke development progressed from south to north beginning in the early Cretaceous. The zone is a good example of an active, intraplate tectonic feature.

J.A. Lyons has completed the interpretation of a reversed reflection/refraction profile recorded within the Charlevoix crater (see 1975 Bulletin, p. 32). The first arrivals show a uniform refractor having a velocity of 6.08 km/s beneath a weathered low velocity layer just under 1 km thick. Secondary arrivals following up to several seconds behind the first kicks show a pattern of discontinuous, oblique segments. These probably represent reflections from structural contortions in the upper crust resulting from impact of the meteorite some 350 million years ago.

J.A. Lyons has studied the P travel-time data from a series of calibration shots fired on both sides of the St. Lawrence River and recorded by a distributed network of stations. The results are in qualitative agreement with a simple model of the Precambrian-Palaeozoic contact consisting of a plane striking along the north shore and dipping to the SE about 20^{o}. Numerical modelling of the sedimentary wedge is in progress. An investigation of the crustal structure of the La Malbaie region, combining the above two studies with data from blasts at Thetford Mines timed by D.A. Forsyth, is progressing.

J.A. Mair has continued the interpretation of the refraction data recorded over the Beaufort Sea during the AIDJEX project in 1976. The crust grades from typically oceanic to intermediate as the section nears the continental slope off northern Alaska. A preliminary interpretation of the velocity anisotropy indicates a 4% variation of Pn velocity with azimuth, with the highest velocity normal to the coastline of Alaska.

J.A. Mair, G.G.R. Buchbinder, D.A. Forsyth and F. Andersen will conduct a crustal refraction survey, over the Lomonosov Ridge near the North Pole, as part of the EMR/EPB LOREX project during May 1979.

A.J. Wickens has completed a study of S-wave travel-time residuals at standard stations of the Canadian network from mainly deep-focus earthquakes. The S residuals clearly outline the Canadian Shield. The definition of the eastern and western limits of the shield are as expected; to the south, however, the transition is surprisingly near the Canadian-U.S. border. A plot of P against S residuals yields a straight line of slope greater than $\sqrt{3}$, showing that the average Poisson's ratio for the uppermost layers of the Earth is greater than 0.25.

A 'Vibroseis' deep reflection project through the Rocky Mountain Trench, near Golden, B.C., was contracted out to industry and conducted in July 1978. Transients in the recording instrumentation have rendered the data useless. The contractor has accepted the responsibility for this failure and the costs of the project.

The seismic study of the Churchill-Superior Boundary in southern Saskatchewan and Manitoba, obtained in a cooperative venture by the Universities of Manitoba, Saskatchewan, Alberta, Toronto and the Earth Physics Branch in 1977, is now available from EPB as an open-file report (78-9). Seismic data consisting of a N-S refraction profile in the Superior Province of about 220 km in length, an E-W refraction profile, also of this length, from the Superior Province near Brandon, Manitoba, westwards over the transition zone and into the Churchill Province, and about 80 km of 400% coverage, dynamite reflection profiling, from near Brandon westwards, were obtained. The report also contains a compilation of the gravity and magnetics, an extensive bibliography, a preliminary refraction interpretation and descriptions of magnetic tapes and tape format. This material is available to the public for the costs of reproduction (about $40.00 for the written material and about $160.00 for magnetic tapes, large maps and seismic reflection sections).

Seismological experiments have been conducted during 1977 and 1978 at Chalk River, Ontario, and at Whiteshell, Manitoba, by both the Geological Survey of Canada and the Earth Physics Branch, as part of the joint EMR-AECL program on the investigation of potential sites for the disposal of radioactive waste. In the following four paragraphs, progress in the interpretation of seismological data by Earth Physics Branch personnel is described.

C.P. Lam and C. Wright have determined seismic velocities in a rock body at Chalk River Ontario, believed to consist largely of gneiss and monzonite. The solutions for the P and S wave velocities at distances of up to 1.3 km were 6.56, 6.48 and 5.40 km/s and 4.07, 4.33 and 3.18 km/s respectively along each of three profiles at azimuths of 33^{o}, 133^{o} and 331^{o} from a central borehole. The P wave velocities for two profiles are significantly higher than those measured in the laboratory on samples from the borehole, whilst the comparatively slow travel times to the southeast of the borehole suggest a change in lithology a few tens of metres from the borehole.

The foregoing experiment used a mechanical 'hammer' or weight drop device and a shear wave gun as the seismic sources. The shear wave gun and the hammer operated during the day and night respectively, giving a total of 24 hours of recording along each of the three profiles. C. Wright is analysing the data to determine whether or not there is a small change in seismic travel times caused by the opening and closing of cracks in the rock body due to the solid earth tide. One profile shows a small but significant change in P travel times of about 0.1 ms over a fourteen hour period and a distance of about 0.7 km. The two other profiles show apparent changes in P travel times of a few tenths of a millisecond over a similar time interval, but a smaller distance range. These relatively large changes may be due to systematic deviations in wave shape produced by the source.

Two high resolution seismic reflection profiles were also recorded at Chalk River; these profiles, roughly normal to each other, were each approximately 2 km in length, with recorder spacings of 30 m. The weight drop device used in the small-scale refraction and tidal stress experiment provided the seismic energy source, recorded at 1000 Hz sampling rate by 24 multiple arrays of geophones. J.A. Mair and C.P. Lam have processed the data, which allows a 600% common position and a 1200% common reflection point stacking capability. The rock body at Chalk River appears to be virtually homogeneous to this technique for seismic frequencies up to 125 Hz.

C.P. Lam has completed a preliminary analysis of the seismic refraction survey conducted jointly by D.A. Forsyth and staff from the Geological Survey of Canada at Whiteshell, Manitoba, in November 1978. The objective of the experiment was to investigate the anisotropy of the granitic rock body in that region.

(b) The Whole Earth

C. Wright has started processing P wave arrivals from earthquakes recorded at the Yellowknife Array from a wide variety of source regions. The objective of the work is to search for triplications in the travel-time curve that might be diagnostic of radial velocity anomalies in the lower mantle. The interference method of studying $dT/d\Delta$ data devised by Wright and Lyons over the last few years is being used as an aid in the interpretation.

(c) Seismic Sources and Wave Propagation

During 1978, P.W. Basham continued to represent Canada at the Conference of the Committee on Disarmament (CCD)-sponsored "Ad Hoc Group of scientific experts to consider international cooperative measures to detect and identify seismic events". The first report of the Group, document CCD/558, was completed in March, 1978. The Group continued its work, with a meeting in July, 1978 and another planned for February, 1979, under a new mandate to study the scientific and methodological principles of a possible experimental test of a global network of seismological stations.

A study has been completed by P.W. Basham in cooperation with Swedish seismologists which applied seismic detection and discrimination criteria to seismic events in the U.S.A. in 1972.

C.W. Chou and H.S. Hasegawa are jointly studying spectral amplitudes of local earthquakes recorded by the Eastern Canada Telemetry Network. Preliminary results indicate a higher corner frequency than comparable magnitude earthquakes in the northeastern United States. This implies a relatively higher percentage of high-frequency energy in Shield earthquakes.

(d) Seismological Instrumentation

The Instrumentation Section has supported an active field program during the year which has included deployment of the six 'Backpacks' at Charlevoix, Québec, in May, August and November, and deployment of the smoked paper recorders at St-Donat, Québec, and on Baffin Island in September. Standard stations were calibrated at EDM, SES, SCH, STJ and PGC according to schedule. The array at Windsor was closed down and replaced with a conventional regional station (SPZ), and a short telemetry link was prepared for MCC. The borehole seismometer (SRO type) at Glen Almond, Québec, (GAC) has operated routinely with analog transmission over the two hop radio link to Ottawa.

During the year development effort has been focussed in two main areas. A new remote digital telemetered station package has been developed with enhanced performance, microprocessor control and option of using transmission by UHF radio at rates up to 4800 bps as an alternative to telephone facilities. Three of the new stations have been deployed in the region of the new reservoir at LG2, (LAQ, LBQ, LCQ), with radio links to the nearest microwave tower, as part of a cooperative program with Société d'Energie de la Baie James. Data are telemetered to Ottawa. Early in 1979 the regional station at Chats Falls, Ontario, (CFO) is to be replaced by similar hardware as a result of an agreement with Ontario Hydro.

These developments have delayed plans for the Mark II 'Backpaks' and for multicomponent digital transmission of borehole seismometer data. However, a powerful set of hardware modules has been developed and implemented as printed circuit boards. These include a three-channel seismic amplifier with 108 dB dynamic range, inverter, transmitter and receiver.

As part of a Federal program for the transfer of technology to industry (COPI), the National Research Council is supporting a research and development contract with D.G. Instruments Ltd. to package hardware and develop software for the Mark II 'Backpaks'. Key specifications of the systems will include operation in both timed and event triggered modes, compactness and the ability to operate at temperatures down to $-30^{o}C$.

The second major development effort has been in software for the telemetered networks. The PDP11 operating systems are being changed from RT11 to RSX11M to support multi-tasks and multi-users. The application software is being developed to cater for sixteen channels of data and to permit flexibility in multiplexing several locations or components onto one communication link. DEC net, a proprietary data communications package, is being installed to permit rapid transfer of data between networks. This work will continue in 1979, and will include development of more versatile seismological applications software for interactive graphics.

II Physics of the Earth's Interior

(a) Heat Flow and Heat Production

As in the previous year, most data gathering activities during 1978 were concentrated in Arctic and Cordilleran regions. T.J. Lewis organised a second cruise in the fjords of the northern part of the British Columbia coast. During this cruise, six months after the first, changes in bottom-water temperature were detected at some locations indicating that heat flow corrections are necessary. A total of one hundred heat flow stations was occupied.

The heat generation of rock samples collected from outcrop on shore during the first cruise has been measured. Low values, typical of the Coast Crystalline Complex were obtained for all samples except those from the areas of Alice Arm and Observatory Inlet, which gave results about three times as high. Heat generation of core samples from holes in the Squamish and Lillooet Valleys was also typical of the Coast Plutonic Complex.

Two holes of about 450 m depth were drilled in the Coryell syenites near Lower Arrow Lakes, British Columbia. Early results suggest a high heat flow and a continuation of Blackwell's "Thermal Anomaly Zone" into Canada from the south. Measurements of heat generation will determine if the reduced heat flow is above normal.

In eastern Canada, high values of heat generation of about 4 $\mu W/m^3$ have been derived for a few samples from Mont St. Hilaire, Québec, one of the Monteregion Hills.

(b) Permafrost Studies

A.S. Judge and A.E. Taylor conducted a programme of further deep temperature observations in northern drill-holes, successfully logging a further 50 wells primarily in the Mackenzie Delta and Tuktoyaktuk Peninsula. A fifth volume of the data collection in bilingual format containing over 100 permafrost thickness determinations is in press. Sufficient data have now been collected to determine equilibrium thermal conditions at many sites. A.E. Taylor has examined the northern Québec results to determine terrestrial heat flow and palaeoclimatic implications. Permafrost thickness exceeds 540 m in the region and is probably still aggrading in response to climatic change.

A further offshore hydraulic drilling programme of 12 holes to 60 m depth, conducted jointly by A.S. Judge and M. Burgess with members of the Geological Survey of Canada, outlined shallow permafrost conditions beneath the Beaufort Sea on an east-west line across the Mackenzie Delta. Temperature measurements have now been monitored in 34 holes across the Delta front, and define very well the areas of relict permafrost.

Drilling and geophysical studies outlined the permafrost distribution beneath Illisarvik Lake ("a place of learning") in the Mackenzie Delta. Subsequently, the lake has been drained, and the resulting growth of permafrost is being monitored by the Earth Physics Branch, the Geological Survey of Canada and the University of British Columbia.

Special funding has permitted a small contract programme on the role of moisture migration in permafrost. Under it the hydraulic conductivity, unfrozen water content, thermal properties and stable isotope distributions are being investigated for frozen and partially frozen soils. In addition, the feasibility of the Time Domain Reflectometry technique for unfrozen moisture content determination is being examined.

Two permafrost scientists from the Peoples Republic of China joined the Geothermal Studies section for the five months from July to December, participating in the field programme and undertaking research on the differences in the nature of permafrost between China and Canada.

(c) Geothermal Energy

The study of the geothermal energy potential of the Regina area was completed by the University of Regina team, headed by L. Vigrass. This study was based on existing data, with the addition of a 10 km seismic line to the south of the city of Regina. As a result of the favourable results of the study, the Department of Energy, Mines and Resources agreed to fund a 2200 m well on the campus of the University, to provide the proof of the resource and the production well for a space heating demonstration project. Water at 71-74°C with a salinity of 150,000 ppm is expected from the Deadwood and Winnipeg formations. Depending on production rates, heat at the rate of up to 5 MW is expected. Since the water is so saline, reinjection through a second well will be required.

In the Meager Mountain geothermal area, north of Vancouver, two holes were drilled by diamond drill, on each of the north and south sides of the mountain. Both holes encountered temperatures in excess of 100°C. At the same time, B.C. Hydro were completing an extensive resistivity survey of the flanks of the mountain. Experimental radon and mercury surveys were also undertaken. A major review of all data gathered so far is taking place during the winter of 1978-79.

Two boreholes were drilled in the Coryell syenites near Lower Arrow Lakes, British Columbia (see also section (a)) to examine the potential of the area as a useful geothermal reservoir. The high temperature gradients observed in the rocks indicate that further work is justified in the search for hot dry rock sources.

(d) Tectonophysics

D.A. Forsyth continues studying the seismotectonics of eastern Canada. The two main areas of seismic activity are the West Québec and Charlevoix seismic zones. There appears to be another area of continuing low-level seismicity beneath the St. Lawrence River south of Sept-Iles. Within this region, there is a correlation between the seismicity and the gravity and magnetic anomalies, suggesting that the earthquakes may be related to the peripheral area of a major gabbroic body below the river. A similar phenomenon occurs along the eastern edge of the West Québec zone, which appears to be associated with the western margin of the Morin Anorthosite body. Gravity, magnetic and recent geological data are being studied to try to define a western boundary to the West Québec zone.

A contract to Gregory Geoscience Limited to study the lineations from Landsat imagery for the Charlevoix crater area has been completed. The results show a halo of deformational effects that extends to approximately twice the diameter of the peripheral valley and coincides with the extent of the active zone beneath the St. Lawrence River.

In connection with the radioactive waste disposal program, C. Wright, K. Langley and D.C. Kamineni have estimated the intrinsic velocities of P waves in samples of gneiss and monzonite taken from one of the boreholes at Chalk River, Ontario, using the modal analyses and estimates of mineral velocities given in the literature. The results were systematically higher by about 0.5 km/s than the velocities measured in the laboratory on dry samples at 2.5 kb pressure by G. Simmons and his co-workers at the Massachusetts Institute of Technology. Much of this discrepancy is possibly due to residual porosity in the core samples at 2.5 kb pressure. The two sets of velocities, however, show similar layering when displayed as a velocity-depth profile. Using the calculated intrinsic P velocities and those derived from a borehole log, values of the crack density parameter were estimated using the crack theory of O'Connell and Budiansky. These crack density parameters show a significant correlation with the number of observed microscopic fractures in each depth interval of 5 m. Finally, the calculated intrinsic velocities correlate well with the measured densities, but the slope of the velocity-density line is 1.96 ± 0.31, which is significantly less than the values normally associated with Birch's law. This anomalously low slope appears to be caused by the P wave velocities assumed for microcline and biotite, which are very high and low respectively in relation to the mineral densities.

B. Pacific Geoscience Centre

I Seismology

(a) The Whole Earth

G. McMechan has found a general closed solution for Wiechert-Herglotz inversion which involves integration on a closed contour. This extends the applicability of Wiechert-Herglotz inversion to non-surface source p-Δ curves, and permits reference depths other than the surface of the Earth. The usual line integral form is shown to be a degenerate special case.

G. McMechan has completed the determination of an amplitude-constrained model for the upper mantle beneath eastern North America. The resulting velocity profile is similar to those previously determined for the regions to the north and west, but has a broadening of velocity transitions relative to those in the western United States.

(b) Seismic Sources and Wave Propagation

R.D. Hyndman has completed a review of laboratory and field data on Poisson's ratio in the oceanic crust. The use of shear velocity data in the form of V_p/V_s ratio (or Poisson's ratio) should permit the discrimination in seismic refraction measurements of a number of different rock types with similar compressional velocity but significantly different Poisson's ratios. The discrimination is particularly important along continental margins where there is a considerable overlap in the compressional velocity ranges of high velocity sediments, upper oceanic crust and upper continental crust.

G.C. Rogers has completed a study of the mechanism solutions of earthquakes in the vicinity of Vancouver Island. All are consistent with a north-south orientation for the principal compressive stress. The predominant type of faulting is strike slip, either dextral slip on northwest striking fault planes or sinistral slip on northeast striking fault planes.

(c) Seismological Instrumentation

The Yellowknife seismic array continued routine operation. The CANSAM detection bulletin is available on ARPANET. In addition, D.H. Weichert placed the bulletin on the World Meteorological Organization network (WMO/GTS) for 3 months in 1978, in anticipation of requirements by the Geneva Group of Experts of the CCD. Quality and reliability of seismic data transmission over this network were evaluated, in cooperation with the U.K. nuclear detection and discrimination group, and found to be equivalent to ARPANET.

II Physics of the Earth's Interior

(a) Heat Flow and Heat Production

E.E. Davis has measured geothermal heat flow on a series of multipenetration profiles on the east side of the Juan de Fuca ridge. In this area the sediment cover is thick and uniform so that hydrothermal exchange between the ocean crust and ocean is restricted, and the measured heat flow may approach that from the cooling lithosphere.

E.E. Davis and R.D. Hyndman, with C.R.B. Lister and U.S. Wade (University of Washington), have completed a study outlining the pattern of hydrothermal circulation in the oceanic crust and its effect on crustal temperatures based on 150 new measurements in the area of the Explorer and Juan de Fuca ridge. Very efficient hydrothermal heat transport and low crustal temperatures are estimated.

R.D. Hyndman, E.E. Davis, and J.A. Wright (Memorial University, Newfoundland) have made heat flow measurements using the ocean probe technique in Powell Lake, east of Vancouver, in Howe Sound and in Saanich Inlet as a part of a continuing program to determine the geothermal structure of southwestern British Columbia.

R.D. Hyndman, E.E. Davis, and J.A. Wright are also studying the theory and application of the heat pulse technique for the in situ probe determination of the thermal conductivity of ocean, inlet, and lake-bottom sediments. The results of field and of laboratory measurements,

and of numerical and analytic models are being compared. Some refinements have been made in the digital, telemetering multipenetration heat probe. With M.N. Bone and T.J. Lewis (EPB), a new lightweight digital recording heat probe for use in lakes is being constructed.

(b) Tectonophysics

E.E. Davis has completed a study of the origin of the Winona basin off northern Vancouver Island, and has commenced a study of the tectonic development of Juan de Fuca Ridge offsets.

R.D. Hyndman, with C.E. Keen (Atlantic Geoscience Centre), has completed a review of geophysical studies on the eastern and western margins of Canada. On the east coast the development of the margin structure was primarily in response to initial rifting processes and subsequent subsidence and sedimentation. On the west coast there is continuing active tectonics with processes dominated by plate convergence and subduction.

Ocean bottom seismometer deployments, reflection profiling and other multidisciplinary studies between the north end of Juan de Fuca Ridge and Vancouver Island by R.D. Hyndman, R.P. Riddihough and R.L. Herzer (Geological Survey of Canada) confirm the existence of the Nootka Fault. This is an active plate boundary feature between the Explorer Plate and the Juan de Fuca plate which accommodates the left lateral movement between them of up to 2 cm/yr. It should be present in the subducted lithosphere beneath Vancouver Island and may affect the pattern of crustal seismicity observed there.

R.P. Riddihough, R.G. Currie (Geological Survey of Canada), R.D. Hyndman, E.E. Davis and G.L. Rogers have undertaken bathymetric, magnetic, gravity, seismic profiling, seismicity and heat flow studies over the Dellwood Knolls in an attempt to better define their role in the plate tectonic configuration of the northeast Pacific. The results confirm that the Knolls are an active feature, but show that the form of sea-floor spreading is neither usual not simple. The Knolls are probably no older than 1 million years, and their history is closely connected to that of the Paul Revere Ridge.

G.C. Rogers has identified three large explosions west of Vancouver Island previously thought to be earthquakes. The location of these events on the continental slope confused the seismicity pattern. Thus, their removal from seismicity maps will assist in tectonic interpretation.

5. University of Alberta

I Seismology

(a) Theoretical Studies

V. Cerveny and F. Hron have applied the Ray Series Method (also known in English literature as Asymptotic Ray Theory) and Dynamic Ray Tracing to seismic wave propagation in three-dimensional generally inhomogeneous media, which may include layers with lateral inhomogeneities separated by curved interfaces. A special ray-centered coordinate system recently proposed by Popov and Psencik has been used to simplify considerably the evaluation of amplitude coefficients in the ray series, especially in the case of S waves, since with ray-centered coordinates the curvature and torsion of the ray do not have to be known. When the ray-centered coordinate system is applied to an eikonal equation, a very convenient system of three differential equations of the first order, called the Dynamic Ray Tracing System is obtained. The main advantage of this new system rests with the fact that most of the quantities needed in ray

tracing procedures (wavefront curvatures, geometrical spreading of the ray tube, second derivative of travel-time fields) can be obtained rather easily. It has been shown that the Dynamic Ray Tracing System, in the case of two-dimensional layered media with lateral inhomogeneities, reduces to a single differential equation of Riccati type. Since most of the formulae can be written in matrix notation, they can be easily coded and incorporated into any computer program designed for numerical modelling of seismic waves in three-dimensional inhomogeneous structures.

M. Yedlin and F. Hron are developing both theory and computer programs to generate synthetic seismograms using a combination of finite difference and normal mode techniques. The methods are being developed for shear waves in vertically inhomogeneous media; both can also be applied for vertically polarized P-SV propagation. Together with R. Teshima they have implemented an extremely fast and accurate technique of calculating the spatial eigenfrequencies required in the above computation. The synthetic seismograms obtained by this method will be compared to those obtained by the Ray Series Method and Disk Ray Theory. It is also expected that this new method will be optimal for studying the near-field effect of seismic sources of low frequency.

Z. Berkes and F. Hron have initiated research dealing with the dynamic properties of diffracted waves which are frequently observed in oil exploration. The boundary layer method and the method of successive approximations by integrals of the Sommerfeld-Malyuzhints type are being implemented in the modification of the Ray Series Method in an attempt to incorporate diffraction effects into existing programs used for seismic numerical modelling. Several methods, proposed mainly by K.D. Klem-Musatov, will be tested numerically for optimum efficiency. It is expected that a suitable computational technique will be developed for amplitude computation for diffracted waves both inside the shadow zone and in the vicinity of its boundary.

A.P. Choi and F. Hron have successfully combined the Ray Series Method with a modified third-order saddle-point approximation of an integral wave solution in order to achieve fast and reasonably accurate computation of ray amplitudes in vertically inhomogeneous layered structures in all regions. Traditionally, the ray amplitude in the vicinity of caustics, where the Ray Series Method breaks down, was expressed in terms of the Airy function Ai. Unfortunately, there is a loss of accuracy if 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 Hankel functions of one-third order of both kinds.

P.F. Daley and F. Hron have continued their efforts to develop a complete package for comprehensive modelling of horizontally polarized SH waves. Special attention was given to transversely isotropic layered structures because of their importance in oil exploration. Theoretical investigations of wave propagation in such media were carried out using two independent methods, namely, the Ray Series Method and the method of integral transforms applied directly to the equation of motion. Since both theories agreed pretty well in all regions with the exception of the interference zone, where the Ray Series Method is not justified, their combination may be used for the effective computation of ray amplitudes for both body and head waves. The Ray Series Method has also been used for the theoretical study of azimuthal anisotropy displayed by seismic waves propagating beneath oceans. The theoretical formulae will be implemented in computer programs for comparison with observed data.

E.S. Krebes and F. Hron have concluded a theoretical investigation of seismic wave propagation through anelastic media. The linear theory of viscoelasticity has been used to model the anelasticity of real media. Calculations of various physical quantities, such as energy flux and dissipation of plane waves propagating in a viscoelastic medium, have been carried out. The calculations are independent of the type of viscoelasticity, and are based on an energy conservation equation derived from first principles. This represents an improvement over previous energy calculations for such media.

L.W. Marks and F. Hron have inaugurated an investigation of the effect of higher order terms in the ray series expansion. Prior to this, most researchers produced results based on the leading terms in the ray series only. Numerical evaluation of higher order terms is expected to produce some interesting non-geometric features in wave propagation in inhomogeneous media.

Ray methods are being studied by D.C. Ganley, E.R. Kanasewich and G. Churney. The significance of incorporating certain multiples in a seismogram for which detailed velocity logged information is available is producing useful results. A method for obtaining attenuation where check shots in a deep well are available has been developed by D.C. Ganley. Y.C. Athias and E.R. Kanasewich are developing finite difference techniques for modelling an inhomogeneous section.

Computer programs developed by F. Hron and later modified by his students have been used for the computation of synthetic seismograms for crustal models provided by scientists from several Canadian and foreign institutions as the contribution to the continuing cooperation of the group with the scientists from these centres. Notably, a series of detailed and compact seismograms have been computed with the collaboration of V. Cerveny for several models of a layered crust proposed by I.P. Kosminskaya of the Soviet Academy of Sciences on the grounds of Deep Seismic Sounding carried out in the U.S.S.R. Synthetic seismograms were also computed for several models distributed by F. Gilbert and J. Orcutt for the participants of the Workshop on Synthetic Seismology held in Oregon under the auspices of the U.S. Office of Naval Research last spring. Direct comparison of these seismograms with those computed by other methods (reflectivity, Cagniard-de Hoop technique, WKBJ method) proved that the Ray Series Method in its modified form, which implements various alternative high frequency techniques in regions where the Ray Series approach is not applicable, represents a very powerful tool for the numerical modelling of the seismic response in complicated geological structures. It was clearly demonstrated that unless an automatic ray generation, producing all multiply reflected and critically refracted body waves with up to five conversions in a single ray, is used during the computation, serious inaccuracies will occur. Thus a new computational algorithm has been developed by F. Hron for the construction of groups of kinematically and dynamically equivalent waves (i.e. kinematic and dynamic analogs) which constitutes a partial ray expansion during synthetic seismogram computations in layered media.

A. Choi and F. Hron have implemented a new interpolation formula for the approximation of an arbitrary velocity-depth function, $v=v(z)$, in their program for synthetic seismogram computation for vertically inhomogeneous layered structures. In their approach, the velocity-depth function, $v(z)$, is first decomposed into individual monotonically varying parts. Then the inverse dependence, $z=z(v)$, can be 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 which are found numerically. As a result of this approximation, analytic expressions are available for all the kinematic characteristics (range, travel time and geometrical spreading) necessary for synthetic seismogram computation, and thus costly numerical integration can be avoided.

P.F. Daley and F. Hron have used a combination of the Ray Series Method with matrix formulation of the exact wave solution in their programs for synthetic seismogram computation in the case of multilayered structures containing stacks of very thin layers. Direct comparison with synthetic seismograms produced by the reflectivity method indicates that the new combined technique reduces enormously the number of rays in the partial ray expansion needed to achieve a desired accuracy of results. In addition, all the major advantages of the ray method, such as clear identification of all major arrivals and the decrease in ray amplitude due to geometrical spreading, are retained in this method, rendering it very attractive for seismic numerical modelling in the case of typical structures frequently met in oil exploration.

E.S. Krebes and F. Hron have completed the development of computer programs for the computation of reflection and transmission coefficients of seismic plane waves impinging upon plane interfaces separating two anelastic media. The numerical results obtained indicate that energy-partitioning plays a crucial role in the determination of the dynamic characteristics of seismic waves, and has to be incorporated into synthetic seismogram computation if serious inaccuracies are to be avoided. The phase speed varies with the direction of phase propagation, which indicates the presence of a type of velocity anisotropy, even though the medium itself is homogeneous and isotropic. This suggests that some effects which are ordinarily completely attributed to anisotropy of the medium, may in fact be partially due to anelasticity.

L.W. Marks and F. Hron have used a modified Ray Series Method (allowing amplitude computation in the vicinity of caustics) when developing their complete package of computer programs for numerical modelling of seismic waves in generally inhomogeneous layered structures which may contain lateral inhomogeneities and curved boundaries. Ray diagrams, travel time branches, amplitude-distance curves and synthetic seismograms have been computed for various models of the Earth's crust based on deep seismic soundings in Central Europe and Western Canada.

In connection with the modal expansion used in the synthetic seismogram computation, M. Razavy and M. Yedlin have investigated ways of rearranging the summation of the modal series, with a view to improving convergence. It appears that their technique is applicable to a spherical earth model, when the eigenfunctions are the Legendre polynomials. In a flat earth model, the eigenfunctions are Bessel functions, and the method is more complex to implement.

M. Yedlin is extending the results of his thesis, which deals with Disk Ray Theory in transversely isotropic media, to include more general earth models. Modifications of the techniques to calculate the singluar ray integrals occurring in transversely isotropic media are also being implemented.

E. Nyland is on leave at Universidad Nacional Autonoma de Mexico (UNAM). There, in his work with Instituto de Investigaciones en Matematicas Aplicadas y en Sistemas (IIMAS) he is assisting with the development of RESMAC (Red Sismica Mexicana de Apertura Continental). He is collaborating in this project with J. Gil and A. Tubilla for hardware and software respectively. REMAC currently is acquiring data from 3 digital stations (Acapulco, Cerrillo and Mexico), and has a feed from the four analog stations of the SISMEX net used by Instituto de Ingenieria (II) for ground acceleration studies near Mexico City. Nyland spends half of his time with II on studies of induced seismicity. There he has installed modified versions of the stress analysis programs developed by R.J. Withers and used them in analysis of the proposed Itzantum dam. Micro-geodetic networks will be installed in the Mexican state of Chiapas near this dam as well as near the Chicoasen dam and on the triple junction

near Motocintla in order to monitor ground movement. Design of concrete pillars for monumenting these networks is well underway, brass plugs for the monuments have been designed and initial field reconnaissance has been done.

(b) Crustal Field Studies

The interpretation of data from a seismic reflection study in southern Manitoba is continuing. The work is being carried out by G.D. Mann, E.R. Kanasewich and G.L. Cumming. Plans are in progress for a continuation of this program as a joint cooperative venture involving the Universities of Alberta, Saskatchewan, Manitoba, British Columbia, Toronto, and the Federal Department of Energy, Mines and Resources, Earth Physics Branch.

The use of shear waves in shallow seismic mapping is being investigated by E.R. Kanasewich and D.C. Ganley.

(c) Instrumentation

An event detecting digital seismic system incorporating a microprocessor and cassette recording system has been developed by M.D. Burke, L. Ramsdell and E.R. Kanasewich. The detection system is being investigated by C. Marston as a Master's thesis in collaboration with the above investigators. A prototype of the system is presently being tested in the field.

With J.S. Rogers of the Low Temperature Group in the Department of Physics, F.W. Jones is constructing two Stacey-type mercury tiltmeters to be used for measuring earth tides and local tilts. The instruments are in the final assembly stage and will be ready for field testing early in 1979. It is intended that a number of tiltmeters will be built, and measurements conducted in the Rocky Mountains and Great Plains of Alberta.

II Physics of the Earth's Interior

(a) Geodynamics

E. Nyland and co-workers are carrying on investigations in geodynamics of plates. G. Margrave is studying the geological and geophysical evidence bearing on the Nazca Ridge-South America collision. He believes a large part of this evidence is consistent with the notion that the Nazca Ridge is a strong brace ramming South America. D. Lamoreaux spent the summer working at the California Institute of Technology with V.I. Keilis-Borok. They have made significant progress on the use of unusual bursts of aftershocks as predictors of major seismic events. C.J. Rebollar has joined the group from CICESE at Ensenada, Mexico. He is applying the skills he learned there in the analysis of small seismic events in the foothills of the Rocky Mountains of Canada.

E.R. Kanasewich and J. Havskov have begun a study correlating the past geographic and geologic setting of continents with the occurrence of hydrocarbon deposits. The work is an outgrowth of the earlier study on plate tectonics by Kanasewich, Havskov and Evans (1978). For this study we have plotted the positions of major oil and gas fields, oil shales and oil sands on the maps of each period. Many petroleum deposits seem to have been formed within 35° of the palaeo-equator in the Palaeozoic Era. The reconstruction may help in delineating broad exploration targets, particularly in the Cambrian and Ordovician basins of North America and Asia. The tectonic activity and pattern of continental groups, which influences ocean currents, is also important in the development of favourable basins.

(b) Properties of rocks

T.J. Spanos is working on two problems as a Research Fellow of the Alberta Oil Sands Technology and Research Authority. In the first he is developing new theoretical techniques for the numerical simulation of recovery processes for tar in deep strata. This work involves investigation of the various dynamic processes that occur. In the second problem he is constructing a comprehensive and consistent theory of fracture mechanics for tar sands applications. This requires a theory of fracture stability and propagation in a non-Hookian material.

6. University of British Columbia

I Seismology

Seismicity in the McNaughton Lake (Mica Reservoir) region has continued to be monitored under the direction of R.M. Ellis. Major changes in the telemetered system have been made by B. Chandra and R.D. Meldrum with the expansion of the array of 8 elements, reconfiguration to also provide monitoring of the Revelstoke Reservoir, and transmission of the data to Vancouver by microwave link. At 2237 GMT on May 14, 1978, a magnitude 4.8 earthquake occurred near the northern end of McNaughton Lake. This is the largest earthquake since initiation of monitoring in 1972. Initial investigations by G.C. Rogers and R.M. Ellis suggest that it was not a reservoir induced earthquake. The earthquake epicentre ($52^{o}65'N$, $118^{o}87'W$) and focal depth (8 km) to be determined. There were no foreshocks but a normal aftershock sequence. Preliminary interpretation of the focal mechanism indicate predominantly right-lateral strike-slip faulting along the strike of the mountains with a significant thrust component. A well-developed Lg phase was recorded to the south of the earthquake. The isoseismals are elongated in a north-south direction and intensity attenuation with distance to the south is similar to the relationship for eastern North America.

The data for the February 4, 1918, east-central British Columbia earthquake have been re-examined by G.C. Rogers and R.M. Ellis. Based on damage, felt reports, and the number of instrumental observations, this earthquake had been assigned a location near Revelstoke and a magnitude about 5. Analysis of instrumental records from SPO, SAS and OTT and examination of newspaper reports indicates the event had a magnitude m_{bLg} of 5.6 to 6.1 and was located approximately 150 km north of Revelstoke. These records and those from more recent events indicate that the Lg phase which in general is not well-observed at Cordillera stations may efficiently propagate along strike in this region.

G.C. Rogers continues to study the seismotectonics of Canada's west coast to improve tectonic models of the region by better defining the constraints that earthquakes impose. Relocation experiments with both local and international nets of seismograph stations are underway with the objective to provide optimum locations for western Canadian earthquakes during various stages of development of the Canadian seismograph network from 1900 to the present. Data are also being gathered for a comprehensive study of earthquake focal mechanisms on the west coast.

R.M. Clowes and R.M. Ellis have revised and extended the interpretation (with W.B. Cumming) of a partially reversed seismic refraction profile which was recorded across southern British Columbia from Sparwood to the Highland Valley. The westwardly directed profile consisted of 32 short-period seismograms covering 440 km, while the reversed line extended 330 km with 41 seismograms. From a starting model based on first arrival times and previous geological and geophysical data, a seismic structural section is developed using both synthetic seismograms and a program for ray tracing through inhomogeneous media. The refraction

data indicate that the M-discontinuity dips to the east from an approximate depth of 30 km east of Highland Valley to in excess of 40 km beneath the Purcell Anticlinorium. Undulations of about 165 km wave-length and several kilometers amplitude characterize the crust-mantle boundary. The Pn velocity is 7.8 km/s. Above the M-discontinuity, secondary arrivals are interpreted to be from a lower crustal layer of thickness near 10 km and velocity of 6.9 km/s. The upper boundary of this layer also dips gently to the east. The seismic structure of the upper crust correlates closely with the regional geology as evidenced by travel-time and amplitude anomalies where the profile crosses the Rocky Mountain Trench and the Interior Plateau-Eastern Metamorphic Belt boundaries. The crustal P and S phases in the Interior Plateau yield a relatively low value of Poisson's ratio of 0.23. The detailed data close to the Highland Valley indicate significant velocity heterogeneity. For the Guichon Creek Batholith, the inner Bethlehem phase is found to have a higher velocity than the surrounding Highland Valley phase.

R.M. Ellis and R.M. Clowes are continuing acquisition of seismic refraction data in the Rocky Mountain trench. Explosions at Kaiser Resources mine near Sparwood and Cominco's Sullivan mine near Kimberley are being used as sources to obtain a detailed reversed profile across the trench. The data are consistent with those recorded in the project described immediately above and confirm that the trench is the locus of travel-time and amplitude anomalies observed on the seismograms.

K. Whittall and R.M. Clowes have developed a simple and efficient computer program for tracing rays through a two-dimensional laterally inhomogeneous medium. Preliminary interpretation of recent marine and land seismic profiles indicated that such a technique was necessary. The FORTRAN program allows irregular layer outlines and linear velocity gradients. Every boundary in the model is given a constant velocity along its length and a non-zero, linear velocity gradient normal to its direction of dip. As a result, all ray paths within a layer are long, circular arc segments. This technique is in contrast to some other ray-tracing algorithms which use small distance increments while travelling through a detailed grid of velocity-depth values. The computer program outputs a plot of the model with the ray paths superimposed. It also produces a reduced travel-time plot of all the rays (including critically refracted or pseudo-head waves) that reach the surface.

M. Yedlin has completed a study using the first motion approximation to calculate synthetic seismograms in transversely isotropic, linear, elastic media. To achieve this end the equations of motion have been solved in a geometrical optics regime. Formally, this has been accomplished by the use of asymptotic propagator matrices. This formalism is important, since the phase of the JWKB reflection coefficient can be easily calculated by consideration of the radiation condition. Calculation of this reflection coefficient has shown that the turning point behaviour is identical to that obtained for an isotropic medium. The similarity of the turning point behaviour is a direct consequence of the physical result that at a turning point the phase and group velocities are in the same direction. To understand the results of the first motion approximation applied to a simple upper mantle model, it is first necessary to understand the basic physics of transversely isotropic media. This has been achieved by examination of the dispersion relation arising from Newton's Laws for an elastic solid. From the dispersion relation, it has been demonstrated how the Green's Function can be constructed using elementary projective geometry. Subsequently, the nature of the Green's Function has been analyzed. The analysis of the Green's Function (wave surface) is important because it facilitates comprehension of any dynamical results. The synthetic seismograms were calculated using ray parameter versus distance curves. These curves were obtained by integration of the ray equations derived from dispersion

relations. A Gaussian-Katorovich method was utilized to perform the required integration. This hybrid integration technique proved to be extremely fast and accurate. When the resulting p-delta curve was used to calculate the synthetic seismogram, the main effect of the anisotropic model considered was a kinematic one - the main arrivals were earlier than those for an isotropic model.

A. Jurkevics and T.J. Ulrych have extended their previous work (Jurkevics and Ulrych (1978)) which entailed the evaluation of the time-dependent spectral content of strong motion accelerograms. In the present approach the behaviour of the three time-dependent autoregressive parameters is examined by analysis of 40 'rock site' accelerograms obtained from intermediate sized earthquakes in southern California. The results of this analysis are used to estimate the duration and attenuation of shaking amplitude with epicentral distance.

A marine seismic system for recording near-vertical incidence to wide-angle reflected waves and refracted waves with penetration from the ocean bottom to the upper mantle (deep seismic sounding or DSS) has been developed. During 1975, three reversed profiles and additional subcritical incidence reflection profiles were recorded in Winona Basin, a deep-water sedimentary basin west of the northern end of Vancouver Island. Profiles 75-1 and 75-1R were recorded along the length of the basin to distances of about 95 km, while profiles 75-2, 75-2R, and 75-3R were recorded across the basin to distances of about 60 km.

In last year's report, S. Lynch and R.M. Clowes provided details of the interpretation of profiles 75-1 and 75-1R. A.J. Thorleifson and R.M. Clowes now have completed interpretation of the profiles across the basin. Analyses of the reflection data indicate an upper sedimentary structure of three or four prominent horizons with interval velocities ranging from 1.6 to 3.8 km/s, and having a total depth extent of ~2 km in the central basin. This is underlain by a lower sedimentary structure with velocity of ~4.3 km/s and a thickness ~2 km. Travel times and amplitudes of the refraction data along the basin were interpreted with the aid of synthetic seismograms. Due to significant lateral variations in crustal structure across the basin, a ray tracing approach was used. Along the basin, the interpretation indicates three sub-sediment 'layers' having significant velocity gradients. The average velocity of the sub-sediment crustal section is ~6.0 km/s; its thickness is ~10 km. The upper mantle velocity is 7.8 km/s. Across the basin, the model shows that the crustal layers on both sides dip toward the centre. Gravity calculations based on the seismic model are compatible with a -160 mgal free air anoamly. The seismic interpretation is consistent with a proposal of oblique subduction between the Explorer and American plates.

H.P-Y. Cheung and R.M. Clowes have completed a detailed interpretation of an 80 km refraction line. The data were recorded on an array of three ocean bottom seismometers located 5 km west of the northern tip of Explorer ridge and parallel to Revere-Dellwood fracture zone on the Pacific plate. The combined use of rotated SV component and polarization filtered record sections enabled identification and timing of the refracted S-wave on most sections. The travel time-distance relation for both P and S waves is interpreted in the intercept time (tau) and ray parameter domain using both extremal and linearized inversion methods. Amplitude analysis using disk ray theory synthetic seismograms further refine the P-wave velocity-depth models. The P- and S-wave velocity-depth profiles show a general increase of velocity with depth and no distinct structural discontinuities. A normal oceanic crustal thickness of 6.5 km and an anomalously low Pn velocity of 7.3 km s^{-1} are interpreted. The results of this study contrast markedly with the existence of an abnormally thick crust (~ 10 km) for Explorer plate on the opposite side of the ridge, as determined in other studies. Such a contrast lends

support to the proposal that the complex structure and thick crust are the result of compressive interaction between the young, small Explorer plate and the older, larger North America plate. Values of Poisson's ratio in the range of 0.25 to 0.32 are determined for the crustal material, but better resolution of the velocity-depth profiles is required before a meaningful geological interpretation can be made.

D. Au and R.M. Clowes are proceeding with the interpretation of an extensive set of marine seismic data obtained in August 1977. Three OBS's (ocean bottom seismometers) were deployed around the Nootka fault zone, the narrow region along which relative movement between the Explorer and Juan de Fuca plates is taking place. Three refraction profiles, using 6810 kg of explosives and 150 individual charges, were shot through the array. To supplement the explosion data, a sixteen litre (1000 cu in) airgun provided closely spaced shots for reflection and short range refraction information at each OBS site. Corrected shot origin times plus the shot distances and azimuths for the data on each OBS have been determined. The seismic data, recorded in direct mode in the OBS's, are transcribed to FM mode and then digitized. The procedure is complete for the explosion seismograms and in progress for the airgun ones. The combined data consist of about 1000 individual seismic traces. One seismic record section has been compiled. The individual traces were amplitude corrected for the square root compression used in the original recording and bandpass filtered. Charge size corrections and an r^2 geometrical spreading factor, to enable arrivals at all distances to be seen clearly, also have been applied. The record section shows travel-time and distance offsets of the first arrivals. These correlate well with the Nootka fault zone as detailed by Hyndman, Riddihough and Herzer.

Marine seismic records are often difficult to interpret because they are contaminated by signals from the bubble pulse. S. Levy and D. Oldenburg are applying inverse theory to determine the bubble pulse wavelet and "debubble" the marine records.

II Physics of the Earth's Interior

A recent re-examination by G.C. Rogers and H.S. Hasegawa of the available seismic data from the June 23, 1946 Vancouver Island earthquake (M_S =7.2) indicates that the earthquake was of relatively shallow (30 km or less) focal depth and the epicentre was located in central Vancouver Island rather than beneath the Strait of Georgia some 30 km or more to the east as previously thought. J.C. Savage and W.F. Slawson have tested the Rogers-Hasegawa solution by resurveying a triangulation network in the epicentral area which had first been surveyed in 1935. The distortion of the network was found to be greater than could be accounted for by either secular strain accumulation as indicated by measurements of a nearby network or survey error, but is consistent with oblique slip on a northwestward extension of the Beaufort Range fault. The best model for slip on the fault involves 1.0 $\pm$ 0.25 m right-lateral and 2.50 $\pm$ 0.65 m normal slip on a shallow (0 to $\overline{5}$ km) segment dipping 70°NE. However, pure right-lateral slip of about 1 m over a depth interval 0 to 20 km on a vertical fault is not excluded at the 90 percent confidence limit. Thus the geodetic data support the conclusions of G.C. Rogers and H.S. Hasegawa that the 1946 earthquake was caused by right-lateral, normal slip in the vicinity of Forbidden Plateau, central Vancouver Island.

7. University of Manitoba

I Seismology

A.G. Green and D.H. Hall at the University of Manitoba are involved with the interpretation of data collected from two major crustal seismic experiments. In the first experiment, data from two reversed seismic

refraction/wide angle reflection profiles and 80 km of 400% common reflection point coverage were collected from the neighbourhood of the Churchill/Superior boundary in southern Canada. Standard processing and seismogram simulation analyses are being used in the interpretation of these data. The second crustal experiment was conducted across the Churchill/Superior boundary in northern Manitoba. Approximately 20 km of 400% common reflection point data was shot across the faulted contact between the Thompson nickel belt and the Churchill province. These data, which are currently being processed, should give information on the attitude and depth extent of the fault contact. A small profile was also shot across the ore body at the Birchtree mine.

8. McGill University

I Seismology

P. Tyraskis has obtained a Burg-like solution for the multi-channel prediction-error system. The forward and backward prediction-error operators provide filters for the deconvolution of multi-channel data. Current efforts involve the deconvolution of three-component particle motion data obtained from a refraction survey in the Montreal region using complex quarry-blast sources.

R. Leskinen is comparing the parametric models of seismic data to non-parametric models of seismic data described as auto-regressive, moving-average and mixed processes. A wide variety of seismic data from mine blasts, rock bursts, exploration and earthquakes is being studied as examples of these models.

Efforts are now being directed towards the assembly and installation of an extremely long period seismograph in the Montreal region. The three-component instrument will have a flat acceleration response from 5 hour to 5 minute period for the vertical component and from 1 hour to 5 minute period for the orthogonal horizontal components. Also, since the instruments are basically gravity and tilt-meters, DC acceleration measure is available, though with less quality. This installation will support a research effort concentrated in the seismic response of the Earth in the normal-mode and core-mode bands. Further details are given in the chapter entitled Geodesy and Gravity.

II Physics of the Earth's Interior

D.J. Crossley has for the past few years been investigating the free oscillations of a contained, rotating, stratified fluid with particular application to the core of the Earth. The aim of the work is to compute theoretically a spectrum of possible long period (i.e. greater than 1 hour) fluid motions which may exist in a realistic seismological model of the Earth. Through a global perturbation of the static gravitational field at the Earth's surface, such fluid motions could be detected by a sensitive long-period accelerometer such as that described by O.G. Jensen.

A general solution of the interactive behaviour of uniform rotational and radial buoyancy forces in a spherical shell remains hampered by the truncation effects necessary by the casting of the problem into a spherical harmonic formalism. Nevertheless, of the results that have emerged from the studies so far, three will be mentioned here. First, any seismological Earth model that allows the core density profile to depart from the Adams-Williamson condition possesses a long period spectrum of both internal gravity waves ('undertones'), whose periods appear to lie between the Brunt-Vaisala buoyancy period and half a sidereal day, and inertial waves with periods greater than half a sidereal day. Second, the most likely values of the buoyancy period of Earth models span a range from a local value of 6 hours through infinity (a neutral core) to an imaginary

value of 5 hours (a convecting core), indicating that the free motions will overlap in period the semi-diurnal, solid-Earth tidal response. Third, D.J. Crossley and M.G. Rochester (Memorial University, Newfoundland) have shown that mantle structure, core boundary deformation and the combined effect of self gravitation and fluid compressibility can be relegated to minor roles in the dynamics of the core at long periods. This conclusion simplified considerably the equations of motion such that the truncation effects are partially alleviated. However, definitive evidence supporting the first and second results above has not yet been obtained.

9. Memorial University

I Seismology

Field work with 2 portable triggered seismographs is continuing, being concentrated on a refraction line (unreversed) across the island from Baie Verte. Teleseismic events are also monitored for P-wave residual studies. Fixed seismographs STJ and CBK are used for reference times. No seismicity has been detected in the center of the island.

Published data for teleseismic PP reflections have been used to delineate regional structure in the lithosphere in the vicinity of Newfoundland. The analysis has been extended to the Arctic, especially in northern Eurasia and the adjacent Arctic Ocean. Good correlation of anomalous reflection times with the major tectonic features has been obtained.

10. University of Saskatchewan

I Seismology

Z. Hajnal and B. Reilkoff applied several aspects of a complex velocity spectral algorithm to the expanding spread portion of the 1976 Brandon crustal seismic experiment data. Significant coherence was found in several time intervals along the seismic traces. The study of the nature of these seismic events and the derivations of stacking and interval velocities is being attempted in the next phase of the program.

Study of seismic characteristics of Precambrian outcrops was continued by Z. Hajnal and M.R. Stauffer. Reflection seismic signal characteristics are investigated by vertical stacking of data that were recorded from a single hole at gradually changing depth. Velocities derived from the stacking and the velocity spectral analysis are compared with sonic log information. The variation of close surface velocities are correlated to possible porosity changes in this region.

A mini-Sosie high resolution reflection experiment was conducted by Z. Hajnal and B. Reilkoff in the Athabasca sandstone basin in the summer season of 1978. The mapping capability of this method was investigated in several locations utilizing a 7-man crew and helicopter transportation. Observations from several multi-kilometer line segments are under data processing at the present time.

A recent study by D.J. Gendzwill and H. Geerlof outlines the techniques used to recover seismic frequencies up to 125 hz at reflection times up to 1 second, and shows examples of improved interpretation compared to conventional industry practice. A theory is presented to explain some unexpected differences observed between standard and high frequency seismic section displays.

Our computer-controlled seismic recording system for detecting local microseismic activity is again in the field after several months of inactivity. Recent small earthquakes in Saskatchewan have drawn some interest to the problems of tectonism in what was considered a stable area, but some earthquakes may be due to activity such as underground mining or brine injection. We hope to record some of the events with our system near to the source.

An acoustic borehole logging system for determining the presence and degree of fissuring in rock masses has been developed and field-tested by M.S. King, M.R. Stauffer and B.I. Pandit. The logging sonde is designed to operate in boreholes oriented in any direction and ranging in diameter from 47 to 59 mm, either water-filled or dry, to a depth of 65 m. The system has been tested at a number of western Canadian nickel mines, an iron ore mine in Sweden and from the surface in the Canadian Shield in water-filled and dry boreholes oriented in all directions. It is concluded from five years' experience that the system is sufficiently sensitive to locate fissuring adjacent to a borehole precisely. A quantitative estimate of the degree of fissuring can be made from harmonic analyses of the received signals, in conjunction with laboratory measurements of acoustic P and S wave velocities and amplitudes on samples of intact core from the borehole.

When ductile materials such as rock salt and potash are subjected to the loading which occurs when mining deep potash in Saskatchewan, they tend to yield. In the process of yielding, these rocks produce bursts of subaudible microseismic energy, which can be detected by sensitive accelerometers. The amount of microseismic energy emitted can be related to the degree of loading to which the rock is subjected. The object of the research is to develop a portable electronic system for monitoring the microseismic events emitted in underground pillars of potash and to use the results to predict the degree of loading on the pillars. Knowledge of the loading to which the pillars are subjected is important in the design of safe but economical extraction systems in potash. Preliminary findings by B.I. Pandit and M.S. King indicate that the stresses predicted by the microseismic tests correlate well with those measured directly by pressure cells, with the advantage that the microseismic probes are recoverable and are much simpler to use.

II Physics of the Earth's Interior

(a) Permafrost

As more attention is paid to the search for hydrocarbons and other minerals in northern Canada, large and small-scale geophysical surveys are being conducted in areas of permafrost. The objective of the research is to determine the seismic velocities and electrical properties of samples of rocks and soils in the laboratory at permafrost temperatures typical of those found in northern Canada. The information gained in this way can then be used in the interpretation of geophysical records for mapping the extent of permafrost and in the prediction of the behaviour of these rocks and soils when subjected to loading by the foundations for large structures or by blasting.

Ultrasonic compressional and shear-wave velocities are measured as a function of triaxial loading conditions on specimens of water-saturated porous sedimentary rocks and soils at permafrost temperatures. Also being measured are the complex resistivity and phase-angle relationships as a function of frequency. It has been observed that there are abrupt changes in ultrasonic-wave velocities and in the electrical properties as the water in the pore spaces is permitted to unfreeze.

Knowledge of the thermal properties of permafrost is important in predicting its behaviour when disturbed, as during excavation for the foundations for large strctures. It is also important in predicting the extent of large areas of permafrost. The objective of the research is to determine the thermal conductivity of permafrost specimens at their naturally-occurring temperatures, using a divided-bar type apparatus with small temperature drops and temperature gradients across the specimens. This is achieved by the use of high-stability thermistors for temperature measurements along the divided bar. During each series of tests at different temperatures, the temperatures recorded are compared with each other at some point when the whole bar is at the same temperature. Two water-saturated porous sandstones and a limestone have been tested with the apparatus. The results are in excellent agreement with published values of thermal conductivity for these rock types at temperatures above freezing.

(b) Dynamic Properties of Moist Rock

The amount of vapour present in a porous rock can vary from exceedingly small quantitites, as under high vacuum and elevated temperatures, to a fully water-saturated condition. It has been demonstrated experimentally that the addition of small quantities of water vapour alters the velocities and attenuation of elastic waves in a dry rock. However, the results reported for other studies performed at low and high frequencies are conflicting.

The variation of compressional, shear and bar-wave velocities and attenuation in a porous sandstone have been studied as a function of changes in moisture content and frequency. Velocity measurements have been made at high frequencies (in the range 100 kHz to 1 MHz) using an ultrasonic first-pulse arrival technique and at low frequencies (in the range 1 kHz to 25 kHz) by a resonant bar technique. The experiments were performed in a chamber in which the relative humidity can be controlled precisely in the range 30 percent to 100 percent. The results of tests by M.S. King at different moisture contents indicate the same behaviour for velocities and attenuation at both low and high frequencies.

11. University of Toronto

I Seismology

W. Moon, with C.H. Chapman, has found a connection formula of WKBJ solutions at the turning point using Langer expansion. This can be used to study tunnelling effects of seismic wave when a turning seismic ray grazes through very closely to a discontinuity.

W. Moon is currently investigating the scattering of elastic waves by circular objects (cylindrical and spherical) to improve the previous results and to make it more applicable to practical seismology.

II Physics of the Earth's Interior

(a) Mathematical Geophysics

W. Moon has completed the variational formulation of generalized geodynamic equations. In this formulation generalized spherical harmonics is used rather than conventional spherical harmonics. In the studies including wobble and nutation this seems more appropriate since the Earth's rotation axis moves. The coupling due to rotation, ellipticity and the cross coupling due to rotation and ellipticity are represented by Glebsch-Gordan coefficients. In the present formulation a torsional eigenfunction chain is chosen to include the Chandler wobble and nutation. However the changeover to spheroidal chain to include certain

core modes is trivial. This generalized formulation may be solved to study free oscillations, Chandler wobble and nutation and core modes. The complete numerical solution is in progress.

(b) Thermal Studies

The model constructed by S. de la Cruz began operation during the year. An original feature of the design is that the system consists of two liquid-filled cells, one stable to convection and one in convection. Temperatures at desired points in the convecting fluid are measured as differences against those at corresponding points in the stable fluid. Experiments are in progress on the effect of Rayleigh number, rate of internal heating and the temperature-viscosity relationship of the working fluid, on cell geometry.

(c) Theoretical Studies

H. Sharpe, working with W. Peltier, completed a numerical study on the thermal history of the Earth, on the assumption of an origin by cold accretion. The numerical model, which employs parameterized convection theory, traces in detail the variation in temperature, adiabatic gradient and surface heat flow through geological time.

J-C. Mareschal and G. West have continued the 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 designed to trace the downwarping of the weakened, gravitationally unstable, crust. The model explains many of the features of greenstone belts in the Shield.

12. University of Western Ontario

I Seismology

An analysis by A. Yapp and R. Mereu was made of over 100 teleseisms recorded at the 3 station seismic array near London, Ontario, Deviations of measured values of slowness and azimuth from theoretical values revealed that a well-defined pattern of anomalies exist around the array. The consistency of the pattern for a large number of ray paths suggest that its cause is localized near the array and may be the result of lateral structures in the crust in southwestern Ontario.

S. Ojo and R. Mereu are studying the effects of absorption and scattering of seismic waves which pass through earth models having lateral inhomogeneities. It is felt that this study may explain some of the observed complexities in crustal and upper mantle array seismograms which cannot be predicted by layered models.

Two of the main problems which are encountered during the digital filtering of large two-dimensional arrays of geophysical data are those of core storage and computational time. C. Harrison and R. Mereu completed their studies of the effectiveness of the rotated recursive filter in overcoming some of these obstacles. These filters are stable, symmetrical two-dimensional filters which require much less storage to implement than the conventional fast Fourier transform method.

Surface waves propagating along cylindrical concave and convex boundaries are being investigated by F.K. Maxwell and L. Mansinha. Attenuation and group velocity curves are used to predict dispersion characteristics of several types of undulating boundaries. The results are being extended to solid-fluid boundaries of the earth.

The periodicity of earthquakes is being investigated by I.F. Jones and L. Mansinha. The reality and reliability of the spectral highs and lows are established by relating to dynamical processes within the earth.

II Physics of the Earth's Interior

(a) High Pressure Studies

A full analysis by N.S. Brar, M. Barker, A.E. Beck and H.H. Schloessin of the calcite aragonite transformation and the aragonite calcite inversion under pressures between 12 and 20 Kb has been completed. Quantitative results of rate constants, exponents and activation energies are based on the determinations of transformed volume fractions by X-ray diffraction. Direct observations of transformaton nuclei and growth were made by optical microscopy using staining and etching techniques. The transformed volume fractions vary roughly linearly with pressure beyond equilibrium and almost exponentially with temperature. The apparent activation energy for the calcite aragonite transformation varies between 17 and 26 Kcal $mole^{-1}$. In the case of polycrystalline calcite samples the transformed volume fractions obtained for constant times are found to decrease as the square root of the grain size. This finding suggests that already transformed volume fractions are self-stressing, especially when subjected to high pressures, and that on account of their shape they are acting as stress concentrators. This conclusion is also supported by the actual distribution of transformation nuclei, which in stained samples are observed to be concentrated along glide and twin bands.

The thermal conductivities of various earth materials under conditions of high pressure and varying temperature are at present being investigated using the cylindrical rod method with -quartz as a standard. Results have been obtained for basalt samples from Brazil and calcite single crystals. The latter show variations indicating the transformations to calcite II and III.

The dependence of the viscosity $\eta = \sigma/\dot{\varepsilon}$ on the creep rate corresponding to different creep mechanisms has been investigated by Weertmann and Stocker and Ashby. In determining $\dot{\varepsilon} = f(\sigma,L)\ D(p,T)$, it has been practical to assume that the stress function $f(\sigma,L)$ varies little with pressure and that the diffusion term can be approximated by $D_o \exp(-g\ T_m/T)$, where T_m is the melting temperature and 'g' a constant. In the past the pressure melting point has been determined mostly from the Simon equation. Results from high pressure melting experiments enable us now to deduce creep rates, viscosities and diffusion constants in different ways: (a) by using the observed $T_m(p)$ values in the D(p,T) approximation, (b) from ionic conductivity values in the melt phase using the Einstein mobility equation and the Stokes-Einstein relationship, and (c) from activation energies for the conductivity mechanisms as suggested by Magnitskii and Zharkov. Using (a) for a shell between 100 and 165 km with temperatures from 1000 to 2000 K and deviatoric stress of 10 KPa gives the following viscosities in (Pa s): Nabarro-Herring creep: 10^{20}-10^{24}; subgrain boundary (power law) creep: 10^{24}-10^{19}; dislocation glide (Nabarro) creep: 10^{23}-10^{18}.

In-situ high pressure measurements of elastic wave propagation and attenuation have been started using a two-channel digital oscilloscope, pulse generator and a high voltage/low variable frequency transformer. So far time-of-flight and phase lag measurements have been carried out with PZT-transducers mounted at the back faces of two opposite anvils acting as transmitter and receiver. At the present time the experimental arrangement seems to be capable of resolving 10^{-8}s.

Pressure, temperature, and ambient effects on the electrical conductivity of basalt and olivine show that the conductivity mechanism changes from electronic to ionic over a temperature range extending from just below the solidus to the temperature at which a contiguous melt forms. In the solid phase, polycrystalline samples of olivine have higher conductivities, lower activation energies and are more susceptible to ambient atmospheres than single crystals of olivine. This suggests that the solid phase conduction is dominated by a boundary layer mechanism. Accepting this interpretation, it becomes necessary to revise existing models for the determination of partial melt fractions from the apparent conductivity values. Most of these models based on either connected or dispersed distributions of spheres or ellipsoids, have shortcomings when applied to very small volume fractions which are just sufficient for the formation of a contiguous melt phase. They also overlook complications in electrical and thermal resistance arising from constrictions at contacts. A boundary layer model is regarded as superior, since it comes closest to physical reality both below and above the melting point; moreover, it can explain pre-melting and after-melting effects without altering the model concept.

The size frequency distributions of vesicles in Leg-37 basalts from the Mid-Atlantic Ridge were determined by analysis of X-ray absorption topographs. Variations in the distributions with depth below the ocean floor indicate strong effervescence caused by the evolution of gases during magma emplacement. Considering different possible situations causing super-saturation, estimates are being made of the heat loss by the expulsion of volatiles from magmatic liquids below the ocean floor.

(b) Heat Flow

A.E. Beck and S. Fodemesi are continuing their investigation of the induced thermal convection in needle probe conductivity measurements in contact resistance problems and in high resolution temperature gradient logging systems.

13. York University

(a) Dynamics of the Earth's Core

An analytical approach to core dynamics which takes into account both the Coriolis force and non-neutral stability for the first time is being pursued by D.E. Smylie with M.G. Rochester of Memorial University. In particular, the effect of compressibility has been thoroughly analysed and an approximation valid at subseismic frequencies has been used to reduce the governing system to a single second order partial differential equation. Two hyperbolic regimes for this equation are obtained and separated solutions are now being investigated.

On the observational side, development of very stable gravimeter systems is being continued. Seven sensors of our own design and construction have now been built. A computer based data acquisition system is being assembled to replace the present digital tape recording equipment. It is hoped the complete system will be put in operation in the new year.

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III(A) GEOMAGNETISM

Compiled by: P.J.C. Ryall and J.M. Hall

1. Geomagnetic Surveys, Charts and Compilations

(a) Atlantic Geoscience Centre

(i) Magnetic data covering 12 Natural Resource Map areas northeast of Newfoundland have been released as part of Geological Survey of Canada Open File 525. Each map covers 1^{o} of latitude by 2^{o} of longitude at a scale of 1:250,000. Total field and magnetic anomalies are presented in contour and posted form.

Magnetic data for 6 Natural Resource Map areas covering southern Saglek Bank and the adjacent Labrador Sea have been contoured and will be released on Open File shortly.

(ii) A total of 7280 km of magnetic data was collected in the Labrador Sea. This data was collected during a combined hydrographic-geophysical survey of the Labrador Sea. The line spacing is 10 km or less on the Labrador margin.

(iii) A compilation incorporating all existing data of the Labrador Sea magnetics at a scale of 1:2,000,000 has been completed; the map will be published in the Marine Sciences Map Series. As mentioned in the previous report, a great deal of difficulty was encountered in merging data reduced using IGRF-75 with data reduced using IGRF-65. To eliminate this problem until a more definitive model of IGRF is decided upon, a better representation of the regional field for the offshore regions of Eastern Canada is being sought with the help of the Geomagnetism Division of Earth Physics Branch in Ottawa. Models proposed by them are being

evaluated using the existing data in the offshore regions of Eastern Canada.

(iv) An additional 5700 km of magnetic data were collected northeast of Newfoundland to complete the mapping of that area. These data will help define the offshore extent of the ophiolitic units that are exposed along the shores of the Bay. Detailed coverage was also obtained off northern Newfoundland where the apparent source of the Hare Bay allochthon is marked by a major gravity and magnetic anomaly. Interpretation of the data in this location will be assisted by the interpretation of a seismic refraction program carried out over the suspected structure.

(v) A compilation is underway of all the magnetic (and gravity) data for the Appalachians which will be compatible with the Tectonic-Lithofacies Map of the Appalachians published by Hank Williams (Memorial University Map No. 1). It is hoped to publish this 1:1,000,000 magnetics compilation late in 1979, but a smaller scale draft compilation should be available as a GSC Open File, early in 1979. The compilation and its interpretation will be an objective of the Caledonian/Appalachian Orogen project (Project 27) of the International Geological Correlation Programme, and should be extended to cover European areas later in 1979.

(b) Earth Physics Branch

(i) *Magnetic Repeat Station Survey*

As part of a continuing study of magnetic secular variation 18 repeat stations were occupied, by contract, in parts of the Northwest Territories during the months of April to June. In the autumn 4 stations were occupied in B.C.

Datel cassette recordings provided a digital record of the variations in the magnetic declination (D), the horizontal (H) and vertical (Z) components of the field to reduce the uncertainties caused by diurnal variation and disturbance. These operated for a minimum period of 30 hours at each station. Auxiliary portable analogue recorders were also used in a back-up role. Absolute measurements of magnetic declination D, dip (I) and total intensity (F) provided baseline control. (L.R. Newitt, E. Dawson)

(ii) *Hudson Bay Survey*

As part of a continuing multi-disciplinary survey of Hudson Bay by DOE and MOT, the CCGS Narwhal covered approximately 20,500 km in Hudson Bay between July 17 and October 5, 1978. The Earth Physics Branch provided and operated a proton precession magnetometer giving digital samples of the total magnetic intensity at 10-second intervals. The magnetometer sensor was towed 110 m behind the ship.

Because of the high geomagnetic latitudes of the area, disturbance fields present major problems in data reduction. A correction technique has been developed and is being applied to survey data from 1975 and 1976. (R. L. Coles and G.V. Haines)

2. Interpretation of Magnetic Surveys

(a) Atlantic Geoscience Centre

Magnetic and seismic data have been used to map the extent of the Tertiary basalts off Baffin Island in the vicinity of Cape Dyer. The offshore occurrences are much larger (8000 km^2) and more continuous than the onshore basalt areas of eastern Baffin Island.

(b) Earth Physics Branch

(i) *Magnetic Repeat Station Surveys*

Recent secular change measurements show that over much of the country the magnitude of the annual change in D has at least doubled since the early 1970's. For example, near Edmonton the annual change is now 13' west compared to 3' west in 1970.

While H is still increasing over most of the country, reaching a maximum of 70 to 75 nT per year in the southeast, it appears that this increase is slowing down particularly in Alberta and British Columbia. There is a small area north of latitude 75°, where H is decreasing.

The large decrease in Z, noted in the 1977 report, is rapidly extending northward. For example, the decrease at Ottawa now exceeds 100 nT per year. Churchill now shows a decrease in excess of 30 nT per year and secular change measurements in parts of the western Arctic Islands also indicate a decrease in Z. (E. Dawson and L.R. Newitt)

(ii) *The Cross-Over Error and Reference Station Location for a Marine Magnetic Survey*

A marine magnetic survey was conducted over the Dellwood Knolls area in September 1977. Geomagnetic field reference stations were located at Victoria, Port Hardy and an ocean bottom site in the survey area. The cross-over error, a measure of survey accuracy, and the factors contributing to it are discussed. The work was done in cooperation with the Geological Survey of Canada (R.C. Currie). In high magnetic gradient regions, approximately 6 nT of the error is related to the uncertainty in ship position, which implies that the repeatability of the Loran-C system is the order of 30 metres. Part of the error is also due to time variations of the geomagnetic field. This effect can be significantly reduced by correcting to a well-located reference station. Because of the areal distribution of the geomagnetic coast effect, it is shown that a land station close to the survey area may not be as effective as a more distant site. The results also show that referencing to an ocean bottom magnetometer, at least to moderate levels of disburbance, is comparable to correcting to a well-located land station. Using a combination of land and ocean bottom reference data produces a more accurate marine magnetic survey. (K.R. Auld and L.K. Law)

(c) Université Laval - M.K. Séguin

Work continues on the interpretation of magnetic surveys in the Southern Sector of the Appalachians of Quebec. With groups of students in engineering physics, colour maps of the AM field were constructed and a qualitative interpretation of this potential method undertaken. This is then followed by a semi-quantitative interpretation and a comparison with surface geology.

(d) University of Manitoba

Lynn Lake Area - the interpretation project reported in Vol. 30 is now in its final year, in which an interpretation of the Questor aeromagnetic maps (1:20,000) released by the Manitoba Mines Branch is being carried out. Measurement of surface susceptibilities and remanent magnetization was completed in the summer of 1978, and these are being used as an aid in modelling of magnetic anomalies. The project is supervised by Dr. D.H. Hall.

(e) University of Toronto

(i) *High Resolution Aeromagnetic Data Interpretations over Abitibi Greenstones - J. Bambrick, S. Letros, D.W. Strangway*

A study of the high resolution aeromagnetic maps over the Blake River volcanics and volcanics in the Timmins area has been initiated. Maps have been subjected to upward and downward continuation and equivalent susceptibility maps have been derived. These maps quite accurately locate boundaries inferred by mapping.

The measurement of the samples will provide a base level and a scale for these maps so that we can seek to examine deviations from the known properties. In some of the magnetically quiet calc-alkalic volcanics we have been able to use residual maps to detect strong north-south trends not readily recognized in any other way.

We are also examining the effect of the Superior Province granite-greenstone belt anomalies to see if these major features could be detected at satellite height and hence be detectable by the forthcoming MAGSAT to be launched in the near future.

(ii) *Intercontinental Magnetic Correlation - B. Kwiecien, D.W. Strangway*

We have renewed our effort to compile aeromagnetic data from West Africa and eastern South America to see if the new data that has become available in the past few years can give us more information about detailed anomaly correlation. We also hope to use satellite data from the forthcoming MAGSAT for this purpose since we are searching for major differences in magnetic provinces.

3. Magnetic Observatories and Instruments

(a) Earth Physics Branch

A new Automatic Magnetic Observatory System (AMOS Mk III) is essentially complete. The new AMOS employs a microprocessor in place of the control logic of the original AMOS design. The system will carry out various tests on the data being recorded, and will store diagnostic messages, mean hourly values, ranges, and one-minute digital data for limited duration, for interrogation by telephone from the control centre. Additional facilities include provision for the acquisition of data with sampling rates faster than 1 minute, and limited remote debugging of software and hardware, from the control centre. The major part of the system has now been developed and tested successfully.

Eleven magnetic observatories operated throughout 1978: Mould Bay, Resolute Bay, Cambridge Bay and Baker Lake in the Arctic; Yellowknife, Fort Churchill and Great Whale River in the auroral zone; Victoria, Meanook, Ottawa and St. John's in southern Canada.

At all magnetic observatories except Mould Bay, an Automatic Magnetic Observatory System (AMOS) records three orthogonal components (X,Y,Z) of the magnetic field plus total intensity (F), once per minute in digital form on magnetic tape. The tapes are sent to Ottawa at the end of the month for editing by computer. The operation of each AMOS installation is checked five days a week from Ottawa, by means of a telephone verification system.

Photographic magnetograms are produced only at Mould Bay, Victoria, Meanook, Ottawa and the variation station Alert. For the other magnetic observatories, and the variation station at Whiteshell, Manitoba, computer plots are made from the one-minute digital data in the standard format of a Ruska magnetogram.

Analogue and digital recordings are reduced to the absolute field reference of the observatory by means of absolute measurements of the magnitude and direction of the field made twice a week at each observatory. A fluxgate magnetometer is used to measure declination and inclination; total intensity is given by a proton precession magnetometer.

Microfilm copies of magnetograms from the eleven magnetic observatories plus Alert and Whiteshell are sent monthly to World Data Center A, Boulder, Colorado. Edited versions of the digital magnetic tapes containing minute values, mean hourly values and hourly ranges for one year for each observatory are also deposited in World Data Center A. 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.

27-day forecasts of Geomagnetic Activity are issued on request every three weeks by the Ottawa Magnetic Observatory. Details of other services available from the Division of Geomagnetism are listed in the Catalogue of Services for the Division of Geomagnetism.

A contract has been given to EDA Instruments Inc. to develop a production model Automatic Magnetic Observatory System (AMOS) based on the EPB prototype AMOS Mark III. The prototype is microcomputer controlled and has been used over the past year for the development and testing of software to perform self-checking and data-reduction tasks and to respond to interrogation and commands from a remote terminal. At the end of 1978 the software is virtually completed. Under the contract EDA will also write diagnostic routines for servicing the instrument and will prepare complete hardware and software documentation packages. The contract, to be completed in September 1979, is administered under the new COPI program which is intended to assist Canadian manufacturers in the commercial exploitation of government R&D projects.

A magnetotelluric measurement and analysis system to study changes in apparent resistivity as a possible precursor of earthquakes has been designed and the prototype is undergoing testing and development. The system employs a microcomputer to sample the geomagnetic and geoelectric field components and to perform digital filtering by fast Fourier transform to yield the inphase and quadrature coefficients averaged within narrow period bands centred on 3, 10, 100 and 300 seconds. The latter are recorded every 30 minutes on a casette tape which will last for 30 days. By condensing the sampled data into coefficients the duration of a cassette is doubled, and the amount of subsequent computer processing to obtain apparent resistivities and Parkinson vectors is greatly reduced. Most of the software has been written and tested. The remaining development mainly involves microcomputer hardware modifications which are required to complete the filtering computations within the prescribed 30-minute recording interval.

A Geofyzika JR4 spinner magnetometer has been interfaced to an Interdata minicomputer. The components measured by the magnetometer are resolved by the computer into declination, inclination and intensity of magnetization of the rock specimen. Declination and inclination are computed with respect to both the horizontal and the bedding plane, and the precision of measurement is also computed. These results, together with identification and information concerning treatment of the specimen as entered by the operator are printed out and also punched onto paper tape for further computer processing.

(b) University of Alberta - N. Riebeek, M.D. Burke, D.I. Gough, A.O. Alabi, I. Morrison

Sixteen new magnetometers of improved Gough-Reitzel type are under construction, eight for the University of Ife and eight for the University of Alberta, in a cooperative program between these universities. Dr. Alabi arrived on sabbatical leave in October and will remain until late Febraury, 1979, to assemble parts made in our machine shop over the last year and to carry out those construction operations which require the skills of experimental physics. Simultaneously the twenty-five existing magnetometers of the Alberta set are being improved in optical design and in the camera-drive mechanism. In these improvements we acknowledge helpful input from the South African version of the magnetometer. The clock and switching logic are undergoing modification. The new version incorporates the Texas Instruments DataChron calculator/clock.

(c) Instrumentation for Tensor Audiofrequency Magnetotelluric Sounding - J.D. Redman, D.W. Strangway

We have received a microprocessor system and the related prototyping devices for the construction of our new AMT tensor system. Design work has been completed and the preliminary system is now being assembled. The on site processing of individual transients and resolution into the tensor components is expected to increase the quality of our results quite considerably.

4. Electromagnetic Induction in the Earth

(a) Earth Physics Branch

(i) *Ocean Bottom Magnetometer Results from the Juan de Fuca Ridge*

Three component geomagnetic variation data have been obtained at two sites 60 km apart on opposite sides of the northern end of the Juan de Fuca Ridge. The data were obtained over a two week period in June 1978. The horizontal fields are strongly suppressed relative to the fields at Victoria Observatory. The sea floor vertical fields are also significantly attenuated with respect to their own horizontal fields and no reversal of phase in the vertical fields at the two sites is evident. The data will also be compared with previous sea floor results and numerical models of the ridge area. (L.K. Law, J.P. Greenhouse)

(ii) *Investigation of Volcanic Areas in the Cascades*

Variations in the geomagnetic field were recorded along a line crossing the western part of the Cordillera at approximately 46°30'N. Fluxgate magnetometers were used and the data recorded digitally on cassettes at a 5 or 20 second sampling interval. The project was carried out in cooperation with the geophysical group at the University of Washington (J. Booker). Single station transfer functions and power spectra for each site have been computed. The "coast effect" is examined and compared with previous results obtained in this region. The line crossed an anomalous zone coincident with the recent Cascade volcanics which was observed at both short and long periods (30 to 3000 seconds). Results from the previous work north of the 49th parallel indicate the anomalous zone does not extend from the Cascade to Garabaldi volcanic regions. The existence of an east-west boundary between these two volcanic regions is proposed. A model depicting the subsurface conductivity structure beneath the southern cordillera is presented and its relation to the plate tectonic models proposed for this region is discussed. (L.K. Law, D.R. Auld)

(iii) *Geomagnetic Depth Sounding over the Central Arctic Islands*

A previous Bulletin (Vol. 26) reported on a seven day experiment which placed 3-component magnetometers at six sites over the central Arctic Islands between Isachsen and Resolute. The northern site, Isachsen, displayed the strong suppression of short period vertical component amplitudes that is observed at Mould Bay, 490 km to the west. Induction arrows and responses, or Z/H energy density ratios, are now available.

The observed responses at 10 minute periods provide estimates of the integrated conductivity of a surface layer over an insulator. For Mould Bay and Isachsen, these are 7400 S and 8700 S; for the remaining five sites, the integrated conductivities range from 1600 S to 2600 S. All sites are located on islands which are surrounded by channels filled with up to 0.5 km seawater. The conductivity of this seawater dominates the bulk conductivity of a thin surface layer about 1 km thick. The sub-aqueous materials are known to be sediments and are presumably porous and saturated. One dimensional model studies suggest that this surface layer be less than 2 km thick (conductivity of 1 S/m) in order to give reasonable fits to the short period responses. Integrated conductivities between 1600 S and 2600 S can therefore be explained with a heterogeneous layer consisting of seawater in the inter-island channels and of sub-aqueous, porous sediments. Most of the Arctic Islands are covered by this highly conducting thin sheet.

It is however more difficult to explain the high integrated conductivities observed at Mould Bay and Isachsen. Presumably the thin surface conductor exists beneath these stations so that integrated conductivities between 4800 S and 6100 S remain to be explained. One-dimensional modelling suggests that a 5 km layer, its top boundary 7 km deep, with a conductivity of 1 S/m can account for these integrated conductivities. But a high conductivity of 1 S/m requires through Archie's Law porosities of the order of 25 percent to exist between 7 and 12 km depths. Under normal compaction conditions, porosities should decay exponentially with depth to less than 5 percent near 7 km. Conductivities in this case are much less than 0.1 S/m which do not contribute significantly to the integrated conductivities. Either porosities at depth are extremely abnormal beneath these stations or some other conductivity mechanism is required. A detailed discussion is being prepared for publication. (J.M. DeLaurier)

(iv) *Time Dependence of Magnetotelluric Parameters and its Association with Seismicity*

Magnetotelluric (MT) fields have been monitored for over 4 years near the centre of seismicity in a tectonically active region in Quebec's Charlevoix County on the north shore of the St. Lawrence River. Previous results are given in last year's Bulletin. Impedance values have been very stable over the past year at the central recording site in contrast to changes of up to 30% that have been observed in the past. The reference station in Parc des Laurentides continues to display stable impedance estimates. However, the impedance at the station established southwest of Baie-St-Paul has been increasing slightly. The other station established near Ste Mathilde in 1977 was relocated 4.5 km to the east during the summer of 1978. Seismic activity was relatively low during 1978 and it has not been possible to develop a clear association between the low level of activity and impedance changes.

Three previous MT stations along with the 5 MT stations referred to above have indicated major differences in the electrical conductivity of the crust and upper mantle in the Grenville Province. In cooperation with Ecole Polytechnique additional data have been obtained at 5 stations in the frequency range from 30 Hz to 0.01 Hz. These results confirm the existence of highly conducting regions in Parc des Laurentides and in Charlevoix County. (R.D. Kurtz, E.R. Niblett)

(v) *Magnetometer Array Studies, Saguenay - Laurentide Area of Québec*

As reported in Canadian Geophysical Bulletin 1976, substorm fields recorded in summer 1975 by this array of 26 variometers show only minor anomalies. The smooth gradients thus mapped have been exploited to yield a layered model of the electrical conductivity structure. Assume that the Earth here consists of a resistive layer above a conductive half space. Then $Z/(\partial X/\partial x + \partial Y/\partial y)$, for the best result at period 174 min, suggests that the resistive layer is 300±100 km thick and that the half space has conductivity 0.06–0.6 S/m. At pulsation periods, Z variations appear to be severely attenuated over the eastern third of the array for some polarizations of the horizontal field. (P.A. Camfield)

(vi) *Magnetic Daily Variations Compared Between the East and West Coasts of Canada*

Observatory data from St. John's, Ottawa, Agincourt, Newport and Victoria have been examined for the five international quiet days of August 1968. The horizontal components of the daily variation are spatially uniform across the continent, but the enhanced vertical components at St. John's and Victoria demonstrate a long-period coast effect similar to that observed for two coasts of Australia and for California. Separate from the coast effect, Sq(Z) has a much smaller amplitude at Ottawa and Agincourt than at Newport. This may be a source effect, or it may indicate a contrast in internal electrical conductivity between the two inland regions. The latter explanation implies higher conductivity to the east and lower to the west, the reverse of many currently accepted models. (F.E.M. Lilley, visiting from the Australian National University)

(vii) *Partial Melt in the Asthenosphere*

Modelled electrical conductivity variations with depth in the upper mantle obtained from published geomagnetic depth sounding and magnetotelluric studies have been compared to predicted conductivity variations derived from published laboratory data on dry material assumed to occur in the mantle. Higher than predicted conductivities at the base of the oceanic lithosphere suggest the presence of highly conductive (3-10 S m^{-1}) partial melt in the form of a continuously connected network. The volume fraction of this melt could be up to approximately 9%. Conductivities at the base of the lithosphere beneath stable shield areas are not significantly different from values predicted for dry material, which suggests that these areas may have no well-developed asthenosphere. Partial melt content may reach a few percent if the melt exists in isolated pockets. The apparent difference in melt content - and hence viscosity - of sub-oceanic and sub-continental asthenosphere might explain, at least in part, why the spreading rate of Pacific-type lithospheric plates, which carry no continental block, is commonly observed to be greater than that of Atlantic-type plates, which do carry a continental block. (M.J. Drury)

(viii) *Dilatancy and Electrical Conductivity Changes in the Crust*

Examination of published laboratory data has indicated that much of the large increase of electrical conductivity (up to a factor of x5) of stressed rocks prior to failure is accounted for by 'surface conductivity' in electrical double layers at rock-fluid interfaces in microcracks (of width $\leq 1\mu m$). Conductivity changes in a water-saturated dilating crust might be observed before other dilatancy-induced precursory phenomena are observed because of the strong effect of the surface conductivity. Measurement of conductivity changes with time cannot be used for predicting the time of occurrence of an earthquake because of uncertainties in factors such as pore fluid pressure and degree of saturation of newly-formed cracks. However, observations of time-dependent conductivity variations might provide information on crustal behaviour during dilatancy, since as cracks begin to form in some preferred direction the conductivity anisotropy of the crust should change. Such changes might be seen, for example, in the magnetotelluric impedance tensor elements. (M.J. Drury)

(ix) *Magnetovariation and Magnetotelluric Studies in Viscount Melville Sound*

Data from a magnetovariation and magnetotelluric station on the sea ice of Viscount Melville Sound in the Western Canadian Arctic (lat. 74°28'N, long. 104°19'W) obtained during April 1978 have been analysed, along with simultaneous magnetic variation data from Resolute, 300 km to the east. One-dimensional modelling of the geomagnetic response (Z/H ratio) suggests that an upper mantle conductor (conductance of the order of 10^5S) underlies both sites, with its top surface at a depth of 70-100 km. The data also require that the models have a surface layer with conductance 1000-3000 S. The in-phase components of the induction vectors point generally south to southwestwards (i.e. towards the centre of the sea channel) at both sites, at all periods at which the vector is well-defined. The transfer function amplitudes at the Viscount Melville Sound site are small at all periods, and tend to zero at periods greater than about 1 hour. At Resolute the transfer function amplitude peaks at intermediate periods and decays rapidly, tending to zero at periods greater than about 1 hour. At both sites the induction vector is poorly defined at long periods.

The telluric field at the Viscount Melville Sound site is strongly polarized in an east-west direction, which coincides with the major axis of anisotropy of impedance. Apparent resistivities in the major axis of anisotropy are well defined, but in the minor axis apparent resistivities show high scatter. The one-dimensional model which fits the Z/H data also fits the phase data in the major axis of anisotropy, but not the apparent resistivity. The observed apparent resistivity in this direction is higher than predicted resistivity for reasonable one-or two-dimensional models. We speculate that the observations can be explained if currents induced elsewhere (e.g. the deep ocean) are being channelled into Viscount Melville Sound. (M.J. Drury, P.A. Camfield)

(b) University of Alberta

(i) *Array Study in South Africa - J.H. de Beer, D.I. Gough, J.S.V. van Zijl, D. Sinclair, J. Blume*

Simultaneous recordings of time-varying magnetic fields in three components at 53 stations, covering the southern tip of Africa south of 30°S, were secured between late September and early

December, 1977. Fifty-one of the instruments were of Gough-Reitzel type, 25 being the University of Alberta set and 25 new instruments built at the South African National Physical Research Laboratory. The other two stations were permanent magnetic observatories. Numerous excellent events of substorm type were recorded with efficiencies of 85 to 95 percent and data processing and editing is well advanced. All of this large task is being handled in Pretoria, under the direction of Dr. de Beer. The study was aimed mainly at full investigation of a large conductive body in the lower crust and upper mantle, discovered in an earlier array study (Gough, de Beer and van Zijl 1973, Geophys. J. 34, 421) and known to carry large east-west induced currents. This conductor lay outside the earlier array, which could therefore only roughly locate it. At the present stage of the current study, it is clear that the structure has been covered and will soon be mapped in some detail. The anomalous fields are large and the limits of the structure are evident from the magnetograms. It appears to be related in a coherent way to topography, to geology, to geochronology and to gravity and magnetic anomalies in a way that is consistent with a late Proterozoic subduction of oceanic crust under the tip of Africa. Confirmation of this hypothesis must await full analysis of the data.

(ii) *Western Canadian Magnetometer Array Program - D.I. Gough*

Preliminary planning is in progress for a comprehensive mapping of conductive structures in the crust and upper mantle of western Canada, to commence in 1979.

(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. Also, in collaboration with Dr. H.W. Dosso and Dr. W. Nienaber of the University of Victoria, Dr. L.K. Law of the Pacific Geoscience Centre, Sidney, B.C. and Dr. V. Ramaswamy, now of the Institute of Petroleum Exploration, Dehra Dun, India, numerical and analogue model measurements are being compared.

In collaboration with Dr. W.D. Parkinson of the Department of Geology, University of Tasmania, a literature review of the geomagnetic coast effect has been undertaken by Dr. Jones in an effort to evaluate the weight of observations and opinions on the question of the relative importance of electric currents flowing in sea water against that of currents in the deeper parts of the earth. In relation to the question of the origin of the geomagnetic coast effect and the effect of sea water, Dr. Jones is also studying 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.

(iv) *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.

(c) University of Toronto

(i) *Controlled Source Experiments - R.C. Bailey, R.N. Edwards, G.D. Garland*

Field work was carried out with the broad-band (0.01-10 kHz) pseudo-random binary source system, using the higher end of the frequency range in a shallow sounding experiment. The purpose was to investigate the application of the technique to local, detailed mapping of conductors in sedimentary sections. Over a Palaeozoic section in southern Ontario, it was found possible to map a shale-limestone interface, using a maximum source-receiver distance of 2.2 km.

While no further measurements were made at the low end of the frequency range, the interpretation was completed of observations made near Timmins, Ontario, in 1977. These involved the use of a bipole 20 km long, with observations of the magnetic field at distances up to 70 km from the source. The primary magnetic fields never exceeded 5 milligammas and were often much smaller, but could be extracted from the observed signal by the cross-correlation technique. The interpretation shows the existence of conductive material in the lower crust beneath the region, but it also suggests that the conductor is discontinuous laterally.

(ii) *Geomagnetic Depth Sounding - R.C. Bailey, R.N. Edwards, G.D. Garland*

Further measurements were made in the large-scale sounding project of eastern North America. Geomagnetic and telluric electric field variations were recorded at periods from several hours to several minutes at six sites. Three of these: London, Windsor, and Owen Sound were in southwest Ontario; the other three: Conneaut, Ohio; Clarion, Pa.; and State College, Pa. lay south of Lake Erie. These measurements are intended to establish the continuity of the Appalachian conductivity anomaly found with previous work. Further analysis of previous work has indicated that the detailed behaviour of the conductivity anomaly in New England is controlled by the high crustal temperatures associated with the White Mountain heat flow anomaly.

(iii) *Magnetotelluric Sounding for Water, Permafrost and Nuclear Waste Disposal Site Testing - J.D. Redman, J.S. Holladay, C. Horne, D.W. Strangway*

We have continued our audiofrequency magnetotelluric studies over test sites for nuclear waste disposal. These studies are particularly useful to determine water content and to map fractures in high resistivity regions. In the Chalk River area we extended our earlier studies to a grid survey mapping out the location and orientation of a large number of water-filled fractures. These results show the region to be highly fractured. A study at the Whiteshell Nuclear Reactor Site, Pinawa, Manitoba was also conducted. A grid survey was also conducted in this clay covered region. Clay cover is highly conductive and makes sounding for detection of bedrock fractures difficult. We could only penetrate the cover at our lower frequencies of 100 hz or so. This means of course that no conventional electrical or electromagnetic method will be capable of mapping the bedrock fractures uniquely. There is nevertheless a strong indication that there are no major conductive fractures in the bedrock in this region. A paper was presented at a

Canadian Geoscience Council Forum on the application of geophysical methods to this problem.

(iv) *Magnetotelluric Sounding Over Proterozoic Sediments - D.W. Strangway, J.D. Redman*

Studies of the electrical properties of Proterozoic sediments in the Blind River-Elliott Lake area and in northern Saskatchewan show that in many places, these sediments have an extremely high resistivity. Resistivity values of 100,000 ohm meters or more are common and suggest that there is essentially no water in the pore spaces and that the pore spaces must be closed, with little interconnection between them. Fractures associated with the diabase intrusions in the Elliott Lake region introduce local resistivity lows.

(v) *Electrical and Magnetic Signatures of Paleoimpact Structures, Williston Basin - A. Gubins, D.W. Strangway*

An M.A.Sc. thesis on the magnetic and magnetotelluric signature of apparent paleoimpact structures in the Willison Basin has now been completed. Structures examined include the Viewfield and Dumas structures in Saskatchewan and the Hartney structure in Manitoba. Very weak but local magnetic anomalies suggest the presence of reversely magnetized material in at least two of these structures. It is possible that heating remagnetized the sediments at the time of the impact.

The resistivity values of the shales overlying the structures are very low, so that it is not likely that we have been able to detect an electrical effect even at the lowest frequencies of 10 hz. Nevertheless, the values of resistivity are extremely uniform from station to station so that small variations have been detected that may be of significance.

(vi) *Induced Polarization Modelling and the Determination of Water Content of Various Media - J. Wong, D.W. Strangway*

J. Wong is completing his Ph.D. thesis. A portion of his work has been the development of an electrochemical model for the induced polarization effect. This model contains many parameters but it appears that one of the dominant ones is that of particle size, which controls the frequency response and determines the peak relaxation frequency. It suggests that the spectral response of ore deposits is at least in part dependent on the habit of the mineral assemblage and that responses with no spectral peak represent a distribution of grain sizes.

Experimental studies are now being conducted to confirm the analytical calculations. Studies both analytical and field-based are being conducted to detect moisture content in the soil layers. Field data from permafrost regions and at a calibrated agricultural test site have been collected.

(d) The University of Victoria - H.W. Dosso, J.T. Weaver, R.D. Hibbs, W. Nienaber, U. Raval, R. Chan, T.W. Dawson, V.R. Green, G. Heard, T. Miles.

Improved boundary conditions have been found for application around the edge of the numerical grid in the general finite-difference solution of E-polarization induction problems. The use of these boundary conditions allows the same accuracy to be attained on much smaller numerical grids than were previously necessary.

Theoretical studies of electromagnetic induction in a thin sheet of variable conductance underlain by a conducting half-space are continuing. The general H-polarization problem of induction in two thin half-sheets has been solved analytically by the Wiener-Hopf technique. The solution has been used to verify the accuracy of a numerical method that has been developed to solve general 2-dimensional models in which the conductance of thin sheets can vary arbitrarily. It also serves to provide an explanation of the coast-effect in the H-polarization mode, which affects both magneto-telluric observations on land, and magnetic variations on the adjacent sea floor.

The solution of the general 3-dimensional problem, in which the conductance of the thin sheet varies arbitrarily in both horizontal directions, has been expressed as a coupled pair of integral equations which can be solved numerically. This permits 3-dimensional models that approach either E- or H-polarization configurations at infinity to be analyzed. It is planned to study induction in local regions of the Earth by using this method on computer models approximately representing the geographical areas in question.

The continuing analogue model studies include the response of embedded conducting bodies, various aspects of the coast effect problem, and magnetic variations induced by ocean waves. In collaboration with Dr. S.O. Ogunade, University of Ife, Ile-Ife, Nigeria, the problem of a conducting cylinder embedded in a layered conductor for an overhead line current source, for a line current on the surface of the Earth, and for a uniform source, is being studied both analytically and with aid of an analogue model.

A scaled model of Vancouver Island and the surrounding region has been 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 are being compared with magnetotelluric measurements from field stations at various locations on Vancouver Island and the mainland. The model results are also being compared with finite difference numerical calculations. These studies are 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 are compared with field measurements at two stations in a bay at Port Renfrew on Vancouver Island. The contour of the coastline is found to play an important role in determining the behaviour of the coast effect.

An analogue model, employing mercury to simulate an ocean, has been used to carry out a scaled laboratory study of magnetic variations induced by ocean waves moving in a steady magnetic field. For a shallow ocean, model studies of a sloping ocean floor with a shelf, a sloping floor in a bay, a reef, and a sea mount have been carried out. The changing depth of the ocean was found to be the important factor in determining the behaviour of the induced field for the models studied.

Collaboration with Dr. V.R. Hutton (Edinburgh) in carrying out a model study of the British Isles is underway. The analogue model results will be compared with available field station results. In collaboration with Dr. R.C. Bailey (Toronto), Dr. J.P. Greenhouse (University of Waterloo) and Dr. J.A. Wright (Memorial University), a laboratory analogue model of the eastern coast of Canada is being constructed and measurements will be used as an aid to understanding field data for that region.

5. Paleomagnetism, Rock Magnetism and Tectonomagnetism

(a) Earth Physics Branch

(i) *Precambrian*

Recent studies (Seton, Pearson and Douglas Peninsula Formations and Epworth Group) from the Coronation Geosyncline have been published, or are in press. Under study from this region are the Cameron Bay Group, the Hornby Bay and Port Radium Sills; and a collection from 2.0 b.y. old intrusives including the Blanchford Complex. Experimental work on the Katherine Group and the Tsezotene of the Mackenzie Mountains is continuing and a paper on the Little Dal Formation is being prepared. An extensive study of Belcher Island rocks is now being written up. In or near the Grenville Province, works on the Charlevoix anorthosite and the Seal Group have been submitted for publication, and experimental work on the Larrimac and Bryson diorites continues. A paper has been published on the Jacobsville Formation. Work continues under contract on the Sudbury Irruptive.

(ii) *Appalachians*

Papers on the Botwood Formation and Mt. Peyton intrusives of Newfoundland, and on the Mascarene Formation and St. George and St. Stephen's intrusions of New Brunswick are in press. Experimental work is completed and papers are being prepared on Sept-Iles anorthosite of Quebec and Leading Tickel lamprophyre dikes of Newfoundland. Work is continuing on Ordovicain and Silurian redbeds of the Arisaig region, on the Coldbrook Formation of New Brunswick, on Carboniferous sedimentary rocks (Boss Point Formation, and Petitcodiac and Moncton Groups), and on the Chaleur Bay Group of Gaspé.

(iii) *Cordillera*

Further collections of the Takla, Asitka and Hazelton Groups and the Axelgold intrusion have been made and experimental work is expected to be completed by early 1979. A paper is being prepared on the Karmutsen Fromation.

(iv) *Technical and Analytical Program*

Technical procedures outlined in last year's Bulletin are continuing to be applied, and new procedures for data listing and graphics designed to automate the study of multicomponent magnetization are now in place. A paper discussing the impact that such studies have on paleomagnetic interpretations has been published.

(v) *Interpretation and Map Program*

Much effort is being devoted to constructing apparent polar wandering (APW) paths and to consideration of associated problems: the determination of original rock attitudes (paleohorizontal), the ambiguity in polarity (in which hemisphere was a rock unit formed?), the non-random nature of paleopole distributions, errors caused by magnetic overprinting etc. Papers have been published discussing the methodology of the reconstruction of Precambrian APW, describing a new APW path for Gondwana, and discussing the statistical deficiency in the number of high latitude Precambrian poles observed. As these technical problems become better evaluated however, the results come to have an increasingly important application for tectonics and the mechanics of continental accretion. Numerous paleopoles from the

Western Cordillera show that certain terrains, now embedded in the Cordillera, were once displaced relative to "stable" North America by thousands of kilometres in the Mesozoic and Tertiary. Recent studies in Siluro-Devonian rocks in the Appalachians have yielded paleopoles up to 60° away from poles of comparable age from "stable" North America, and the question arises, do these poles represent displaced terrain like those found in the Cordillera? The paleomagnetic record is very fragmentary for this time interval, and it is possible therefore that these Appalachian paleopoles fall in time gaps in the record from "stable" North America and do not record tectonic displacements. Obviously more data are required, but at least this important question can be put.

Papers describing a sequence of paleocontinental maps for the Phanerozoic have been published or are in press. A review of paleopole studies in North America for Canadian Geodynamics Committee's report has been completed.

(b) Geological Survey of Canada

(i) *Athabasca Formation*

Paleomagnetic study indicates that the Athabasca Formation of northern Saskatchewan, Canada, was deposited about 1550 or about 1700 Ma ago at a latitude of 39°. A Rb/Sr isochron on regolith from below the Athabasca (R.K. Wanless, pers. comm., 1977) suggests that the younger age is correct. Reversals in the polarity of the earth's field occurred a number of times during deposition of the Formation and these promise to be of value in the chronostratigraphic correlation of redbed units within the formation.

(ii) *Boothia Uplift*

Oriented samples (107) have been drilled for paleomagnetic studies from diabase sills and dykes on either side of the Boothia Uplift, Canada. Six sites at Savage Point are in sills which intrude the Aston Formation; three, at Whitehead Point, north of Savage Point on the east coast of Prince of Wales Island, are in sills which also intrude these strata. Six sites in the Aston Bay area of Somerset Island are in dykes and a sill which cut the Aston Formation; the former also intrude the Hunting formation. No meaningful results were obtained from the Whitehead Point samples. Paleomagnetic measurements on the Savage Point samples, together with new K-Ar data, strongly suggest these sills belong to the Mackenzie igneous episode (ca. 1240 Ma). The sill in the Aston Bay area apparently belongs to this episode too, whereas most of the dykes are Franklin dykes (ca. 675 Ma). One large dyke was possibly emplaced in Tertiary times. Thus the Aston Formation is older than 1240 Ma and the Hunting Formation is bracketed between 1240 and 675 Ma.

(c) University of Alberta

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

The possibility of lateral correlation by means of paleomagnetic features, particularly reversals, is being pursued by means of extensive collections from two ancient sedimentary basins in northern Canada; the Athapuscow Aulocogen (Great Slave Supergroup) and the Kilohigok Basin (Burnside River and Peacock Hills Formations). These sedimentary basins, and others like them, represent almost unique opportunities to probe the history of geomagnetism and geotectonics during very remote times. In 1977 twenty-six stratigraphic horizons were sampled from the Burnside

River Formation and five from the overlying Peacock Hills Formations. The resulting data indicated that higher resolution and more extensive sampling in the younger sequence were essential, and to this end a further collection at forty-two new horizons has been made this year. Processing of this material and related samples is now going forward.

Chemical demagnetization of these Proterozoic red beds is being attempted in addition to standard thermal cleaning. The low permeability of the beds to percolating fluids results in very long leaching times, and the construction of a high-pressure cell to force acid through the specimens is therefore planned.

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

Work is continuing on the magnetostratigraphy of the Cretaceous/Tertiary Boundary in Alberta. In conjunction with Dr. J.F. Lerbekmo and Dr. H.A. Baadsgaard of the Geology Department of the University, some 500 samples have been magnetically analysed, and eleven high-quality K-Ar dates have been obtained. The samples are weakly magnetized and it is expected that further work will be greatly expedited by the sensitive cryogenic magnetometer currently on order.

(iii) *Quaternary and Tertiary Formations* - M.E. Evans, G.S. Hoye, C.J. Oberg, I.B. Hussin

Detailed sampling of a 7-metre sequence of sediments from the Olympia Interglaciation in British Columbia has yielded a very 'clean' record of geomagnetic secular variation spanning 9,000 years (31,200 to 22,100 B.P.). A sequence of smooth oscillations in declination and inclination is observed and when combined these demonstrate that the geomagnetic vector traced out a remarkable pattern. Three-quarters of an open loop is traversed first in one direction and then in the opposite direction. Preliminary modelling suggests that this pattern most likely results from dipole wobble, and this is supported by FFT and MEM spectral analysis which indicate periodicities of 5,000 to 6,000 years, with smaller peaks at 2,000 to 3,000 years. The mean paleomagnetic pole lies at 0.0^{o}E, 85.6^{o}N ($K=72$, $A_{95}=1.7^{o}$), and is distinct from the earth's spin axis - it is, in fact, both "far-sided" and "right-handed". There is no indication of the so-called Mono Lake and Lake Mungo geomagnetic excursions, and this supports the view that these phenomena represent spatially restricted anomalies which are associated with localized non-dipole sources in the outermost core.

The complex MEM spectral analysis technique offers several advantages to paleomagnetists forced to work with short and noisy time sequences. A series of numerical experiments employing synthetic signals contaminated with Fisherian noise has been conducted to assess the capabilities of the method. Several interesting conclusions emerge, the most important of which is that the method enables one to identify both the frequency and sense of looping in the presence of noise levels twice that of the signal amplitude.

In conjunction with Dr. J.A. Westgate of the Geology Department, University of Toronto, we have studied several outcrops paleomagnetically with a view to improving our knowledge of geomagnetic secular variation, and helping to elucidate the Quaternary geological history of western Canada. The most important finding so far is the demonstration that geomagnetic signatures can be used for geological correlation. This, in turn, has helped

establish the stratigraphy of the Glacier Peak ash-falls which are important geological marker horizons.

In conjunction with Dr. C.M. Scarfe and Mr. T.S. Hamilton of the Geology Department, University of Alberta, we have collected samples from two sections on Level Mountain (northwestern B.C.), which is a continental shield volcano of uppermost Tertiary and Quternary age. Each section consists of 25 separate cooling units (flows or tuffs; 5 cores per unit). Magnetic measurements on these samples are now complete and statistical analysis is well-advanced. At least eight polarity reversals are present, as well as some rare and very interesting intermediate directions.

(iv) *Archeomagnetism - G.S. Hoye*

With the cooperation of Drs. A.M. Small and R.J. Buck of the Classics Department, University of Alberta, a dig in southern Italy was visited and a collection of 100 samples drilled from a Roman kiln. The samples are now being prepared for laboratory analysis. This project is still in its infancy, but it is hoped that such data will gradually enable relatively short term geomagnetic variations to be elucidated and, in return, provide a means of dating archeological sites of uncertain affinity.

(v) *Rock Magnetic Studies of Synthetic Materials - M.E. Evans, G.S. Hoye, J.K. Park*

Olivine is an important rock-forming mineral, and its oxidation products represent a potentially significant source of paleomagnetic information. We have extended our earlier work on the magnetic properties of oxidized synthetic olivine powders to different compositions (viz. $Fe_xMg_{2-x}SiO_4$) where x takes the values 1.8, 1.0 and 0.6 in the samples investigated. All compositions acquired a measurable CRM, but, in contrast to our earlier results, this was found to be weak in comparison to NRM's in typical igneous samples.

Despite much effort and a great number of paleomagnetic studies the origin of remanence in red beds is still not clear. We have therefore begun an investigation intended to contribute to the understanding of this important phenomenon. "Synthetic sandstone" specimens are being made by growing magnetic oxides on a substrate consisting of commercially available porous pyrex discs. Preliminary work indicates that a CRM is acquired by such material, and we thus have a means at our disposal of investigating the magnetization and demagnetization properties of material resembling red beds, in the laboratory.

(vi) *Magnetic Anisotropy and Rock Fabric - P. Guntur, D.I. Gough, M.E. Evans*

Analysis of a suite of samples from the late Precambrian Miette group near Jasper, Alberta, is going forward. All measurements are now complete and a coherent sequence of magnetic ellipsoid patterns has emerged. The task of comparing this to the structural geology has been delayed as a result of the tragic death of Dr. Pullaiah Guntur on October 11.

(vii) *Paleomagnetic Reconstructions - E.R. Kanasewich, J. Havskov*

Dr. E.R. Kanasewich and Dr. Jens Havskov have begun a study correlating the past geographic and geologic setting of continents with the occurrence of hydrocarbon deposits. The work is an

outgrowth of the study on plate tectonics by Kanasewich, Havskov and Evans (1978). For this study we have plotted the positions of major oil and gas fields, oil shales and oil sands on the maps of each period. Many petroleum deposits seem to have been formed within 35° of the paleo-equator in the Paleozoic Era. The reconstruction may help in delineating broad exploration targets, particularly in the Cambrian and Ordovician basins of North America and Asia. The tectonic activity and pattern of continental groups, which influences ocean currents, is also important in the development of favourable basins.

(d) Dalhousie University, Paleomagnetism Laboratory, Department of Geology

(i) *Iceland - J.M. Hall, J. Clark, J.W. Pierce, D. Plasse, N. Cruver*

Two projects involving Icelandic geology have been in progress this year. Paleo- and rock magnetics are being studied on a 3 km crustal section (1 km exposed section plus 2 km drillhole section) in eastern Iceland.

Determination of the part of the polarity sequence recorded in the section indicates that the top kilometer of the drillcore, at least, records sea floor spreading magnetic anomaly number 5. Alteration of the 400 flows in the section increases continuously with depth. The highest flows are essentially unaltered while the deepest contain abundant epidote. Study of the magnetic changes following this increase in alteration is underway. It is already known that initial susceptibility decreases strongly and approximately linearly with depth in the core.

A second study in Iceland is concerned with the contentious question of the reality, number and nature of young Brunhes reverse polarity events. Discovery of two reversely magnetized, subglacially erupted flows in the active zone near Thingvallir supports the reality of such events and may imply a worldwide nature of one such event. The event, designated "Maelifell" following the tradition of geographic naming, is well defined magnetically but cannot be dated as a consequence of the very low potassium and uranium contents of the lavas involved.

(ii) *The Ocean Crust - J.M. Hall, P.J. Ryall, N. Gruver, D. Plasse, J. Clark, J.W. Pierce, P. Rice*

Work in several directions has continued in this area. Hall, with Robinson of University of California, Riverside, has developed models for the inner median valley tectonic evolution of Atlantic crust. The models invoke large scale subsidence, fragmentation and tilting of volcanic edifices as an integral part of the process of crustal formation. Widespread anomalous cleaned paleomagnetic inclinations in DSDP drillcore basalts are the main line of evidence for these models. The models were described in an invited paper given at the second Ewing Symposium and will appear shortly in a Science review article.

A second line of attack on the tectonic state of upper layer 2 of the oceanic crust is being made by Nancy Gruver as a contribution to an M.Sc. thesis. Using a combination of stable paleomagnetic inclinations and the orientation of the menisci in segregation vesicles she finds that completely defined tectonic rotations much in excess of those involved in the Hall-Robinson model appear to be present in DSDP hole 332A. Tests of the reliability of this technique are presently in hand.

The magnetization of basalts dredged from the Cayman Trough, a short spreading centre linking two segments of a major Caribbean transform fault, has been studied. Comparison of principal profiles of magnetic properties across the Cayman Trough and Mid-Atlantic ridge spreading centres suggests that the Cayman Trough section is considerably disarranged tectonically. A number of apparently reversely magnetized samples dredged from the centre of the axial valley are an enigmatic feature also seen on the Mid Atlantic Ridge.

Philip Rice completed an M.Sc. thesis on the magnetics of the pillow lavas forming the uppermost 800 m of the Bermuda Seamount. The main result is the identification of volumetrically widespread stable thermochemical remagnetization of the flows following a later period of intense dyke injection. It is possible that such a uniform remagnetization mechanism could produce a magnetic anomaly source layer in the lower part of oceanic layer 2.

Daniel Plasse has nearly completed a combined experimental and observational study of the production of titanomagnetite granulation in basalts. This type of alteration is a feature of rocks altered to mid-zeolite zone conditions and is relevant to changes in magnetic properties with alteration.

Patrick Ryall started work in May 1978 on the joint development with the Bedford Institute of Oceanography of a deep-ocean version of the BIO electric bottom drill. It is intended that this drill will be used on a major attack on Mid Atlantic Ridge problems, including basalt polarity distributions, probably in 1981.

(iii) *Hungary - H.B.S. Cooke, J.M. Hall, W. Kay*

Our collaborative study with the Hungarian Geological Institute of the paleomagnetism of sediments from deep drill holes in the Hungarian Plain has continued. Stable paleomagnetic inclinations at one meter intervals are now available for the 1200 m Devavanya core, and from the top kilometer of a second core from a drill site 50 km from Devavanya. Both cores show high uniform sedimentation rate (180 m/My) back to at least 6 My, with all the major geomagnetic epochs and events identifiable. Much detail is apparent in the high resolution records. Perhaps the most interesting feature is the large fraction of time (about one third of the interval) in which the geomagnetic field appears to oscillate rapidly between the normal and reverse polarity states.

(e) Université Laval - M.K. Séguin

Paleomagnetic studies were undertaken with graduate students in engineering physics and physics in the following regions:

1) Appalachian internal domain.
2) Cambrian-Precambrian diabase dykes cutting the Grenville province.
3) Ultramafic and basaltic rock suites of the Abitibi greenstone belt.
4) Proterozoic redbeds from the Sakomi River district, Northern Quebec.

In the Appalachians, intrusive and extrusive rocks from Cambrian to Cretaceous age have been investigated paleomagnetically.

This includes:

a) Upper Devonian Nylmer Mountain intrusives and surrounding Ordovician metalavas and metasediments.
b) Upper Devonian Winslow intrusives and Ordovician-Silurian country rocks.
c) The Gould-Wredon volcanic series.
d) The Scotstown Middle Devonian intrusive and surrounding hornfels and Silurian metasediments.
e) The Megantic Cretaceous intrusives and related country rocks.

(f) University of Manitoba

(i) *Churchill Geologic Province*

Surface induced and remanent magnetization and stability of remanence are being measured on oriented cores taken between Thompson and Lynn Lake, Manitoba.

(ii) *Superior Geologic Province*

A similar project is being continued over the Winnipeg River batholithic belt of the English River subprovince, as well as over the Dryberry batholith. These projects are supervised by Dr. D.H. Hall.

(g) University of Toronto

(i) *D.J. Dunlop, G.W. Berger, M.E. Bailey, C.J. Hale, L. Schutts, C. Blackburn*

David Dunlop and Dr. Michel Prévot of the Laboratoire de Geomagnétisme, Université de Paris VI carried out a joint study of magnetic properties of mafic and ultramafic intrusive rocks drilled from the ocean crust during Dr. Dunlop's research leave at Paris. Many are magnetically very soft, but after alternating-field demagnetization a stable magnetization is generally revealed. Gabbros from DSDP (Deep Sea Drilling Project) Leg 30 have stable magnetization directions that agree with the expected dipole-field inclination. Tectonically emplaced gabbros and peridotites from DSDP Leg 37 have more scattered stable directions. Drill-stem remanence masks stable magnetization in all DSDP Leg 45 peridotites.

Dr. Dunlop has completed the analysis of paleomagnetic measurements on eleven formations (granites, gneisses, mafic volcanics and intrusives, iron formations) of Archean age from the western Superior Province. All formations have a strong, well-grouped metamorphic overprint dating from the close of the Kenoran orogeny. Some have, in addition, a superimposed magnetization which is either primary and about 2800 Ma in age or, more likely, an overprint dating from the 1200 Ma Mackenzie igneous activity. Companion stepwise heating $^{40}Ar/^{39}Ar$ studies of one of the formations, the Shelley Lake granite, by Glenn Berger confirm the principal metamorphic age of 2600 Ma and a ca. 1200 Ma reheating (recorded by K-feldspars).

Dr. Berger's determination of a pre-Grenvillian-orogeny $^{40}Ar/^{39}Ar$ hornblende data of 1200 Ma for the Thanet gabbro has prompted a renewed search for pre-Grenvillian magnetic components in the comparateively low-grade Hastings Basin of the Grenville Province. The Cordova gabbro (preliminary study by J. Mark Stirling) shows a novel magnetization at one site, but its direction does not correspond to 1200 Ma directions for North America.

In the course of our multicomponent studies, the utility of Zijderveld vector diagrams in resolving mixed components has become apparent. Dr. Dunlop is exploring the merits of this approach vis-à-vis simple vector decomposition, and intersecting remagnetization circle methods.

One of the key questions in both magnetic and $^{40}Ar/^{39}Ar$ studies of orogens is the relation of magnetic or Ar 'blocking temperatures' measured in the laboratory to temperatures experienced during slow uplift and cooling of the orogen. Dr. Dunlop in cooperation with Dr. Derek York has produced graphs of blocking temperature as a function of cooling rate based on a recent theory of Dr. York's (Earth Planet. Sci. Lett. 39, 89-97, 1978). Dr. Dunlop has also shown how the exact equations can be simulated, starting from the constant-temperature Néel relaxation theory.

Monika Bailey, Christopher Hale and David Dunlop have begun a pilot archeomagnetic study of a 19th century brick kiln near Niagara Falls, in hopes of using early magnetic observatory records of declination and inclination at Toronto to date the last firing of the kiln.

While in Paris, Dr. Dunlop measured the buildup and decay of viscous (time-dependent) magnetization for synthetic 'pseudo-single-domain' (psd) magnetites. The eight samples range in grain size from truly single-domain (<0.05 μm) through the submicroscopic and microscopic psd range (≤ 20 μm) to large multidomain (100 μm). Temperatures were varied from 20°C to 500°C. Plotted as a function of log (time), all the curves are significantly and consistently non-linear at all temperatures. The tendency is for magnetic viscosity to accelerate with time compared to simple theory, an observation that has serious implications for long-term stability of paleomagnetic signals.

Larry Schutts has incorporated a spherical distribution of grain easy axes into the basic energy equations for an assemblage of magnetized grains. Implications of the theory currently being laboratory tested are that several rock magnetic effects attributed to peculiar volume distributions or to grain interactions may, in fact, be partly due to a random distribution of grain axes.

Mr. Schutts has also measured the effects of contact heating on rocks from a well-dated, well-mapped area of Arizona. Samples have been taken from Late Precambrian diabase sills at various distances from a Laramide dioritic stock intrusion. As expected, the degree of magnetic resetting depends not only on the sample's distance from the contact, but also on the grain volume-coercivity distribution of the sample.

The combined effects of contact and regional heating are being investigated by Mr. Schutts using specimens taken throughout the geological column in the Canadian Shield Abitibi sub-province. Paleomagnetic results imply the widespread existence of contact and regional heating secondary moments due to Matachewan and Abitibi diabase intrusion and, possibly, also to a Hudsonian age heating. Sample hysteresis properties at various temperatures are currently being determined in order to compare theoretical and actual secondary moment acquisition.

Monika Bailey is investigating magnetic and tectonic models of the ocean crust. Magnetic inclinations measured for deep ocean basalts are frequently shallower than expected. This result can be explained either in terms of tectonic rotation or variations in the

direction of the earth's magnetic field, such as occur during secular variation or a reversal.

Paleointensity determinations, using Thellier's method, on DSDP Leg 37 and Leg 45 material give normal intensity values indicating that a field reversal mechanism is not the explanation. A startling result of the paleointensity work is that the deep sea basalts continue to have natural remanent magnetism even when heated above their bulk Curie temperatures. One possible explanation is that the Curie temperatures are strongly biased towards large unoxidized titanomagnetites, whereas a significant component of the NRM is in small oxidized titanomagnetites. Such a grain size distribution is not clearly evident in standard rock magnetic measurements of hysteresis, coercive force, saturation magnetization or alternating field demagnetization.

Ms. Bailey is also carrying out acid leaching experiments. The acid is expected to dissolve fine magnetic grains first, causing the remaining NRM to be easier to demagnetize in alternating fields. Early results indicate that fine grain oxidized titanomagnetites may be important.

Tectonic rotation at the ridge axis appears to be a more promising explanation for low magnetic inclination values. A general expression relating axis of rotation, amount of rotation, dipole direction and present NRM direction has been derived and simplified for the special case of rotation parallel to the ridge axis.

The results are surprising. A calculation for the Mid-Atlantic Ridge at 37°N at about 3.5 Ma when the axis trended 50°NE shows that rotations of 30° away from the ridge axis shallow inclinations on the east side of the ridge to ~30° but steepen inclinations on the west side to ~69° (dipole inclination ~56°). Ms. Bailey is currently looking for evidence of this important difference in inclinations, and its effect on the intensity of ocean floor anomalies, on the east and west side of ridges.

Christopher Hale is contributing to our ongoing Precambrian paleomagnetism effort and extending it to include the Archean. Thermal demagnetization results from the Geotraverse area Shelley Lake granite have shown that the NRM is in part carried by titanomagnetite with a Curie temperature between 250 and 300°C, while the majority of the remanence is carried by nearly pure magnetite with a Curie temperature between 525 and 580°C. Both populations are present within a single sample. The correlation between the degree of exsolution of the magnetic minerals and the Curie temperatures is currently being examined through further reflected-light microscopy and thermomagnetic analysis, in order to substantiate the somewhat surprising evidence of widely differing exsolution states coexisting under the supposedly near-equilibrium conditions of granite formation.

The stability of remanence during reheating episodes is being investigated experimentally in an attempt to test the theoretical thermal activation diagram of Pullaiah et al. (1975). Synthetic samples have been prepared for use in high temperature storage experiments and preliminary measurements of VRM acceleration at elevated temperature have been made using our VRM system (Dunlop and Hale, 1977).

Mr. Hale expects to collect samples from dated Archean formations during the 1979 field season. Two proposed sampling targets are the Saglek Bay gneisses of Labrador and the Isua

supracrustal rocks of western Greenland. If it proves possible to 'see through' the regional metamorphism, we may be able to shed some light on the largely unknown behaviour of the Archean geomagnetic field.

(ii) *Magnetic Properties of the Blake River Volcanics* - A.M. Tasillo, D.W. Strangway

We have initiated a study of the magnetic properties of the Blake River volcanic group in northeastern Ontario. These volcanics are only slightly metamorphosed and seem to yield useful pole positions. A preliminary pole position shows that the direction of magnetization is almost exactly the same as that of the Matachewan dikes. This is in agreement with the recent age determinations by Krogh et al. Even though the eruption time is short there are a number of reversals contained in the sequence. The calc-akaline volcanics are weakly magnetic, but they nevertheless yield useful and stable remanence values. These results will be presented at the GAC meeting in May, 1979.

(h) University of Western Ontario

(i) *Magnetization of John O'Groats Sandstone* - K. Storetvedt, C.M. Carmichael

Work on the middle to late Devonian John O'Groats sandstone of Aberdeenshire, Scotland has been completed. By using the techniques of chemical leaching, alternating field and thermal treatment, and slicing of specimens in some cases, two axes of magnetization have been isolated. These are directed at 190° and -40° for the dominant magnetization and NNE-SSW and horizontal for a poorly defined component. As in the case of the Duncansby neck, which intrudes the sandstone and which has similar directions of magnetization, it is inferred that the horizontal magnetization dates from Devonian time while the 190°, -40° magnetization was acquired during the Mesozoic.

(ii) *Magnetization of the Younger Gabbros of Aberdeenshire, Scotland* - C.M. Carmichael, K. Storetvedt

The study of a small suite of samples of these Ordovician age intrusions was begun during Dr. Storetvedt's stay at Western and completed during a short visit this year. The samples show evidence of multicomponent magnetization that is thought to have been acquired during mild metamorphic changes while the intrusive bodies were cooling. Most of the magnetization is carried by needles and small blebs of magnetite exsolved out of silicates. The original Ordovician axis of magnetization is inferred to be directed NNW-SSE and horizontal.

(iii) *Paleomagnetism of Jurassic and Cretaceous Rocks from Chile* - H.C. Palmer and A. Hayatsu, U.W.O. and W.D. MacDonald, SUNY, Binghamton, New York

Two papers describing this work have been submitted for publication and the main conclusions are summarized in: H.C. Palmer, A. Hayatsu and W.D. MacDonald, 1978, Tectonic rotations in the Andes of Chile, Trans. Am. Geophys. Union, 59, p. 1059.

(iv) *Northern Ontario Dikes* - H.C. Palmer

The study involves the dike rocks in part equivalent to those of Matachewan, Abitibi-Nipissing, and Sudbury-MacKenzie swarms. In

general, the sampling has been concentrated in areas remote from the type areas of each of these swarms. Emphasis has been placed on baked contact studies particularly where dikes of one set cross-cut those of an older set. To date, positive baked contact tests have been obtained from Abitibi-Matachwan contacts.

(v) *Paleomagnetic Investigations of Middle Keweenaway Conglomerates, Lake Superior - H.C. Palmer, U.W.O. and H.C. Halls and L. Pesonen, University of Toronto*

This study is complete and a manuscript describing the study and the results obtained is in preparation.

(vi) *Natkusiak Formation Lavas and Related Diabases, Victoria Island, N.W.T. - H.C. Palmer and M. Fortier, U.W.O. and W.R.A. Baragar and J. Foster, G.S.C.*

The paleomagnetic laboratory investigations of a large collection of lavas and sills obtained by Foster, Baragar and Fortier from Victoria Island is being conducted at U.W.O. by Fortier and Palmer. The initial results reveal that both normal and reversed polarities of the Franklin Magnetic Interval are present and thus the reversal stratigraphy of the Franklin Interval can probably be established.

(vii) *Paleomagnetic Studies of the Aston and Hunting Formations, Somerset and Prince of Wales Islands, N.W.T. - H.C. Palmer and G.M. Young, U.W.O. and W.A. Morris, Ottawa*

Samples from 25 sites in the Aston and Hunting Formations on both flanks of the Boothia Arch were obtained during the summer of 1978. The preparation of specimens suitable for paleomagnetic measurements is complete and laboratory work has begun.

(viii) *Magnetostratigraphy of the Port Stanley Till - Maumee Silt Boundary, Southwestern Ontario - H.C. Palmer and B. Broster*

Three profiles spanning the Port Stanley Till - Maumee Silt boundary were obtained during the Spring of 1978. Paleomagnetic measurements on samples from these profiles are now complete. The results indicate that systematic trends in declination and inclination may be useful for regional time correlations.

(i) University of Windsor

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

Paleomagnetic studies on glacial till and interstatial units of middle Wisconsin age in the Toronto area are continuing. A paper has been sumitted concerning the 12 m thick Meadowcliffe Till unit involving approximately 700 specimens in 5 vertical profiles. An excursive segment has been identified in 3 profiles. The swing in remanence directions is markedly similar to that found in the Lake Mungo aboriginal fire pits which, coupled with existing radiocarbon dates in the Scarborough Bluffs section, sets the till's age at 30,500 $\pm$ 1,500 yr. B.P. Other units are also being examined.

(ii) *D.T.A. Symons and J. Foster*

A paleomagnetic study of 36 sites (452 specimens) from Oka and four adjacent plutons on the western end of the Monteregian Hills has been completed. Unlike previous Monteregian results, these

plutons are normally magnetized. Their poles, however, are about antiparallel. Combining all Monteregian remanence data along with petrologic characteristics suggests a gradational sequence from west to east of 2 normal and 2 reversed polarity zones. In turn this suggests that the Monteregian Hills were emplaced during an approximately 2-4 Ma period from approximately 118 to 122 Ma.

(iii) *D.T.A. Symons and M. Stupavsky*

A major project has been undertaken to examine the component magnetization of Precambrian Algoman-type magnetite facies iron formations and associated ore deposits. The object is to: (a) analyse their bulk susceptibility, anisotropy of susceptibility, natural remanence and its viscosity to permit accurate statistical modelling of their expected aeromagnetic anomaly, and thereby to assist in anomaly interpretation, and (b) to analyse their AF and thermal demagnetized remanence, and ferromagnetic mineralogy to generate information on their ore genesis. In the first stage of the study some 71 sites (710 specimens) of host rock and 204 hand samples (816 specimens) of iron formation and ore near the Sherman Mine at Temagami are being examined. Preliminary analysis shows that vertically-dipping iron deposits can be expected to give approximately 7000 nT anomalies (as found) but that flat-lying deposits will give only approximately 1500 nT anomalies.

(iv) *M. Stupavsky and D.T.A. Symons*

Study of the use of the least-squares method for analysing AF and thermal demagnetization data continues. A paper showing its application to AF data has been published. The technique separates the total remanent magnetization to give the directions, magnitudes, and decay rates of the inherent magnetization components. The method is particularly suitable for resolving data from multicomponent metamorphic specimens.

(v) *D.T.A. Symons and M. Fedikow*

A paleomagnetic study on the Beltian Aldridge Formation, the Moyie Sills, and the mineralization of the associated Sullivan ore deposit is essentially completed. M. Fedikow has written a M.Sc. thesis on the mineralization.

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

Paleogeothermometry studies of dike contracts continue. Two papers have been presented on results from contacts in northern Ontario and Washington State. Additional contacts have been collected in northern Ontario and in British Columbia.

(vii) *D.T.A. Symons*

Study continues on selected rock units in the Superior, Southern and Grenville tectonic provinces. Two papers have been published. The Huronian 2.4 Ga Thessalon volcanics retain a remanence that predates the updated Rb-Sr isochron age of 2.0 Ga, and it shows that the Blind River-Elliot Lake uranium deposits were formed at a semi-tropical 35° paleolatitude rather than the previously indicated polar 62° paleolatitude. The Grenvillian 1180 Ma Umfraville gabbro study suggests that the remanence of this body is primary and postdates regional metamorphism in the Hastings Basin.

6. Lunar and Planetary Magnetism

(a) University of Toronto

(i) *Lunar Sample Paleointensity - N. Sugiura and D.W. Strangway*

During this past year we have continued to work on methods for preventing changes to the magnetic minerals during heating. A set of experiments on lunar samples in a controlled fugacity system showed some improvement during heating, but we were unable to recover paleointensity values for four different samples. We have also used a sealed container with a titanium getter which has given even better results permitting us to heat to 600°C or more without changes to the samples. One sample of very young glass from Apollo 17 has been shown to have a paleointensity of 2500 oersteds. This is a large field for most current models of lunar magnetic history. These results were presented at the Lunar Science Conference and are being obtained in cooperation with L. Taylor of the Univ. of Tennessee.

(ii) *Magnetic Fields When the Solar System Formed - N. Sugiura, M. Lanoix and D.W. Strangway*

The study of the magnetism preserved in the Allende meteorite has continued by an examination of individual chondrules retaining the mutual orientation during measurement. The directions of the soft components of magnetization are found to be directionally well grouped suggesting a thermal overprint perhaps acquired at the time of accretion of the meteorite or subsequently during low temperature metamorphism. The stable components however are found to be randomly oriented thus indicating that they became magnetized before the meteorite accreted. These chondrules are often strongly magnetic and preserve a magnetization acquired before the meteorite cooled. Paleointensity values of 10-15 oersteds seem to be present in these samples indicating directly the presence of large magnetic fields in the early solar system. These results were presented at the Lunar Science Conference and will be published in the proceedings of a Conference on Planetary Magnetism.

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III(B) AERONOMY

Compiled by: M.E. Evans

1. Introduction

The past year has seen the official incorporation of the Canadian Corporation for University Space Science. Founding members are: University of British Columbia, University of Calgary, University of Saskatchewan, University of Toronto, University of Western Ontario and York University. Associate membership is held by the University of Alberta. Each member is represented on the board of directors of the corporation. Corporate executives are currently C.D. Anger, University of Calgary, President; J.H. deLeeuw, University of Toronto, Vice-President; and G.F. Lyon, University of Western Ontario, Secretary-Treasurer.

University researchers in the space science field have long been aware of the benefits to all concerned of close collaboration with industry and government but have lacked any consistent mechanism for such collaboration. In response to this need, Canadian universities involved in space science have formed the above non-profit corporation through which they can collectively interact with industry and government, and with each other, in joint undertakings - especially those that will benefit the space science community and the country as a whole. We also expect that the corporation will act as a point of contact for industry and government with the university space science community and thus facilitate better communication. We have been maintaining close liaison with other universities, industries, and government departments which have interests in space science. Membership in CCUSS is open to any university involved in space science, and inquiries are welcome.

2. University of Alberta

While the operation of the ground magnetometer array as part of the International Magnetospheric Study remained a major ongoing project of the group, several new projects were initiated and old ones completed.

Dr. Gordon Rostoker continued his studies of magnetospheric and ionospheric current systems and geomagnetic micropulsations with several collaborators within the space physics group and outside the University of Alberta. As part of a major study relating energetic particle fluxes in the topside ionosphere to auroral electrojets, several different projects have been undertaken. In a study with Drs. Koji Kawasaki and J.D. Winningham (University of Texas at Dallas) it has been shown that the equatorward edge of the eastward electrojet maps to the equatorward boundary of the central plasma sheet (cps), while the poleward boundary of the eastward electrojet lies inside the boundary plasma sheet (bps). Downward field-aligned current in the evening sector is found in the cps while upward current is found in the bps. In a further study with Drs. Kawasaki and Winningham, together with Drs. J.R. Burrows (National Research Council of Canada) and T.J. Hughes, it is

found that the equatorward portion of the eastward electrojet in the pre-dusk quadrant is often associated only with conductivity generated by solar UV radiation and not by particle precipitation. This component of electrojet current diverges to flow up the field lines at the dusk terminator. In an ongoing study with Drs. Winningham and Y. Kamide (Kyoto Sangyo Industrial University), the characteristics of particle precipitation across the westward electrojet in the hours immediately after local midnight are being investigated.

Drs. Terry J. Hughes and G. Rostoker have completed their study of a comprehensive model current system for high latitude magnetosphere-ionosphere coupling. Model current configurations were developed for both steady state and substorm disturbed conditions, and detailed comparisons of the model perturbation patterns with meridian line magnetometer observations were carried out. The theoretical portion of the investigation yielded, among other things, the fact that vorticity on the convective flow of magnetospheric plasma was consistent with a space charge distribution whose discharge through the ionosphere led to all observed high latitude current flow.

Drs. Koji Kawasaki and G. Rostoker have carried out a detailed study of large amplitude quasi-periodic variations in the D-component of auroral zone stations during periods of substorm activity. These variations have been termed Ps 6, and are normally found only in the morning hours. These variations are thought to stem from longitudinally localized regions of enhanced energetic electron precipitation where the ionospheric electric field has a south-east orientation. This leads to longitudinally localized three-dimensional current loops with a strong component of equatorward current flow, which are observed to drift eastward with velocities of $\simeq 0.8 - 2.0$ km/sec. In a following study, Mrs. J.C. Barichello and Dr. Rostoker have found the peak occurrence of Ps 6 to be at approximately local dawn. In addition there is a pronounced seasonal dependence of the occurrence frequency of Ps 6 with noticeably more events being observable near the summer solstice compared to the winter solstice. Dr. Kawasaki has also recently completed a study of the magnetic perturbation pattern in the immediate vicinity of an auroral surge at the time of its formation. He finds that a substantial westward current flows in the brightened area in the vicinity of the region where the surge ultimately forms. This fact is likely important for the understanding of the mechanism for substorm generation. More recently Drs. Rostoker and Kawasaki have initiated an investigation of the influence of the azimuthal component of the interplanetary magnetic field on the magnetic perturbation pattern at average auroral zone latitudes in the sector around local noon. In particular the latitudinal structure of the auroral electrojets across noon is being studied, and the influence of the DPY currents in the cleft is being evaluated.

Dr. Jerry L. Kisabeth is continuing his development of model three-dimensional current systems which couple the outer magnetosphere to the ionosphere. These models are of great use in the study of both satellite and ground magnetometer perturbation patterns. A new 'grid cell' model is presently being developed in which the high latitude ionosphere is broken up into concentric rings of arbitrary latitudinal width, the rings being subdivided into an equal number of uniform cells. By specifying the height-integrated Pedersen and Hall conductivities and the electric field in each cell, the overall three-dimensional current configuration can be specified assuming $\nabla \cdot \underline{J} = 0$. Using Z-transform techniques, the magnetic field perturbation on the ground and in space can be evaluated with a reduction in computer time of a factor of $\sim 10^5$ over conventional methods. In another study Dr. Kisabeth has developed algorithms for the evaluation of the vector magnetic potential for complex time-varying three-dimensional current configurations from which the induction electric field distribution has been calculated. He has further shown that neglect of Earth induction effects can cause serious errors in the induction electric field estimates even at satellite altitudes.

Dr. John V. Olson has continued his studies of the relationship between solar wind parameters and dayside micropulsation activity which he has carried out in collaboration with Dr. E.W. Greenstadt (TRW Laboratories, Los Angeles) and Dr. C.T. Russell and co-workers (University of California, Los Angeles). Correlations of ground micropulsation power with solar wind velocity and interplanetary magnetic field (IMF) orientation have been carried out and threshold values of the velocity and IMF direction were established which are consistent with Kelvin-Helmholtz theories for the generation of Pc micropulsations. As well it has been suggested that the bow shock might be a source of wave energy which would be modulated by solar wind conditions. In addition, Dr. Olson has commenced a detailed study of riometer data from the University of Alberta IMS array. In particular, a coherent seasonal modulation is apparent in the amplitude of the diurnal component of the quiet day curves at each station, which is attributed to seasonal variations in ionospheric parameters that affect its opacity to radio waves. Drs. Olson and Rostoker have also carried out a detailed study of the events of December 1-15, 1977 which are being analyzed by many space scientists around the world as part of the International Magnetospheric Study. Initial results of this investigation have been presented at the IMS Working Conference in Innsbruck, Austria and more detailed studies were carried out at the Coordinated Data Analysis Workshop held in Washington in December, 1978.

Dr. John C. Samson, who has recently rejoined the group, has continued his studies of spectral analysis techniques using quantum mechanics formalisms. In particular he is dealing with descriptions of the polarization states of n-dimensional time series in terms of the scalar invariants of the spectral matrix. These invarients lead naturally to a measure of the dipolar moment in two dimensions and the dipolar and quadrupolar moments in three dimensions. Since spectral parameters constructed from the invariants do not require diagonalization of the spectral matrix, the computer algorithms are very efficient for this analysis technique. Dr. Samson is also carrying out the construction of generalized Stokes parameters using matrices based on n^2 linearly independent combinations of the outer products of a complete set of n vectors in unitary space. The algebra of these Stokes vectors has been applied in the construction of polarization detectors for n-variate time series. Drs. Olson and Samson are using these detectors in an ongoing study of dayside Pc 5 micropulsations, and have found them to be useful in defining the presence or absence of particular waveforms.

Mr. W.G. Tighe and Dr. Rostoker have concluded their study of the longitudinal structure and propagation characteristics of westward travelling surges. They have found that the longitudinal scale size of surges is sometimes small enough so that the form lies within the bounds of the east-west portion of the University of Alberta magnetometer network ($< 12°$ of longitude). The surge motion is often rather irregular with both smooth expansions and discrete jumps being observed. A complex three-dimensional model current system has been used to simulate the magnetic perturbation pattern produced during the development of several substorm events.

Dr. Rostoker has completed a study of the sun-weather relationships initiated by Dr. Raj Sharma and himself some years ago. They find a clear reduction in surface pressure at observatories ringing the Aleutian low pressure region at times of 'sector boundary crossings' (SBC's) of the interplanetary magnetic field. The long time scale (a few days) variations of surface pressure appear to be anti-phase for toward-to-away SBC's compared to away-to-toward SBC's during the 1960's, but this behavior deteriorates in the 1970's. While physical mechanisms to which such effects can be attributed are difficult to understand, the anti-phase behavior described above suggests that the interplanetary electric field (and hence the magnetospheric electric field) play an important role in the manifestation of the sun-weather effect.

3. University of British Columbia

The main activity of the UBC Aeronomy Group during the past 12 months was concerned with concurrent observation of ULF geomagnetic variations (magnetic pulsations) at multiple stations. This is part of the Canadian IMS Project. The simultaneous ULF observation which is a cooperative work of UBC, University of Victoria (R.E. Horita) and University of Tokyo (T. Oguti and K. Hayashi), was carried out in summer of every year since 1976. In 1976 and 1977, ULF observation was carried out at five stations in Manitoba, the observation period being two to six weeks depending on location. The observation of this year, the last during the IMS period, was made at the following ten stations: eight stations on the Winnipeg Churchill line and its extension, viz., Rankin Inlet, N.W.T., Churchill, Gillam, Thompson, Island Lake, Little Grand Rapids, Star Lake, all these six in Manitoba, Minneapolis, Minn., and two additional stations, one at Boulder, Colorado and the other at Primrose Lake, Alberta. At the last station, observation of CNA by a riometer was also carried out. The period of observation was five weeks on the average. At a few locations, it was more than six weeks, and at one location, it was only two weeks. At two stations, more than 50% of the data were lost due to malfunction of the tape recorders. The recorders used are a slow-speed analogue tape recorder in type. This type of recorder is still the best for a long-term continuous observation of ULF variations. However, analogue slow-speed tape recorders are expensive and difficult to keep operational. In every IMS field operation carried out so far, we had some difficulties relating to tape recorders. Something has to be done about data-logging for future ULF observations.

We are about to embark on intensive analysis of the accummulated data. It will be a long term project itself: it will take at least several years. However, we have carried out some preliminary analyses. A few new findings about Pi 2 type pulsations have been obtained. Some new results have also been obtained about those magnetic pulsations which are concurrent with pulsating aurorae. These results will be published soon. From the data obtained during the field operation of September, 1977, we have obtained evidence that behavior of higher harmonics of 60 Hz man-made electric power is controlled by ULF geomagnetic variations. Behavior of even harmonics of 60 Hz is especially interesting: their strength was found to change concurrently with ULF variations. Generation of even harmonics seem to be controlled by telluric currents which are induced by ULF geomagnetic variations and flow into power lines through neutrals of Y-connected transformers (solar-induced-currents, abbreviated with S-I-C's). S-I-C's are likely to give rise to a quasi-d.c. bias to transformer cores which yields even harmonics of 60 Hz. It is interesting that higher harmonics of 60 Hz originating in Canada and propagating via magnetospheric paths, were detected in Antarctica. We plan to look into relations between S-I-C's and ULF geomagnetic variations in more detail with regards to the power line system in British Columbia.

4. University of Calgary

(a) Balloon-borne Studies in the Stratosphere

Emission spectra taken on AES Stratoprobe balloon flights in 1976 at significantly different altitudes have been fully analyzed to provide good measurements of stratospheric column densities of H_2O and O_3 and tentative measurements of NO_2, OH and HCl from their pure rotational emission spectra measured with high resolution Michelson interferometers. Data taken during sunrise and sunset periods and during atmospheric limb scanning sequences is being analyzed to provide altitude profiles of these and other minor constituents (e.g., HNO_3, N_2O).

The University of Calgary balloon-borne solar telescope was flown twice in 1977 and once in 1978 and provided significantly improved steering performance with the addition of automatic sensor gain controls

(for sunrise and sunset periods), offset guiding and improved sensor design and servo phase-shift networks. The high resolution far-infrared Michelson interferometer, with a new long-path mirror movement and 70° beamsplitter geometry provided good data during the recent flight which is now being analyzed for minor constituent concentrations. The telescope was unfortunately almost totally demolished during a rough descent in a storm and will now require major refurbishment and rebuilding for the upcoming balloon season.

(b) Infrared Solar Studies

A far-infrared photometer is being prepared for flight into the total solar eclipse of February 26, 1979, on the NASA Lear Jet Observatory. This experiment is designed to evaluate the influence of spicules on the radiation outflow from the high solar photosphere.

Automatic inflight calibration systems have been built into the balloon telescope to provide careful calibration for the overall solar spectral envelope. The data from a recent flight are under analysis to verify this calibration method and provide more precise parameters for the final system to be used on future flights.

Analysis of a near infrared eclipse observation of the extreme solar limb in 1972 has yielded evidence of a sharp limb spike which may be associated with an active region beyond the limb.

(c) ISIS

Analysis of data from the auroral imaging photometer on the ISIS-2 satellite continues as the major activity of our group. With the completion of Matthew Moshupi's Ph.D. thesis and publication of its results, we are putting less emphasis on the subject of trough region auroras, although the subject is not entirely abandoned.

Syed Ismail is continuing his study of polar cap aurora and airglow. Of particular interest to him are two phenomena: sun-aligned arcs and temporal variations in the OI 5577 Å airglow emission rate. Ravi Khaneja completed his M.Sc. thesis and returned to his teaching position at Delhi University. The investigation he began into the characteristics of the mid-latitude enhancement of OI 5577 Å airglow has been expanded into a study of global characteristics from which we derive information about the distribution and transport of atomic oxygen.

Major analysis efforts are currently going into cooperative studies involving other experiments aboard ISIS-2 and ground-based measurements. These include a study of the airglow/aurora transition region, ISIS-2/Chatanika measurements of the aurora in December, 1975 and ISIS-2/riometer measurements with F.T. Berkey. Statistical studies of intensity and ratio variations within the aurora are also continuing.

Several new studies are now underway. One involves producing large scale contour maps of our transformed data for studying more quantitatively the morphology of auroral features. Another area of involvement is the construction and analysis of an airglow data base. The data base contains E- and F-region intensities for large regions of latitude and longitude as well as for many months of acquired data. It is expected that results from this study will lead to an understanding of upper atmospheric circulation as well as the daily and seasonal variation in airglow in response to varying solar and magnetic parameters.

Our major technical developments for the year include the production of full-resolution color pictures of our transformed data, and development of techniques for finding and displaying significant I(5577)/I(3914) ratio

variations in the images, and the ability to handle 6300 Å data from Dr. G.G. Shepherd's Red Line Photometer aboard ISIS-2 in our data processing system.

Ian Robertson is completing his Ph.D. thesis based on a thorough analysis of scanning photometer data obtained from rocket VB 39. He is immersed in models and mechanisms. All this plus a full time job with an oil company keeps him busy.

(d) Arecibo Observatory

Our involvement at the observatory has declined over the past year. The only problem to receive attention was the relation of NI 5200 A and OI 6300 A nightglow to each other and to the composition of the thermosphere.

(e) Imaging System Development

The ground-based image dissector all-sky scanner system has undergone further refinements to its optics and extensive tests during the past year, following field trials at Cold Lake. The system is now fully operational and is installed on our roof awaiting aurora.

Spurred on by the outstanding characteristics of CCD imaging arrays, we have acquired a 100 x 100 array, a gated channel plate intensifier, and a microcomputer system for control and data handling. We are in the process of understanding the CCD array and determining its low-light-level capabilities. The technique looks very promising, and we hope to develop a second auroral imaging system based on this technology.

(f) Galileo

Membership on the Imaging Team for the NASA Galileo (formerly 'Jupiter Orbiter') program has provided some rewarding experience during the past year. The technical problems in using the CCD camera for viewing aurora on the darkside of Jupiter are numerous and challenging. Measurement of the off-axis rejection characteristics of the optical system was recently carried out at Utah State University and provides much needed information. The exposure to front-line technology in the CCD imaging array field has also been profitable.

(g) Investigation of Auroral X-rays

A balloon campaign was organized from Roberval, Quebec during three weeks of August as part of the IMS program. We obtained useful auroral x-ray data on August 28, 1978, associated with a large magnetic storm and auroral activity. This event is of particular interest to the international community. Pulsations were observed during six hours of data at floating altitude. Our newly developed PCM system has proven satisfactory. Necessary computer software development and data reduction are in progress. (Participants: J.S. Vogel, K.F. Deane, K.K. Vij and D. Venkatesan)

The analysis of auroral x-ray data from the flight of October 11, 1977 launched from Cold Lake, Alberta has been partially completed. Comparison with the optical emission data gathered by Berkey (University of Calgary) with the ground-based detector system has been attempted. The results were presented at the AGU meeting in September at Tacoma, Washington. The separation between the locations of the x-ray observations (balloon) and the optical emission (ground-based) at the time of pulsations makes any comparison or correlation difficult and far from ideal. (Participants: J.S. Vogel, K.F. Deane, K.K. Vij and D. Venkatesan)

Two small auroral x-ray payloads were launched in February, 1978 from Fort Churchill, Manitoba using Black Brant VI rockets. The parachute deployment system (Bristol Aerospace) had malfunctioned thus preventing the payload from floating down slowly under parachute and making measurements at various altitudes. Bristol Aerospace has been looking into the problem. An engineering flight (rocket launch) is planned for March - April, 1979. Observations of auroral x-rays above balloon altitudes is vital for understanding the propagation of auroral x-rays through the atmosphere. (Persons involved: J.S. Vogel, K.K. Vij and D. Venkatesan)

(h) Magnetospheric Studies

The study of the simultaneous observations of energetic protons and electrons in the distant magnetosheath, magnetotail and upstream in the solar wind, using IMP 7 and 8 satellite data has been completed. The investigation has resulted in a publication in Geophysical Research Letters, November, 1978. The conclusions have an important bearing on the postulated energy release in a field line merging at the sub-solar magnetopause. This work has been in collaboration with Applied Physics Laboratory/Johns Hopkins University, Maryland (S.M. Krimigis). Other co-authors are E.T. Sarris and J.C. Barichello.

The study of high latitude magnetospheric protons (E_p > 0.27 MeV) and Electrons E_e 0.14 MeV) using NOAA-2 satellite data has been completed. The morphology of the proton events, associated with electron events, and the possible origin in the plasma sheet have been discussed. This work is an essential part of the material for a Master's thesis (Barichello, April, 1978).

(i) Cosmic Rays and Solar Modulation

The solar feature 'coronal holes' has drawn particular attention since the Skylab XUV observations. The solar polar coronal hole data and cosmic ray data from the two polar stations, Thule and McMurdo, in opposite hemispheres, have been used for a comparative study. The relation between the cosmic ray N-S anisotropy, and the asymmetry in the polar coronal hole areas has been established. The work has resulted in a publication in Geophysical Research Letters, July, 1978. This is in collaboration with Bell Laboratories, New Jersey (L.J. Lanzerotti) and S.P. Agrawal visiting from A.P.S. University, Rewa, India.

(j) Solar Particle Events and Interplanetary Medium

The solar flare particle event of November 22, 1977 has been studied comparing it with that of February 25, 1969. These two events have occurred at different levels of the 11-year solar cycle. This enables us to discuss the solar modulation region. The investigation has resulted in a publication in Geophysical Research Letters, December, 1978. Another paper giving the flare data of the November, 1977 event is appearing in the special UAG report, of the World Data Centre (In Press, 1978). The study has been extended further and the results were presented at the AGU meeting in San Francisco, December, 1978. The investigators are T. Mathews, S.P. Agrawal and D. Venkatesan.

(k) Daily Variation of Cosmic Ray Intensity

A comparison of two approaches in the study of the daily variation of cosmic ray intensity, namely, Fourier Series and Power Spectral Methods, has been made. The study covers the period mid-December, 1965 to April, 1966, (five solar rotations) when interplanetary magnetic field data from Pioneer 6 also was available. There is general agreement between the observed and the theoretically predicted diurnal variation for parameters derived from the interplanetary magnetic data. The study has resulted in

a publication in the Journal of Geophysical Research, November, 1978. The work has been in collaboration with Calspan Corporation, Buffalo, New York (J.W. Sari) and Bell Laboratories, New Jersey (L.J. Lanzerotti).

(l) X-ray Astronomy

Balloon observation: Balloon-borne payloads, particularly at low latitude (where background is low) are quite useful for study of cosmic x-rays above 20 keV. Our x-ray payload consists of four NaI (Tℓ) - CsI (Na) phoswiches with graded shield collimators. The payload ~165 Kg (gross payload 550 Kg) was successfully launched from Hyderabad, India at 10:15 a.m. on April 7, 1978, using 3.3 million cubic feet balloons. Two hours after launch, sudden failure of an essential component resulted in loss of the pulse height and pulse shape data which corresponds to x-ray events. However, average counting rates in the two high energy channels (125 - 255, 255 - 530 keV) every 250 msec, have been obtained. The recovered payload has been flown on December 16, 1978; five hours of data have been obtained.

Satellite data: The collaboration program with CALTECH, Pasadena to look at low energy x-ray data from the x-ray astronomy satellite, HEAO-1 has been successful in identifying the source HB3 as a soft x-ray source. This has resulted in an IAU telegram involving graduate student, Chris Galas from the University of Calgary and G.P. Garmire and I. Tuohy from CALTECH, Pasadena. A paper was also presented at the September meeting of the American Astronomical Society at San Diego. Two proposals have been submitted to NASA for Guest Observer Program on HEAO-2 (newly named Einstein). The proposals are to obtain surface brightness distribution of x-rays from HB3 with 3' resolution using HEAO-2 detector IPC-A and to obtain high resolution spectral measurement of x-ray emitting region(s) of HB3 using HEAO-2 detectors SSS and IPC.

(m) Sulphur Mountain Cosmic Ray Laboratory

We regret to inform the members of DASP, that the monitoring of cosmic ray intensity at the Sulphur Mountain Laboratory has come to an end from August, 1978. Specific support from NRC in the core grant for maintaining the facility ceased and thus it has become impossible to continue the operations at Sulphur Mountain. Thus, after continuous operation over 22 years (two solar cycles) the land-mark facility has been closed down.

The laboratory at Sulphur Mountain was established in 1957 by the Cosmic Ray Group of the Division of Pure and Applied Physics of the National Research Council, Ottawa, under the direction of Dr. D.C. Rose. It was set up as part of Canada's contribution to the International Geophysical Year 1957 - 1958. Dr. B.G. Wilson was the first officer-in-charge. The laboratory was subsequently transferred to the University of Calgary.

Early instrumentation at the Sulphur Mountain Laboratory consisted of a neutron monitor and a set of mu-meson counter telescopes. The facility was expanded in 1963 when a high counting rate super neutron monitor was installed. The laboratory was used also, for some time, to study nuclear interactions at mountain altitude and the growth of extensive air showers.

With a companion monitor at Calgary set up in 1964, the two neutron monitors acted as a kind of spectrometer which would be used to identify solar and galactic components of the cosmic radiation. The two monitors had essentially the same asymptotic cones, but the different altitudes made them respond differently to particles of solar and galactic origin.

Future monitoring of cosmic ray intensity variations will continue from Calgary alone. A number of research papers using the data from the two stations have appeared over the years, a process which is still continuing.

(n) Measurement of Cosmic Ray Electrons

The final flight of a series of balloon-borne experiments to measure cosmic ray electrons in July, 1977 yielded interesting results. Data analysis shows that the flux was much higher than in previous years indicating the lack of solar activity responsible for modulation. Interpretation of the data is hampered by the destruction of the payload which was dropped from a helicopter during recovery. An exact replica of the sensor unit has been constructed in order to carry out calibrations.

(o) Aeronomy Application of Astronomy Programs at The University of Calgary

During the course of undergraduate and staff observational work at the Rothney Astrophysical Observatory, near Priddis, Alberta, we have been accumulating detailed information on the atmospheric transparency of starlight in the Johnson UBV bands. In fact, undergraduate astrophysics majors are obliged to study and obtain self-consistent sets of extinction and transformation coefficients using our 16-inch telescope, as part of their laboratory experience. Consequently, these data are available for the past few years and may be compared to extinction coefficients obtained with the same method (R. Hardie in Astronomical Techniques, ed. by A. Hiltner, U. of Chicago Press, 1962) as coefficients for other sites in North America where we have obtained data.

Further study with a proposed infrared telescope will permit this work to be carried out to wave lengths $\gtrsim 10$ μm.

Occasionally, DC monitoring in th U (ultraviolet) band ($\lambda_{effective} \approx 3800$ A, $\Delta\lambda \approx 600$ Å) of faint constant stars shows irregular variation due to aurorae. Consequently, these data, useless for astronomy purposes, may be used to study auroral brightness variation at a selected point as sampled through an aperture $\gtrsim$ 20 arcsec in diameter, and recorded on strip chart output with an effective time constant of 1 s.

(p) Atmospheric Physics Group

A ground-based spectrometer is being used to obtain absorption spectra of nitrogen dioxide in the stratosphere using the same twilight observing technique employed by Noxon and Kerr. This project forms the basis of Qasim Syed's Ph.D. thesis program.

Studies of ambient aerosol size distributions and their relation to visual range are being conducted using integrating nephelometer and spectronephelometer instrumentation. Simultaneous monitoring of aerosol mass loading of the atmosphere using cascade impactors is being carried out by Rosaline Pi, an M.Sc. student. The aerosol scattering coefficient as a function of wave length is used to determine the Angstrom coefficient α which can then be related to the power law exponent of the associated aerosol particle size distribution.

A standard ruby lidar system is being developed based on a Korad QSI system for studies of local urban pollution patterns during Chinook and temperature inversion events. The lidar is destined to operate in tandem with the established acoustic sounder system of the department.

A high power acoustic sounder system with bistatic doppler facilities has been installed at a small airport near Calgary. This will be used to study wind and turbulence profile, especially during Chinooks, up to an altitude of several thousand feet.

5. Department of Energy, Mines and Resources - Earth Physics Branch

(a) Pc5 Micropulsation Studies (H. Lam)

Data from an east-west line of magnetometer stations extending approximately along 67° geomagnetic latitude from western Alberta to western Quebec have been used to study the longitudinal characteristics of Pc5 micropulsations in the daytime sector from pre-dawn to post-dusk. It was found that the activity is localized in longitude in the morning sector and confused in the afternoon sector. The source region in the morning sector appears to be localized at the dawn meridian. Our study on the longitudinal variations of phases along the east-west line suggests the propagation of the signals away from noon toward the dawn-dusk meridian in agreement with the findings of Olson and Rostoker (1978). Studies of polarization in the horizontal plane for an event when the intensity maximum was located north of 67° indicate systematic switching in the sense of polarization from counter-clockwise to clockwise when the line of stations rotate across noon. The polarization characteristics in the vertical planes of the events recorded by stations in eastern Canada (i.e. for stations distributed between 318° and 350° in geomagnetic longitude) appear to be stationary with time suggesting the control of polarization characteristics by internal geoelectric structures.

(b) Pi2 Studies (J.C. Gupta)

Helicorder records from Meanook, Baker Lake, and Resolute taken during 1970-71 have been scaled to obtain Pi2 data. These data along with those recorded at Ottawa during the same period have been processed through various computer programs to obtain the morphological character of Pi2s.

(c) Magnetic Storm Analysis (E.I. Loomer, J.C. Gupta, J.K. Walker, H. Lam, G. Jansen van Beek)

An analysis of the magnetic storms occurring after the solar flares of September 16-19, 1977 was carried out using magnetograms from stations located in Canada. SSC's, pulsations, polar substorms and bays that occurred during September 19-23, 1977 were examined in detail. The analysis showed that the eastward and westward auroral electrojets occurred simultaneously in the day sector and that the westward electrojet that occurred on September 21 produced the most intense magnetic substorm which began at 0940 UT on that date.

An analysis of the magnetic activity, following the cosmic ray event of November 22, 1977 was carried out using magnetograms from Canadian stations. The magnetosphere was found compressed for an unusually long duration of about 5 hours after the sudden commencement of November 25.

A statistical analysis of the magnetic substorms that occurred during 1972-1978 to the north of Cambridge Bay has been carried out using magnetograms from Cambridge Bay, Yellowknife, Fort Churchill and Great Whale River. Several characteristics of these substorms have been studied. Also, the occurrence of these substorms has been found to have an important influence on AE-index. It is found that the present method of obtaining AE underestimates it by 150 nT or more.

(d) Solar and Lunar Variations (J.C. Gupta)

The hourly values from Nurmijarvi Observatory (1952-1973) have been analysed to obtain solar and lunar harmonic coefficients using revised programs for the Chapman-Miller method. The manuscript is under preparation. Also, geomagnetic hourly values from Meanook (1932-1976) and Agincourt (1932-1966) have been analysed by the Chapman-Miller method to study various characteristics of Sq and L at these Canadian observatories.

(e) Magnetic Stations (J.K. Walker, E.I. Loomer, G. Jansen van Beek, J. Hruska)

The Division of Geomagnetism continued to operate 11 magnetic observatories, 2 magnetic variation stations with limited absolute control and 8 standard variation stations. The observatories are: Resolute Bay, Mould Bay, Cambridge Bay, Baker Lake, Fort Churchill, Great Whale River, Yellowknife, Meanook, St. John's, Ottawa, and Victoria and those with limited absolute control are Alert and Whiteshell. The IMS variation stations are: Pelly Bay*, Rankin Inlet*, Eskimo Point*, Back*, Gillam*, Island Lake*, Thompson and Ft. Severn. A catalogue has been prepared which lists the geographic and geomagnetic locations of these stations, their recording intervals and types of recorders and the cost and availability of these data. Analogue data (magnetograms) are available from all these stations while digital data are also available from all the stations except Alert. Real-time data from the 6 variation stations indicated with an * are available the following UT day from the U.S. Space Environment Laboratory in Boulder, Colorado. A four-week forecast of magnetic activity is available from the Ottawa Magnetic Observatory on request. Induction magnetometers for Pc1 studies were operated at Ottawa and Resolute. We would greatly appreciate being informed on research or other uses of these data and we welcome the opportunity to collaborate on problems of mutual interest.

(f) Sunlit Cleft and Polar Cap Currents (J.K. Walker, F. Primdahl and collaborators)

Intense sunlit cleft and polar cap Pedersen and Hall currents were determined from rocket-borne plasma and electric field observations over Greenland. Currents were also determined from rocket-borne total magnetic field measurements on the same rocket. These two independently derived currents agree in peak magnitude and height and they indicate a peak Hall current of 34.2 $\mu A/m^2$ at 107 km altitude. Only the height-integrated Hall current compared favourably in magnitude and direction with that obtained from ground-based magnetic observations. Field-aligned currents were estimated ($\sim$13 $\mu A/m^2$) and they were coincident with the polar edge of the cleft.

(g) Harang Discontinuity Currents (J.K. Walker, F. Primdahl, D. Behm, R. Arnoldy)

Currents flowing in the Harang discontinuity and an associated arc were determined from rocket-borne plasma and electric field observations north of Andoya. Their magnetic fields will be compared with those determined from magnetic field observations on the same vehicle. Intense eastward electrojets occur equatorward and within the arc and a weak westward current is poleward of the discontinuity. A northward current is enhanced within the arc and is probably associated with downward field-aligned currents on the equatorial edge of the arc and outward field-aligned currents on the poleward edge.

(h) IMF Studies (E.I. Loomer)

A study has been carried out of the effects of changes in the interplanetary magnetic field on the reduction of magnetic data from the polar cap.

Changes in character of the diurnal variation between November and February and of the annual variation in X and Y at Resolute Bay and Mould Bay, with change in IMF sector polarity, have been identified. The importance of classifying days at polar cap observatories according to sector polarity is emphasized.

6. Herzberg Institute of Astrophysics

(a) Auroral Spectra, Photometry, and Models

The 12-inch H_β photometer has been in operation since October, 1977 at the Shiels Observatory near Ottawa. It scans the meridian from north to south about twice per minute at 4709 Å (N_2^+ING 0-2 band), 4790 Å and 4935 Å (background), and 4861 Å (H_β). Digital data is retained only for periods when aurora is detected. The system has been interfaced with a telephone interrogation/command system to verify instrument status in the automated mode. Observations will continue for at least another winter season.

Analysis of spectrometric and photometric results from auroral observations has yielded information on auroral heights and excitation mechanisms in both normal and Type-B aurora.

Observations of the auroral spectrum in the 1.1 to 1.6 micrometer region are planned for the 1978 - 1979 winter.

The search for the NO visible continuum emission related to the strong auroral displays is continuing. So far the results have been negative; this is not entirely unexpected since no very strong long-lived displays have been observed. Likewise, no large enhancements (> 50%) in the O_2 1.27 micrometer emission have been observed in auroral events.

(b) IMS Project

The Swan River-Thompson-Churchill line of meridian scanning photometers was operated successfully during the February and March, 1978 New Moon periods. Plotting of the data (intensity versus elevation angle) from the three stations individually is essentially complete. Plotting of the merged data (intensity versus invariant latitude) from the three stations simultaneously is progressing. Summaries of the all-sky data have been prepared for each station. Initial results indicate that it will be possible to obtain very useful information on proton precipitation morphology during substorms.

(c) Rocket Photometry of the Nightglow

The shape of the vertical profile of the O_2 Atm (0,0) nightglow emission was measured during the flight of rocket AMF-NVB-03. Other emissions measured by the photometer are N_2 IPG (4,2), N_2 IPG (3,1) and O_2 Atm (0,1). Absolute placement of the O_2 Atm (0,0) profile in altitude has not yet been possible because of uncertainties in the vehicle's altitude versus time performance.

(d) Radio Aurora

It was reported last year that diffuse radio aurora in the postnoon sunlit auroral oval is associated with region 2 (downward) field-aligned

current (consistent with previous observations in the pre-midnight sector) and also with weak proton precipitation. This precipitation was insufficient by a wide margin to explain the field-aligned current.

More recently we have shown that the amplitude of the diffuse radio aurora is related to the current flow in the prenoon sector in a manner very similar to that previously reported by Greenwald et al. (1973) for the pre-midnight sector. Our data for the post-noon sector do not yield definitive results but are not inconsistent with the pre-noon results.

(e) Pc 5 Pulsations

The equivalent circuit formulation of Pc 5 activity mentioned last year has both been extended and further analyzed. This formulation is of interest because the underlying assumptions do not include that of an axisymmetric magnetosphere - an assumption which is obviously grossly in error. The analysis of these circuits shows that the length of the field line and plasma density are not the only major influences on the resonant frequency. The ionosphere conductivity is also of major importance.

The circuits are characterized in each hemisphere by two currents which differ both in phase and in amplitude envelope from each other. The phase difference contributed to the polarization properties of pulsation. The amplitude modulation of the circuit response is a consequence of the circuit and not of the generator since a modified step function was assumed for the generator. It results from circuit losses and also, under certain conditions, from frequency heating. In other words, the amplitude modulation of a pulsation cannot be entirely attributed to the generator (i.e., excitation mechanism).

(f) Meteor Research

The meteor radars and cameras at the Springhill Meteor Observatory were operated for brief periods during the year as part of a continuing study of meteor showers. We now have observations of the major meteor showers over a 20 year period. The data on the Geminid meteor shower are being reassessed in order to determine the cross-section of the stream and the distribution of particles around the streams. There are slight differences in both distributions depending on size of meteoroids. Analysis of the Quadrantid shower is also underway.

The meteor radars and an all-sky camera were also operated to provide comparison data for the meteor infrasound observations.

(g) Infrasound from Meteors

Ability to record low-frequency pressure waves generated by large meteors permits the detection of meteorite entry on a round-the-clock basis. An array of four detectors operates near Saskatoon. The system is designed to respond to infrasound generated by large meteorites, so as to complement most effectively the Meteorite Observation and Recovery Project (MORP) network of cameras. Atmospheric pressure variations (via noise-reducing spatial filters) are recorded digitally on magnetic tape on a continuous basis. The infrasonic detectors have a pass band from 0.02 Hz to 0.2 Hz, a dynamic range of about $\pm$ 16 microbar, and a resolution of 1/8 microbar.

A recording system at Springhill Meteor Observatory consists also of a 4-microphone array, but is oriented toward detection of smaller meteoroids. The fully automatic digital system is under control of a microprocessor. Because the data rate is high, observations are carried out for limited periods of time.

Highly correlated signals were observed at both stations during the winter of 1977 - 1978, with an exceptionally strong peak of activity on January 2 - 4. The coincidence of this peak with the Quadrantid meteor shower generated some enthusiasm, but detailed study demonstrated that the signals could not be due to meteors. Careful examination of these low level signals over several months showed that they were highly correlated with geomatic activity (K_p index) and are presumed to be examples of auroral infrasound, particularly at the Saskatoon site. At Springhill, arrival directions from the southeast suggest that some of the signals are microbaroms from storms on the Atlantic. Hudson Bay and Lake Superior may also be sources.

(h) Meteorite Recovery

The MORP network of cameras has continued in routine operation. None of the bright meteors photographed in the past year has qualified as a serious candidate for a meteorite search. More than a dozen meteors from the early years of operation have now had their orbits reduced and data for the determination of flux values continue to be recorded. Three additional fragments of the Innisfree meteorite were recovered by the farmer near the site of the earlier finds in the spring of 1977 and these were acquired from him in 1978. The total recovery now stands at nine fragments which fell with a maximum separation of 1.0 km and a total mass of 4.6 kg. Studies of the atmospheric paths and luminous efficiency of the separate fragments are in progress.

No meteorite recoveries have been reported from the spectacular daylight fireball of November 4, 1977 near Kitchener, Ontario during the 1978 agricultural season.

(i) Dayside Aurora

Good photometric data were obtained at Cape Parry in December, 1977, except for H_β (due to degradation of the interference filter). Data analysis is in progress with particular stress on burst-like 5577 Å emissions and gross motions of the emission regions. Data for selected periods have been provided to Drs. Duncan and McEwen to supplement the Sachs Harbour data for two-station modelling of the emission profile.

7. Space Science Coordination Office

(a) Polaire

In accordance with a Cabinet decision, the Interdepartmental Committee on Space considered two major space projects put forward by the National Research Council and the Department of Communications (POLAIRE and MUSAT). Both projects were considered to be a logical continuation of the Canadian space program. After the process of interdepartmental decision had begun in the ICS, the government announced reductions in public expenditures. It also took a decision to support ANIK-C and D procurements, which lead to a relatively healthy situation in loading of industry. Hence, NRC and DOC withdrew or deferred their projects at this time.

The ICS recommended that both departments continue their studies and seek to define appropriate means of meeting their objectives.

(b) A Canadian Space Science Program for the Period 1979 - 1983

Subsequent to the withdrawal of POLAIRE, the SSCO set out to define a draft program for the area of aeronomy and physical space science which is presently under discussion. The Associate Committee on Space Research, at its 26th meeting on October 19, 1978, discussed the draft and endorsed in principle its general objectives and its philosophical basis.

This was stated as follows:

- To sustain and improve Canadian research competence in the area of space science

- To provide a significant fraction of the new knowledge needed to make science-based decisions relating to Canada's use of space and to provide access to the remainder of that knowledge by effective participation in international programs

- To provide training for young scientists and engineers in an area that will be the focus of much activity in the future

- To provide Canadian industry a series of opportunities for industrial innovation

- The scientific objectives include improving our knowledge of the physical interactions between the magnetosphere, ionosphere and atmosphere, particularly at high latitude, by directing Canadian activity towards selective participation in international programs.

(c) Shuttle Involvement

The SSCO was instrumental in the preparation of a proposal for a Wave Injection Facility. The main objective of the WIF is to study the certain phenomena of the upper atmosphere using a Shuttle-borne high power radio wave transmitter with associated antenna and receiver systems. This proposed facility is now being studied by the AMPS Science Definition Working Group for possible incorporation as a Canadian contribution.

(d) Working Groups

Many members of DASP have been involved in the deliberations of the Campaign and Balloon working groups set up by the SSCO. Both groups have completed their reports and copies were circulated to the entire DASP membership. Out of these reports arose the establishment of the Space Science Evaluation and Planning Group and the setting up of planning teams to deal with the pulsating aurora campaign in the La Ronge area in early 1980 and the later cleft campaign at Cape Parry in December, 1980. A continuing working group is studying the participation of Canadian scientists on space astronomy.

(e) Watching Briefs

The SSCO maintains watching briefs in several areas where Canadian activity does not warrant the setting up of working groups. The specialties (and their watches) include Lasers (Alan Carswell), Solar Power (Barry French) in cooperation with the NRC Energy Project Coordination Office, Large Space Structures (Peter Hughes), Life Sciences (Richard Malcolm) and Space Processing (Rod Tennyson). The objectives of these watching briefs are to have a central information source within Canada, to survey the extent of interest and when appropriate to suggest actions for Canadian involvement in this type of work.

(f) Study Contracts

Arising out of the working groups have come suggestions for studies in specific areas to increase knowledge of particular problems. These have included studies on a possible Canadian space telescope on the sensitizing of charge-coupled devices to ultraviolet radiation and on the measurement of electric fields in the upper atmosphere.

(g) Other Programs

Science related to meteorology and remote sensing and the needs of data platforms rests with the Departments of Fisheries and Environment, Energy, Mines and Resources and Communications respectively.

(h) Cleft Study in 1979

In December, 1979 a NASA project involving the launch of two Terrier Malamute rockets will take place at Cape Parry, N.W.T. The purpose of the project is to compare mechanisms of energization of charged particles in the pre- and post-noon magnetospheric cleft. The rocket apogee in each case will be about 650 km, with a payload of 550 kg. The experiment team includes scientists from Denmark and Sweden. The payload contains the following experiments:

1. D.C. Magnetometer
2. A.C. Magnetometer
3. A.C. Electric Field
4. D.C. Electric Field
5. Digital Langmuir Probe
6. A.C. Langmuir Probe
7. Soft Particle Spectrometer
8. High Energy Particle Detector
9. Differential Ion Flux Probe
10. Fast Ion Mass Spectrometer

It is intended that one rocket be launched into the region of the cleft between 0800 and 1000 hr. magnetic local time and the other between 1400 and 1600 hrs. The project scientist is J.D. Winningham, University of Texas at Dallas.

(i) The SSCO Working Group on Space Astronomy

The working group, which has common membership with the subcommittee on astronomy in space of the NRC Associate Committee on Astronomy, has as its terms of reference:

"To provide timely advice to SSCO on Canadian interest and competence in research on space astronomy and to make specific recommendations and proposals as necessary, on scientific, technological, logistic and fiscal matters related to Canadian activities in that field."

It has a membership of 12 drawn from the university, government and industrial community with interests in applications of space technology to astronomical problems.

It meets two or three times a year to assess Canadian involvement in a variety of space-astronomical endeavours, such as Space Telescope, Shuttle and other satellites.

One of its principal activities has been to encourage the performance of short term (three month) studies by small groups on such technological problems as:

a) A Canadian Space Telescope
b) UV Sensitization of Solid State Imaging Devices
c) Fluorescent materials for UV Sensitization of Silicon detectors
d) Membrane mirrors in space,

all of which have a strong potential for industrial applications.

8. University of Saskatchewan

(a) Aeronomic Studies

A recent coordinated rocket study of the oxygen emissions in the nightglow has provided emission height profiles which can be interpreted in terms of oxygen atom recombination. It has been shown that the apparent recombination yields of the various excited states is not in agreement with the statistical weights of the states and that for currently accepted quenching coefficients it is not possible to derive a consistent (O) concentration height profile. It has been found that a satisfactory interpretation can be obtained if the oxygen emissions, including the green line, are formed in two step excitation processes similar to that proposed by Barth. These ideas have also been extended to the atmospheres of other planets and it has been found that the absence of the Herzberg I emissions is consistent with postulated O_2 concentrations for Mars and Venus.

These new aeronomic ideas have been extended to the excitation of the green line in the aurora and it has been found that the observed height profiles are consistent with electron impact excitation of an intermediate O_2 state and subsequent transfer to atomic oxygen. Further work designed to extend the proposed auroral model to other emissions and to the cleft is in progress. At present we are attempting to improve our understanding of the rocket and ground-based observations made during the 1977 expedition to Cape Parry and the importance of the model atmosphere to the observed emissions. For the vehicle ADD-11-128 we have been able to derive a background atmosphere appropriate to the time of the measurements and hope to be able to extend these ideas to following aurorally induced changes in mesospheric composition.

Further observations of the OH Meinel bands have also been made in an attempt to clarify the excitation reaction. At present it appears that only the hydrogen-ozone contributes significantly to the airglow although the $HO_2 + O$ reaction may contribute to the ground state OH concentrations.

(b) Dynamical Studies of the Mesosphere and Thermosphere

The partial reflection radiowave system at Park Site has been used to measure winds, electron densities and characteristics of radiowave scattering processes in the D- and lower E-region. New internal consistency analyses have been used in conjunction with improved winds analysis methods, so that data of excellent quality and quantity are being obtained. The major technical development has been the use of two microprocessors to completely control the recording and processing of data, so that continuous realtime winds are now available, commencing in the summer of 1978. These constitute 5 minute profiles, from 50 - 110 km, in 3 km height intervals. This represents a considerable technical and analytical achievement, and lowers the net cost of winds acquisition considerably, making it very cost effective when compared to other systems.

Winds from four 10-day intervals in 1976 have been analyzed to obtain the amplitudes of planetary, tidal (24, 12 hours), and internal gravity (I.G.) waves (1.5 hrs $\leq \gamma \leq$ 6 hrs). Energy densities and scale heights have been found for each season, and lie in the range 10^{-3} - 10^{-2} (J/m^3) and 3 - 15 km respectively. In general wave dissipation from 80 - 100 km is smallest in the spring (April) and largest in the summer (August); and for I.G. waves the rates of dissipation are 0.08, 0.05, 0.05, 0.02 W/kg in winter, spring, summer and fall seasons respectively. These are some of the first estimates of these important parameters. It has been found that the periods of I.G. waves vary with the background flow, in a most unexpected fashion. This coupling has allowed the periods (1.5 - 8 hrs), horizontal wave lengths (300 - 1300 km), phase speeds (25 - 90 m/s) and polarization of the waves to be determined.

A series of wind observations which allow the resolution of waves of $\gtrsim$ 4 minutes has been completed at Saskatoon, and I.G. waves of periods 5 - 90 minutes have been identified. The autocorrelation functions of the reflected radiowaves have been used to calculate the turbulent velocity ($\sim$ 1 - 5 m/s), turbulent energy dissipation rates ($\sim$ 0.03 - 0.05 W kg^{-1} at 90 km) and eddy diffusion coefficients ($\sim$ 2 x 10^3 m^2/s at 90 km), as well as dissipation rates. The energy balance of this region is now being studied in detail.

Finally, the morphology of the lower ionosphere (30 - 90 km) is being studied, and related to the precipitation of electrons and protons and their association with auroral events and magnetic storms. It is becoming increasingly apparent that these sources of ionization are always important and are frequently dominant at this location. The seasonal and diurnal variation of the particle spectra are being sought, and estimates of the energy dissipation and chemical perturbations as a function of height will be made.

These studies, of winds, waves and sources of ionization are all relevant to the Middle Atmosphere Program (MAP), and serious efforts are being made to increase the scope of these measurements in space (several Canadian stations) and time (continuous, real-time data acquisition and analysis).

(c) Cleft Studies

Rocket and ground photometric measurements of dayside aurora were major activities. Two electron spectrometers (radial and axial) were flown on each of two Black Brant rockets from Cape Parry, December 5 and 12, 1977. The first rocket flew across the auroral oval into the polar cap during enhanced activity. Good electron spectra were obtained showing energized electron influx of 500 - 1000 eV characteristic energy through much of the cleft. Full pitch angle distributions were obtained and data interpretation is proceeding. The second rocket failed due to rocket malfunction.

A 6-channel meridian scanning photometer was operated by Dr. C. Duncan at Sachs Harbour (Λ = 76.7°) November 30 to December 19, 1977. Very good morphological data were obtained on the 11 clear days showing position, extent and dynamical behavior of the cleft. Some auroral modelling is underway using two station photometric data to extract 6300 and 5577 Å emission heights. The analysis of the extensive auroral and polar cap night observations is also well advanced, giving significant information on the poleward side of the continuous auroral oval. The rocket overflew the photometer site with the cleft also overhead. The 0.9° field of the ground photometers provided detailed structure of the cleft which is now being related to the in situ rocket electron spectra obtained.

(d) Auroral Photometric Studies

The multichannel photometer operated at La Ronge (Λ = 64.6°) for three weeks in February-March, 1978. This was part of a four station array of measurements organized by Dr. A.V. Jones, NRC, as an IMS project. Analysis of the several nights' data when there were major auroral substorms and pulsating aurora is progressing.

(e) Rocket Payload

A major payload (VA-48) is being prepared for reflight scheduled for December, 1979 into bright aurora from Churchill. A second electron spectrometer is being added to provide full pitch angle coverage 0 - 120° and permit study of acceleration mechanisms. The energy range is being

extended to cover 24 keV - 20 eV. Detailed analysis of some recent flights has shown that in particular inverted-V electron events there are appreciable electron fluxes at 18 keV, the present upper limit of the spectrometer. The 1/4 m spectrometer has been modified for use in the 2000 - 3200 Å region, a collaborative project with Drs. Gattinger and Vallance Jones. Auroral spectra (275 - 1300 Å) obtained from the 0.4 m spectrometer first flown in January, 1977 are currently being analyzed to determine whether instrumental changes are necessary for this flight.

This payload for auroral diagnostic studies has had four successful flights since 1971 with refinements and additions following each flight. While all of the data have been processed substantial effort is yet required on its full interpretation, particularly the VUV and EUV spectra obtained.

9. University of Victoria

(a) Plasma Waves

IPDP generation was studied using S^3 satellite particle data and ground-based micropulsation data with Dr. J.N. Barfield of the Space Environment Laboratory, Dr. R.R. Heacock of the University of Alaska and Dr. J. Kangas of the University of Oulu, Finland. The correlation of these data indicates that IPDP are generated by the proton cyclotron instability with protons of energies 1 - 100 keV at about L = 5 in the evening sector.

A joint project with Dr. R.R. Heacock of the University of Alaska involves the analysis of Carib Peak Observatory ELF data. Initial results include the observation of fine structure in chorus at harmonics of the oxygen gyrofrequency. This observation was expected since fine structure at the proton and/or helium gyrofrequencies in whistlers, auroral hiss and ELF hiss had been observed on ISIS data. Studies are continuing in an attempt to determine the physical processes involved.

Analyses of data obtained from the University of Tokyo, University of British Columbia and University of Victoria Cooperative IMS Project is continuing. One recent result is a paper by Hayashi et al. to appear in Nature which reports the observation of enhanced harmonics of 180 Hz in power lines, presumably due to solar-induced currents in the power lines which have as their source, telluric currents induced during geomagnetic disturbances. At present efforts are also being made to improve our data handling capabilities at the University of Victoria.

A project with Dr. T. Watanabe of the University of British Columbia with the cooperation of the Division of Research and Development of B.C. Hydro, concerns geomagnetic disturbances in power line systems and the associated economic loss due to the degradation of power transformers. Two micropulsation stations at Prince George and Albert Head (near Victoria) were established this past summer. Another station at a more northerly location is planned as well as observations of power line parameters with the cooperation of B.C. Hydro.

(b) Airglow Studies

The Upper Atmosphere Section of the Department of Physics participated in project CAMEO, a cooperative NASA-ESA experiment which involved the release of barium and lithium vapor clouds from the NASA Nimbus G meteorological satellite which was placed in a nearly polar orbit by a Delta rocket launched on October 22, 1978.

The barium release took place at a height of 953 km between the Alaska-Canada border on the morning of October 29, 1978. Although a filter photometer designed to monitor the neutral Ba line at 5535 Å and the ionized Ba lines at 4934 Å and 4554 Å had been built, and an array of cameras had been set up to photograph the cloud, the sky was almost completely overcast at the time of the release so that no photometric signal was detected and no photographs were obtained.

The lithium release took place over Scandinavia, at about the same height as the barium release, on the morning of November 6, 1978. 1.2 kgm of Li metal was contained in the payload. Again the sky was overcast so that no photographs were obtained; however, enhanced Li emissions were observed during the twilights following the release for a period of about one week. The enhancements, although not spectacular, reached values in excess of 60 rayleighs, about three times the expected intensity for that time of year. Detailed analyses of the observations are being carried out.

(c) Calibration of Low-brightness Sources

A 5-foot Ebert Fastie scanning spectrometer has been constructed for the purposes of photometer calibration and intercomparison of low-brightness sources. The spectral resolution is 0.5 Å at a wave length of 6000 Å.

10. University of Western Ontario

(a) Rocket-borne Auroral Radar

In February, 1978, a coherent-pulse radar operating at a frequency of 108 MHz was flown in a BB VI rocket launched at Fort Churchill. The rocket reached the vicinity of a radio-auroral event (as detected by the NRC ground-based auroral radar) and an auroral echo was present on the radar for most of the upper part of the flight. The spectral characteristics of the radar echo are those of the ion-acoustic (Farley-Buneman) plasma instability. The technique seems to be suitable for the detection of this electric field driven instability in the E-region and could be applied to the search for such instabilities inside the polar cap. It has long been recognized that conditions inside the polar cap are appropriate for the widespread generation of ion-acoustic waves but such waves, if they occur in the normal E-region, could not be detected by ground-based radars.

(b) Ionospheric Irregularities

The experiment using separated receivers at 150 MHz using NNSS satellites was operated at Cambridge Bay at irregular intervals during the year. The analysis is continuing and shows interesting height changes to the north of the station compared to south of the station. The preliminary analysis of the three station results are about completed. A fourth receiver has been added to improve the observations. This station now makes the array three stations along a NS line 1 km long and one station 1/2 km west of this line.

(c) Total Electron Content

Routine Faraday rotation observations of geostationary satellite signals have been discontinued. Total electron content figures obtained from earlier observations together with those from other mid-latitude stations have been examined for possible correlation with Interplanetary Solar Magnetic Field sector crossings. Epoch analysis indicates that there is an enhancement of TEC on the key day for toward-to-away (-,+) sector boundary crossings only and that this effect is greater in winter than in summer.

(d) Travelling Ionospheric Disturbances

Systems for simultaneous observation of doppler and azimuthal variations in the CHU (7.335 MHz) signal have been in operation for some months. Interpretation of the preliminary results in terms of a simple corrugated reflector model are somewhat ambiguous. At the present time the equipment is being refined to separate the ordinary and extra-ordinary waves in the received signal and microprocessors are being incorporated for preliminary signal processing.

(e) Meteor Physics

The meteor physics group has been carrying out two-station low light and observations of sporadic meteors as part of the meteroid ablation study program. The measurements so far seem to indicate that the luminosity is not proportional to mass as has been assumed for many years. It is hoped to shed more light on this question by observing shower meteors with this method so as to reduce the number of independent variables.

A great deal of effort has been put into methods of obtaining radiant distribution from single station observations. Using these methods T.V. observations of the Perseid Shower have been analyzed and the observed variation of radiant diameter with meteor brightness provides a convenient method to obtain the age of meteor showers by means of gravitational perturbation calculations. A radio meteor system for day to day production of radiant activity maps is in the final stages of completion.

(f) Long Line System for Ionospheric Irregularities

This is the system of spaced receivers looking at geostationary and moving satellites. The system was first set up in an approximately 1/2 mile by 1/2 mile cross shaped configuration and used to look at the ground pattern of irregularities using the NNSS moving satellites on 150 MHz as a source. This study clearly showed the field-aligned nature of the irregularities. Studies were also made of the heights and distributions of the irregularities which were confirmed as being in the F-region and usually were distributed in irregular patches.

After this initial study the system was modified so that the weaker geostationary satellite beacons could be used to study the movement of the irregularities. This movement should give information on the ionospheric electric fields. The system has just been put back into operation in this mode and already has shown its ability to give good information on movements. The data processing systems to permit 'automatic' analysis of the movements are also progressing well. It is hoped to present some interesting results from this system at the spring DASP meeting.

11. Communications Research Centre, Ottawa

(a) Polar Ionosphere

An attempt was made to find a dependence of the polar ionosphere on the Y component (B_y) of the interplanetary magnetic field. The anti-sunward drift of F-layer plasma across the polar cap, due to magnetospheric convection, gives rise to a 'tongue' of ionization extending from the sunlit hemisphere into the dark hemisphere. It is known from electric field measurements that the convective flow is often concentrated on either the dawn or dusk side of the polar cap, depending on the sign of B_y. Therefore the tongue of ionization should also move from one side to the other as B_y changes sign. F-layer densities obtained from dawn-dusk polar transits by topside sounders have been examined for such an effect. For passes on the sunlit side of the solar

terminator, the expected shift in density can be seen, superimposed on the dawn-to-dusk gradient due to co-rotation. However, on the dark side of the terminator, the tongue of ionization tends to occur persistently on the dusk side of the polar cap, with no apparent dependence on B_y. The reason for such behavior is not known; one possibility is that variations in the composition of the neutral atmosphere are involved.

(b) Chatanika - ISIS Comparisons

During the past winter, several passes of ISIS II were scheduled over the Chatanika radar while the radar was in operation under the sponsorship of M.H. Rees. Data from one of these, on December 2, 1977, are now available. A preliminary comparison of sounder and backscatter N(h) profiles indicates agreement at F-layer heights to about 20%, assuming, as we usually do at these latitudes, that radio propagation from the sounder is field-aligned.

(c) Ionospheric Modification

Characteristics of the HF-enhanced plasma lines in sporadic E observed at Arecibo can be explained by the propagation of electrostatic waves. These waves are generated by the purely-growing instability in irregularities imbedded in the layer. The waves then propagate to where they can be detected by the Arecibo radar.

A frequency asymmetry exists between the upshifted and downshifted HF-enhanced plasma lines in the F-region. This asymmetry has been explained by assuming that the electrostatic waves responsible for the plasma lines propagate in ducts which have a small density gradient component in the direction of the magnetic field.

(d) Arecibo - ISIS Experiments

Transmissions on two closely spaced frequencies (e.g., 429.5 and 430.5 MHz) were made using the Arecibo Transmitter. The ISIS satellites were recording on a fixed frequency equal to the difference frequency (1.00 or 1.95 MHz). The telemetry tapes from Quito, Equador and Kourou, French Guiana have not yet been received.

(e) Intersatellite Propagation

Recently we concluded some work on intersatellite radio-wave propagation in the lower frequency branch of the extra-ordinary mode, or Z mode, using data recorded by the ISIS I and ISIS II sounders during a rendezvous near the north pole. In contrast to the 100 μsec length of the emitted pulses, the received pulses were stretched to about 10 msec. Some of the observations, such as the frequency content of the pulses and the time delay of their leading edges, are in good agreement with the predictions of ray optics applied to a smoothly varying medium. However, the detailed pulse shape is quite unlike the theoretical shape predicted using the WKB approximation. This suggests that scattering causes a multiplicity of energy paths between emitter and receiver. As in previously reported results for the whistler mode, ionospheric irregularities appear to strongly influence the propagation of a wave that can have large refractive indices.

We presently plan to continue scheduling rendezvous of ISIS I and ISIS II at the Resolute Bay and Alaska telemetry stations as long as support by both DOC and NASA continues.

(f) Transionospheric HF Propagation

In January 1977, the feasibility of using the ISIS sounder receivers for transionospheric HF studies was established. The experiment was repeated during May to August, 1978, this time with a more sophisticated ground transmitter at Shirley Bay. The transmitter pulses and frequency were synchronized in real time to the sounder through the CRC Ground Control Centre. At the Ottawa telemetry station approximately 1000 passes of ISIS I and ISIS II were recorded which contain evidence of transionospheric transmission, at fixed frequencies of 4.0 and 9.3 MHz and at swept frequencies above the F-region critical frequency. These data can be used to measure the refractive distortion by the ionosphere of the radiation pattern of the ground antenna and to understand details of propagation leading to pulse distortion and intermode interference fades.

(g) The Future

As the inevitable end of the ISIS era approaches, the group has given some thought to its future activities in spatial radio science. During the last year, we have participated in planning for a Wave Injection Facility (WIF) on Shuttle. On behalf of the Space Science Coordination Office (SSCO) of NRC, we edited a report 'The Wave Injection Facility: an opportunity for Canadian participation in the Shuttle/Spacelab/AMPS program'. The report proposes that Canada undertake to design and build the WIF as the national contribution to the extensive AMPS program. Such an undertaking would be a natural development of expertise in spatial radio technique that was acquired through the Alouette/ISIS program. The report examines the scientific potential for radio-wave related experiments in the AMPS program and lists the Canadian workers who have already expressed interest in using the facility. It contains the results of a preliminary systems study of the WIF, arguing for an orderly development of a modular facility that eventually would cover the frequency range of 1 Hz to 50 MHz. NRC/SSCO is presently looking for financial support for WIF, and is using the document to inform various government agencies about its scientific and technological possibilities.

12. MPB Technologies Inc.

(a) Laser Propagation Experiment

Summary: A laser propagation experiment to determine the absorption statistics has been performed for the region of Montreal. This was done for two links going through essentially the same path, one using a He-Ne laser, the other a CO_2 laser. A direct comparison was thus possible. Efforts were made to keep the systems operating 24 hours a day whenever possible. Results were analyzed using data over the full 24-hour daily periods and for the hours between 9 a.m. and 5 p.m. This was done to determine the effect of the time of day on the statistics.

The resuls were then applied to the two laser communication systems that were previously built by personnel of MPB Technologies Inc. (a CO_2 system and a He-Ne system). The reliability figures determined, suggest that over-the-air laser communication systems could be attractive alternatives to other over-the-air links.

(b) Depolarization due to Multipath Propagation in Radio Relay Systems

Abstract: The effect of multipath rays on the content of cross-polarization in a radio relay system is examined. Medium effects due to refractive index variations, antenna effects characterized by the cross-polarization antenna pattern, and surface reflection effects are analyzed separately and then combined into a unified formulation. Many new developments in the theory are obtained. Available experimental

results of various authors on cross-polarization due to multipath are reviewed and plotted. A start on a computer program is outlined. Further computer development and possible experiments are suggested.

(c) Combined Effects of Rain and Imperfect Antennas on Depolarization in Microwave Propagation

Expressions are given on cross-polarization resulting from the combined effects of rain and imperfect antenna isolations in satellite-to-Earth links. The calculations at 4 and 11 GHz frequencies differ from previous work in two ways, namely, that the theory adopts a worst phase relationship between receiver and transmitter antennas in clear weather, and that a more realistic expression is used for the rain extent. Sample results are illustrated on cross-polarization versus misalignment angle, clear weather antenna isolations, canting angle, attenuation, and rain rate.

(d) Development of a Remote Sea-Ice Thickness Sensor

A remote sea-ice thickness sensor is important for ice surveillance and arctic navigation. Various radar techniques for remote sensing of ice thickness have been tried in the past decade. Successful fresh water ice thickness sensors at microwave frequencies have been developed by several workers. Unfortunately due to the severe attenuation of sea water ice on microwaves and optical signals, most of these techniques turned out to be useful only in identifying sea-ice types but unreliable for sea-ice sounding.

A conventional impulse radar with an amplitude modulated carrier below 200 MHz can be used for sounding sea-ice. But practical applications, which often require a pulsewidth narrower than 50 nsec, require an unrealistically broadband antenna causing severe technical problems such as antenna directivities and transients.

A synthetic pulse radar (SPR) avoids these problems by transmitting and receiving continuous signals. By combining harmonically related cw sinusoidal signals at VHF frequencies to synthesize a series of narrow video pulses, it allows the use of tuned filters with tailored characteristics. Thus the SPR requires less transmitter power, has an increased receiver sensitivity and yet can provide a high thickness resolution with its narrower video pulses.

At MPB Technologies Inc., we have completed a detailed design and are building an SPR sea-ice thickness sensor package for the Transportation Development Centre, Canada. The electronic package will be tested in a specially designed laboratory facility with simulated sea-ice. This will be followed by controlled field experiments in the next phase.

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IV VOLCANOLOGY

Compiled by: R.F.J. Scoates

1. Introduction

Studies of volcanic rocks in 1978 were made across Canada in rocks ranging from Archean to Cenozoic in age. As in other years Archean greenstone belts received the greatest amount of attention, and the Ontario-Quebec Abitibi Belt continues to be the focus for a variety of studies. Volcanic rocks of the Appalachians are being mapped and examined utilizing geochemical techniques, and Upper Triassic volcanic rocks of the Cordillera are being compared petrographically with Archean volcanic rocks of the Blake River Group.

In addition petrochemical, geochronological and metallogenic studies of volcanic rocks are being carried out by Canadians in the Central Andes, from the Mascarene Archipelago in the western Indian Ocean, in Gran Canaria and from the Kane Fracture zone in the North Atlantic Ocean. Discussions of experimental work regarding metastable pyroxene crystallization in komatiites as well as definition and nomenclature of komatiites are presented in this report.

2. Aspects of Komatiitic Volcanic Rocks

(a) Experimental Work

(i) *Metastable pyroxene crystallization in komatiites; N.T. Arndt, University of Saskatchewan, M.E. Fleet, University of Western Ontario, and I.H. Campbell, University of Toronto*

This project involves a petrographic, crystallographic and geochemical study of highly magnesian pigeonite and augite which appears to have crystallized metastably in spinifex-textured mafic komatiite lavas. Petrologic experiments (1 atm., contolled fO_2) have shown that the equilibrium liquidus phase in these rocks is olivine. In dynamic cooling experiments carried out at University of Toronto these rocks have been annealed above the liquidus then cooled rapidly to temperatures well below the liquidus. Pyroxene grows as the principal silicate phase under these conditions, duplicating the mineralogy and textures of the komatiites.

(b) Nomenclature

(i) *Definition and nomenclature of komatiites; N.T. Arndt, University of Saskatchewan, and R.A. Binns, CSIRO, Australia*

In an attempt to ease the confusion that surrounds the definition and nomenclature of komatiites, questionnaires have been circulated to over 40 geologists working with these rocks. Replies have now been received from a majority of participants and a compilation has been circulated for comment. It is anticipated that the results of this survey will be discussed at a forthcoming Penrose Conference on komatiites (to be held in Quebec in August), and it is hoped than an acceptable definition and scheme of nomenclature for komatiites will be established.

3. Archean Greenstone Belts, Comparison With Phanerozoic Volcanism

(a) Petrology

(i) *Comparative petrology of Archean and Phanerozoic tholeiitic and calc-alkaline sequences; T.H. Pearce and F. Balint, Queen's University*

The Upper Triassic Karmutsen Formation (tholeiitic) and overlying Bonanza Formation (calc-alkaline) of Vancouver Island bear at least a superficial resemblance to the Kenojevis and overlying Blake River Groups in the Archean Superior Province. A detailed study is underway to determine the extent of the analogy between the two different ages of rocks.

(ii) *Comparative petrology of volcanic rocks in space and time; T.H. Pearce, Queen's University*

The precursor of this general study was reported last year. Work is continuing, and is closely associated with thesis projects of S. Dykes and F. Balint.

4. Archean Greenstone Belts, Superior Province, Canadian Shield

(a) Abitibi Belt, Ontario-Quebec

(i) *Gitologie prévisionnelle dans l'Abitibi-est; L. Imreh, Ministère des Richesses Naturelles du Québec*

Les travaux de révision détaillée (1/15 840) de 1978 sont la continuation de l'étude commencée en 1972. Ils couvrent le terrain volcanique archéen des cantons de Figuery et de Landrienne entre la ville d'Amos au nord et les batholites de La Motte et de La Corne au sud (Abitibi-est méridional).

Les résultats des travaux de 1978 se résument comme suit: nous avons prouvé que la région étudiée forme la continuation septentrional du flanc nord de l'anticlinal majeur de La Motte-Vassan défini en 1972-73. La corrélation entre les deux flancs de cet anticlinal majeur basée sur l'évolution du volcanisme étant très satisfaisante, la lithostratigraphie du sillon majeur de La Motte-Vassan établie sur le flanc sud de l'anticlinal (Imreh, 1966) devient applicable régionalement.

L'évolution du volcanisme se divise dans la région considérée en trois cycles majeurs, du bas en haut:

1) Produit du volcanisme type initial: coulées métamafiques, méta-ultramafiques (subordonnées).

2) Produit du volcanisme type arc insulaire: coulées mafiques à acides et volcanoclastites surtout acides.

3) Produit du volcanisme type initial: coulées métamafiques et filon-couche ultramafique-mafique (région d'Amos). Ce cycle comprend le début d'une nouvelle mégaséquence volcanique; actuellement nous n'avons cartographié que se termes basaux.

A la lumière de l'ensemble des travaux 1972-78, nous sommes en mesure de proposer au cours du congrès de la G.A.C. en 1979, une lithostratigraphie définitive basée sur le levé d'environ 1500 km^2 effectué à l'échelle de 1/15 840. Cette lithostratigraphie est le résultat de la régionalisation et de l'élaboration de celle publiée en 1976 (L. Imreh, DPV-349 du MRN du Québec). De plus, nous avons concilié dans le mesure du possible, la nomenclature nouvelle avec l'ancienne en usage ailleurs donts les coupures n'ont pas été définies en fonction des limites naturelles des entités volcaniques.

(ii) *Géochimie et géostatitique comme outil combine pour l'exploration des gisements volcanogenes de sulfures massifs; L. Carignan et R. Darling, Ecole Polytechnique, Université de Montréal*

The volcanic host rocks of the No. 14 lens in the Millenbach mine have been sampled, analysed for major, minor and trace elements and the results have been interpreted using geostatistical methods.

(iii) *The geochemistry of altered wallrocks surrounding the Manitou-Barvue volcanogenic ore deposits, Val d'Or, Quebec; F. Robert, R. Darling and L. Gélinas, Ecole Polytechnique, Université de Montréal*

The sampling and geochemical analysis was completed before the start of this project which comprises petrographic studies and data interpretation.

(iv) *Volcanological and sedimentological studies in the Rouyn-Noranda area, Quebec; E. Dimroth and students, Université du Québec à Chicoutimi*

This project was initiated in 1971 by the Ministère des Richesses Naturelles du Québec and its field aspects have now been completed. The approach and methodology of this work is based on comparison with recent volcanic rocks. The work has focused on the following aspects.

1) Facies and flow mechanism of basalt and rhyolite flows,

2) Mechanisms of fragmentation and emplacement of pyroclastic rocks,

3) Depositional environments of sedimentary rocks,

4) Alteration and metamorphism of volcanic rocks, and

5) Vertical facies changes in relation to paleo-volcanic evolution.

The key outcrops to aspects 1), 2) and 3) will be shown during a field trip in May, 1979. The field trip guidebook will contain a tentative synthesis of the volcanic and sedimentary evolution of the Rouyn-Noranda area.

During the period 1971-1975, work was done in collaboration with the following universities: Université de Montréal (1 Ph.D., 1 M.Sc.), Queen's University (1 Ph.D.), Carleton University (1 M.Sc.), Université Laval (1 M.Sc.) and Université de Clermont-Ferrant (1 Doctorat du 3^{e} cycle). Since 1975 work has been done at Université du Québec à Chicoutimi and has included 5 M.Sc. theses and 6 assistants.

(v) *Trace element evaluation of lavas from the Abitibi region Quebec; J. Ludden, L. Gélinas, Ecole Polytechnique, Université de Montréal*

(vi) *A morphological, chemical and petrological examination of Archean pillowed basalts, Kinogevis volcanic group, Rouyn-Noranda area, Québec; G. Wells and T.H. Pearce, Queen's University*

This study, outlined in last year's bulletin, is continuing. Preliminary results of the objectives outlined there and proposed future work are as follows:

The major element chemistry tentatively supports the petrological interpretation that plagioclase and clinopyroxene are involved in a shallow-level fractionation model for the origin of these high-iron (>12 wt% FeO) basalts. Trace element analyses are being done on selected, well-preserved samples as a further test of this hypothesis. Electron microprobe analyses are also in progress to determine the composition of quench plagioclase and pyroxene crystals found in these rocks.

Field work was done in the fall of 1978 to examine as in previous years the relationships between pillowed, massive and fragmental units. Further examination of pillows has provided evidence that many of the elongate ones are indeed lava tubes. The orientation of broken selvages can be used to determine flow direction within the tube. Several, fairly complete stratigraphic sections have been made. Compared with oceanic sections from Deep-Sea Drilling Project data, there appears to be a greater proportion of massive flows in the Archean than in modern examples. Additional data on recent volcanic rocks is being accumulated to evaluate the significance of this observation.

Preliminary work to date has been submitted for publication.

(vii) *Immobile trace elements and Archean volcanic stratigraphy in the Timmins Mining area, Ontario; J.F. Davies, R.W.E. Grant and R.E.S. Whitehead, Laurentian University*

Stratigraphic analysis, correlation and structural interpretation of many Archean volcanic belts are hampered by a number of factors amongst which are: lack of traceable marker horizons; mineralogical, textural, and gross chemical similarities between different flows; complex folding and faulting; pervasive alteration which has changed the original character of the rocks.

This study of Archean volcanic rocks of the Timmins area, northeastern Ontario, demonstrates that the distribution of certain relatively immobile trace elements, notably Zr, Y, Ti and Cr, effectively distinguishes different lithostratigraphic units and constitutes a potentially valuable tool in deciphering Archean volcanic stratigraphy and structure. The trace element data provide strong support for structural and stratigraphic interpretations, suggesting that trace element characteristics may be useful in

distinguishing and correlating volcanic units in other areas, where structure and stratigraphy are uncertain or unknown.

(viii) *Petrography and geochemistry of the volcanic carbonatized basaltic and komatiitic metavolcanic rocks, Parmour Mine, Timmins, Ontario;* A. Jak, R. James and R.E. Whitehead, *Laurentian University*

A suite of approximately one hundred specimens, representative of the stratigraphic sequence of intercalated basaltic and carbonate-rich metavolcanic rocks (from four levels) at Parmour Mine have been collected for detailed petrographic and geochemical analysis. These rocks form a portion of the Goose Lake Formation which lies at the base of the Tisdale Group in the Timmins region. Samples of this formation elsewhere in the Timmins area provide a basis for comparison between the carbonatized basalts and komatiites so well exhibited at the Parmour Mine locality and less altered hydrated assemblages typical of the Goose Lake Formation north and west of the mine site.

Progress to date indicates that the rocks from the mine have been intensively recrystallized and metasomatised during one or more periods of low greenschist to subgreenschist facies metamorphism. Primary textures are rarely observed in the mine samples but are not uncommon in the less altered regional samples. The three assemblages listed below characterize recognizable stratigraphic units in the mine.

1) Dolomite + magnesite + quartz + chlorite $\pm$ talc $\pm$ fuchsite (carbonate unit)

2) talc + dolomite + chlorite + quartz $\pm$ tremolite (talc-carbonate unit)

3) dolomite + chlorite + quartz + albite $\pm$ zoisite $\pm$ calcite (altered basalt unit).

The altered basalt unit 3) is distinguishable from units 1) and 2) on the basis of mineralogy, textures, and chemistry. The genetic relationship between units 1) and 2) remains unclear. Stable pentlandite-pyrite-cobaltite in one specium from the carbonate unit indicates a final re-equilibration temperature of 150°-250°C for the talc-carbonate alteration at high sulphur and oxygen fugacities.

(ix) *Petrology and geochemistry of peridotitic komatiites from the Goose Lake Formation, Timmins, Ontario;* R.S. James and R.E. Whitehead, *Laurentian University*

A suite of specimens has been collected adjacent to the North Tisdale Anticline (west of Burrow-Benedict fault) and underground at Parmour Mine (east of the Burrow-Benedict fault). Previous studies (Pyke, 1975) form the basis of correlation between the two sample localities. Equant-shaped (pre-extrusive?) olivine, skeletal clinopyroxene, chromite, and minor glass appear to be primary minerals in all specimens from both localities. At the first locality, serpentine and tremolite replace olivine and almost all clinopyroxene respectively. Chemistry for these secondary phases has been determined; primary clinopyroxene in a single sample ranges from $Wo_{17}En_{72}Fs_{11}$ to $Wo_{38}En_{45}Fs_{17}$. Talc forms rims about relic olivine and dolomite and is normally a minor phase interstitial to the relic olivine overgrowing tremolite and relic glass. At

Parmour Mine, talc and particularly carbonate alteration is well developed; relic primary textures are very poorly preserved. Carbonate zones at this locality are conformable to the metabasalt stratigraphy and locally contain linear zones of small pillow-like structures which are believed to represent polysutured flow-top material from peridotitic komatiites (Arndt, 1977, J. Petrol.). Magnesite-rich carbonate replaces relic olivine and dolomite and/or quartz replaces skeletal climopyroxene. Talc alteration of olivine appears to precede the formation of magnesite although textural data not support this conclusion. Molecular ratio plots using the major element chemistry of these samples eliminates problems interpreting volatile-bearing data (i.e. samples with high CO_2 and H_2O). These data indicate that during the carbonate alteration of the ultramafic rocks, SiO_2, MgO, K_2O and Na_2O were depleted and CaO added to the system.

(x) *Stratigraphy, petrology and alteration of Archean andesite and rhyolite in the Blake River Group, Abitibi belt, Quebec; H.L. Gibson, A.D. Hunter, J.M. Moore, D.H. Watkinson, Carleton University*

Areas around the Aldermac and Norbec Mines afford good exposures of andesite and rhyolite flows and pyroclastics, and their hydrothermally altered equivalents. Transitional relations, textural relicts, and minor element chemistry demonstrate that many flows and breccias, formerly identified as rhyolite, are actually andesites silicified around hydrothermal vents. Cycles of silica and chlorite replacement accompanied volcanic activity; early, altered rocks are included as fragments in later, less altered deposits. Because hydrothermal centres are closely associated with base metal deposition, criteria are being evolved to distinguish primary siliceous rocks from altered varieties, as an exploration guide.

(xi) *Shining Tree Area, Ontario; M.W. Carter, Ontario Geological Survey*

This work is a compilation of twelve contiguous maps of townships mapped by the author. The volcanic rocks range from komatiitic to alkaline and comprise a composite volcano. It is proposed that this composite volcano be named the Natal volcano. The rocks form a synclinorium. The oldest rocks are mafic tholeiitic flows and the youngest are calc-alkalic and fragmental. The alkalic rocks are best developed between the older theoleiitic and younger calc-akalic suites.

(b) Other Archean Greenstone Belts

(i) *Benny greenstone belt; K.D. Card and D.G. Innes, Ontario Geological Survey*

Archean metamorphic and metasedimentary rocks form an east-west belt approximately 40 km long and up to 5 km in outcrop width in the southern part of the Superior Province some 60 km northwest of Sudbury, Ontario. This sequence, which is surrounded and intruded by Archean gneissic, migmatitic, and massive felsic plutonic rocks, dips steeply southward and is considered to represent the remnant of a previously more extensive supracrustal sequence. Rock types present include tholeiitic and calc-alkaline basaltic and andesitic flows; intermediate and felsic pyroclastics, and metasediments arranged in a number of mafic-felsic cycles, many of which contain stratabound sulphide-bearing inter-calations. The sulphides are mainly pyrite and pyrrhotite, but noteworthy concentrations of sphalerite, galena, and chalcopyrite occur at the Lake Geneva Mine, Hess Township and in Stralak Township.

(ii) *A study of the South Bay Mine complex, northwestern Ontario; S.M. Dykes and T.H. Pearce, Queen's University*

This study involves the petrological and geochemical analysis of the calc-alkaline rock suite, with special emphasis on the quartz-feldspar porphyry and hornblende andesite units, that comprise the South Bay Mine complex. The hornblende andesite unit is of interest since it contains primary igneous hornblende along with altered pyroxene and plagioclase. Detailed examination of alteration phases, mineralogy and composition is being undertaken and comparisons will be made using bulk composition and phenocryst phases with modern examples. The data are being used to develop a genetic model and a history of the complex.

(iii) *Alteration in andesite associated with Cu-Zn mineralization, Uchi belt, Ontario; D. Andrews, University of Manitoba*

Small concordant Cu-Zn sulphide deposits occur in a sequence of aphyric to phyric andesite flows and tuff, 30 km southeast of Red Lake. A large alteration zone composed of anthophyllite, cordierite, chlorite, quartz, and biotite occurs along the footwall of the deposits.

(iv) *Lake of the Woods greenstone belt, northwestern Ontario; H.D.B. Wilson, University of Manitoba*

Regional stratigraphic and geochemical work has been completed and the results are being prepared for publication.

(v) *Manitou Lakes area; C.E. Blackburn, Ontario Geological Survey*

The project involves a synopsis of the general geology of the area bounded by 92°30' and 93°00'W, and 49°15' and 49°30'N, previously mapped at one inch to one half mile scale by the author during the 1972-75 field seasons.

Volcanologic study is an integral part of the program. Komatiitic, tholeiitic, calc-alkaline and alkaline assemblages have been delineated by examination of chemical analyses of approximately 300 samples of volcanic rocks collected during the detailed surveys and the synoptic project. Centres of felsic volcanism have been identified, and known mineral deposits are being tied in with volcanic stratigraphy.

(vi) *Savant Lake-Crow Lake project; C.E. Blackburn and N.F. Trowell, Ontario Geological Survey*

The project involves a regional study of the stratigraphy structure and economic geology of the metavolcanic-metasedimentary belts between Savant Lake and Crow Lake.

The aims of the project are to gain a better understanding of the petrogenetic and structural evolution of this portion of the Wabigoon Belt and to determine, more clearly, the interrelationships of geological environment and mineral deposits within the area.

Volcanological studies are an integral part of the program. Over the three years of the project, field analysis of volcanic sequences aided by chemical analysis of somewhat in excess of 1000 volcanic rock samples, will enable a more concise delineation of volcanic environments and successions. This will aid in delineating

favourable areas for exploration, both for base metal sulphides, and other commodities.

(vii) *Shoshonitic rocks from Oxford Lake, Manitoba; J. Ludden, C. Brooks and M.Y. Pigeon, Ecole Polytechnique, Université de Montréal*

(viii) *The Beaulieu River volcanic belts, Slave Province, N.W.T.; M.B. Lambert, Geological Survey of Canada*

Detailed stratigraphic analysis along 80 km of this homoclinal volcanic belt of Archean age is nearing completion. This work is yielding a new understanding of the internal structure and nature of volcanic units and their relationship to basement gneisses. Volcanic effusions in a submarine environment produced thick (up to 4200 m) accumulations of basaltic pillowed lavas, lesser amount of andesitic lavas, and minor domes of rhyolite. The locus of volcanism was along fracture systems in granitic basement rocks.

(ix) *The Back River cauldron subsidence complex, Slave Province, N.W.T.; M.B. Lambert, Geological Survey of Canada*

New petrographic material and chemical data are now available following completion of mapping in 1977 of this volcanic complex of Archean age. Ninety-three samples have been analyzed for 12 major and 13 minor elements. Zircons from a late-stage rhyolite dome have yielded a concordia age intercept of 2668 $\pm$ 7 Ma. This age is in close agreement with a K-Ar age determination from biotite in the same sample of 2629$\pm$42 Ma. (R.K. Wanless, personal communication). The age is the same as that of greywackes that underlie or interfinger with the volcanic complex, and is very close to dates for other volcanic complexes in the Slave Province. This correlation suggests that voluminous volcanic effusions took place in many areas of the Slave Province during the same short interval of time.

5. Volcanic Rocks of Proterozoic Age

(a) Grenville Province

(i) *Petrology and stratigraphy of metavolcanic rocks in the Grenville Supergroup, eastern Ontario; J.M. Moore, Jr., R.L. Morton and John A. Ayer, Carleton University and Ontario Geological Survey*

In the course of detailed remapping of the Clarendon Lake area (NTS 31C/14-NE) new stratigraphy was established for the succession, including the Tudor metabasalts and overlying, more siliceous, central volcanic complexes, all inferred to be 1300-1250 Ma in age. Petrographic and chemical data of 150 samples have been compiled and interpreted. The Tudor succession of olivine tholeiite and tholeiite has been divided into three subcycles. It is succeeded conformably by tholeiitic andesite, dacite and rhyolite in the north of the area, and unconformably by calc-alkali basalt, andesite and dacite in the eastern parts. Three centres of intermediate and silicic volcanism are marked by intrusive and extrusive breccias, and varied subvolcanic intrusions. Volcanogenic metasediments and carbonate rocks separate the siliceous tholeiites from the calc-alkali rocks. Despite regional metamorphism to upper greenschist-lower amphibolite facies, chemical trends are coherent for most major and trace elements determined.

(b) Circum Superior Belt

(i) *Trace element and isotopic studies of komatiites and tholeiites from the Cape Smith fold belt; N.T. Arndt, University of Saskatchewan, A.H. Zindler, M.I.T., and B.W. Chappel, Australia National University*

Trace element contents and Sr and Nd isotopic compositions are being determined in mafic and ultramafic, tholeiitic and komatiitic lavas and high level intrusive rocks from the Cape Smith fold belt, northern Quebec.

(ii) *Compositional variation and stratigraphy of the Cape Smith-Wakeham Bay volcanic belt; W.R.A. Baragar, Geological Survey of Canada*

The petrology and geochemistry of samples collected along three profiles mapped in detail across the Cape Smith-Wakeham Bay belt are under study. Basaltic rocks composing the belt are extraordinarily magnesium and range from komatiites to tholeiites; associated sills include peridotites. In comparison with the Labrador Trough, a very high proportion of this segment of the Circum-Ungava Belt is igneous but the sedimentary rocks that are present are unmistakably correlative with those of the former.

(iii) *Stratigraphy and compositional variation of the komatiitic to tholeiitic volcanic rocks of the Fox River Belt, northeastern Manitoba; R.F.J. Scoates, Manitoba Mineral Resources Division*

(c) Churchill Province

(i) *Environment of eruption and geochemistry of Flin Flon volcanics; N.T. Arndt and M.L. Stauffer, University of Saskatchewan*

Field mapping, petrography and major and trace element analyses are being used to deduce the environment of eruption and the geochemical character of Aphebian Amisk volcanics in the Flin Flon area, Saskatchewan and Manitoba.

(ii) *Structural analysis of the Amisk volcanics, northeast of Amisk Lake, Saskatchewan; S.J. Longiaru, University of Saskatchewan*

(iii) *Lynn Lake Project; H.V. Zwanzig, E.G. Syme, H.P. Gilbert, Manitoba Mineral Resources Division*

The Lynn Lake Project is a program of geological mapping, chemical sampling, and stratigraphic and structural analysis of the volcanic rocks and volcanogenic sedimentary rocks in the Lynn Lake region. Mapping was completed in 1976 and 1977, and a brief correlation program was completed in 1978. Descriptions of the main volcanic piles and their sedimenatry aprons are planned for publication with short interpretations of the volcanic environments in spring 1979 under DREE. A comprehensive report including the chemistry, stratigraphy and structure of the region will be published in a later report by the Mineral Resources Division.

(iv) *Stratigraphy, geochemistry, and depositional environment of the Rusty Lake greenstone belt adjacent to the Ruttan Mine, Manitoba;* M. Jackson, *University of Manitoba*

The volcanic sequence near the Ruttan Mine shows an upward transition from mafic flows to intermediate and felsic pyroclastic rocks and volcanogenic sedimentary rocks. The entire sequence is proximal and subaqueous. Geochemical trends are consistent with the upward compositional change except for local areas of alteration associated with the mineralization.

(v) *Missi Island volcanic centre, Amisk Lake, Saskatchewan;* L.D. Ayres, M.E. Chute and J. Biczok, *University of Manitoba*

At Missi Island in the western part of the Flin Flon greenstone belt, subaqueous to subaerial basalt and andesite of the Amisk Group were intruded by two subvolcanic, plutonic suites. Within the volcanic sequence there is an upward change from subaqueous volcanism dominated by flows to subaerial volcanism dominated by pyroclastic rocks. Within the pyroclastic sequence there is an upward change to more felsic and more phyric compositions. In addition two distinct subaerial environments are present: a lower distal environment represented by tuff, and a proximal environment represented by tuff-breccia. The intrusive suites, which have been described in previous bulletins, represent a vent complex.

(vi) *Physical volcanology, sedimentology and stratigraphic reconstruction of part of the Flin Flon volcanic-sedimentary belt, north Athapapuskow Lake and Flin Flon area, Manitoba;* A.H. Bailes and E. Syme, *Manitoba Mineral Resources Division*

Detailed mapping at 1:20 000 and careful examination of primary structures and textures will be used to define environment of deposition of volcanic and sedimentary rocks. The morphologic evolution of the volcanic succession and the relationship between volcanic and sedimentary deposits will be emphasized. The project will be initiated in the White Lake and Mikanagan Lake areas in 1979.

(vii) *Volcanism in the Dubawnt Group, N.W.T.;* A.N. LeCheminant, M.B. Lambert and A.R. Miller, *Geological Survey of Canada*

Volcanic rocks of the Dubawnt Group, of Paleohelikian or late Aphebian age, were studied as part of 1:250 000 scale mapping in NTS areas 65P and 65O. The Christopher Island Formation contains several cycles of alkaline volcanism that began with explosive activity followed by effusion of mafic then felsic lavas. Intercalated volcaniclastic sediments are predominantly fluvial and shallow water turbidite deposits. Mass wasting or landslides formed local talus cones and sheets of laharic breccia. Small intrusions of biotite lamprophyre and syenite are probably cogenetic with the lavas. Both epigenetic and syngenetic uranium mineralization is commonly associated with the alkaline volcanics and intrusions.

Wedges of red alluvial fan sediments unconformably overlie lavas of the Christopher Island Formation. Volcanism resumed with eruptions of rhyolitic calc-alkaline lavas and welded ash-flow tuffs of the Pitz Formation. Plutons of micrographic granite and numerous quartz-feldspar porphyry dykes intrude both the alkaline and calc-alkaline volcanics.

(viii) *Petrogenesis of the Klondike Schist, a possible felsic volcanic unit; P. Metcalfe, University of Manitoba*

The Klondike Schist forms the upper part of the Yukon Group, which is part of the Yukon crystalline terrain near Dawson City. The schist has been involved in at least three deformational and metamorphic events, which have obscured its original nature. Research is in progress to determine the pre-deformational nature of the schist.

6. Volcanism in the Canadian Appalachians

(a) Early to Middle Paleozoic

(i) *Metallogeny of volcanogenic Cu-Zn mineralization in the Lac Mégantic region, Eastern Townships, Québec; S. Chevé, A. Brown, and W. Trzcienski, Ecole Polytechnique, Université de Montréal*

Lithostratigraphic mapping in a structurally complex terrain has been undertaken in collaboration with the Quebec Ministry of Natural Resources. The aim of the mapping is to identify paleogeologic features of a Cambro-Ordovician (?) volcano-sedimentary sequence which is host to volcanogenic copper-zinc mineralization (e.g. Clinton deposit). In addition, specific geologic controls which may serve as guides in exploration for additional mineralization (e.g. centres of volcanism, favourable ore horizons) may be identified.

(ii) *Geology of the ophiolitic complexes of the Quebec Appalachians (Eastern Townships, Quebec); R. Laurent, T. Feininger, Y. Hebert, J. Beaudin, R. Hebert and R. Beullac, Laval University*

This project involves the study of ophiolite assemblages. The volcanic rocks of the ophiolites are being studied in detail (petrology, geochemistry) as well as the volcanic rocks of the Cambrian formations that underly the ophiolites within the internal zone of the Quebec Appalachians. The paleomagnetic properties of these rocks are being studied by M.K. Seguin. The project was initiated in 1972 and is planned to be completed by the end of 1981.

(iii) *Petrological study of the Paleozoic volcanic rocks from Gaspé Peninsula, Québec; R. Laurent, J. Belanger, Laval University*

Detailed sections of Cambrian volcanic rocks from the Shick-Shock allochthon, and of Silurian and Devonian volcanic rocks from the Chaleur Baie area have been made. The sections have been selected on the basis of excellent stratigraphic control established by P.A. Bourque and coworkers from Laval University. Petrological and geochemical studies are in progress on the samples collected across the detailed sections. The goal of the project is to unravel the history and evolution of the volcanic activity in Gaspé Peninsula during the Paleozoic.

(iv) *The Roberts Arm Group, Notre Dame Bay-Tommys Arm River area, Newfoundland; H.H. Bostock, Geological Survey of Canada*

The project involves the mapping of the Roberts Arm Group (spilites) and includes petrography and computer examination of major and some trace elements of samples collected at 500 foot intervals in

five sections across the group. A suite of TiO_2-enriched basalts has been identified at the base of the volcanic pile.

(v) *Mineralization of Upper Ordovician (?) felsic volcanics at Pilleys Island, Newfoundland; E.C. Appleyard and E.G. Bowles, University of Waterloo*

The Roberts Arm Group forms an extensive belt of calc-alkaline volcanics in the Exploits Zone of the Central Mobile Belt of Newfoundland. The Group and its correlative, the Buchans Group, hosts syngenetic sulphide mineralization at Philleys Island, Gull Pond, Lake Bond and Buchans. At Pilleys Island several small massive sulphide lenses have been discovered in the area of the "Old" Mine and worked in the past; these are associated with sulphide-bearing vein stockworks.

The volcanic sequence comprises a lower basaltic sequence overlain by an upper, variably massive to pyroclastic and autoclastic sequence of felsic volcanics with a thickness of about 150 m. Over much of the island the sequence is relatively fresh and unmineralized though it shows the effects of subgreenschist facies metamorphism. Massive sulphide mineralization is confined conformably to the felsic volcanics and is overlain by distinctive dacite lithic breccia units. Areas of intense alteration are strikingly associated with mineralization. Quartz-sericite $\pm$ feldspar, sericite-quartz $\pm$ sericite $\pm$ chlorite and chlorite $\pm$ sericite facies have been recognized. Zones of intense quartz-sericite-chlorite and chlorite $\pm$ sericite alteration coincident with horizons of felsic vitric tuffs and lithic breccias are particularly favoured sites for sulphide accumulation.

The objective of this study is to elucidate the lithogeochemistry of the host felsic volcanics with emphasis on the chemical effects of alteration associated with mineralization.

(vi) *Geology and lithogeochemistry of altered volcanic rocks of the Roberts Arm Group, Gull Pond area, Newfoundland; E.C. Appleyard and D.W. Healing, University of Waterloo*

A stratiform zone of highly altered volcanic rocks which forms the host for the former Gullbridge Mine deposit has been traced a distance of at least 10 km despite poor exposure at the extremes of the zone. This zone lies generally between a sequence of locally pillowed calc-alkaline metabasalts to the east and rhyolites to the west belonging to the Roberts Arm Group. Alteration is not continuous over this strike length but appears to consist of discontinuous lens-shaped zones at a variety of levels within a relatively narrow (150 - 300 m) stratigraphic interval. Zones of strong alteration commonly appear to be succeeded upwards by thin jasperoid cherts.

The host of the altered rocks at most locations seems to consist of intermediate to acid pyroclastics, tuffs and reworked tuffs with relatively minor intercalations of basic tuff and/or massive basalts. The original size of the clasts is often difficult to determine due to strong, penetrative tectonic deformation, but generally appears to have been less than several centimetres. Very coarse units with clasts up to about one metre are found, however, at several localities.

The alteration consists predominantly of Mg-enrichment leading to the development of strongly chloritic facies. Under the

influence of a granitic pluton to the east, static metamorphism led to the extensive development of cordierite and anthophyllite in the altered facies.

The objective of the study is to elucidate the origin of this stratiform alteration zone and the chemical exchange involved in the production of these Mg-enriched rocks.

(vii) *Geochemistry of volcanic rocks from the Appalachians of Quebec; J. Ludden, C. Hubert, C. Brooks and C. Gariepy, Ecole Polytechnique, Université de Montréal*

7. Volcanism in the Canadian Cordillera

(a) Mesozoic

(i) *Mapping of late Triassic Nicola volcanic rocks near Merritt, B.C.; W.J. McMillan, British Columbia Ministry of Mines and Petroleum Resources*

Field mapping at scale 1:50 840 of the late Triassic volcanic rocks which comprise the Nicola belt is continuing. Previous works by Preto (for references see McMillan, 1978) is being extended northward and westward in the vicinity of Merritt, B.C.

The study is intended to delineate stratigraphy in the Nicola Belt and to gain insight into control and distribution of metallic mineral occurrences both in the volcanic and related or younger intrusive rocks in the belt.

A summary of progress to date is in the B.C. Ministry of Mines Fieldwork 1978 which is expected to be published in early 1979.

(b) Cenozoic

(i) *Tertiary stratigraphy and resource potential in south-central British Columbia; B.N. Church, British Columbia Ministry of Mines and Petroleum Resources*

This is an ongoing project intended to further define the regional stratigraphy, structure, and history of the Tertiary assemblages with a view to establishing their energy and mineral resource potential. During the past year, reconnaissance investigations have been extended from the south Okanagan - Boundary region to Kelowna and Vernon districts.

One result of this work is the discovery of a belt showing intense radioactivity west of Penticton. Full geochemical and mineralogical definition of the rocks of this belt awaits additional field work and laboratory studies.

(ii) *Late Cenozoic volcanic rocks of the Canadian Cordillera; R.L. Armstrong, N. Greene, University of British Columbia; P. Read, Geotex; J. Souther, J. Muller, Geological Survey of Canada; J.E. Hurakal and K. Scott, University of British Columbia*

All late Cenozoic volcanic belts in the Cordillera have been extensively sampled for a Sr isotope study that is now complete. Garibaldi and Alert Bay belts are ready for publication of K-Ar dating studies; further K-Ar work is in progress in the Stikine and Wrangell belts.

(iii) *Kamloops Group volcanic rocks and their tectonic setting, B.C.; T. Ewing, University of British Columbia*

One summer of mapping and collecting is complete as the first stage of a general chemical-petrologic-isotopic study of these volcanic and volcaniclastic rocks of Eocene age.

(iv) *Coquihalla volcanic complex, Cascade Mountains, Southern B.C.; R. Berman, University of British Columbia*

Mapping of this and the Miocene volcanic centre is complete and laboratory studies are in the final stages. The complex is composed of rhyolitic ash flows and volcaniclastic and fan deposits that fill a partially fault bounded basin. Dykes, sills, domes and a composite stock of more basic composition intrude the basin fill.

(v) *Rainbow Range volcano, near Anahim Lake, B.C.; M.L. Bevier, University of British Columbia*

The thesis on these late Miocene rocks has been completed (Bevier, 1978) and defended during the past year. Two papers (Bevier, 1979; Bevier et al., 1979) are now ready for submission to journals. Preliminary results were presented at GSA and GAC meetings.

8. Geothermal Studies

(a) British Columbia

(i) *Isotope hydrology of the Meager Creek thermal waters; F. Michel and P. Fritz, University of Waterloo*

Thermal waters discharging near the base of the Mount Meager volcanic complex can be subdivided into two systems. Those waters encountered along the length of Meager Creek to the south of the complex are derived from the same source and have isotope contents similar to present day winter precipitation. Exchange of oxygen-18 between the water and the wall rocks of the aquifer indicates that the potential exists for the generation of geothermal power, although it is unlikely that any vapour phase exists. Waters associated with the Pebble Creek hot springs have isotope contents which indicate a supply source formed during colder climatic conditions than presently exist in the region. On the basis of oxygen-18-deuterium relationships, these waters do not appear to have undergone the same degree of heating as the Meager Creek thermal waters. Mixing of shallow groundwaters with the deeper thermal waters makes the interpretation of the subsurface history of these waters difficult. The absence of tritium in the thermal waters suggests a minimum subsurface residence time of 25 years with the maximum age probably controlled by the last eruption 2440 B.P. Further geochemical and isotopic investigations of the groundwater system are currently underway. The use of isotope geothermometers is also being investigated at this time.

9. Projects Outside of Canada Undertaken at Canadian Institutions

(a) The evolution of the magmatic arc of the Central Andes: petrochemical, geochronological, and metallogenic aspects; A. Clark, and E. Farrar, Queen's University, M. Zentilli, Dalhousie University, J. Dostal, St. Mary's University, R. McNutt, McMaster University and G. Tilton, University of California, Santa Barbara.

This continuing program is directed towards the classification of the development of magmatism in the Central Andes

(Lats. 15°-30°S) since the initiation of the Andean orogeny in the Late Triassic. The project differs from most other recent research in the region in that it covers pre-Neogene volcanic and plutonic rocks, both essentially ignored by others. It is, therefore, possible to define evolutionary trends in igneous rock compositions. The study aims to determine petrochemical data, within a firm geochronological framework, which would place constraints on the source regions and processes of magma generation. One practical goal is to increase our understanding of the ultimate controls on the boundaries of metallogenic domains within the orogen.

Presently active research concerns: 1) the composition and age relationships of granitoid plutons in the Eastern Cordillera of northern Bolivia-probably back-arc crustal melt products; 2) lead isotope studies of volcanic and plutonic rocks in the 26°-29°S transect; 3) rock-and ore studies in the transect from southernmost Peru to northern Bolivia; 4) oxygen isotope studies in the 26°-29°S transect; 5) the timing and mutual relationships of stratovolcanic and regional ash-flow tuff eruptions in northern Chile and southern Peru, and their correlation with the progressive uplift of the Andes; 6) research on fumarolic sulphide concentration during the cooling of rhyolite lavas and ash-flow tuffs in the continental environment.

(b) Geochemical evaluation of the lavas from the Mascarene Archipelago, western Indian Ocean; J. Ludden, Ecole Polytechnique, Université de Montréal, and A.N. Baxter, University of London, U.K.

(c) Geochemical evaluation of lavas from Gran Canaria; J. Ludden, Ecole Polytechnique, Université de Montréal, and H. Schmincke, Rhur Universität, Bochum, W. Germany.

(d) Geochemical evolution of alkaline rocks from oceanic fracture zones; J. Ludden, Ecole Polytechnique, Université de Montréal, and G. Thompson, Woods Hole Oceanographic Institute.

(e) The Kane Fracture Zone, north Atlantic Ocean; J. Ludden, Ecole Polytechnique, Université de Montréal, W.B. Bryan, G. Thompson, H.B.J. Dick and M. Mott, Woods Hole Oceanographic Institute.

(f) Iztaccihuatl Volcano, central Mexico; G.T. Nixon, University of British Columbia.

Mapping of this large, multivent Pleistocene volcano is complete and chemical petrologic and isotopic work are well advanced, with completion of lab work expected before May, 1979.

(g) Paricutin Volcano, Mexico; R.L. Armstrong, University of British Columbia, A.R. McBirney, University of Oregon.

We have contributed Sr isotopic data for a comprehensive new study of this volcanic suite.

(h) D.S.D.P. Legs 59 and 60 igneous rocks; R.L. Armstrong, G.T. Nixon and D.J. Whitford, University of British Columbia

Twelve of the freshest core samples from this profile of drill holes across the Mariana Arc and adjacent basins and ridges are being studied. Sr isotopic analyses, chemistry and petrography will be completed initially. Later studies will include other isotopes (Nd, Pb, O) and additional trace elements useful for petrogenetic tracers and modelling.

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V ISOTOPE STUDIES AND GEOCHRONOLOGY

Compiled by: P.H. Reynolds

1. University of Alberta - Department of Geology

Investigators - H. Baadsgaard (with associates as listed).

(a) Isotope Geology of the Polymetamorphic Early Archean Rocks of West Greenland and Labrador (with F. Longstaffe, V. McGregor, D. Bridgwater and K. Collerson)

A three week field excursion (summer 1978) enabled the principal researcher to acquire sufficient samples to investigate the following sub-projects: (i) K-Ar, Rb-Sr and U-Th-Pb correlative isotope systematics of the Isua Gneisses; (ii) the age and geochemistry of the unaltered Ameralik dykes at Isua, West Greenland (primitive basaltic material); (iii) the Pb isotope variations in the widespread pegmatite dykes of the Qôrgut granite; (iv) U-Pb on zircons and Pb-Pb on matrix of ancient crustal boulders from the Isua supracrustals; (v) detailed U-Pb and Rb-Sr isotope study on the minerals and whole rocks of the intermediate Nuk gneiss sequence in West Greenland - samples from "type sections".

(b) Magnetic Reversals and Stratigraphic-Time-Scale Correlation in the Upper Cretaceous (with J. Lerbekmo and M. Evans)

An excellent set of bentonite samples has been collected within one metre of the Cretaceous-Tertiary boundary in the Hall Creek area of N. Montana. This bentonite horizon will be dated by K-Ar, Rb-Sr and U-Pb to calibrate the boundary. At the same time, palynological correlations will be made to establish the floral hiatus in the section containing the bentonite. This work is underway and will complement work completed on the boundary section in the Red Deer Valley of Alberta.

(c) The Isotope Geology and Nature of Deposition of the Saskatchewan Proterozoic Uranium Deposits (with G.L. Cumming, R. Morton and J. Howe)

Enough data on five deposits have been accumulated to present a reasonable picture of the time and nature of the "first stage" pitchblende deposition. The five deposits appear to have co-eval first-stage deposition with only minor variation in discordant U-Pb patterns. "Second stage" mineralization is characterized by complex isotope patterns for U-Pb, but fairly simple Pb-Pb systematics - indicating remobilization and relocation of U during this stage. The "third stage" ores have not yet been investigated since they present special problems of sampling and identification.

(d) Geochronology and Lead Isotope Variation in a Zoned Complex Pegmatite (with C. Chaplin)

A major aim is to study the lead isotope distribution in the zones of a complex pegmatite. In particular, the distribution of lead isotopes within apatite and feldspar will be studied to aid in establishing initial igneous behaviour as contrasted with metamorphic effects on lead isotope homogenization. The Rb-Sr geochronology of the pegmatite will also be carried out.

University of Alberta - Department of Physics

Investigators - G.L. Cumming, J. Gray, P. Thompson, S.J. Song and A. Sasaki

(a) Mass Spectrometer Instrumentation

The Micromass 30 solid source mass spectrometer has now been operating on a full-time basis for approximately a year and a half. Nearly 1500 analyses have now been completed, with only a few minor technical difficulties being experienced.

We have now completed the rebuilding of the machine originally used for the Rb half-life measurements. A new magnet controller and electrometer amplifier were built and both are proving very satisfactory. The measurement precision is at least as good as that of the Micromass 30. The instrument will be used primarily for Rb analyses with Sr measurements also being carried out when the Micromass machine is overloaded.

(b) Radiogenic Isotope Studies

Twelve separate dating studies are in progress involving common Pb in various areas of Canada, Mexico and the Caribbean, U-Pb dating of pitchblende ore bodies in northern Saskatchewan and comparisons of U-Pb and Rb-Sr dates for some selected rocks as a means of checking the newly determined half-life of 87 Rb. We are fortunate to have Dr. A. Sasaki from the Geological Survey of Japan visiting this year. He will be studying the Pb isotope ratios in a group of stratiform sulphide deposits in Japan and other countries.

(c) Stable Isotope - Climate Studies

(i) Experiments are underway to determine the effect on the isotope composition of cellulose from plants grown in the laboratory, of temperature, relative humidity and light intensity. Early results show good correlation between $\delta^{18}O$ of whole plants with the light intensity used throughout growth, $\delta^{18}O$ increasing with increased light intensity. A positive correlation between mean temperature and $\delta^{18}O$ has been observed and relative humidity studies are still being carried out. These early results suggest that the $^{18}O/^{16}O$ composition of cellulose may be determined by evaporative transpiration processes at the leaf surface and that variations in the climatic parameters which control this process may be recorded in the $\delta^{18}O$ values of cellulose. This project is being carried out with Dr. D. Aikman of the Biosciences Centre, University of East Anglia.

(ii) A project funded by Alberta Forest Research has been completed. This involved determining past climates (200 years) in three locations in Alberta from the isotopic composition of the cellulose from three trees. The results are being analyzed and while there is good general agreement between the mean annual temperature curves for the three sites (and with Edmonton) there are some interesting local anomalies. In particular when two trees are analyzed from one area, one tree being considerably older

than the other, the variations shown in the isotope curves correlate very closely but with a difference in absolute values of 1 to 2°/oo. This may be due to different shading histories of the trees so that light intensity may be playing a role. With trees of similar ages, and hence likely similar shading histories, this effect is not found.

(iii) Work continued on the 2000 year old giant Sequoia. A specimen of modern Sequoia has been obtained to bring the record up to the present time. The offset effect of 1°/oo discussed in (ii) has however been observed so that interpretation is complicated. It may be necessary to wait until another old tree with growth rings up to the present becomes available. Meanwhile the climate record has now been extended to some 400 years before present.

2. Bedford Institute of Oceanography - Chemical Oceanography Division, Atlantic Oceanographic Laboratory

Investigators - F.C. Tan and P.M. Strain

(a) Stable Isotope Studies in Nearshore Environments

A paper discussing the significance of variations of C^{13}/C^{12} ratios in suspended particulate organic matter from the Gulf of St. Lawrence has been submitted for publication.

Experiments for assessing the precision of sampling for C^{13}/C^{12} ratios of suspended particulate organic matter in nearshore environments have been performed on Bedford Basin, Nova Scotia and on the Scotian Shelf using a Rosette sampler.

(b) Stable Isotope Studies in the Eastern Arctic

Analytical work has been completed for O^{18}/O^{16} determinations of various water masses and sea ice in the Eastern Arctic (Davis Strait, Labrador Sea, Baffin Bay, Lancaster Sound, Jones Sound and Smith Sound). Interpretation of the data is underway. The O^{18}/O^{16} data will be used to: (i) assess the contributions of melt-water from sea ice and meteoric water in the surface waters; (ii) examine the formation of brines in Baffin Bay; (iii) elucidate the origin of deep bottom water in Baffin Bay.

C^{13}/C^{12} determinations for suspended particulate organic matter and plankton tows will be performed in the future. The C^{13}/C^{12} analysis of total dissolved CO_2 has been completed.

(c) Stable Isotope Studies in the Region of the Mid-Atlantic Ridge.

Suspended particulate organic matter and total dissolved CO_2 samples have been collected at selected deep ocean stations during the Chemical Oceanography Mid-Atlantic Ridge Cruise in June, 1978. They are being analyzed for C^{13}/C^{12} ratios. These data will be used to study the nature and behaviour of particulate organic matter in the deep ocean as well as for the estimation of the relative sources of CO_2.

It is also planned to conduct detailed C^{13}/C^{12} speciation studies on particulate organic materials collected using a combination of large volume sampler and a fine-mesh plankton tow.

3. University of British Columbia - Department of Geological Sciences

Investigators - R.L. Armstrong (with students and associates as noted)

(a) Paleozoic to Paleogene Igneous Rocks, Coast Mountains and Intermontane Belt, B.C.

The recently completed study of Coast Plutonic Complex rocks between Prince Rupert and Terrace (Armstrong and Runkle, 1979; Harrison et al., 1979) will soon be published. Rb-Sr and K-Ar studies of Colin Godwin will extend this traverse of plutonic rocks into the intermontane belt east of Terrace. R. Parrish and R.L. Armstrong collected on the Bella Coola to Bella-Bella traverse for similar dating and isotope work as well as cooling history studies. Additional Sr isotopic sampling over much of the southern Coast Mountains has been done by G. Woodsworth and N. Green. Fission track cooling history studies of the entire, but mostly southern, Coast Complex form the Ph.D. thesis topic of R. Parrish.

Manuscrips are planned for several aspects of Sr and K-Ar work in the intermontane belt. Two Rb-Sr isochrons (189 and 191 Ma) for Toarcian volcanic rocks in northern B.C. were obtained by L. Erdman as an honors thesis project. This and other Sr and Ar data for northern B.C. Jurassic igneous rocks will be incorporated in a paper with H. Gabrielse. G. Woodsworth is now preparing a manuscript on the Hogem batholith (~175 to 195 Ma) that will incorporate honors thesis data of T. Eadie and other work in that region. C. Godwin, R. Cann, J. Harakal, and R.L. Armstrong will publish a detailed K-Ar and Rb-Sr geochron study of the Kemess deposit (190 Ma) that is another part of this major Early Jurassic igneous episode.

A paper by Preto et al. (1979) will summarize recent K-Ar and Rb-Sr work in the Nicola belt of southern B.C. Two papers (Morrison, Godwin, Harakal, and Armstrong; Bultman and Armstrong) will report Ar and Sr studies in the Whitehorse trough region, dominated by mid Cretaceous (80 to 116 Ma) and Eocene (~50 Ma) igneous activity.

J. Grette (1978) has completed her thesis on Nicola and Cache Creek rocks in southern B.C., including a 196 Ma Rb-Sr isochron for slightly altered Nicola volcanic rocks. L. Werner is writing up his study of the Coast Plutonic complex southwest of Atlin Lake. P. van der Heyden has collected rocks from the Coast complex in the Whitesail Lake area for a dating-petrology thesis. J. Miller will be dating Coast Plutonic rocks near the Northair Mine, north of Vancouver. One K-Ar data from that study has been published (Miller and Sinclair, 1978).

C. Godwin and A. Sinclair are supervising several theses in the Yukon where K-Ar and/or Rb-Sr dating are being applied as part of studies of economically significant mineralization.

(b) Omineca Belt

Randy Parrish (1978, 1978) has written up his Master's thesis study of the Wolverine Complex plus some later dating work to nail down the cooling and uplift history following Jurassic (pre-166 Ma) metamorphism. L. Pigage (1977) likewise established a Jurassic age for metamorphism at the northern end of the Shuswap complex. A 162 Ma Rb-Sr muscovite and whole rock isochron date for the Oliver granite on the west side of the Shuswap and similar dates for the Nelson batholith (R. Parrish and I. Duncan, unpublished data) on the east side extend this late Jurassic upper-bracket for Shuswap metamorphism around the perimeter of the complex. Within the complex there is evidence of younger ductile deformation, perhaps as young as Eocene locally.

Ian Duncan (1978) has found Archean paragneisses, Hudsonian intrusion, and Hadrynian migmatization in the core of the Thor-Odin dome. We are now studying core gneisses from Frenchman's Cap dome (R. Brown) and Valhalla dome (R. Parrish). R. Parrish has mapped and collected for dating in an area between the Valhalla and Pinnacles domes. Duncan and Parrish will do fission track cooling history studies on suites of rocks they have collected. Another uplift and cooling study (K-Ar, fission track) is under way in the Trinity Hills (W.H. Mathews) where the Eocene unconformity is observable overlying Shuswap rocks with Eocene reset K-Ar dates.

Eocene resetting (~45 Ma) dominated a number of mica-whole rock Rb-Sr isochrons done for E. Ghent (Calgary) on schists from the Encampment Creek area. P. Simony (Calgary) will provide samples of Trail Gneiss to expand an initial abortive study by Parrish and Duncan.

From south of the border in Idaho a suite of paragneiss and later pluton samples was analyzed for Sr for B. Otto (1978) of the University of Montana. A crude Rb-Sr isochron was consistent with a Purcell-Belt age for the paragneiss. Similarly two K-Ar dates on Idaho batholith rocks were provided for L. Williams (1977). These extended the area involved in Eocene resetting of K-Ar dates, confirming a pattern inferred from earlier data.

(c) Cascade Mountains

High-pressure metamorphism of two different ages (240 Ma and 150 Ma) has been Rb-Sr and K-Ar dated in the northwestern Cascade Mountains of Washington. This has been done for thesis projects (Bernardi, 1977; Wilson, 1978) and on samples supplied by N. Brown (W.W.S.U.) and samples collected with P. Misch (U.W.) from localities he has studied. This work is nearing completion and will be reported in a multiauthor paper.

A suite of crystalline rocks from the high-temperature core of the North Cascades, collected by J. Engels and P. Misch, has been analyzed for Rb-Sr and Sr isotopic composition as the first stage of a study of that area - to seek for older rocks, and to date Mesozoic plutons and metamorphism as a complement to work in the high-pressure belts to the west.

University of British Columbia - Department of Geophysics and Astronomy

Investigators - W.F. Slawson and R.D. Russell (with students and associates as noted)

The five lysimeters installed by W.F. Slawson in 1977 have been checked on a weekly basis for over one year. Waters from these and the U.B.C. rain gauge have been analyzed for oxygen-18. The data awaits compilation and interpretation. The program continues.

The lead isotope program continued with the assistance of an NSERC Core Grant. An extensive study is underway by Ryan of carbonate-hosted lead-zinc deposits in the Mackenzie Mountain region and stratiform deposits in the Selwyn Basin. Trace element analyses were completed for sphalerites from some of these deposits. These indicated a bimodal distribution that correlated well with lead isotopic distributions. Volcanogenic leads from the Pelly Mountains, southwestern B.C. (including Northair, Seneca and Britannia Mines) and northwestern B.C. (including Dolly Varden, Ecstall and Granduc deposits) are also being analyzed. These studies are in cooperation with the Department of Geological Sciences, and in particular with A.J. Sinclair and C.I. Godwin.

A zircon laboratory has been set up and the necessary techniques are being implemented by R.L. Armstrong and P.J. Shore. D.J. Whitford has been appointed to assist with these studies. Zircon dating will likely start in early 1979, with initial studies in the Coast Mountains near Vancouver and in the Omineca belt on suites previously studied by rubidium-strontium methods.

T.K. Ahern and P. Whaite are continuing the automation of an oxygen mass spectrometer, including the use of mini-computer and micro-processor controls. R. Ahern has completed several hundred $^{18}O/^{16}O$ analyses of water samples, including a re-analysis of the IAEA standards.

Some preliminary copper isotopic analyses were carried out in cooperation with the Federal Department of Agriculture. This tested the possibility of establishing balances of copper in bovine metabolism.

R.D. Russell is continuing his studies of lead isotopic constraints on the early history of the earth. Recently these have included applications of inversion techniques, with D.W. Oldenburg, described elsewhere in this Bulletin.

4. University of Calgary - Departments of Physics, Geology, Biology and Members of The University of Calgary Interdisciplinary Sulphur Research Group (UNISUL)

Investigators - H.R. Krouse, H.M. Brown, C.J. Bland and J.A. Case in Physics; F.A. Campbell, E.D. Ghent and A.A. Levinson in Geology; E. Laishley and D. Bewley in Biology

Dr. H.M. Brown recently joined the stable isotope laboratory of Imperial Oil Limited, Calgary. Dr. V.A. Grinenko of the Vernadsky Institute, Soviet Academy of Science, visited the laboratory for three months.

(a) Instrumental

An Analogic AN5800 analogue multiplexer with a 14-bit A to D converter has been interfaced to a TI980 Minicomputer to process stable isotope data from a number of mass spectrometers. Currently, a Dynabyte microprocessor is being adapted to process stable isotope data and control mass spectrometry operation. A facility for simultaneous H/D and $^{13}C/^{12}C$ determinations on organic matter is under construction.

(b) Stable Isotope Studies

(i) Sullivan, B.C. - In a second major phase of this study, $\delta^{34}S$ values for 146 pyrrhotite specimens were used to locate a predicted exhalative vent in the western portion of the ore body. $\delta^{34}S$ values near the vent were $+3^{o}/oo$ and decreased outwards down to $-3^{o}/oo$ over the sampling area 250m x 300m pattern. The data are consistent with chemical reduction of a concentrated sulfate brine at about $250^{o}C$. (F.A. Campbell, V. Ethier and H.R. Krouse)

(ii) Medicine Hat Gas Field - Fluids and cores have been extensively sampled for measurements of H, C, N, O and S isotope abundances in order to understand the genesis of the natural gas (biological versus thermal) maturation and migration processes and interaction with formation waters. This is the subject of the Ph.D. investigation of Miss F. Oro, Department of Geology. (F. Oro, H.R. Krouse and E. Ghent)

(iii) Coal of Western Canada - In a preliminary survey, C and S isotope abundances have been measured on two dozen coal specimens from Alberta and British Columbia. The $\delta^{13}C$ values are in a relatively small

range -24 to -26°/oo and the δ^{34} values range from -1 to +13°/oo. Increase in $\delta^{13}C$ values generally correlated with decrease in $\delta^{34}S$ values. Nitrogen isotope abundances are currently being measured. (V. Grinenko and H.R. Krouse)

(iv) Selenium Isotopes - Selenium isotope abundances were measured using SeF_5^+ ions and the multislit collector of the 12" radius mass spectormeter. $\delta^{80}Se$ and $\delta^{82}Se$ values were determined in reference to ^{76}Se. Plots of $\delta^{82}Se$ versus $\delta^{80}Se$ for terrestrial and laboratory fractionated samples gave a slope of 1.5, in agreement with theory. Kinetic isotope effects found during chemical and microbial selenite reduction were best explained by a two-step model. This work comprised K. Rashid's Ph.D. thesis. (K. Rashid, E. Laishley and R.G.L. McCready of Lethbridge Agricultural Research Station; H.R. Krouse)

(v) Sulphur isotope fractionation by microorganisms - This involves several projects, one being the Ph.D. thesis of Miss G. Harrison (Biology). Studies of SO_3^{2-} reduction by C. pasteurianum have continued. These include the effects of selenium compounds on sulphur isotope fractionation and experiments using cell-free extracts to reduce SO_3^{2-}, $S_2O_3^{2-}$ and S_3O^{2-}. SO_3^{2-} reduction experiments have also been carried out with Salmonella and inverse isotope effects were found which had previously been noted with C. pasteurianum. Sulphur isotope fractionation during microbial breakdown of $BaSO_4$ sludges was interpreted in terms of the relative rates of dissolution and reduction. Thiosulphate dissociation by Proteus was also investigated. (V. Grinenko, G. Harrison, H.R. Krouse, E. Laishley and R.G.L. McCready)

(vi) Sulphur isotope fractionation during chemical SO_3^{2-} reduction - These experiments are being carried out in order to interpret the isotopic selectivity during microbial reduction and hence to interpret the natural variations. The isotope fractionation varies considerably with experimental conditions and is related to the formation of intermediates. (V. Grinenko and H.R. Krouse)

(vii) Environmental sulphur studies, Peace River area - Soil and vegetation in the Peace River area are characterized by negative δ^{34} values (down to -20°/oo) whereas the emissions for sour gas plants in the area typically have $\delta^{34}S$ values greater than +20°/oo. Increasing concentrations of sulphur in soil and vegetation were identified with more negative $\delta^{34}S$ values showing that subsurface salt layers were the major source of sulphur to the environment while industry was a minor contributor. (J. Case and H.R. Krouse)

(viii) Continuing Projects - Projects continuing with descriptions similar to the 1977 report are:

Kidney stones (A.A. Levinson and H.R. Krouse).
Uranium Deposits, Amer. Lake, N.W.T. (A. Knox, A.A. Levinson and R. Krouse).
Mineral Springs (R. van Everdingen, Environment Canada; H.R. Krouse).
Geohydrology, south of Great Slave Lake (U. Weyer, Environment Canada; H.R. Krouse).

(c) Terrestrial Radioactivity

Research into methods of removing radioactive contamination from uranium mine effluents has led to the development of equipment and techniques to measure pCi levels of certain nuclides in liquid and solid samples. These nuclides include U, Th and Ra, which may be determined by alpha particle spectrometry. For the latter type of determination, the adsorbtive properties of manganese dioxide have been used to extract activities from solutions directly on to specially treated plastic

planchets. Gamma Ray Spectrometry is also used for studies into the disequilibrium of certain uraniferous ores. (C.J. Bland and A.A. Levinson)

5. Canada Centre for Inland Waters

Investigators - J.O. Nriagu and R.D. Coker

(a) Stable Isotope Studies of Sulphur Pollution in the Great Lakes Basin

The study aims to determine the isotopic composition of sulphur from various sources and to evaluate the subsequent isotopic changes during the cycling of the sulphur in the Great Lakes Basin. The project should provide important information on the sources, dispersion pathways and ultimate sink of the pollutant sulphur in the Great Lakes Basin.

Gram quantities of humic and fulvic acids have been extracted from large (1.5-5.0 kg wet wt) samples of Lake Ontario sediments. Sections from 15-20 cores were pooled to obtain the sample size required. Aliquots of the humic and fulvic acids have been analyzed for total sulphur and trace metals following the $HClO_4$ + HF digestion. The measurement of the isotopic composition of the sulphur is now in progress. The trace metal data are being processed for publication.

The results of previous years' work on isotopic studies of sulphur pollution around Sudbury have been published.

6. Dalhousie University - Department of Geology

Investigator - P.H. Reynolds (with associates as noted)

(a) Nova Scotian Granites and Slates (with G.K. Muecke and M. Zentilli)

Our age study of the major granitic plutons of southwest Nova Scotia is nearing completion. Altogether, some 35 mica concentrates have been analyzed by either the $^{40}Ar/^{39}Ar$ or the conventional K-Ar method. The resulting argon age pattern appears to correlate very well with the regional metamorphic zonation. Initial results have been obtained on a selection of slate samples from the Meguma Group. Well-defined plateau ages at 410 Ma have been interpreted as a minimum value for the time of initiation of the Acadian Orogeny in Nova Scota. This value is substantially higher than the older time limit as derived from well-established stratigraphic constraints.

(b) Plutonic Rocks from the Coastal Cordillera of North Chile (with M. Zentilli and C. Ulriksen)

Following detailed mapping of regional geology, we are carrying out K-Ar and $^{40}Ar/^{39}Ar$ age studies of various mineral phases from the plutonic rocks in the Taltal area of Chile. The overall objective is to understand more completely the geological, and in particular, the metallogenic evolution of the region.

7. Université Laval - Department of Geology

Investigator - R. Laurent

Of primary concern is the dating of various members of the ophiolitic complexes which are situated in the Québec Appalachians. These samples have very low K_2O concentrations and have also had quite complex histories. Preliminary K-Ar apparent ages range from Devonian to early Cambrian.

8. McGill University - Department of Geological Sciences

Investigators - R. Doig, A. Fowler and M. Higgins

(a) Uraniferous Granites

Age determinations of various Grenville province uraniferous granitic rocks from Bancroft, Mt. Laurier and Johan Beetz areas have shown that these rocks are younger than the ages normally associated with the widespread Grenville orogeny ca. 1150 Ma ago. Previous studies have attributed the origin of many of these occurrences to in-situ anatexis of uraniferous protoliths which may be related to the base of the Grenville supracrustal sequence.

A Rb-Sr whole rock isochron made up of pegmatitic granite samples from the now defunct Canadian Dyno, Greyhawk and Bicroft mines in the Bancroft area yields an age of 970 Ma. This contrasts with the age of 1200 Ma determined for the adjacent Cheddar granite. The radioactive granites and associated pegmatites of Mt. Laurier are about 950 Ma in age whereas the area's barren granites are 1107 Ma old. An age of 950 Ma was obtained from a pegmatite in the Johan Beetz area, where field evidence suggests that there are also older granites.

Some of these uraniferous granites are spatially, and in part temporally, related to abundant alkalic rocks which occur from Bancroft to Mt. Laurier. In addition they appear to have crystallized from melts produced after the main pulse of the Grenville orogeny rather than through processes of in-situ anatexis or metasomatism. Considerable control over the location of these rocks may have been exerted by large fractures within the crust.

(b) Sept-Iles Anorthosite

Rb-Sr studies of the Sept-Iles anorthosite complex have shown that it is Cambrian in age, and related to the St. Lawrence Rift System.

Measurements of REE abundances for the rock units of the complex yield patterns with negative Eu anomalies for the major syenite and granite bodies associated with the anorthosite, as well as for the minor acidic dikes and granitic "segregations" within the anorthosite.

The slopes of the normalized REE spectra are constant for all the various basic cumulate rocks, as well as for the associated diorite and syenite. In addition, the abundances of REE and residual elements such as Th, Ta and Hf vary in a systematic way in these rocks. However, the slope of the REE spectrum of the granite is greater than that of the syenite, and the REE and residual element abundances are lower.

This overall pattern may be explained by a differentiation process dominated by the precipitation of plagioclase from an original gabbroic magma until a syenitic magma has been produced. At this point apatite and zircon joined the precipitates, removing REE and residual elements, leading to the lower abundances and the REE pattern observed in the granite. These abundances are very similar to those reported for other granites showing negative Eu anomalies.

9. McMaster University - Department of Chemistry

Investigators - J. Monster, 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 of the possible role of living organisms in the early Precambrian.

Measurements of the four stable sulphur isotopes in meteorites and lunar samples is being continued in order to investigate the isotopic homgeneity 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.

McMaster University - Department of Geology

Investigators - R.H. McNutt and H.P. Schwarcz (with students and associates as listed)

(a) Archean Studies (R.H. McNutt, H.P. Schwarcz, G. Beakhouse and F. Longstaffe)

During the past year work was completed on a project to analyse $^{18}O/^{16}O$ ratios in a variety of plutonic granitoid rocks from the Wabigoon and English River belts in southwestern Ontario. In both the gneiss belts and within the greenstone belts gneissic granitoids exhibited similar isotopic compositions suggesting modest contributions of crustal material during genesis of the magmas. Metasedimentary rocks could be isotopically related to nearby felsic to intermediate volcanic rocks from which they had apparently been derived. The effects of intense metamorphism and migmatism could be seen.

A geochemical and Rb-Sr geochronological study is in progress on the southern portion of the English River gneiss belt. Approximately 100 analyses for major and trace elements have been completed and isotopic analyses are in progress. Particular attention is being paid to the gneissic rocks. We will study the extent of the disturbance in Rb-Sr systematics in rocks showing disequilibrium in their O isotopes.

(b) Andean Cordillera (R.H. McNutt with F. Longstaffe)

The results of O^{18}/O^{16} whole rock analyses on samples with a spread in initial Sr^{87}/Sr^{86} (.703-.708) and variable Pb^{206}/Pb^{204} over the past 180 m.y. have values that fall consistently in the range +6 +8‰ with the volcanics having slightly higher values. Mineral isotopic analyses are in progress. These preliminary data suggest a crustal or upper mantle source for the magmas.

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

We propose to date the igneous and metasedimentary units in the Chandos Township region, using the Rb-Sr method. The instrusive rocks consist of mafic to felsic varieties, but the two main units are the Loon Lake pluton and the Silent Lake granite. The metasediments include marble, amphibolite and quartzo-feldspathic gneisses. It has been suggested that some phases of the Loon Lake pluton phases are hybrids, the result of assimilation. We plan to test this hypothesis with the Rb-Sr method.

(d) Stable Isotopic Studies of Pleistocene Paleoclimate Effects in Speleothems (H.P. Schwarcz, R. Harmon, M. Gascoyne and D. Ford)

Further studies of oxygen and hydrogen isotope variations in calcitic cave deposits and their included waters are being pursued to evaluate changes in the temperature of deposition of the calcites and hence the average annual temperature on the ground surface above the cave. Hydrogen

isotope studies of the fluid inclusions also are revealing changes in the isotopic composition of meteoric water during ice ages, and hence of changes in storm tracks and isotherms in North America.

(e) Radiometric Dating of Archaeological Sites (H.P. Schwarcz and B. Blackwell)

Layers of travertine ($CaCO_3$) are found interstratified with archaeological deposits ranging in age from the early Old Stone Age to the Neolithic. We are using the Th-230/U-234 method to obtain dates for such samples up to the 350,000 year limit of the method. Results compare favourably with estimates obtained by archaeologists on the basis of climatic and paleontologic data.

(f) Paleomagnetic Stratigraphy of Speleothems (H.P. Schwarcz, A. Latham, D. Ford (McMaster) and W. Pearce (U. of Toronto))

Weak but measurable natural remanent magnetisation can be detected in cave-deposited calcite samples. These can also be dated by the Th/U method and hence we can construct curves of declination and inclination at a given site versus time. These curves do not suffer from problems of distortion of the orientation record due to compaction, slumping, etc., as have been observed in sediment cores. Consistent D, I variation curves have been observed from several sites.

(g) Paleosea-level Determinations (H.P. Schwarcz, M. Gascoyne and G. Benjamin)

By measuring the age of speleothems from submerged sites in caves now flooded due to post-glacial rise in sea-level, we are able to establish points on a sea-level curve for the past 350,000 years. A low sea-stand from the Illinoisan (140,000 y. B.P.) has been observed in a cave in the Bahamas.

10. Queen's University - Department of Geological Sciences

Investigators - E. Farrar, D.A. Archibald and R.M. Tosdal

(a) A K-Ar geochronological study of the southeastern part of the Kootenay arc (British Columbia) is in progress. The research is concentrated on the Batholith and plutonic rocks. The aim of this research is to determine the age relations of the intrusions comprising the batholith and thereby to determine the role of the batholith in the structural and metamorphic history of the area. $^{40}Ar/^{39}Ar$ analyses on selected samples are planned to help achieve this aim. Also, the U-Pb ages of zircons from rocks suspected to be of Precambrian age are being determined. This latter research is being done in collaboration with Dr. T.E. Krogh of the Royal Ontario Museum (Archibald and Farrar).

(b) A K-Ar study of the timing of the geomorphic and tectonic evolution of the southernmost Peruvian Andes is nearing completion. Conventional K-Ar analyses on mineral separates from the late Cenozoic volcanic rocks in a transect of the western Andes in the vicinity of Moquegua indicate that uplift began in the early Miocene and has continued until the present. The most rapid uplift occurred during the mid-Miocene (Tosdal and Farrar).

(c) A K-Ar study of the Nazca Group volcanics in the vicinity of Puquio, southern Peru is continuing. Several widespread ash flows associated with a collapse caldera complex are being dated (Farrar).

11. University of Toronto - Department of Physics

Investigator - R.M. Farquhar (and associates as noted)

(a) Lead Isotope Studies

Using double spiking procedures and analysis of standards to determine accurately instrumental mass fractionation factors, and reproducible silica-gel filament loading and thermal ionization of lead, we now regularly and straightforwardly analyse lead extracted from sulphides to produce lead isotope ratios with a reproducibility of better than $\pm$ 0.15% (2σ). Chemical extraction procedures are routine and lead contamination levels are less than 0.5 nanogram.

Using the technique he has developed, Mr. I.R. Fletcher has completed a thorough re-examination of his earlier work on galenas associated with the Grenville, and made an extensive study of lead from galenas and sulphides at Balmat, N.Y. His work confirms the general isotopic trends observed and reported earlier, but the improved reproducibility has resolved a number of features and will make it possible to sharpen considerably the interpretation of the age significance of the data.

A short paper on the Mississippi Valley-type lead-zinc sulphides was presented at the recent International Conference on Geochronology. Mr. Fletcher undertook the study of galenas and sulphides at Balmat in an effort to better understand the genesis of the ore in that deposit and to try to relate the peculiar Balmat lead isotope ratios to the main Grenville lead distribution.

Two other aspects of the Grenville lead isotope program are of interest. Some of the galenas found in cavities in Paleozoic sediments overlying the Grenville do not have isotopic lead ratios which fit the main Mississippi Valley-type distribution and have thus had a different history. Since we now have an extensive bank of lead isotope data for the Grenville region, we felt that identification of the sources of the galena artifacts occasionally found in Ontario archaic Indian graves might be possible. In fact, it appears that galena from an early gravesite on the Ottawa river apparently came from the Wisconsin-Illinois-I area, while two more recent but widely separated graves contain galena from a mineral occurrence near the south shore of Lake Ontario.

Our mass spectrometer has also been extensively used by Dr. J.R. Richards, on leave from the Australian National University, Canberra, who has made a number of analyses of an international lead isotope standard; the results are in excellent agreement with data from his own and other laboratories.

(b) Fission Track Studies

During the past year, the aim of this work has been to attempt to etch the tracks in flint and other quartzes, produced by fission of a ^{252}Cf source. Mr. Y.F. Huang has observed low densities of ill-defined track-like features etched by HF in the surface of thin sections of flint. Progress on this project has been unsatisfactorily slow, and it has been decided to discontinue the work at this stage.

12. University of Waterloo - Department of Earth Science

Investigator - P. Fritz (with associates and students)

(a) Studies related to low permeability rocks are of special importance due to the current interest in projects related to nuclear waste disposal. Initially, in Sweden, the Lawrence Berkeley Laboratories of the

University of California (in collaboration with Swedish authorities) investigated mechanical, hydrologic and geochemical factors in order to evaluate the suitability of a certain granitic rock for the long-term containment of nuclear waste. Stable and natural radioactive isotopes were used to define age, origin and history of groundwaters encountered, and to aid in the description of geochemical environments prevailing in the fracture systems. Similar programmes have now been initiated with the support of AECL and Environment Canada in several areas on the Canadian Shield.

(b) Other projects include: the age and formation of permafrost and its hydrogeology; methane in groundwaters - the degree of maturation and origin of natural gas in Southern Ontario (funded by the Ontario Department of Mines); applications to geothermal power developments in B.C.

13. University of Western Ontario - Department of Geophysics

Investigator - A. Hayatsu (and associates)

(a) Solubility of Argon in Basalt Melts (with C.E. Waboso and A.K. Baksi)

Basalt melts were equilibrated for 8 hours at 1200°C with argon pressures up to 40 torrs and quenched. The amounts of incorporated argon were found to increase linearly with increased pressure, yielding a pressure coefficient of 2.1×10^{-5} ccSTP/g/atm. These results are similar to those obtained by Kirsten for enstatite at 1500°C and show that just above the solidifying temperature, about 2×10^{-7} ccSTP/g of argon can stay in silicate melts under subaerial conditions.

(b) K-Ar Isochron Ages and Initial Argon Ratios of Mesozoic Rocks (with various co-workers)

The following samples were analyzed or reanalyzed for K-Ar isochron studies and yielded well-defined isochrons.

	Geologic Age	Conventional K-Ar ages	Isochron Age	Initial $^{40}Ar/^{39}Ar$
Andesite from Camaraca formation Arica, Chile	Middle Jurassic	105 - 153 Ma	157 Ma	1
North Mountain Basalt Nova Scotia	Late Triassic	125 - 196 Ma	191 Ma	195
Trans-Avalon Dike Newfoundland	Late Triassic	172 - 201 Ma	201 Ma	215
West Rock Sill Connecticut	Late Triassic	182 - 188 Ma	191 Ma	154
Buttress Dike Connecticut	Late Triassic	179 - 190 Ma		

The results indicate that the $^{40}Ar/^{36}Ar$ ratio in the upper mantle in the Mesozoic Era was significantly lower than the present atmospheric $^{40}Ar/^{36}Ar$ ratio.

14. University of Windsor - Department of Geology

Investigators - A. Turek (with T.E. Krogh (Royal Ontario Museum), T.E. Smith and C.H. Huang)

(a) Geochronology and Geochemistry of the Gamitagama Area, Ontario

The Gamitagama greenstone belt is approximately 40 km south of Wawa, Ontario, and is in the Shebandowan belt of the Superior province. Rb-Sr whole rock isochron ages and U-Pb zircon ages together with other geochemical data elucidate the evolution of this Precambrian terrain. The volcanic pile and related metasediments are at least 2715 m.y. old. This is a U-Pb zircon age obtained for an acid volcanic unit in the upper volcanic sequence. The volcanics and the metasediments are intruded by trondhjemite plutons which have been dated as 2645 m.y. old by Rb-Sr and 2663 m.y. by U-Pb. Normalized REE patterns for the trondhjemitic plutons are typical of the calc-alkaline suite. The Gamitagama gabbroic complex, which is a layered and differentiated pluton gives a 2640 m.y. Rb-Sr age and a 2662 m.y. U-Pb age. Post tectonic potassic plutons yield a 2565 m.y. Rb-Sr age. The Southern Batholith is mostly a migmatitic terrain, which is in fault contact with the greenstone belt and the associated intrusives. The Rb-Sr age for this migmatite area is 2560 m.y. and the corresponding U-Pb age is 2608 m.y. This is a somewhat younger age for a migmatite than is general for the Superior province and may represent younger tectonic uplift of this block.

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VI METEOROLOGY AND ATMOSPHERIC SCIENCE

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1. Introduction

Research activities continued at a steady pace during 1978 even though the mid-year slowdown in the Canadian economy and the cutback in government spending was affecting future program strategy. The full impact of financial restraint on research has yet to be felt. However, the fruit of previous years' efforts is reflected in the wide-ranging reports presented below.

At year-end the Global Weather Experiment was off to a good start with the deployment of Canadian drifting meteorological buoys in the southern Atlantic and Pacific Oceans. Other commitments to this highly intensive research program are being met, including preparations to equip the CSS Parizeau for its measurement program on the Equator southeast of Hawaii.

The Canadian Meteorological and Oceanographic Society held its Twelfth Annual Congress at the University of Western Ontario from May 31 to June 2, 1978. Meteorologists and oceanographers shared full partnership in the Congress for the first time, as reflected in the theme session, Energy, the Meteorologist and the Oceanographer. The Society prizes for 1977 were awarded to: P.E. Merilees, President's Prize; J.I. McPherson, Dr. Andrew Thomson Prize in Applied Meteorology; K. Lee, the Rube Hornstein Prize in Operational Meteorology; M. Béland and L.W. Diehl, Graduate Student Prize (double award). A citation was awarded to the Directors of The ARK, New Alchemy Institute, P.E.I. for their initiative in promoting environmental improvements by the conception and the building of a self-contained, self-sufficient living environment, The ARK. This concept is based on the philosophy that wasteful human technologies must be replaced by efficient low consumption technologies, powered by the renewable resources of sun, wind and biological systems.

2. The University of British Columbia - Department of Geography

(a) Turbulence and the Surface Energy Balance at a Suburban Site

A preliminary analysis of the energy balance of suburban terrain is near completion. It is based on data from a 30 m tower in Vancouver. The Bowen-ratio energy-balance technique has been evaluated for use over urban surfaces, and a detailed error analysis conducted. The characteristic partitioning of energy in such an area has been studied with special emphasis on the value of the Bowen ratio and the role of evapotranspiration.

An intensive observation schedule at the suburban tower was undertaken in July-August 1978. Complete radiation budget and energy-balance information was gathered for 26 consecutive days. The sensible heat flux density was measured by three independent system: by the Bowen ratio-energy balance approach, with a yaw sphere-thermometer eddy correlation system and a UVW anemometer-thermometer system. The UVW system also provided a measure of the surface shearing stress and the data necessary to analyze turbulence spectra. The height of the urban boundary layer was monitored continuously by acoustic radar, and by approximately 100 mini-sonde flights.

Analysis is underway to study the structure of turbulence, the nature of the fluxes of heat, water vapour and momentum, the relationships between the surface heat flux and the depth of the boundary layer, and the role of the sea-breeze system in all of the above.

(b) Lawn Evapotranspiration

Mini-lysimeters installed in a surburban irrigated lawn clearly demonstrate that such surfaces act as 'micro-oases' in the urban area.

(c) Modelling Urban/Rural Cooling Rates

Nocturnal cooling of "urban" and "rural" surfaces has been simulated using models in a cold chamber. The results are in agreement with certain aspects of field observation.

The following radiation projects have been in progress while Dr. Hay is on sabbatical leave.

(d) Measurement and Modelling of Short-wave Radiation on Inclined Surfaces

(e) Distribution of Diffuse Short-wave Radiation over the Sky Hemisphere

(f) Distribution of Cloud and Effective Radiating Temperature over the Sky Hemisphere

(g) Assessment of the Mesoscale Spatial Variability of Solar Energy at the Earth's Surface

(h) Satellite Data and its Application to Radiation Climatology

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

(a) Cloud and Precipitation Physics

Theoretical work on stable isotope ratios in precipitation is continuing.

Work on cloud physics measurements in the vicinity of cooling towers at low temperatures is being completed.

Experiments are underway to examine the time dependence of the growth of ice accretions on stationary circular cylinders. A successful theoretical model of this process has already been developed, and it is being extended to treat the icing of aerofoils, particularly helicopter rotor blades.

A cloud physics model is being constructed to examine the dynamics and thermodynamics of cloud droplets injected into high speed icing tunnels.

(b) Synoptic-Scale Studies

In the past year, synoptic-scale studies of the atmospheric circulation have relied heavily on satellite data from western Canada and the high Arctic. Procedures developed previously have been modified and extended to serve current research projects. D. Oracheski has completed an M.Sc. thesis on the influence of the Canadian Cordillera on frontal cloud bands. He found that, with cross-barrier flow, the Coast Mountains and the Cascade Range frequently give rise to two distinct bands of orographic cloud. The cloud band associated with the Coast Mountains is very persistent, and clearing normally expected after a frontal passage is very slow and usually incomplete. However, clearing with frontal passages occurs readily in the lee of the Cascades.

R. Hopkinson has 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 IR images are used to estimate the height of all significant cloud masses.

B. Greaves, using NOAA-5 data, is extending B. Green's work on thermal patterns observed over Banks Island and the Beaufort Sea. In a related project, R. Cross is investigating the distribution of cloudiness in the western arctic. The analysis of cloud in the Arctic is complicated by the fact that the difference in temperature between the surface and the tops of low cloud is usually small. Resolution of cloud or ground ambiguities thus depends on the ability to discriminate between slight differences in the IR radiation temperatures. R. Cross is attempting such resolution by largely objective methods supported by stringent statistical criteria.

P. de Souza used Fourier analysis to extract wave information from the Hovmöller diagram data. Such diagrams show how the 500-mb mean heights change with longitude and time. De Souza's analysis suggests a relation between the 500-mb heights and solar radiation. Some forecast skill was shown when comparisons were made to climatology and persistence forecasts. However, the error in the best forecasts was rather too large to warrant operational use at the present time.

4. Alberta Oil Sands Environmental Research Program

The Alberta Oil Sands Environmental Research Program was established in 1975 by agreement between Environment Canada and Alberta Environment to provide information which will permit the orderly development of the oil sands without undue damage to the environment. Research is directed to the solution of practical social and technical environmental problems and is structured into four main sectors of land, air, water, and human environmental systems.

The program is in the fourth year of an initial five year period of operation. During the first three years, a priority has been placed on establishing baseline states of the four environmental systems. In years four

and five, the number of research projects will increase as baseline monitoring activity decreases.

Several scientific reports relating to meteorology and air quality have been published by the program and are listed in the bibliography.

5. Alberta Environment

An air system research program describing a rationale and priority for research topics was finalized. Three research projects have been funded to study the physical and chemical composition of particulate matter and aerosols over Edmonton and Calgary. Alberta Environment assumed full responsibility for the operation of meteorological towers in Edmonton and Calgary as a result of the withdrawal of the Atmospheric Environment Service from the Tall Tower Network.

A lower atmosphere sounding program commenced at a site in the Restricted Development Area to the southwest of Edmonton. A monostatic acoustic radar is operated continuously. During the middle month of each season, up to five temperature and wind profiles are measured each week-day using a balloon-borne minisonde traced by a single optical theodolite. Additional measurements include: incoming and net radiation, wind speed and direction at 10-m height, turbulence, atmospheric pressure, surface temperature and turbulent heat flux.

A province-wide precipitation monitoring program was initiated to detect any significant changes in the ecosystem resulting from industrialization and long range transport of air pollutants. The six stations are located at Edmonton, Calgary, Red Deer, Whitecourt, Suffield, and Beaverlodge. Operating procedures are similar to those used by CANSAP.

Alberta Environment cooperated with the Alberta Petroleum Industry and the Alberta Energy Resources Conservation Board in carrying out a series of pipeline burst experiments near Pincher Creek to develop and test techniques for creating controlled pipe breaks and to study gas dispersion under various atmospheric conditions.

6. Alberta Research Council - Atmospheric Sciences Division

(a) Introduction

The Atmospheric Sciences Division (ASD) pursued research in two main areas: hailstorm research and atmospheric chemistry research.

ASD performed research on hailstorms under contract with the Alberta Weather Modification Board (AWMB). This year, 1978, was the last year of the five-year Alberta Hail Project. Seven sub-programs were continued from past years and an additional one, cloud physics, was initiated.

In the area of atmospheric chemistry, an in-house program on "Precipitation sampling and anlysis" was continued from last year. A second program on the "Chemical composition of particulate matter and aerosol" was initiated under contract with Alberta Environment.

(b) Hailstorm research

This program comprised eight subprograms: storm environment, storm modelling, radar studies, hailfall studies, rainfall studies, cloud physics, evaluation studies and data processing.

During 1978, the goal of the Storm Environment Program has been to determine why hailstorms tend to form in preferred areas in the Alberta foothills. These areas are northwest and southwest of Rocky Mountain House and north and west of Edson. A physical model of the events leading to

hailstorm formation in these areas was postulated as follows: brisk surface winds develop and flow up major river valleys. The winds in the middle of the atmosphere blow with a component across the continental divide causing the surface flow up major river valleys to intensify. Near the headwaters of the rivers, the air spills out of the valleys on either side causing convergence in areas between the valleys. This converging air reinforces cloud develoment and hailstorms form.

To test this physical model, the Rocky Area Genesis Study (RAGS) was designed. On 9 August 1978, the University of Wyoming research aircraft flew over three hailstorm formation areas. Early indications are that the aircraft found a systematic turning of the wind direction consistent with the postulated model. Wind data for 9 August and all days in 1978 with hailstorms originating northwest and southwest of Rocky Mountain House are under analysis. If the physical model is verified, it will be possible to predict a few hours in advance when these preferred hailstorm areas will be active.

The study to determine the optimum atmospheric sounding location for obtaining good estimates of the hail production potential of a convective storm was completed. For storms that are large and well-developed, soundings 20 to 80 km ahead of them and away from the area shaded by the anvil cloud indicate the potential for hail very well. Soundings behind the storms are of little value in this regard.

The goal of the Storm Modelling Studies is to develop numerical models of clouds and storms by the use of computers. The numerical models are to be used to test the efficacy of cloud-seeding methods presently used by the Alberta Hail Project and to devise and test other methods of influencing the growth of hail and rain in a storm.

To date, much effort has been devoted to using very simple cloud models to help evaluate the hail-suppression effort statistically. In this regard, the role of the simple numerical model is to provide some measure of the natural ability of the storm to produce hail. A number of such measures of "predictors" are calcualted; for instance, a predicted maximum hail size, storm energy, water content, or updraft speed. All of these "predictors" are statistically related to some measure of the hailfall produced by a storm. Measurements of the hailfall produced by a storm of other storm characteristics are called "predictands"; some predictands that have been used are reported maximum hailstone size, hailswath area and radar-measured cloud top height. Statistical relationships between "predictors" and "predictands" for non-seeded storms and for seeded storms have been developed for all storms that occurred in the Alberta Hail Project Area during 1975 and 1976. A comparison of the "non-seeded" relationships with the corresponding "seeded" relationships shows no statistically significant difference. This suggests that no seeding effect could be detected by this method.

It must be pointed out that the measurements upon which the predictors and predictands are based are very crude. The simple numerical models require a vertical temperature and humidity profile of the air going into the storm. The Storm Environment Program has derived empirical threshold of time and space where soundings are representative. For many storms, however, the available information is obviously not close enough. Moreover, the simple numerical models are very sensitive to the cloud-base height and temperature which must be specified. It is clear now that the cloud base determined from the surface temperature and dew point sometimes differs considerably from that measured by a specially instrumented aircraft. Finally, the predictions are mostly based on reports supplied by voluntary observers and so their accuracy can be expected to vary tremendously.

Considerable time has been spent in the past two years on a project dealing with the modelling of the growth of hail embryos, which involves constructing a detailed numerical model of the portion of the hailstorm in which hail embryos are believed to originate. In order to ensure the realism of this model, a new program was initiated to obtain airborne measurements of temperature, water content, horizontal and vertical winds as well as concentrations and sizes of water particles in the "new growth zone" of Alberta hailstorms, where hail embryos are believed to originate. These measurements are being used as input data to derive the numerical model and will also be used to test it.

Finally the numerical simulation of the seeding of clouds with AgI or dry ice has now been initiated. Although AgI has been the seeding agent used heretofore by the Alberta Hail Project, dry ice seeding experiments conducted during this summer and observations made during the past year or so in the U.S.A., suggest that dry ice should be considered seriously as a seeding agent.

The Radar Studies Program provides operational support for cloud-seeding activities of the Alberta Weather Modification Board, and conducts research on unknown aspects of rain and hail formation. Precise measurement of rainfall and hailfall at the ground is also an important part of the radar studies program. Radar measurements are also used by other groups in ASD to support storm modelling, storm environment and hail suppression evaluation studies.

Resulting from collaboration with the computer group, a comprehensive set of radar-related computer programs has been developed which permit the display of maps of contoured radar reflectivity or storm intensity and of the tracks of as many as eight cloud-seeding aircraft. This display, on a cathode ray tube (CRT), can be generated by the computer in real-time for the direction and coordination of the cloud-seeding aircraft operations or post-facto, from reflectivity data stored on computer tape, for post-facto analysis of the recorded storm intensity data. Moreover, these programs can generate in real-time or post-facto, contoured maps of rainfall rates (mm hr^{-1}) and of accumulated rainfall amounts (mm) over the whole area of the radar scan. These programs are considered to be useful in other radar meteorology projects throughout the world. Therefore, steps are being taken, in consultation with an Alberta firm, to market specific radar-related hardware and software items developed by ASD.

Although research is directed towards many aspects of severe storm phenomena, an important project designed to remotely distinguish hail from rain by radar is showing tremendous potential. Based upon sophisticated polarization and dual wavelength measurements, and upon a new scattering theory developed under contract to the Alberta Research Council, it now appears possible to identify those storms with a propensity to produce hail; more important however, the ability to remotely estimate hail size by radar now appears quite feasible. Refinements of these techniques are expected to contribute significantly to future measurements and studies of rainfall, hailfall and snowfall. Since only point rainfall or hailfall measurements are available from commonly used gauge networks, radar offers a unique advantage in measuring areal precipitation amounts because of its ability to scan large areas (50,000 km^2). Following a successful pilot program in 1977, accumulated radar-derived rainfall amounts in central Alberta were produced during the summer of 1978 for the Flow Forecasting Branch of Alberta Environment. This program has demonstrated that the use of routine weather radar rainfall measurements can help hydrologists provide more precise forecasts of high water conditions in central Alberta's rivers and streams.

The aim of the Hailfall Studies Program is to study the fine-scale variations in hailfall at the surface and to correlate crop damage to the physical characteristics of hailstones in a hailfall. The ultimate goal is to determine the usefulness of these measurements in evaluating hail suppression experiments. To address these questions, a network of 159 hailpad stations in 922 km^2 (dense network) and two small networks of 26 and 16 hailpads in 0.64 km^2 quarter sections (micro-dense networks) were used to gather data on hailfall and rainfall quantities. Four storms with grape-size or smaller hail crossed the micro-dense networks, but since little crop damage was caused, no crop damage estimates were available for comparison. The dense network was used to gather information on variations in seeded storm hailfalls, for use in correlating crop damage to hallfall type. Previous studies have shown that crop damage is most related to the impact energy density, hence, changes should also be reflected in crop damage. Also collected in the dense network are daily total rainfall measurements, used to examine the variability of rainfall in the area.

Of the ground measurements, hailpad measurements are considered to be the prime source of objective hailfall data. These hailpad data come from a network with an average spacing of one hailpad per 70 km^2. Before the data are used for evaluation, it is desirable to know how accurately the hailpad network measures the true hailfall. Since the objective of the measurement is to obtain an accurate estimate of the mean areal energy density or of the total energy of the hailswath, the required network density can be specified in terms of the possible error that one is prepared to accept. To address this problem, a study presenting five different random sampling techniques, and using Monte-Carlo simulation, was performed.

The results obtained for the different sampling methods are similar in the sense that they all indicate that the standard deviation of the Monte-Carlo means varies as k^{-x} (k is the sample size), where x is a positive quantity which varies from 0.5 to 1.25 depending upon the sampling approach. The overall magnitude of the errors is controlled by the y-intercept at k = 1, which is the standard deviation of the available hailpad observations. It was further found that the standard error for a particular hailswath, measured with a network of given density, increases with diminishing hailswath area. Thus, in order to sample each and every hailswath to better than a certain maximum error, the required network density is determined by the size of the smallest hailswath of interest. On the other hand, in trying to esimate the total energy of an ensemble of many hailswaths, the smallest hailswaths will not contribute substantially, and one may be prepared to tolerate a sizeable error in their estimated energies.

Five large hailstorms which occurred in 1974 and 1975 were examined. The results suggest that the density of the dense network, 1 station per 5.7 km^2, is sufficient to obtain an impact energy accurate to within 10%. More work needs to be done to verify whether this behaviour is representative of other hailswaths.

The objectives of the Rainfall Studies Program was to determine the effects of cloud seeding for hail suppression, on the rainfall in the dense network. Rainfall records from 1975 to 1978 were examined and compared with the long-term rainfall average for the months of June, July, and August. The results show that, for all years except 1975, the summer precipitation totals are within 20% of normal. In fact, the average for the four years was 91% of normal. However, 1975 and 1976 were randomized years in the north area where the dense network was located. During those years, seeding occurred on only half of the haildays. On the contrary, seeding was performed on every hailday of 1977 and 1978. The average departure from normal for the randomized years, 79.5%, is smaller than

that for the non-randomized years, 103%. However, the wide range in totals, evident within an area as small as the dense network, is a reflection of the very nature of convective precipitation. Two- or three-fold variations occur naturally within the district. These should be kept in mind when attempting to relate short-term precipitation totals to seeding effects.

The primary goal of the Cloud Physics Program was to test the hypothesis, suggested by ASD radar and photographic studies of hailstorms, that the hail embryos originate in the new growth zone to the south, southeast of mature hailstorms. To this end, the Alberta Research Council contracted with the University of Wyoming for the operation, during the first three weeks in August, of the University's Queen Air instrumented aircraft and scientific team in conjunction with the Alberta Hail Project. Secondary studies such as the formation of precipitation in cumulus clouds, the atmosphric structure conducive to hailstorm formation in the Rocky Mountain House area (RAGS), the effect of dry ice on the ice crystal population of cumulus clouds, and the coordinated aircraft-radar-distrometer study of precipitation at the 0°C level were also pursued.

The Queen Air flew through the "new growth zone" of mature hailstorms as well as through cumulus clouds measuring temperature, humidity and wind parameters but in particular measuring sizes and concentrations of water and ice particles. Some samples of water particles were also photographed. At least one flight was devoted to each of the secondary studies. In spite of the low frequency of thunderstorms during the three-week period of airborne observations, the quality and the quantity of airborne research data is ample to address each study, secondary as well as primary, at least in a preliminary, exploratory fashion. The data collected during these three weeks will be analyzed jointly by ASD and University of Wyoming staff.

The objectives of the Evaluation Program is to use conventional and to devise new statistical tests with which to evaluate the AWMB five-year hail suppression test.

Statistical comparisons of hail measures between the seed and no-seed cases were performed as requested by the Alberta Weather Modification Board. The hail measures examined include hailswath area, hail impact energy, hailstone size distributions and hail crop insurance loss-to-risk ratios.

The statistical techniques employed in the above analyses include the latest techniques developed for weather modification evaluation as well as some classical statistical tests. Both parametric and non-parametric methods are involved. Furthermore, a new multivariate permutation testing procedure is used in certain appropriate cases. This procedure represents a new dimension in hail suppression evaluation techniques. The statistical analyses of storm model outputs as predictors and of hail measures as predictands also involves the multivariate permutation procedure. Intermediate outputs from the LMA (Loaded Moist Adiabatic) storm model are used and so far, only hailcard-derived predictands were considered. Various approaches involving multiple regression and principal components analyses were attempted. The determination of the best approach for general application will be made after a more detailed examination of both the physical and statistical relations among the variables is completed.

The objective of the Data Processing Program is to provide computer support for the data processing and analysis in ASD.

Steadily increasing demands for continuous computer support for research as well as expanding operational commitments led to the acquisition by AWMB and installation and operation by ASD of a separate computer at the field site in Penhold. A PDP-11/34, with a floating point unit and 192KB of memory, was purchased early in 1978. Disks and magnetic tape drives were moved from the existing system to provide one complete facility in Penhold and one in Edmonton throughout the year. The radar interface hardware and test equipment were also moved to the Penhold computer system. Existing software for the data collection and for the real-time display system was simply moved from the 11/50, since the two machines support the same operating system. This compatibility also permits extensive development and testing of programs before installation on the machine in the field, thus reducing interruptions of data collection. New software was developed for the 1978 season to support 24-hour data collection, and operation by the radar study program staff. A program to record highly compressed, one-channel data from the C-band radar (5-cm wavelength) was implemented. The analysis and real-time support was modified to make this data format completely compatible with two- and four-channel S-band data (10-cm wavelength reflectivity and polarization). Separate calibration programs for each radar were established to allow calibration of one radar during operation of the other. A set of simplified commands was established to allow the radar staff to operate the computer system with little training in computers. The real-time display system was enhanced by using disk storage for data to be displayed. This support facilitates re-display or calculations based on real-time data, as well as providing increased reliability for the real-time system as a whole. Data collection on the 11/34 system was extended to cover a full 24-h day, and simplified to the extent that no computer-oriented staff were required for routine operations.

The existing 11/50 system, also operated 24 hours a day, remained in Edmonton and provided research and program development support during the day and overnight processing of data tapes received from Penhold each night. Routine products of the overnight processing included quality control of data recording, rainfall accumulations for Alberta Environment, and a daily maximum reflectivity map for telephone survey direction. Detailed radar calibration information was also available in Edmonton within 36 hours.

(c) Atmospheric Chemistry research

The Atmospheric Sciences Division and the Chemistry Division of the Alberta Research Council have been jointly involved in two programs in atmospheric chemistry. An exploratory program to determine the chemical composition of precipitation and evaluate its relationship to general air quality is being conducted in central Alberta and in the Edmonton urban area. Approximately 800 rain and snow samples have been collected and are being analyzed for 23 inorganic chemical species. A program to study the chemical composition of particulate matter over Edmonton has been undertaken for Alberta Environment. To support these programs, trace analytical methods using ion chromatography and atomic absorption spectroscopy have been developed. A study to determine the effect of container type and storage on trace concentrations of various inorganic species has been completed. Samples stored in polyethylene bottles at -15° were stable for four months even at concentrations as low as 0.1 μg/ml.

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

A ground-based spectrometer is being used to obtain absorption spectra of nitrogen dioxide in the stratosphere using the same twilight observing technique employed by Noxon and Kerr. This project forms the basis of Qasim Syed's Ph.D. thesis program.

Studies of ambient aerosol size distributions and their relation to visual range are being conducted using integrating nephelometer and spectronephelometer instrumentation. Simultaneous monitoring of aerosol mass loading of the atmosphere using cascade impactors is being carried out by Rosaline Pi, an M.Sc. student. The aerosol scattering coefficient as a function of wavelength is used to determine the Angstrom coefficient which can then be related to the power law exponent of the associated aerosol particle size distribution.

A standard ruby lidar system is being developed based on a Korad QSI system for studies of local urban pollution patterns during Chinook and temperature inversion events. The lidar is destined to operate in tandem with the established acoustic sounder system of the department.

A higher power acoustic sounder system with bistatic doppler facilities has been installed at a small airport near Calgary. This will be used to study wind and turbulence profiles, especially during Chinooks, up to an altitude of several thousand feet.

8. Western Research & Development Ltd.

During 1978 Western Research & Development supplied meteorological consulting services to the sulphur extraction industry, power plant companies, municipal and provincial governments and other clients. The consultations covered a wide variety of topics including plume diffusion amid mountainous terrain, urban air pollution, cooling pond fog generation, arctic climatology, pipeline ruptures, ad sulphur deposition. Major field studies involved assessments of cooling pond fog, observations of plume diffusion in a mountainous valley and the collection of wind data on Melville Island.

9. Intera Environmental Consultants Ltd.

Three major meteorological studies have been undertaken: seeding of some Alberta hailstorms; targetting and dispersion of AgI in the Alberta Hail Project; plume dispersion measurements at an Oil Sands extraction plant.

In addition to these studies, Intera has provided numerous reports to industrial clients and government agencies. One of the larger projects involved measurements of turbulent dispersion characteristics using a tethersonde and SO_2 ground level concentrations using a mobile SO_2 sensor in the vicinity of the Nevis Gas Plant on behalf of Gulf Canada Ltd. The observed concentrations over three field studies were compared to numerical model predictions using a Gaussian model and a potential flow model capable of handling terrain effects (Intera's EMS model). This study is the first study under Alberta's new reduced exit temperature regulations and may lead to significant savings of nonrenewable natural gas resources.

Another major area of activity has been in the problem of assessing the dangers associated with potential rupture of sour gas pipelines. Work has included several reports for clients and a workshop with Alberta DOE and the Energy Resources Conservation Board with the objective of handling the physics of a transient explosive jet in a more realistic manner in dispersion simulation models.

10. Saskatchewan Research Council

Air pollution studies were undertaken in four broad areas:

(i) downwind drift of herbicides, including worker exposure levels,

(ii) grain-dust levels within prairie elevators during various operations;

(iii) measurement of potash dust effluent at the stack for a number of Saskatchewan mines;

(iv) studies of airborne SO_2 concentrations and sulphates in precipitation along the western edge of Saskatchewan.

The downwind herbicide work was a direct extension of previous studies on off-target spray drift, which was continued this year as well, and included tests on a novel air-cushion sprayer for its ability to operate independently of ambient winds. The results are presently being analysed.

The grain-dust investigation, which is part of a larger epidemiological study of grain-worker health conditions funded by Health and Welfare Canada, is a continuation of the project initiated and reported on last year. The same is true for the SO_2 research funded by an AES contract. Measurements were taken throughout the summer and fall of 1978. Potash dust effluent is being intensively investigated to aid the industry in meeting environmental standards for this material; this will be an ongoing service program.

In cloud physics research, the investigation of silver iodide levels in the air and biota was continued in 1978. Two areas of the province were covered, west central and southeastern Saskatchewan, both adjacent to areas where cloud seeding is being carried out on an operational basis. Efforts to improve specific identification of the particles as AgI, via scanning electron microscope and x-ray diffraction are being intensified. This work has been carried out under an AES research contract.

Finally, a study on the provision of weather services to the province, and of future forecast needs, was undertaken late in the year for the Saskatchewan Department of Agriculture and a report published in December.

11. University of Windsor

(a) Department of Geography

(i) *Radiation Measurements - Essex County*

The measurement and continuous recording of incoming global radiation, using a precision Eppley pyranometer, is being continued at the University of Windsor. A contract for the measurement of global and net radiation at Pelee Island begun in 1974, has been terminated because of AES budget cuts. Analysis has begun on the 4 1/2 years of record.

(ii) *Precipitation - Quantity and Quality*

The network of 18 recording precipitation gauges is being continued with support from the Essex Region Conservation Authority (publication, Sanderson and Gorski).

The research on precipitation chemistry and runoff for PLUARG is now completed (publications: Sanderson, International Joint Commission and Sanderson and Ramasastry, University of Alberta Press).

(iii) *Arctic Climatology*

The program of synoptic energy budget studies in eastern Baffin Island, being carried out jointly with the Institute of Arctic and Alpine Research (U. of Colorado) was completed in 1977. A three-year program of topoclimatic studies was begun in 1976 with

National Research Council Support. Field studies are being conducted in southern and eastern Baffin Island to provide a basis for modelling topoclimates in coastal areas of moderate relief.

(b) Department of Physics

Measurement of fundamental parameters relevant to minor atmospheric species is continuing.

12. The University of Waterloo - Environmental Fluid Mechanics Group

Two studies have recently been concluded using an 8-level primitive equations numerical model incorporating orography, surface and internal friction, fluxes of heat and water vapour from water surfaces, and both large-scale and parameterized convective precipitation and release of latent heat.

One investigation employed a grid size of 48 km and investigated lake-effect snow to the lee of Lake Huron. The convective parameterization scheme was modified to include sensible heating; i.e. the temperature excess of a convective cloud over the environment was assumed to be caused by vertical transport of sensible heat from the water surface as well as from convective-scale precipitation and release of latent heat. The model was applied to three lake-effect cases, and was also employed to isolate the various physical influences on precipitation including heat and moisture input from the lake surface, shoreline frictional convergence and orographic lift.

The model was also applied to three examples of cyclogenesis off the east coast of North America. The grid size was 190 km. Twenty-four hour prognoses were made for four time intervals with similar results: orography and fluxes of sensible and latent heat from the ocean were of little consequence, while the effect of the land-water roughness contrast was significant. The lack of appreciable orographic influence was partially attributable to the fact that the lows studied crossed the Appalachians south of the highest terrain. A definite contribution from surface fluxes was absent because the fluxes were large south-west of the low centre as cold air poured over the warm water. The Laplacian of the heating did not favour development at the low centre according to Petterssen's development equation. The dramatic effect of friction was associated with a decrease in low-level mass convergence as the low moved from rough land to smooth sea. Similar influences should occur off the east coast of Asia where the AMTEX observations were taken in February of 1974 and 1975.

A good deal of work has also been done on models of the planetary boundary layer (PBL). These studies are also relevant to large-scale phenomena. For example, the heat-balance equation at the earth's surface has been solved including long- and short-wave radiation, sensible heat exchange between earth and atmosphere, heat flux from the soil below the surface, and evaporation of soil moisture. This may be directly incorporated into synoptic and global scale models.

A study has been carried out correlating mean precipitation to solar radiation reaching the ground S (or, more precisely, to S/S_o where S_o is the theoretical maximum solar radiation in the absence of an atmosphere. S_o is a function only of latitude and time of year). Since many more stations report precipitation than solar radiation, detailed maps of insolation can now be prepared.

Full-scale experiments on tall-stack diffusion within the PBL have been completed at Cartersville, Sudbury, Ont. and Nanticoke, Ont. The Cartersville and Sudbury work involved plume cross-sectional identification using instrumented fixed-wing aircraft, while the Nanticoke study employed the use of a LIDAR system. The effects of cross-wind shear on plume cross-sectional shape is clearly evident in the data. The LIDAR-produced cross-sections are

more truly representative of time-averaged cross-sections than that obtained using the aircraft and SO_2 sampling. Signal-to-noise ratios proved to limit the range of the particle LIDAR.

A numerical model for diffusion in the PBL including buoyant plume rise and using empirical estimates of eddy diffusivities has been completed. A primitive equation (two-dimensional) numerical model of the PBL was completed and successfully tested using the data gathered at Nanticoke, Ontario.

Work is presently progressing on the development of simplified methods for predicting ground-level concentrations of contaminants under the presence of significant cross-wind shear. A significant data base is developing to test such a model.

Current work includes further development of PBL modelling and diffusion. The significance of the baratropic assumption used in PBL modelling as well as numerical modelling of diffusion in the PBL under strong cross-wind shear is being pursued.

13. McMaster University - Department of Geography

(a) Aerosol effects on solar irradiance - J.A. Davies

An initial investigation for selected Canadian stations using 1974 data is near completion. Stations representative of "background" and "polluted" atmospheres were included.

(b) Radiation transfer in tropical clouds - J.A. Davies

Aircraft measurements (GATE) of solar irradiance are to be combined with radiative transfer calculations to examine radiative properties of clouds.

(c) Evaporation from cropped surfaces - J.A. Davies

Field investigations of evaporation from soybeans in southern Ontario and pasture in the Peace River District of British Columbia have been completed. The performance of various combination model forms has been assessed.

(d) Permafrost and Microclimatic Interaction in Heavy Clay Soils - W.R. Rouse

A 2-year study of the thermal and soil moisture regimes during thaw and freezeback in wet heavy clay soils at Churchill, Manitoba.

(e) Radiation and Energy Budgets in Tundra - W.R. Rouse

A comprehensive set of measurements of component radiation fluxes, energy budgets and soil thermal and moisture regimes during late winter, snowmelt, mid-summer and late summer at an open tundra site near Churchill, Manitoba.

14. The University of Toronto

(a) Department of Physics

Cloud Physics - (Dr. R. List). The fragment distribution of drops which break up after collision has been described by 4-dimensional analytical functions and the matrices were calculated to include the information in cloud models dealing with the evolution of warm rain. Numerical experiments demonstrated that the collision efficiency of small droplets is further enhanced through electrical effects when fields and charges are arranged such that the relative speeds of the droplets are small.

The heat transfer of still and rotating spheres simulating hailstones was measured and numerically calculated. A theoretical boundary-layer model agrees with the observations.

New icing experiments are being set up in a wind tunnel which will make use of the processor-controlled Knollenberg 2-D Probe. They are aimed at understanding the water losses from an object growing in a supercooled cloud. The design of a pressure- and temperature-controlled icing tunnel progressed to the point that orders could be placed. The new facility is supposed to contribute particularly to the growth and melting of ice particles (graupel, small hail, hailstones) with diameters of up to 1 cm.

The phenomenon of ion evaporation from charged droplets has been investigated by Dr. J.V. Iribarne for different types of aqueous solutions, by using a quadrupole mass spectrometer.

Nucleation in gas phase by chemical reactions and the influence of ions in the process is being investigated. The system $NH_3 + HC\ell + H_2O$ was studied, and the systems $SO_2 + NH_3 + H_2O$ and $SO_2 + O_2 + H_2O$ are under study.

Research is being conducted on the field-controlled capture of ions by ice crystals in a monopolar atmosphere. This phenomenon is related to the formation of shielding layers in thunderclouds.

Further work has been completed by W.R. Peltier and his students applying ideas developed in previous work on the stability of parallel flows to large-scale barotropic and baro-clinic flows. It has been shown that the ideas of over-reflection and quantization are fundamental to these instabilities. Detailed analyses of the non-linear development of Kelvin-Helmholtz billows and of non-hydrostatic mountain waves have also appeared and further work is ongoing. As part of a new effort in paleo-climatic research, data on relative sea-level variations since the last glacial maximum have been used successfully to infer the thickness of the major Northern Hemisphre ice sheets ca. 20,000 BP.

GATE A/B-and B-scale aerological data have been analyzed by Dr. H.R. Cho for two three-day periods in Phase III. The analyses of A/B-scale heat, moisture, vorticity and potential vorticity budgets for the periods have been completed. A formulation representing the effects of cumulus clouds in the large-scale vorticity equation has been completed. The difficulty presented by the tilting effects of clouds has been resolved. Clouds are found to modify the mean vorticity through two processes. One process is the vertical advection of mean vorticity by cloud-induced vertical circulations and the other is the twisting of horizontal vorticity into the vertical direction by an inhomogeneous spatial distribution of the cloud population.

Dr. T. Gal-Chen has developed and tested zonally averaged energy-balance climate models. Considerable progress has been achieved in validating some of the qualitative results of the "simple" models. The "superposed epoch" analysis method of compositing temperatures was used as an aid in the search for evidence of a drop in surface temperature due to large volcanic dust veils.

An investigation of the atmospheric balance of water vapour for Western Canada and the Northwestern U.S.A. has recently been started. Upper-air data representative of the years 1961-1976 were obtained from the Canadian Atmospheric Environment Service (AES) and the U.S. National Center for Atmospheric Research (NCAR). From these it is possible to calculate moisture fluxes and evaporation (e.g. Peixoto). Vertical velocity can also be evaluated from the aerological data by use of the continuity equation.

We wish to determine the minimum information needed to construct statistical dynamical climate models as opposed to detailed general circulation models. The viability of the representation will be tested with a detailed multi-level quasi-geostrophic numerical model.

Steady progress has also been made in the project concerning four dimensional data assimilation and initialization of a mesoscale convection model. The feasibility of deducing temperature and pressure fluctuations from non-simultaneous Doppler radar measurements of the wind has been demonstrated. The sensitivity of the method to observational errors has been assessed. Recently, an important extension of the method has been completed, namely an estimation of the kinematics when only the two-dimensional component of the wind is known and the lower (or upper) boundary conditions are not known; therefore, one cannot use the continuity equation in a straightforward way. This problem was identified as a key outstanding difficult problem in Radar Meteorology.

(b) Institute for Environmental Studies

Professor F. Kenneth Hare acted as a focal point for studies of climate and human response at the University of Toronto, and as a consultant to both the AES Canadian Climate Program and the WMO World Climate Conference. Both Professor Hare and Dr. Munn were active in the preparations for the World Climate Conference.

Dr. Munn coordinated the activities of the Institute in the design of environmental monitoring systems, and he completed a major review of the published literature on air pollution monitoring networks. Dr. S. Daggupaty began a major review on the topic of trajectory analysis for long-range transport of pollutants.

The Institute has had a long-standing interest in the long-range transport of air pollutants and on the effects of acid precipitation on the biosphere. In May 1978, the Institute hosted a NATO Advanced Research Institute on the Effects of Acid Precipitation on Terrestrial Ecosystems.

15. Ontario Ministry of the Environment - Air Resources Branch

(a) Air Quality and Meteorology Section

A model to predict dispersion from tall stacks emitting in the upper part of the planetary boundary layer is currently under development. The model is based on recent understanding of the convective boundary layer and it represents a significant departure from conventional Gaussian plume modeling techniques. It has been applied with a fair degree of success to the 381-m stack in Sudbury, Ontario.

A model has been developed to study the long-range long-term impact of pollution. Novel statistical methods have been used to incorporate wet and dry scavenging processes in the model. It has been used to predict SO_2 and SO_4 concentrations over northeastern Canada and the United States.

Two models have been formulated to predict the occurrence of high pollutant concentrations. The first is an improved box model and has been used to predict concentrations during stagnation episodes. The second is based on empirical concentration frequency distributions and has been applied to estimation of the number of air quality violations associated with point sources.

(b) Special Studies Unit

Studies of the effect of atmospheric temperature structure, solar radiation, and wind speed on plume dispersion from a tall stack at Sudbury, Ontario.

Studies of impact of Sudbury smelting activities and long-range atmospheric transport on local wet and dry atmospheric deposition of acids, sulfates and trace metals.

Studies of the impact of Nanticoke industrial activities and long-range transport on local wet and dry atmospheric deposition, and concentration, of various gaseous and particulate pollutants.

Winter and summertime studies of atmospheric turbulence and pollutant dispersion in a complex terrain as a function of meteorology in the Nanticoke area, with particular emphasis on lake effects.

16. Trent University - Department of Geography

The land and lake snow-cover and the ice cover projects described previously continued. So did the snow gauge study.

17. Communications Research Centre

As part of its research program, the Radio Propagation Laboratory is engaged in studies of some of the meteorological factors that influence the transmission of radio waves through the troposphere. Particular emphasis is on those rare and anomalous conditions that give rise to adverse propagation. These studies encompass two main areas of investigation. The first involves the analysis of radio refractive index from the surface to the tropopause. More than a decade of both surface weather observations and rawinsonde records, including both mandatory and significant level data, for approximately 70 stations throughout Canada and neighbouring portions of the U.S. were processed in this endeavour. A comprehensive report detailing many of the results relating to both surface refractivity and ground-based refractive gradients has been published.

The second area under investigation is aimed at the problem of atmospheric attenuation of microwaves by hydrometeors. Tipping-bucket records from 47 Canadian stations have been scaled to provide a continuous, high-resolution rainfall history for each site. A total of 490 station-years of data has been processed with records for individual stations ranging up to 20 years. A report containing the cumulative rainfall-rate distributions for locations across the country is currently being completed, and is to be followed shortly by predictions of microwave attenuation by rain for frequencies aboves 8 GHz.

18. National Aeronautical Establishment

For the fifth successive year, the Flight Research Laboratory of the NAE cooperated with the Atmospheric Environment Service, Cloud Physics Research Division, in a rainfall enhancement research program. The broad aim of this experiment is to determine whether cloud seeding can be used to modify convective clouds upwind of large forest fires in order to produce precipitation for fire control. A T-33 turbulence research aircraft, a Twin Otter instrumented for cloud microphysical measurements, and a Beech 18 for precipitation measurement at cloud base were used. The T-33 can seed clouds using end-burning silver iodide flares, while the Twin Otter possesses a dry ice seeding capability. A four-week experiment was conducted in the Thunder Bay area during June and July in which both natural and seeded clouds were studied. A total of 193 hours were flown in support of this project during 1978, bringing to 734 the total number of hours flown since the experiment began in 1974.

In March 1978, the Twin Otter was used in a brief series of exploratory flights to examine the microphysical nature of clouds causing airframe icing. These flights were made in conjunction with helicopter icing trials being performed by the Aeroplane and Armament Experimental Establishment of Britain.

19. Agriculture Canada - Agrometeorology Section

(a) Indroduction

At the present time the Section program is designed to meet the user requirements in three areas: Crop-Environment Modeling, Operational Systems, and Agrometeorological Research Services. In addition, a fourth area, contract research, is quite prominent in that the Section has considerable input into two Branch programs: Land Evaluation, and Crop Information System.

By 1983 the goal of the Agrometeorological Section is to have developed improved methodology for the assessment of agroclimatic resources and for analyzing and monitoring crop response to weather, soil and land management in order to provide agrometeorological information as required for agricultural research and services and as input to planning, marketing and farm management decision-making.

Inclusion of Agrometeorology in the new Research Branch Institute (LRRI) has resulted in a more positive alignment of Section productivity and should prove complementary to current and future commitments, both research and service. Other major developments were the approval by CASCC of a Task Force to study a National Farm Weather Service for Canada; the establishment of an operational crop (wheat, oats, barley) yield-prediction system based on real-time weather data; the upgrading of the real-time agroclimatic information system for use by Branch projects; the determination of soil moisture normals (30-yr) for 80 locations in the Prairie Provinces; the publication of agroclimatic resource maps for the Niagara Peninsula; and analysis of field work-days for 18 locations across Canada.

(b) Crop-Environment Modelling

A new integrating and recording system for monitoring plant environments was constructed, and improvements were made to micrometeorological instrumentation (i) air bearing wind vane and anemometer (ii) CO_2 analyzer (iii) leaf chambers.

Development of a forage/yield model using non-linear regression analysis is complete. Marquardt Algorithm approach was used to solve a series of non-linear equations.

An implicit finite-element model was translated and adapted for computer simulation on the minicomputer.

Adaptation of a modified Marquardt estimation technique was made in order to fit pressure head and hydraulic conductivity functions.

The Akaike Information Criteria for selection of the optimum Markov Chain probability model was introduced and found to be effective.

A package of computer programs was developed using coordinate transformations and a Thiessen polygon procedure for evaluation of areal averages of meteorological variables.

Using the Mann-Whitney U test on climatic variables, monthly winter survival indices were developed relative to alfalfa survival in Canada.

A report was prepared from the results of a national survey on alfalfa winter survival for the 1976-77 season.

(c) Operational Systems

The 1941-70 climatic normals have been obtained from the AES in the form of a 1290 equal-area grid system. This climatic information has been incorporated with the LRRI soils data on a grid-square basis.

An operational real-time weather-based crop-yield prediction for wheat, oats and barley was prepared on a monthly basis. Updates were made at the ends of April, May, June, and July 1978.

Assistance was given to the Lands Directorate, Fisheries and Environment Canada, including information and maps on ACRI (Agroclimatic Resource Index) and on the resources for maturing barley and wheat in Canada in the Lands Directorate's study on Critical Lands.

A national spring workday probability analysis involving 18 selected stations was completed. A computer program for specifying horsepower needs from climatic estimates was also published.

A revision of the documentation on the Versatile Soil Moisture Budget was published as a result of the universal interest in this budgeting technique.

Agroclimatic resource maps at a 1/250 m scale were prepared using SYMAP for several variables for the Niagara Peninsula and for the Wynyard map sheet area of Saskatchewan.

The 1978 Soil Moisture Evaluation Program (SMEP) introduced a new base map depicting the crop-report districts (Statscan). District values were generated using a Theissen polygon approach.

A technique to interpret climatic data useful to farm operations was introduced by a series of crop maturity calendars based on various levels of risk and time of maturity using 3 threshold temperatures (5, 10, 13°C).

(d) Agrometeorological Research Services

Agrometeorological data processing services were integrated with other activities in LRRI and the Branch to meet requirements in 3 major areas: research and development, user requirements, and operational user systems. Requests for services have increased in number and complexity. Responsibilities have also increased due to collaboration with the Sibbald Group and the recent alignment with LRRI. Data processing support was also extended to support the Branch Crop Information System and the use of WMO Synop data.

All 5 Branch projects using real-time agroclimatic data remained active during 1978. With the inclusion of on-line synoptic traffic, the available station coverage will now number well over 100 points across Canada.

20. McGill University

(a) Department of Meteorology

Previous work on the structure of forced planetary waves in numerical models has been pursued using models with spherical geometry. Emphasis has been placed on the vertical resolution required in these models to simulate the waves correctly, and on the effects of the upper boundary condition. A numerical weather prediction model developed by the Atmospheric Environment Service is being used in these studies.

The dynamics of atmospheric blocking is also being investigated by means of a numerical model. The main objective is to test the hypothesis recently discussed in the literature that blocking may be a manifestation of a quasi-resonance phenomenon.

Two potential mechanisms for planetary wave growth are being investigated with a view to explaining anomalous flow patterns which are sometimes observed during the winter. Attention is centered on two possibilities:

(1) growth associated with the existence of forcing and wave reflection near zero-wind lines (nonlinear critical layers);

(2) resonant interaction with forced planetary waves.

The energy-budget model developed earlier at McGill has been extended to include a water surface and is being applied to forecast the onset of freezing in the Beaufort Sea.

Numerical studies of the absorption of solar radiation in the atmosphere are continuing, with emphasis on the role of aerosols. The aim of these studies is to provide a fast, accurate method of accounting for solar radiation in global climate models.

It has been speculated that some of the discrepancy between observed and calculated sizes of ice particles following cloud seeding might be due to ice crystal aggregation. A numerical model of ice crystal aggregation has been developed to investigate this.

Work was completed on the climatology and certain physical aspects of freezing rain occurrences in the Montreal area.

Investigations of the dynamics of convective clouds using a three-dimensional numerical model have been continued to include the effects of rain production and evaporation, water loading, and non-hydrostatic pressure perturbations. The model thus elaborated will be used in a comparison of radar-observed cloud behavior with model predictions.

Research has continued on the time and space variability of rain, and methods are being sought to generate spatial rainfall statistics from time records.

At the McGill Radar Weather Observatory work is continuing on the analysis of GATE data and radar-satellite comparisons of rainfall patterns. New work has been started on a comparison of ground-based radiometric observations of precipitation with radar data. A new round of experiments has also begun in which radar observations are being used to assess the effects of rain on earth-to-space communications.

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

Field and laboratory tests on the effect of intermittent air flow (gusts) on environmental heat and mass transfer were continued.

The absorption by plant material of beta-particles from radioactive sources was studied in the laboratory. Being a function of the water-content of a leaf, beta-absorption suggests the possibility of a portable and non-destructive tool for field-measurement of crop water content.

Work has begun on the microwave irradiation of nematodes. It is hoped that they (nematodes) may represent a suitable biological indicator to test for the controversial presence (or absence) of non-thermal radiation effects.

In-crop temperatures in corn were again observed, as described in the 1976 report.

21. Ministère des Richesses Naturelles du Québec - Service de la Météorologie

Le projet de connaissances intégrés a été poursuivi sur le bassin de la Yamaska et entrepris sur le bassin de la Rivière l'Assomption. Les aspects hydrométéorologiques de ce projet inclues les sujets suivants:

- caractéristiques générales du climat du bassin.
- date de la débâcle en fonction des degrés-jours de fonte.
- répartition spatiale de la pluie et de la neige.
- variations spatiales des valeurs hauteur, fréquence-durée des pluies.
- fréquences et variations saisonnières des hauteurs de pluie quotidienne.
- pluies maximales probables de 24 heures.
- périodes continues de pluie et de sécheresse.
- chute de neige saisonnière maximale possible.
- évapotranspiration potentielle moyenne.
- degrés-jours de fonte cumulés sur une base quotidienne.
- périodes de dégel durant l'hiver.
- estimation des hauteurs de neige au sol.

Une étude sur l'homogénéité des séries de données nivométriques et thermométriques est en voie d'exécution, dans le cadre de l'étude de rationalisation du réseau météorologique du Québec.

Une étude des besoins de stations météorologiques est effectuée en vue de la rationalisation des réseaux de précipitation (pluie et neige) et de température.

Les conditions climatologiques propices à la thermographie aéroportée des pertes de chaleur ont été investiguées et appliquées à un nouveau programme de prévisions reliées aux opérations de thermographie aéroportée.

On travaille actuellement à la mise au point d'un modèle de simulation du rayonnement solaire à partir de la durée d'ensoleillement.

On commence à appliquer les méthodes de cartographie automatique aux paramètres climatologiques, tels que l'ensoleillement, la température, la précipitation et autres.

On fait usage à cette fin d'une banque de données physiographiques dont on retient les variables suivantes: l'altitude, les coordonnées, la pente moyenne, l'azimut de cette dernière, pour des grilles de 10 x 10 km.

Un programme d'extraction automatique des pluviogrammes à l'aide d'un digimètre est en voie de développement.

Un projet expérimental a pour but de tester sur le terrain la possibilité de mesurer directement l'évapotranspiration réelle à l'aide d'un système simple de bacs placés dans les conditions naturelles.

Une étude donnant des statistiques décadaires de température et degrés-jours pour plusieurs seuils, et portant aussi sur la durée de la saison sans gel est en voie de parachèvement.

22. Université du Québec

(a) Programme

Chacune des trois constituantes (UQAM, UQAR et UQAC) a continuée d'accentuer sa recherche dans les voies qu'elles s'étaient tracées précédemment, soit: la météorologie urbaine (UQAM), la climatologie du Moyen-Nord (UQAC), la météorologie marine (UQAR).

Plus spécifiquement, l'UQAM est en voie de diversifier davantage sa recherche, tout en lui assurant un caractère appliqué. L'ensemble des projets de recherche peuvent se classer en deux catégories soit celle qui traite des précipitations (pluie et neige) et celle qui traite de la pollution urbaine.

A Rimouski (UQAR), on termine le traitement des données de la campagne de mesures effectuée sur le St-Laurent (été 77) en collaboration avec le SEA (Toronto). L'analyse des profils est déja terminée et les résultats sur le point d'être publiés. L'analyse spectrale est en partie réalisée. Toutefois, avant d'interpréter les résultats, nous avons cru nécessaire d'entreprendre une étude des performances des sondes BLIPS utilisées au cours de l'expérience. Cette étude d'intercomparaisons entre les sondes BLIPS et GILL est maintenant terminée. On se prépare maintenant à faire des calculs de flux à partir des données recueillies en été 1977. Finalement, nous projetons une prochaine campagne de mesures pour l'été 1979 dont les objectifs seront déterminés à la lumière des analyses déjà effectuées.

L'UQAC poursuit ses recherches dans le domaine de la micro-climatologie. Plus spécifiquement, elle continue l'étude du climat nordique en montagne et du micro-climat des serres. Mentionnons que l'équipe d'ingénierie sous la direction de M. C. Luan Phan qui étudie les problèmes de givrage des lignes de transport, a manifesté beaucoup de dynamisme et les résultats publiés en font preuve.

(b) Projets

(i) UQAM

Comportement du paramètre "C" dans le modèle de dispersion Gifford-Hanna (C. East et R. Gilbert).

Etude des niveaux d'ozone à Montréal (R. Catalfamo, R. Thivierge et Yves Guertin).

Couche limite urbaine (C. East et R. Thivierge).

Isotopes stables dans la précipitation (I. Zawadzki et R. Sarrazin).

Propriétés acoustiques de la neige (I. Zawadzki et A. Caillet).

Développement d'un distromètre (I. Zawadzki et R. Sarrazin).

(ii) *UQAC*

Adhésion de la glace (J. Druez, C.L. Phan et J.L. Laforte).

Arcs électriques sur les isolateurs en présence du givre et du verglas (C.L. Phan).

Vibration des conducteurs sous pluie (C.L. Phan, T. Adachi et A. Sevigny).

Collision des cristaux de glace en présence d'un champ électrique (C.L. Phan et P. Dinh-Van).

(iii) *UQAR*

Intercomparaison des sondes BLIPS et GILL (étude expérimentale) (J. Dionne et D. Lefaivre).

Analyse des profils de la CLA (expérience du St-Laurent, été 1977) (J. Dionne et L. Bilodeau).

Calculs de flux et analyse spectrale de séries chronologiques obtenues à niveaux élevés (expérience du St-Laurent) (J. Dionne et J. Boisvert).

Modèle numérique bi-dimensionnel de brise de mer avec injection d'une équation évolutive de l'épaisseur de la couche limite (J. Dionne et S. Massé).

23. Bedford Institute of Oceanography - Atlantic Oceanographic Laboratory

Buoy Technology (BIO, Dartmouth, N.S.) - The development of buoy technology in Canada has continued at Hermes Electronics Ltd., Dartmouth, N.S. through an expansion in commercial sales by the company and through further government R&D contracts. The main contract is called Phase III CODS. Earlier phases were reported in previous issues. The present contracts place more emphasis on sensor, data processing and system long-term (1 year) reliability and less on platform performance. Many of the buoy systems now utilize satellite communications. In addition to some laboratory and analytical work, the program is responsible for the deployment and monitoring of (1) a large (10-m diameter) meteorological buoy on Georges Bank, (2) medium size meteorological buoys in the Great Lakes, (3) fast drifters with thermistor chains which are transecting the North Pacific, (4) drifters with meteorological sensors deployed in Hudson Bay, (5) drogued drifters deployed in the North Pacific, (6) drifters with thermistor chains in the Gulf of St. Lawrence associated with the Ice Forecast, and (7) other small buoy systems meant for use in sheltered waters.

24. The 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 conditions and other weather-dependent environmental parameters. Emphasis is on applied research although some 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 phenomena 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*

Changes from the specifics reported in 1977 include the following.

Extensive tests were made of a 10-level hemispheric spectral model with parameterization of all physical effects, including boundary-layer fluxes and radiation. This was introduced as the standard operational forecast model for AES in December.

The non-linear normal mode initialization scheme was tested successfully in a multi-level spectral model with finite-element formulation in the vertical. Some success was also obtained with an experimental spectral model with finite-differencing in the vertical.

Several versions of a fully three-dimensional finite-element model with variable resolution underwent exhaustive testing with excellent results.

A four-dimensional data assimilation scheme for the transform grid of a 29-wave 12-level spectral model was tested and implemented into routine operation.

The data assimilation scheme was modified to permit global analyses in preparation for the Global Weather Experiment (formerly FGGE). Analysis and forecast tests were begun using DST6 and GATE data sets.

A scheme for the analysis and prediction of surface temperature was under development. In conjunction with this, routines were developed for the specification and updating of fields of ice cover, snow cover, sea-surface temperature, albedo, and soil moisture and heat conduction parameters.

The Beaufort regional prediction model was improved by changing from a Lagrangian to a Eulerian numerical formulation, incorporating an improved physics package, and including a model to predict the motion of oil slicks on open water away from coastal influences.

Development and testing of planetary boundary-layer models now involves work to operate a K-profile version in conjunction with one-dimensional higher-order turbulence versions operating at selected locations.

The Small Area Model for predicting surface winds has been applied operationally for a few specialized applications and is also being applied in an R & D context for developing a methodology for selecting suitable sites for wind-powered generating stations.

Physical-statistical procedures for automated prediction of weather elements received greater emphasis than in the past. The statistical procedures use physically significant meteorological and geophysical parameters. Production has begun on a data base consisting of 10 years of data (observed, analysed and derived parameters) for 91 major sites in Canada.

Testing has been completed on the three-dimensional trajectory model. Comparison of 24-h trajectory and hemispheric spectral model forecasts of temperature and dew-point profiles show the trajectory technique to be satisfactory for weather element prediction in the lowest levels of the troposphere, but NWP models are superior at middle and higher levels.

Several R&D projects have been undertaken jointly by Meteorological Services Research Branch and Regional Weather Centres. Projects that are currently active include: programming and operational evaluation of a model to predict snow squalls induced by water bodies; studies on probability of precipitation with applications to agriculture, and prediction of areas likely to experience severe convective storms and associated high winds, hail and heavy precipitation.

New equipment has been installed at Toronto and Edmonton to acquire data from the Advanced Very High Resolution Radiometer (A/VHRR) on the Tiros-N series of spacecraft. The lower orbit of the TIROS-N spacecraft will require an additional station to obtain A/VHRR coverage of the high Arctic. Work has begun to evaluate operational applications of radiance data from the Tiros Observational Vertical Sounding (TOVS) system.

The Satellite Data Laboratory is now acquiring both visual and infrared imagery direct from the GOES-EAST geostationary weather satellite positioned above the equator at Longitude 75° West. Visual Infrared Spin Scan Radiometer (VISSR) data are processed and sectorized to produce 4 sectors simultaneously at resolutions which can be varied from 2 to 8-km resolution. VISSR data processing provides a visual and an infrared image of each sector every half hour during the daylight hours and an infrared sector during the nighttime hours. It is planned to distribute 4 sectors in real-time to Halifax, Montreal, Toronto and Winnipeg via dedicated facsimile circuits. The processing system produces a fifth sector on magnetic tape which is used for research applications.

The Satellite Data Laboratory has developed and is operating an image analysis system which is designed for research and has the capability to display data as visual and infrared images from the VISSR or A/VHRR system in colour or black and white at any suitable scale on a TV monitor. It is being used to study storm tracking, ice mapping, and to correlate radar and satellite imagery to develop an automated short-range prediction system. Limited areas of the satellite image, compared with detailed ground-truth rainfall data in the range of the radars will be extrapolated to give indications of

rain over the larger area of the satellite image. Data tapes are also being provided to other sections of AES to show water-surface temperature contours for major lakes where such information is required for hydrometeorology projects. Results indicate water-surface temperatures (corrected for atmospheric absorption) can be derived with a degree of accuracy approaching $\pm$ 1°C.

(b) Atmospheric Processes Research Branch

(i) *Cloud Physics Research Division*

Cloud Physics/Weather Modification Program - This joint program, in cooperation with the National Aeronautical Establishment, continued to assess the potential of rainfall enhancement as a means of suppressing large forest fires. Another four-week experiment, based at Thunder Bay, was undertaken using 3 aircraft. (A full description can be found in previous Bulletins.) Data analysis of the 1977 field experiment was completed and reports written.

Cloud Modelling - Further work on a more sophisticated model is continuing beyond that described previously.

Radar Meteorology - Weather radar data continues to be archived on magnetic tapes 5 days/week during significant weather periods as a data base for case studies; radar echo displays are also generated and transmitted to operational users in real-time. A program of hardware/software development and improvement continues, e.g., greater integrity to record by measuring antenna and power variations, new CRT display, greater versatility in program selection and processing, fast playback.

Studies continue on the variation of reflectivity factors, rainfall notes and drop distributions at point locations and their relationship with synoptic and geographic influences. Raindrop distributions are measured with a Joss spectrometer and PMS airborne systems. An integrated display of sferics and radar echoes was developed as an operational aid for severe storm identification in the study of precipitation-lightning interrelationships.

(ii) *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.

Results of the NASA intercomparison of the STRATOPROBE and University of Michigan payloads, which was carried out at Palestine, Texas in December 1977, were reported at the WMO Symposium on "Geophysical Aspects and Consequences of Changes in the Composition of the Stratosphere" which was organized by the Atmospheric Environment Service and hosted by York University.

In February, a joint experiment with York University was flown at Cold Lake, Alberta to further study the winter chemistry of the ozone layer.

In October and November, two flights of the STRATOPROBE payload were flown at the National Scientific Balloon Facility in Palestine, Texas. These flights were intended to obtain "ground truth" measurements in conjunction with the LIMS and SAMS experiments on the NIMBUS VII satellite. The measurements included HNO_3, NO_2, NO, O_3, H_2O and CH_4.

Daily surface-based measurements of total atmospheric ozone, made with the Dobson ozone spectrophotometer, continue at Churchill, Edmonton, Goose, Resolute and Toronto. The vertical ozone profile from the surface to 30 km is measured by balloon sounding with electrochemical sondes each Wednesday at the first four of the stations.

Observational testing of the new ozone network spectrophotometer is continuing. The new commercial instrument, manufactured by SED Systems Ltd., is being compared with the Dobson instrument and its performance is being evaluated. A second instrument has been delivered and will be sent to NASA at Wallops Island for intercomparison testing with the New Zealand and Russian instruments.

Theoretical simulations of the constituent data sets from the STRATOPROBE flights are being carried out in collaboration with York University. Comparisons indicate that hydroxyl densities in the 15 to 30 km region are smaller than current models predict. The consequences of low hydroxyl densities on ozone depletion by CFMs have been evaluated with a scenario model. The depletion of ozone by freons at the 1973 usage rate is much smaller than predicted by models with current photochemistry.

(c) Air Quality and Inter-Environmental Research Branch

(i) *Long-range Transport of Air Pollutants (LRTAP)*

In response to recognized environmental concerns in eastern Canada, a research team has been investigating sources, transport mechanisms and sinks of pollutants carried for long distances in the atmosphere, often across political boundaries. In particular, the group: documented an emissions inventory for SO_x and NO_x; tested and refined air parcel trajectory and concentration-deposition models (wet and dry); prepared a regional sulphur budget; and integrated data received from fully operational air quality networks, including CANSAP to verify models and experiments. Future activities will be reported through a special publication series.

(ii) *Environmental Assessment*

An intensive, integrated Canada/Ontario air quality investigation of the Nanticoke region industrial complex took place over 16 consecutive days in June. A well-developed lake breeze bringing frequent on-shore flows of stable air having high potential for trapping pollutants emitted by lakeshore industrial stacks received particular attention. Atmospheric structure, air constituents and plume dispersion were measured by stationary and mobile facilities including high technology correlation spectrometers (COSPEC), light intensity detection and ranging (LIDAR), acoustic sounders, sonic anemometers, minisondes, and sensor-equipped helicopters for vertical probing to 500 m. Measurements and air samples were analysed by field laboratories, and results are being reviewed for publication.

(iii) *Alberta Oil Sands Environmental Research Program (AOSERP)*

During the year analysis of data collected in the 1977 field experiments were completed and reports submitted to the Program Management. These included studies of the concentrations and deposition rates of sixteen elements including sulphur and a number of heavy metals measured by a network of 15 collectors and by snowpack chemical analysis. All concentrations were found to be

within commonly acceptable 24-h standards. An evaluation of numerical models suitable for the regional prediction of dispersion and deposition of pollutants was completed. Having fulfilled its mandate to research and assess the effects of the air quality of the oil sands development, the AES will withdraw from the program by April 1979.

(iv) *Environmental Contaminants*

A two-year study of sources, dispersion and sinks of organic pollutants, having possible carcinogenic effects or widespread persistence, is underway. These include polychlorinated biphenyls (PCB's), hexachlorobenzene and benzo (a) pyrene. The measurement and techniques of analysis of ambient atmospheric mercury in various chemical forms are receiving priority attention in view of widespread reports of concentrations in fish and plant life. Metal loadings of arctic vegetation are being analysed while linkages with atmospheric transport and deposition processes remain to be quantified.

(v) *Environmental Monitoring*

The Canadian Network for Sampling Precipitation came into full operation with 50 stations providing precipitation pH and turbidity data. A 12-station sub-network, operated in conjunction with EMS-IWD, measures organic constituents; the data are archived by NAQUADAT.

In cooperation with NRC and the University of Toronto the 557-m CN Tower was instrumented to measure vertical temperature and wind profiles and higher elevation pollutant concentrations (NO_x, SO_x, O_3). Such data will assist a current study of oxidants in Toronto where ground-level O_3 values have exceeded 150 ppb on several occasions.

(vi) *Measurement Techniques and Systems*

To aid in distinguishing particulate characteristics in urban/industrial aerosols a polar nephalometer capable of measuring Mie light scattering has been developed. A multi-wavelength sunphotometer was built for use in the WMO turbidity program. This wholly Canadian instrument could conceivably replace existing network sunphotometers.

(vii) *Boundary-Layer Research*

In 1978 three major field studies were conducted using the Division's tethersonde and acoustic sounder facilities. The most extensive was the six-week measurement program conducted over the snow and ice-covered surface of Lake Simcoe. A data report is available and the data analysis is underway. A second cold weather experiment was carried out in cooperation with AES Pacific Region to investigate the characteristics of strong inversions along the route of the Alcan Pipeline. The data from the 1977 study at Beaver Creek suggest that the valley inversion is radiationally driven, with isothermal conditions existing during heavy overcast, and strong surface-based inversions (20°C/100 m) during clear conditions. Layering of winds within the valley during inversion conditions were evident. The third field project was a contribution to the Nanticoke Environmental Study.

Numerical model development has continued on three fronts. The mesoscale model has been expanded and tested on changes in roughness and elevation. A series of numerical models of airflow

above gentle topography combined with changes in surface roughness have been developed for surface and planetary boundary-layer flows. To date these have been restricted to two-dimensional (x, z) and neutral stratification cases. Theoretical and numerical studies of the decay of wakes behind hills and other surface mounted obstacles in atmospheric boundary layers have also been undertaken.

A Monte Carlo type pollution transport-turbulent dispersion numerical model has been developed. Application to cases of vertical dispersion in the atmospheric surface layer showed good quantitative agreement with observations in the literature. The model was modified and applied to provide numerical estimates of pesticide spray transport, turbulent dispersion, evaporation and deposition. This application was part of a task force environmental study of impacts of pesticide spraying for spruce budworm infestation in New Brunswick.

Other activities in 1978 included extending the method for determining boundary-layer parameters from limited profile data and further analysis of GATE radiation data. Similarity theory has been applied to the problem of predicting maximum ground level concentration in a freely convective boundary layer, which has led to interesting results. Further work has also been done on the use of acoustic sounders to monitor the diffusivity in stable boundary layers. A two-week field experiment to measure surface fluxes of heat in support of Ontario Ministry of Environment studies was conducted near Sudbury in June.

(viii) *Spruce Budworm Project*

Studies on the airflow pattern over New Brunswick, particularly mesoscale convergence lines, during the period of spruce budworm moth dispersal were continued. In view of the 1977 results which indicated that significant sea-breeze frontal incursions from the east coast were nearly as frequent as those from the Fundy coast, additional surface and upper air observing stations were established in eastern New Brunswick.

(ix) *Biometeorological Projects*

Testing of a new insulated sunken evaporation pan was continued and a report was prepared for the World Meteorological Organization comparing the performance of this new pan with a number of standard evaporation pans using data collected in a number of countries.

A mesometeorological study relating airflow patterns across southwestern Ontario to local ambient ozone concentrations and the resulting injury to white beans was initiated in cooperation with the University of Guelph.

(x) *Hydrometeorological and Environmental Impact Research*

Hydrometeorological basin research is being conducted at a number of basins as part of the National Basin Program and comprises both in-house and contracted research. Projects include the spatial analysis of meteorological parameters, in particular temperature, rain and snowfall, the influence of land use on snow-cover characteristics and large- and small-scale water-balance modelling. The snowfall measurement program was expanded with the addition of a high Arctic site at Resolute, N.W.T. Several operational hydrological models are being studied with the view to incorporating results of ongoing research programs.

The capability was developed for real-time measurement and analysis of sensible heat, latent heat and momentum fluxes using the eddy-correlation technique over various surfaces including open water. The system was used to obtain sensible heat flux during the Nanticoke Environmental Study in June, 1978.

The branch is cooperating with OAS in an Arctic experiment to study the heat budget of semi-persistent open water areas called Polynyas. A feasibility study was conducted in April at the field site north of Cornwallis Island near 76°N and 94°W. Major field trips are planned for the springs of 1979 and 1980.

Research into hydrometeorological aspects of remote sensing continues with the participation in the Canadian Surveillance Satellite project. Satellite and aircraft microwave imagery will be used to study seasonal snow-cover properties and the variations associated with land-use during periods of accumulation and ablation.

(d) Canadian Climate Centre

Early in 1978 the Atmospheric Environment Service established a new Canadian Climate Centre bringing together various components of the Meteorological Applications Branch and the Atmospheric Processes Research Branch under one organization. The objectives of the new AES venture are to bring into focus Canadian activities related to climate; to provide an effective and efficient climate service; to improve our understanding of the climate system; to develop the ability to forecast climate on a monthly, seasonal, annual and longer period basis; to understand and predict the effects of man on climate, and to better understand and improve the ability to predict the impact of climate on human activities, the economy and the environment.

(i) *Numerical Modelling Division*

General circulation modelling - Extensive analysis of an early January simulation with the five-level general circulation model (GCM) has resulted in considerable improvement to the model. As a result, a new January simulation has been completed and analysed.

Physical processes following a formulation by Mintz and Arakawa have been added to a two-level spectral GCM. This model runs very efficiently. A January simulation has been performed and is being analysed.

Diagnostics - Diagnostic capability continued to be improved. Some existing routines were modified to increase their accuracy and utility and many new routines were added. Several new programs provide diagnostics in the wavenumber domain. These programs are being applied both to model output and to data.

Data studies - A study of climatic variability was completed. Despite the often-quoted suggestion that climate has become more variable in recent years a careful study of the data has reversed our earlier impression and has offered little support for this contention.

Two-dimensional modelling studies of the stratosphere - Taking into account recent advances in stratospheric chemistry, the previously developed stratospheric model was used to determine the possible impact of anthropogenic sources of freons, NO_x, N_2O, and CO_2 on stratospheric ozone and its climate. Efforts are now being made to extend the radiative-photochemical transport models to the earth's surface to assess the possible influences of anthropogenic effects on climate at the earth's surface.

Other activities - The Division organized and hosted a "Canadian Climate Modelling Workshop", April 24-26, 1978, as part of its activities in the climate area.

(ii) *Archiving and Quality Control Division*

The system for selecting and processing data directly from teletype circuits was extended to upper air data. All data handling systems have been adapted to handle SI units. The charts showing various observational networks in Meteorological Stations in Canada (METSTAT) were completely revised.

Number of Climatological Stations in Canada

December 1978

Principal climatological	315	Soil temperature	68
Ordinary climatological	2263	Evaporation	141
Synoptics	242	Bright sunshine	311
Hourly weather - 24-h	157	Upper air	36
Daily extremes of temperature	2082	Automatic stations	36
Daily precipitation	2478	Radiation	53
Rate of rainfall	512		

Over the past year there has been a slight decrease in the number of observing stations. In 1978 financial restrictions have limited the increase in radiation stations to five or less. Prospects for increases in other climatological stations over the next few years depend chiefly on the development of automatic stations.

(iii) *Climatological Services Division*

Demands for climatological data and services continued to grow during 1973, with more than 11,000 requests for routine climatological information, and more than 300 enquiries for data from the digital archive. More than 3900 pages of historical data were published in regular periodicals during 1978, and close to 800,000 frames of climatic data were placed on microfiche during the year, including all radiation data abstracts for 62 Canadian stations.

The Monthly Record of Meteorological Observations is now published in three parts: Western Canada, Northern Canada and Eastern Canada. Tables are presented in fully bilingual format and, in most instances, in metric units. The contents of the Monthly Record have been revised. Data on daily rainfall and snowfall, mean daily temperature and a monthly summary of "the number of days with" for several meteorological parameters have been added.

In order to conform to the policies on metric conversion established by the government of Canada it was necessary to commence conversion of the National Archives of climatological data to metric units. At the same time and, as resources permit, the archives are being reformatted into a tape format which is compatible with any high level computer language. The existing archives were organized by observational program and each record type has its own unique format. The new archives will include three record formats (hourly, daily and monthly) and will be identified by element number.

(iv) *Climatological Impacts Division*

In response to the increasing demand for meteorological information pertaining to renewable energy resources a number of projects were initiated. With regard to solar energy efforts were undertaken to expand the radiation data base using hourly weather observations to determine optimum collector angle and azimuth to evaluate techniques for the estimation of solar radiation using satellite data and to correlate energy demand (heating requirements) and solar energy. In the area of wind energy potential a project to standardize archived wind data to an anemometer height of 10 m was commenced.

Investigations to determine the impact of climatic variability on agriculture and forestry continued. Among active projects were the production of a Handbook on Agricultural and Forest Meteorology, a study of blocking situations during the past 30 years in the Northern Hemisphere, a statistical study of atmospheric mean monthly temperatures and monthly total precipitation for Toronto, as well as studies of the local growing season and frost-free season and phenological observations.

The applications of climatology in bio-physical land classification, environmental and urban planning were examined by three national workshops in 1978. The impacts of climate on Ontario environment, society and economy, were studied cooperatively with the province. Reports on regional climate for outdoor recreational activities in several areas were completed.

A study of the climatology of the Arctic Islands and adjacent waters was completed as a two-volume study. The report emphasizes probability estimates of temperature, wind and precipitation, as well as the duration of critical weather types. Energy exchange, wind chill, blizzards, sea state, sea ice, temperature inversions and typical synoptic patterns were also studied. An Arctic climate impact study is in progress to investigate month to month changes of temperature and wind during the last twenty years, as well as the effects of such weather parameters as wind waves, freezing spray and wind chill on personnel and metals.

(v) *Hydrometeorology Division*

A final report was completed for the World Weather Watch Project on the Saint John River Basin, by the United States/Canada Task Force Committee. Spinoffs from this pilot project included further developments in precipitation network planning. A catalogue of meteorological data from all Canadian IHD research basin projects was compiled for the National Basin Program. A program to process and map the weekly national water-budget components in near real-time was implemented on an experimental basis. The Division continued to play a lead role in an international assistance (CIDA) project in South America by providing direction for the project team and training in flood forecasting for Fellows sent to Canada.

A program was developed to extract surface water temperatures from satellite infrared data and display them in map format utilizing both automated and manual procedures. The program, developed for the Great Lakes, was applied initially to Lake Winnipeg and the Bay of Fundy. Work commenced on the climatology of surface water temperatures of the Great Lakes using data acquired in airborne radiometer surveys since 1966. Projects were initiated to study the effect of precipitation on water levels of the Great Lakes, and to produce a Great Lakes wave climatology and a climatology of the Labrador Sea.

An interactive program was developed to produce computer-enhanced snow-cover analyses from satellite imagery for the Saint John River Basin. Four of the five SCEPTRE radars started recording quantitative precipitation radar data on magnetic tape. The Northern Ontario Water Resources Survey network of 16 Fischer and Porter precipitation gauges was closed in June 1978 after the collection of over ten years of observations. Preliminary results have been obtained from a project to examine the time distribution of precipitation in one-hour and twelve-hour storms at thirty-five locations across Canada.

(e) Central Services Directorate

(i) *Ice Branch*

The ice observing program maintained the high level of activity of previous years, both in the Great Lakes, Gulf, Newfoundland areas and in the Arctic. Several ice reconnaissance missions, partly funded by industry, were flown in the Arctic during the winter dark months using Sideways-looking Airborne Radar, to acquire some winter-time baseline data for the Arctic. Increasing amounts of near real-time satellite data, both NOAA and LANDSAT imagery, were incorporated into the ice chart and ice forecast products provided to support marine navigation, fishing and offshore drilling operations. Regular Seasonal Outlooks, one for the forecast break-up pattern for northern Canadian waters, and one for the freeze-up and severity of the winter in the Gulf of St. Lawrence and Newfoundland waters, were published during the year. Long-range ice forecast support, including forecast freeze-up dates, was provided for the offshore drilling activities in the Beaufort Sea during the summer. Work on production of an Eastern Canadian Seaboard ice atlas had reached the point where printing should be done in 1979. Write-up and chart preparation for the Arctic ice atlas were also under way, at year's end.

(ii) *Network Standards Division*

Metrication of existing Observational Systems Manuals was completed during the year with the publication of "Evaporation", "Soil Temperature" and "Abstracting Recorded Precipitation". A revised edition of the "Manual of Climatological Observations" was published and a long-standing requirement for a uniform set of tables for barometer comparisons was satisfied with the production of the publication "Temperature Correction Tables - AES Mercury Barometers". Instructions and reporting forms were prepared for a new marine program - "Sea-Surface Current Observations". Additional chapters were added to the "Data Acquisition Reference Manual, Planning of Meteorological Observational Networks" (METNET) including snow survey courses, soil temperature and moisture, air quality, wind, RVR and DADS. Several other chapters were amended. The Division was deeply involved in the testing of the pre-production models of the Automatic Data Reduction System (ADRES) - computer based equipment which will automate procedures for obtaining upper-air data.

25. Canadian Forestry Service - National Forestry Institutes - Chalk River

The past year has seen a major change in the research program in the Canadian Forestry Service. Three research establishments, the Petawawa Forest Experiment Station, the Forest Fire Research Institute and the Forest Management Institute have been amalgamated, reduced in staff and reestablished as the National Forestry Institute - Chalk River. The meteorology program, formerly located in the Forest Fire Research Institute will likely be

broadened in scope to include all of forestry. Final decisions as to its size and its level of funding have yet to be decided. The current research programs can be summarized as follows:

(a) Remote Weather Station for use in Forestry

A remote weather station communicating via the GOES satellite has been designed and is currently under construction by Hermes Limited of Halifax. The first model is expected to be completed in April, 1979. The station measures temperature at two levels, relative humidity, wind speed and direction, rainfall, and cloud to ground lightning within 32 km. It is intended for operation during the seven warm months of the year. It reports hourly in meteorological units and has a local readout capability.

(b) Rainfall from Satellite Measurements

Work is progressing in the use of NOAA-5, TIROS-N and GOES data to estimate the location and intensity of precipitation in remote forested areas. The accurate location of the images constitutes a major problem.

(c) Blowdown

Blowdown by the June 27, 1978, Masson, Québec tornado is being used to infer the wind speed and direction as the tornado moved over very rough terrain. Both the structure of the tornado and the effect of wind on forest trees are being studied.

(d) Forest Energy Budget

Work continues on the estimation of the rate of drying of forest litter through measurement of the energy balance in a forest.

(e) International Grid Index

The development of an International Grid Index will make a uniform method of locating geographical reference points indexed to standard EMR maps.

(f) Fire Weather Index

Work continues on the improvement of the fire weather index.

(g) Fire Ecology from LANDSAT Imagery

A project to determine the age, species and density of forest regrowth after fire is temporarily in suspension.

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VII OCEANOGRAPHY

Compiled by: Paul H. LeBlond

1. Introduction

This year again, the oceanography report concentrates on research on physical oceanography, although some coverage is given to chemical, geological and geophysical investigations. Only the activities of universities and government research institutions are reported; the problem of gathering together the work done by the growing private sector presents problems which this author has not had the audacity to tackle. Gaps found in last year's reports have been filled and a new section, on recent theses, has been added to the bibliography.

2. Memorial University: Centre for Cold Ocean Resources Engineering

Most of the research undertaken by the Centre for Cold Ocean Resources Engineering (C-CORE) is concerned with marine ice in its many forms, its detection, measurement, and effects on marine operations. Individual projects involve remote sensing of sea ice and icebergs by radar (J.R. Rossiter) or satellite imagery (E. Wedler), measurements of ice properties by developing creepmeters (A. Allan) and strainmeters (K. Butt) and by remote sensing (J. Rossiter). Studies of iceberg bottom scouring on the Labrador coast (E. Wedler, A. Gustajtis) and of ice distribution and characterization in the Labrador offshore area and the Labrador Sea continue to receive attention (A. Gustajtis, W. Winsor).

Many projects involve hazards to petroleum drilling operations at sea and consequent dangers of oil spills. In collaboration with the Canadian Coast Guard, the FRAMO oil skimmer has been tested in actual field conditions. Oil spill scenarios for the Labrador Sea have been formulated by B.R. LeDrew and A. Gustajtis. Work has continued, led by S.K. Parashar, in the study of the use of microwave systems in detecting and monitoring oil slicks over ice and in ice-infested waters.

3. Dalhousie University: Institute of Oceanography

(a) Physical Oceanography

Tidal problems, both from a general point of view and in particular problems concerning tides in the Bay of Fundy and their possible modification by tidal power plants, continue to receive considerable attention. A study of the 18.6-year modulation of the diurnal and semi-diurnal lunar tides through its effect on tidal mixing in shallow

seas has revealed some evidence of the nodal cycle in sea surface temperature variations at some North American locations (J.W. Loder and C. Garrett). The influence of tidal mixing was compared to that of thermal stratification by examining hydrographic data from the Bay of Fundy and the Gulf of Maine and using estimates of tidal velocities from a numerical model (C. Garrett, Keeley and D. Greenberg); predictions were made of the changes in extent of well mixed areas that would be caused by tidal power development.

Studies of the region of contact between Warm Slope Water and Labrador Slope Water masses off Nova Scotia and of their interleaving at depth has been studied by E. Horne. Further studies of frontal circulation due to cabelling and double diffusion have been pursued by C. Garrett and E. Horne. On a much smaller scale, the influence of tidal mixing and the penetration of flood tide intrusions have been studied in a small embayment, Little Narrows Pond (J.R. Birch).

Studies of air-sea interaction, and more specifically of the theory of energy transfer by the wind to the surface mixed layer, have been completed by J. Richman and C. Garrett.

R.L. Blackford (of the Department of Physics, at Dalhousie) has worked a theory to account for some of the features of internal tide generation over a sill. The theory predicts internal wave generation at twice the tidal frequency as well as at the forcing frequency itself. Applications are presented to the St. Lawrence-Saguenay River junction and to Glacier Bay, Alaska. The same author has also completed a study of wind-driven inertial currents in the Magdalen Shallows, in the Gulf of St. Lawrence.

Studies of nearshore wave behaviour and of the influence of waves and longshore currents have continued. On the basis of time series of shoreline run-up on two natural beaches, it has been suggested by Huntley et al. that, for the frequency band over which incident waves are large enough to break, a universal saturation form for the vertical run-up spectrum occurs. The theory of resonant interactions between edge waves and surf has been compared by A.J. Bowen and R.T. Guza to laboratory experiments; the results strongly suggest that surf beat (the low frequency modulation of incoming surf) is predominantly an edge wave phenomenon. In a more descriptive vein, E.H. Owens and A.J. Bowen have presented a review of coastal environments in the Maritime Provinces, providing a survey of coastal processes and morphology characteristics of beaches and shore areas in that region.

(b) Chemical Oceanography

A number of previously reported on-going projects have now been completed as graduate theses. A.V. Hincks analyzed the role of seaweeds as a source of dissolved organic compounds within the framework of a carbohydrate budget of Sandy Cove, N.S. R. Zika has completed a study of photoreactions in seawater. K.G. Sellner has presented a thesis on primary production and the flux of dissolved saccharides and dissolved primary amines in several marine environments. B.D. Johnson has completed a thesis on the role of bubbles on gas exchange and particle production in coastal waters. M. Hartwell has carried out work on the binding of transition metals by organic ligands and the effect of classical elutriate tests performed by environmental protection groups and other agencies.

Work on the role of particulate matter in the productivity of ocean waters and studies of nutrient regeneration by bacteria have been completed by P. Wangersky. A voluminous review of the whole topic of the production of organic matter in the ocean has also been prepared by P. Wangersky and has appeared in Vol. 4 of Marine Ecology (O. Kinne, Ed.).

(c) Geological-Geophysical Oceanography

Work by P.E. Kepkay on the role of free gas as a sub-bottom acoustic reflector in the fine-grained sediments of Halifax Harbour and St. Margaret's Bay has been completed as an M.Sc. thesis. D. Stow and A.J. Bowen have presented a quantitative model of lamination of deep-sea fine-grained sediments based on a mechanism of depositional sorting by increased shear at the base of the boundary layer. A number of other problems in sedimentology are being investigated by D. Piper.

Among the problems of lithospheric rheology under study by C. Beaumont and his students and colleagues, one may mention the results that they have obtained from improved ocean tide models in calculating tidal loading in Nova Scotia. Further studies of tidal loading and its relation to the crustal structure under Nova Scotia are underway. The theory of the response of a viscoelastic lithosphere has also been developed and applied to the Nova Scotia area.

4. Université du Québec à Rimouski: Section Océanographique

Les programmes de recherches de la Section Océanographique de l'Université du Québec à Rimouski (SOUQAR) continuent à se pencher sur divers aspects des processus physiques, chimiques et biologiques qui déterminent les conditions océanographiques de l'estuaire et du golfe du St-Laurent. On distingue quatre grands programmes de recherches:

(a) Etude de la couche limite atmosphérique et interaction air-mer

Ce programme est décrit sous la rubrique "météorologie" de ce bulletin.

(b) Processus physiques et biologiques dans l'estuaire et le golfe du St-Laurent

Ce programme comprend des études à long terme de la circulation de l'estuaire maritime du St-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 échantillonage 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 St-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.

(c) Biogéochimie de la phase solide dans l'estuaire du St-Laurent

On trouve groupées dans ce programme des études de la zone de turbidité maximale de l'estuaire supérieur du St-Laurent: composition chimique de la matière particulaire (B. Sundby et al.), transport et dépot du seston (B. Sunby et N. Silverberg). La sédimentologie de la région de Rimouski a été étudiée par N. Silverberg et al. en collaboration avec G. Drapeau de l'INRS. La géochimie des sédiments, et en particulier la teneur en soufre, a été étudiée par A. Ouellet et B. Sundby dans le Chenal Laurentien et le Fjord du Saguenay. J. Lebel et E. Pelletier ont mesuré les concentrations de bore inorganique et la teneur en carbonate des eaux de l'estuaire moyen du St-Laurent. Enfin, B. Sundby, N. Silverberg et

J. Lebel ont développé un nouveau programme d'étude de la couche limite benthique portant sur les relations biogéochimique des eaux, organismes et sédiments.

(d) Molysmologie estuarienne

Les travaux groupés sous ce titre (μολνσμος = souillure) portent sur des problèmes de pollution et d'impact écologique: distribution de matières azotées sur la radiale de Rimouski (J.R. Brindle et al.); étude de l'impact écologique d'un port de mer à Cap Dauphin, et autres travaux de nature plus biologique.

Quelques projets indépendants des quatre programmes ci-haut incluent une analyse statistique multidimensionelle des spectres de taille des particules en suspension (J.-P. Chanut); des mesures de distribution de métaux en traces dans l'eau et de leur influence biologique (J. Dubé et D. Cossa), et quelques autres projets plus apparentés à la biologie marine.

5. Groupe Interuniversitaire de Recherches Océanographiques du Québec

Les activités du Groupe Interuniversitaire de Recherches Océanographiques du Québec (GIROQ) ayant rapport à l'océanographie physique ou géologique sont décrites au paragraphe suivant, où sont regroupés les travaux d'un des membres du GIROQ, le Centre des Sciences de la Mer de l'Université McGill.

6. McGill University: Marine Sciences Centre

(a) Physical Oceanography - R.G. Ingram

During the past year, research has focussed on three geographically unconnected estuaries: the St. Lawrence River, the Great Whale River (on the southeast coast of Hudson Bay) and Rupert Bay (located off James Bay).

In the St. Lawrence, long term moorings and thermistor chains were completed in the Trois Pistoles - Manicouagan region to determine the fluctuations of the internal tide and intermediate cold layer and to estimate the mean flow along both the northern and southern coasts of the estuary. Moorings were also completed at the mouth of the Saguenay fjord to determine bottom water intrusion. Studies of tides and fluxes of suspended matters were undertaken (with B. d'Anglejan) in Baie Ste Anne and Rivière Ouelle.

Work in the Great Whale River consisted of numerous current moorings and profiles during the winter of 1978 to determine the influence of complete ice cover on tidal propagation, mean circulation and T-S properties. In Rupert Bay, a survey of suspended matter, water mass and circulation was completed at four stations for 13-hour periods.

(b) Geological Oceanography - B. d'Anglejan

Instrumental development and field trials were undertaken to monitor suspended particulate matter characteristics in the epibenthic layer of the St. Lawrence estuary. Detailed work was carried in and around the turbid plume which advects the turbidity downstream over the South Channel of the St. Lawrence. More detailed measurements were made on the Baie Ste Anne-Rivière Ouelle subtidal platform. Studies of the sedimentation regime of Rupert Bay were also carried out.

(c) Ice Research - E.R. Pounder and M.P. Langleben

Measurements of tides and water properties were made in 1977 and 1978 from a camp on the ice in Barrow Strait at a number of locations. The information will be used to prepare a summary of the tidal current regime in the Barrow Strait area.

7. University of British Columbia: Institute of Oceanography

(a) Physical Oceanography

Estuarine studies now focus on the description and understanding of the Fraser River plume and associated circulation in the Strait of Georgia. S. Pond has been refining radar-tracking techniques of free drogues, putting drogues at many levels and simplifying the data analysis; two trial cruises have been made in the Fraser River plume and further work is planned. W.J. Emery is proposing to instrument some of the ferries which ply the Strait of Georgia with thermo-salinometers in addition to collect data with the help of "boats-of-opportunity"; combined with LANDSAT imagery of the Strait of Georgia it is hoped that these data will improve the space-time description of the plume. J. Stronach has continued his work on a numerical model of the upper layer, refining the grid and performing sensitivity tests with respect to various parameters.

Air-sea interaction studies (R.W. Burling and S. Pond) have foccussed on the measurement of the drag coefficient at high wind speeds. The instrumentation package developed to measure momentum flux by the dissipation method has been found to give results which agree well with those found by direct measurements; the package has been exposed to high winds at Station PAPA and in the JAIN 1978 experiment, in which W. Large took part. An examination of data from all Atlantic weatherships and stations N and P in the Pacific has been performed (R. Marsden) to see how the bulk aerodynamic parameterizations need to be modified in order to estimate fluxes from climatological or synoptic data. Participation in the Mixed Layer Experiment (MILE) by M. Miyake and R.W. Burling has taken the form of XBT's and Aircraft XBT surveys over an area south of Adak, Alaska.

W.J. Emery has analyzed multi-ship XBT swaths across the Atlantic and compared the data with 7 POLYMODE XBT surveys to identify the eddies in each by their three-dimensional structure. Preliminary results indicate that the POLYMODE is relatively poor in eddies. In conjunction with J. Dugan of the U.S. Naval Research Lab and E. Harrison of M.I.T., a series of statistical computations are being performed to develop an objective criterion for the identification of mesoscale eddies from single sections.

For the second year, thermal sections across the Antarctic Circumpolar Current have been collected by supply vessels. W.J. Emery plans to use these data along with simultaneous observations of surface meteorological parameters to carry out a study of the heat budget of the Southern Ocean.

Studies of tides in shallow rivers (P.H. LeBlond) has shown that frictional forces exceed accelerations over most of the tidal cycle and that tidal propagation is more properly pictured as a diffusive than as a wave phenomenon. Application to the Fraser and the St. Lawrence explained the long time lags observed at low water, unaccountable by a simple wave propagation model. An extension of these ideas to the fortnightly tidal modulation in the St. Lawrence accounts for the main features of the forced fortnightly sea level modulation in that river.

L.A. Mysak has developed the theory of equatorial topographic waves for a fluid of uniform density and is now extending this work to the stratified case. The propagation of shelf and Rossby waves in the presence of randomly varying currents is being examined by L.A. Mysak and J. Helbig. The diffraction of shelf waves by a coastal barrier, such as is formed by Brooks Peninsula on the coast of Vancouver Island, has been studied by A.M. Davis and L.A. Mysak. Low frequency currents have been investigated in the Strait of Georgia, in terms of a long topographic wave

model in a two layer fluid. D. Wright has completed a Ph.D. thesis on mixed baroclinic-barotropic instability with applications to the Strait of Juan de Fuca. The stability of coastal currents, both baroclinic and barotropic is also under study by L.A. Mysak and E.R. Johnson.

Research on ocean turbulence, and more specifically on the measurement and interpretation of small-scale velocity fluctuations, continues to be carried out by T.R. Osborn. Measurements taken in the Atlantic Equatorial Undercurrent with W.R. Crawford are soon to appear. Design work continues on airfoil velocity probes and on its application to the study of turbulent dissipation in the ocean. Closer to home, studies of the horizontal extent of microstructure have been carried out in Howe Sound with L. Bilodeau. In addition, a fundamental study of the time response of heated sensors to temperature and velocity fluctuations is nearing completion (with R. Lueck).

(b) Chemical Oceanography

Chemical studies are being conducted by E.V. Grill of sediments collected from Explorer and Juan de Fuca Ridges, high heat flow areas near the west coast of Vancouver Island, which are presumably sea-floor spreading centres. The data available so far indicate that the trace metal content of these sediments is generally lower that that of Pacific pelagic clays. However, some near surface sediments, particularly on Juan de Fuca Ridge, show a marked enrichment in Mn, Cu, Zn, and to a lesser degree, Fe.

With S. de Mora, E. Grill is also studying the estuarine chemistry of Mn; detailed field and laboratory observations of the chemical behaviour of Mn during the mixing of Fraser River water with seawater are underway.

R.J. Andersen is studying the natural products chemistry of marine sponges and phytoplankton. Clionamide has been found as a major metabolite in the boring sponge Cliona celata; novel zoanthoxanthins with antibiotic activity have been found in a local soft coral.

(c) Geological-Geophysical Oceanography

Sedimentological studies have been carried out in the Fraser River delta tidal flats by J. Murray and D. Swinbanks. The area between the Tsawwassen and Coalport causeways have been examined more closely and found to be an area of intense bioturbation. Suspended sediment studies have been conducted (J. Murray and J.P. Syvitski) in Howe Sound; the analysis of sediment traps has led to the conclusions that: 1) water turbidity cannot be used as a measure of downward particle flux; 2) deep water sand discharges are common near the mouth of the Squamish river, near the head of the sound and; 3) size distributions of sediment deposited are complicated functions of the suspended sediment size distribution. The study of mine tailing discharge in Rupert Inlet (J. Murray, A.E. Hay and R.D. Macdonald) has continued with observations of the meanders of the submarine channel produced by the tailing outflow. Attempts have been made to observe turbidity currents associated with the tailings by using acoustic techniques coupled with current measurements.

The Pacific Ocean Minerals Project (R.L. Chase, E.V. Grill and J.W. Murray) continued, with a three week cruise to the Juan de Fuca Ridge, from which twenty five cores were raised to recover sediments. Analysis of lead isotope ratios indicate that lead in these sediments is originating from the underlying basalt rather than from the ocean or from terrigenous detritus.

R.M. Clowes has continued deep seismic studies of Winona Basin; interpretation of the seismic profiles obtained is consistent with a proposed oblique subduction between the Explorer and American plates. Ocean bottom seismometer records have been interpreted with H.P. Cheung; three instruments were mounted on the ocean floor near the northern tip of Explorer Ridge. The geological interpretation of the results is not yet available and presents some difficulties. Other ocean bottom seismometers were placed near the Nootka Fault and their records are now being interpreted.

8. Bedford Institute of Oceanography: Atlantic Oceanographic Laboratory

(a) Chemical Oceanography

Studies of the distribution and behaviour of trace metals and particulate organic material in the St. Lawrence estuary and the Saguenay Fjord have resulted in a better appreciation of the speed and magnitude of nearshore sedimentation of material of terrigenous origin. These processes effectively reduce the flux of riverborne materials entering the deep ocean and also limit the effectiveness of coastal water monitoring for the detection of compositional changes resulting from increased anthropogenic activity. Geochronological studies of the Saguenay Fjord sediments, which contain appreciable quantities of mercury of anthropogenic origin, and the composition of waters in the eastern Canadian Arctic and Baffin Bay are also being conducted.

Marine pollution research has involved the study of petroleum residues in the North Atlantic and Eastern Canadian Arctic and the measurement of organohalogens in coastal sediments of Atlantic Canada. Earlier indications that relatively high concentrations of petroleum residues existed in waters at Scott inlet and Buchan Gulf have been confirmed and efforts are presently underway to determine whether, as suspected, these residues and efforts result from local submarine oil seeps.

Nutrient research has been conducted largely in the eastern Arctic with particular attention having been paid to the nutrient characteristics of the various outflows from the Arctic Ocean. It appears that the influence of silicate rich water, entering the Arctic Ocean from the Bering Sea, decreases in an easterly direction so that the silicate content of the outflowing water decreases markedly between Jones Sound and Nares Strait. These results have been interpreted in terms of the size and depth of the western surface gyre in the Arctic Ocean. Studies of the composition and settling rates of deep ocean particles have also been started in an effort to examine the types of particles which are the predominant carriers of trace metals and biogenic material from surface waters to pelagic sediments.

Experiments on the direct measurement of vertical carbon dioxide fluxes near to the sea/air interface are being continued with the objective of empirically relating these fluxes to physical and chemical parameters. Measurements of the fluxes of organic and inorganic chemical substances in aqueous and particulate atmospheric precipitation will also be made in order to estimate the importance of atmospheric transport, relative to river discharge, to the introduction of such compounds to the surface ocean.

Studies of physical, chemical and radiochemical conditions in several environmental phases in the vicinity of Point Lepreau, New Brunswick, have also been started. This work forms part of an environmental monitoring program associated with the operation of the Point Lepreau Nuclear Generating Station.

(b) Coastal Oceanography

The research activities of the Coastal Oceanography Division are directed toward understanding physical processes in Canadian coastal waters and providing answers to questions of fisheries management, pollution control, coastal engineering design.

Major field experiments during 1978 include: 1) the Shelf Break Program; 2) the Gaspé Current Array, and; 3) the Laurentian Trough Experiment. Measurements from the Shelf Break mooring array have been used to identify important low-frequency exchange processes, driven by atmospheric winds and the Gulf Stream. Mixing with nutrient-rich slope water supports high levels of primary production at the shelf edge and makes significant contributions to the heat and salt budgets for shelf waters. Data from the Gaspé Current will be used to investigate the effects of fresh water regulation on mixing in the estuary and study the dynamics of current itself. Long-term current measurements from the deep waters of the Laurentian Channel are aimed at identifying low-frequency variability associated with fresh water discharge and atmospheric forcing. Smaller scale field programs have also been carried out in the Saguenay Fjord and in the St. Lawrence estuary off Rimouski.

A numerical study of the M_2 tide in the Bay of Fundy and Gulf of Maine has been completed. In addition to assessing the feasibility of constructing tidal power dams at the head of the Bay, model results have been used to investigate variations of tidal mixing and stratification in the region, to simulate sediment movement and deposition in the Bay, and to provide tidal current estimates for studies of oil spill movement. Other numerical models have been developed to represent tidal flow through the Strait of Canso, to study variations in the mixed layer over the Magdalen shallows, and to define the normal modes of the Gulf of St. Lawrence with periods of 6 to 120 hr.

In fisheries-related studies, models for the circulation in St. Georges Bay, N.S. have been used to define mean and transient circulations in the Bay and to estimate flushing times which affect the distribution of fish eggs and larvae. In addition, a long-term monitoring program for bottom temperatures on the continental shelf commenced this year to support studies of the invertebrate fishery. Investigations of sediment dynamics have been carried out in various estuaries (e.g. Miramichi, St. John River) in order to determine rates of flocculation and settling in the natural environment. These studies are related to and coordinated with ocean dumping investigations.

Ongoing analyses of surface wave data have produced a seasonal picture of wave climate on a $5^{o}x5^{o}$ grid over the entire North Atlantic as well as a detailed climate for northern Canadian coastal waters. These results, which include estimates for the 100-year "design" wave varying from 14 to 24 metres along the east coast of North America, continue to find wide practical use. Short-term engineering and/or environmental impact studies are also carried out by this group in the nearshore region.

(c) Hydrographic Research

The Atlantic Region of the Canadian Hydrographic Service conducts some research in the area of navigational aids. Considerable progress has been made in the development of an integrated shipboard navigation system, BIONAV, and of software to analyze rho-rho LORAN-C data. The tidal group continues its program of measuring ocean tides on the continental margin in such areas as the Bay of Fundy and on the Labrador Shelf.

(d) Ocean Circulation

This program is directed toward understanding physical processes in the ocean's interior and at its upper boundary with the atmosphere. Projects fall basically in three categories: 1) large-scale field experiments; 2) small-scale field experiments, and; 3) theoretical studies.

An example of the large-scale experiments is the Labrador Sea Project. Elements of this project include long-term measurement of the Labrador Current and the inflow past Cape Farewell at 44°W as well as localized studies of deep convection off the Labrador Shelf. Data return from the Labrador Current has so far been limited by losses due to icebergs, but measurements from 44°W are presently being analyzed. As part of the deep convection study, neutrally buoyant floats have been tracked acoustically in the horizontal while measuring vertical velocity and temperature. The results reveal areas of strong penetrative convection and an associated eddy field similar to that observed in the Mediterranean Sea.

The other major large-scale experiment is designed to study low-frequency eddy motions in the vicinity of the Gulf Stream. Results from one mooring array near 55°W reveals strong (60 cm s^{-1}) low-frequency (40 d period) motions which are coherent over 50 km. These measurements made in conjunction with the international POLYMODE program will be used to relate eddy motions to the general circulation. A seçond array, placed in the vicinity of 50°W is expected to return the first long-term moored measurements in the Gulf Stream itself, thanks to advances in mooring technology.

The small-scale studies at the air-sea interface are aimed primarily at parameterizing turbulent exchange processes. Measurements of eddy heat and momentum fluxes in the atmospheric boundary layer have been made from a stable tower off Halifax and are providing data to formulate a relationship between wind and surface stress at high wind speed. Studies of wave growth and microstructure in the mixed layer are also being conducted using instruments developed at the laboratory. Part of these investigations were contributions to the JASIN '78 experiment in the North Sea.

Numerical modelling is an important component of the theoretical studies in this group. Large-scale barotropic and (diagnostic) baroclinic models have been developed for the Labrador Sea and Baffin Bay in order to illuminate the effects of atmospheric forcing and variable boundary conditions. In addition, smaller-scale numerical models for three-dimensional tidal currents and estuarine circulation have been produced. Other theoretical work includes a simple analytical model to explain the response of coastal water levels to wind and investigations of the role of baroclinic instability in the general circulation.

(e) Ocean Technology

The Metrology Division's function is to investigate and evaluate appropriate new measuring techniques, to collaborate with BIO scientists in the application of such techniques, to manage related contract research projects, to operate specialized facilities such as a Standards Laboratory, and to serve as a centre of excellence on measuring techniques in the ocean. Contract management presently includes the Canadian Ocean Data Systems projects being done by Hermes Ltd. and the zooplankton counter development being carried out by NRC and Guildline Instruments Ltd. The Division also supplies the Atlantic Geoscience Centre with assistance in managing the SEABED geotechnical and sediment classification program with Huntec (70) Ltd.

Staff of the Division are expending considerable effort to acquire equipment and assemble it into systems for the measurement of physical (conductivity, temperature, dissolved oxygen, etc.) and biological (chlorophyll, zooplankton, light attenuance, etc.) parameters in the ocean. This effort includes the analysis, interpretation and presentation of data concerning both vertical and horizontal variability in the water column. This work also includes the study of the materials composing and dynamics of current meter moorings.

The Division is concerned with bottom sampling techniques in support of the Atlantic Geoscience Centre's (AGC) program. This work includes modifications and improvements to an electrically powered hard rock coring drill, installation of a seismic system on the drill and provision of an acoustic positioning system aboard ship to improve site selection and relocation capabilities, and support to AGC and Huntec (70) Ltd. in the SEABED program.

Work is continuing in collaboration with components of 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 preparations are underway to provide navigation for the Lomonosov Ridge Experiment. This experience will lead to implementation of improved high Arctic navigation methods at sea. Research effort is also being expended to employ acoustic positioning methods in the solution of oceanographic and geological problems such as measurement of vertical current profiles.

9. Ocean and Aquatic Sciences: Central Region, Burlington, Ontario

(a) Physical Oceanography

General physical oceanographic studies are conducted in the regions of Hudson Bay, James Bay, St. Lawrence River Estuary, Chesterfield Inlet, and the Arctic. Studies in the Hudson/James Bay region deal with modifications to the aquatic system resulting from the hydroelectric development of the La Grande River and other hydroelectric developments. The modification to the circulation of James Bay as a whole was studied analytically with the use of current and STD data. Winter oceanographic features are being examined, with emphasis on the plume of brackish water extending beyond the mouth of the La Grande River. This plume will be modelled numerically to predict changes in its vertical and horizontal extent, stability, and rate of entrainment as the outflow of the river increases, through regulation, by over 500%.

The current and STD surveys of the St. Lawrence River estuary and Chesterfield Inlet (N.W.T.) have been completed and will be used to obtain a spacial and temporal variation in tidal heights, tidal currents, non-tidal currents, ST structure, and internal wave structure. A two-dimensional salt intrusion and tidal propagation model is being developed and will use the Chesterfield Inlet data in order to study which physical processes cause the observed distributions. The internal wave structure and propagation observed in the St. Lawrence River data is being studied analytically.

Winter physical oceanographic surveys have been carried out in the Arctic since 1976 with the primary objective to describe the circulation pattern and magnitudes of tidal and non-tidal motion in the Canadian Archipelago. Data analysis has been completed for the 1976 Penny Strait Survey (currents and STD), 1977 Prince of Wales and M'Clure Strait Survey (currents and STD), 1978 Barrow Sill Survey (STD), while analysis is still continuing on the Barrow Sill current meter data. A proposed 1979 Arctic current and STD survey is planned for the Sverdrup Basin and will again

add to the circulation knowledge needed for environment impact assessments concerning the energy exploration and marine transportation in the Arctic.

(b) Shore Properties Studies

Resarch concerning Great Lakes shore erosion continues including a Shore Erosion Monitoring Programme, as well as Flood and Erosion Prone Area mapping. Other projects include the study of effects of headlands; of significant storm-related and ice push incidents; and of other geomorphologic phenomena. The Canada/Ontario site specific Shore Management Study and the brochure series "Coping With the Coast" aim toward better public awareness and coastal zone management. Also, studies of major James Bay estuaries and Hudson Bay Lowland areas are underway.

10. National Water Research Institute: Canada Centre for Inland Waters, Burlington, Ontario

The National Water Research Institute (formerly the Canada Centre for Inland Waters, which is now only the name of the building) conducts research in the areas of water management, shore and coastal zone management and toxic substances research and also provides services of instrument manufacture, design and calibration. Studies are conducted in three administrative divisions.

(a) Applied Research Division

Research on physical limnology is concentrated in the Basin Investigation and Modelling Section and includes environmental simulation model studies of physical, chemical and biological properties (T.J. Simons, A. El-Shaarawi, E. Halfon and D.C.L. Lam), sampling of water movements and thermal variability in the Great Lakes (F.M. Boyce and D.G. Robertson), work on coastal physical processes (C.R. Murthy) and the development of an in situ water quality monitor (A.S. Fraser). In the Microbiological Laboratory Section one may mention studies of the effects of oil on fresh water ecosystmes (B.J. Dutka and J. Sherry). The Remote Sensing Section is concerned with the application of satellite imagery and of optical methods to limnology (J.E. Bruton, J.H. Jerome). Finally, the Analytical Methods Research Section is interested in the application of a variety of chemical methods to detection and analysis of various chemicals in the environment: trace metals, thiocompounds, radionuclides (F.I. Onuska, P.D. Goulden, I. Sekerka, R.W. Durham).

(b) Hydraulics Research Division

The Environmental Hydraulics Section of the division groups a number of studies on river flow: mathematical river response modelling and studies of meander formation are conducted by B.G. Krishnappan; problems of icing and the formation and effects of ice jams are studied by R.K. Carson and G. Tsang; flood frequency studies are modeled by J. Marsalek. In the Shore Processes Section, one encounters more traditionally oceanographic studies, such as those conducted by M. Donelan on wave breaking and air-sea interaction, together with combined wave and geology investigations on littoral drift and erosion models and sediment transport (M.G. Skafel and J.P. Coakley) as well as various studies on nearshore sediments (N.A. Rukavina) and of water level regulation (T.M. Dick).

(c) Process Research Division

This section includes a Geology Section, concerned partly with geochemical studies, mostly of heavy metals in lakes (H.K. Wong, J.D. Williams and J. Capobianco), and with the ecology of wetlands. The Nutrient Dynamics Section conducts research in nutrient chemistry of lake

waters and its relation with algae and phytoplankton. The Toxic Substances Section is concerned with the effects of various toxis substances, their accumulation (W.M. Strachan), their distribution (R.J. Maguire), their persistence in the environment (D. Liu); it also includes studies of sediment fractionation of PCB's (W.M. Strachan), the effect of oil on fresh water ecosystmes (B.F. Scott), and the fate of pentachlorophenol in aquatic ecosystems (M.E. Fox). The Water Chemistry Section pursues similar interests, including studies of sources of carcinogenic organics in water (B. Oliver), photo-dechlorination of pesticides (J. Carey) and the effect of humic acid on the fate of selected biocides (J. Lawrence).

11. National Water Research Institute: Pacific and Yukon Branch
4160 Marine Drive, West Vancouver, British Columbia

Since its inception, the branch's research activities have focused on the large, deep, mountain-valley lakes of southern B.C. These intermontaine systems are often the geographical focus for intense urban, industrial and agricultural activities as well as the site for hydroelectric and flood-control dams. Despite their economic and social importance, the limnology of these shore-resident-time lakes is poorly understood.

The bulk of the recent research effort of the branch has been directed to a large, three year study of the limnology of Kootenay Lake in southeastern B.C. This study has been accompanied by an investigation of the Kamloops Lake-Thompson River system from which have evolved a number of general descriptive models of river-dominated lake ciruclations, including a conceptual model of seasonal circulation (P.F. Hamblin and E.C. Carmack), studies of delta progradation and of sediment density surges (C. Pharo), and models of river plume dispersion. Interests also include Antarctic and upwelling studies (E. Carmack) and models of linked lake-river systems (E. Carmack and P. Killworth of Cambridge University).

12. National Water Research Institute: Western and Northern Region
501 University Crescent, Winnipeg, Manitoba

The research staff of this regional branch of N.W.R.I. has for overall research objectives to predict the response of specific regional freshwater systems to the impact or removal of various environmental stresses. The stresses focused on at the present are: 1) nutrient-rich effluents of urban or agricultural origin; 2) toxic substances from various sources; 3) reservoir construction and operation related to thermal and/or hydroelectirc power generation.

Research studies include nutrient loading models and their effect on productivity, especially in the Qu'Appell Lakes (R.J. Allan); studies of phosphorus bioavailability in various lakes (T.A. Jackson); work on sediment resuspension by wind in shallow lakes and mass transfer problems in Lake Winnipeg (B.C. Kenney); chlor-alkali and heavy metal toxicity in Manitoba (Jackson and Allan), and water quality effects of Boundary Dam Reservoir in Saskatchewan and of the Churchill-Nelson Diversion in northern Manitoba.

13. Institut National de la Recherche Scientifique: Océanologie, Rimouski

Regroupée sous le thème de l'aménagement côtier, la recherche à l'INRS-Océanologie en 1977-78 a porté sur différents aspects de la biologie, de la physio-écologie et de la biochimie marine reliés à des problèmes spécifiques de nutrition et de pollution. Les recherches en océanographie physique ont été réalisées pour la plupart en collaboration avec la Section d'Océanographie de l'Université du Québec à Rimouski; elles ont porté en particulier sur le mélange et la circulation de masses d'eau dans l'Estuaire maritime du St-Laurent, sur l'importance de la marée sur le mélange et la circulation de la région côtière de Rimouski, et sur l'hydrologie et les

conditions de vagues dans la région de Cap-du-Dauphin, aux Iles-de-la Madeleine. Avec la collaboration additionelle de l'Ecole Polytechnique de Montréal, un prototype de bouée océanographique autonome, conçue pour les conditions particulières du St-Laurent, est en voie de développement. Enfin, l'étude de l'impact du harnachement hydro-électrique des rivières de la Côte Nord sur le milieu marin a été entreprise, à la demande de l'Hydro-Québec, en collaboration avec des chercheurs de l'Institut Bedford. Dans le domaine de la sédimentologie, les travaux de recherches ont été confinés à l'étude de la zone littorale du transport de sédiments dans le port de Gros-Cacouna et dans la région de Trois-Pistoles.

Les travaux de l'INRS-Océanologie continuent à être regroupés dans trois programmes: 1) exploration du milieu marin: projet qui comprend plusieurs études biologiques ou biochimiques, un essai de quantification des échanges de matières nutritives et polluantes entre l'Estuaire et le Golfe du St-Laurent (V.G. Koutitonsky et collaborateurs), une étude de l'importance de la marée sur le mélange et la circulation de la région de Rimouski (M. Gagnon et M. El-Sabh), des observations le long de deux sections transversales visant à caractériser le mélange et la circulation des masses d'eau dans l'estuaire maritime du St-Laurent (V.G. Koutitonsky et M. El-Sabh), le développement d'une bouée océanographique autonome (M. Gagnon et collaborateurs), des études de dynamique des sédiments littoraux dans la région de Trois-Pistoles (G. Drapeau et R. Morin) et de sédimentation dans le port de Gros-Cacouna (G. Drapeau et G. Fortin), et enfin une étude d'interactions air-mer entreprise à l'aide de la bouée océanographique autonome (J. Landry et collaborateurs); 2) le deuxième programme inclut les études d'exploitations de ressources marine et comprend des travaux d'impact du harnachement des rivières de la Côte Nord (G. Drapeau et collaborateurs) et des études de conditions océanographiques à Cap-du-Dauphin (J.R. Brindle et collaborateurs) telles que mentionnées plus haut; 3) enfin, le troisième programme, sur la conservation du milieu marin, a pour but de développer la recherche dans les secteurs où la qualité de l'environnement naturel est menacée. Ce programme comprend des études de la distribution des métaux traces dans le seston de l'estuaire de St-Laurent (D. Cossa, S.A. Poulet et J.-C. Marty) ainsi que divers travaux se rapportant sur l'influence des métaux lourds et des émulsions de pétrole brut sur certains organismes.

14. Marine Sciences Directorate: Fisheries and Ocean, Ottawa

The Marine Environmental Data Service (MEDS) falls under this Directorate and provides an archival and distributive for all Canadian marine data pertaining to sea water properties. It also provides a routine analysis service for wave rider buoys data. The research interests of the staff include tidal analysis (G. Godin) and numerical modelling (D. Greenberg) and are reflected in the Manuscript Report Series published by the Directorate.

This group organized a Symposium on Long Waves in the Ocean in June 1978; the papers presented related to tides, tsunamis, storm surges and continental shelf waves. Abstract will appear in a future Manuscript Report.

15. Institute of Ocean Sciences, Sidney, British Columbia

(a) Arctic Studies: Arctic Marine Group

The activities of the Arctic Marine section have been concerned in 1977/78 with the Beaufort Sea, the Sverdrup Basin and Lancaster Sound. In the summers of 1976 and 1977, in cooperation with Imperial Oil, CanMar and Gulf Oil, wave rider buoys were deployed in the southern Beaufort Sea, and data put on file at MEDS in Ottawa. During January, 1978, thirteen NOAA satellite-positioned buoys were deployed around the southeastern perimeter of the Beaufort Sea, from Prince Patrick Island to Herschel Island. These buoys moved with the ice throughout the year. Some buoys had pressure elements on them for meteorological coverage of the area.

Studies in the Sverdrup Basin and Parry Channel were carried out to determine pollution pathways. These included 1) satellite imagery studies to determine seasonal ice movements; 2) radar tracking of summer ice movements from Griffith Island (Barrow Strait) and Hope Monument (mouth of Lancaster Sound). These studies were also in support of an Impact Study to be carried out on offshore, exploratory drilling in the Lancaster Sound area. Other studies included: 1) the NOAA satellite-positioned drift buoys deployed in eastern Barrow Strait at intervals during the summer of 1977; 2) portable weather stations set up to aid in the interpretation of the drift data; 3) four current meter moorings set-out during the months of August and September, 1977 in the deep waters across the mouth of eastern Lancastern Sound, and relayed for winter observations. The support of Defence Research Establishment Pacific, Dobrocky-Seatech Ltd., Norlands Petroleum Ltd., Environmental Protection Service, Petro-Canada and Polar Continental Shelf Project was received in these projects.

Support was given to DINA in their monitoring of two of CanMar's well blowouts in the Beaufort Sea.

(b) Arctic Studies - Frozen Sea Research Group

During 1978 the Frozen Sea Research Group has made field trips concerned with measurements of currents in channels of the Canadian Arctic Archipelago, the oceanography of Bridport Inlet on the southern shore of Melville Island, and a preliminary investigation of the problems of taking measurements within polynyas. Additional work has been done on instrument development, the physics of underwater oilwell blowouts, pollution in an arctic fjord, and the "Practical Salinity Scale (1978)".

Current meters were recovered from Crozier Strait between Cornwallis and Bathurst Islands and the tracked vehicle train moved around the northern tip of the former island to deploy current meter chains in Wellington Channel. The data from Crozier has been worked up showing that currents were mainly tidal but suggesting that the residual southerly transport maximized around mid-winter, there being almost an order of magnitude difference between summer and winter current speeds recorded at two current meters near the bottom. A major effort was deployment of the sonically orientated current meter arrays in Wellington Channel. These direction determining devices were developed for us under contract and work is continuing in their refinement and in obtaining operational data. Bridport Inlet was visited in February and in August 1978, the former occasion being in conjunction with commercial interests. Preliminary oceanographic data was acquired sufficient to enable the planning of the full scale investigation scheduled for 1979.

The polynya existing off Cape Collins on Dundas Island (76°08'N, 95°00'W) was investigated to define problems in logistics and equipment design encountered in operating on the polynya and the surrounding ice sheet. Inflatable boats were operated at air temperatures of -40°C. The design of a new salinity cell suitable for use on a chain has been published and the first such chain deployed. Work continues investigating long term stabilities. A major instrumental effort has been in the development of electronic packages for model aircraft to be used to investigate temperature fields above the polynya. Work is progressing on the data package which should telemeter information on temperatures and pressures as well as provide over ice/over water identification in the spring of 1979. A system enabling the position of the aircraft to be determined utilizing a Decca mini fix system should be available by the spring of 1980.

Further work has been done on data acquired during the simulated shallow oilwell blowout in 1976 with a view to obtaining a more accurate understanding of the bubble plume. Work has continued at the Department of Chemical Engineering, University of Calgary on the contract to investigate phenomena, such as hydrate formation, that will occur during a deep oilwell blowout. Hydrate formation, a theoretical possibility under the pressures and temperatures to be expected in arctic waters below about 500 feet, were shown to occur by a gas release from the submersible Pisces in Jervis Inlet, B.C. These results have now been duplicated in the vertical high pressure water tunnel which has been built in Calgary. Problems of supersaturation of gas in oil drops during ascent to the sea surface are also being studied and it is hoped that a complete picture of deep oilwell blowout dynamics will be available early in 1979 and so enable a proper scenario to be written. A study of the natural disposition of oil and gas arriving at an ice/water interface has shown that oil will lie below the gas bubble unless in sufficient quantity to spill over and upwards onto the surrounding ice. Studies made of pollution in a fjord on the west Greenland coast due to mining operations at Marmorilik demonstrated the effect of the rejection of salt by sea ice during growth on vertical winter circulation and pollutant movement. We have deployed recording instruments in conjunction with the Danish Geological Survey program. The group has been very active in studies leading to the new "Practical Salinity Scale (1978)" due to be promulgated shortly with a view to standardizing salinity obervations taken throughout the world.

(c) Ocean Chemistry

Long-term trends of chemical parameters at Ocean Weather Station P are being studied as a continuing effort of the division. Observations have been made on: 1) tar balls and other surface pollutants; 2) atmospheric CO_2, surface alkalinity and total CO and surface radiocarbon, to study the ocean-atmosphere CO_2 exchange; 3) continuous infrared measurements of marine air CO_2 and water pCO_2; 4) daily nutrients at surface waters; 5) surface hydrocarbon by fluorescence measurements.

Trace metal studies have been carried out in relation to assessing the natural and man-made inputs of physiologically significant contaminants into the marine environment and their interaction with suspended matter, planktonic biota and sediments. A NATO study is underway for accurate measurements of trace metals in sea water, in cooperation with Institute fur Meereskunde, Kiel and Department of Oceanography of University of Liverpool. Mercury studies have been carried out in Howe Sound, Alberni Inlet, Rupert and Neroutsos Inlets. Sedimentation rate in Saanich Inlet, Beaufort Sea and B.C. coastal inlets was measured using lead-210 dating technique. Bio-uptake of metals, in connection with mine tailing disposal in Howe Sound and Quatsino Sound and with ocean dumping activities at Point Grey, were conducted. Methylation of metallic compounds, such as mercury, lead and arsenic, was conducted for sediments from various coastal inlets.

PCBs and petroleum hydrocarbons were intensively studied. CEPEX controlled experiments were utilized to study the pathways of PCBs, oil dispersant and alkyl lead in the marine environment. Controlled oil spill experiments were also conducted in Victoria waters to understand the behaviour of oil in seawater.

Chemical and environmental studies were carried out on board the PANDORA II in August 1977 in the Amundsen Gulf area, to collect sea water, sediment and plankton samples for hydrocarbons and trace metal work. Coastal cruises were conducted in B.C. coastal waters for environmental studies, in Alberni Inlet, Howe Sound, Porpoise Harbour and the Kitimat

areas. In particular, an 18-month baseline study is underway on contract to assess the background hydrocarbon levels and other chemical environmental parameters in the Kitimat area.

Instrumental projects include a NATO project to develop a water-correcting infrared analyzer for CO_2, a trace metals and hydrocarbon sampler prototype development and a CHEMCELL project to develop a medium-scale experimental system for pathway study of gases, metals and organics between air, sea and sediment reservoirs.

(d) Coastal Oceanography

The intensive study of circulation in Knight Inlet continued through 1978 yielding surprising results. It now appears that interactions between the barotropic tidal flow and the sill can drive the internal gravitational circulation of the inlet. Though we can monitor the rate of loss of energy from the tide to other modes, the specific manner in which this energy is converted to potential energy of the mean state appears to be extremely complex. Studies with high frequency echo sounders show that at times internal hydraulic jumps form, at other times vortex sheets formed by separation of the tidal flow over the sill are formed. In both cases turbulence is generated near the pycnocline leading to relatively efficient energy exchange mechanisms. The Knight Inlet study is being carried out jointly with J. Smith at the University of Washington.

The monitoring study of Saanich Inlet was concluded in 1978; however, a large number of instruments were deployed in the fall of 1978 in an attempt to observe, in detail, a deep-water renewal event.

Other smaller studies carried out in 1978 include: studies of the salt wedge in the Fraser River; internal hydraulic events in Boundary Pass; and, mooring dynamics studies.

(e) Remote Sensing

Evaluations and experimental use of various satellite and aircraft remote sensing techniques including:

A program of airborne water colour measurement using the 256 channel silicon diode spectrometer which has demonstrated the possibility of using this technique for rapid chlorophyll surveys. An airborne inertial navigation and sighting system which has been developed and used for tracking surface features and floating drogues. The system records the position of any target indicated by an operator in the aircraft to an accuracy of about 10 metres. Studies of satellite data including use of images from Landsat, NOAA and synchronous satellites for studying atmospheric and sea surface features. Wave height estimates made by the GEOS-3 satellite radar altimeter and coastal observations with the SEASAT synthetic aperture radar which have been compared with ship measurements and observations.

(f) Numerical Modelling

A linear model of semi-diurnal tides was developed for Queen Charlotte Sound/Hecate Strait/Dixon Entrance. A baratropic, β-plane ocean circulation model with variable eddy-viscosity is under development.

Wind-driven circulation and tidal models of Lancaster Sound are being developed. Tests are progressing on simulation of non-linear internal hydraulic jumps over sills in stratified fjords.

Exploratory field and numerical investigations, directed towards the simulation of the three-dimensional circulation in the Georgia/Fuca system, are being undertaken.

(g) Ocean Mixing

Trials of the new microstructure/turbulence systems on PISCES IV were carried out successfully in 1977 in the Strait of Georgia and adjacent waters and in Bute Inlet. The effectiveness of the system was proven in a variety of circumstances, but useful analysis of the data has been limited by malfunction of the data-acquisition system.

With a completely re-designed data system a further series of measurements have been carried out over a six-week period in late 1978 in two areas: 1) in the region of the Fraser River outflow in the southern Strait of Georgia to investigate mixing and entrainment in the boundary layer between river water and Strait of Georgia water, and 2) in the vicinity of the sill in Knight Inlet, in conjuction with the work reported under Coastal Oceanography. The Pisces was driven horizontally through trains of internal waves (sometimes unstable and "breaking") and through the vortex sheets found in regions of flow separation, in order to determine the intensity of turbulent activity and the turbulent energy dissipation rates. Analysis of data is in progress.

(h) Offshore Oceanography

Support to the First GARP Global Experiment is continuing. Dr. Garrett has been seconded to the International Drifting Buoy Program Centre in Toulouse, France and a Parizeau cruise, as part of TWOS (the Tropical Wind Observing System), will carry out physical oceanographic CTD and current profiling sections within $\pm$ 3° of the equator in the Pacific in January 1979.

Climate Dynamic Studies centred upon 20 years of Weathership STD data at Station P and along line P from 1957 to 1977 are assessing climatology and water transport. Attention is paid to small scale variation of vertical structure of the order of 10 metres. Short time-scale response due to synoptic storms is being investigated with a data set from the Mixed Layer Experiment (MILE). One-dimensional modelling of the upper ocean can only account for one-half of the thermo-modification and therefore the significance of two-dimensional structure of the upper ocean and advective processes is now clearly recognized. Conditions relevant to the onset and maintenance of these advective processes are under study.

A field program to study the current structure of Johnstone Strait and Vancouver harbour are being continued with the aid of a new current profiler measurement technique. A theoretical study of the current structure at a partial sill near Kelsey Bay is also underway.

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VIII GLACIER STUDIES

Compiled by: C.S.L. Ommanney

1. Energy, Mines and Resources Canada

(a) Geological Survey of Canada (R.N.W. DiLabio and W.W. Shilts)

Bylot Island - Geochemical and mineralogical data from lateral moraines and debris bands of glaciers draining the Precambrian highlands indicate that the latter contain significant amounts of debris from the base of the glacier and that compositions of the former vary systematically with distance from source or with relationship to tributary ice streams. Sediment carried by each of the five glaciers studied is geochemically distinct.

(b) Polar Continental Shelf Project (R.M. Koerner)

Queen Elizabeth Islands - The mass balances of the Meighen, Devon and Agassiz ice caps were measured in April and May. Strain nets, bore-hole diameters and temperatures were remeasured on the Agassiz Ice Cap. A new device was successfully constructed to measure down-bore-hole ice conductivities to detect major volcanic events present as H_2SO_4. The results complement similar ones made on the core extracted in 1977.

Laboratory investigations - The origin of lichen-free areas in the High Arctic has been examined and the effect of instant glacierization on feedback processes studied.

A fabric and textural analysis of the Devon Island ice cap cores was completed. They were further analysed for elemental concentrations, chiefly of Al and Na but also for Si, Mg, Ca and K, as was a suite of samples from the Agassiz ice cap. While levels of Al are higher on Agassiz than Devon, the reverse is true for Na. Volcanic layers in the cores are being studied for micro-particle concentrations, chemistry, electrolytic conductivity, and pH. The Thera event which ended the Minoan civilisation has been identified by its high sulphate content but no similar increase is apparent in micro-particles ($> 0.5\ \mu m$) or the six elements listed above. Camp Century, Greenland microparticle concentrations and $\delta^{18}O$ profiles have been compared to those for Devon Island and used to infer surface level changes of the Camp Century locality of the past 100,000 years. Noise levels in the time series of $\delta\ ^{18}O$ values derived from ice cores have been studied.

B. Alt, under contract, has studied the relationships between synoptics and ice cap mass balance in extreme warm and cold summers to obtain a better understanding of climatic change and ice cover fluctuations in the High Arctic during the Holocene.

2. Fisheries and Environment Canada

(a) Applied Hydrology Division (I.A. Reid and J.O.G. Charbonneau)

Glacier Surveys, British Columbia - The Nadahini, Sentinel, Sphinx, Kokanee and Bugaboo glaciers were resurveyed by terrestrial photogrammetry. Maps and reports from these and previous biennial surveys are in preparation.

(b) Glaciology Division (D.K. MacKay, A/Chief)

Glacier Inventory (C.S.L. Ommanney) - 35 new basins were added to the Yukon inventory. The first phase of the Yukon study will be completed by April 1979 (S.G. Collins). A special inventory of Glacier National Park, B.C., has been commissioned by Parks Canada based on 1978 aerial photography supplemented by uncontrolled glacier photos taken in 1977 and 1978.

Aerial Photography (A.C.D. Terroux) - Glacierized areas on Ellesmere and Axel Heiberg islands were photographed in early August using a Wild RC-10 camera mounted in a PCSP support aircraft. In early July the Tweedsmuir, Steele, Lowell and Donjek glaciers were photographed. Follow-up studies of these surging glaciers are contemplated.

Mount Logan, Y.T. (G. Holdsworth) - A final short field operation was carried out on the NW Col (5340 m) prior to the planned core drilling in mid 1979. Measurements were made of accumulation rate (1.5 m of snow), ice flow rate (0-2 ma^{-1}) and ice depth; the latter using two sounders - a 620 MHz system and a 5 MHz monopulse system. Thicknesses varied considerably up to about 360 m within a 0.5 km^2 area around the col. An 18.5 m SIPRE hole provided isotope data for about the last two decades. The 10 m temperature was about -29°C. Recovery of a core spanning the last millenium is planned for 1979.

Alcan Pipeline (G.J. Young, M. Perchanok and S.G. Collins) - Detailed field work was undertaken at the Donjek Glacier snout and at Haines Junction to reconstruct the chronology of glacier lake formation and outburst floods.

Mass Balance, Western Cordillera (O. Mokievsky-Zubok) - Measurement of winter and summer balances, meteorological variables and meltwater flow continued on Sentinel and Place glaciers for the 13th and 14th years respectively and of mass balance only on Helm Glacier for the 4th year. Hydrochemical balance studies were continued on the former to determine sources of discharge and sediment load from glacierized areas (with J.L. Zeman).

Water Management in Remote Basins (O. Mokievsky-Zubok) - Further studies to determine the effect of glaciers on basin runoff in the Bridge River headwaters were made. A Data Collection Platform was installed below Bridge Glacier for continuous monitoring of hydrological and meteorological parameters.

Iskut river glaciers, northern B.C. (O. Mokievsky-Zubok) - Studies of two galciers (102 km^2) in heavily glacierized watersheds have been initiated to assess the impact of glacier variations and runoff on a proposed reservoir. "Andrei" and "Yuri" glaciers had negative balances of -0.83 and -0.05 mH_2O respectively.

Yoho National Park, B.C. (G.J. Young) - Monitoring of the hydrology and climatology of non- and glacierized catchments continues.

Columbia Icefield - Further work in the cooperative study consisted of completing the control survey in August, using an inertial survey system, and compiling orthophotos of the Athabasca and Saskatchewan glaciers for a comparison of mapping accuracy between these and conventional maps.

Peyto Glacier, Alberta (G.J. Young) - The basic monitoring of mass balance, meteorology and hydrology continued. A detailed radiation balance study was initiated (D.S. Munro, Toronto University), a water and sediment study undertaken (D.N. Collins, Manchester University) and snow pack densities investigated (J. Edworthy, Carleton Universtiy). Ten studies participated in graduate hydrology course given by Dr. Gunnar Ostrem through Carleton University.

3. National Research Council of Canada

Photogrammetric Research (M.C. van Wijk)

Axel Heiberg Island glaciers - The generation of Digital Terrain Models of the glacier surfaces and their immediate surroundings has been completed. This digital information is being used at the Department of Photogrammetry, Technological University of Vienna, to produce stereo-orthophotos on a Wild Avioplan OR1. They will be used for cartographic purposes and to investigate various glaciological applications (F. Müller et al., ETH, Zürich).

4. Karl E. Ricker Ltd., Vancouver, B.C.

Wedgemount Glacier and Lake, Garibaldi Park, B.C. (with W.A. Tupper) - Topographic maps at 1:5 000 have been produced from 1964, 1969 and 1972 vertical air photos, and glacier tongue planimetric maps from 1947, 1976 and 1977 oblique aerial and terrestrial photography. A composite map and cross section, showing glacier tongue positions over several years, ice thicknesses and tree ring sample sites with dates, has been published (Canadian Alpine Journal 1978). 1978 field work was limited by bad weather to collection of a few additional tree ring samples and a terrestrial resurvey. A slight advance and retreat is indicated for 1977-78 and the pronounced development of a rotational slump behind the glacier snout suggests a much reduced extension of the lake under only the central axis of the glacier if retreat by calving continues. The advance is on the south side under a 200 m high rock wall.

"Snowcap Icefield" and Lake, Garibaldi Park, B.C. - From "Snowcap Icefield", lying due south of Snowcap Lake, three of several outlet glaciers extend to the north. "Thunderclap Glacier" currently extends into the west lake basin and has thickened quite noticeably (since 1972) at the snout which shows a slightly advanced position relative to 1951. At its maximum it filled the entire west lake basin causing a 15 m water level rise and drainage reversal into the Lillooet River system. "Griffin Glacier" and "Glacier de l'Escalier" once reached the eastern lake basin but much earlier than the climax of "Thunderclap". After an intervening period of dramatic ice recession "Griffin Glacier" has advanced hundreds of metres since 1951, has thickened considerably at its two-pronged snout since 1972 and is overriding vegetation. Neighbouring "Glacier de l'Escalier" continues to retreat from its 1951 position at an average 2.8 ma^{-1}. Field work in 1978 included the levelling and mapping of various strandlines of Snowcap Lake to relate them to the numerous climax and recessional moraines. Tree ring samples were collected and cairns established at the snouts of all three glaciers for long-term monitoring.

5. University of British Columbia

(a) Department of Geology (W.H. Mathews)

Berendon Glacier, B.C. - With the closing of the Granduc Mine at the end of June field work on Berendon Glacier has been terminated. A report reviewing work over the past decade has been prepared for the Glaciology Division.

Glacial Abrasion - Studies on simulated glacial abrasion are continuing.

(b) Department of Geophysics and Astronomy (G.K.C. Clarke)

Lowell Glacier, Y.T. - A USGS-type monopulse radar was used to measure ice thickness at 60 locations near the divide with Cathedral Glacier. The maximum ice thickness along the flow line is probably over 800 m, but the radar transmitter had insufficient power to sound ice thicker than 650 m.

Ice-dammed Lakes, Y.T. - The 1978 drainage of Hazard Lake was recorded using a pressure sensor and cassette data logger. A levelling survey of the staircase-like set of 30-60 beaches of Recent Lake Alsek was carried out with R.W. May and S.G. Collins; from this it may be possible to reconstruct the history of formation and destruction of the Lowell Glacier ice dam. Photogrammetric control was established on the giant ripple marks in the lake bed for an analysis of the drainage hydraulics.

6. McGill University, Montreal, Quebec and ETH, Zürich, Switzerland

Department of Geography (F. Müller)

Axel Heiberg Island Glaciology - Mass balance data and equilibrium line observations were obtained for the Baby and White glaciers. A methodological study on ice ablation was completed (K.C. Arnold). The snout positons of the White, Thompson and Crusoe glaciers were resurveyed. Two automatic weather stations are still being maintained. The heat balance and meso-climatic data has been analysed and a major report is near completion (A. Ohmura). A study of the empirical relationship between melt on the glacier and some synoptic parameters was completed and will be published (R.J. Braithwaite).

North Water Glaciological Program - Research is continuing into the mass balance of a number of glaciers on Coburg Island.

7. Memorial University of Newfoundland

Department of Geography (R.J. Rogerson)

Temperate Glacier Sedimentation - Field work focussed on collecting samples from the supraglacial, englacial and subglacial sediments of Vice-President and Emerald glaciers, B.C., and from the large Neoglacial maximum moraines in their vicinity. All samples are presently undergoing textural analysis. The Neoglacial moraines contain complex stacked and stratified units which probably represent the intercalating of sediments from the different glacial transportation zones and extraglacial slopes. Subglacially precipitated calcium carbonate is common between the moraines and present ice implying warm-based ice during deposition. Comparisons are being made with Wisconsinian 'bay-head' tills on the Avalon Peninsula, Newfoundland, which may also have been formed from warm-based ice.

8. University of Minnesota

Department of Geology and Geophysics - (R.LeB. Hooke)

Barnes Ice Cap, Baffin Island - A 300 m hole was drilled 2 km from the divide and fabric studies on cores from the hole were completed. A random fabric in fine-grained ice near the surface gives way downward to a small circle fabric at 150 m and two or three maximum fabrics below 175 m.

Temperature and deformation measurements were continued in three existing holes along a flowline, as well as mass balance measurements along the same line. Analysis of the data suggests that temperature profiles are adjusted to a velocity field compatible with requirements for a balanced mass balance. The profiles are incompatible with vertical velocities measured by the Glaciology Division in 1970-71, suggesting that the glacier then was responding to higher than normal accumulation sometime in the past.

Considerable progress has been made on finite-element models of the temperature distribution and flow field along the flowline. Other computer modelling suggests that the transition from 'random' to single maximum fabrics (in existing boreholes) occurs at cumulative strains with axial ratios, in the vertical plane along the flow direction, of 3-6; the transition from single maximum to multiple maxima fabrics occurs at strains of axial ratio 10-100.

9. University of New Hampshire

Department of Earth Sciences - P.A. Mayewski and G. Pregent

Athabasca Glacier - Ablation, meltwater discharge, velocity, surface temperature, ice chemistry, lichenometry, sedimentology and moraine distribution were observed in August. Detailed ice surface reconstructions are being used to determine volumetric changes of the Athabasca Glacier since 1870 as a key to its mass balance history.

10. University of Ottawa

Department of Geography and Regional Planning (P.G. Johnson)

Rock Glacier Studies, Y.T. - In a cooperative program with W.G. Nickling, Guelph University, emphasis has been placed on the rates of movement or collapse of the forms and their age. Data on morphometric parameters has been obtained for modelling and the engineering testing of materials has continued. Work has commenced on the drainage system of rock glaciers. A thesis on catastrophic origins of rock glaciers is in the final stages of completion.

11. University of Toronto, Erindale College

Department of Geography (D.S. Munro)

Shortwave Radiation Investigations for Glacierized Basins - Studies were carried out in Banff National Park and on Peyto Glacier to measure and estimate global radiation and its components and to determine the topographic variation of net shortwave radiation.

12. University of Wisconsin - River Falls

Department of Plant and Earth Sciences - R.W. Baker

Barnes Ice Cap, Baffin Island - Creep tests were continued on polycrystalline ice with variations in both grain size and degree of preferred crystallographic orientation. Specimens for these tests were collected from various places within the wedge of deformed superimposed ice of the Barnes Ice Cap and were deformed in simple shear, both in ice tunnel in the field and in the laboratory. Results thus far show that ice with a strong single maximum of c-axes perpendicular to the plane of shear deforms about three times as readily as ice with an isotropic fabric. a creep apparatus is being developed to deform samples in simple shear with simultaneous uniaxial compression.

Detailed fabric investigations were conducted on a recumbent-synclinal fold exposed in a 24 m high ice cliff of the Barnes Ice Cap. The fabric was found to change progressively from isotropic in the lower limb to a reasonably strong single-pole fabric in the upper limb. This suggests that the fold was formed by the partial overturning of initially down-glacier dipping stratification in the wedge of superimposed ice at the ice cap margin and allows for an estimate of the magnitude of shear strains to have affected this wedge ($\gamma \simeq 10$-15).

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IX HYDROLOGY

Compiled by: Dr. I.C. Brown

1. Introduction

The current restraints on research funding have resulted in a reduction in hydrological research accompanied by a swing from long term process oriented studies to short term studies designed to provide answers to operational problems. Another effect of the restraints has been a low level of reporting due to hydrologists being occupied with reorganizing their programs. Consequently, this report is far from complete though it is representative of the type of activity in Canada. Glacier studies are reported separately so only hydrology related work is mentioned here.

2. National

The Hydrological Atlas of Canada, compiled under the auspices of the Associate Committee on Hydrology, was printed and is available from the Department of Supply and Services. The Associate Committee has prepared a report on the status of hydrology education and a state of the art report on Ice Covered Rivers - Resistance to Flow Aspects. The latter will be available in the proceedings of the 1979 Canadian Hydrology Symposium.

Agriculture Canada has undertaken and supported hydrologic research in the near surface zones such as drainage, desalinization and return flows from irrigated lands. Agrometeorology research included studies to improve water use efficiency, crop yield prediction from soil water and weather data, and modeling of water use by crops. The soil resource inventory program included research in soil-water processes and studies of the impact of shallow groundwater processes on soil properties and uses. Increasing activity is taking place in studies on nutrient runoff from farm land.

The Atmospheric Environment Service has been studying methods of providing areal snow cover information and information on snow conditions. Thermal infra-red imagery has proved particularly useful for snow cover. Regular maps have been supplied to the St. John River Basin Flood Forecasting Center using data from the NOAA-5 satellite and the GEOS satellite. The X and L band synthetic aperture radar is being evaluated for the discrimination of snow conditions at a test site at Crystal Beach near Ottawa. Lake temperature determinations from NOAA-5 and TIROS-N infra-red data are being used for Lake Winnipeg and the Great Lakes and present studies indicate that satellite retrieved temperatures are within 1.5K of airborne radiation thermometer and buoy measurements. The use of data collection platforms for transmission of hydrometric information via satellite is continuing to increase and the question of standards for such data is being looked into as a number of provincial and other federal government agencies are expanding their use of DCP's.

The Environmental Management Service's Gamma-Ray Snow Survey Project in Lake Superior completed the gathering of field data but has encountered difficulties in analysis of data.

Hydrologic research in the Environmental Management Service is now concentrated in the National Water Research Institute located at the Canada Center for Inland Waters in Burlington and in the National Hydrology Research Institute to be located at Saskatoon. The National Water Research Institute is studying the effects of toxic chemicals, their identification, pathways and sinks, on freshwater eco-systems. The processes effecting oxygen supply to bottom waters of the Great Lakes and oxygen depletion rates at the sediment water interface are being investigated along with eutrophication and studies of the geochemistry of nutrients and their relation to wet-lands. They are also developing predictive and operational models and conducting studies on the atmospheric loading of aquatic systems, environmental hydraulics and shore processes as well as river processes and urban hydrology.

National Hydrology Research Institute activities involve snow and ice research and hydrogeology along with hydrological modeling dealing with rainfall input relationships, the estimation of runoff from ungaged areas, evaporation, stochastic models of surface water and reservoir storage optimization as well as the development of specialized models for predicting the movement of salt water intrusion fronts in coastal aquifers. Modeling studies also include an evaluation of a newly developed evaporation model and a model of hydrothermal processes near arctic streams as well as adaption of the U.S. Sacramento model as a framework for testing new insights into hydrologic processes and interactions.

Groundwater research in northern hydrology is aimed at understanding and describing the quantity and quality of water moving into, through and out of the subsurface in the northern environment and the interactions between groundwater and permafrost systems. In cooperation with AECL, contaminant hydrogeology studies of the feasibility of storing high level radio-active wastes in deep crystalline rocks and of the spread of radio-nuclides from shallow disposal areas are continuing. Cooperative studies are underway in the Maritime provinces on arsenic contamination.

Studies of the breakup processes continued on the MacKenzie River System. Alpine Hydrology studies emphasize the contribution of mountain snow pack to river flooding and the importance of glacier melt as a water supply component during years of drought. Perennial snow and ice studies leading to an understanding of the hydrology of glaciers and their role as natural and variable water storage systems were concentrated on the Columbia Ice Field and Peyto Glacier. An inventory of glaciers in Canada is continuing in the Yukon Territory and Glacier National Park. Models are being developed for use in describing the mechanism of glacier flow and for assessment of the environmental hazards related to glacier surges and jokulhlaups with their concomitant threat to reservoirs, transportation systems and other resource development. The glaciology laboratory is conducting studies of the mechanical properties of sand-ice mixtures in cooperation with the National Research Council of Canada and testing the flow laws for ice under hydrostatic pressure for use in ice core studies.

The Great Lakes Forest Research Center is conducting a study of the impact of acid rain on the hydrological cycle particularly its effects on soil and vegetation characteristics. Research by consultants continued into the applications of LANDSAT and NOAA data for monitoring snow, river ice and sea ice in the Canadian Arctic and winter time NOAA thermal infra-red imagery was used for mapping ice in northern Baffin Bay.

3. Provincial

(a) Newfoundland

Studies deal with community water supplies, effects of urbanization and the impact of sanitary landfills.

(b) Prince Edward Island

The Winter River Basin Study is continuing with the aim of further development of well fields and watershed protection guidelines. Hydrological studies are underway on sanitary landfill sites and petroleum product disposal sites.

(c) Nova Scotia

The problem of well contamination by arsenic released during rock weathering is being studied particularly in the Schubenacadie Basin. Studies continue in the Bras D'or Watershed to further the understanding of this unique salt water lake.

Nova Scotia Technical College is conducting an urban storm water quantity and quality study on a small catchment in Halifax and is assessing the use of a non-point source model in this study. Dalhousie University is studying the effects of atmospheric precipitation on lake waters in the Maritime area, particularly those due to man's activities.

(d) New Brunswick

The joint New Brunswick government and University of New Brunswick study of the St. John River Estuary is continuing and making use of a hydraulic model of the reversing falls. Groundwater information is being collected in conjunction with a coal exploration drilling program in a major aquifer area.

University of New Brunswick basin studies continue to study snow melt and the effects of clear cutting in the North Nashwaakasis and Nashwaak Rivers. Prehistoric and post-glacial flood features in the St. John and Nashwaak Rivers are being studied in the Fredericton area for comparison with the records from the six serious historic floods.

(e) Québec

Thermography and aerial photography of the Magog and St. François Rivers have been used in the study of sources of pollution and the dynamics of the rivers. Québec is moving rapidly into the retransmission of data via satellite to obtain hydrometric data from its remote areas or areas where access is difficult and real time data are of importance. Two gamma-ray automatic snow measuring devices will be tested for data retransmission and the data obtained compared with snow courses in the area. Remote sensing is being used to study the recession of the snow cover and relate this to hydrologic modeling for management purposes.

At the University of Laval satellite imagery is being used in the inventory of characteristics of the lakes of New Québec and a model is being developed to convert radiances to reflectances for application in studies of the quality of water. Remote sensing is being used to study the dynamics of transport of sediments in Rupert Bay for the Society for the Development of James Bay.

The Institut National de la Recherche Scientifique - Eau (INRS-EAU) is continuing studies of the Lac St. Jean area comparing the spatial variation of suspended solids and the depth determined by secchi disc with

data furnished by Band 5 LANDSAT images. Also INRS is undertaking a number of studies involving the development and adaption of models to basin data. They are also studying urban hydrology, dynamics of chemical and biological processes in the aquatic environment and have a large study underway of the Great and Little Whale Rivers.

(f) Ontario

Snow distribution and melt and the related runoff are being studied in a number of basins. Groundwater pollution studies are particularly related to radio-active waste migration and the migration of leachate from landfill sites. Low level colour and multi-spectral photography was used to study the distribution and concentrations of aquatic bio-mass in shallow streams and to delineate algae in the coastal zone of the Great Lakes. Infra-red scanning is being used to study thermal plumes from nuclear generating plants in relation to environmental assessment impacts.

The University of Guelph is studying the mechanisms which control the redistribution of solutes in freezing soil to help develop a model describing subsurface transport of solutes and including the effects of surface freezing.

McMaster University is studying the movement of landfill leachates into the ground and streams and in particular the sources of organics in the leachates. Modeling studies are being undertaken related to glacier surges. The relation of snow distribution and snow ablation processes in the Arctic are being studied in high arctic basins on Cornwallis Island.

Queens University is studying the mobility of radio-active components in the groundwater flow system at Chalk River in cooperation with AECL and also the long term movement of materials from landfills through the groundwater system.

Trent University of Waterloo is studying the attenuation of several types of contaminant solutions from sanitary landfills and septic tank drain fields, during the passage from groundwater through sandy sediments into surface waters.

York University is studying water characterization by scattering properties to provide basic information needed in various forms of remote sensing of lakes and rivers.

There are a large number of studies at universities across Canada dealing with chemical and biological aspects of water bodies and aquatic eco-systems. Many of these are closely related to hydrological water quality studies but most will probably be reported through various chemical and biological publications.

(g) Manitoba

Hydrological studies continue to be concentrated in the areas of water supply and conservation and are contributing information to a variety of water management studies now underway and relating to flood control and irrigation return flows. Such studies are particularly concentrated on streams crossing the international border where knowledge of the possible effects of various U.S. projects is required.

The University of Manitoba is studying non-point source pollution, particularly runoff from agricultural lands, and is testing a mathematical model for predicting nutrient loads from small watersheds in southern Manitoba. This model will be used to assess the effectiveness of various strategies for minimizing this type of pollution.

(h) Saskatchewan

The potential of both airborne and spaceborne remote sensing is being assessed as a means of keeping track of groundwater inflow and outflow to potash mine tailing ponds.

University of Saskatchewan continues to center its research on hydrology of the Prairie environment with the aim of gaining a basic understanding of the natural processes of the hydrological cycle on the Prairies. Emphasis is on snow hydrology problems particularly aimed at gaining an understanding of the melt process and how the water moves through snow-clogged channels to contribute to flooding and infiltration. Studies of the variations in time and space of rainfall and soil moisture are underway to provide data to test the applicability of different models for estimating evapotranspiration.

(i) Alberta

The Alberta Department of the Environment is conducting applied research on the effects of landfill leachate on groundwater quality and on the long term effects of strip mining on groundwater quality and resources. Radar is being used to provide mean basin precipitation values and the results look encouraging for application on an operational basis by the Alberta River Forecast Center. Research is underway into the best form of imagery to use in obtaining lake bed contours from air photos.

A number of hydrological studies are being undertaken jointly by the Alberta Government and Alberta universities related to water quality and the movement of pollutants in the Alberta tar sands area and in the front ranges of the Rockies, where the aim is to be able to increase production of water from the forested slopes. These studies cover such subjects as snow distribution and melt, breakup and peak runoff, ice jamming, ice loading and the bearing capacity of ice sheets, erosion and sediment transport in rivers together with their mixing characteristics and longitudinal dispersion.

(j) British Columbia

Studies using natural isotope techniques are being undertaken on hydro-chemical aspects of groundwater occurring in fractured crystalline bedrock in coastal areas and in superfical deposits of the southern interior of the province. Work continues on the analyses of rainfall distribution in mountainous terrain which, in turn, will be used to estimate runoff for input to forest folios and for water supply and road culvert design. Also, work continues on the design of a simplified flood warning system for the Squamish River involving the collection and input of a real-time hydrometeorological data. Both snow line flights and remote sensing techniques are being used to provide snow cover input to runoff simulation models in mountainous areas for use by B.C. Hydro. Three data collection platforms (DCP) are presently in operation in B.C. transmitting streamflow, air temperature and precipitation data from inaccessible areas.

At the University of British Columbia there is considerable research into the understanding and modeling of hydrological processes in forested mountain areas and particularly studies of snowmelt, high intensity rain, infiltration and runoff and the resulting erosion in rivers. Modeling studies are also being carried out in relation to urban hydrology and to many aspects of water management in the arid but fertile interior valleys. The Westwater Research Center is continuing its study of energy sources in the lower Fraser marshlands.

X ENGINEERING GEOPHYSICS

Compiled by: P. Hoekstra

Engineering geophysicists in Canada in 1978 contributed to the world literature in fields specifically related to Canadian climate and geography. During the Third International Permafrost Conference there were six Canadian contributions on permafrost geophysics. Furthermore the mapping of permafrost required for planning of Arctic pipe lines was instrumental in adopting into engineering practice the new techniques and methods developed in recent years i.e. magnetic induction sounding, high frequency radar probing, and radiohm measurements.

The first National Hydrogeological Conference was held in Edmonton (October, 1978). The program of this conference had a strong emphasis on the use of geophysical methods in hydrogeology. There were several reviews and case-history papers presented and the proceedings of this Conference will be published.

Activities in other areas of engineering geophysics, sesimic refraction surveying, and high resolution acoustic profiling, also continue to increase at a rapid rate. The main reasons for continued growth appear to be i) stricter land use regulations that make drilling an exploration tool of last resort and that require evaluation of alternatives, and ii) the on-going planning of large scale projects particularly in Western Canada. The lack of academic programs educating students in geophysics with strong backgrounds in geotechniques is strongly felt in industry.

XI MINING GEOPHYSICS

Compiled by: N.R. Paterson

1. General
2. McGill University
3. University of Toronto

1. General

Energy-related exploration geophysics continued to be very active in 1978, with a correspondingly high level of industry recruitment at both the graduate and post-graduate levels. Base metal exploration showed some signs of recovery, with more mining companies undertaking geophysical programs in the Yukon, B.C., Newfoundland and, to a lesser extent, in the Central Provinces.

The major event in exploration geophysics this year has been the application of a wide variety of complementary techniques to the search for Uranium in the Athabasca Basin of N. Saskatchewan. The apparent relationship of the mineralization at Rabbit Lake, Key Lake and Midwest Lake to graphitic shears in the Aphebian basement has encouraged companies to carry out large-scale surveys combining EM and magnetics to locate favourable environments and structures. Airborne INPUT surveys, followed by wide-band, large separation ground EM, have been applied, with apparently increasing success, to depths of up to 800 feet. Quantitative magnetic analysis has been used effectively to determine basement topography. Large crystal gamma ray spectrometry has led to several discoveries both in the Athabasca Basin and in other Proterozoic areas of the NWT. There has been increasing acceptance of the multi-channel analyzer in both Uranium exploration and radiometric mapping. The growing availability of high sensitivity spectrometer data has stimulated research into the problems of obtaining accurate estimates of elementary abundances in the ground. Research work is also underway in the area of pattern recognition and computer-zoning of spectrometer data.

The spectrometer had an unexpected stimulus in 1978 with the untimely demise of the Soviet COSMOS 914 nuclear satellite over Great Slave Lake, NWT. Using a combination of airborne and ground methods the GSC and private contractors carried out an intensive and amazingly successful search for radioactive fission products. The pieces recovered varied from pin-heat size to several 10's of cm. The generally low energy levels of the debris called for the measurement of bands and ratios not normally recorded in exploration geophysics - a good example of the ability of geophysicists to adapt techniques to the problems in hand.

In base-metal geophysics wide-band EM, drill-hole methods (including VLF), and computer processing and analysis of data all received active research, and increasing field application. Studies continued at U of T in the application and interpretation of wide-band EM for both layered and 3-dimensional structures. Some of this work was sponsored by the new Ontario Geoscience Research Grant Program. At the Mineral Exploration Research Institute in Montreal federally sponsored work was undertaken in drill-hole VLF and telluric current measurements. Magneto-telluric research continued at the same Institute, with emphasis on applications to mineral exploration; experiments were conducted in the Abitibi greenstone belt. The U of T conducted Ontario Govt. supported research into the magnetic properties of well-studied volcanic rocks (Blake River volcanics) in order to establish relationships of use in magnetic prospecting in such environments. The University of Windsor - also supported by the Ontario Govt. - started a program of detailed magnetic analysis of iron ore deposits, for the purpose of aiding quantitative interpretation of magnetic surveys as well as to study ore genesis.

There is an increasing interest in the application of geophysics to the location of sites suitable for nuclear power development and nuclear waste disposal. The CGC sponsored a symposium at the November GAC-GSA meeting in Toronto on this subject. Airborne magnetic gradiometer and wide-band EM surveys were carried out on both a research and production basis for this purpose in 1978. Seismic refraction and reflection, electrical resistivity/IP, VLF and audio frequency EM and micro-gravity were applied to site investigation problems for federal and provincial governments and utilities.

University enrolment appears to be about the same as in 1977 but at the graduate level there may be a shortage of students as more are being attracted into industry. We may be faced in 1979 with a problem of finding qualified M.Sc. and Ph.D. level students to carry out research programs already started and for which funding is available.

2. McGill University

(a) VLF Studies

C. Mathieson and D.J. Crossley have devised a single chart for the interpretation of all possible two-layer model, single-frequency resistivity measurements, the principle of which also simplifies the case when two or more layers may be present. A simple numerical technique has been developed and successfully applied to such field situations. Another aspect of resistivity interpretation, namely the effect of lateral inhomogeneity in the form of a lateral variation in depth of the interface between two uniformly resistive media, is being studied by F. Teemull and D.J. Crossley. The interface is modelled by a Fourier series, following the procedures of Hughes and Wait, and the parameters of the interface are determined by a linear inversion of the data. Although strightforward to apply the technique ignores the alternative interpretation of a uniform interface depth with lateral variations in resistivity, hence its field utility is at present uncertain.

(b) Radon Diffusion

C. Huang and D.J. Crossley have been attempting to determine the relationship between radon diffusivity and media properties such as porosity and water saturation. Several vertical soil columns were used as test media with radioactivity assessed by gas sampling up the columns. As usual in quantitative studies on radon diffusion the results are variable but appear to indicate that soil particle size is at least as important as porosity in contributing to radon diffusion.

3. University of Toronto

The wideband, time domain, ground EM system developed by Lamontagne and West, UTEM was used in several trial and exploration surveys during the year. Most were in Canada, but a survey in Australia was undertaken in December. Some improvements have been made in the transmitter electronics (West, Lamontagne, Macnae).

A program of interpretation studies has begun with the support of the Ontario Geoscience Research fund. The activities in 1978 were mainly in the complete reconstruction of the analogue modelling facilities. Some theoretical modelling is also underway (West, Villegas, Tejero).

A series of field experiments on high resolution EM sounding in the paleozoic stratigraphy of south-west Ontario have been carried out using the EM pulse system developed by Edwards and Duncan. Stratified earth interpretations using iterative inversion techniques have been applied to the data with considerable success. (Edwards, Huang, Gomez-Trevino)

A computer model for the Magnetometric Resistivity Method has been applied to study a variety of interpretation situations. (Edwards, Gomez-Trevino)

An investigation has been started into methods of utilizing all the gamma ray spectral information obtained in modern airborne radiometric surveys in interpreting K, U, Th, concentrations. The methods of generalized linear inversion theory are applied. (Bailey)

A theoretical study of the induced polarization in an idealized disseminated ore has been completed. A method of in-situ measurement of the dielectric and loss properties of soils in the 100 MHz region is under investigation. (Strangway, Wong)

XII PETROLEUM GEOPHYSICS

Compiled by: A.E. Wren

The recovery which began in 1976, thrived in 1977, has seen a boom year in 1978. Geophysical exploration has reached record levels in Alberta and is increasing in British Columbia, Saskatchewan, Ontario, offshore Eastern Canada and the Arctic. Seismic crew counts reached 100 in January 1977 and will reach the same level by Christmas 1978. The overall activity level in crew months is double that for 1977.

The reason for this is primarily economic and reflects world oil prices as well as the drilling and geophysical incentive programmes initiated by the Provincial Government of Alberta. However the economic momentum has been accompanied by an influx of new techniques and technology in the areas of acquisition, processing and interpretation. The larger more obvious hydrocarbon targets have long since been investigated and geophysics is being finely tuned to the more subtle stratigraphic traps.

The recent successes at Pembina (D.2 - Nisku reef) and Elmworth (Cretaceous Sandstone) are indicative of geophysical plays. There is no question that there is a growing appreciation and understanding of geophysics by management of most oil companies. The realization that geophysics can minimize the statistical odds in exploratory drilling is rapidly becoming accepted.

A highlight of the year was the Canadian Society of Exploration Geophysicists Annual Convention in the Calgary Inn. A fine technical programme was well received by a large audience of 800 delegates.